PREDICTING ECOSYSTEMS VULNERABILITY UNDER LANDSCAPE CHANGES IN THE LIVINGSTONE MOUNTAIN RANGES IN MBINGA DISTRICT, TANZANIA

BY

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ABSTRACT

Predicting future conditions of the ecosystems resulting from different human activities is very important in spatial planning for sustainable resources utilisation. This study has developed a spatial decision making supporting system (SDSS) or a model for predicting ecosystems vulnerability under landscape changes in the Livingstone Mountain Ranges in Mbinga District, Tanzania. Various datasets collected through remote sensing and cross-section survey were used in this study. Changes in the spatial extent of the habitats were assessed from remotely sensed data based on land use and cover changes. Variables extracted from remotely sensed data were used to generate parameters and were integrated in the GIS environment to develop the prediction model called, Livingstone Mountain – Conversion of Land Use and Its Effects (LIM-CLUES) Model.

Predicted results from the developed model were based on the business as usual and policy scenarios used in this study. The results from the business as usual scenario showed that there would be a continuous decrease in the woodland ecosystem up to the year 2020 mainly at the expense of agro-ecosystem due to livelihood strategies of the local communities in deriving goods and services. Predicted results also showed that there was an increase in the area of cultivated land at the expense of the upland woodland and upland bushland with scattered cropland from year 2005 to 2020. The results also showed that upland cultivation would continue to expand towards the south eastern side up to year 2020. Encroachment would also start to take place in the upland woodlands located in the southern part between the boundaries of Chiwanda (lowland) and Tingi (upland) wards. Likewise, simulated results from the policy scenario showed that upland bushland with scattered cropland category would be extending upwards in Kingerikiti ward between years 2005 and 2010. Upland woodland started to regenerate in the same Kingerikiti ward from year 2005. As a result of this study, a LIM-CLUES model helped

to understand factors influencing landscape changes and can be used to project near future land use trajectories, which are important for targeting spatial management decisions in the study area.

DECLARATION

I, Vedast Max Makota, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work, and it has not been submitted for any degree award at any other institution.

7th/11/2011

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ATF	African Technology Forum
ASCII	American Standard Code for Information Interchange
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CA	Cellular Automata
CARITAS	International Confederation of Catholic Organization for Charitable and Social Action
CLUES	Conversion of Land Use and its Effects in Small Regions
CMT	Council Management Team
DEM	Digital Elevation Model
EOS	Earth Observing System
EPA	Environmental Protection Agency
EMA	Environmental Management Act
ESRI	Earth Sciences Research Institute
ETM+	Enhanced Thematic Mapper plus
EU	European Union
EURURALIS	European Rural Areas Project
FAO	Food and Agriculture Organization of the United Nations
FBD	Forestry and Beekeeping Division
FGDs	Focused Group Discussions
FRMP	Forest Resource Mapping Project
GIS	Geographical Information Systems
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System

HTS	Hunting Technical Services
ICRA	International Centre for Research in Agroforestry
IGBP	International Geosphere and Biosphere Project
IHDP	International Human Dimension Project
IPCC	Intergovernmental Panel on Climate Change
IRA	Institute of Resource Assessment
Lbsc	Lowland bushland with scattered cropland
Lgsc	Lowland grassland with scattered cropland
LUCAS	Land Use Change Analysis Software
LUCC	Land Use and Cover Change
LULC	Land Use and Land Cover
LTM	Land Transformation Model
Lwd	Lowland woodland
MA	Millennium Ecosystem Assessment
MBICU	Mbinga Cooperative Union
MBIDEA	Mbinga Development Association
MOA	Ministry of Agriculture
MLIS	Multipurpose Land Information System
MNRT	Ministry of Natural Resources and Tourism
MSS	Multi-spectral Scanner
MTPE	Mission to Planet Earth
MWARP	Miombo Woodland Agro-Ecological Research Project
NASA	United States National Aeronautics and Administration
NEMC	National Environmental Management Council
NGOs	Non–Governmental Organizations
NEP	National Environmental Policy

Oth	Others
R&AWG	Research and Analysis Working Group
ROC	Relative Operating Characteristic Curve
SCSRD	SUA Centre for Sustainable Rural Development
SUA	Sokoine University of Agriculture
SMD	Surveys and Mapping Division
SDSS	Spatial Decision Support System
SPANS	Spatial Analysis System
SPSS	Statistical Package for Social Sciences
TANESCO	Tanzania Electric Company
TM	Thematic Mapper
UN	United Nations
UNEP	United Nations Environmental Programme
UNESCO	United Nations Education, Science and Cultural Organisation
Upbsc	Upland bushland with scattered cropland
Upcl	Upland cultivation
Upw	Upland woodland
URT	United Republic of Tanzania
USA	United States of America
VC	Village Government Councils
VEOs	Village Executive Officers
WCED	World Commission on Environment and Development
WSSD	World Summit for Sustainable Development
WWF	World Wildlife Fund

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Problem

Land as a main resource base is used for most of the human activities including agriculture, industry, forest, energy production, settlements, water catchments storage, and recreation. Also land resources are supporting different ecosystems that are crucial to human survival and prosperity (Turner II *et al.,* 1993). According to the Biology on-line dictionary (2007), ecosystem is defined as a system that includes all living organisms (biotic factors) in an area as well as its physical environment (abiotic factors) that are functioning together as a unit. An ecosystem may therefore include people, wildlife, fish, trees, water and several other living and non-living elements. From this definition human beings are part and parcel of the ecosystem and they rely on the other ecosystems to derive their goods and services. Ecosystems provide a number of vital goods and services for people and society, such as food, fibre, water resources, carbon sequestration and recreation.

Although the concept of "environmental" or "ecosystem services" is about 30 years old, its development has been receiving more growing attention in recent years than before (Maass *et al*., 2005). This is illustrated by the Millennium Ecosystem Assessment (MA), which is a recent comprehensive global study of ecosystem services and their effects on human well-being, initiated by the United Nations Organization (MA, 2005). However, human activities and population growth have been among the factors threatening availability of ecosystem services by generating pressure on the natural resources and environment hence pose a considerable challenge to sustainable resource utilization (Mascarenhas, 2000; Vanacker, 2002; Misana *et al.,* 2003; Luoga *et al.,* 2005a). While human activities in many parts of the world have greatly shaped the natural landscapes, the population increase raised the demand for land based resources resulting into deforestation, encroachment of protected areas and subsequent change in land use patterns leading to disturbances to the ecosystems.

It is estimated that 27% of 3.5 billion hectares of the earth's surface is covered by forests ecosystems (Palo and Uusivuori, 1999). In tropical Africa, forests ecosystems cover 520 million hectares (FAO, 1999) whereby Miombo woodland is an important component of tropical forests that occupies an area of 270 million ha in southern and eastern Africa (Campbell *et al.*, 1996). However, the current global deforestation rate (14.4 million hectares annually) cause a loss of biological diversity in tropical forests that contain between 70% and 90% of the world's species (FAO, 2001; ATF, 2005). In most cases, subsistence agriculture is the principal cause of forest loss in much of Latin America, Asia, and Africa (FAO, 2001). In tropical Africa, the forest loss is estimated around 0.85 million hectares per year (WWF, 2004). Large tracts of forests have been converted into croplands and natural wetlands have been drained and filled in order to feed and shelter the expanding population (WCED, 1987). The traditional techniques such as slash and burn farming system together with the expansion of commercial farms and livestock grazing areas have therefore been influencing forest loss in Africa, Asia and much of Latin America (FAO, 2001).

As a result of human activities and population growth, one of the critical land use change is that the world's forests, grasslands and woodlands have declined, the cropped land areas have expanded in the same magnitude (Skole *et al.*, 1994; Scherer, 2003; Slayback, 2003). In line with this argument, Goldewijk (2001) reports that the area of cropland has increased about five fold globally in three centuries. The cropland has increased from an estimated 300 to 400 million ha in the year 1 700 to about 1 500 to1 800 million ha by the year 1990. The increase of cropland in the twentieth century was 50 percent net to that of 300 years back (Goldewijk, 2001). Moreover, the increase in cropland correspond to decrease of forest cover from 5 000 to 6 200 million ha in the year 1 700 to 4 300 to 5 300 million ha in the year 1990, as reported by Ramankutty and Foley (1999). Similarly, FAO (2001) found that the net global decrease in forest area was 9.4 million hectares per year from 1990 to 2000 and estimated that tropical regions lost 15.2 million hectares of forests per year during the 1990s. However, deforestation in the dry tropical forests may often be underestimated.

According to Ramankutty (2002), Latin America, south and Southeast Asia, Australia and Africa experienced very gradual expansions of cropland until 1850, but since then, these regions have experienced dramatic increases in cropland, especially during the second half of the twentieth century. In Asia, intensified shifting agriculture, including migration into new areas, gradual change of existing areas toward more permanent agriculture, and logging explain most of the deforestation. On the other hand, cropland expansion by smallholders dominates in many parts of Africa where population growth increases rapidly (Turner II *et al.*, 1993). The African continent is seriously affected by desertification and land degradation due to increased unsustainable human activities (Darkoh, 1993). For instance, agricultural development in the cotton zone of Mali is transforming the landscape and the environment (Benjaminsen, 2001). The most obvious and visible environmental impact of this development is the extension of cultivated land at the expense of pastures and Miombo woodland. Similarly, Miombo ecosystem directly supports livelihoods of most people in southern Africa countries. Such woodland form one of the most extensive dry forest vegetation types in Africa occurring in seven countries in eastern, central and southern African; namely Angola, Malawi, Mozambique, Tanzania, Zaire (now Democratic Republic of Congo), Zambia and Zimbabwe (White, 1983). They occupy an area of about 2.7 million km^2, almost equal to the combined land area of Mozambique, Tanzania, Malawi, Zambia and Zimbabwe. These woodlands constitute the largest comparatively contiguous block of deciduous tropical woodlands and dry forest in the world.

In Tanzania these biomes make up about 90% of all forest, out of which 54% is under general lands (URT, 2001). Tanzania has about 38 811 322 million hectares of forest and woodlands representing about 41% of the country total area of land (MNRT, 2002). According to UNEP (2002), the decline of Africa's biodiversity has relationship with changing land use patterns as a result of human population growth and increasing demand for agricultural land and other human activities like establishment of settlements, livestock keeping, logging, charcoal making and mining. Inappropriate land use practices have been reported to be the major cause of land degradation in areas such as Dodoma, Shinyanga, Singida, Mwanza, Iringa, Mbeya, Arusha and most of the catchments areas leading to threatening people's livelihood (Misana, 1992; Kikula and Mwalyosi, 1994; URT, 1999; Mnkabenga, 2001). Likewise, land degradation in other parts of Africa such as Ethiopian Highlands is considered mainly as due to anthropogenic pertubations that started with the clearing of dry evergreen forest since 2000 years ago (Hurni, 1993). Rapid increase in population density in many localities of Africa has been found to be related to agricultural expansion and intensification and in some regions to forest loss (Turner II *et al.*, 1993).

When we consider land degradation in the mountain areas, many of Africa's mountain areas are increasingly important for providing natural resources for rapidly growing populations. For Africa, there is high population pressure and cultivation in the mountain areas where about 45 percent of the continent (30 113 Million km^2) consists of slopes of at least 8 percent (FAO, 1986). Messerli *et al.* (1990) report that 90 percent of the cultivated land in Africa is in mountains and high plateaus above 1 500 m. These landforms cover 43 percent of the total land surface. In line with situation, Shively (2001) noted that area devoted to upland agriculture in the Philippines increased six-fold between 1960 and 1987, and coincided with a rapid decline in forest cover whereby high rates of forest clearing in the uplands were driven, in part, by the efforts of low-income farmers to secure subsistence. An elaborate example in Tanzania is cultivation on Mount Kilimanjaro slopes which is believed to have taken place as long as people have inhabited the slopes of the mountain probably more than 2000 years back in time (Masao, 1974). Likewise, Madulu (2004) suggests that almost 70 percent of the rain forests in the Usambara Mountains have been destroyed since 1954 mainly to meet livelihood needs of the people. However, mountain environments are very fragile and delicate ecosystems and therefore overexploitation of natural resources has affected living conditions and Africa's natural treasures over the last decades (UNEP, 2002). This thinking is shared by The Environmental Policy of 1997 (URT, 1997), which stipulates that major environmental consequences of human perturbations among others include land degradation through vegetation clearance. In the Livingstone Mountain ranges and its adjacent lowland, the population pressure put the Miombo woodlands under very intensive stress mainly for cultivation and settlement hence have become smaller and fragmented (Nindi, 2004).

Deforestation in the study area (Livingstone Mountain ranges) has lead to severe implications not only in terms of vegetation clearing but also in changing river regime, incidence of flooding, increased sedimentation in the adjacent lowland areas, ruined aquatic life, leading to, further deterioration of the physical environment as well as livelihoods of the people in the upland and lowland areas (Nindi, 2007; NEMC, 2008). In addition to the fact that landscape changes modifies the spatial configuration of different land use and cover types, it also has direct impact on the spatial extent of ecosystems resulting from deforestation hence causes ecosystems vulnerability (Turner, 1989; Sala *et al.*, 2002). Indeed, the extent and factors causing ecosystems vulnerability are different hence future conditions of the ecosystems and the livelihoods of the people in both upland and lowland areas of the study area is an important issue of concern in this study.

1.2 Statement of the Problem and Justification

Global environmental change and sustainability science increasingly recognize the need to address the consequences of landscape changes taking place in the environment (Turner *et al.*, 2003). The landscapes that support the major part of the world food supply are inhabited by millions of people and possess valuable biodiversity. Due to increasing population pressure, urbanization, global climate change and market integration, these landscapes are rapidly changing. However, the complex landscape changes in the agricultural and semi-natural areas that make up a large part of the earth's surface are given less attention (Ellis, 2000). As a result of time span and landscape changes due to spatial configuration of certain human activities, the ecosystems are largely becoming vulnerable (DeFries *et al.*, 2004). Hence, research is needed to address the interaction of temporal and spatial dynamics of landscape changes in the Livingstone Mountain ranges.

According to FAO (2001), agricultural expansion has shifted between regions over time; this followed the general development of civilizations, economies, and increasing populations. Thus, better planning requires understanding of the environmental conditions and how land uses and natural resources are likely to change as a result of society's actions (Chambers *et al.*, 1992). Since the anthropogenic processes can have broad impacts on the environment, size and arrangements of natural habitats including forests, an understanding of how landscape changes occur, especially in an upland-lowland nexus such as those found in Mbinga District, and also predicting future situations is critical.

However, not all information on the magnitude of the landscape changes in the Livingstone Mountain ranges that have occurred over a period is known. According to Chambers *et al.* (1992) such changes raise questions as who and what are vulnerable to the landscape changes underway, and where? Thus, predicting the far-reaching implications of these changes on the environment and their impacts on society are needed. Various models/methodologies have been developed to predict changes in the environment. However, none provide sufficient information to explain the spatial and temporal dynamics of landscape changes. In this case, development of models to understand the spatial and temporal dynamics of the landscapes should therefore be given more explicit attention (Lambin *et al.*, 2000).

As pointed out by Strömquist *et al.* (2000), the ability to forecast and making the increasingly complex judgement on our future can not be done without reliable data and informed analysis. In this study this is facilitated by the capability of the LIM-CLUES model to predict ecosystems vulnerability resulting from landscape changes and thereby providing necessary data and information for land use and natural resource management interventions.

Moreover, reviewed literatures show that various studies on land degradation have been conducted in Tanzania (Mwalyosi, 1990; Yanda, 1999; Mascarenhas, 2000; Mbilinyi, 2000, 2004; Mwalukasa, 2002; Misana *et al.*, 2003; Luoga *et al.*, 2005b; Wang, 2005) and those specifically in the Livingstone Mountain ranges from the earliest ones e.g. by

Steinhouse (1944) to the recent ones by (Schmied, 1989; Temu and Bisanda, 1994; Lyimo and Kangalawe, 1997; MWARP, 1998; Itani, 1998; Nindi, 1999; 2004; 2007; 2010; Mhando, 2005; NEMC, 2008) have not worked on modeling the landscape changes. Based on the reviewed literatures, it is only in Kenya (Mara ecosystem) where a land use and cover change prediction model had been developed within the East African region. However, the developed model in the Mara Ecosystem did not consider the slope variable, which is among the important variables in the study area. Moreover, with the exception of Kimaro (2003), other reviewed publications have not demonstrated the spatial linkage that exist between biophysical and socio-economic factors as proximate driving forces to land use and cover changes. Moreover, according to Yanda and Shishira (1999) among the factors influencing land cover changes in Tanzania include pre-colonial long distance trade, the great rinderpest epidemic, colonial intervention, population dynamics, urbanization, and post-colonial government policies. However, this study has considered other biophysical and socio-economic factors than those mentioned by Yanda (1999).

Furthermore a study by NEMC (2008), shows that information or documentation on mountain ecosystems located in the south-western part of the country (including study area) is insufficient compared to other mountain ecosystems such as the Eastern Arc, Kilimanjaro and others found in the northern side. In addition, the drive for this study came due to the fact that the Livingstone Mountain ranges form one of the major catchments for the Lake Nyasa, which contains unique biodiversity such as fish species. Moreover, the ranges are marked by a specialized traditional land cultivation system known as *ngolo* (the Matengo pit farming system) that enables cultivation in steep slopes in the Miombo woodlands, thus extending vegetation clearance in more vulnerable areas. Thus, the local people's perception on the dynamics and driving forces behind landscape change in the Livingstone Mountain ranges and their implication to the livelihood is not clearly understood. This study would increase the scientific understanding of the past driving forces responsible for the changes in order to support decision making in natural resources management.

Effective and efficient land use and natural resources management highly depends upon adequate and accurate data and information. This study has used remote sensing and Geographical Information System (GIS) tools in attempting to add to the understanding of status of the ecosystems in the study area (southern parts of the country), which is crucial for the identification of conservation and management needs of the ecosystems. The use of GIS and remote sensing have become familiar in supporting decision making in many aspects through analysing the trends of resource utilisation, spatial modeling for vulnerability analysis and planning for sustainable land use practises and natural resource management (Campbell, 1997; Zhang *et al.*, 2001).

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study was to predict ecosystems vulnerability under landscape changes in the Livingstone Mount Ranges and its adjacent lowland areas in the periods between years 1979-1990 and 1990-2000.

1.3.2 Specific objectives

The specific objectives were:

i. To determine the extent of spatial landscape changes between 1979 and 1990; 1990 and 2000.

ii. To assess the influence of biophysical and socio-economic factors in landscape changes.

iii. To ascertain implications of landscape changes on people's livelihoods.

iv. To develop a LIM-CLUES model for simulating near future landscape changes as a way of predicting ecosystems vulnerability.

v. To test and validate the LIM-CLUES model.

1.3.3 Research questions

i. What is the extent of spatial landscape changes between years 1979 to 1990 and 1990 to 2000?

ii. How do biophysical and socio-economic factors influence landscape changes?

iii. What are the implications of landscape changes on people's livelihoods?

iv. What can be done to determine the near-future landscape changes for predicting ecosystems vulnerability?

v. What is the reliability of the LIM-CLUES Model?

1.4 Conceptual Framework of the Study

According to Frankfort-Nachmias and Nachmias (1996), a conceptual framework binds facts together and provides guidance towards collection of appropriate data. The conceptual framework underlying this study (Figure 1) provides steps that were involved in developing a model for predicting ecosystems vulnerability under landscape changes in the study area. It indicates types of data and the different stages at which such data needed to be collected and processed. Remotely sensed and socio economic datasets were therefore collected and processed in order to generate spatial layers and statistical data for model development.

Remotely sensed data were pre-processed and digitised to generate different land use and cover categories and were used to determine land use and cover change statistics, as input parameters for modeling purposes. Likewise, population data from National Census of 2002 and data from household surveys were collected, checked and processed before integrated in the GIS to generate parameters used in the model.

Additional data processing was carried out using the Digital Elevation Model (DEM) to generate slope, elevation and aspects, which were important factors taken into consideration to influence landscape changes in model development. Land use and cover categories developed from digitisation were further processed through reclassification, aggregated to seven classes and coded in a GIS environment. Other spatial datasets such as administrative boundary, roads, rivers and population were processed further to generate input parameters for the model. Administrative map at ward level was processed with their respective population data to generate population density map, as an input parameter for the model. Likewise, same administrative map was processed together with layers of roads and rivers to generate maps showing distance to roads and rivers.

The last part of this conceptual framework is on modeling. This stage involved conversion of all spatial datasets generated through steps explained above to formats acceptable in the model. Thus, all spatial datasets were converted to text (ASCII) format and statistically analysed to generate parameters for model setting. Sensitivity analyses were performed to statistically analysed data which were converted to the text format to assess data fitting. Statistical analyses were also performed for scenarios setting. Different model parameters were entered in the model and finally the model was runned. After successfully running the model, validation was performed to assess the reliability of the LIM-CLUES model. Validation was performed using results of the year 2006 generated from LIM-CLUES model correlated with results of the same year obtained from digitisation of satellite imagery.

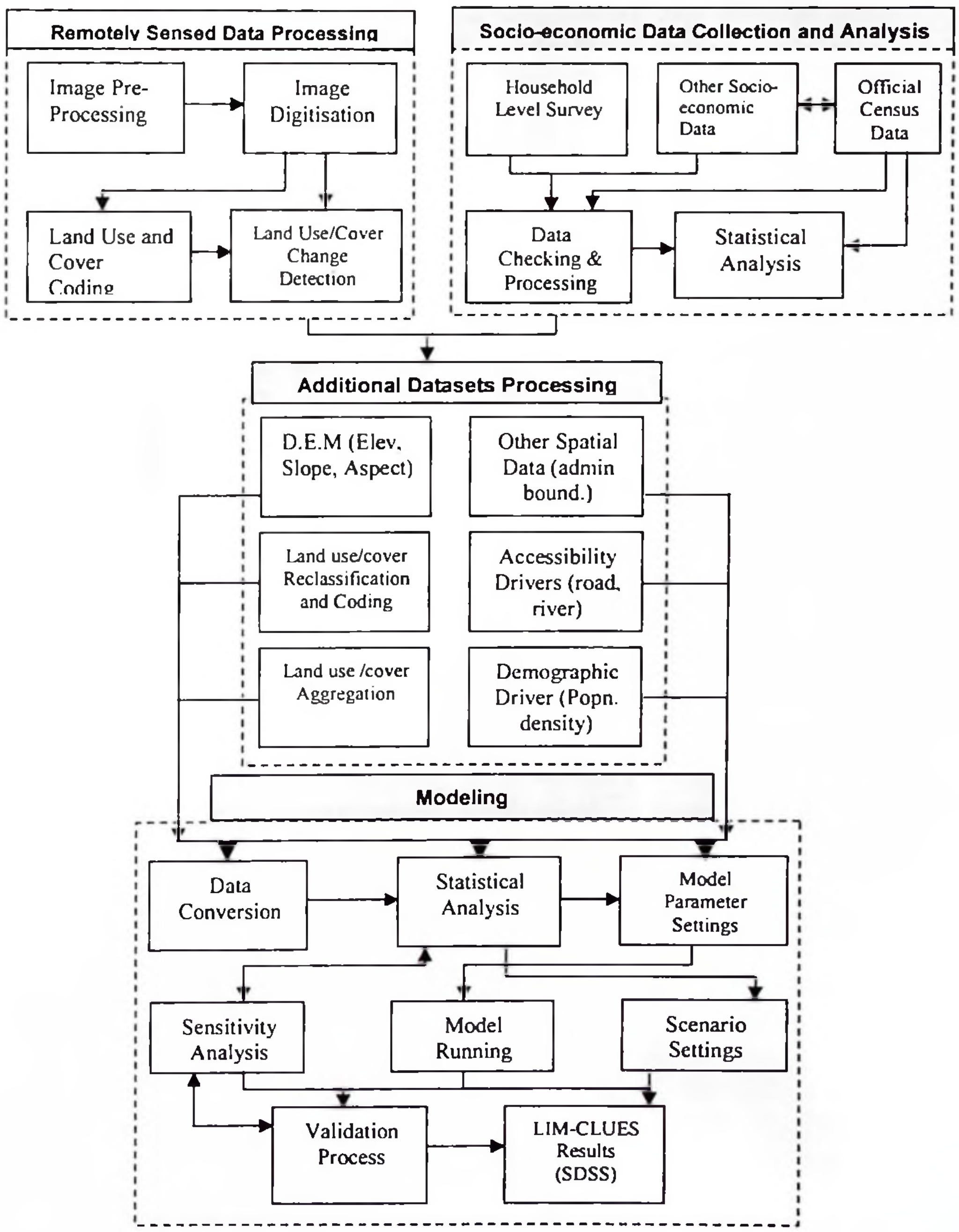

Figure 1: Conceptual Framework for developing LIM-CLUES model for predicting ecosystems vulnerability under landscape changes in the Livingstone Mountain ranges in Mbinga District.

Source: Modified from Orékan (2007)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

This chapter presents literature review on landscape changes and how it relates to ecosystems vulnerability. It starts with highlighting how landscape changes have been observed by assessing the land use and cover changes using remote sensing and GIS tools and implications of these changes to the livelihoods of the communities. Then, it reviews factors or drivers that influence the landscape changes and discusses ecosystems vulnerability resulting from such landscape changes. Moreover, it reviews some of the landscape changes prediction models including the CLUES (also referred to as Dyna-CLUES) modeling framework that has been used in this study. The chapter ends by highlighting on policy issues related to environmental management and also explanations on how land use and cover change prediction models are validated.

2.2 Definitions of Terms: Landscape, Ecosystems and Ecosystems Vulnerability

2.2.1 Landscape

Landscape is a complex concept encompassing several definitions. According to WWF (2001), a landscape is defined as a contiguous area intermediate in size between an eco-region and a site with a specific set of ecological, cultural and socio-economic characteristics distinct from its neighbours. However, the definition that has been adopted in this study is considering landscape as an area containing a mosaic of land use and cover patches. Patch means a territorial unit, which represents an area covered by one single land use or cover class.

According to Di Gregorio (2005) land use corresponds to the socio-economic description *(functional dimension)* of the landscape areas such as residential, industrial or commercial purposes, farming or forestry, recreational or conservation purposes and other related functions. Land use is the intended employment and management underlying human exploitation of a land-cover. It is characterized by the arrangements, activities and input people undertake in a certain land-cover type to produce, change or maintain it (IGBP/IHDP-LUCC and IGBP-DIS, 1997). On the other hand, Turner *et al.* (1995) referred to land cover as the observed biophysical cover on the earth's surface and immediate subsurface. It therefore includes vegetation, water (surface water, ground water), desert, ice, soil, topography and human-made structures such as mine exposure and settlement (IGBP/IHDP-LUCC and IGBP-DIS, 1997; Di Gregorio, 2005). Therefore, land-cover is about the description of vegetation and man-made features which overlays or currently covers the ground.

Consequently, there is a link between land cover and human activities in the environment because contemporary land cover is changed mostly by human use (Allen and Barnes, 1985; Turner II *et al.*, 1990; Whitby, 1992 quoted by Turner *et al.*, 1995). Generally, land use is closely related to land cover. Thus, land cover can be referred to as all the natural and manmade features that cover the earth's surface, whereas land use referred to as the human activity that is associated with a specific land unit, in terms of utilisation, impacts or management practices (FAO, 1997). However, often land use and land cover are not quantified in a way that makes them easy to separate, and so reference to use/cover, or simply cover, is common (Verburg and Chen, 2000).

In this study, land use and land cover have been used to detect landscape changes. Landscape changes detection is regarded as detecting changes taking place to the land use and cover categories. Ashbindu (1989) defined change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, it involves the ability to quantify temporal effects using multi-temporal data sets. Amongst the many aspects of global change, land use change has been highlighted as a key human-induced effect on ecosystems (Lambin *et al.*, 2001). This comes from the fact that ecosystems provide important goods and services for the livelihood of the people (Metzeger, 2006).

2.2.2 Ecosystems

Ecosystems can be defined as all of the factors that allow a healthy environment to function; the complex relationships among an area's resources, habitats and residents. An ecosystem may include people, wildlife, fish, trees, water and several other living and non-living elements. Ecosystem services are the benefit people obtain from the ecosystems (Brauman *et al.,* 2007). Examples include provision of clean water, maintenance of liveable climates (carbon sequestration), pollination of crops and native vegetation, and fulfilment of peoples' cultural, spiritual, intellectual needs (FAO, 2005). On that regard, land use and cover change directly causes ecosystems vulnerability and subsequently affects services rendered (Daily, 1997; Millenium Ecosystem Assessment, 2003; Reid *et al.,* 2005).

2.2.3 Ecosystems vulnerability

According to Turner *et al.* (2003) ecosystem vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor. This implies that it is the likelihood of a system to be affected as a result of any stress subjected to it. Hence, vulnerability assessment incorporates a significant range of parameters in building quantitative and qualitative pictures of the processes and outcomes of vulnerability (Adger, 2006).

Since ecosystems are attributes of the landscape, then the landscape is composed of ever-changing elements. The spatial and temporal patterns of ecosystems distinguish a landscape to an observer; at the same time they inform us of the complexity of dynamic processes at various scales. In the study area, landscape changes have led into increasing ecosystems vulnerability resulting from catchments degradation, soil erosion and siltation in water bodies such as rivers and streams as well as the Lake Nyasa (MWARP, 1998; Nindi, 2007; NEMC, 2008). Therefore, what will be the future situation of the ecosystems in the study area? The answer is not clearly known without prediction.

It is therefore important to predict ecosystems conditions in the future. Predicting ecosystems conditions in the future depends on a number of factors including the different scenarios that are applied. According to Alcamo and Ribeiro (2001) studies on scenario development are based on the methods that combine recognised evidences or facts about the future such as geography, demography, ecology and political, industrial information with key conceivable alternate driving forces including trends on social, technical, economic and political. Wikipedia (2006), a free encyclopaedia, presents scenarios as a strategic planning method, which can be used (especially by military resort) to make flexible long-term plans. On the other hand the Intergovernmental Panel on Climate Change (IPCC, 2000) defines scenarios as "images of the future, or alternative futures". Buson (2007) suggests that scenario planning is a method for learning about the future by understanding the nature and impact of the most uncertain and important driving forces affecting our future. This study adopted a definition by

Nakicenovic *et al.* (2000), which characterizes scenario method as *"an alternative images of how the future might unfold"*.

2.3 Determination of Landscape Changes Using Remote Sensing and GIS Tools

Effective and efficient natural resources management highly depends upon adequate and accurate data and information. Remote sensing and GIS are among the major means where data are collected, analysed and presented to support decision-making to policy makers, researchers, planners and other stakeholders. The field of remote sensing has been defined many times. However, in this study the adopted definition is from Campbell (1997) who defined remote sensing as "the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface".

Aircraft and space-based sensor systems have become standard methods of gathering large amounts of different types of data about the Earth on regular basis. The most widely used remotely sensed data for large-scale Earth resource applications have been from the Landsat series, the first of which was launched by the United States National Aeronautics and Administration (NASA) in 1972. This study used Landsat imagery because the Landsat systems have been operational since year 1972. It was therefore possible to get archival imagery for this study. The ability of remote sensing techniques to acquire data beyond the visible region of the electromagnetic spectrum during both day and night makes it one of the most important sources of data from which different information about the earth can be derived.

On the other hand, Geographical Information System (GIS) refers to an organised collection of specific computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information (e.g. raster/vector) that can be drawn from different sources (EC, 2006). Ideally, GIS is used as a decision support system to integrate spatially referenced data in a problem-solving environment (Jensen, 1996).

Remotely sensed data effectively employed within a GIS can be used to facilitate measurement, mapping, monitoring, modeling and management of natural resources (Jensen, 1996; Campbell, 1997). Remote sensing is well documented as an effective tool for mapping and characterizing cultural and natural resources (Holz, 1985; Lo, 1986; Jensen, 1996; Campbell, 1997). The multispectral capabilities of remote sensing allow observation and measurement of biophysical and socio-economic characteristics, while the multitemporal and multisensor capabilities allow tracking of changes in these characteristics over time. A common use of satellite data is the production of land-cover maps that indicate landscape patterns and human development processes (Turner, 1990; Baker and Cai, 1992). These capabilities also make remote sensing very useful for land-management (Quattrochi and Pelletier, 1991).

The advantages of satellite images over aerial photographs or videography for change detection studies include cost effectiveness, extent of coverage, and ability to reveal landscapes at large scales (Wang and Moskovits, 2001). Remote sensing technologies are increasingly used to monitor landscape change in many parts of the world (Chowdhury, 2006). In order to assess the landscape change comparison of maps of two times, (T1 and T2) has been used as a common technique in a GIS environment and interpretation of the comparison results would lead to the conclusion that the differences between the maps of T1 and T2 indicate landscape change (Jensen, 1996; Campbell, 1997).

GIS technology is a powerful tool that can improve the information base essential for sustainable natural resource management. The strength of GIS lies in its ability to integrate data and information on different themes and from different sources using a common geographical reference, which ultimately helps in decision making (Mahajan *et al.,* 2001). GIS combine land-use mapping capabilities with relational databases and statistical analysis tools to enable planners to link numerous types of information, rapidly perform sophisticated analyses, and effectively communicate complex information with maps and graphical reports. They are powerful tools that could be a component of a model or modeling system. GIS is used to explain events, visualize trends, project outcomes, and strategize long-term planning goals.

The spatial dimension provided by the GIS allows the research community with the ability to ask the question about why and how landscapes are changing and to evaluate the spatial location or proximity in which it is occurring (Gimblett, 2006) This has many advantages when developing site specific, long term planning and monitoring strategies. Fox *et al.* (2003) conclude that "the human dimensions research community, Land use/Cover Change (LUCC) programme, and human and landscape ecology communities are collectively viewing the landscape with a spatially-explicit perspective, where humans are viewed as agents of landscape change that shape and are shaped by the landscape and where landscape form and function are assessed with a space-time context." The speed, extent and spatial influence of human alterations of the Earth's surface are unprecedented. Changes in land cover (biophysical attributes of the Earth's surface) and land use (human purpose or intent applied to these attributes) are among the most important aspects (Lambin *et al.*, 2001). In this situation remote sensing and GIS technologies serve as key components of emerging land-use change modeling approach.

One of the major attributes of space-based remotely sensed data for environmental monitoring purposes include their repetitiveness and wide-area coverage. For example, the temporal resolution and ground coverage of the Landsat TM are 14 days and 185 by 185 km respectively (Campbell, 1997). This permits observations to be made under comparable or identical conditions of illumination or for comparatively long periods. These attributes permit environmental changes to be assessed in terms of their location and spatial relationship to other features, their magnitude and the rate of change at a low cost much lower than by aircraft and other conventional methods (Lillesand *et al.*, 1994; Campbell, 1997; Jensen, 1996).

Information on the land use and land cover is very important in environmental-based projects and broader programmes for natural resource management aimed at strengthening the viability of economic and social development (Weismiller *et al.*, 1977). Efforts to monitor tropical landscape increases the use of remote sensing and change analysis as powerful tools in monitoring the rates and patterns of tropical forest change (Iverson *et al.*, 1989; Hansen *et al.*, 2000). The increasing transformations of terrestrial ecosystems are regarded as an important element of global change. However, quantitative data on where, when and why land-cover changes take place globally are still incomplete (Lambin, 1997).

Different studies have been conducted to determine land use and cover changes. For instance in Mozambique, the Gorongasa National Park used remote sensing techniques to understand the spatial patterns of resource use by local communities and also determine what areas were likely to be heavily impacted by community use of resources. In collaboration with two communities living in, and on the edge of Gorongosa National Park (GNP), they researched on the importance of different landscape units to these communities and used the information to develop a management plan for this national park (Lynam, 2004). Likewise, a study conducted by Slayback (2003) in the Takamanda forest reserve in Cameroon using remote sensing and GIS showed that most of the areas of forest conversion into other land uses were located on the periphery of existing villages and the rates of forest clearing appeared to be increasing, as indicated by the expanding patterns of forest conversion. Furthermore, a study (Mumbi, 2002) in the former Kameza forest reserve in Zambia using remotely sensed data, assessed the land use in the light of sustainable agriculture. In this study it was found that about 26% of closed woodland was converted into agriculture.

The use of satellite remote sensing for general vegetation and land cover mapping in Tanzania has been applied since 1980s. According to Wang *et al.* (2005) Landsat Multispectral Scanner (MSS) images of 1974 were interpreted to compile a map of Tanzania vegetation types at a scale of 1:2 000 000 in 1984. Moreover other general land cover mapping initiatives in Tanzania include a Forest Resource Mapping Project (FRMP) executed by Hunting Technical Services (HTS) of the United Kingdom and the Africover project (1994 to 1996) hosted by the United Nations Food and Agricultural Organization (FAO). According to Wang *et al.* (2005), the thematic maps prepared by the HTS at 1:250 000 Scale were based on interpretation of scale-controlled mosaics of Landsat TM and SPOT image scenes acquired between May 1994 and July 1996. Africover's product was produced by visual interpretation of Landsat and SPOT images acquired between February 1995 and June 1998. Land cover categories were compiled using an internationally adopted Land Cover Classification System (Di Gregorio and Jensen, 2000). The final map product is at 1:200 000.

Likewise, in the coastal districts of mainland Tanzania, Wang *et al.* (2005) used remotely sensed images from close to 1990 Landsat Thematic Mapper (TM) sensor and 2000 Landsat-7 Enhanced Thematic Mapper Plus (ETM+) sensor and GIS technologies to discern changes in land cover and land use. Change detection results showed that urban land area had increased dramatically. Mangrove forest area declined modestly, but field verification showed severe deterioration of their conditions near urban areas. The results also showed that the area of dense woodland decreased while the area of open woodland and the area of woodland interspersed with agriculture increased.

Besides, Newman and Ronneberg (1992) cited in Gerdén *et al.* (1992) compared aerial photographs of 1960 and 1990 covering the Lake Babati catchments areas in Tanzania. The study showed that cultivation had increased significantly and was the dominant land use in the catchments areas. Woodland and bushland receded in the same proportion as cultivation increased.

Other studies have combined both, airborne and spaceborne remotely sensed datasets to determine land use and cover changes. Mbilinyi (2000) used remotely sensed data, panchromatic aerial photographs of 1963 and 1978 and satellite data of 1995 from Landsat TM to assess land degradation and its consequences in Ismani Division in Iringa Region, Tanzania. Analytical findings through GIS application showed that a large part of Miombo woodland was cleared during the period 1963-1978 because of resettlement/villagization programme of 1970's. Furthermore, comparing remotely sensed data acquired after resettlement programme (1978-1995), he found that an area covered by Miombo woodland increased by 19% during the study period. He concluded that an increase in woodland was influenced by the Woodland Conservation Programme implemented by the local communities.

Likewise, Yanda and Shishira (1999a) used aerial photographs to determine land use and cover changes taken place in the southern slopes Mount Kilimanjaro between 1952 and 1982. Conclusion from their study showed a decline of natural forest by about 41 km^2 mainly due to increase in the cultivated land. Mwalukasa (2002) also used remotely sensed data from airborne and spaceborne platforms to establish a link between the degradation of upland catchments in Makete – Iringa, Tanzania and land use changes in the plains in Mbarali-Mbeya. The results showed that there had been fast adoption of agroforestry/woodlots planting of 36.7 ha (4.4%) annually by farmers in upland while there was an increased trend of abandoning irrigable land by 111 ha (0.4%) in 1977 and 160 ha (0.6%) in 2001 by farmers in the lowland.

Moreover, a study on land use/land cover change and deforestation rates for the rain forests of the Nguru Mountains in Morogoro carried out by Monela and Solberg (1998) revealed forest encroachment for subsistence agriculture as well as establishment of settlements by indigenous people was the main cause of rain forest degradation. Likewise, Rugenga (2002) used remote sensing to study land use changes between periods 1955, 1976 and 1999 in Ruaha. The results showed that woodland and forest decreased at a rate of about 25 ha per year during 1955-76 and 53 ha per year for the period of 1976-99. At the same time forest decreased by 4 ha per year for the period of 1955-76 and about 14 ha per year for the period of 1976-99.

Another study that was based on the application remote sensing and GIS technologies was conducted in the Livingstone Mountain ranges. NEMC (2008) selected villages within the Livingstone mountain ranges to assess land use and cover changes. The results indicated that there were significant changes in the woodland ecosystem between 1990 and 2000 mainly due to agricultural expansion. Similar trends were also found by Nindi (2004; 2007) in the same district. The findings from GIS analysis support the results obtained from surveys that forests have been seriously cleared for cultivation in various parts of the Livingstone Mountain ranges. Overall cultivated areas increased by almost 20 653 ha from the year 1990 to 2000 (NEMC, 2008).

The changes in land use and land cover can therefore be monitored using the remote sensing technique (Jensen, 1996; Campbell, 1997). Geospatial information science and technologies provide critical information and tools for managers who work at the crossroads of resource use, land-cover change, poverty alleviation, and environmental management (Wang, 2005). In general, satellite remote sensing provides information on the time scale required for environmental monitoring. Using the different remotely sensed data processing software, such as ArcView, ArcGIS, ERDAS Imagine and others, it is possible to determine land use and cover changes and present the results obtained from the analysis in a form of maps, graphs or tables. Land use and cover data generated in a GIS is among the input variables in developing prediction models in most of the developed systems. Information and data on land use and cover changes generated from remote sensing data and GIS tools are very important for supporting decision-making on resource management at various levels. Thus, understanding driving forces behind landscape changes is of great importance in supporting decision making in natural resource management as presented in subsequent sections.

2.4 Driving Forces Influencing Landscape Changes

The main question in land use and cover change studies is "what drives/causes land-use/cover change?" This has always been one of the most common research questions. In response to this question, driving force has been simply defined by Braimoh (2004) as causes or factors responsible for land use and cover changes (LUCC). However, Briassoulis (2000) pointed that a precise meaning of the "drivers" or "determinants" or "driving forces" of land-use change is not always clear. Two principal distinctions are therefore made regarding the origins of the drivers of land-use/-cover change and these are biophysical and socio-economic drivers.

As quoted from Orékan (2007) “the bio-physical drivers include characteristics and processes of the natural environment (weather and climate variations, landform, topography, and geomorphologic processes, volcanic eruptions, plant succession, soil types and processes, drainage patterns, and availability of natural resources). On the other hand, socio-economic drivers comprise demographic, social, economic, political and institutional factors and processes (population and population change, industrial structure and change, technology and technological change, the family, the market, various public sector bodies and the related policies and rules, values, community organization and norms, property regime)”. Thus understanding both biophysical and socio-economic drivers for landscape change is important in developing prediction models.

2.4.1 Biophysical factors influencing landscape changes

Collaboration among remote sensing experts and social scientists has been increasing nowadays in order to improve our understanding of the biophysical factors and human activities that shape land-use/land-cover changes (Geoghegan *et al.*, 1998; Lambin *et al.*, 1999). Satellite remote sensing provides suitable data for mapping environmental conditions over large areas and time series data to monitor seasonal changes and long-term changes in land use and land cover (Jensen, 1996; Campbell, 1997). On the other hand social science provides a better understanding of the driving forces that give rise to proximate causes of land-use/land-cover change (Orékan, 2007). Important evidence of the rate and spatial distribution of deforestation has been provided by the analysis of remote sensing images (DeFries *et al.*, 2004; Makota, 2000; Mbilinyi, 2000, Nindi, 2004; Wang *et al.*, 2005; NEMC, 2008). Other researchers have studied deforestation at detailed scales by identifying the causes and underlying driving factors of the processes leading to deforestation (Geist and Lambin, 2002).

Land use patterns are usually influenced by variety of factors that act over a broad range of scales. Biophysical, climatic, and socioeconomic factors are important and need to be considered, when distribution of land use is to be understood (Kok, 2004; Chowdhury, 2006). The biophysical factors are mainly based on landform. According to Verburg *et al.* (2004), in the study conducted in the Sibuyan island of Philippines it was noted that the slopes and altitude were important factors influencing the suitability of the land for agricultural use. The topographical factor of aspect was also included in the analysis because it was supposed that slopes facing the south (windward side) were more suitable for agriculture due to their more favorable climatic conditions. Ghosh *et al.* (1996) conducted land use and cover change analysis in relation to identified biophysical factors including elevation, slope, aspect and bio-climatic classes. ArcInfo GIS software was used to carry out suitability assessment of land where agricultural extension occurred between 1963 and 1993.

These biophysical factors had different influence in the results of the study. Expansion of agriculture was found to be maximum in 2200-2400 metres elevation zone and 20–30 degree slope classes. When topographic aspects were considered expansion was maximum on south east and west facing slopes. The loss of vegetation cover was estimated to be 15 per cent between 1963 and 1993. However regeneration of forest was found to be maximum in elevation ranges of 1 600 – 2 000 metre and mostly having 20–30 degree average slope. Land deterioration over the two mapping periods was identified and strategies were suggested to mitigate the problem.

The study conducted in Pengyang County in China also indicated that the land-use change was driven by a combination of natural and socio–economic factors including slope, aspect, elevation, distance to road, soil types, and population density (Zhu *et al.*, 2009). Likewise, a study conducted in the Ashwani Khad watershed in India, the altitude, aspect and slope had exhibited marked effect on land utilization whereby agriculture and wasteland were found maximum in mid altitude (1 300 - 1 500m) and moderate slopes (13.2-26.4 degree), whereas, agriculture and forest had been located maximum in flat and north aspect (Mahajan *et al.*, 2001). The area for the Ashwani Khad watershed was divided into seven altitude classes (200m interval), nine aspect and nine slope classes (6.6 degree intervals) using ArcView GIS software.

Based on the above case studies it is clear that slope, aspect, distance from the road and elevation are among the biophysical factors that influence the location of land use and land cover. This understanding of causes and processes provides in-depth interpretations of the patterns of land-cover change derived from remotely sensed observations (Rindfuss and Stern, 1998). Likewise, in a study conducted to determine land use and cover changes in Mexico, among the biophysical variables considered were slope, elevation, soil type, rainfall and type of mature forest. In this study, slope and elevation information were derived from a DEM and subsequently areas falling in lower elevations and slopes were hypothesized to be preferred for agriculture, owing to potentially land cover changes in rugged terrain (Chowdhury, 2006). Moreover, in a study conducted in the western parts of Karpaty Mountains in Poland, Ostapowicz (2006) used distance to road as a factor to determine the distribution and increase in forest area. Different biophysical driving forces have therefore been applied in studies to determine their influences in land use and cover changes in different parts of the world.

In the case of Africa, the continent is characterized by its great natural riches, complex biodiversity and outstanding landscapes. This is certainly true based on the fact that 45 percent of the continent (30 113 Million km^2) consists of slopes of at least 8 percent (FAO, 1986). Farming systems are often cited as one of the major proximate causes of land-cover changes in tropical Africa, through the human interventions that alter the vegetation (Myers, 1994; Turner *et al.,* 1994). During the workshop on African Mountains and Highlands held in Ethiopia in 1986, it was reported that 90 percent of the cultivated land in Africa is in mountains and high plateaus above 1 500 m which covered 43 percent of the land surface (Messerli *et al.,* 1990). In the case of Ethiopia, the impact of human and livestock population is most intense in the higher altitude (highlands) areas, which constitute 43% of the land area but accommodates about 90% of the human and 80% of the livestock populations (Tewolde and Egziabher, 1988; CSA, 1998). Likewise, a study by Strömquist *et al.* (1999) in the southern highlands and Babati in Tanzania that considered topography, drainage systems and soils in the landscape analysis contributed to understanding of environmental change that is required for strategic environmental impact assessments and long-term natural resource-use planning.

Therefore, topographical features are so important in determination of landscape changes.

In the GIS analysis therefore, topographical features such as slope, aspect, and elevation can be derived from a Digital Elevation model-DEM (Kok, 2004; Chowdhury, 2006). According to Theobald (2000) deriving slope from a GIS theme refers to identification of slope or maximum rate of change, from each cell to its neighbours. In the analysis the output slope grid theme represents the degree of slope (e.g., 10 degree slope) for each cell location. Likewise, deriving aspect from a GIS theme refers to identification of the steepest down-slope direction from each cell to its neighbours. The values of the output grid theme represent the compass direction of the aspect; 0 is true north, a 90 degree aspect is to the east, and so forth. Kimaro (2003) observed that land use distributions in the Uluguru Mountains, Tanzania were relating to major geomorphic units. Furthermore he revealed that more than 80% of the V-shaped valleys and landslide scars were planted with banana as the main crop while 80% of the mountain foothills were intensively used for maize production. Banana was intercropped with maize in the talus slopes. Human disturbances in the alterations of most of the landscapes have shown to be among the key factors influencing the land use patterns; driven by the biophysical factors including climatic conditions prevailing in the area.

Climate is a weather condition that is measured in a particular area for a long period of time. Precipitation is among the most important component measured in a particular area for long period of time which largely influences land use systems change and vice versa (Young, 1978; Dale, 1997). The variability of precipitation tends to influence the pattern of land use in short and long terms in which the main effect is the alteration of the resource base. Reynolds *et al.* (1999) report to have noted the impact of short term climate shifts and year-to-year variability on plant production especially perennial grasses where plant production was found to be 50% greater than the normal rainfall variability in grass productivity. A slight shift in seasonal precipitation and/or frequency of extreme rain events could potentially lead to the over-exploitation of the meagre resources and contribute to further degradation of the resource base that human population depends upon (Le Houérou *et al.*, 1988). This implies that rainfall plays important role in determination of farming activities.

In the study area, various on-farm activities correspond to rainfall patterns and the *Matengo* have named such rainfall patterns according to their periods. The rain seasons are classified in four periods which mainly depend on activities that are performed on n*golo* fields (Table 1). The rain season normally starts between November and December (1). These early rains are known as "rains for field preparation". During these rains, old *ngolo* fields are weeded using hand hoes and ridges are reformed and furrows are made on them before sowing maize seeds. The January – February (2) rain period is normally used for weeding and thinning in maize fields and the heavy rains during this time are known as "rains for weeding". As a result of weeding, loose soils from *ngolo* sometimes erode and deposit in the pits. It is very rare to find eroded soils from *ngolo* flowing downhill. This situation happens only when *ngolo* were poorly made. The *Matengo* refer the showering rain period between March and April (3) as "rains for beans". Field preparations and the making of new *ngolo* are normally carried out at this time. The amount of rain decreases and reaches to an end towards late April and early May (4). This period is called the "last rains". Sometimes farmers also prepare new *ngolo* during this time and either plant beans or leave them unplanted until November-December when rain starts.

On the other side, ridges in the *Matengo* highlands are normally constructed either in November/December or March. Ridges are mainly used for planting maize and tuber crops. Those constructed in December can be planted with cassava or sweet potatoes intercropped with maize because maize requires long period of rain which may last from November to May of the following year. While ridges made in March are mainly intercropped with beans. Thus, climatic conditions have shown to be among the reliable factors determining farming hence influencing livelihoods and the general socio-economic aspects of the people.

2.4.2 Socio-economic factors influencing landscape changes

Over the next century society will increasingly be confronted with global changes such as population growth, pollution, climate and land use change (Schröter *et al.,* 2004). By 2050, the human population will probably be 2 to 4 billion larger than today (Cohen, 2003). Projections like these have led to a growing awareness of our vulnerability to global change. For instance, land use changes will have an immediate and strong effect on agriculture, forestry, rural communities, biodiversity and amenities such as traditional landscapes (Watson *et al.,* 2000; UNEP, 2002). Human pressure and land use has become a major problem of environmental degradation worldwide (Erlich, 1988; Wilson, 1992), but developing countries experiences more effects than in the developed countries because of the high population growth rate and the associated rapid depletion of natural resources. Ecosystems from the local to the global levels are under threat from the pressures of human resource extraction and pollution, driven by population, development policies, consumption and technology. Though some exceptions exist, rapid population growth has been condemned as the major cause of pressure exerted on resources such as availability of land for production of various crops and water (Geist and Lambin, 2002).

Rapid increase in population density in many localities has been found to be related to agricultural expansion and intensification and in some regions to deforestation (Turner *et al.,* 1993). Intensification of use of land caused by an increase in human and livestock population can have profound effects on the system by disturbing the ecological balance and this results in environmental degradation and disruption of the ecological interaction between highland and lowland systems, particularly in tropical and sub tropical regions (Mashalla, 1990). Population increase exerts more pressure on natural resources and poses a considerable challenge to sustainable resource utilization (Mascarenhas, 2000; Misana *et al.,* 2003).

Studies at longer time scale showed that increase and decrease of a given population always had and still has tremendous impact on land use/cover change (Geist and Lambin, 2002). Braimoh (2004) reports that increase in population in many regions had tremendous impacts on land use/cover. For example, the population density increase of Volta Basin in Ghana from 1984 to 1999 resulted into decreased area occupied by natural vegetation to cultivated land at a rate of 17% per annum. Orékan (2009) used distance to roads, distance to rivers, population density, and distance to settlements in order to assess their influence as driving forces in land use and cover changes in the Southern Upper Oueme Catchment in Benin. Similarly, Mbilinyi (2002) revealed that population increase in Ismani division in Iringa, Tanzania had caused a substantial decrease of about 2620 ha (85%) in the area under woodlands for the period between 1963 and 1978.

In the Livingstone Mountain ranges the population pressure put the Miombo woodlands under very intensive stress and has become smaller and fragmented. Deforestation has lead to severe implications not only in terms of vegetation cleansing but also changing river regime, flooding, increased sedimentation in the Lake Nyasa, ruined aquatic life, and hence further deterioration of livelihoods as well as the physical environment (Nindi, 2007). A study conducted by NEMC (2008) in the Livingstone Mountain ranges also revealed that increase in population pressure has been claimed by local communities to be the major driver of land use and land cover changes. The major concern was that with the increasing population it has been very difficult to get fertile land, while in many parts agricultural expansion is limited by the hilly terrain. In addition, integration between population pressure in the Matengo highlands (100-200 people/km^2 while district is 34 people/km^2) and changing development policies of market liberalisation that disrupted the common traditional production system have contributed to the recent landscape changes in the study area. It is therefore important to project future situations in terms of resource utilisation in order to support decision making to attain sustainable resource utilisation.

Development of land-use change models to generate projections requires, first, a good understanding of the major causes of these changes in different geographical and historical contexts (Lambin and Geist, 2002; Lambin *et al.,* 2003). Various studies (Ostapowicz 2006; Zhu *et al.*, 2009; Orékan, 2009) have shown the influence of driving factors such as distance to road, distance to river, elevation, and slope in land use and cover changes. The reviewed literature have shown that both socio-economic and biophysical factors are very important in influencing land use and cover changes in different parts of the world. Table 1 provides examples of biophysical and socio-economic explanatory factors used to develop land use and cover prediction models in selected countries within the tropical region (Lambin *et al.* 2000; Geist and Lambin, 2001; Serneels and Lambin, 2001; Soepboer, 2001; Verburg and Veldkamp, 2001; Willemen, 2002; Engelsman, 2002). As cited in Orekan (2007), the six case studies (Table 1) were selected based on the geographical location (tropical region) in which the specific countries are referred by numbers 1 to 6. Table 1 shows that distance to road, distance to river and elevation are among the frequently applied proximate driving forces for land use and cover changes in the various studies. These factors have almost been used in all studies conducted in the six countries. Thus, these factors have also been used in this study in the Livingstone Mountain ranges due to data availability that enabled them to be integrated in a GIS environment. Other important spatial factors such as climate and soils have not been used in this study due to lack of reliable data. Thus the use of the biophysical and socio-economic factors in the model has enabled to determine their influences to the livelihoods of local communities.

2.5 Influence of Landscape Changes to Livelihoods of Local Communities

A key issue that is central to the sustainable development debate is land use and land cover change, which stands as one of the main driving forces of global environmental change. Land use and land cover changes have impacts on a wide range of environmental conditions including the quality of water, land and air resources, ecosystem processes and function (Lambin *et al.*, 2000). Efforts and interventions to manipulate agro-ecosystems in order to meet specific production functions represent costs to the rest of the ecosystems in terms of energy, matter and biological diversity, and often negatively affect goods and services that so far were considered to be free and abundant for the livelihood (Swift *et al.*, 2004).

Table 1: Explanatory factors used in studies for land use and cover changes prediction within tropical countries

Drivers of Land use change	Case study references					
	Kenya (1)	Cameroun (2)	Nigeria (3)	Ghana (4)	China (5)	Philipinnes (6)
Demography						
Population density	x			x	x	x
Urban population					x	
Labour force density					x	
Agricultural labour force density					x	
Economy and infrastructure						
Distance to city (or towns)	x	x			x	
Distance to river (or river)			x		x	
Distance to stream			x			
Distance to road (or road)	x	x	x	x		
Distance to water	x			x		
Distance to forest/non forest		x				x
Market accessibility (or distance to market)						
Distance to settlements			x	x		x
Illiteracy			x		x	
Income					x	
Climate						
Range in precipitation				x		
Total precipitation				x		
Average temperature (temperature)						
Agro-climatic zone	x				x	
Geomorphology						
Mean altitude (or altitude/elevation)	x			x	x	x
Mean slope (or slope)				x	x	x
Aspect				x		
Soil						
Land tenure (or land status)	x			x		x
Suitability for agriculture (aptitude)	x	x		x		

Source: Orékan, 2007

Livelihood is the term widely used by different scholars on poverty and rural development. Its meaning can often appears elusive, either due to different definitions being encountered in different sources. Livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living (Chambers and Conway, 1992). According to Ellis (2000), livelihood comprised the assets and activities required for means of living. There are five main categories of capital that together determine the livelihood of the individual or household. These are: natural (land, water), human (e.g. health, education), financial (e.g. income stored such as cattle or money generated), physical (school, tools, roads, machine) and social (e.g. kin, associations) (Ellis, 2000).

An important attribute of livelihood that is subsumed under assets in Chambers and Conway (1992) definition is the access that individuals or households have in different types of capital, opportunities and services. The capital is not only the funds that are needed but also the basic infrastructure in the society. According to Scoones (1998), the social relations and networks in the village are called the social capital and human capital, in which case knowledge, ability to work and health is of great importance.

In Brazil (Altamira region in the Amazon rain forest), Deadman (2000) showed that people's livelihood improved with increasing levels of household capital accruing from decisions to grow combinations of perennials and pasture instead of annual crops only. The study also revealed that household capital resources and their demographic characteristics resulted into changes in the patterns of land use system and subsequently caused great deal of concern on losses of biodiversity.

Likewise, as pointed out by Sen *et al.* (2002), concentration of agricultural expansion in higher altitudes of the Pranmati watershed in Indian Himalaya where ecological conditions were more favourable for the most profitable crop potato indicated that agricultural expansion was driven largely by farmers' tendency for maximisation of income. Codjoe (2004) studied effect of changes in population and farming system on agricultural land use in Ejura-Sekyedumase district in Ghana and revealed that the higher income earning household through sale of farm produce increased land use systems change and land degradation in the area. In the case the Livingstone Mountain ranges, population pressure evoked a situation that Matengo farmers could no longer produce enough for their subsistence in the farm plots in the highlands instead have started cultivating in virgin land within the woodlands where in most cases they do not need to apply chemical fertilizers (Nindi, 2004; 2007; 2010; Mhando, 2005).

The Livingstone Mountain ranges provide a variety of ecosystem services such as water, food, fuel wood/energy, cultural services, fodder, mining, settlements, building materials, good soils for agriculture and medicinal plants (NEMC, 2008). However, according to FAO (1999), provision of such ecosystem services seem to be most at risk where they are most needed, i.e. in fragile ecosystems which characterize many poor countries and areas in the developing regions. In the study area the mountains provide the life supporting systems which are vital to the surrounding communities. However, it has been reported that these mountain ranges are also facing a severe degradation due to increased demand for ecosystems goods and services (Ellis-Jones *et al.,* 1994, Kangalawe and Lyimo, 2006; Nindi, 2007; NEMC, 2008). Human activities have been reported to be among the major factors threatening sustainability of the ecosystems in the Livingstone Mounatin ranges (Nindi, 2007; NEMC, 2008). The changes in ecosystem goods and services that result from land-use change feed back on the drivers of land-use change (Lambin, 2003). Therefore, landscape changes in the Livingstone Mount ranges has not only caused environmental concerns; but also livelihood stress to the local communities both in the highland and lowland areas, whose livelihoods rely on the use of natural resources (Nindi, 2007).

Mountains are at the origin of more than half of the global fresh water, supplying all the major rivers as well as many smaller ones and providing critical storage in lakes, glaciers and other places. But the critical role of mountain catchments areas is threatened by the major land cover and use changes that take place in mountains and highlands throughout the world. Many of Africa's mountain areas are increasingly important for providing natural resources for rapidly growing populations. When we consider the mountains and the adjacent lowlands, these areas form very complex "Highland-Lowland Interactive Systems" (Messerli *et al.,* 1990). Deforestation and forest degradation are rapid in the mountain areas of developing countries, which often are characterized by rapid population growth and resulting land scarcity and poverty. This is the case especially in tropical upland forests, even though these receive much less public attention than do tropical rain forests (Marcoux, 2000).

The land use patterns in the African continent are diverse and complex. The varied environments of the African continent have deeply influenced the social and cultural patterns of its people (Mashalla, 1990). In the rural areas local communities have interacted with the environment over centuries and people therefore have devised land use patterns and management skills in order to conserve the basis of their livelihood and their culture (UNEP, 2002). Over 30 per cent of the African population depends on agriculture for their livelihood, but in some of the poorest countries this share reaches 90 per cent (UN, 2000). Mountain environments are very fragile and delicate ecosystems and therefore overexploitation of natural resources has affected living conditions and Africa's natural treasures over the last decades (UNEP, 2002). An elaborate example of the Usambara Mountains in Tanzania suggests that almost 70 percent of the rain forests have been destroyed since 1954 (Madulu, 2004). Likewise, according to Masao (1974) cited by Carr (2004), the Chagga in practice farming in the southern slopes of Mt Kilimanjaro in Tanzania mainly between 1 000 and 2 000 meters above sea-level and have lived on the mountain for 250 to 400 years.

Intensification of the use of land caused by an increase in human and livestock population can have profound effects on the system by disturbing the ecological balance. This results in environmental degradation and disruption of the ecological interaction between highland and lowland systems, particularly in tropical and sub tropical regions (Mashalla, 1990). Similar consequences are evident at regional and national levels, including Tanzania. Mascarenhas (2000) studied the links between poverty and environmental degradation along the gradients of the Usambara, which is part of Tanga region in eastern Tanzania. He concluded that to reduce poverty, the protection of environment must be more directed towards the specific needs of the communities. Furthermore he recommended that the specific interventions for each ecological area's problems be addressed in collaboration with the area's inhabitants.

Mwalyosi (1990) studied land use in the Lake Manyara basin and hypothesized that proper utilization of the resources and environmental conservation depend largely on the people's perceptions of maintaining a sound ecosystem which leads to proper land use practices. In his study, the implications of resource utilisation by the local communities in the basin were not considered. Another study by Kajembe *et al.* (2005) considered the role of communities in participatory forest management to evaluate their impact on resource base and people's livelihood and analyzed critically the reasons for success or failure. This study did not critically analyze the implications of changes in the available forest resource to the local communities. Conventional methods used in planning and management of human-landscape interactions fall far short of the needs of decision makers who need to evaluate the impacts of humans causing land degradation in different landscapes.

Land degradation and its intertwining implication on highland-lowland nexus has been reported by various authors (Shetto, 1998; Madulu, 2004; Mascarenhas, 2004; Nindi, 2007). However, most of the analyses have focused on analysing the degradation of vegetation cover influenced by human activities such as overgrazing, ill-land use activities such as slash and burn agriculture, and cultivation on steep slopes without proper husbandry. Moreover, few studies that have focused on the impact of landscape changes to the livelihoods have analysed the livelihood changes and the changes in vegetation cover in isolation than as an integral component (Nindi, 2004; 2007). Recent studies (Nindi, 2007; NEMC, 2008) conducted in the Livingstone Mountain ranges found that deforestation, mostly through expansion of farming land, has lead to severe implications not only in terms of vegetation cleansing but also to the livelihood of the people in the Livingstone Mountain ranges and its lowland areas. The local people put the Miombo woodlands under very intensive pressure hence have become smaller and fragmented (Nindi, 2004). There is need therefore to understand such landscape change implications to local communities in the study area where farming is the main activities for the livelihood.

Farming is reviewed in this study because it has significant impact on both livelihood of the people and changes taking place on the landscape. In this respect farming practices, which forms an important category of ecosystems referred to as agro-ecosystem remains as one of the important human activity defining the land use pattern in the study area. Agro-ecosystems can be defined as ecosystems that have been deliberately simplified by people for the purpose of the production of specific goods of value to humans (Swift *et al.,* 2004). Shifting cultivation, as one of the farming practices, remains a highly successful means of environmental interaction throughout Sub-Saharan Africa (Schneider, 1981) where it forms the economic basis for many societies in the southern continent (Vogel, 1989). Despite the fact that the archaeology of this land use is only recent being detailed investigated (Jones, 1984; Sutton, 1986), it is already evident that its relationship with man in Africa has been long and fruitful (Schneider, 1981; Phillipson, 1985). In practice shifting cultivation is a particularly flexible mode of production, and the continent's farmers have exploited its ability to suit a diversity of environmental situations and many different kinds of social enterprise (Vogel, 1989).

Land use associated with human activities can be practiced anywhere even unusual, regardless of the topographical restrictions, but dependent on other parameters instead (Gerçek, 2008). As reported by Shively (2001), the area devoted to upland agriculture in the Philippines increased six-fold between 1960 and 1987, and coincided with a rapid decline in forest cover. High rates of forest clearing in the uplands were driven, in part, by the efforts of low-income farmers to secure subsistence. In the case of the cotton zone in Mali, Benjaminsen (2001) noted that agricultural development is transforming the landscape and the environment and the most obvious and visible environmental impact of this development is the extension of cultivated land at the expense of pastures and woodland. Likewise, in Mbinga district Miombo woodland is the dominant vegetation type that is also affected by the expansion of the cultivated land particularly in the Livingstone Mountain ranges (Lyimo and Kangalawe, 1997; MWARP, 1998; Itani, 1998; Nindi, 1999; 2004; Mhando, 2005; NEMC, 2008).

In order to address the landscape changes taking place in the in the Livingstone Mountain ranges it is always significant to associate the changes with the slash-and-burn and the traditional farming system of the Matengo called *"ingolu" or "ngolo"* (Plate 1). *Ngolo* farming system has mainly been considered because it is a unique farming system practised only in the Livingstone Mountain ranges where the Matengo people are found and l; subsequently it is being practised within the study area.

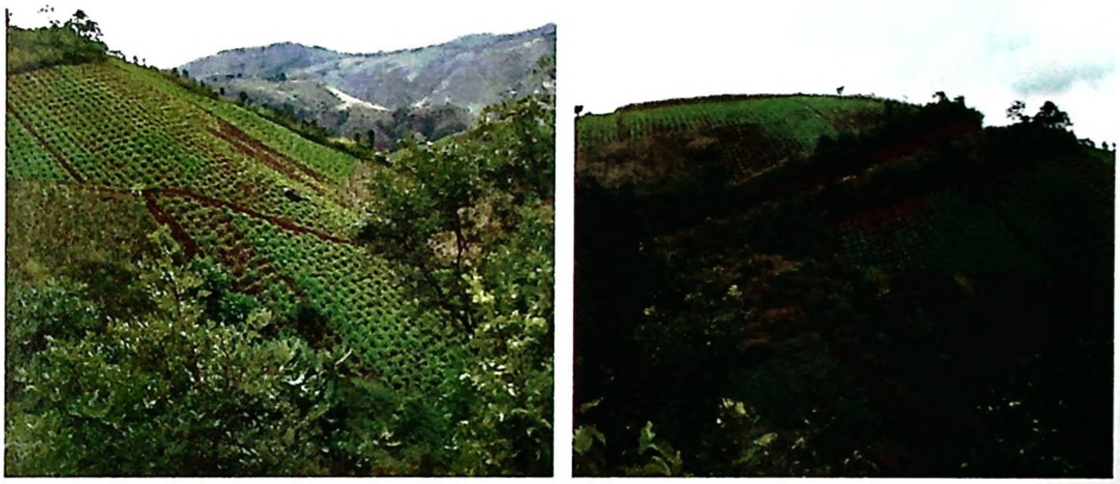

Plate 1: ***Ngolo*** **fields planted with beans in Livingstone Mountain Ranges**

Steinhouse (1944) found the manifestation of this hillside cultivation system that describe the spectacular land use in Matengo highlands very impressive, with an orderly layout, straight-cut edge and curiously pitted surface of the field. In this respect, detailed explanations of *ngolo* farming systems are reviewed in this study. This traditional farming system of the Matengo was also referred to as "the Matengo pit system" in the previous publications (MWARP, 1998).

Prior to *ngolo* establishment, the Matengo cultivators used to make furrows or diversion ditches in the upper slopes of cultivated fields to divert surface runoff away from flat-cultivated fields towards down-slope (MoA, 1983). Logs and twigs of trees reinforced the furrows or ditches. With time these ditches were no longer adequate to control huge volumes of runoff and associated soil erosion. At this time the Matengo had to evolve other best options to conserve their land, hence *ngolo* became into being. Researches have shown that *ngolo* farming system evolved among the Matengo over 100 years ago (MWARP, 1998). Literature on this farming system started to appear since when the German rule reached the Matengo area during 1890's (MWARP, 1998).

Associated problems with the Matengo pit farming system is that it is labour intensive when compared with other compatible systems of land use preparation such as ridges and bench terraces methods. Despite this problem *ngolo* farming is practised by over 75% of farmers who are settled in 6 000 km^2 area within the highlands (MWARP, 1998). Areas where this cultivation system is concentrated include Mikaranga, Mbuji, Nyoni, Langiro, Litembo, Maguu and Mkumbi wards in Mbuji division. This system is not practised along the shores of Lake Nyasa because the topography is less hilly in most of the areas (<10% slope) and the tradition of making pits is not one of the practises by the people living in these areas (Nyasa, Manda, Pangwa, and Kisi). Furthemore *ngolo* farming is less practised in Mbinga and Namswea divisions. Up to this time, *ngolo* making is a special art mastered only by the Matengo people themselves (MWARP, 1998), who also rely on coffee for their livelihood.

Africa has been increasing its market share, sometimes very significantly, for some of the high unit value agricultural products. Africa's agricultural exports are concentrated in a few commodities (coffee, tea, cocoa, sugar, cotton, bananas) and the largest importer of such products from Africa is by far the European Union (EU), now followed by China and the USA (UN, 2007). Market accessibility is one of the effective factors that influences land use changes in agricultural production (Zhou and Skole, 2001). Yanda (2010) noted that impact of free market economy or trade liberalization policy in Tanzania influenced the decrease in the area of Miombo woodlands in the western Tanzania due to an increase in the area cleared for tobacco cultivation. Thus, farmer's decisions on what and how much of agricultural commodities to produce have been influenced by the market systems (Hyden, 1980).

Introduction of coffee economy in the Matengo highlands in late 1920s further boosted the stability in the Matengo highlands. Thus, both the coffee economy and indigenous Matengo pit system (*ngolo*) have shaped land use and settlement stability in the area for many decades (Baserhart, 1972, 1973; MWARP, 1998; Rutatora and Nindi, 2004).

The stability of the Matengo economy as well as their settlement pattern was further strengthened by support from stable institutional setup of the cooperative unions, particularly Mbinga Cooperative Union (MBICU). According to Mhando (2005), MBICU supported production systems in the Matengo highlands through provision of farm inputs and marketing of coffee until it's relinquish in early 1990s. For many years MBICU had been a reliable market for coffee to Matengo farmers and it also used to provide farm inputs such as chemical fertilizers to support agricultural production in farmer's discrete farm plots in the upland areas (Nindi, 2010). The introduction of trade liberalisation of coffee market that also brought in private coffee buyers in early 1990s increased undue pressure to local cooperative union hence collapse of MBICU in the first half of 1990s (Mhando, 2005).

Collapse of MBICU impacted adversely on Matengo farmers' livelihoods as well as their land use and land resource management systems. Inaccessibility to farm input evoked a situation that Matengo farmers could no longer produce enough for their subsistence in the discrete farm plots in the highlands. Among the reasons for deforestation in the Livingstone Mountain ranges is the economic destabilization faced by the Matengo since 1990s especially after collapsing of MBICU (Nindi, 2007). According to Kull (1998), factors that are generally accredited to determine the course of land use and land cover change include state politics, market incentives, climate variations and access to land and water resources. Thus, modeling of such factors that relate to landscape changes is important to help decision makers and planners in effecting their efforts toward livelihood improvement and landscape conservation.

2.6 Spatial Modeling for Predicting Ecosystems Vulnerability

2.6.1 Classification of models

The classification of modeling approaches varies depending either on the issue or goals (land-use conversion, intensification, management) or the discipline (geography, natural science, economics, urban planning, regional science, and geographic information science). Appendix 1 presents a general overview of Land use and cover change (LUCC) modeling approaches developed by different scientists (Kaimowitz and Angelsen, 1998; Lambin *et al.*, 2000; Irwin and Geoghegan, 2001; Lambin, 2004), cited by Orékan (2007). Thus, five broad categories of models are distinguished as follows: empirical-statistical, stochastic, optimization, dynamic (process-based) simulation, and integrated models.

Therefore, different categories of models are used for predicting land use and cover changes. The use of models for predicting future land use and land cover changes are important for a number of reasons including determining the vulnerabilities of various land resources to future land conversions and also for conservation and management purposes. However, as pointed out by Metzeger (2006), most published impact assessments do not address the vulnerability of the human - environment system under environmental changing conditions. Thus, as the conversion of natural resource lands to developed land cover poses a significant threat to ecosystems, this study finds the importance of focusing on simulating and predicting ecosystems vulnerability based on the landscape changes. By observing the prior environment it is necessary to make some assumptions on land-use changes based on scenarios and develop a model to draw the future situation of the landscape using CLUES Modeling Framework developed by Verburg *et al.* (2004).

2.6.2 Scenario development in land use and cover changes studies

According to Millennium Ecosystem Assessment (2005), scenarios are plausible and often simplified descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces and relationships. Furthermore, Alcamo and Ribeiro (2001), pointed out that a typical scenario used in environmental studies consist of description of step-wise change, driving forces as determinants that influence step-wise changes, base year (usually the most recent year in which adequate data are available), time horizon (most distant year covered by scenario), time steps and storyline. They went further defined a storyline as "a narrative description of a scenario, which highlights its main features and the relationships between the scenario's driving forces and its main features". From this definition it is noticeable how important is to expertise a set of driving factors, to define mutual relationships between them, to use different methods to quantify influences and effects of them and to pay attention to important relations and feedbacks. Strömquist *et al.* (1999) emphasise that combination of scientific competence, local knowledge, and experiences of the local environment are important aspects in widening the assessment perspectives and the prediction competence.

Moreover, Wollenberger *et al.* (2000) argue that information about the forces shaping the system includes the structure of resources, actors, institutions, events and relations among them. It contains identification of slow changing, predictable trends and identification of uncertainties and potential major drivers of change. To create a scenario study, we can use e.g., expert's knowledge, extrapolation of trends or mathematical method (e.g., regression). Scenario methods have used various forms of stakeholders input to make relevant to various uses Wollenbereger *et al.* (1999). Alcamo and Ribeiro (2001) have divided scenarios into two essential groups which are qualitative and quantitative. Qualitative scenarios are expressed by words, and quantitative ones are represented by numbers. Another way of classifying scenarios is to distinguish between business as usual versus policy scenarios and exploratory versus anticipatory.

Business as usual scenarios is defined by Alcamo and Ribeiro (2001) as presentation of "future state of society and the environment in which environmental policies either do not exist or do not have a discernible influence on society or the environment". In contrary, policy scenario depicts the future effects of environmental protection policies. Main divergences of mentioned scenarios are in their purposes. Business as usual scenario evaluates the consequences of current policies and try take into account the uncertainty of both driving forces and environmental conditions. In contrast, policy scenario identifies policies that attain specific environmental goals or norms and examines the economic and environmental impacts of specific environmental policies and try to take into account the uncertainty of future environmental conditions and societal driving factors. The last type of scenarios is exploratory and anticipatory. "Exploratory scenarios (also known as descriptive scenarios) are those that begin in the present and explore trends into the future. On the other hand, anticipatory scenarios (also known as prescriptive or normative scenarios) start with a prescribed vision of the future and then work backwards in time to visualise how this future could emerge" (Alcamo and Ribeiro, 2001). Scenarios are therefore used for predicting future situations based on prevailing conditions.

In this study therefore, business as usual, policy and exploratory scenarios have been used. The business as usual scenario has been used to predict future situation based on the assumption that the current trends of landscape changes identified from remote sensing and GIS tools continue in the study area. On the other hand, policies such as a strategy on Urgent Actions on Land Degradation and Water Catchments are the basis used for developing a policy scenario. Likewise, exploratory scenario has also been used based on findings from remote sensing and GIS analysis on landscape changes. In addition, knowledge and experience of a researcher over a study area are of great importance in the formulation of exploratory scenario (Alcamo and Ribeiro, 2001).

2.6.3 The use of remote sensing and GIS in modeling applications

Remote sensing and GIS technologies serve as key components of emerging land-use change modeling approach. Many different types of models have been developed to assess the impacts that both natural and anthropogenic changes can have on the environment. More recently, models have been developed to address the effects that human induced land use changes can have on different aspects of the environment including surface water quality, groundwater recharge and pollution. Other aspects include habitat fragmentation, wildlife loss, floral and faunal community composition, and impaired ecosystem function (EPA, 2006).

The power of a GIS lies in its ability to separate information in layers and combine with other layers of information to support decision making. Thus, GIS is much more than a software application; it is a decision-support tool (Foote, 1997). Many modern GIS software packages offer user-friendly, Windows-based environments. Among the software packages popular with planning professionals are Atlas GIS, IDRISI, ERDAS-

Imagine, MapInfo, and Environmental Systems Research Institute packages such as ArcView, ArcGIS and ArcInfo GIS.

Therefore, remote sensing and GIS are important tools in providing spatial information on land use and cover for supporting decision making. Improved scientific knowledge of historic and current land use and land cover changes is required as a basis for understanding the dynamics and trends in land use and land cover change. This characterization provides a baseline for monitoring land use and land cover change as well as developing understanding that allows models to be developed that project land use and land cover change into the future (Aspinall, 2004). As indicated by Lambin (2004), modeling land use and cover changes provide important answers to questions such as:

- Which socio-economic and biophysical variables contribute to explain land-use changes and why? Which locations are affected by land-use changes – where? And at what rate do land-use and land-cover change progress – when?

2.6.4 Modeling land use and cover changes

The changing patterns of the landscape, including the changing biophysical properties of that landscape, form a central theme in environmental planning. The tasks of land use and cover change modeling are becoming more urgent as a result of increasing anthropogenic impact which causes irreversible local and global change of nature ecosystems. Kasperson and Kasperson (2001) pointed out that the central elements of sustainability research are focused on the vulnerability of coupled human-environment systems. Vulnerability is not only a result of the exposure to hazards, but also resides in the sensitivity and resilience of the system experiencing such hazards (Turner *et al.*, 2003).

Land use change is one of the major determinants of vulnerability within the human-environment system whereby in order to improve our understanding of the mechanisms leading to vulnerability and resilience within the environment and ecosystems, system-based research approaches become more crucial in this aspect (DeFries *et al.*, 2004). Within the land we find the ecosystems that provide a number of vital goods and services for people and society, such as food, fibre, water resources, carbon sequestration, and recreation. However, the future capability of ecosystems to provide these services is determined by changes in many factors including socio- economic, land use, atmospheric composition and climate. Land-use change modifies the spatial configuration of different land-use types; it also has direct impact on the spatial extent of ecosystems resulting from deforestation and desertification (Turner, 1989; Sala *et al.,* 2002). Hence, ecosystem vulnerability and resilience are related to the spatial configuration of land-use types within the landscape. However, DeFries *et al.* (2004) noted that most impact assessments do not quantify the vulnerability of ecosystems and ecosystem services under such environmental change. They further noted that ecosystem functioning can respond to changes in the spatial pattern of land use as a result of habitat fragmentation, changes in landscape diversity, patch shape and size, and similar processes. Therefore, the study of changes in landscape pattern as a result of land-use change is an important component of vulnerability assessments.

While the availability of extensive and timely imagery from various satellite sensors can aid in identifying the rates and patterns of deforestation, modeling techniques can evaluate the socio-economic and biophysical forces driving deforestation processes (Chowdhury, 2006). As indicated by Geoghegan *et al.* (1997; 2001), the use of satellite imagery and GIS tools in modeling applications is more advantageous due to the possibility of generating relevant, spatially explicit variables for analysis. Chowdhury

(2006) pointed out that "in regression models of deforestation processes, for instance, the products of satellite image classification yield the dependent variable, such as locations and/or area of deforestation. Image classification may also yield rich ancillary datasets (independent variables) that can be used to test specific hypotheses about deforestation dynamics. For instance, present-day landscape structure may be hypothesized to influence future deforestation, as fragmented forests tend to be more vulnerable to further change. Similarly, access to roads and hydrology may be driving forces of tropical deforestation".

Within the international Land Use and Land Cover Change (LUCC) project (Turner *et al.* 1995; Lambin *et al.*, 2000), it has been realized that understanding and modeling the factors determining the location of land-use change at different spatial and temporal scales has been the focus of researchers originating from different disciplinary backgrounds (Brown *et al.*, 2000; Pontius *et al.*, 2001; Thompson *et al.*, 2002). Different studies such as that by (Geist and Lambin, 2002) have provided knowledge of the factors responsible for the spatial allocation of land-use change. In a study conducted in Maryland's forests in the USA, it was realised that forests were vulnerable to a variety of other pressures; and vulnerability was characterized in terms of human and other stressors. Forest vulnerability was assessed by analysing the projected or anticipated land use change, development pressures on forested lands, existing patterns of forest fragmentation and susceptibility of the forested land base to fire. In this respect, the use of remote sensing and GIS is crucial in land use and cover change modeling for predicting ecosystems vulnerability in the Livingstone Mountain ranges due to on-going degradation taking place in the ecosystems.

2.6.5 Models developed for predicting land use and cover changes

There are various models developed for predicting land use and cover changes (LUCC) including the Land Transformation Model (LTM) and Land Use Change Analysis Software (LUCAS). Description of the models is summarized below based on a report by EPA (2006).

Development of the Land Transformation Model (LTM) began in 1995 at Michigan State University and is still ongoing. The model uses landscape ecology principles and patterns of interactions to simulate land use change process and to forecast land use change. Though the model can be used in any definable region, precedence is given to watersheds as the spatial extent in LTM applications. Conceptually, the LTM contains six interacting modules: 1) policy framework; 2) driving variables; 3) land transformation; 4) intensity of use; 5) processes and distributions; and 6) assessment endpoints.

The pilot model of LTM was developed for Michigan's Saginaw Bay Watershed and contains two of the six LTM modules; driving variables and land transformation. The pilot model integrates a variety of land use change driving variables, such as population growth, agricultural sustainability, transportation and farmland preservation policies for the watershed. The LTM can address up to eight different land-use types. The ones of interest in this study include Agricultural, Forest, Wetlands, Water, Preservation and Park Land because most of these land use types are also found in the study area. To operate the model, there should be a GIS data base that contains basic land use information. At a minimum, input data (Table 2) are needed in the model.
Output of the LTM includes a time series of projected land uses in the watershed at user specified time steps. Outputs are in the form of land use projection maps GIS (ArcInfo

GRID) and data summaries in Excel format. The strength of LTM is based on the fact that GIS outputs provide stakeholders and resource managers with easy to understand results and also it allows users to explore various types of inputs that are parameterized using GIS.

Table 2: Input data for the Land Transmission Model

No.	**Input Layer**	**Format**
1.	Previous land use	ArcInfo GRID
2.	Roads, highways, streets	ArcInfo Lines
3.	Surface water (rivers, lakes, etc.)	ArcInfo lines or polygons
4.	Elevation	ArcInfo GRID
5.	Public lands	ArcInfo GRID
6.	Population	ArcInfo GRID
7.	Per capita use requirements	ArcInfo GRID

Source: EPA (2006)

Land-Use Change Analysis System (LUCAS) was developed in 1994 by the Department of Computer Sciences, University of Tennessee to examine the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability. LUCAS stores, displays and analyzes map layers derived from remotely-sensed images, census and ownership maps, topographical maps, and outputs from econometric models using the Geographic Resources Analysis Support System (GRASS), a public-domain GIS. Simulations using LUCAS generate new maps of land cover representing the amount of land-cover change. Aspects of biodiversity conservation, conservation goals, long-term landscape integrity, changes in real estate values, species abundance, and land-ownership characteristics can be addressed by LUCAS. However, (LUCAS) requires a UNIX-based workstation (e.g., Sun SPARC station), Microsoft Windows with the OSF/Motif library toolkit, a color monitor and a color printer. GIS (GRASS) and spreadsheet software is necessary to analyze the results.

LUCAS can address many different land-use types. The ones of interest in this study include the non-urban categories such as: Agricultural, Forest, Wetlands, Water, Preservation and Park Land. The GIS used by LUCAS is GRASS, but most commercial GIS software can readily convert their files to the GRASS format. The input data (Table 3) are required:

Table 3: Input data for the LUCAS Model

No.	Input Layer	Format
1.	Transportation networks (access and transportation costs)	GRASS grid
2.	Slope and elevation (indicators of land-use potential)	GRASS grid
3.	Ownership (land holder characteristics)	GRASS grid
4.	Land cover (vegetation)	GRASS grid
5.	Population density	GRASS grid

Source: EPA (2006)

Output of the LUCAS includes a time series of projected land uses in the watershed at user specified time steps. The strength of LUCAS is based on the fact that it provides a graphical user interface that is intuitive and easily understood by users with a wide range of technical abilities and experience. It also provides a flexible and interactive computing environment for landscape management studies. However, the limitations of LUCAS include issues such as many bugs that still exist in the GRASS software because it is a non-commercial GIS package. Likewise, some of the features of GRASS are not well-documented. Furthermore, the model requires training and experience to calibrate. It is not a commercial off-the-shelf product and was developed to be used by a researcher working with resource managers.

Models can therefore be developed to suit different applications. The following are some of the examples of models developed for predicting land use and cover changes in selected studies. Fan *et al.* (2007) conducted a research in Pear River Delta in China using remote sensing and GIS techniques to determine the LULC changes in this region and subsequently developing a land use change prediction model. The main objective of the study was to predict the land use and cover changes from 1998 to 2003 based on biophysical and socio-economic factors. They used four predominant cloud-free Landsat TM/ ETM+ imagery of the core corridor delta. The key of the study was the change detection by post-classification method, which is one of most widely used methods in change detection (Jensen, 1996; Campbell, 1997).

The Markov chain model was divided into two crucial steps. The fist step was to obtain the transition probability matrix of various land use types which could give more detailed information about inter-class transitions among different land-use-types; and the second step was to predict the land use based on the probability values of first step which could provide temporal predict information. Based on the transition probability matrix, predictions of urban expansion and farmland loss in the study area were performed. In order to verify the CA model and build the modeling rules, the CA model was tested and calibrated in the study area using the data of real urban land changes from 1998 to 2003. The urban land image in 1998 was used as the original state and the modeled result image were compared with the real urban land image pixel by pixel. The rules such as converting probability, rate and area were adjusted until the modeled data and the real one become "very similar." Then the modeling rules could be determined. The results from this study showed that remote sensing images and Markov chain model are effective ways to analyze dynamic land use change, monitor and predict the land use/cover change temporally such as urban expansion and farmland vanishing.

Tran and Knight (2005) developed a fuzzy decision analysis model for integrating ecological indicators. This is a combination of a fuzzy ranking method and the Analytic Hierarchy Process (AHP) that is capable of providing an integrated ecological index ranking ecosystems in terms of environmental conditions and suggesting cumulative impacts across a large region. Using data on land-cover, population, roads, streams, air pollution, and topography of the Mid-Atlantic region, it has been possible to point out areas which are in relatively poor condition and/or vulnerable to future deterioration. However, they insisted we should not assume that broadly similar coupled systems have the same vulnerabilities. Since complex dynamics may cause consequences to vary by system or locale.

Moreover, popular approaches, such as location-seeking models and location-allocation models, have been developed (Zhang *et al*., 2001). In this respect, Yanuariadi (1999) developed a GIS-based model for supporting decision making in land allocation for the establishment of sustainable industrial forest plantation in Indonesia. Problems in acquiring lands for such establishment were becoming ever more complex because the rate of land degradation tended to increase, thus decreasing the availability of suitable lands.

Sharma *et al.* (2006) developed a Multipurpose Land Information System (MLIS) for community-wide enterprises. The MLIS is a Spatial Decision Support System (SDSS) which was developed under the GIS software tool, SPANS (Spatial Analysis System) and

ArcView, and the system is running in Microsoft Windows Operating System. The system was tested and implemented successfully in the chosen study area of Hooghly District of West Bengal, India. However, this system is suitable for land management applications particularly for cadastral mapping rather than change detection applications. We need to have a system that can predict ecological vulnerability based on the prevailing local conditions including policies (if any), and trends of resource utilization (land use and cover changes).

Likewise, Zhang *et al.* (2001) developed a spatial dynamic model for urban development for the city of Beihai in southern China. This model was used to simulate the dynamic change of the urban spatial structure by considering urban spatial growth as the result of spatial interaction between of demand and supply of urban resources. This model provides information for decision support in urban planning and land use management. However, this model is applicable in urban environment as opposed to rural areas which have different social, cultural, environmental and economic conditions especially in developing countries.

Likewise, a land use change prediction model was also developed in Kenya, around an area located at the Kenya–Tanzania border and adjacent to the Serengeti National Park in Tanzania. The objectives of this study were to develop a spatial, statistical model of the proximate causes of different processes of land-use change in the Masai-Mara Ecosystem, taking into account the spatial variability of the land-use change processes and to identify how much understanding of the driving forces of these changes could be gained through such a spatial, statistical analysis (Serneels and Lambin, 2001). In this model the main land uses considered were mechanized agriculture, rangeland modification and small holder impacts. On the other hand explanatory factors such as distance to road, distance to water, elevation, population density, agro-climatic zones were used. However, the study area in Kenya had different topographical conditions compared to the study area in Mbinga district. In the Kenyan situation, the area was favorable for mechanized agriculture, showing that the area was relatively flat. This is also justified by the exclusion of the slope variable in the model. In contrary, the study area in the Livingstone Mountain ranges is mountainous with very steep slopes. Thus, slope was considered among the important explanatory variables in this study in Mbinga distict.

Conclusions from the reviewed land use and cover change prediction models show that most of them have been applied in areas outside Africa and in most cases these models are used for prediction of land converted from cultivated to urban categories such as commercial, industrial and residential uses. Most of these models have not been tested in a rural African environment like Tanzania, where the main land use changes results from conversion of natural vegetated environment to cultivated land and settlements. In the case of the model developed for the Mara Ecosystem in Kenya, the existed conditions were different from the study area in Mbinga distict. Thus, substantial need exists to warrant efforts to make land use and cover change predictions.

The driving philosophy is that a better prediction will reduce risks in land use decision-making. Prediction of land-use change involves several steps: selecting the predictor variables, obtaining the measurements (preparing the variable coverages), establishing the relationships between the dependent variables and independent variables, building and running the prediction model, and mapping out the predicted values (Allen *et al.*, 1999). The biggest challenge to GIS experts is on developing GIS applications that suits specific needs of certain situations. This study therefore realized the need to understand future conditions of the land use and cover changes in the Livingstone Mountain ranges in Mbinga district where human induced factors are very influential in the landscape changes taking place. In this case it is important to develop a land use and cover change prediction model whereby predicting the near future situation is crucial for supporting decision making at various levels.

In this study therefore the land use/cover change model framework selected was the Conversion of Land Use and its Effects at Small regional extent (CLUES) model developed by Verburg *et al.* (2002). The CLUES modeling framework is specifically developed for regional applications with a high spatial resolution. The model is developed for the analysis of land use in small regions (e.g., a watershed or province) at a fine spatial resolution Verburg *et al.* (2002). It consists of a non-spatial and spatial model, operating at respectively the regional and pixel level. The pixel level in this study consists of a grid with a pixel size of 100 X100 meter on the ground. The CLUES enables better understanding of land-use change complexity and allows the exploration of future land-use management options and their effects on environment and ecosystems.

2.6.6 The conversion of land use and its effects (CLUES) modeling framework

In general, empirical-statistical models that use regression models are intrinsically not spatial. Spatial statistical models are based on a combination of GIS and multivariate statistical models (Lambin, 2004). In spatial empirical model empirical data and statistical methods are used to quantify the relationships between variables and results are displayed cartographically representing the future land use and land cover patterns as a result of the continuation of the existing land use and land cover. The model is built to describe the relationship between the dependent variable, e.g. the binary variable forested/deforested, and the independent landscape variables (Chomitz and Gray, 1996; Mertens and Lambin *et al.*, 2000).

According to Veldkamp and Fresco (1996), the CLUES (Conversion of Land Use and its Effects) modeling framework was developed to simulate land use change in relation to socio-economic and biophysical factors. The CLUES modeling framework is a dynamic spatially explicit simulation methodology which uses actual and historical land use patterns in relation to biophysical and socio-economic determinants for the exploration of land use changes in the near future (Verburg *et al.*, 2004). The CLUES Group (2004) backed it up that "besides tracking past or historical land use changes, the objective is to explore possible land use changes in the near future under different development scenarios". CLUES model can be described as multiscale stepwise regression model which relates changes in the area of the different land use types to socio-economic and biophysical factors. For this purpose the model uses empirically quantified relations between land use and its driving factors in combination with dynamic modeling of competition between land use types (Verbung *et al.*, 1999b).

The CLUES modeling framework has been implemented in different case studies and countries. Some of the case studies include Costa Rica (Schoorl *et al.*, 1997), Java (Verburg *et al.*, 1999a), China (Verburg and Veldkamp, 2001), Philippines (Verburg and Veldkamp, 2001, Central America (Kok and Winograd, 2002), Central Benin (Judex *et al.*, 2006), Philippines (Overmars, 2007), Vietnam (Castella and Verburg, 2007). The CLUES modeling framework has also been used to develop models to allocate the land use changes at national level to different locations within 25 countries in Europe under the European Rural Areas (EURURALIS) project (Strakova, 2009). The CLUES model is divided into two distinct modules; the non-spatial demand module and the spatially explicit allocation module. Details of the CLUES model are provided in Chapter 3.

The CLUES modeling framework is an example of advanced statistical land-use change (Veldkamp and Fresco, 1997) which simulates land-use conversions based on regression model. The present study aims at adapting a model describing a spatially complex process of interactions between socioeconomic and remotely sensed data in the part of Livingstone Mountain ranges in Mbinga district which faces profound land use and land cover changes. The CLUES modeling framework, especially the CLUES (which can be applied in small extent areas) is suitable for this purpose because it has been implemented in different areas starting from local, regional and national levels including rural areas in developing world where agriculture is the main driver of landscape changes. The CLUES modeling framework therefore, was selected and used in this study based on the conditions of the study area in terms of its spatial extent, dynamics of the land use and cover and functionality and applicability of the framework itself in such kind of environment and best fit of the model framework in rural areas of Africa/developing countries.

2.7 Policies and Statements Related to Environmental Management

Decision-makers need data and tools to monitor and assess natural resource inventories, environmental change, and social change. In 1992 during the landmark U.N. Conference on Environment and Development in Rio de Janeiro, world leaders adopted a work program "Agenda 21". The chapter of Agenda 21 which addresses "Information for Decision-Making" stresses the need for more and different types of integrated social, economic and environmental data. The Rio Conference and other similar environmental milestone activities and happenings, recognized the need for better and more knowledge and information about environmental conditions, trends, and impacts (Segnestam, 2002).

The World Summit for Sustainable Development (WSSD) held in Johannesburg, South Africa in September 2002 was the next milestone event for world leaders in addressing progress made on Agenda 21 and to refine priorities for the future. Prior to the WSSD it was clear that despite significant improvement in earth observation data and information management systems since 1992, much remained to be achieved in applying remote sensing and geographic information to sustainable development in Africa (Wang, 2005).

Tanzania, like other developing countries, is striving to ensure that her environment and ecosystems in general are managed sustainably. To ensure the sustainable management of her environment, Tanzania developed and adopted the National Environmental Policy (NEP, 1997) and the Environmental Management Act (EMA) No. 20 of 2004. The National Environmental Policy of 1997 stipulates major environmental consequences of human perturbations which among others include land degradation through vegetation clearance. EMA, which became operational on 1st July 2005, gives due recognition to ecosystems issues and management as exemplified under Section 58. This section gives the National Environment Management Council (NEMC) the mandates to identify and protect mountains, hills and landscapes that are at risk from environmental degradation.

In 2009, the government of Tanzania launched the Kilimo Kwanza Initiative, which means 'Agriculture First' in English, to transform agriculture into a modern and commercial sector to improve food production. In poor countries such as Tanzania where the livelihood of the majority of people rely on agriculture it is crucial to consider the role played by agriculture in poverty reduction strategies. As pointed out by the Honorable Excellence Mizengo Kayanza Peter Pinda, Prime Minister of Tanzania, *"the world is recovering from a global food and financial crisis --- Africa must take the bull by the horns and end the structural reasons that prevent it from feeding itself"* (AGRA, 2009). Growth in agricultural value added had the largest impact on poverty reduction in Asia (Policy Forum, 2009). Thus, the Kilimo Kwanza Initiative, among others, it also encourages small farmers to increase their production using improved seeds and fertilizers in areas where land is available.

In Tanzania, land degradation is not only taking place in Livingstone Mount ranges alone. Having realised the land degradation taking place in the mountainous areas, the central government has raised a concern and issued a strategy on Urgent Actions on Land Degradation and Water Catchments. Among other things the strategy emphasises that--- "*all those who have invaded the ranges and mountains of Livingstone, Kipengere, Udzungwa, Uluguru and Kilimanjaro for farming, settlement and tree harvesting should vacate, by June 2006. The areas are the main water sources for Nyasa, Ruaha, Kilombero, Ruvu and Pangani basins*" (URT, 2006). This statement also signifies the presence of poor land use and resource management in these areas. As argued by the BirdLife International (2005), conservation issues in the Livingstone Mountain ranges include forest and woodland clearance for agriculture, burning and cultivation of steep valley slopes, all of which threaten the areas. This study has therefore developed a model (LIM-CLUES) for simulating the landscape changes in the study area that will help decision makers, planners, researches and other stakeholders at in their initiatives to manage natural resources for the benefit of all, at local, national and international levels.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Overview

This chapter presents materials and procedures used in data collection, data analysis and model development. It starts with description of location and study area and then explains about the research design and sampling procedures used in the study. Moreover, it provides details on procedures or methods used for data collection and data analysis. Finally it presents processes that have been involved in model development.

3.2 Description of the Study Area

This study was conducted in Mbinga district, which is among the four districts forming the Ruvuma region. The district is situated to the Southwest of the region and it is bordered by Ludewa district to the North, Songea district to the East, the Republic of Mozambique to the South and Lake Nyasa to the West, which borders Malawi. The study area lies between 10°30'S and11°45'S and 34°30'E to 35°15'E (Figure 2). It includes an area which is covered by 19 wards whereby 11 are located in the mountain areas and the remaining 8 are in the lowland area. Therefore, the study area occupies parts of the Livingstone Mountain Ranges and its adjacent lowland areas, bordering the Lake Nyasa. The main survey was conducted in the six villages namely Makonga, Buruma and Lumecha, which are located in the upland area and Chiulu, Nangombo and Ndengele in the lowland area. The entire study area for modeling purposes is about 30% of the total area of Mbinga district.

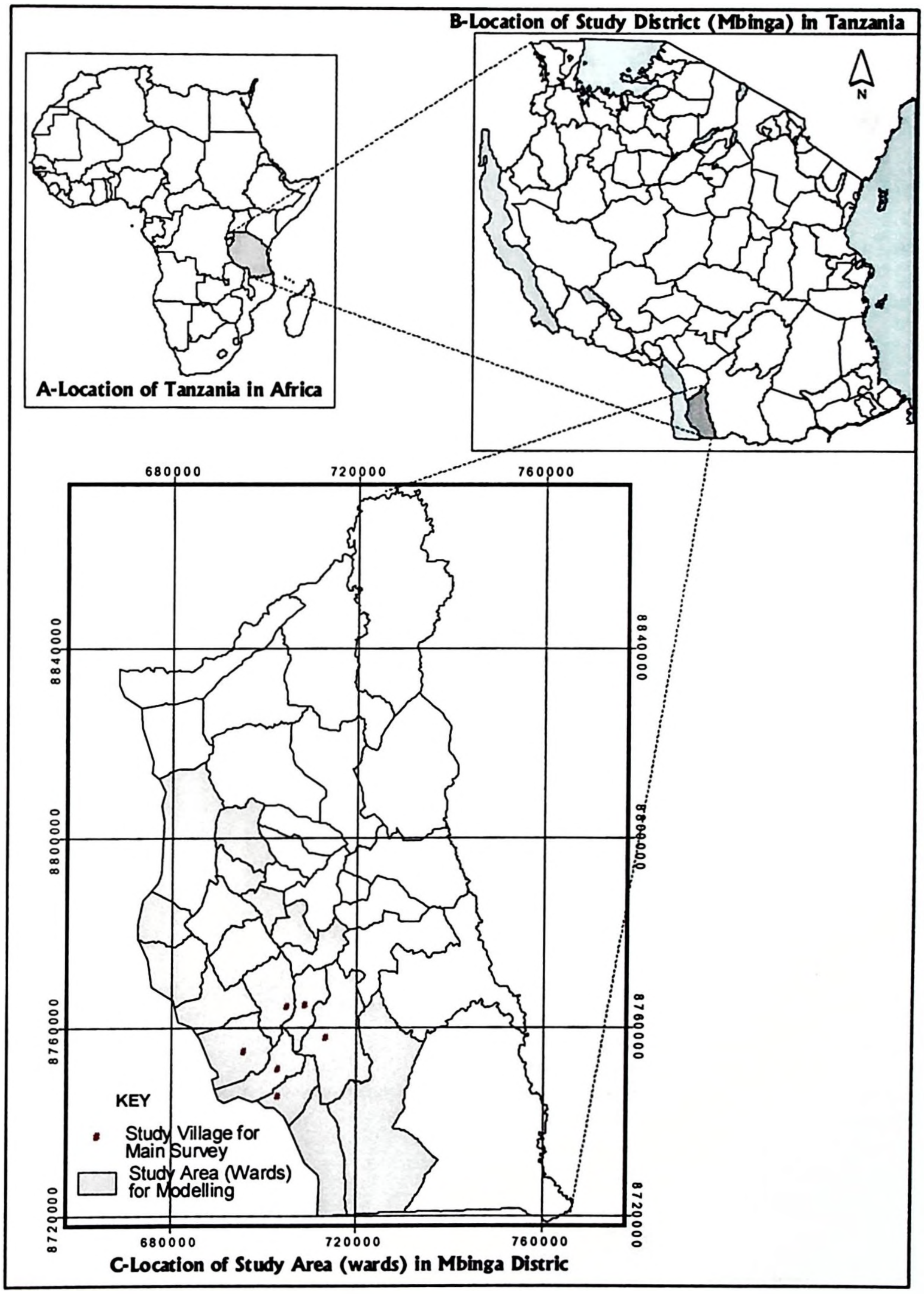

Figure 2: Location of the study area.

3.2.1 Topography

Mbinga District is mainly composed of mountains, Lake Nyasa and its adjacent lowland areas, valleys and plateaus. The district lies within an altitude ranging from 400 to 2100 metres above sea level. The variable characteristics that represent a combination of unique altitude ranges divide the district into four major agro-ecological zones (Table 4). Most parts of the Livingstone ranges are included within the "Mountainous areas" agro-ecological zone of the district (ICRA, 1991; Lyimo and Kangalawe, 1997).

Table 4: Classification and description of agro-ecological zones of Mbinga District

Agro-ecological zone	Altitude (m.a.s.l.)	Annual rainfall (mm)	Descriptive features
Mountain areas			This zone is characterized by strongly dissected mountains with steep slopes and narrow valleys. Because of altitude and local microclimatic conditions this agro-ecological zone is very suitable for coffee production.
High altitude	1600-2100	1400-1600	
Low altitude	1400-1600	1000-1400	
The Hagati plateau	1500	1400-1600	This agro-ecological zone is characterised by gently rolling plateau at the top of the mountains. This zone is located between the mountain zone west of Mbinga and ranges down to Lake Nyasa. The main differences between the plateau and other zones are the shallow soils and unique microclimate (ICRA, 1991). This zone is also suitable for coffee.
Rolling Hills	1200-1300	1000-1200	This is the largest agro-ecological zone covering an area of flat to undulating intra-mountain plains between 1100 and 1400m and intermixed with mountain ranges up to peaks of 1600 m. The landscape is dissected by creeks and streams that give origin to flat and V-shaped valley bottoms. This agro-ecological zone is found in the north and south of the district.
Lakeshore	500-600	900-1400	This agro-ecological zone comprises mainly of a flat narrow coastal strip with undulating hilly slopes rising to steep escarpment adjoining the Matengo Highlands west of the Hagati plateau. It has a hot and humid climate, very different from the rest of the Mbinga district.

The study area is generally mountainous with a narrow strip of lowland along the shore of the Lake Nyasa (Plate 2). Most of the area lies betweem 480 and 1350m a.s.l., but there are few areas of the Matengo plateau which rise about 2100m a.s.l. The Livingstone Mountain ranges is a catchment of numerous rivers opening to the Lake

Nyasa and the Indian Ocean. The Lake depression consists of a series of blocks of the earth that tilted and dropped during the formation of the rift valley. The Lake Nyasa lies within the walls of the Livingstone Mountain Ranges delineated by faults, steep slopes and deep shores in some places. There is a varied landscape of extensive plains in the southern part and steep-sided mountains in the northern side resulted from rift faulting (Nindi, 2007). Near-shore topography varies between gently sloping beaches and steep, rocky shoreline.

Plate 2: Undulating hills and dissected slopes of the Livingstone Mountain ranges

3.2.2 Climate

The average temperature is reported to range from about 13°C in the Matengo highlands and Livingstone Mountain ranges to about 30°C along the Lake Nyasa shores (Mchau, 1993). But the average minimum temperature is between 19°C to 23°C and the maximum temperature ranges from 25 to 31°C (Lyimo and Kangalawe, 1997). Generally most times of the year the climate is cool in the Matengo highlands and the Livingstone Mountain Ranges. The shoreline areas along the Lake Nyasa are hot and humid and the temperature ranges between 29°C and 31 °C.

The rainfall pattern is monomodal starting from November ending in May of the next year. The Matengo Highlands (including the Livingstone Mountain ranges) receives an average annual rainfall of 1 300 mm, distributed in six to seven months (MWARP, 1998). May to October is normally a dry season and its peak is experienced between June and October. During this period evaporation exceeds precipitation (ICRA, 1991). The Lakeshore zone has a hot and humid climate, very different from the rest of the Mbinga district. It receives an estimated annual rainfall of slightly less than 1000 mm.

3.2.3 Geology and soils

The soils are broadly characterized by parent materials and topography. There are three identical geological systems that have close relation with topography: The pre-Cambrian basement complex consisting of either acid plutonic rocks (granites rocks) as an intrusion or metamorphic rocks such as quartzite, gneisses or schist that underlies almost the entire region of the Matengo highlands. The highlands are covered with gneissic rocks while the Hagati plateau and parts of mountain area are composed of granites rocks. The distribution of karol sand stone formed during the period of Carboniferous is only limited to the Lake shore zone which forms parts of the tertiary surface.

3.2.4 Hydrology

Livingstone mountain ranges is a catchment area therefore water sources (streams and rivers) originate from these mountain and feeds Lake Nyasa to the western side and

Indian Ocean in the eastern side through Lumeme River which flows to Ruvuma River. River Ruvuma is a border between Tanzania and Mozambique. There are more than 16 major rivers flowing into the Lake Nyasa, namely Ruhuhu, Lukali, Liweta, Ngano, Lungumba, Mnyamaji, Chindindi, Ndumbi, Yola, Kuluchi, Mbuchi, Yungu, Mbawa, Lwika, Ruhekei and Chiwindi. The Livingstone Mountain ranges is therefore a main water source of the Lake Nyasa drainage Basin. The watershed of the Livingstone Mountain is very essential for the population living along the lake shore zone as well as Matengo highlands zone in Mbinga district. Inhabitants in these areas benefit from several goods and services for their livelihoods such as water for domestic purposes, small scale irrigation, transportation, fishing as well as environmental protection issues (NEMC, 2008). Regardless of the potentiality of Lake Nyasa in terms of endemic fish species, beautiful beaches, small islands, fresh and deep water for diving; tourism industry is not developed in this area (NEMC, 2008).

3.2.5 Vegetation

The natural vegetation of the Livingstone Mountain ranges in general, is largely miombo woodland type of vegetation that include tree species like *Brachystegia* spp, *Julbernardia globiflora, Burkea africana, Uapaca kirkiana, Parinari excelsa, Parinari curatefollia, Afzelia quanzensis, Pterocarpus angolensis, Adina, vitex*, *Syzygium* spp, *Acacia albida*, *Acacia polyacantha*, and many other species (MWARP, 1998). But, degradation is very fast to these vegetations. This vegetation type has almost completely disappeared in the Matengo highlands except for low density remnants on the top of some mountains. At low elevation the dominant vegetation type is secondary wooded grassland. The most dominant grass species are the thatch grass (*Hyperrhenia* spp) and *Hypetheha* spp. Other vegetation types are the Zambezian swamp and afromontane type of forest. In valleys and along streams, creeks and wetland areas the dominant species comprise of *Khaya nyasica, Macaranga capensis, Bridelia micrantha, Treculia africana* and *Fragnitas maritariana* (ICRA, 1991; Ellis-Jones *et al.*, 1994). The only forest reserve found in the study area is called Liwiri Kiteza, which is dominated by tree species such as *Afzelia quanzensis, Brachystegia spiciformis, Brachystegia boehmii,* and *Julbernardia globiflora* (MWARP, 1998).

3.2.6 Population and ethnic composition

Mbinga district had a population of 144 059 people in 1967 which increased to 196 167 in 1978 and 271 845 in 1988. According to the Census of 2002, Mbinga District had a population of 404 799 people (Figure 3). The total population size served by the Livingstone Mountain catchments is estimated to be 173 864 (42.95%) people from 97 Villages, 18 Wards and 4 Divisions. Out of these 173 864 people, 77 861 (44.78%) are living along the Lake shore in 44 villages found in 10 wards and 2 divisions of Ruhekei and Ruhuhu. The rest 96 003 (55.28%) people are living along the Highlands including Hagati plateau subzone of the Matengo Highlands, which have a total of 53 villages, 8 wards in 2 Divisions of Mpepo and Mbuji. The population density may vary from Lake Nyasa shore to the Matengo Highlands zone where it is higher, reaching up to 120 per sq.km.

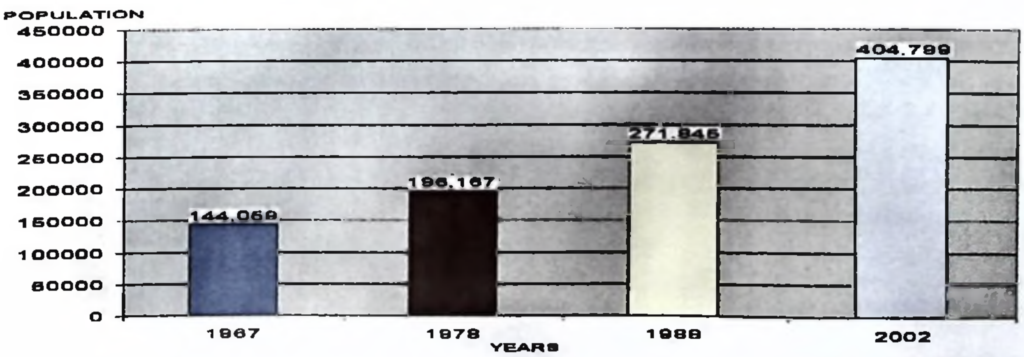

Figure 3: Population trends in Mbinga district based on Census reports.
Source: Nindi (2004)

There are four main ethnic groups in the study area. Three main ethnic groups are occupying the Lake Nyasa shore. These are the Nyasa (Nyanja), which consists of the smaller groups; Mwela and Mpoto, occupying primarily the southeastern part of the Lake shore towards the border with Mozambique (Nindi, 2007). The Manda and Kisi are mainly found in the northern part of the Lake Nyasa shore towards Ludewa district. The Matengo group dominate the eastern side of the Livingstone Mountain ranges together with the Ngoni tribe who are found in very small numbers in the Rolling Hills, North and South.

3.2.7 Socio-economic activities

Agriculture is the main economic activity of the people surrounding the Livingstone Mountain ranges. The major crops grown to the Lake shore include paddy, cassava and sugarcane. Finger millet, groundnuts, coconuts, maize, sweet potatoes, banana and horticultural crops are also grown in small scale. Matengo highlands farmers grow coffee as major cash crops while food crops include maize, cassava, and beans. Other crops grown are wheat and finger millet. The farming system along the Lake shore are mound ridges for cassava and sweet potatoes, while slash and burn is being practiced in finger millet fields whereas paddy and sugarcane are mainly cultivated in the valleys and wetland areas using flat cultivation method. The Matengo Highland farmers also practice slash and burn for finger millet cultivation. Matengo pits *(ngolo)* is the dominant cultivation system in the highlands for planting beans, maize and wheat while agro-forestry land use system is carried out in coffee farms that help to control soil erosion (Nindi, 2004).

On the other hand, both Lakeshore and Matengo highlands people keep cattle, goats, pigs, sheep and poultry in small numbers. The types of livestock rearing include herding, zero grazing, free range grazing and tethering system. Moreover, fishing is another economic development activity undertaken by male from most of the villages along the the Lake Nyasa shore. Moreover, people along the Lake and Matengo Highlands have established some fish ponds through initiatives from various sectors of the Government departments, Sokoine University of Agriculture (through SCSRD), and NGOs dealing with fish farming. However, extensive application of agrochemicals in coffee and maize fields in adjacent Matengo Highlands is believed to impact negatively the quality of aquatic life in rivers that open to the Lake Nyasa hence, the lake itself (Nindi, 2007).

However, the Livingstone Mountain Ranges are endowed with very attractive features in the district which may attract many tourists to come in the site, thus raising income of the people around it. Among the attractive features include Liparamba Game Reserve at Mpepo Division, Lake Nyasa Scenario, Livingstone escarpments and Rift valleys, Wild animals, birds, insects, reptiles and so on (NEMC, 2008). The opening of Mbamba-Bay port where Malawi and Tanzania ships make step over, recently installation of electricity by Tanzania Electric Company (TANESCO) and current plans for the development of the Mtwara Corridor will make Mbinga district become an attractive area to different personalities in and outside the district.

Another area of attraction is a unique indigenous cultivation system (Matengo pit) or "*ngolo*", which is a traditional farming system in steep slopes practiced only by the Matengo farmers. It is a tied ridge structure planted with crops like beans, maize, cassava, peas and wheat. The system has advantages of controlling soil erosion by allowing rain water to infiltrate rather than run off (Itani, 1998). Also, it improves soil fertility due to its incorporated green manure/compost enhance water holding capacity, and controls pests and diseases through its crop rotational system.

3.3 Research Design

This study used both cross-sectional and longitudinal design in data collection. Cross-sectional survey constituted a collection of data from stratified population of villagers in the study area at a single point-in-time on aspects of households' characteristics, environmental and socio-economic issues related to landscape changes. Cross-sectional design also helps to compare variables within and between study points (lowland-highland). In this case, cross-sectional survey design was desirable to gain insights of community's perception and impacts of landscape changes in the study area given there was limited time and resources to undertake the study. Besides, the cross-sectional design provided data used for descriptive analysis. As cross-sectional study is not sensitive to situational changes over time, it was complimented by longitudinal study to assess implications to the livelihood due to landscape changes. Therefore, longitudinal studies based on satellite imagery have been applied to capture the changes in landscape conditions as manifested by changes in land use/covers at three periods separated by years (1979, 1990, 2002). Datasets from both longitudinal studies and secondary surveys have been used to generate input data for modeling purposes.

3.4 Selection of Study District and Villages

A number of reasons resulted to the selection of the Livingstone Mountain ranges and its adjacent lowland as a study area. Among them it includes a requirement indicated in section 58 of the Environmental Management Act (EMA) Cap. 20 of 2004 which became operational as from July 1st, 2005 that accorded priority to the mountain ecosystems in the country. The Livingstone Mountain ranges provide a variety of ecosystem and services such as water, food, fuel wood/energy, cultural services, fodder, mining, settlements, building materials, good soils for agriculture and medicinal plants (NEMC, 2008). The mountains provide the life supporting systems which are vital to the surrounding communities and subsequent lowland area ecosystem. However, it has been reported that such mountain ranges are facing a severe degradation due to increased demand for ecosystems goods and services (Ellis-Jones *et al.*, 1994; MWARP, 1998, Nindi, 1999; 2004; 2007; 2010; Kangalawe and Lyimo, 2006). This has led into ecosystems degradation that includes catchment degradation, soil erosion and siltation of water bodies such as rivers and streams as well as the Lake Nyasa in the lowland area. After consultations with staff from the District Natural Resources Office during research inception meeting six villages namely, Makonga, Buruma, Lumecha (located in the upland), and Chiulu, Nangombo and Ndengele (located in the lowland) were purposively selected, Buruma and Lumecha villages were purposively selected because farming practises in the recent years has been extended in Miombo woodland areas in the mountain slopes that exacerbate landscape changes in the upland areas.

Chiulu and Nangombo villages were purposively selected because they are connected by river Ruhekei whereby its catchment includes areas around Buruma and Lumecha villages. So, it was important to know the influence of catchment's degradation to the lowland areas. Makonga village in the upland and Ndengele in the lowland were purposively selected because they did not have direct drainage influence although their boundaries were located nearby. It was therefore important to include these villages in order to experience different situations in the study when compared to the other four villages.

3.5 Sampling Procedures

A multiple-stage sampling was applied in this study to accommodate various data needs. First step involved stratification of the households based on gender into male and female headed households. Sampling frames for this study were the names of all household heads extracted from the study village registers, obtained from village government offices. Households were assigned as main unit of analysis based on the main reason that implications of landscape changes to livelihoods could easily be captured and differentiated at that level. A unit of analysis is the one from which information is obtained (Kajembe, 1994).

A sample of 40 households in each of the five villages surveyed, except in Makonga village (30 households) were randomly selected from strata using table of random number to meet the minimum statistical requirements (O'leary, 2004). Only 30 households were sampled from Makonga village because it had fewer total households (168) than other five villages. Although the human development study (R&AWG, 2005) reports that 22 percent of all households in Mbinga district are female-headed, significant differences existed in study villages. The total number of households in the study villages was 2 431, of which 230 (9.5%) were interviewed (Table 5). Regardless of the population size, a sample of 30 respondents is considered reasonable sample size for data collection and statistical analysis usually used in social science study and statistically large enough to make scientific conclusion (Bailey, 1998; Saunders *et al.*, 2007). Similarly, Matata *et al.* (2001) argued that having 80-120 respondents is adequate for social-economic studies in sub-Saharan African households. In this study therefore a total of 230 respondents have been interviewed from a total of 2 431 households in the study area. Out of 230 respondents, the total number of female-headed households ranged from 7 to 20 whereas male-headed households ranged from 20 to 33 in each surveyed village. Thus, the total male headed households were 64.8 percent and female 35.2 percent of the interviewed sample. The number of households in the study villages ranged from 168 to 570.

Besides stratified random sampling that was used to select 230 respondents for main survey, snowball sampling was employed to get 120 villagers, 20 from each village who participated in focused group discussions (FGDs). Based on the advice from Village Executive Officers (VEOs), two to three participants who had more information on the village history and natural resources issues were selected. These assisted in selection of remaining members of FGDs for each village. Each village had four groups for FGDs. Regarding gender aspect, five males and five females were considered in each age category. The first and second groups were made of five male and females members, respectively aged above 40 years old. The third and fourth groups were of five male and female members aged below 40 years old, respectively.

Table 5: Distribution of respondents in the surveyed villages in the study area

Village	Total number of households	Number of sampled households	Sample size interviewed (%)
Makonga	168	30	18
Buruma	570	40	
Lumecha	327	40	12
Nangombo	467	40	9
Chiulu	560	40	7
Ndengele	339	40	12
Total	**2431**	**230**	**9.5**

The composition of FGDs members based on age and gender enabled to get differences on their perceptions and experiences about landscape changes and the implications to the livelihoods as well as possible factors influencing landscape changes. In addition, 30 members of the village government councils (VCs), six VEOs and three District Council Management Team (CMT) members from departments of agriculture and livestock development, cooperative and markets, and natural resources management were purposively selected and used as key informants on various issues related to landscape changes, farming systems, and natural resource management and livelihoods.

3.6 Selection of Study Area for Modeling Purposes

For modeling purposes, the study area had to cover more villages than those (six) included in the main study in order to include the Livingstone Mountain ranges and its adjacent lowland area in Mbinga district. In this respect the total area covered by the model included 19 wards whereby 11 were located in the upland area and the remaining 8 are in the lowland area. This area was selected because it includes almost all area occupied by the Livingstone Mountain ranges in Mbinga district and its adjacent lowland areas, bordering the Lake Nyasa. The only small part of the Livingstone Mountain ranges that is not included in the modeling was the one bordering Ludewa district. The reason for its exclusion was lack of good quality satellite imagery for years 1990 and 2000. The other reasons include the existing differences in ethnic composition that defines the farming systems in the areas hence land use and cover distribution.

3.7 Data Collection

Various types of data were collected for this study such as primary, secondary and remotely sensed data. It is important to note that data used for modeling purposes were extracted from these three data types.

3.7.1 Primary data

A structured questionnaire (Appendix 2) was used as main instrument for obtaining information from the heads of households (HH). This questionnaire was pre-tested in Chimate (lowland) and Ukata (upland) villages, which were not among the villages included in the main survey for this study. Minor modifications were made to some questions based on pre-testing results of the questionnaire. The researcher administered the questionnaire to the heads of households in their homesteads. The researcher was led by Village Chairpersons and Village Executive Officers (VEO), who identified the selected households and hence moved from one selected household to another. Therefore, the questionnaire enabled collection of information on household characteristics, perception on factors influencing landscape changes and implication of such changes on their livelihoods.

A Participatory Rural Appraisal (PRA) method was also used to collect information from interviewees. The importance of PRA approach is from the fact that it describes a growing family of approaches and methods to enable local people to share, enhance, and analyse their knowledge of life and conditions, to plan and to act (Chamber, 1992; Luoga, 2000). The PRA methods of focus group discussions, key informants interviews and direct observation were adopted. As an example of PRA methods, transect walks were made across the study villages to assess distribution of different land use/cover categories, landform features and changes that had taken place over time. Transects were made based on the setting of the village in terms of topography and kinds of land use and cover occupied in different areas. Two transects were made in each village. Transect walks enabled the researcher to get general view of change in land use and cover in the study area. A Global Positioning System (GPS) was used to collect geographical coordinates of important locations like vegetation types, which appeared to be useful for supporting satellite imagery interpretations.

On the other hand, FGDs were conducted to get complementary information from those provided in the household questionnaire administration. Each FGD comprised of 5 village members whereby age and gender balance were important aspects taken into consideration. FGDs were guided by a checklist (Appendix 3) that provided information on community's perception regarding factors influencing landscape changes and implication of such changes to their livelihoods. In contrast to household questionnaire administration, FGDs were held at the village offices.

Moreover, informal discussions were held with key informants to improve the validity of information provided by household heads. The key informants in this study included members of Village Government Councils (VCs), VEOs and District Council Management Team (CMT) members from departments of agriculture and livestock development, cooperative and markets, and natural resources management. The discussions provided information on trends of land use/cover changes, opinion regarding availability of farming land resulting from such changes, farming systems practised, factors influencing land use/cover changes, community participation in natural resources management, and uses of forest products in the study area. Apart from expanding the researchers understanding of the diversity of issues in the study area, information on landscape changes from key informants were compared and cross-checked by evidences provided in satellite image interpretations. Key informants also provided information on landscape changes that had taken place over space and time.

Thus, different variables were collected from household surveys, focus group discussions and key informant interviews for assessing ecosystems vulnerability in the study area.The variables included decrease or disappearance of some wildlife species which used to be found in the woodland ecosystem such as *Tagelaphus scriptus* (Mbawala), *Panthera leo* (Simba), *Panthera pardus* (Chui), *Laxodanta africana* (Tembo), *Syncerus caffer* (Nyati), *Lepus sexatilis* (Sungura), *Papio cynocephalus* (Nyani), *Manis tricuspis* (Nungunungu) and other species. Likewise, decrease or disappearance of some fish species such as *Opsaridium microlepis* (Mpasa), *Opsaridium microcepharus* (Mbelele or Sanjika) and *Oreochromis species* (Magege or Chambo) due to destruction of fish breeding sites along the riverine/wetlands ecosystems and Lake Nyasa that resulted from siltation and excessive floods due to influence of landscape changes were also collected to determine ecosystems vulnerability.

3.7.2 Secondary data

Secondary data were collected to gain insights on global, regional, national and local status on state of knowledge on demographic characteristics, land use and land cover dynamics and livelihood as well as modeling land use/cover changes. Various documents including research reports, project reports and journals were reviewed at libraries of the Sokoine University of Agriculture (SUA), University of Dar-es-Salaam (UDSM), National Bureau of Statistics, Ardhi University and also from various Internet sources. District social economic profile, reports and publications were obtained from Mbinga District Council Office. Furthermore, topographical maps at a scale of 1:50,000 of 1974 and digital shapefiles for roads, river and administrative boundaries were obtained from the Surveys and Mapping Division of the Ministry of Lands and Human Settlements Development. Digital shapefiles for Land use and cover maps of 1995 and 1996 were obtained from the Institute of Resource Assessment of the University of Dar es Salaam and Surveys and Mapping Division, respectively. These datasets provided important information such as village locations, landform features, roads, rivers, wards, vegetation types and distribution. Therefore, these data were used during fieldwork and ground truthing, satellite imagery processing and interpretation and also in model development.

3.7.3 Remotely sensed data

Remote sensing was the major method used to capture data on spatial extent and trends of changes in land use/cover in the study area. In this study datasets on land use and cover were obtained from satellites belonging to the Landsat systems (Appendix 4). Satellite imagery from Landsat2 Multispectral Scanner (MSS) path 180 row 068 of 25th July, 1979, Landsat5 Thematic Mapper (TM) Path 168, Row 068 of 11th July, 1990, and Landsat7 Enhanced Thematic Mapper Plus (ETM+) Path 168, Row 068 of 31st August, 2000 were freely downloaded from http://www.landsat.org/landsat_gallery/ website.

The imagery of dry season (July, August) for the study area were selected as they had little atmospheric haze, more visible cultural features, and vegetation. In this regard, no image enhancement or atmospheric corrections were carried out because all clipped parts of satellite imagery were of good quality with only very few cloud cover in one area of the imagery. In order to be able to derive slope, aspect and elevation from remotely sensed data, it was important to use Digital Elevation Model (DEM), which was captured by Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor which has been in operation since 1999. The DEM was downloaded for free from https://wist.echo.nasa.gov/wist-bin/ website.

3.8 Data Analysis

3.8.1 Data analysis to determine landscape changes

Remotely sensed data from Landsat MSS, TM and ETM+ were processed using ERDAS Imagine 8.6 software. These Landsat imageries were orthorectified using the UTM projection, zone 36 with Clarke 1880 spheroid and Arc 1960 datum. A vector layer of study area polygon was used to subset the three Landsat imageries of 1979 (MSS), 1990 (TM) and 2000 (ETM+) using ERDAS Imagine. These Landsat imageries were processed to generate land use/cover types and also analysed to determine changes taken place within the study between years 1979-1990 and 1990-2000. Different vector data (generated from remotely sensed data) were also used in the study. Land use/cover data from Institute of Resource Assessment (IRA) and Surveys and Mapping Division (SMD) which were generated in 1993 and 1996 through Forest Resources Mapping Programme (FRMP) and Africover Projects, respectively were used during digitisation in order to assist identification of the different land use/cover types from satellite imagery. Moreover, GPS points captured during transect walks were also used in identifying locations of different land use/cover categories and other interesting features. ArcView GIS program was used for digitising seven (7) land use and cover types from each landsat imagery.

The land use and land-cover classification scheme developed for the FRMP project was used in order to generate land use and cover classes that are compatible with existing national datasets hence facilitating data sharing. The digitised land use and cover were: Upland bushland with scattered cropland *(Upbsc)*, Upland woodland closed *(Upwc)*, Upland woodland open *(Upwo)*, Upland cultivation *(Upcl)*, Lowland bushland with scattered cropland *(Lbsc)*, Lowland woodland closed *(lwc)*, Lowland woodland open *(Lwo)*, Lowland grassland with scattered cropland *(Lgsc)*, and others *(Oth)*.

Having digitised all land use and cover categories from all three Landsat scenes, data cleaning was done using ArcInfo software to determine and correct errors made during digitisation such as dangle nodes, island polygons and others. Then, areas for each land use and cover category were calculated from all three digitised datasets using ArcView software before doing change detection analysis. Change detection is a process of comparing any two datasets from the same area acquired at different times. In order to assess the landscape changes, comparison of maps of two times (T_1 and T_2) were made for the two pairs of digitised data. This is a common technique in a GIS environment and interpretation of the comparison results would lead to the conclusion that the differences between maps of times T_1 and T_2 indicate landscape change (Jensen, 1996; Campbell, 1997). In this particular study, comparisons of digitised pairs of data (1979 – 1990 and 1990 – 2000) were made using ArcView software to determine the landscape changes in the study area. Therefore areas of changes were determined for each land use and cover category and the change detection matrix that shows the *"from-to"* change categories were generated.

Each shapefile of land use/cover types had to be reclassified using ArcView software in order to specify areas occupied by that specific land use/cover type and areas which were not occupied by such land use/cover within the study area. Areas occupied by land use cover types (information area) were coded as 1 and non occupied areas (non information areas) were coded as 0. On the other hand, areas outside the study area were coded with a default value of -9999. It should be noted that each land use/cover type was treated separately during reclassification process in the GIS in order to allow coding of the information and non information areas.

3.8.2 Data analysis to assess influence of driving forces in landscape changes

Spatially explicit tabular data of national census of 2002 at ward level have also been used in the analysis. A Spatial Analyst Extension of the ArcView GIS software was used to analyse population density, distance to roads and distance to rivers in order to use them as location/explanatory factors in the analysis in the CLUES modeling framework. A map of study area showing population density (***popden_mbg***) at ward level (Figure 4) was prepared using such national census data and administrative map. Population density was calculated based on ward population data and ward land area (people/km^2). Maps showing distance to roads (***distrd_mbg***) and distance to rivers (***distriv_mbg***) as shown in Figure 4 were also calculated using the spatial analyst extension of ArcView software and used in the model to determine their influences in landscape changes. Distance to road and river variables were calculated as a series of buffers of 100m (1 pixel) expanding from each arc of the road and river networks, respectively.

The remotely sensed data of Digital Elevation Model (DEM) was used to generate biophysical factors used in the model to assess their influences in landscape changes. The DEM had a spatial resolution of 30m but it was re-sampled at a spatial resolution of 100m, which has been used for all spatially related datasets in the model. The spatial resolution was increased in order to reduce the number of rows and columns hence improving the time taken to analyse data in the CLUES modelling framework (Verburg *et al.,* 2002). Thus, the DEM was clipped with a vector layer of the study area using Erdas Imagine 8.6 software and then processed using ArcView software to generate the biophysical factors (elevation, aspect and slope) as shown in Fig. 5.

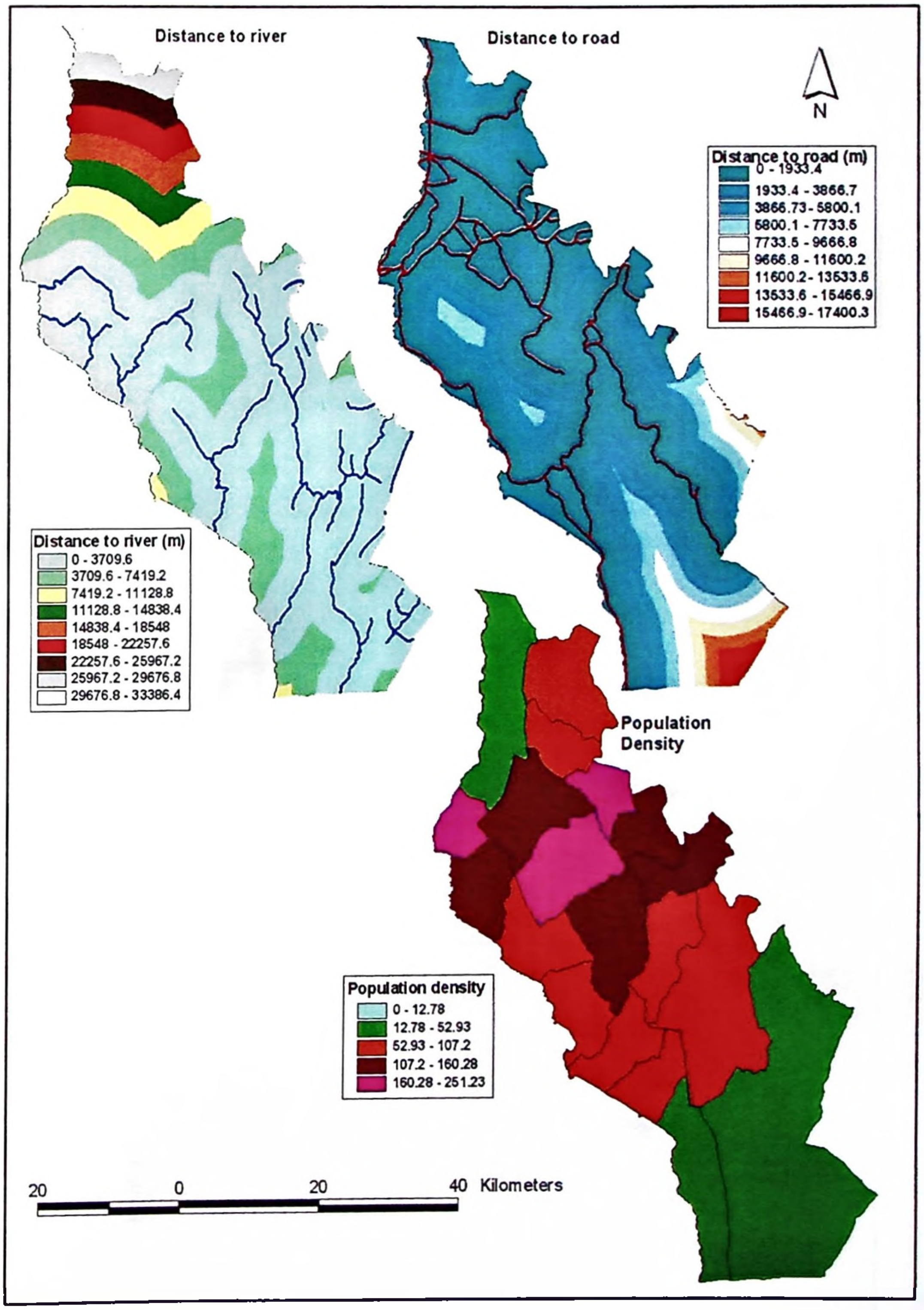

Figure 4: Map showing explanatory factors derived from secondary data.

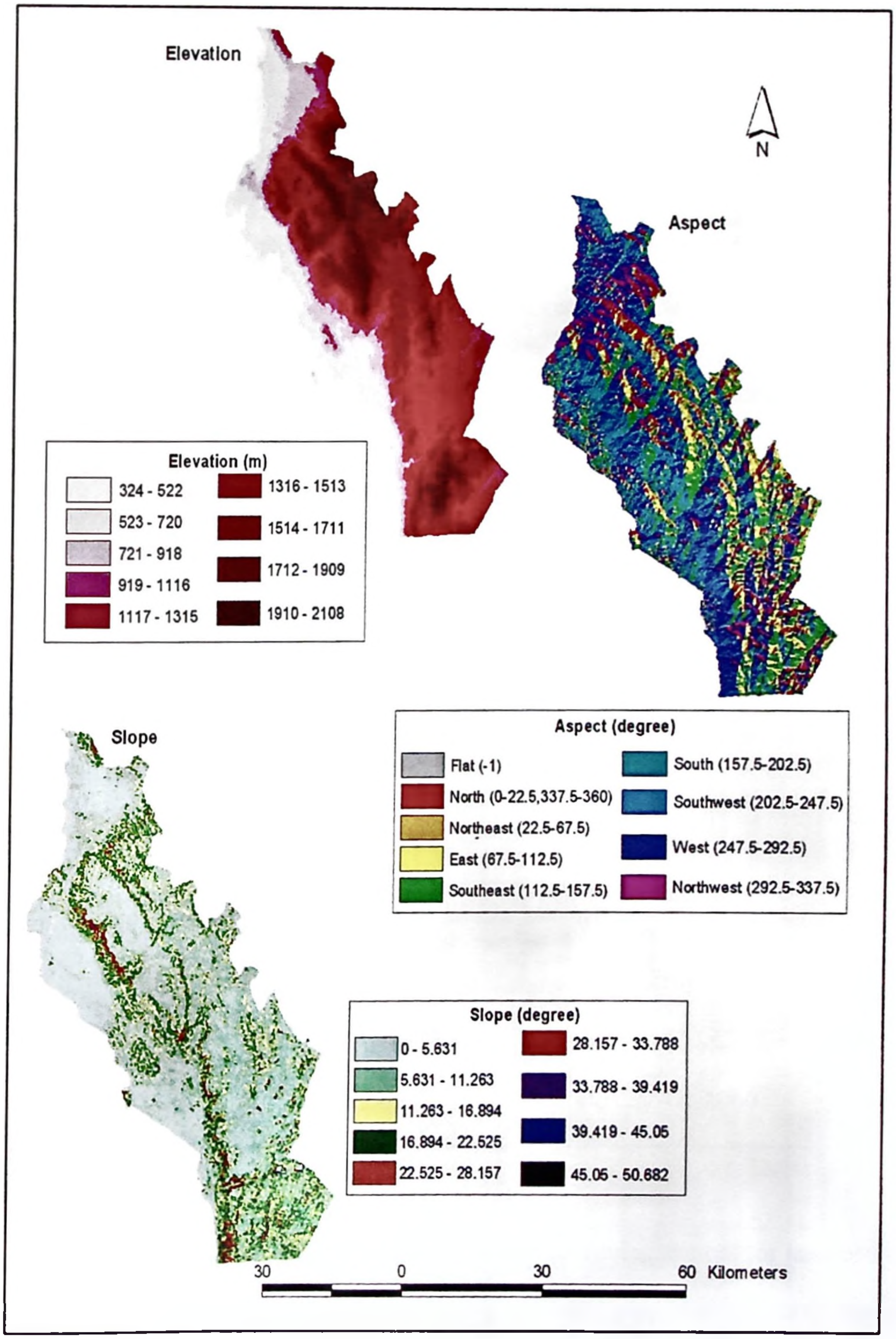

Figure 5: Map showing biophysical factors derived from remotely sensed data.

The CLUES model uses ASCII format for all spatially related dataset files. Thus, all shape files (vector based) generated had to be converted to grid (raster based) format and then exported to ASCII files within the ArcView software. At this stage the geographical extent (coordinates), cell size, number of rows and columns and geo-reference system were defined and remained the same for all grid maps that were used in the modeling in order to maintain consistence and analytical functionality. These settings are as shown in Table 6.

Table 6: Description and specifications of parameters used for each GIS layer entered in the model

No	Description	Specifications
1	Eastings Extent: Lowest coordinates	676 106m
	Highest coordinates	737 806m
2	Cell size	100m
3	Number of rows	932
4	Number of columns	617
5	Georeference system	UTM Projection, Zone 36, Spheriud Clarke 1880, Datum Arc 1960

In this study, files names for location characteristics or driving factors for land use/cover changes used in the framework had to be changed when exported to ASCII format as shown in the brackets; aspect (***sclgr0***), elevation (***sclgr1***), slope (***sclgr2***), distance to road (***sclgr3***), distance to river (***sclgr4***) and population density (***sclgr5***). The land use and cover categories used are as shown in Fig. 6.

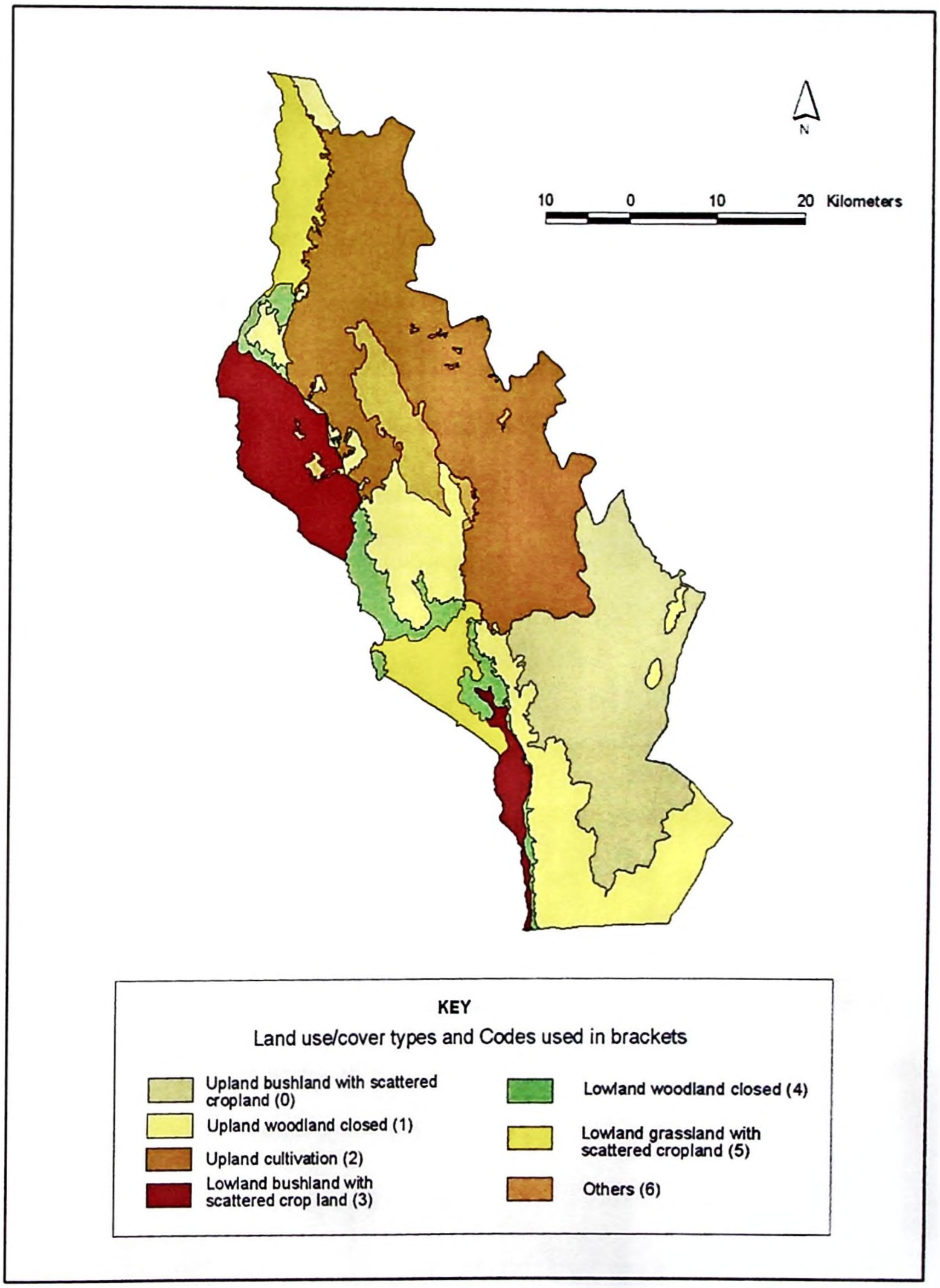

Figure 6: Map showing land use/cover categories in 2000 used as basis of analysis in the model.

Land use/cover file for year 2000 (*cov_all.0)* shown in Fig. 6 had to be prepared in ArcView software and also converted to ASCII format. Since most of the standard statistical packages do not support the use of GIS data directly, a number of conversions were carried out in order to translate the GIS data into a data format supported by such statistical packages (in this study SPSS 11.5 software). The file conversion program called convert.exe, which is supplied together with the CLUES was used to translate ArcView ASCII grids for land use types and location characteristics (biophysical and social economic factors) into a tabular format. Once created, this file lists all data values of the different input files. In this table the files are in columns and the observations in rows. For each cell, they contain the land use/cover and location characteristics in a single row.

Land use conversions are expected to take place at locations with the highest 'preference' for the specific type of land use at that moment in time. Preference represents the outcome of the interaction between the different actors and decision making processes that have resulted in a spatial land use configuration. The preference of a location is empirically estimated from a set of factors that are based on the different, disciplinary, understandings of the determinants of land use change. The preference was calculated using the following equation (suggested by Verburg *et al.*, 2002):

$$Rk_i = akX_{1,i} + bkX_{2,i} + \ldots \qquad \text{ii)}$$

Where: R is the preference to devote location i to land use type

k, $X_{1,2,\ldots}$ are biophysical or socio-economical characteristics of location i

ak and bk are the relative impact of these characteristics on the preference

for land use type k.

The exact specification of the model should be based on a thorough review of the processes important to the spatial allocation of land use in the studied region. In this case, a statistical model can be developed as a binomial logit model of two choices: convert location *i* into land use type *k* or not. The preference Rk_i is assumed to be the underlying response of this choice. However, the preference Rk_i cannot be observed or measured directly and has therefore to be calculated as a probability. The function that relates these probabilities with the biophysical and socio-economic location characteristics is defined in a logit model, as suggested by Verburg *et al.* (2002).

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \ldots \beta_n x_{n,i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iii)}$$

Where: P_i is the probability of a grid cell for the occurrence of the considered land use/cover type at location i,

X's are the explanatory/location factors

β are the coefficients estimated in logistic regression, where land use/cover becomes dependent variable and explanatory/location factors as independent variables.

Thus, the file that contained both driving factors and land use and covers types created by *convert.exe* program was imported in SPSS 11.5 software for statistical analysis. The logistic regression analysis was carried out with driving factors (aspect, elevation, slope, distance to road, distance to rivers and population density as independent variables while land use/cover types as dependent variables. As binary variable there were only two options of dependent variable, 1if there is change and 0 otherwise. During the statistical regression, a 'Forward: Conditional' for stepwise regression method was selected in order to remain with only significance location variables for each land use/cover type.

Assessments of goodness of fit for the logistic regression analysis were carried out using Relative Operating Characteristic (ROC) method. The ROC characteristic is a measure for the goodness of fit of a logistic regression model similar to the R^2 statistic in ordinary least square regression. A completely random model gives a ROC value of 0.5, while a perfect fit produces a ROC value of 1.0. The 'Probabilities' option was checked during the analysis in order to save the predicted probabilities for the evaluation of the goodness of fit. The analysis were carried out to each land use/cover type by selecting the observed land use/cover as 'State Variable' with value 1 for occurrence of it and the 'Predicted probability' as 'Test Variable'. The results for the ROC for each land use and cover types are as shown in the Appendix 5. From the regression analysis of each land use/cover type, the coefficients β and significance level (p-value) were the values used to determine the influence of biophysical and socio-economic factors in landscape changes. The significance level was set at $p \leq 0.05$. It is important to note statistical parameters generated in the regression processes were the ones used in developing the LIM-CLUES model in the subsequent sections.

3.8.3 Data analysis to ascertain implications of landscape changes

The techniques used in qualitative data analysis depend on the source of data, data collected, participants in generation of data and the procedures used in the interpretation of data (Lee and Fielding, 2004). Information on key emerging issues collected through FGDs and key informants interviews were transcribed, sorted, and labelled in order to make decisions about meanings as it stands or in the context of interviews, relevance, and importance.

Content and Structural–Functional Analyses technique was employed to analyze such qualitative data and information. According to Kajembe and Luoga (1996) this technique assists establishing values and attitudes of respondents hence generating themes and tendencies. Through this method, it has been possible to know different opinions of respondents on issues such as reasons for land use/cover changes, implications of such changes to their livelihoods, types of farming systems practised in the area, soil fertility status and participation of community members in natural resource management. Therefore, this has enabled to organize the information in a more objective and systematic manner hence establishing relationship among social facts, and how they are related to the physical surroundings based on direct observations from the study area.

In addition, a Statistical Package for Social Scientists (SPSS 11.5 software) was used in analyzing the quantitative descriptive statistical data. Primary data collected from questionnaire administration were coded, entered and cleaned before performing statistical analysis. Moreover, the open ended questions were categorized and transformed into a form acceptable for coding and further analysis in the SPSS. Cross-tabulations of study variables and groups were run to summarise data on household characteristics, social economic attributes and environmental issues to generate descriptive statistics such as percentages, ranges, standard deviations and statistical significance, which was set at $p \leq 0.05$. All these statistical analyses enabled to ascertain the influence implications of landscape changes to livelihood.

3.8.4 Data analysis for modeling purposes

The CLUES Model uses different datasets. Large databases of factors that are important have been considered in this case study of modeling spatially explicit changes in land use pattern within the Livingstone Mountain Ranges. In order to run the model it is minimally needed to have spatially explicit data for at least 1 year. However, to allow model calibration and validation, it is necessary to have data of another 2 years, preferably about 10 years apart (Verburg *et al.*, 2004). Different datasets for the land use and land cover distribution as well as a number of biophysical and socio-economic parameters that are considered as important potential drivers of the land use pattern are needed for the simulation of dynamics of the spatial pattern of different land use and cover types (Verburg and Veldkamp, 2004).

The CLUES model uses the logit regression model in the allocation procedure of the land use/cover types based on identified explanatory factors. From the regression analysis of each land use/cover type (explained in part 3.8.2), the coefficients β and location characteristics (*X's*) were values entered in the regression results field in the model in the file called ***alloc1*** through Edit Input menu in the model framework and sometimes it was done using a note pad text editor. It is important to note that for modeling purposes the land use and cover types were reduced from 9 to 7 in order to have a manageable size within the model. Upland woodland closed and upland woodland open were merged to form upland woodland.

Likewise, lowland woodland closed and lowland woodland open were also merged to form lowland woodland. The category represented by 'others' include areas which have been held constant in the analysis within the model. The others category represent areas with natural forests, plantation forests, and stabilized settlements. Therefore the land use/cover types were coded using ArcView software as shown in the brackets; Upland bushland with scattered cropland (0), Upland woodland (1), Upland Cultivation (2), Lowland bushland with scattered cropland (3), Lowland woodland (4) lowland Grassland with scattered cropland (5), and Others (6). Thus, this shapefile containing all the land use cover types for the year 2000 was converted to ASCII format and was called (***cov_all.0***). This (***cov_all.0***) ASCII file contains the grid values indicating the dominant land use/cover type for each grid cell at the start of the simulation (year 0). The grid values contains the code of the land use/cover type, as indicated in the main parameter file (***main.1***) or -9999 for the areas outside the simulation area. The coding for the land use/cover types in the main parameter (main.1) file starts with 0. At this stage, all necessary parameters for model development were analysed and generated.

3.9 Spatial Data Modeling using CLUES Modeling Framework

3.9.1 Structure of the CLUES Framework

The Conversion of Land Use and its Effects modeling framework (CLUES) (Veldkamp and Fresco, 1996; Verburg *et al.*, 1999a) was developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modeling of competition between land use/cover types. There are different versions of CLUES framework but the most recent version of the CLUES model includes autonomous developments through bottom-up simulation. This version has also been developed for the spatially explicit simulation of land use/cover change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems.

The CLUES framework consists of two (2) modules: a non-spatial demand module and a spatial explicit allocation module, operating at respectively the regional and pixel level. In this case regional level refers to the study area. Fig. 7 shows the structure of CLUES framework.

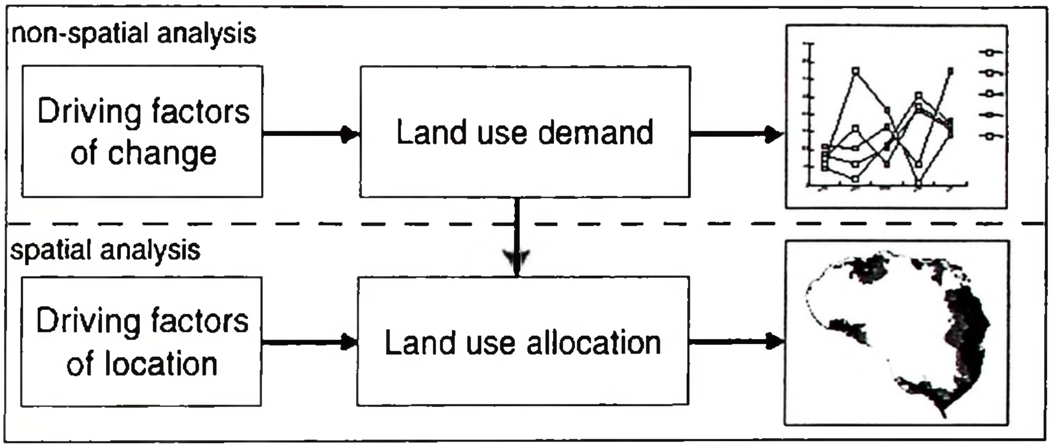

Figure 7: Overview of the modeling procedure in CLUES.
Source: Adapted from Verburg *et al.* (2002)

The non-spatial demand module is separated from the model framework. It defines for each land use/cover type the area needed for each year at the regional (aggregate) level, i.e. the study area, without paying attention to its the spatial configuration (Willemen, 2002).

Furthermore, the land use allocation is calculated using a combination of empirical, spatial analysis and dynamic modeling. An over view of the information needed to run the model is as shown in Fig. 7. This information is subdivided into four categories that together create a set of conditions and possibilities for which the model calculates the best solution in an iterative procedure. The four categories are: spatial policies and restrictions, land use type specific conversion settings, land use requirements (demand) and location characteristics (Fig. 8).

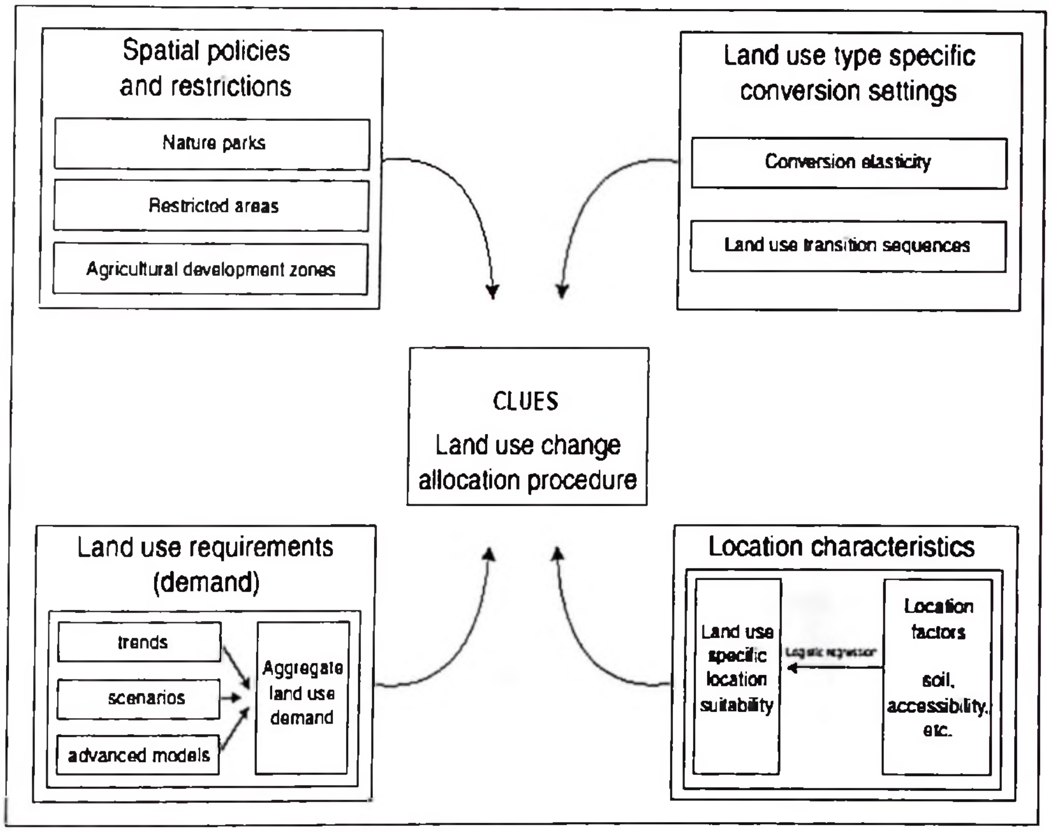

Figure 8: Overview of the information flow in the CLUES model.
Source: Adapted from Verburg and Veldkamp (2004).

3.9.2 Spatial policies and restrictions

Another important area that is taken in consideration in the CLUES modeling framework is on spatial policies and restrictions. The spatial policies and land tenure issues can influence the pattern of land use and cover change. In the CLUES model areas where land use/cover changes are restricted through policies or tenure status, are mostly indicated by spatial policies and restrictions. Beside, spatial policies can imply stimulation arrangements for a certain land use on a location. For the simulation purposes, maps that indicate the areas for which the spatial policy is implemented must be supplied. In this study, maps named ***region_park1*** and ***region_park2*** have been used to restrict land use/cover changes from specified areas. Thus, ***region_park1*** include natural and plantation forests and stabilized settlements areas whereas ***region_park2*** is areas occupied by upland woodland in the year 2000. It is important to note that the naming of these files is due to model requirement and do not mean all restricted areas were park reserves.

Some land use policies restrict a set of specific land use conversions, e.g., in the study area the a statement issued by the Vice President's Office on 1st April 2006 regarding Urgent Strategy on Land Conservation and Water Catchments has been taken into consideration in this study. By using GIS, it has been possible to identify areas of remaining upland woodlands, steep slopes and water catchments that need to be conserved hence restricted from cultivation and other land uses. These areas need to be left fallow to allow regeneration to take place. This issue has been considered under the second policy scenario used in the study.

3.9.3 Land use type specific conversion settings

Land use/cover type specific conversion settings determine the temporal dynamics of the simulations. There are two sets of parameters that are needed to characterize the individual land use/cover types. These are conversion elasticities and land use/cover transition sequences. The conversion elasticities are related to the reversibility of land use/cover change depending on either the level of investment undertaken on an existing land use at a certain location or the preference/restriction put upon to retain a certain land use/cover type. Land use types with high capital investment will not easily be converted in other uses as long as there is sufficient demand. An example for this situation in the study area is that it can be linked up with some built-up areas which have stabilized in such a way that no significant land use/cover changes are expected to occur in the near future, e.g. villages within the Hagati plateau. The CLUES model therefore requires one to specify for each land use/cover type a value that represents the relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change). Decision on this factor is based on expert knowledge or observed behavior in the recent past. The conversion elasticities for this study are presented in subsequent sections.

The land use/cover type specific conversion settings and their temporal characteristics is the second set of land use/cover type characteristics that needs to be specified in the CLUES model. These settings are specified in a conversion matrix. The conversion matrix defines: to what other land use types the present land use type can be converted or not, in which regions a specific conversion is allowed to occur and in which regions it is not allowed and how many years (or time steps) the land use type at a location should remain the same before it can change into another land use type. The conversion matrices used in this study are as shown in Appendix 5.

3.9.4 Land use/cover allocation procedure in the CLUES Model

When all input is provided the CLUES model calculates, with discrete time steps, the most likely changes in land use/cover based on the given restrictions and suitabilities. The allocation procedure is summarized in Fig. 9.

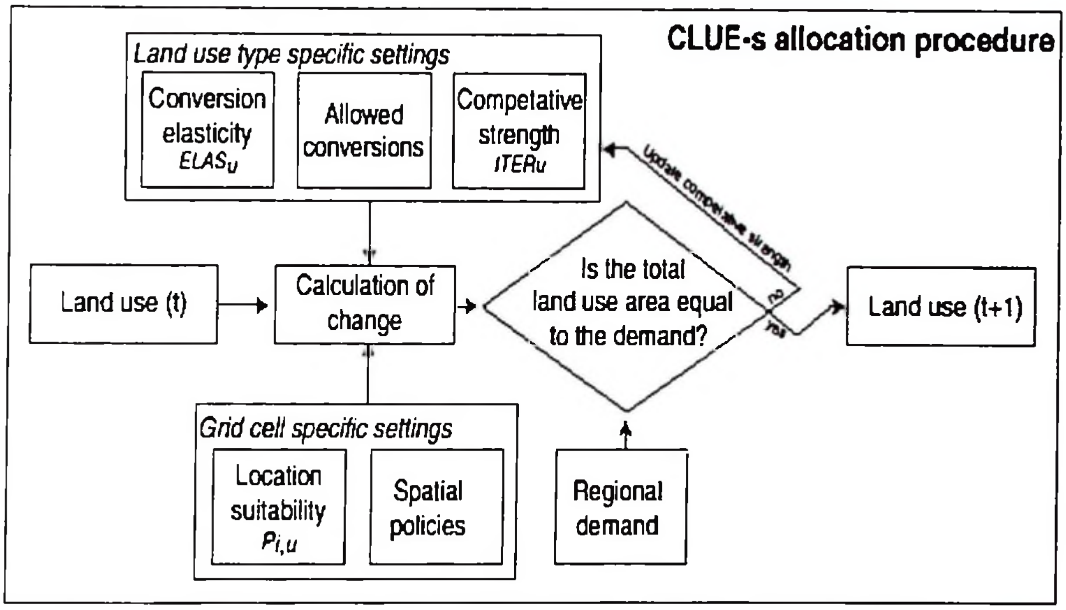

Figure 9: Flow chart of the allocation module of the CLUES model.
Source: Adapted from Verburg and Veldkamp (2004).

According to Verburg *et al.* (2002), the following steps are taken to allocate the changes in land use/cover within the CLUES framework:

1. The first step is to determine all grid cells that are allowed to change. In this process, grid cells that are either part of a protected area or had been classified as a land use/cover type that is not allowed to change are excluded from further calculation. Also the locations where certain conversions are not allowed due to the specification of the conversion matrix are identified.

2. For each grid cell *i* the total probability ($TPROP_{i,u}$) is calculated for each of the land use/cover types u according to:

   where $P_{i,u}$ is the suitability of location *i* for land use type *u* (based on the logit model), ELAS $_u$ is the conversion elasticity for land use/cover *u* and ITER $_u$ is an iteration variable that is specific to the land use/cover type and indicative for the relative competitive strength of the land use/cover type. ELAS $_u$, the land use/cover type specific elasticity to change value, is only added if grid-cell i is already under land use/cover type u in the year considered. $P_{i,u}$ consists of a part based on the biophysical and socio-economic factors, and a neighborhood interaction part.

3. A preliminary allocation is made with an equal value of the iteration variable ($ITER_u$) for all land use/cover types by allocating the land use/cover type with the highest total probability for the considered grid cell. Conversions that are not allowed according to the conversion matrix are not allocated. This allocation process will cause a certain number of grid cells to change land use.
4. The total allocated area of each land use/cover is now compared to the land use requirements (demand). For land use/cover types where the allocated area is smaller than the demanded area the value of the iteration variable is increased. For land use/cover types for which too much is allocated the value is decreased. Through this procedure it is possible that the local suitability based on the location factors is overruled by the iteration variable due to the differences in regional demand. The procedure followed balances the bottom-up allocation based on location suitability and the top-down allocation based on regional demand.

Steps 2 to 4 are repeated as long as the demands are not correctly allocated. When allocation equals demand the final map is saved and the calculations can continue for the next time step.

3.10 Development of the Livingstone Mountain (LIM)-CLUES Model for Predicting Ecosystems Vulnerability

This part provides information and methodology used in developing the LIM-CLUES model for predicting ecosystems vulnerability under landscape changes in the study area. Since ecosystems are the habitats of the different species identified to have decreased or disappeared from the study area, ecosystems vulnerability was assessed based on the spatial extent of landscape changes. This part therefore provides explanations on the remaining stages for developing a model using CLUES framework. As it does so, it also provides methodologies used for the actual development of the LIM-CLUES model, thus providing parameters generated in each stage of model development.

3.10.1 Land use/cover requirements (demand)

The way to derive these results can be chosen in regard to the nature of the major conversions that are taking place and the aim of the study. According to Verburg *et al.* (2002), land use requirements (demand) are calculated at the aggregate level (the level of the case-study as a whole) as part of a specific scenario. The land use requirements constrain the simulation by defining the totally required change in land use. All changes in individual pixels should add up to these requirements. In the CLUES model approach, land use requirements are calculated independently from the model itself. The calculation of these land use requirements is based on a range of methods, depending on the case study and the scenario. The extrapolation of trends in land use change of the recent past into the near future is a common technique to calculate land use requirements.

The demand module predicts the changes in demand for the total study area on a yearly basis, in area per land use/cover type (Soepboer, 2001). The spatial explicit allocation module translates the changes in demand by allocating changes in land use/cover pattern.

For every year in the specified time frame, this module creates a land-use prediction map taking into account the required decisions rules and the results of statistical analysis of selected driving factors. In this study the demand have been computed based on exponential trend scenario, between 1990 and 2000 and extrapolated to the year 2020, starting with 2000 as the initial year. However, expertise knowledge and prevailing policies in the study area are also important. The land use demands in this study are presented in the files named as ***demand1, demand2*** and ***demand3*** (Appendix 7) which have been used in the model. Having prepared the parameters explained in the previous sections, the CLUES model requires the use of other input parameters such as conversion matrix and finalising data needed in the main parameter file (main 1).

3.10.2 Conversion matrix

In the CLUES modelling framework, conversion matrix is stored in a filed named allow.txt. It is a file that indicates the allowed conversions of the different land use and cover types. It is a y x y matrix where y equals the number of land use types. In this study there are 7 land use and cover types therefore a 7x7 matrices have been used. According to Verburg *et al.* (2002), rows denote the present land use type and columns the potential future land use type. Moreover, a value of 1 in a matrix indicates that the conversion is allowed whereas a value of 0 indicates that the conversion is not allowed. Matrices used in this study (Appendix 5) are based on the different scenarios developed.

3.10.3 Information required in the main parameter file

In the LIM-CLUES Model, the main parameter file (***main.1***) contains all important parameters that determine the configuration of the simulation. This file can also be edited by Notepad or any other text editor. The parameters that were filled in the main parameter file and details of each parameter are as shown in Table 7.

3.10.4 Scenarios used in the study

This study has used scenarios in order to predict future landscape changes in the study area. Two types of scenarios, which are business as usual and policy were applied based on the prevailing conditions in the study area.

Table 7: Main parameter file showing formats and specifications of each parameter entered in the model

Line No.	Description	Format	Parameter entered
1	Number of land use types	Integer	7
2	Number of regions	Integer	1
3	Max. number of independent variables in a regression equation	Integer	6
4	Total number of driving factors	Integer	6
5	Number of rows	Integer	933
6	Number of columns	Integer	617
7	Cell area	Float	1.00 ha
8	xll coordinate	Float	676106
9	yll coordinate	Float	8720076
10	Number coding of the land use types	Integers	0 1 2 3 4 5 6
11	Codes for conversion elasticities	Float	0.8 0.6 0.8 0.7 0.4 0.8 1
12	Iteration variables	Float	0 0.35 3
13	Start and end year of simulation	Integers	2001 2021
14	Number and coding of explanatory factors that change every year	Integers	0
15	Output/input file choice	1, 0, -2 or 2	1
16	Region specific regression choice	0, 1 or 2	0
17	Initialization of land use history	0, 1 or 2	0
18	Neighbourhood calculation choice	0, 1 or 2	1
19	Location specific preference addition	Integers	0
20	Optional iteration parameter	Float	0.04

Business as usual scenario for this study assumed that the annual rate of increase in the area of upland cultivation observed between 1990 and 2000 is maintained. From this fact, the scenario used considers that there will be an increase of 3 400 ha of upland cultivation each year up to the last year (2020) for prediction. Thus, it is assumed that upland cultivation will increase at the expense of upland woodland and upland bushland with scattered cultivation, as it was observed in the landscape change detection between years 1990 and 2000. The areas for both, upland woodland and upland bushland with scattered cropland will decrease annually by 1 700 and 2 000 ha, respectively.

Likewise, the area for lowland grassland is assumed to increase by 832 ha annually. The increase in the lowland grassland with scattered cropland will be at the expense of lowland bushland with scattered cropland and lowland woodland, which are decreasing by 648 and 184 ha respectively. All annual rates of increase or decrease in the various land use and cover categories are based on the results obtained in the land use and land cover change detection matrix (Table 9). The business as usual scenario will assist the Mbinga District Authority to identify possible areas where more woodland clearance will be directed in the future. This can help the district authority to plan prior to realisation of the anticipated landscape changes. The demand settings for this business as usual scenario are as shown in Demand_1 file in Appendix 7.

In addition, policy scenarios have been considered in LIM-CLUES Model development. The first policy scenario considers that the policies that will attract investment in coffee business will be introduced by the government. This assumption is made on the basis that different initiatives such as cooperative unions and private businessmen will invest in coffee business by providing necessary farm inputs and securing reliable coffee market, as it was the case when MBICU was operating. Once this is achieved, it is assumed that coffee growing will stabilize hence improving income of the Matengo. As a result this situation will cause more Matengo to engage in coffee production hence reducing pressures of cultivating in the virgin Miombo woodlands, which is the main cause of landscape changes in the study area. Part of the income obtained from coffee will be used to buy supplementary food, hence reducing cultivation in the woodlands. It is therefore assumed that the observed (1990-2000) annual rate of increase in the area under cultivation (3 400 ha) will be reduced by half (1 700 ha) in each year, allowing regeneration to take place in areas previously under cultivation.

This scenario will therefore assist the Mbinga District Authority to identify possible areas for upland woodland regeneration from the previous agricultural land. In addition, it will also be possible to understand areas for increased upland cultivation. Under this policy initiative, it is therefore assumed that upland woodland will increase by 1 000 ha and upland bushland with scattered cropland by 700 ha annually, at the expense of upland cultivated land. This implies that the area of upland cultivation will be decreasing by 1 700 ha annually up to the year 2020.

Moreover, this scenario considers that the policy to reduce clearance of the woodlands will not be introduced in the lowland area because the rate at which the land use and cover categories changed between 1990 and 2000 years are not so alarming compared to the upland area. Therefore, lowland grassland with scattered cropland will be increasing by 832 ha annually at the expense of lowland bushland with scattered cropland and lowland woodland, which are decreasing by 648 and 184 ha, respectively. It is important to note that the annual rates of increase or decrease in the various land use and cover categories in the lowland area have been derived from change detection matrix (Table 9). The demand settings for this policy scenario are as shown in Demand 2 file in Appendix 6.

The second policy scenario is predicted based on the demand requirement settings (Demand 3) as shown in Appendix 7. This policy scenario assumes that the district authority intends to recover the area of upland woodland that was observed in the year 2000. This scenario is a response to the strategy issued by the Central government, instructing all those who have invaded the ranges and mountains including the Livingstone Mountain ranges for farming, settlements and tree harvesting should vacate (URT, 2006). It means that a policy will be introduced to restrict clearance of upland woodland for any human activities in order to conserve the remaining patches which are located in the catchments and steep slopes of the Livingstone Mountain ranges. Based on the GIS analysis, the remaining upland woodlands are located in areas with elevation ranging from 670 to 1 940 m and slope from 0 to 47 degrees. Based on this strategy this scenario is developed in order to assist the Mbinga District Authority in decision making regarding what area should be vacated. At the same time the predicted results will also provide information on locations where future cultivations can be directed within the upland bushland with scattered cropland. Therefore increase in the future cultivation is regarded to be half of the annual rate of increase as it was in the previous policy scenario. In this regard, the demand requirement in this scenario was set in a way that about 1 700 ha of upland bushland with scattered cropland would be decreasing annually to allow upland cultivation.

3.10.5 Model testing and validation

In order to test and validate the model results, a methodology by (Kok, 2001) of correlating areas of measured and simulated changes aggregated at administrative units was employed. This method requires determination of areas of each land use cover types from both measured and simulated changes based on a spatial unit such as administrative units and agro-ecological zones. The results from correlation (R^2) determine the predictability of the model. The higher the value approaching 1 the good the model is in prediction. This model validation approach was selected because it has been used by Kok (2001) and it does not require much time to develop the required parameters. Landsat imagery of the year 2006 (Appendix 8) was used to validate the model.

3.11 Limitations of the Study

The major constrains of this study were unavailability of satellite imagery that could cover the entire Livingstone Mountain ranges within Mbinga district. The Livingstone Mountain ranges in Mbinga district are covered by two Landsat scenes. However, it was not possible to acquire Landsat Imagery for a small area bordering Ludewa district. Out of three Landsat imagery required to cover this small area over the study periods, two of the scenes could not be available. Thus, out of 132 km of the total distance of the Mbinga district within the Livingstone Mountain ranges, about 22 km could not be included in this study. The missed area covered Mbaha and Lituhi wards. Besides, a researcher could not acquire satellite imagery for the period beyond 2000. This was due to financial problems. As a result, the latest satellite imagery used for the study was that of the year 2000. Moreover, it was not possible to obtain important biophysical factors such as soil and climate which could be included in developing the LIM-CLUES model. This was due to the fact that the existed soil and climate data were at very course scale that would not meet the requirements of this study. Although landscape changes in the study area were nmainly triggered by collapse of the local institutions, particularly MBICU, it was not possible to use this parameter in model development since its spatial extent could not be determined.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Overview

This chapter presents findings on the extent of landscape changes that had taken place between year 1979 and 1990; and between 1990 and 2000 in the study area. It also provides details on the influence of the socio-economic and biophysical factors to the landscape changes. Moreover, it looks at the implications of landscape changes to the livelihoods of the local communities. Finally, it provides simulated results of the near future landscape changes as a way of predicting the ecosystems vulnerability based on results from the LIM-CLUES Model.

4.2 Landscape Changes Between 1979-1990 and 1990-2000

Figures 10, 11 and 12 show the distribution of different land use/cover types based on the GIS analytical results from interpretations of Landsat scenes (Appendix 8) for the study area. Comparisons of the interpretation results provide landscape changes based on the change detection analysis carried on pairs of Landsat scenes of 1979 and 1990; 1990 and 2000. The major land use and cover types that were used for the landscape change detection are forest natural (Fn), forest plantation (Fp), lowland bushland with scattered cropland (lbsc), lowland woodland open (lwo), lowland woodland closed (lwc), lowland grassland with scattered cropland (lgsc), upland bushland with scattered cropland (upbsc), upland woodland open (upwo), upland woodland closed (upwc), upland cultivated land (upcl), and others (oth).

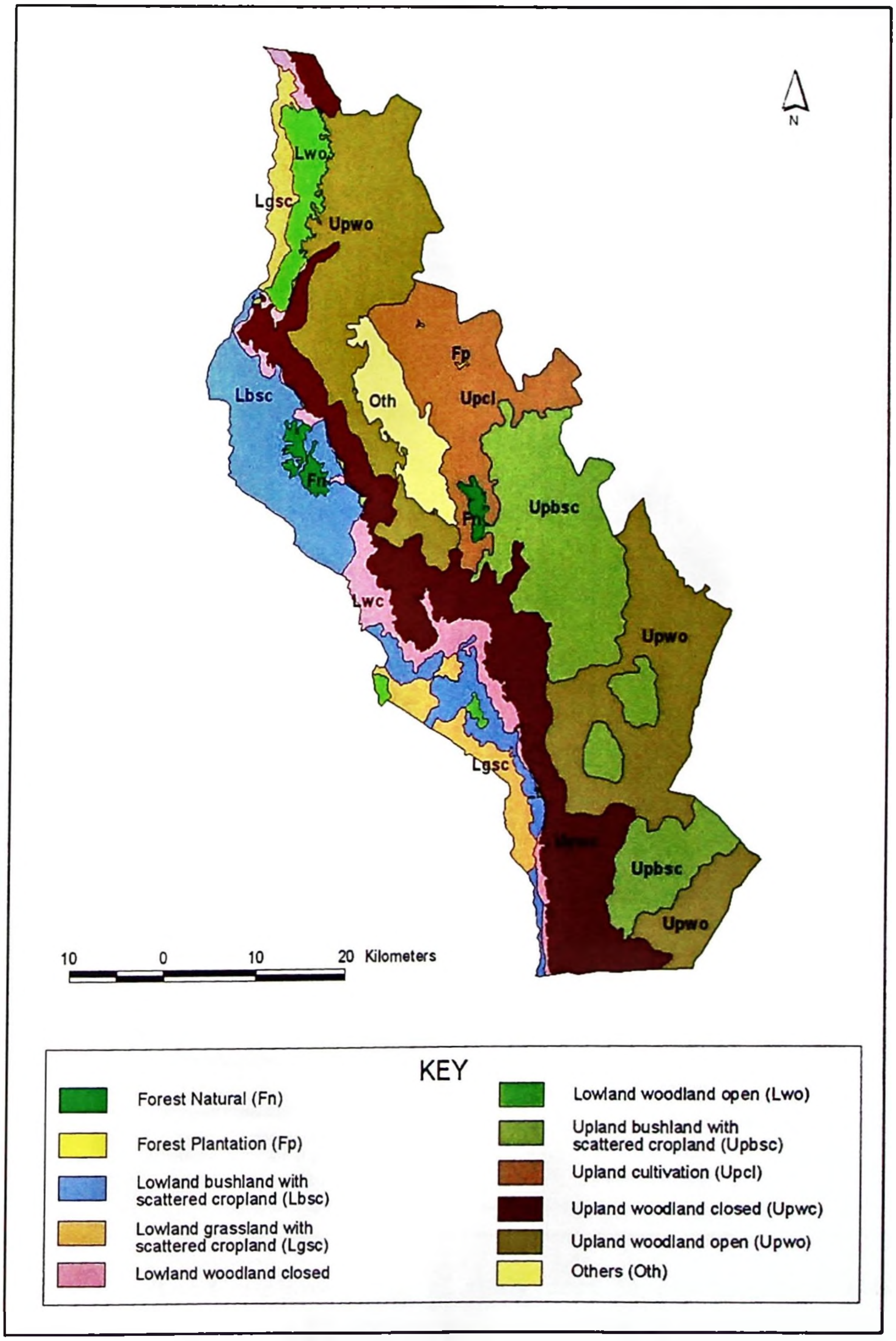

Figure 10: Land use/cover map of study area in Mbinga district based on interpretation of satellite imagery of 1979.

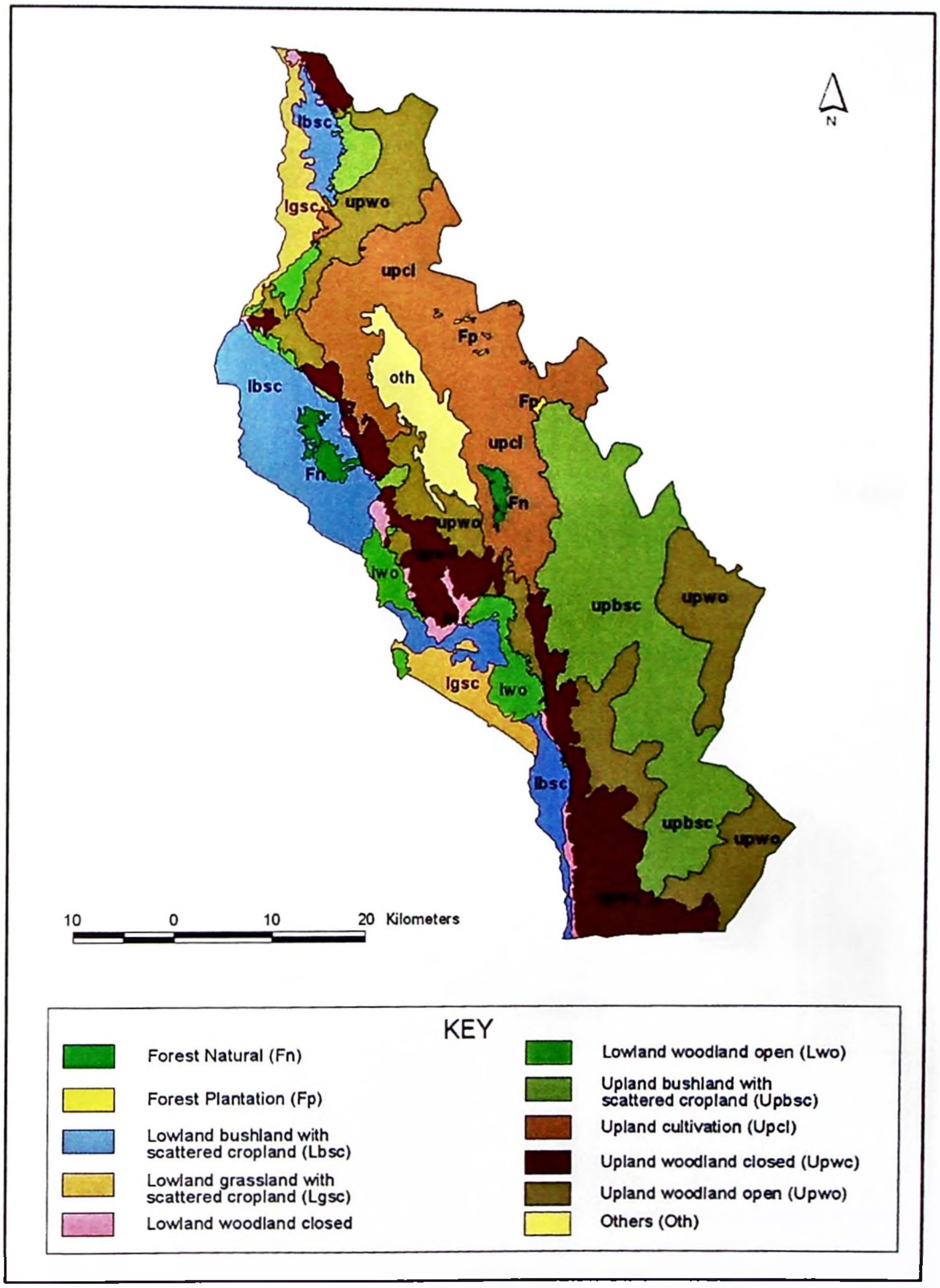

Figure 11: Land use/cover map of study area in Mbinga district based on interpretation of satellite imagery of 1990.

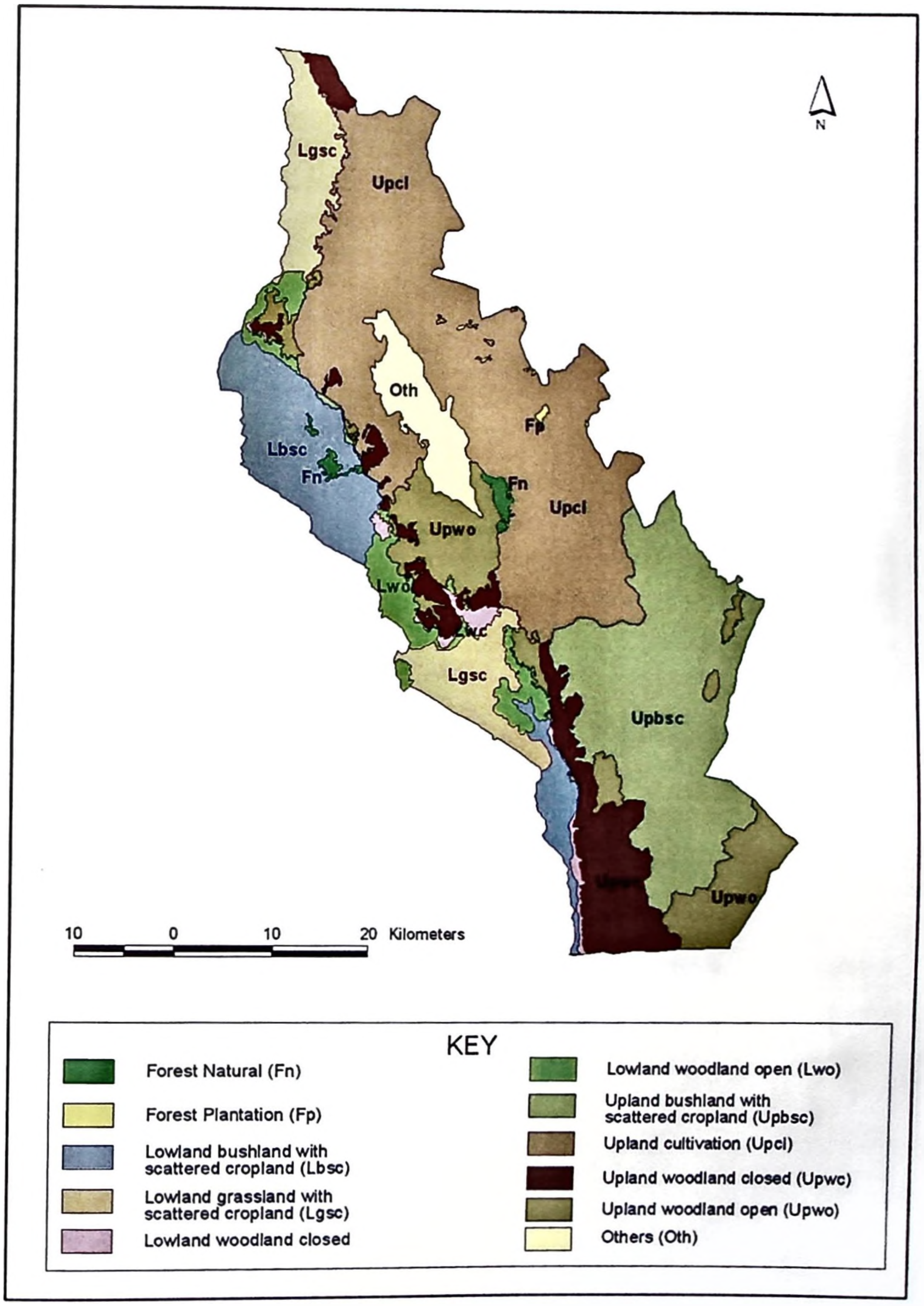

Figure 12: **Land use/cover map of study area in Mbinga district based on interpretation of satellite imagery of 2000.**

The satellite imagery analysis results in (Table 8) showed that during the year 1979 large part of the study area 70 432 ha (28.5%) was occupied by upland woodland open. The next dominant land use/cover categories were upland woodland closed 43 980 ha (17.8%), upland bushland with scattered cropland 43 215 ha (17.5%), lowland bushland with scattered cropland 25 433 ha (10.3%) and upland cultivation 23 455 ha (9.5%). During that time 1979, a total for each area occupied by forest natural, forest plantation, lowland grassland with scattered cropland, lowland woodland open, lowland woodland closed and others was less than 5% of the total study area.

Table 8: Area occupied by land use/cover types in the study area in different years

Land use/cover type	1979		1990		2000	
	Ha	%	Ha	%	Ha	%
Forest Natural	2 727	1.1	2 749	1.1	1 405	0.6
Forest Plantation	68	0.0	351	0.1	359	0.2
Lowland Bushland with Scattered Cropland	25 433	10.3	28 980	11.7	23 431	9.5
Lowland Grassland with Scattered Cropland	10 520	4.3	11 687	4.7	19 551	7.9
Lowland Woodland Closed	11 309	4.6	3 883	1.6	2 600	1.1
Lowland Woodland Open	6 812	2.8	9 447	3.8	9 673	3.9
Upland Bushland with Scattered Cropland	43 215	17.5	52 730	21.3	49 525	20.0
Upland Cultivation	23 455	9.5	47 368	19.2	84 646	34.2
Upland Woodland Closed	43 980	17.8	30 060	12.2	21 162	8.6
Upland Woodland Open	70 432	28.5	50 470	20.4	25 944	10.5
Others	9 293	3.8	9 519	3.9	8 948	3.6
Total	247 244	100	247 244	100	247 244	100

In 1990, upland bushland with scattered cropland occupied large part of the study area (Fig. 11). The area of upland bushland with scattered cropland increased from 43 215 ha (17.5%) to 52 730 ha (21.3%). This was followed by upland woodland open 50 470 ha (20.4%), upland cultivated land 47 368 ha (19.2%), upland woodland closed 30 060 ha (12.2%), lowland bushland with scattered cropland 28 980 ha 11.7%. Similarly, as was for the year 1979, the remaining land use and cover types (forest natural, forest plantation, lowland grassland with scattered cropland, lowland woodland open, lowland woodland closed and others) total area for each of these categories occupied less than 5% of the total area.

In contrary to years 1979 and 1990, Table 8 shows that in the year 2000 upland cultivation turned to be the dominant land use type in the study area by increasing from 47 368 ha (19.2%) in 1990 to 84 646 ha (34.2%) in 2000. This was followed by upland bushland with scattered cropland which occupied 49 525 ha (20.0%), upland woodland open 25 943 ha (10.5%), lowland bushland with scattered cropland 23 431 ha (9.5%), upland woodland closed 21 162 (8.6%), and lowland grassland with scattered cropland 19 551 ha (7.9%). The increase in cultivated land was also confirmed by decline in combined total area for upland bushland with scattered cropland, upland woodland closed, and upland woodland open from 53.9% in 1990 to 39.1% in 2000 due to increased deforestation in the upland area. Likewise, the results (Table 8) showed that increase in the area of lowland grassland with scattered cropland was also linked with a decrease in combined total area for lowland bushland with scattered cropland, lowland woodland closed, and lowland woodland open from 17.11% in 1990 to 14.44% in 2000.

The increase in upland cultivation was facilitated by the use of *ngolo* cultivation system as shown in Plate 3 (a and b), which increases the possibility of cultivating in the steep slopes whereas lack of application of *ngolo* farming system in the lowland area has limited cultivation in the steep slopes. However, cultivation in the lowland area took place mainly in the areas occupied by lowland grassland with scattered cropland.

Plate 3(a): Ngolo fields on slopes of the Livingstone Mountain Ranges

Plate 3(b): Ngolo fields on slopes of the Livingstone Mountain Ranges

The results (Table 8) also showed that area occupied by lowland grassland with scattered cropland increased from 10 520 ha (4.25%) to 11 687 ha, and to 19 551 ha (4.73%) in 1979, 1990 and 2000, respectively. Areas occupied by lowland grassland with scattered cropland were mainly flat areas including flood plains and seasonal wetlands, which were used mostly for cultivating, paddy, cassava, and regume crops.

Furthermore, the results (Table 8) showed that 73 155 ha of the total area of woodland in both areas (upland and lowland) were cleared between 1979 and 2000. This area was equivalent to a loss of 3 484 ha per year. The total area lost was equal to 55% of the total woodland area in 1979 in the study area. Results (Table 8) therefore implied that there was a decline in the area occupied by natural vegetations in both upland and lowland areas. However, such decrease in natural vegetations was more serious in the upland compared to lowland. The reasons for this could be linked to, among others, variations in the climatic conditions between the two areas. According to MWARP (1998), the upland areas were estimated to receive an annual rainfall of about 1 300 mm while lowland areas received an estimated annual rainfall of less than 1000 mm. The average annual temperatures for Mbinga district were reported to range from about 13°C to about 30°C on the shores of Lake Nyasa (Mchau, 1993). In this case, it was obvious that in a situation where cultivation was based on rainfed, more cultivation should be practised in the upland areas due to favourable climatic conditions. This was confirmed by a continuous increase in the area occupied by upland cultivation in the study area (Table 8) from 23 455 ha (9.49%), to 47 368 ha (19.16%), and to 84 646 ha (34.24%) in years 1979, 1990 and 2000, respectively. Moreover, the population density in the highlands ranged between 100 -120 people/km^2 compared to 34 people/km^2 of the district. In this regard, people from the highlands used more land for cultivation compared to people from other parts of the district including the adjacent lowlands.

According to Focused Group Discussions (FGDs) and key informant interviews, decrease in the natural vegetation in the Livingstone Mountain Ranges was associated with the establishment of new farms and settlements. The same concern was raised by respondents from the household survey whereby out of 230 respondents, 176 (76.5%) reported about decrease in the trees due agricultural practises and establishment of settlements. Likewise, transect walks in the study area enabled to observe areas where recent woodland clearance took place for farming and settlements establishment. This implies that there was more encroachment for farming in the woodlands that caused conversion of such woodland areas into bushland with scattered cropland in both upland and lowland areas. This was the reason for an increase (Table 8) in the areas of upland bushland with scattered cropland from 43 215 ha (17.5%) and lowland bushland with scattered cropland 25 433 ha (10.3%) in 1979 to 52 730 (21.3%) and 28 980 (11.7%) in 1990, respectively. Fig. 13 shows areas occupied by different land use and cover categories for the study years (1979, 1990 and 2000).

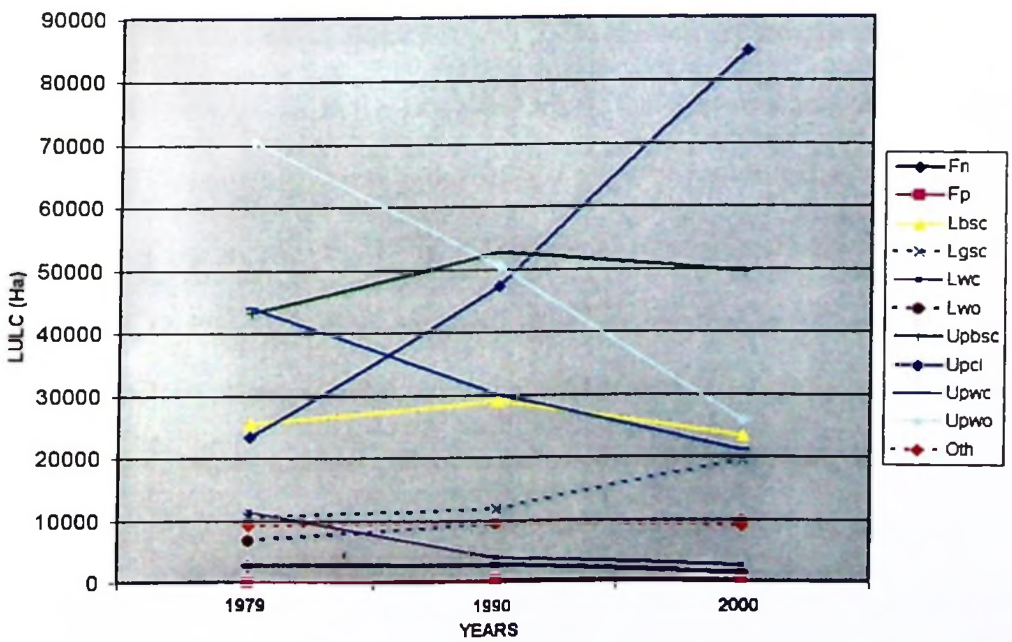

Figure 13: Areas occupied by different land use and cover categories in 1979, 1990 and 2000.

In contrast, a decline in the area for upland bushland with scattered cropland and lowland bushland with scattered cropland between years 1990 and 2000 (Fig. 13) implied that there was a total conversion of bushland to cultivated land rather than encroachment. Moreover, when compared the opinion of the participants in the FDGs regarding increasing and decreasing trends of the bushland with scattered cropland between years 1979 and 2000, their opinion corresponded to the reality on the ground whereby the general observations showed decrease in the natural vegetation regardless of which type of land use/cover was actually affected in the study area where cultivation is based on rainfed.

The same kind of results were also obtained by Nautiyal *et al.* (2005) in a study conducted in the Indian Central Himalayan region where the rainfed agriculture on steep terraces was the predominant form of land use, while only about 15-20% of the total cultivated land was irrigated. Likewise, a study by Luoga *et al.* (2005b) in the general lands of Tanzania between 1964 and 1996 showed a decline of 50% of woodland, 599% increase in bushlands and croplands, and 277% increase in the settlements and home-gardens. Moreover, Campbell *et al.* (2003) reports that the forest area on the upper slopes of Mount Kilimanjaro adjacent to the national forest in Tanzania declined 2.3% from an estimated 646 ha in 1973 to 417 ha in 2000 due to expansion of cultivated land whereas the area of rainfed agriculture expanded by 177% and that of irrigated agriculture by 45.2%. Similarly, Masao (1974) reported degradation of forest along Mount Kilimanjaro slopes due to unsustainable utilization of resources. Furthermore, study by Madulu (2004) in the Usambara Mountains reported about destruction of almost 70 percent of the rain forests since the year 1954 due to expansion of cultivated land and population growth. A study by NEMC (2008) also reported that increased deforestation in the Livingstone Mountain ranges was mainly caused by expansion of agricultural area and population growth, in which case the population density for the Matengo highlands (upland) ranged between 100 – 120 people/km^2. This showed that unsustainable cultivation on catchment areas was a common phenomenon in the areas where population pressure heightening. Natural vegetation therefore decreased in most places at the expense of human activities, mainly agriculture.

The results from this study showed that upland woodland was the most affected category that changed drastically. In most cases, upland cultivation increased at the expense of upland woodland and upland bushland with scattered cropland (Plate 4). There have not been significant changes in the natural vegetation (woodland) in the lowland areas compared to upland. Also in all reported cases above, agriculture was mainly dependant on rainfed rather than irrigation. This implied that areas which received higher amounts of rainfall (like the upland area of the study) were likely to be affected more by the conversion of natural vegetation areas to cultivated land. These findings conform to other studies (Nindi, 2004; 2007; NEMC, 2008) conducted in Mbinga district whereby results showed a decrease in natural vegetation was mainly due to agricultural expansion and settlements.

Plate 4: Natural vegetation clearance in the Livingstone Mountain ranges

4.2.1 Change Detection Matrices based on satellite imagery analysis

The extent at which the land use and cover types were converted from one type to another are provide in Table 9. The results showed that different land use/cover types were converted from one type to another in the study area. The interpretation of the Table 10 setup was as detailed by Mnkabenga (2001) where the numbers along each row represented part of land use/cover category (ha) replaced by the category in columns during the temporal period. On the other hand, numbers along the column represented transformation (ha) of the categories (arranged in rows) towards the category bearing the heading of the column. Row total represented area coverage of the category of land use/cover in the initial year, while column total represented area coverage of the category in the final year of temporal period.

The results (Table 9) showed that between 1979 and 1990 out of 43 980 ha total area covered by upland woodland closed, 28 577 ha (65%) remained unchanged whereas 10 149 ha (23.1%) were changed to upland woodland open, 2 864 ha (6.5%) to upland bushland with scattered cropland, and 2 390 (5.4%) to upland cultivation. On the other side, out of 70 432 ha covered by upland woodland open between 1979 and 1990, 38 364 ha (54.5%) remained unchanged, while 15 596 ha (22.1%) were converted to upland cultivation, 15 015 ha (21.3%) to upland bushland with scattered cropland, 1 208 ha (1.7%) to upland woodland closed, and 249 ha (0.35%) to others.

During the same period, more than half of the total area (11 309 ha) of lowland woodland closed, that is 5 846 ha (51.7%) were converted to lowland woodland open whereas 3 621 ha (32.0%) remained unchanged. Conversion of lowland woodland closed to lowland woodland open implies increased shifting cultivation and encroachment for other purposes particularly extraction of forest products which also lead to a decreased area occupied by closed trees to open trees. Most of the lowland woodland closed areas changed to lowland woodland open were located in relatively flat areas. This situation enabled the application of the famous cultivation systems used in the lowland area such as long ridges, mounds and flat seedbed to cultivate within the lowland woodland open. Moreover, advancement of the Matengo to the lowland areas might have contributed to this situation.

Land use/cover changes between 1979 and 1990 (ha)												
	Fn	Fp	Lbsc	Lgsc	Lwc	Lwo	Upbsc	Upcl	Upwc	Upwo	Oth	1979
Fn	2 328	0	305	0	0	0	0	94	0	0	0	2 727
Fp	0	56	0	0	0	0	0	11	0	0	0	68
Lbsc	292	0	21 341	1 784	255	1 761	0	0	0	0	0	25 433
Lgsc	0	0	2 768	7 677	6	69	0	0	0	0	0	10 520
Lwc	91	0	1 491	260	3 621	5 846	0	0	0	0	0	11 309
Lwo	0	-	3 075	1 966	0	1 771	0	0	0	0	0	6 812
Upbsc	1	17	0	0	0	0	34 842	6 214	265	1 876	0	43 215
Upcl	37	278	0	0	0	0	9	23 019	10	66	36	23 455
Upwc	0	0	0	0	0	0	2 864	2 390	28 577	10 149	0	43 980
Upwo	0	0	0	0	0	0	15 015	15 596	1 208	38 364	249	70 432
Oth	0	0	0	0	0	0	0	44	0	15	9 234	9 293
1990	2 749	351	28 980	11 687	3 883	9 447	52 730	47 368	30 060	50 470	9 519	247 244

Land use/cover changes between 1990 and 2000 (ha)												
	Fn	Fp	Lbsc	Lgsc	Lwc	Lwo	Upbsc	Upcl	Upwc	Upwo	Oth	1990
Fn	1 361	0	1 270	0	0	0	0	79	0	39	0	2 749
Fp	0	328	0	0	0	0	0	23	0	0	0	351
Lbsc	12	0	21 476	6 479	42	971	0	0	0	0	0	28 980
Lgsc	0	0	29	11 234	0	424	0	0	0	0	0	11 687
Lwc	0	0	241	458	2 004	1180	0	0	0	0	0	3 883
Lwo	0	0	415	1 380	554	7098	0	0	0	0	0	9 447
Upbsc	0	1	0	0	0	0	32249	20 236	63	181	0	52 730
Upcl	32	30	0	0	0	0	0	45 657	22	1 475	152	47 368
Upwc	0	0	1	0	0	0	679	2 974	20 618	5 789	0	30 060
Upwo	0	0	0	0	0	0	16 597	15 470	459	17 933	11	50 470
Oth	0	0	0	0	0	0	0	207	0	527	8 785	9 519
2000	1 405	359	23 431	19 551	2 600	9673	49 525	84 646	21 162	25 944	8 948	247 244

Table 9: Change detection matrix for the period of 1979 to 1990 and 1990 to 2000

In addition to the conversion that took place in the lowland woodland closed, about 1 771 ha (25.9%) of lowland woodland open remained unchanged out of 6 812 ha. The rest 3 075 ha (45.1%) were converted to lowland bushland with scattered cropland and other 1 966 ha (28.9%) were converted to lowland grassland with scattered cropland. Conversion of both cases of land use cover types above implies that there was expansion of scattered cultivation at the expense of the lowland woodland open. Likewise, between 1979 and 1990 out of 25 433 ha of lowland bushland with scattered cropland 21 341 ha (83.9%) remained unchanged. The rest area were converted to different land use and cover types such as lowland grassland with scattered cropland (1 784 ha), lowland woodland open (1 761 ha), forest natural (292 ha), and lowland woodland closed (255 ha). The land use and cover changes in the lowland could be linked to the villagization/resettlement program of the mid 1970s, which might have had impact to new encroachment and scattered cultivation in the lowland at that time, as the area was severely hit by the program.

From the 2 768 ha of lowland grassland with scattered cropland which were converted to lowland bushland with scattered cropland and 1 784 ha of bushland with scattered cropland converted to lowland grassland with scattered cropland, it implied that both areas of lowland grassland with scattered cropland and lowland bushland with scattered cropland were used interchangeably for shifting cultivation. That is why areas occupied by lowland bushland with scattered cropland could be converted to lowland grassland and vice versa. Likewise, the conversion of lowland woodland closed to lowland wood open shows a decline in the woodlands due to scattered cultivation.

Besides, from 1990 to 2000, results (Table 9) showed extensive clearance of upland woodland open (16 597 ha and 15 470 ha) to upland bushland with scattered cropland and upland cultivation, respectively. Out of 50 470 ha of total upland woodland open only 17 933 ha (35.5%) remained unchanged. This showed that there was more conversion of the upland woodland open to full cultivated land and also encroachment for scattered cultivation and extraction of goods and services.

In the case of upland woodland closed, 20 618 ha (68.6%) remained unchanged out of 30 060 ha. whereas only 2 974 ha were converted to upland cultivation and 5 789 ha were converted to upland woodland open. This situation implied that clearance of the areas occupied by natural vegetation from upland woodland closed to upland cultivation was less than the conversion of upland woodland open to either upland cultivation or upland bushland with scattered cropland. However, it is important to note that most of the remaining upland woodland closed areas were in very steep slopes that required more labour, time and mostly *ngolo* cultivation system in order to be converted to upland cultivation category. These entire requirement posed a considerable burden to farmers when were engaged in clearing upland woodland closed areas for cultivation. Contrary, it was therefore easier in terms of labour input and time required to expand cultivation in open woodland areas compared to clearing woodland closed areas. This argument is also supported by the fact that the largest expansion of upland cultivation (20 236 ha) was directed towards areas occupied by bushland with scattered cropland, which are easier to work on, rather than upland woodland open or upland woodland closed.

During the same period (1990 and 2000), about 21 476 (74.1%) out of 28 980 of the lowland bushland with scattered cropland remained unchanged whereas 6 479 ha were converted to lowland grassland with scattered cropland. Also, about 971 ha of lowland bushland with scattered cropland were converted to lowland woodland open. This shows that this area of lowland bushland with scattered cropland was left to fallow hence allowed regeneration of the lowland woodland open. However, only 1 380 ha of lowland woodland open and 458 ha of lowland woodland closed were converted to lowland bushland with scattered cropland. This shows that cultivation was extended in the areas occupied with lowland grassland with scattered cropland. It therefore implies that there was less clearance of natural vegetation in the lowland areas compared to the upland areas. This justifies the fact that communities in the lowland areas do not use *ngolo* cultivation system that would have enabled them to cultivate in steep slopes where woodlands are located. As a result, extensive cultivation was practised in relatively flat areas such as flood plains and seasonal wetlands.

The conversions of the land use and cover types in both upland and lowland areas (Table 9) therefore implied that there was an increase in the clearance of natural vegetation to other land use and cover types in favour of expanding farming land. This argument is based on the facts that upland/lowland woodland open includes areas occupied by upland/lowland woodland with scattered cropland, therefore, conversion of upland/lowland woodland closed to upland/lowland woodland open means increasing shifting cultivation within the upland/lowland woodland closed. Moreover, conversion of all categories of upland/lowland woodlands to upland/lowland bushland with scattered cropland also implied the expansion of cultivation area and for extraction of other goods and services from the natural vegetation by the local communities hence reduced the area covered by trees to bushes with scattered crops.

This could be associated with the impact of livelihood strategies such as extraction of tree products like charcoal making, fuel wood collection and building materials, hence degradation of woodland to bushland. In addition, since some areas occupied by upland woodland closed, upland woodland open, and upland bushland with scattered cropland were converted fully to cultivated land it implied that more areas with natural vegetation were cleared for cultivation and provision of goods and services. Similar results are reported in Ethiopian Highlands by Feoli *et al.* (2002) that the conversion of woodlands and shrublands into croplands has resulted in loss of the natural vegetation cover.

In supporting these findings, FGDs from all six survey villages revealed that natural vegetation (woodlands) supports the provision of goods and services such as water, food (mushroom), wild fruits, fuel wood, building materials and medicines. NEMC (2008) also reports a myriad of ecological goods and services derived by the local communities in the Livingstone Mountain ranges in Mbinga district such as water, food, fuelwood/energy, building materials, pasture, medicinal plants, cultural services, and micro climate moderation. However, key informant interviews revealed that most of the goods derived from the woodlands had decreased because of natural vegetation clearance. Likewise, report from key informants agree with results by NEMC (2008) that goods and services derived from the natural vegetation declined in the Livingstone Mountain ranges due to expansion of farming land and settlements. Transect walks in the study area showed that remaining woodlands were located away from settlements and were found mainly in very steep slopes, resulting to difficulties in accessing goods and services from them.

4.3 Influence of Socio-Economic and Bio-Physical Factors in Landscape Changes

4.3.1 Socio-economic factors influencing landscape changes

The influence of socio-economic factors on landscape changes is given in Table 10. The results show that out 22 variables used in the logistic analysis only 5 were statistically significant at $p \leq 0.05$. These were scarcity of farming land (CMASLF at $p \leq 0.000$), education (EDUCAT at $p = 0.018$), occupation (OCCUPAT at $p = 0.021$), cultivation of cereals on ridges (CRPCERD at $p \leq 0.000$) and cultivation of banana for domestic use (CRPBAUS1 at $p = 0.005$).

4.3.1.1 Scarcity of farming land

The results (Table 10) show that the probability of increase in the conversion of the landscape to cultivated land in the study area was associated with an increase in scarcity of farming land at coefficient of 4.285. The odd of land conversion with scarcity of farming was 72.59 times that of other factors. The statistical significance of scarcity of farming land (CMASLF) at $p \leq 0.000$ in the conversion of landscape to cultivated land comes from the fact that the soil fertility of the land was depleted by continuous cultivation brought by increase in population. This has increased the conversion of potential virgin farming lands found in the Livingstone Mountain ranges and its adjacent lowlands that were dominated by woodland and bushland. In correspondence to this study, MWARP (1998) also showed that shortage of land was a common complaint of farmers in the study area.

Furthermore, the results show that cultivation of cereals on ridges (CRPCERD) was also statistically significant at $p \leq 0.000$ and increased the odds of conversion of the landscape to cultivated land by a factor of 38. This was based on the fact that ridges were used in both upland and lowland areas for the cultivation of cereal crops, particularly maize. It is important to note that maize was a staple food crop in the study area. Key informants and FGDs associated the collapse of the local cooperative union, MBICU in early 1990s to reduced maize production.

Table 10: Logistic regression model for landscape changes

Variable	Coefficient (B)	Wald	Exp(B)	p- value
Ngolo farming system (NGOLOFSY)	1.482	0.037	4.402	.847 ns
Type of cultivation system (FARMSYS)	0.309	0.447	1.362	.504 ns
Scarcity of farming land (CMASLF)	4.285	26.210	72.590	.000 **
Location (LOCAT)	-3.540	0.207	0.029	.649 ns
Age (AGE)	0.355	2.315	1.426	.128 ns
Marital status (MARITAL)	0.184	0.276	0.832	.599 ns
Education (EDUCAT)	-4.076	5.569	0.017	.018 **
Occupation (OCCUPAT)	1.051	5.312	2.860	.021 **
Possession of Livestock (WHTPROP2)	-0.492	0.195	0.612	.658 ns
Possession of Woodlots (WHTPRP3)	-1.775	2.807	0.169	.094 ns
Commercial farming (FARCOMM)	-2.124	1.939	0.120	.164 ns
Income level (INCOME)	0.368	2.417	1.444	.120 ns
Roots and tuber for selling (CRPRTUS2)	-2.170	2.995	0.114	.084 ns
Roots and tuber cultivated on ridges (CPRTCSR)	-0.260	0.061	0.771	.805 ns
Roots and tuber cultivated on ridges-mounds (CPRTCSRM)	-0.969	0.901	0.379	.343 ns
Cultivation of cereals for domestic use (CRPCEUS1)	1.853	1.021	6.376	.312 ns
Cultivation of cereals for selling (CRPCEUS2)	-0.113	0.012	0.893	.913 ns
Cultivation of cereals on ridges (CRPCERD)	3.656	12.385	38.703	.000 **
Cultivation of banana for domestic use (CRPBAUS1)	3.039	7.770	20.888	.005 **
Cultivation of banana for selling (CRPBAUS2)	-1.918	3.318	0.147	.069 ns
Cultivation of legumes for domestic use (CRPLGUS1)	-0.786	0.482	0.456	.488 ns
Cultivation of legumes for selling CRPLGUS2	0.828	0.768	2.288	.381 ns
Constant	6.536	0.535	689.740	.464 ns

Significant at $p \leq 0.05$**, ns - not significant

The collapse of this local institution (MBICU) was attributed to liberalisation of coffee market that also brought in private coffee buyers in early 1990s. Similarly, Nindi (2004) reported that MBICU had been a reliable market for coffee to Matengo farmers for many years and it also used to provide farm inputs such as chemical fertilizers to support agricultural production in farmer's individual farm plots in the upland areas, which helped to reduce pressure to the woodlands. The private coffee buyers poses stiff competition price of coffee marketing to the extent that MBICU could not compete with the private buyers (Mhando, 2005). The collapse of MBICU denied local communities' accessibility to farm inputs in the Matengo Highlands. As a result, the Matengo farmers could no longer produce enough for their subsistence in their discrete farm plots in the upland areas. Hence, they were compelled to look for virgin land in the woodlands within the Livingstone Mountain ranges and towards the lowland areas where they could cultivate without applying chemical fertilizers, thus, more conversion of the landscape. The results are also supported by Benjaminsen (2001) who found that the most obvious and visible environmental impact of agricultural development is the extension of cultivated land mainly at the expense of woodland in the Malian cotton zone. Same results are echoed by Mumbi (2002) in the former Kameza forest reserve in Zambia, where about 25.8% of closed woodland was converted into agriculture.

Likewise, results in Table 10 show that cultivation of banana for domestic use (CRPBAUS1) was statistically significant at $p \leq 0.005$ and increased the odds of conversion of the landscape to cultivated land by a factor of 20. The probability of increase in the conversion of the landscape with banana cultivation (with coefficient at 3.039) was attributed to the fact that banana can grow and support subsistence for almost throughout the year where there is soil fertility depletion. Local communities in both upland and lowland areas in the Livingstone Mountain ranges have opted to increase production of banana as a food security crop as banana can be grown even in marginal lands (steep slopes, river banks, wetlands and valley bottoms) and can stay in fallow. Many studies (MWARP, 1998; Nindi, 2004; NEMC, 2008) have reported decline in soil fertility in the Matengo highlands (upland area) which have been associated with increase in banana cultivation in the study villages.

In contrast, the results (Table 10) show that an increase in the cultivation of banana for selling out (CRPBAUS2) was statistically insignificant at $p \leq 0.069$ and associated with decrease in the conversion of landscape to cultivated land (with a coefficient of -1.918). This was due to the fact that there was no enough suitable land to support commercial cultivation of banana and also farmers lacked farm inputs and technology to increase banana productivity within a limited land area. For instance, in the Matengo highlands (upland area), banana cultivation had been practised for so long mainly as an intercrop with coffee hence had not caused expansion of farming land to new areas.

As was the case with banana, results in Table 10 show that increase in cereal cultivation for domestic use (with a coefficient of 1.853) and selling out (with a coefficient of -0.113) lead to both an increase and a decrease in the landscape converted to cultivated land. Even though, the cultivation of cereals for both domestic use (CRPCEUS1) and selling out (CRPCEUS2) were statistically insignificant at $p \leq 0.312$ and $p \leq 0.913$, respectively. The probability of increase in the conversion of the landscape with cultivation of cereals for domestic use was high by factors of 6.376 compared to that of selling out (0.893). The results implied that increase in the cultivation of cereals for domestic use increased the need for local communities to acquire new farming land whenever possible, depending on the rate at which soil fertility decreases. In this case of cultivation of cereals for domestic use promoted more shifting cultivation that causes further landscape changes. Contrary, increase in the cultivation of cereals for selling out would probably decrease the conversion of landscape as commercialisation promote intensification and limit the flexibility of engaging in shifting cultivation.

This can be linked to the reality existed among majority of the Matengo people whereby most of the income accrued from coffee were used for acquisition of farm inputs before trade liberalisation period. The application of farm inputs especially fertilizers reduced need for extension of farming land to new lands, particularly woodland areas. In most cases, increased application of farm inputs resulted into more yields, hence more income. In most cases, incomes from coffee were used to purchase supplementary cereals (maize) for domestic use which reduced demand for self produced food. Most of the cereals particularly maize sold in the Matengo highlands were brought from other places of Mbinga or Songea districts. In this case, with decline in income from coffee, which was used for purchasing food crops, increased the dependence of Matengo people in self produced food which compelled them to extend cultivation in the lowland and rolling hills areas. Therefore, when there is no enough food particularly maize, expansion of farming land to the virgin woodland areas become the most likely option.

In the case of lowland area, participants in the FGDs and key informant reported that there was no any reliable cash crop grown in the lowland that would have boosted their income and encourage the use of farm inputs as it was the case in the upland area, which relied on coffee as their main cash crop. In addition, respondents from household survey showed that people in the lowland mainly grew paddy, cassava, maize and vegetables. Although lowland farmers had once engaged in growing cashew nuts based on advice from political leaders including district authority, however, market for cashew nuts was the biggest problem they faced. In this situation, there was no way for the lowland farmers to boost their income through cashew nuts growing. In this regard, it was observed during transect walks most if not all cashew nuts tree were left in the wild without any care and some of them were being cleared for fuelwood. Moreover, lack of reliable income from fishing also exacerbated income level for majority of the people in the lowland area. As a result, application of farm inputs was not possible based on the existed income situation of the people in the lowlands. This is supported by NEMC (2008), which found that most of the people living along the Lake Nyasa shore (lowlands) are faced with low income to invest in agricultural production and other socio-economic development activities. Moreover, FGD and key informant interviews revealed that tourism industry that could have also supported their livelihood is not developed in the lowland area although the Lake Nyasa is potential for various attractions such as beautiful beaches, small islands and deep waters for diving. Thus, cultivation remains the only alternative for their livelihood. In turn, poor farming techniques might further lead to continued poverty and increased dependency on natural resources. Hence shifting cultivation for subsistence in the woodlands and bushlands, where the use of agro-chemicals was not necessary, became the only way of sustaining farming in the lowland area.

The regression results (Table 10) also show increase in conversion of the landscape with *ngolo* farming (with coefficient of 1.482). However, a landscape change due to conversion by *ngolo* farming was statistically insignificant at $p \leq 0.847$. The main question that raised from these results was why *ngolo* farming was statistically insignificant if at all it was the main farming system used for producing food crops in all villages in the upland area? According to MWARP (1998) *ngolo* is mostly practised in slopes ranging between 15 – 60% and rarely practiced in areas with slopes less than ten percent. Other studies (Temu and Bisanda, 1994; MWARP, 1995; Lyimo and Kangalawe, 1997; Itani, 1998; Nindi, 1999; 2004) have also reported that *ngolo* farming system is traditionally practised only by the Matengo tribe who are mostly concentrated in the upland areas in Mbinga district. This situation implies that lowland people seldom use *ngolo* cultivation. Besides, the insignificance of *ngolo* could be come from the fact that the total area in the lowland that is potential for *ngolo* cultivation is relatively small.

Results from the study have also shown that the probability of increasing in the conversion of the landscape to cultivated land based on the cultivation of legume crops for home use and selling out were associated with a decrease in the coefficient at -0.786 and an increase in the coefficient at 0.828, respectively. In addition, probability of conversion of landscape to cultivated land based on legume cultivation for both domestic uses and selling out were both statistically insignificant at $p \leq 0.488$ and $p \leq 0.381$, respectively. A decrease in coefficient is mainly attributed to the fact that the area used by legume crops for domestic uses is relatively small because legume crops are intercropped and mostly grown in *ngolo* farms which have also shown to be statistical insignificant. However, increase in landscape changes as farmers opt to cultivate legumes for selling out is likely to increase cultivation in other areas especially in the woodlands, because there is limited potential area for *ngolo* cultivation.

4.3.1.2 Lack of possession of woodlots among community members

On the other hand, results from logistic regression (Table 10) also show that the possession of woodlots among community members was associated with decrease in conversion of landscape with coefficient of -1.775. The possession of woodlots (WHTPRP3) was statistically insignificant at $p \leq 0.094$. The reality for these results was based on the fact that areas of woodlots were restricted from vegetation clearance as opposed to woodlands found in general lands, which are prone for encroachment. Therefore, the more people possess woodlots, the more chances for landscape changes decreases. In contrary, lack of woodlots possession implies that chances for the conversion of the landscape or vegetation clearance in the woodlands within the public land increases due to uncontrolled human activities. Focus Group Discussions and key informant interviews indicated that local communities relied on the goods and services such as fuelwood, building materials, traditional medicines mostly from the woodlands. Similarly, establishment of woodlots by the farmers increase the possibility of using infertile land for planting trees hence limiting landscape conversion. In addition, availability of goods and services from the woodlots reduce local communities' dependence on natural vegetation for deriving goods and services. Consistent to FGDs, NEMC (2008) findings on integrated ecosystems assessment show that decrease in the size of woodland in the Livingstone mountain ranges and its adjacent lowland areas was a result of lack of alternative sources of goods and services such as fuelwood, building materials and other forest products to local communities.

More results from FGDs regarding possession of woodlots show that with exception of Makonga village, there was less effort by decision makers in encouraging villagers to establish village woodlots in the remaining study villages. Participants in the FGD in Makonga village reported that they had planted about 6 387 trees out of which 2 700 belonged to a village school, 3 667 to a village government and 20 to individuals. Besides, out of the two NGOs, that is, MBIDEA and CARITAS found in the study villages, only MBIDEA was involved in environmental conservation and management issues. MBIDEA was raising awareness on the need for planting trees as an income generating activity as well as meeting domestic needs such as fuel wood, building materials, and fodders.

4.3.1.3 Population density

The results in Table 11 show that an increase in the population density is corresponding to an increase in the area occupied by upland cultivation, because upland cultivation is normally carried out around settlements. Nindi (2004) elaborated the land use setup in the Matengo highlands which shows that houses are surrounded by cultivated land such as coffee and kitchen gardens, and *ngolo* fields.

Table 11: Combined results of logistic regressions for all land use and cover types (independent variables) based on population density as an independent variable

Dependent Variable	Independent Variable	Coefficient	p-value	Exp(B)
Lowland bushland with scattered cropland	Population density	.0181	.000	1.018
Upland bushland with scattered cropland	Population density	-0.0319	0.000	0.969
Upland cultivation	Population density	0.0209	0.000	1.021
Lowland grassland with scattered cropland	Population density	-0.0030	0.000	0.997
Upland woodland	Population density	-0.0181	0.000	0.982
Lowland woodland	Population density	0.0067	0.000	0.993
Others	Population density	0.0068	0.000	1.007

Significant at $p \leq 0.05$

On the other hand, results from Table 11 also show that increase in the population density was associated with increase in lowland bushland with scattered cropland (with coefficients at 0.0181), upland cultivation (with the coefficients at 0.0209), lowland woodland (with the coefficients at 0.0067), and others (with the coefficients at 0.0068). In addition, the result show that population density was statistically significant at $p \leq 0.000$ and increased the odds of conversion of the land use and land cover types by factors ranging from 0.969 (for upland bushland with scattered cropland) to 1.021 (for upland cultivation).

The results implied that as population density increases more land was converted in lowland bushland because areas occupied by lowland bushland were also used for shifting cultivation and settlements. In the Matengo families, when population increases, some family members would move to other places where they could find land for cultivation and establish their settlements. As population density increases it therefore results to establishment of more settlements and practising shifting cultivation and fallowing in less populated areas. *Ngolo* cultivation would probably be started after soil ripening, which takes some few years since vegetation clearance. Also, lowland woodland area increases as population density increases. This was because there was less conversion of lowland woodland areas to other land use and cover types due to the fact that most of the lowland woodland areas were not used extensively by the majority of the lowland local communities for cultivation purposes. The lowland woodlands were located in relatively higher altitudes and steep slopes, which were currently not potential for the traditional farming systems applied in the lowland area. Besides, based on the transect walks carried out in the lowland areas it was observed that patches of the lowland woodlands were located away from the lowland area settlements. Most of the settlements/villages were located near the Lake Nyasa shoreline, thus facilitate fishing from the Lake Nyasa. However, lowland people still had access to the limited goods and services from the distant lowland woodland areas. Moreover, the threat to lowland woodland that was located in the distant upland was the encroachment by people from the upland mainly for planting finger millets in the slash-and-burn agricultural forms.

The results from FGDs and key informant interviews revealed that most of the men in the lowland area were also engaging in fishing in the Lake Nyasa. This could also be the reason for the reduction of pressures in the lowland woodland, although population density increased. This implied that fishing absorbed the time that could be spent by the local communities in either extending cultivation or extracting goods and services from the distant lowland woodland areas. As a result the lowland woodland increased as population density increased. Moreover, the implication could be linked to the fact that cultivation and other human uses in the lowland area could be carried out in lowland bushland with scattered cropland and lowland woodland areas, which intensified as population density increased. It therefore implied that people in the lowland area had more options for converting the landscape to different land use and cover types including extracting goods and services. Anthropologically, people from the lowland hardly utilize the woodland areas for farming. Their crops mostly (cassava, paddy, sugarcane, etc) flourish in low lying areas, where there were no woodlands.

Thus, the results showed that there were natural vegetation clearance as population density increased especially in the upland area.Similar results were reported by Braimoh (2004) in Volta Basin in Ghana where population density increase from 1984 to 1999 resulted into decreased area occupied by natural vegetation to cultivated land at a rate of 17% per annum. In Tanzania, Mbilinyi (2002) found that population increase in Ismani division in Iringa caused a substantial decrease of about 85% in the area under woodlands for the period between 1963 and 1978. The influence of human perturbations in reducing the land cover particularly woodland in the Livingstone Mountain Ranges and the Lake Nyasa catchment in general is also reported by Nindi (2007), where woodland cover decreased from 64% to 51% between 1967 and 1990.

However, results from this study do not complement the views of Boserup (1965) in her neo-classical model of land use. Among other things she insisted was that there would be a need for adoption of more intensive farming methods with increasing population, which would require additional labour inputs per unit area, in order to sustain a growing population in highly populated areas. The Matengo highlands are also facing high population pressure. By the year 2000 an average population density in Mbinga District was 34 people/km^2, but in the Matengo highlands it was up to around 100-120 people/km^2 (DALDO, 2001). Although the study area (upland) might have experienced the sort of population density described in her model, it did not warrant the use of more intensive farming techniques. Instead, the results show that increase in population has resulted in the extensification of the agricultural land use since 1979, through clearing more woodland areas. The same results are reported by MWARP, (1998), Kato (2001) and Nindi (2004) that the application of intensive agriculture by the Matengo of south-western is done even in sparsely populated areas, once they move in. The results from this study therefore showed that applicability of Boserup's population density-agricultural intensification model in all agricultural lands that experiences increase in population density is uncertain. Nindi (2004) reports that studies from other places such as Pare, Fipa, and Kerewe Island showed that increase in population density does not necessarily result into agricultural intensification. Other factors (Malthus, 1960; Ricardo, 1817); in Nindi (2004) therefore need to be considered in population density-agricultural intensification issues. As reported by Nindi (2004), demographic pressure is believed to lead to cultivation of agriculturally marginal land (steep slopes) or to degradation and unsustainable use of existing fields (clearance of woodland areas) in the case of the study area. Furthermore, enforcement or enhancement of policies could justify Boserup's model in areas prevailing conditions like those observed in the study area.

4.3.1.4 Distance to the roads

The results in Table 12 shows that increase and decrease in the distance to the roads were associated with conversions of the landscape to the different land use and cover categories. The increase in distance to the road was associated with a decrease in upland cultivation (with coefficient at -0.0003), lowland woodland (with coefficient at -0.0003), lowland grassland with scattered cropland (with coefficient at -0.0005), and others (with coefficient at -0.0007). The results implied that all these land use and cover types (upland cultivation, lowland woodland, lowland grassland with scattered cropland, and others) were located near the roads. Regarding upland cultivation, this was an area which was also occupied by settlements hence road infrastructure was concentrated in this area. Moreover, many people tended to concentrate along the road hence reducing land cover due to cultivation and other human uses including settlements. Similarly, other literatures (Chomizt and Gray, 1996; Overmas and Verburg, 2005) report that farmers in the villages prefer having farms near their houses because of accessibility and safety reasons.

Table 12: Combined results of logistic regressions for all land use and cover types (independent variables) based on distance to road as an independent variable

Dependent Variable	Independent Variable	Coefficient	p-value	Exp(B)
Lowland bushland with scattered cropland	Distance to road	0.0008	0.000	1.001
Upland bushland with scattered cropland	Distance to road	0.0000	0.000	1.000
Upland cultivation	Distance to road	-0.0003	0.000	1.000
Lowland grassland with scattered cropland	Distance to road	-0.0005	0.000	1.000
Upland woodland	Distance to road	0.0002	0.000	1.000
Lowland woodland	Distance to road	-0.0003	0.000	1.000
Others	Distance to road	-0.0007	0.000	0.999

Significant at $p \leq 0.05$

On the other hand, increase in distance to the road which was associated with a decrease in lowland woodland could be linked to different factors. It is first of all important to note that the lowland woodland category is a combination of lowland woodland open and lowland woodland closed. Secondly, with exception of the lowland wood closed, which was mostly located away from the roads, lowland woodland open included areas with scattered cropland located closer to the settlements hence to the roads. Thus, when these two (lowland woodland open and lowland woodland closed) land use and cover categories were combined in a GIS, the merged area extended closer to the roads meaning that these areas were likely to be used for cultivation thereby influencing landscape changes.

Moreover, the increase in the distance to road was associated with the conversion of the landscape for lowland bushland with scattered cropland (with coefficients at 0.0001), upland bushland with scattered (with coefficients at 0.0000), and upland woodland (with coefficients at 0.0002). Furthermore, results showed that distance to road was statistically significant at $p \leq 0.000$ and increased the odds of conversion of the land use and land cover types by factors of 0.999 for the *others* category. These results (Table 12) implied that areas with lowland bushland with scattered cropland, upland bushland with scattered cropland, and upland woodland had limited accessibility that is why they still had natural vegetations. Likewise, Ostapowicz (2006) reported that the western parts of Karpaty Mountains in Poland the proportion of forest area increased with the increase of the distance from road from 23 % for the class with the lowest distance from road (below 500 m) to 70 % for the highest distance from road (above 3 500 m). Similarly, a study by Stromquist (2009) showed that access to transport (distance to road) was among the factors that caused greater deforestation of Miombo woodlands in Kilosa, Tanzania through increased cultivation. The results also showed more accessible areas were likely to be cleared for cultivation compared to areas with limited accessibility.

4.3.2 Influence of biophysical factors on landscape changes

4.3.2.1 Elevation

Logistic regression results from the GIS analysis (Table 13) show that, increase in elevation was associated with increases and decreases in the conversion of the landscape to the different land use and cover categories. Increasing in elevation was associated with a decrease in the conversion of the landscape for lowland bushland (with coefficients at -

0.0254), lowland grassland with scattered cropland (with coefficient at -0.0147), upland woodland (with coefficient at -0.0006), lowland woodland (with coefficient at -0.0062). In addition, the results show that increase in the conversion of the landscape was associated with increase in elevation for the upland bushland (with coefficients at 0.0032), upland cultivation (with coefficient at 0.0034), and others (with coefficient at 0.0046). Furthermore, results show that elevation was statistically significant at $p \leq 0.000$ in increasing the conversion of the land use and land cover types by factors ranging from 0.975 (for lowland bushland) to 1.005 (for others).

Table 13: Combined results of logistic regressions for all land use and cover types (independent variables) based on elevation as an independent variable

Dependent Variable	Independent Variable	Coefficient	p-value	Exp(B)
Lowland bushland with scattered cropland	Elevation	-0.0254	0.000	0.975
Upland bushland with scattered cropland	Elevation	0.0032	0.000	1.003
Upland cultivation	Elevation	0.0034	0.000	1.003
Lowland grassland with scattered cropland	Elevation	-0.0147	0.000	0.985
Upland woodland	Elevation	-0.0006	0.000	0.999
Lowland woodland	Elevation	-0.0062	0.000	0.994
Others	Elevation	0.0046	0.000	1.005

Significant at $p \leq 0.05$

The results (Table 13) implied that as the elevation changes from lower to higher altitudes there was increase in the upland cultivation, upland bushland, and others. This was due to the fact that upland cultivation and settlements in the Livingstone Mountain ranges started in areas with very high altitudes and is extended to areas with lower altitudes in the woodlands. Most of the high altitude areas were therefore dominated with upland cultivation including coffee farms. The same applied to upland bushland category. There was a continuous conversion of woodlands to upland bushland and upland cultivation due to shifting cultivation and extraction of goods and services. As elevation increased there was also an increase in the area occupied by upland bushland, at the expense of natural vegetation particularly woodland.

From the results (Table 13), decrease in the conversion of lowland grassland with scattered cropland, lowland bushland with scattered cropland, and lowland woodland that result from increases in elevation is due to the fact that most of the areas occupied by these land use and cover types are located in the lower altitudes. It is important to note that cultivation in the lowlands took place mainly in the areas occupied by lowland grassland and lowland bushland with scattered cropland in the altitude ranging from 500 to 900 m a.m.s.l

The logistic regression results for elevation (Table 13) were also supported further by evidence from the GIS analytical results from the land use and cover types used in the study (Table 14).

The results showed that during 1979 upland wood covered most of the altitude ranges from 600 to 1800 m and the area that was under upland cultivation was located within altitude ranges between 1 200 to 2 100 m.a.s.l.

Table 14: Distribution of land use and cover in the altitude ranges in the study area during study periods

Altitude range (m)	Area (Ha) 1979					
	Upbsc	Upw	Upcl	Lbsc	Lw	Lgsc
<600	0	0	0	23 105	5 133	
600 – 900	317	21 294	0	2 324	12 984	209
900 – 1200	2 666	33 835	0	9	0	0
1200 – 1500	27 745	46 871	222	0	0	0
1500 – 1800	12 121	11 313	17 384	0	0	0
1800 – 2100	363	1 073	5 847	0	0	0
	Area (Ha) 1990					
	Upbsc	Upw	Upcl	Lbsc	Lw	Lgsc
<600	0	0	0	23 562	4 733	1 0228
600 – 900		18 089	543	5 414	8 594	1 444
900 – 1200	5 136	28 294	3 052	0	0	0
1200 – 1500	35 532	29 183	10 031	0	0	0
1500 – 1800	8 733	4 941	26 842	0	0	0
1800 – 2100	346	0	6 898	0	0	0
	Area (Ha) 2000					
	Upbsc	Upw	Upcl	Lbsc	Lw	Lgsc
<600				21 421	4 871	13 468
600 – 900	262	11 485	9 864	2 006	7 399	6 069
900 – 1200	12 366	12 443	11 691	0	4	0
1200 – 1500	30 190	17 337	27 384	0	0	5
1500 – 1800	6 355	5 621	28 953	0	0	0
1800 – 2100		204	6 746	0	0	0

The results also showed that there was no upland cultivation undertaken below 1200 m by the year 1979. However, results show that upland cultivation was mostly (17 384 ha) practised in the altitude ranging between 1 500 to 1 800 m. This result concurs with Messerli *et al.* (1990) who found 90 percent of the cultivated land in Africa is in mountains and high plateaus above 1,500m which covered 43 percent of the land surface.

Likewise, most of the upland bushland with scattered cropland were concentrated in the 1 200 – 1 500 and 1 500 – 1 800 m ranges. At the same time most of the lowland bushland with scattered cropland (23 105 ha) were found in elevations below 600 m whereas concentration of lowland woodland were between 600 and 900 m. It should be noted that areas of lowland bushland with scattered cropland are also used for shifting cultivation. As elevation increases it therefore implies that the conversion of the lowland bushland with scattered cropland to any of the land use and cover types decreases (Table 14). This is because majority of the people in the lowland areas did not have the tradition of farming in higher altitudes where the dominant vegetation was lowland woodland; whose conversion to other types of land use and cover decreases as elevation increase.

The results in Table 14 also showed that in 1990 upland wood dominated most of the altitude ranges (600 – 900, 900 – 1 200 and 1 200 – 1 500 m) but decreased in the altitude range of 1 500 to 1 800 m. This can be due to increase in upland cultivation within this range that increased from 17 384 ha in 1979 to 26 842 ha in 1990. At the same time upland cultivation started to be extended to lower altitudes within 600 to 900 m and 900 to 1200 m ranges and lowland grassland with scattered cropland emerged in the less than 600 m range.

The GIS results (Table 14) revealed that upland cultivation increased from 222 ha in 1979 to 10 031 ha in 1990 and to 27 384 ha in 2000 within the 1200 – 1500 altitude range. This shows that upland cultivation has been more undertaken in higher altitudes, where the Matengo preferred to establish their settlements. Furthermore, there was a slight increase in the upland cultivation from 5 847 ha in 1979 to 6 898 ha in 1990 within the 1 800 to 2 100 m range. This shows that upland cultivation was still extended in areas which were available for cultivation within the 1800 to 2 100 m range by 1990. The reduction of lowland woodland from 12 984 ha in 1979 to 8 594 ha in 1990 within the 600 to 900 m range shows increase in human activities in the natural vegetation areas. Moreover, decrease in the upland bushland with scattered cropland in the altitude range of 1 200 – 1 500 from 35 532 ha in 1990 to 30 190 ha in 2000 show signs of scattered cultivation within the bushland areas.

In the year 2000 the results (Table 14) showed that, there was significant decrease in the upland woodland in all three altitudinal ranges (600 – 900, 900 – 1 200 and 1 200 – 1 500 m) from the year 1990 to 2000. This decrease in upland woodland was directly linked to an increase in upland cultivation that was evident in the same three altitude ranges. GIS analytical results also showed that the lowest attitude at which cultivation was extended to in the year 2000 reached 558 m. This was a decrease of 225 m compared to the altitude level that was under cultivation in the year 1990. Considering the situation in 2000, results (Fig.14) showed that cultivation was extended further down towards south eastern side of the study area where land for cultivation was available. This trend shows that there was more cultivation in the higher altitude areas than lower altitudes within the upland area. Expansion of cultivation in the upland areas was therefore extended towards lower altitude areas at the expense of woodland and bushland. The results implied that landscape conversion to upland cultivation increases as elevation increases in the upland area.

Similar results are reported by Shively (2001) in the Philippines where the area devoted to upland agriculture increased six-fold between 1960 and 1987, and coincided with a rapid decline in forest cover, in part, due to efforts of low-income farmers to secure subsistence.

The results from this study imply that there has been continued upland cultivation in the higher altitudes in all study years (1979, 1990 and 2000). However, upland cultivation has been extended in lower altitudes across the study period. The area of upland cultivation has been increasing while that of upland woodland decreased in all altitude ranges over the study periods.

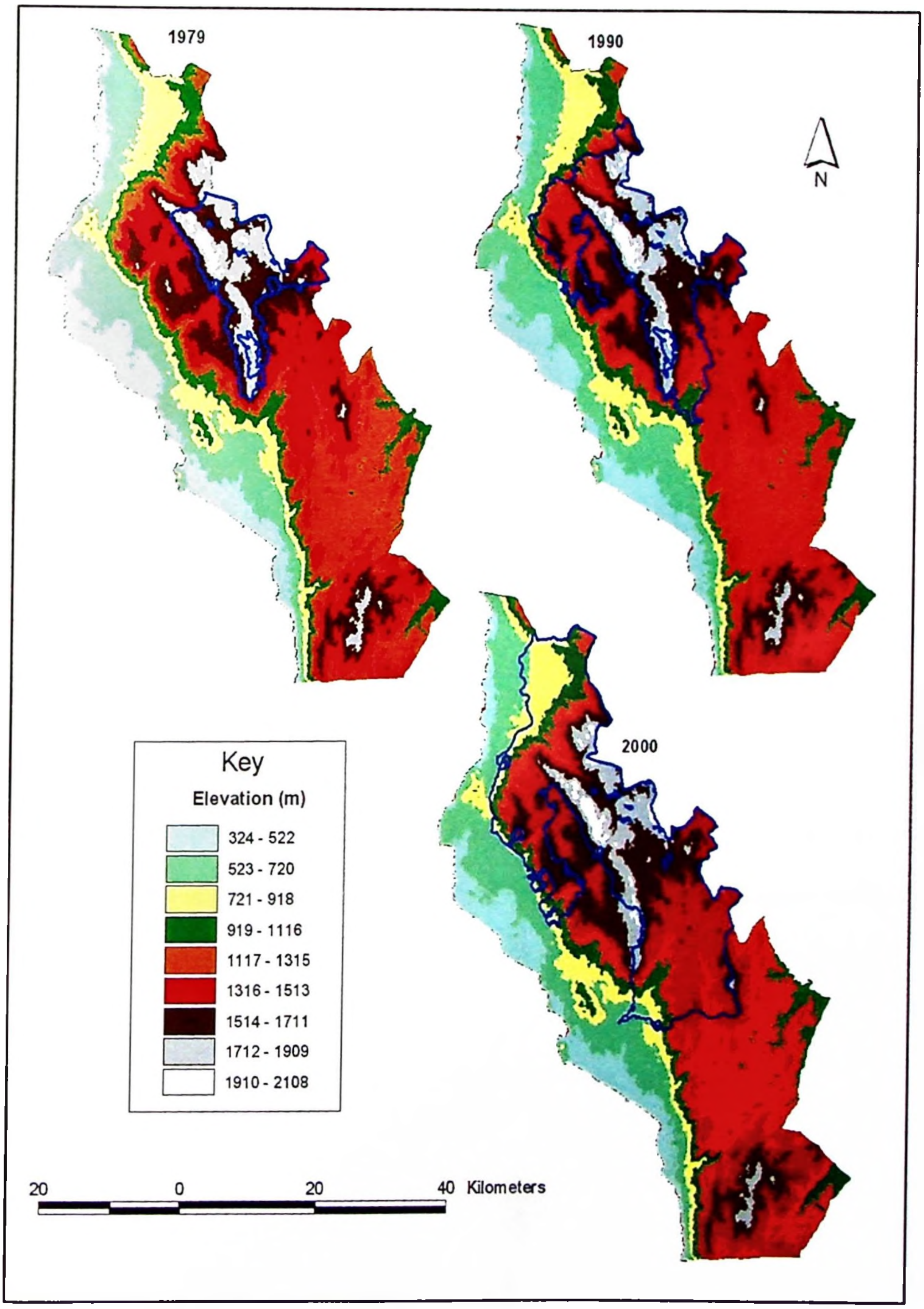

Figure 14: **Influence of elevation in relation to landscape changes for the upland cultivation category during the study periods.**

4.3.2.2 Slope

The logistic regression results from the GIS analysis (Table 15) shows that, the probability of increase in the conversion of the landscape to the different land use and cover categories was associated with both increase and decrease in the slope. Increasing in slope was associated with a decrease in the conversion of the landscape for upland bushland with scattered cropland (with the coefficients at -0.0483), lowland grassland with scattered cropland (with the coefficients at -0.0600), and others (with the coefficients at -.2054). This is based on the fact that most of the upland bushland with scattered cropland are not located in the steep slopes. Instead, areas with steep slopes are occupied by the remaining upland woodland, lowland woodland, and upland cultivation. This is justified by the results (Table 15), which show that increase in the slope was associated with increase in the conversion of the landscape for upland cultivation, upland woodland, and lowland woodland.

Table 15: Combined results of logistic regressions for all land use and cover types (independent variables) based on slope as an independent variable.

Dependent Variable	Independent Variable	Coefficient	p-value	Exp(B)
Lowland bushland with scattered cropland	Slope	.0127	0.000	1.013
Upland bushland with scattered cropland	Slope	-0.0483	0.000	0.953
Upland cultivation	Slope	0.0510	0.000	1.052
Lowland grassland with scattered cropland	Slope	-0.0600	0.000	0.942
Upland woodland	Slope	0.0963	0.000	1.101
Lowland woodland	Slope	0.1096	0.000	1.116
Others	Slope	-0.2054	0.000	0.814

Significant at $p \leq 0.05$

Furthermore, slope was statistically significant at $p \leq 0.000$ for all land use and cover types used in the study. The odds of increasing the conversion of the land use and land cover types ranged by the factors from 0.814 (for others) to 1.116 (for lowland woodland). In contrast, results in Table 16 showed increase in the upland bushland with scattered cropland and lowland grassland with scattered cropland with decrease in slope. This was because extension of upland bushland with scattered cropland was towards areas which are less steep, and in most cases were found in slightly lower altitudes within the upland area.

Moreover, the results from the GIS analysis (Table 16) showed that by the year 1979 most of the upland cultivation was within areas with slope range of less than 10 degrees and 10.1 – 20.2 degrees. For example, in the year 1979, 10 916 ha and 10 593 ha were used for upland cultivation in areas with slope ranges of less than 10 and 10.1-20.2 degrees, respectively. Thus, out of the total area under upland cultivation (23 459 ha) about 10 916 ha (46.5%) were within the slope range of less than 10 degrees and 10 593 ha (45.2%) in the slope range of 10.1 – 20.2 degrees. During the period (1979), there were still extensive coverage of upland woodland of about 50 772 and 47 983 ha in the slope ranges of less than 10 degrees and 10.1 – 20.2 degrees, respectively. Also, about 26 105 and 14 726 ha of upland bushland with scattered cropland were found in the slope ranges of less than 10 and 10.1 – 20.2 degrees, respectively.

Table 16: Distribution of land use and cover in different slope ranges in the study area

Slope (degree)	Area (Ha) 1979					
	Upbsc	Upw	Upcl	Lbsc	Lw	Lgsc
<10	26 105	50 772	10 916	24 018	13 149	9 875
10.1 – 20.2	14 726	47 983	10 593	1 201	11 309	498
20.2 – 30.4	2 183	14 313	1 876	181	657	124
30.4 – 40.5	193	1 308	70	40	44	32
40.5 – 50.7	31	100	4	0	3	0
	Area (Ha) 1990					
	Upbsc	Upw	Upcl	Lbsc	Lw	Lgsc
<10	34 389	31 927	21 217	27 207	8 964	10 806
10.1 – 20.2	15 733	36 281	21 097	1 487	3 681	792
20.2 – 30.4	2 186	11 384	4 802	239	642	79
30.4 – 40.5	389	927	256	59	44	13
40.5 – 50.7	79	48	8	0	3	0
	Area (Ha) 2000					
<10	52 479	15 118	42 825	22 070	7 846	18 270
10.1 – 20.2	16 222	23 806	33 220	1 068	37 31	1 200
20.2 – 30.4	2 717	7 545	8 140	246	6 60	62
30.4 – 40.5	481	631	460	58 241	38	22
40.5 – 50.7	90	22	23	0	0	1

Moreover, about 14 313 ha of upland woodland were within the slope range of 20.2 – 30.4 degrees; whereas only 1 308 ha were located in the slope range of 30.4 – 40.5 degrees. In the lowland area results showed that the biggest areas of all land use and cover types were located in areas with less than 10 degrees slope. This was because large part of the lowland area was relatively flat. However, it is important to note that areas with lowland grassland with scattered cropland were mostly used for lowland cultivation. As a result, areas with lowland grassland with scattered cropland were mainly located in less steep areas (Table 16). This was due to the fact that people from almost all ethnic groups found in the lowland area did not have the tradition of farming in the steep slopes, therefore lowland grassland with scattered cropland increased as slope decreased.

The results (Table 16) also showed that was a continuous decrease in the area of upland woodland in all study periods in the slope ranges of less than 10 and 10.1 – 20.2 degrees. The reverse of this decrease was what existed in the area for upland cultivation within the same slope ranges. The results implied that increase in the area of upland cultivation was at the expense of upland woodland. More justifications were based on the fact that the two slope ranges were also suitable for settlement purposes due to less steepness. Moreover, results (Table 16) revealed that in all study years almost half of the land under upland cultivation (53.5% in 1979, 55.2% in 1990, and 49.4% in 2000) was within slopes ranging above 10 degrees. Likewise, results showed an increase in the upland cultivation within the steep slope across the study period. For example, upland cultivation increased from about 70 ha in 1979 to 256 ha in 1990 and to 460 ha in 2000, within the slope range of 30.4 – 40.5 degrees. Moreover, upland cultivation also increased from about 4 ha in 1979 to 8 ha in 1990 and 23 ha in 2000, within the slope range of 40.5 – 50.7 degrees. Indeed, this is very steep slope for cultivation.

These findings justify the fact that the Matengo established their settlements and farms in higher altitudes with steep slopes (Fig. 18) while relying on *ngolo* as their main farming system along the steep slopes. Influence of biophysical factors in land use and cover changes were also reported by Ghosh *et al.* (1996) in a mountainous terrain area in India where expansion of agriculture was found to be within 20–30 degrees slope classes. Likewise, Mahajan *et al.* (2001) report the maximum extent of agriculture in the Ashwan Khad watershed in India was within 13.2 to 33 degrees due to slope limitations. However, results from this study imply that slope is not a limiting factor for upland cultivation in the study area. MWARP (1998) also found that *ngolo* farming system could be practised in very steep slopes of up to 60% in the Livingstone Mountain ranges in Mbinga district. The results implied that slope was among the factors influencing land use and cover changes. However, the extent at which slopes were used for farming depended on many factors including the kind of farming system employed in the area.

4.3.2.3 Distance to the river

Distance to the river was used as the basis to determine the distribution of the land use and cover categories in the study area. The probability of increasing in the conversion of the landscape to the different land use and cover categories based on the distance to river was associated with increase and decrease in the coefficients depending on the specific land use and cover type. The results in Table 17 showed that as the distance to river increased, the conversion of the landscape increased for upland cultivation (with coefficient at 0.0001), upland woodland (with coefficient at 0.0000), and lowland grassland with scattered cropland (swith coefficient at 0.0002).

In the case of increasing in the conversion of both upland cultivation and lowland grassland with scattered cropland the results (Table 17) showed that concentration of rivers in the upland cultivation and lowland grassland with scattered cropland areas was less compared to areas with upland bushland with scattered cropland and lowland bushland with scattered cropland. Likewise, results (Table 17) showed that increase in the probability of conversion of the upland woodland increased with an increase in the distance to river. The reason for this was that upland woodland areas were mainly located away from rivers and mostly in steep slopes. Mbinga district by-laws also restrict farmers to cultivate along or near river valley.

Table 17: Combined results of logistic regressions for all land use and cover types (independent variables) based on distance to river as an independent variable

Dependent Variable	Independent Variable	Coefficient	p-value	Exp(B)
Lowland bushland with scattered cropland	distance to river	-0.0002	0.000	1.000
Upland bushland with scattered cropland	distance to river	-0.0006	0.000	0.999
Upland cultivation	distance to river	0.0001	0.000	1.000
Lowland grassland with scattered cropland	distance to river	0.0002	0.000	1.000
Upland woodland	distance to river	0.0000	0.000	1.000
Lowland woodland	distance to river	-0.0001	0.000	1.000
Others	distance to river	-0.0001	0.000	1.000

Significant at $p \leq 0.05$

This situation implied that most of the cultivation undertaken in the study area relied on rainfalls rather than irrigation. This situation concurred with the extensive application of *ngolo* farming system in the Matengo highlands which was, among others, used to hold the rainwater from runoffs. In line with this argument, MWARP (1998) reports that *ngolo* is practised by over 75% of the farmers in the Matengo highlands. The GIS results from this study showed the concentration of rivers was in the southeast side of the study area which were not extensively utilised for farming, hence, distances to rivers was not much influential in the landscape changes (Fig. 19) in the upland areas. The sparsely populated areas which have high occurrences of rivers justify the fact that the upland areas rely on rainfed agriculture instead of irrigation from river waters. Reliance of rainfall for agriculture is seen in the way the Matengo have named the different rain seasons with respect to on-farm activities (Nindi, 2004) while none are mentioned on irrigation agriculture.

The results from this study showed that aspect, elevation and slope were very influential factors in landscape changes in the study area. Upland cultivation started in higher altitudes moving downwards across the study period towards areas with remaining woodlands. Results also showed that upland cultivation was undertaken in very steep slopes of up to 50 degrees due to the use *ngolo* farming system. Moreover, results showed that cultivation was mainly taking place away from rivers; implying that the study area relied mostly on rainfed agriculture rather than irrigation. In the lowland area, lack of farming system such as *ngolo* hindered cultivation in steep slope areas. As a result, there were less landscape changes in the lowland woodland compared to the upland woodland based on the influence of biophysical factors.

4.4 Implications of Landscape Changes to the Livelihoods of Local Communities

The Livingstone Mountain Ranges and their adjacent lowland areas provide different ecosystems goods and services to the local communities in the study area. However, the results from this study showed significant changes in the landscape, which subsequently affects the local communities in different ways. Specific objective three of the study investigated on the implications of the landscape changes to the livelihood of the local communities in the study area. The results (Table 18) show that only 5 out 11 variables have been retained by the model. Furthermore, out of the 5 variables used in the analysis, only one was not statistically significant at $p \leq 0.079$. The significant variables were scarcity of farming land (CMASLF at $p \leq 0.000$), scarcity of grazing land (CMASLG at $p = 0.016$), drying of wetlands (CMADW at $p = 0.020$), and siltation of the Lake (CMASTLN at $p = 0.005$).

Table 18: Logistic regression model for implication of landscape changes from respondents

Variable	B	Wald	p – value	Exp(B)
Scarcity of farming land (CMASLF)	3.597	19.303	0.000	36.494
Scarcity of land for grazing (CMASLG)	-2.343	5.792	0.016	0.096
Scarcity of fuel wood (CMASFW)	1.957	3.080	0.079	7.080
Drying of wetlands (CMADW)	2.703	5.383	0.020	14.922
Siltation in Lake Nyasa (CMASTLN)	2.069	7.964	0.005	7.918
Constant	-.771	6.863	0.009	0.462

4.4.1 Increased scarcity of farming land

The results (Table 18) showed that the probability of increase in the conversion of landscape based on the scarcity of farming land was associated with an increase in the coefficient at 3.597. The odds of scarcity of farming land to landscape changes were accelerated by an exponential coefficient of 36.494 times that of other factors. The statistical significance of scarcity of farming land (CMASLF) as an implication of landscape changes can be explained as, people in the upland areas were forced to increase farming in steep slopes in order to sustain livelihood. Given the fact that people had less income from coffee harvests due to collapse of MBICU, hence their purchasing power for farm inputs such as fertilizers and manure was reduced tremendously. This situation increased competition for acquiring farming land in the virgin land (Plate 5) where they could farm with less or no fertilizers. Similarly, results from Soini (2005) in Kilimanjaro showed that lack of capital for farm inputs such as fertilizers and manure was among the most pressing problems that caused farmers to extend farming in the forest areas hence increasing clearance of natural vegetation.

Plate 5(a): Establishment of new fields and settlements in the Miombo woodlands in Livingstone Mountain ranges.

Plate 5(b): Establishment of new fields in the Miombo woodlands in Livingstone Mountain ranges

A situation of having less income therefore increased across time exacerbated the need for more new farming land. The remained challenge was how to sustain livelihood in this kind of situation where cultivation was the only reliable means of survival while at the same time land became scarce. Sen *et al.* (2002) indicates agricultural expansion in higher altitudes of the Pranmati watershed in the Indian Himalaya was largely driven by farmers' tendency for maximization of income. Similarly, Soini (2005) reports continued clearance of new farming land in the Kilimanjaro region to be the main livelihood activity due to lack of other livelihood options in the region. Findings from this study in Mbinga district showed that farmers were mainly driven by lack of diversification options to meet their subsistence needs hence extended farming in woodland areas.

As a result of this situation there was an increased clearance of natural vegetation particularly in the upland area hence causing a decrease or completely disappearance of some wildlife species which used to be found in the woodland ecosystem such as *Tagelaphus scriptus* (Mbawala), *Panthera leo* (Simba), *Panthera pardus* (Chui), *Laxodanta africana* (Tembo), *Syncerus caffer* (Nyati), *Lepus sexatilis* (Sungura), *Papio cynocephalus* (Nyani), *Manis tricuspis* (Nungunungu), *Pigymy antelope* (Ngolombwe) and others, as reported in the household surveys, focus group discussions and key informant interviews from all surveyed villages.

4.4.2 Increased scarcity of grazing land

Assessment has been made to determine implications of landscape changes based on the scarcity of grazing land. The results (Table 18) showed that scarcity of grazing land was statistically significant at $p = 0.016$. The results showed that the probability of increasing in the conversion of changes in the landscape based on the scarcity of grazing land was associated with a decrease in the coefficient at -2.343. This result implied that increase in the scarcity for the grazing land leads to a decrease in the probability for landscape changes. In order to have more information on this issue, statistical results from respondent's opinion were considered.

The study found that there were different animal rearing methods that were used in the study area. Animal herding, free range, zero grazing and tethering have therefore been considered in the analysis. More results (Table 19) showed that out of 230 respondents 203 (88%) were not using herding, 195 (84.78%) not using free range, 108 (46.96%) not using zero grazing, and 65 (28.26%) not using tethering. The results implied that majority of the respondents 140 (60.87%) and 98 (42.61%) were using tethering and zero grazing as the methods of keeping their livestock, respectively. Moreover, results showed that 36 (30%) of all respondents from the lowland and 62 (51.66%) of respondents from the upland areas were using zero grazing for rearing their animals, respectively. Likewise, 46 (38.33%) of all respondents from the lowlands and 87 (79.1%) of all respondents from the upland areas were using tethering as a way of keeping their animals, respectively.

The results implied that tethering and zero grazing were more applied in the upland than lowland area. This was precisely because the system did not require big areas and in most cases it could be done in harvested farms. On the other side, zero grazing was more practised in the upland area due to scarcity of grazing land and more appropriate during cold seasons. However, it is important to note that zero grazing is more labour intensive compared to free range rearing or tethering. If there would be enough land for grazing, probably respondents from the upland would have opted to use other livestock rearing methods most of the times instead of zero grazing. Nindi (2004) reports that in Kindimba village (upland) in Mbinga district grazing land and/or pasture availability is one of the salient problems facing livestock sector to the extent that animals are largely grazed in restricted areas in mountaintops.

Table 19: Types of livestock rearing applied in the study area

Type of rearing		Name of villages						Total
		Chiulu	Ndengele	Nangombo	Buruma	Makonga	Lumecha	
Herding	Yes	2	0	4	0	0	0	6
	No	29	34	30	40	30	40	203
	n/a	9	6	6	0	0	0	21
Total		40	40	40	40	30	40	230
Tethering	Yes	6	22	25	28	28	31	140
	No	25	12	9	12	2	5	65
	n/a	9	6	6	0	0	4	25
Total		40	40	40	40	30	40	230
Free range	Yes	1	9	4	0	0	0	14
	No	30	25	30	40	30	40	195
	n/a	9	6	6	0	0	0	21
Total		40	40	40	40	30	40	230
Zero grazing	Yes	23	12	1	23	19	20	98
	No	8	23	33	17	11	16	108
	n/a	9	5	6	0	0	4	24
Total		40	40	40	40	30	40	230

Advantageously, zero grazing is more important for landscape conservation because it reduces the effects of soil erosion resulting from continuous soil trampling and unsustainable utilisation of grazing lands. However, sustainable utilisation of grazing land requires determination of land carrying capacity and other factors. A report by UNEP (2002) shows that landscape conversion to crop or grazing land is leading to loss of forests and other land cover which can accelerate erosion and soil loss as well as have impacts on wildlife and water resources. Therefore if an area is over grazed, it results into exposing the soils, depleting the vegetation cover especially grasses and bushes hence leads to landscape changes.

In order to have more information on grazing issues it was also important to consider types of animals owned by the respondents. The results (Table 20) show that 151 (65.6%) of respondents in both upland and lowland areas kept goats/sheep. Out of 79 (34.3%) of respondent who did not own goats/sheep 43 (54.4%) of them were from the lowland villages. This shows that there were more goats/sheep in the upland area compared to lowland area. Thus, results showed that significant number of respondents owned goats hence grazing land was an important issue of concern in the study area.

Table 20: Types and numbers of animals owned by respondents

List of goats/sheep owned by HH	Name of villages						Total
	Chiulu	Ndengele	Nangombo	Buruma	Makonga	Lumecha	
Yes	21	20	26	32	22	30	151
No	19	20	14	8	8	10	79
Total	40	40	40	40	30	40	230
List of cattle owned by HH	Chiulu	Ndengele	Nangombo	Buruma	Makonga	Lumecha	Total
Yes	9	1	12	10	10	9	51
No	31	39	28	30	20	31	179
Total	40	40	40	40	30	40	230

Likewise, in the case cattle ownership, most of the respondents 179 (78%) did not own cattle in both upland and lowland areas. However, the results (Table 20) show that, the number of respondents kept cattle was almost same in both upland and lowland areas. There were few people owned cattle. For example, out of 110 respondents from upland villages, only 29 (26.4%) respondents owned cattle. Similarly, out of 120 respondents from lowland villages, only 22 (18.3%) of them owned cattle. This could be linked to the fact that cattles require more pasture compared to goats/sheep, implying more grazing land would be required if they were kept in big numbers.

However, regardless of the importance of grazing land, results presented in the previous section (Table 10) showed that possession of livestock (WHTPROP2) was statistically insignificant at $p \leq 0.658$. This situation raised a concern as to why scarcity of grazing land was an important issue of concern while engaging in livestock keeping was associated with a decrease in conversion of landscape (with coefficient of -0.492). The answer for this is based on the fact that land was a limiting factor for grazing especially in the upland areas where even scarcity of farming land is also a big challenge (Nindi, 2004; NEMC, 2008). However, increase in the number of people engaging in livestock keeping would probably reduce expansion of farming land because the manure from the livestock could be used to improve soil fertility. It is assumed that application of manure could increase crop production through intensification within existing discrete farms hence reduce the motive to expand farming in the virgin land (woodland).

4.4.3 Drying-up of wetlands

Another significant variable in the study was drying-up of wetlands (CMADW). The above situation on soil fertility is well linked with results in Table 18 in variable (CMADW). The increase in drying-up of wetlands was statistically significant at $p \leq 0.020$ and was associated with increase in the conversion of landscape with coefficient at 2.703 by a factor 14.922. According to information from FGD, some wetlands have been used for cultivation for many years. However, increase in the landscape changes in the upland areas particularly due to cultivation in the steep slopes (woodland and bushland) areas have resulted in deposition of eroded soils and other materials in the wetlands. FGD and key informant reported further that there has been decline in soil fertility in some wetlands and others have been completely covered by depositional materials to the extent that they can no longer be used for cultivation as wetlands. Nindi (2007) also reports about increasing drying up of wetlands and their increasing conversion into farming land. Likewise, NEMC (2008) reports deterioration of aquatic ecosystems in terms of decreasing water flows in rivers and streams, as well as drying up of some wetlands.

Moreover, drying-up of wetlands was among very serious problems resulted from landscape changes in the upland area that was identified by interviewed households especially in the lowland villages (Fig. 15). The results showed that there were different opinions on landscape changes from the respondents.

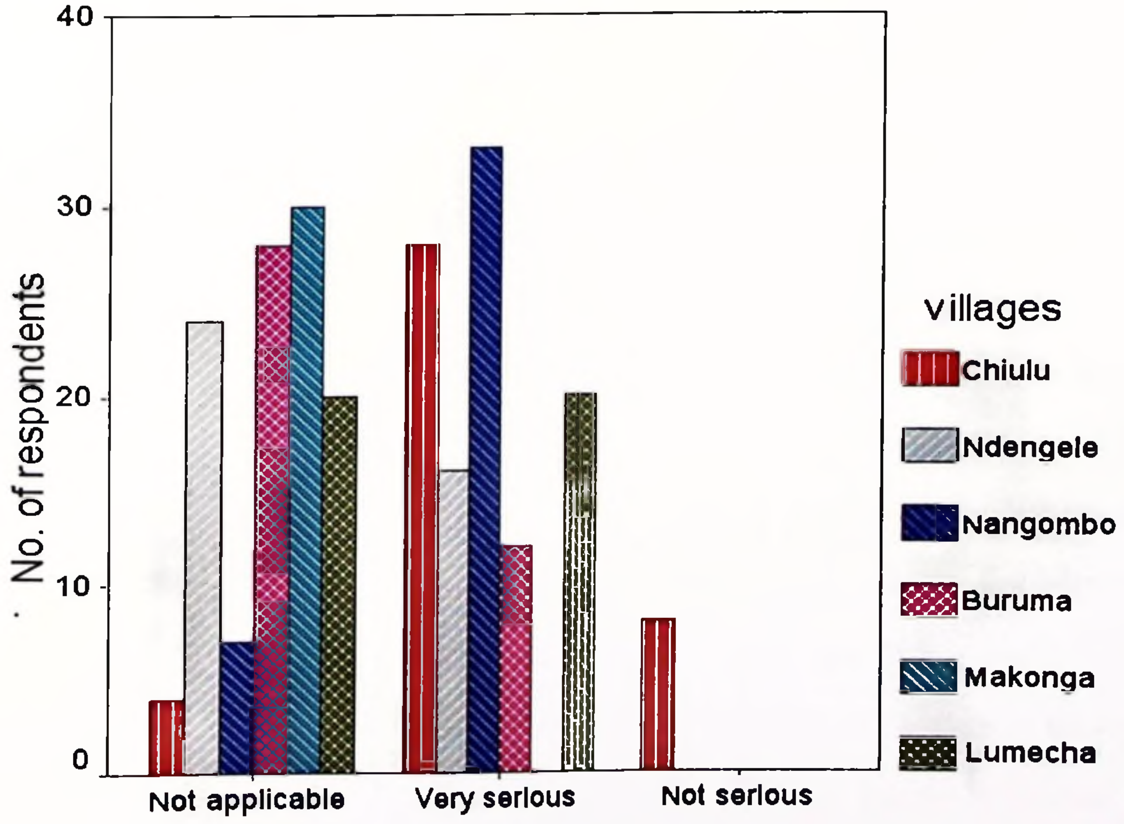

Figure 15: Respondent's opinion on drying-up of wetlands due to landscape changes.

The results (Figure 15) showed that out of 40 respondents interviewed from each of three villages, Nangombo 33 (82.5%), Chiulu 28 (70%) and Lumecha 20 (50%) considered drying-up of wetlands as a very serious problem. However, the results also showed that out of 230 respondents, 113 (49%) of respondents considered drying up of wetlands as not applicable or there was no such problem in their area. The remaining 109 (47.4%) considered it as a very serious problem whereas the other 8 (3.5%) respondents considered it not a serious problem. Moreover, the results show that out of 113 respondents who considered drying-up of wetlands as not applicable 78 (69%) of them were from upland villages of Buruma (28), Makonga (30), and Lumecha (20). This was based on the fact that impact of drying-up of wetlands was mostly experienced by people living in the lowland areas. The result connoted that the implications of the landscape changes were also perceived differently among community members in the upland and lowland areas of the study.

Moreover, it was revealed during FGDs and key informant interviews that people in the lowland area were forced to increase the sizes of their ridges in order to withstand excessive waters from upland area that run in their farms within the wetlands. This was justified by the transect walks in Chiulu village, where big ridges were seen in the farms located in low lying areas. Increasing the size of ridges had caused more labour time in the preparation of the ridges. Across time this situation has had significant implications to the livelihood of the local communities because more time is spent for preparation of ridges rather than doing other income generating activities like fishing. Furthermore, excessive deposition of eroded materials results into drying-up of wetlands in the long run. However, key informants from the same Chiulu village reported *a blessing in disguise* situation that happened in one of their wetlands. It was reported that transportation and deposition of fine eroded soil materials from the upland area to the flood plains in the lowland area, brought along fertile soils which increased soil fertility in a wetland where soil deposition took place hence increased crop production. But, Chisara, 2002 reported that continuous deposition of eroded materials in the riverline wetlands of Lake Victoria lead to drying-up of rivers, changing wetlands to normal cultivation fields and subsequently changed the ecological conditions of the wetlands that resulted to complete disappearance of some wetlands.

4.4.4 Increased siltation in Lake Nyasa and rivers

Landscape changes have increased siltation in the Lake Nyasa due to deposition of eroded materials in the lake. Increase in siltation of the Lake was statistically significant at $p \leq 0.05$. This was justified by opinions raised by 121(52.6%) out of total 230 respondents from both sides of the study area. FGDs from all six surveyed villages attributed decrease in fish availability in the Lake Nyasa to siltation in the past 10 to 15 years. Although the justification for the decrease in fish availability based on increased landscape changes was not within the scope of this study, however, respondents from FGDs in Chiulu and Ndengele villages went further highlighting that increased landscape changes in the upland area have also caused siltation and deposition of eroded materials in the rivers. They explained that some fish species usually breed in the river waters hence siltation and deposition of eroded materials had affected the breeding sites in Lumeme and Luhekei rivers. Some of the fish species reported that had decreased or completely disappeared in the study area due to destruction of fish breeding sites along the riverine/wetlands ecosystems and Lake Nyasa that resulted from siltation and excessive floods due to influence of landscape changes were *Opsaridium microlepis* (Mpasa), *Opsaridium microcepharus* (Mbelele or Sanjika) and *Oreochromis species* (Magege or Chambo). Similar echoes were reported by Nindi (2005; 2007; 2010).

As a result of siltation, participants for the FGDs reported that nowadays reasonable fish harvests could only be available offshore (far in the Lake) because it was very rarely getting many fish within inshore waters, as it used to be in the past 15 to 20 years. This could be linked to changes in the Lake conditions that might have been influenced by continuous siltation. As a result, it was difficult for them to fish along offshore waters because of the traditional fishing gears they used such as canoes and old nets which could not yield much from the lake. It was reported further that fishing has always being practised by youth and middle aged men, mostly between 18 – 40 years. Thus, switching from fisher to a full farmer is inevitable process to almost every man in the lowland of the study area when become aged.

4.4.5 Destruction of properties and infrastructures caused by changes in river regime

It was important for this study to assess the opinion of the respondents regarding destruction of properties and infrastructures caused by changes in river regime as a result of landscape changes. The results from respondents (Table 21) showed that 31 respondents (77.5%) from Chiulu and 32 (80%) respondents from Nangombo villages were of the opinion that there had been very serious changes in river regimes within the study area that caused destruction of properties and infrastructures. The opinion of respondents from upland villages of Lumecha 36 (90%) and Makonga 30 (100%) show that changes in river regime was not applicable. This implied that there were no any changes in river regime that they had experienced. The results therefore showed that perceptions of landscape changes differed between respondents from upland and lowland areas. It appeared that lowland villages were more affected by changes in river regime compared to upland villages.

Table 21: Opinion of respondents regarding destruction of properties based on changes in river regime

Change in river regime	Name of villages						All
	Chiulu n=40	Ndengele n=40	Nangombo n=40	Buruma n=40	Makonga n=30	Lumecha n=40	230
Not applicable	5 (12.5)	22 (55)	6 (15)	23 (57.5)	30 (100)	36 (90)	122 (53.04)
Very serious	31 (77.5)	15 (37.5)	32 (80)	17 (42.5)	0 (0)	4 (10)	99 (43.04)
Not serious	4 (10)	3 (7.5)	2 (5)	0 (0)	0 (0)	0 (0)	9 (3.92)
Total	40 (100)	40 (100)	40 (100)	40 (100)	30 (100)	40 (100)	23 0 (100)

Numbers in brackets are percentages

During the FGDs, respondents from Ndengele village expressed their concerns that excessive clearance of vegetation in the Livingstone Mountain Ranges and along river sides could have caused changes in river regime and subsequently destruction of crops and farms by fast moving waters. For example direct observations in Ndengele village at an area where river regime had changed showed that, there were serious damages to the paddy fields resulted from flood waters from the upland areas. When the river regime changed, excessive flood waters crossed through the farming land and washed away the crops. Plate 6 displays a disappointed farmer (in red T-shirt) explaining the damages caused by flood waters to his farm, resulted from changes in river regime whereby only thick layers of sand and pebbles deposited by river waters could be seen covering the farm. It was not possible to see any sign of clay soils where rice was planted before. *"These catastrophes were not experienced in the past 15 to 20 years"*, lamented one of the key informants.

Plate 6: Invasion of floods in the rice field in Chiulu village in 2007

In order to determine topographical influence on river regime changes, GIS analysis was conducted for Lumeme River based on its total length and the area it flows. The results from GIS analysis showed that total length of the river was 58 km, starting from one of its tributaries in Mbuji ward at an altitude ranging from 1711 to 1514 m *a.s.l.* It is assumed that the erosive power of Lumeme River increases abruptly 6 km before entering the Lake Nyasa at an altitude ranging from 1315 to 721 m *a.s.l.* Within this section of 6 km the river passed over an area of 2.4 km, with a drastic change in slope from 45% to 28%. Furthermore, in the section of 6 km mentioned above, the river flowed in an area with slope decreasing from 22% to 11% in an altitude ranging from 720 to 480 m *a.s.l.* The 480 m *a.s.l.* is almost the altitude at which the Lake Nyasa lies. It was only in the last section of 300 m before entering the Lake where this river flowed in an area with a slope ranging from 5.6% to 0. This area was occupied by bushes, settlements and scattered crops. In this kind of situation factors such as volume of water in the river, slope at which the river passes, vegetation cover, soils and rock type defined the effects that were likely to happen in the lowland due to erosive power of the water, including changes in the river regime.

Likewise, it was thought important to seek opinion of respondents regarding collapse of infrastructure influenced by landscape changes. The results (Figure 16) also showed that 87 (72.5%) out of 120 respondents from the lowland villages considered the collapse of infrastructures in the lowland as a very serious problem. Contrary, 88 (80%) out of 110 respondents from upland villages saw the collapse of the infrastructure as inapplicable to their area. This could be supported by the fact that the upland areas are mostly sources of rivers whereby in most cases they tend to have less waters, although could be speedy. But as a result of fewer waters, rivers tend to have ineffective destructive force within the upland area. However, the distance that river waters travel, total volume of water, load and terrain characteristics (slope, soils, rocks, vegetation cover) have significant impact to the lowland areas.

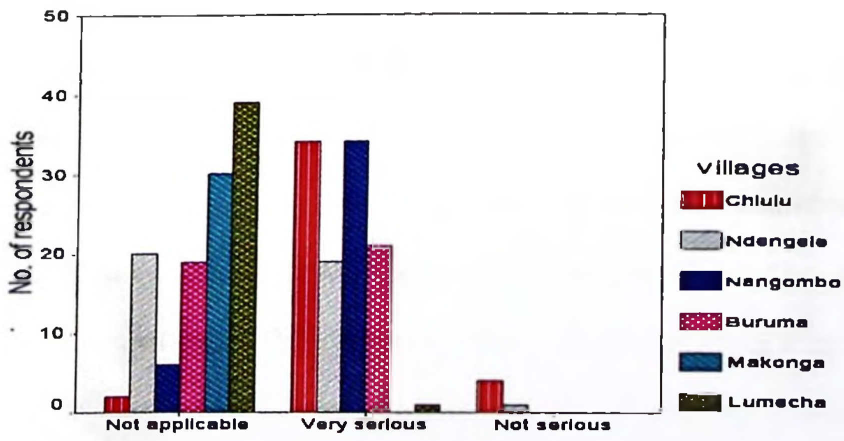

Figure 16: Respondent's opinion on collapse of infrastructures due to landscape changes.

It is assumed that effects such as soil erosion, destruction of infrastructures, properties, deposition of eroded materials in the wetlands, rivers, farms and the Lake Nyasa are likely to happen as a result of changes in river regime. Respondents from FGDs in Nangombo village (in the lowland area) reported that some rivers where certain fish species such as *Opsaridium microlepis* (Mpasa), *Opsaridium microcepharus* (Mbelele or Sanjika), and *Oreochromis* species (Magege or Chambo) have been drastically reduced as opposed to the past 10 to 15 years due to deposited materials brought about by changes in river regime and excessive floods. Such results confirm that changes in river regime have caused different problems to the properties, landscape, Lake Nyasa, hence livelihood. In other places, like Chiulu village rivers had changed their courses due to strong erosive powers, leading to destruction/collapse of infrastructures such as bridge (Luhekei) and roads hence more deposition of eroded materials and siltation in the Lake Nyasa.

4.4.6 Destruction of properties and infrastructure caused by unusual natural disasters

In order to have more insight about other effects experienced by communities due to landscape changes, it was important to seek opinion from respondents regarding unusual natural disasters that have occurred in the past 15 years in the study area. The results (Table 22) showed that unprecedented strong wind was more experienced in the upland villages based on the opinion of respondents from Lumecha 17 (42.5%), Makonga 17 (56.7%), and Buruma 13 (32.5%). On the other hand, floods and strong winds were more experienced in the lowland villages especially Chiulu 39 (97.5%). Chiulu village is located along River Luhekei valley.

Table 22: Opinion of respondents regarding unusual natural disasters occurred in the past 15 years

Natural disasters	Name of villages						
	Chiulu	Ndengele	Nangombo	Buruma	Makonga	Lumecha	All
	n=40	n=40	n=40	n=40	n=30	n=40	230
1. Floods	0	0	1	2	0	0	3
2. Unprecedented strong wind	0	2	0	13	17	17	49
3. Floods and strong wind	39	9	12	8	3	16	87
4. Floods, strong winds and landslides	1	22	27	8	0	2	60
5. Strong winds and landslide	0	0	0	5	2	3	10
6. N/A	0	7	0	4	8	2	21
Total	40	40	40	40	30	40	230

N/A= Not applicable

The results in Table 22 further showed that incidences of natural disaster such as floods, unprecedented strong winds, and landslide have been occurring frequently in their villages for the past 15 years (Plate 7). A total of 196 (85%) of respondents out of 230 from both upland and lowland areas had the opinion that natural disasters, categorised as No.2, 3 and 4 are the leading when combined.

Plate 7: A house roof removed by unprecedented strong winds in Makonga village in the year 2007

In addition to opinion raised by respondents, direct observations conducted in Chiulu village identified two bridges which were demolished by flood waters in the distributaries of river Luhekei. Lack of functional bridge across one of the tributaries, disconnected the shortest road to Mbamba Bay for villages such as Chiulu and Matenje, located further southeast towards Mozambique border. This has made ferrying of people and goods across the river a major income generating activities for youth (Plate 8). Unfortunately, there were no signs of rehabilitating or constructing a new bridge at the time of this study. Instead, government had to change road enroute Mozambique from Mbamba Bay to upper slopes hence increasing expenditure and possibly dwindling of livelihood strategies along old road.

Plate 8: Ferrying goods by youth as a way of earning income in Chiulu village in the year 2007

The results from respondents (Table 22) implied that the extent at which the local communities had been affected by the destruction of infrastructure that resulted from landscape changes differed from one location to another. For example, demolition of a bridge across Luhekei River by increased flood waters due to excessive vegetation clearance in the upland hindered business operations and accessibility of goods and services from Mbamba Bay. The elder key informants from Chiulu village reported that businessmen from their village and other nearby places depended mostly on Mbamba Bay as a shopping centre. Mbamba Bay is the distribution centre of imported products/goods from Malawi and Mozambique or locally made in the country. In this case, the collapse of bridge due to excessive flood waters had seriously affected the livelihoods in terms of difficulties in accessing commodities, increased prices of commodities and transportation problems.

Furthermore, collapse of bridge had affected services such as dispensary which were also accessed from Mbamba Bay. The hiring of transport for carrying goods and accessing services from Mbamba Bay had become expensive and takes more time since, cars had to use an alternative road which is too long. Alternatively, people had to go on foot or use bicycles/motorcycles (which could be carried while crossing the river) in order to go to Mbamba Bay. If flooding can be dangerous, the sick who need referral can suffer most.

4.4.7 Destruction of fish breeding sites and decline in wildlife

Moreover, a historical profile regarding the landscape changes that took place in the Livingstone Mountain ranges was given by elder village members from Ndengele village in the lowland area. They reported that the Livingstone Mountain ranges used to be covered by natural vegetation up to mid 1980s. However, there has been serious natural vegetation clearance in the Livingstone Mountain ranges, which caused among others, destruction of fish breeding sites along the rivers entering Lake Nyasa causing disappearance of different types of fish species in the rivers. Similarly, it was reported during historical profile and FGDs that clearance of natural vegetation particularly woodlands, which was habitat for wild animals have caused decline in their numbers. Information from the historical profile was similar to the opinion raised by FGD respondents from all six villages when they were asked to compare the current situation with the past 15 to 20 years.

The results therefore showed that there were different environmental and socio-economic problems implicating the livelihoods of the communities in the lowland areas of the Livingstone Mountain ranges along Lake Nyasa shore. This situation shows that implications of landscape were felt differently amongst upland and lowland communities due to geographical location and economic situation of the people. Likewise, a report by FAO (2003) show that, high mountain areas have attracted considerable public interest and attention because of their uniqueness and visibility whereas environmental and livelihood issues at lower elevations constitute a more widespread and pressing problem. On realising different problems experienced by communities in the lowland of the study area, Nindi (2007) concluded that the Nyasa people can be categorised as small stakeholders with limited income to acquire most of their basic needs.

Excessive floods, unprecedented strong winds and changes in river regimes have had significant implications to the livelihoods of the communities. Drying up of wetlands, destruction of properties and infrastructures, and increased siltation in Lake Nyasa had complicated accessibility to goods and services by the communities. As a result, landscape changes have caused different implications to the livelihoods of the communities in the study area including scarcity of both farming and grazing lands. The study has therefore demonstrated that there were different implications of landscape changes mostly experienced by communities in the lowland area of the study. This forms serious problems and calls for urgent action based on the highland-lowland nexus.

4.5 Simulating Near Future Landscape Changes Based on LIM-CLUES Model

Different scenarios were taken into consideration based on prevailing conditions in the study area. The policy and business as usual scenarios have used in the LIM-CLUES model.

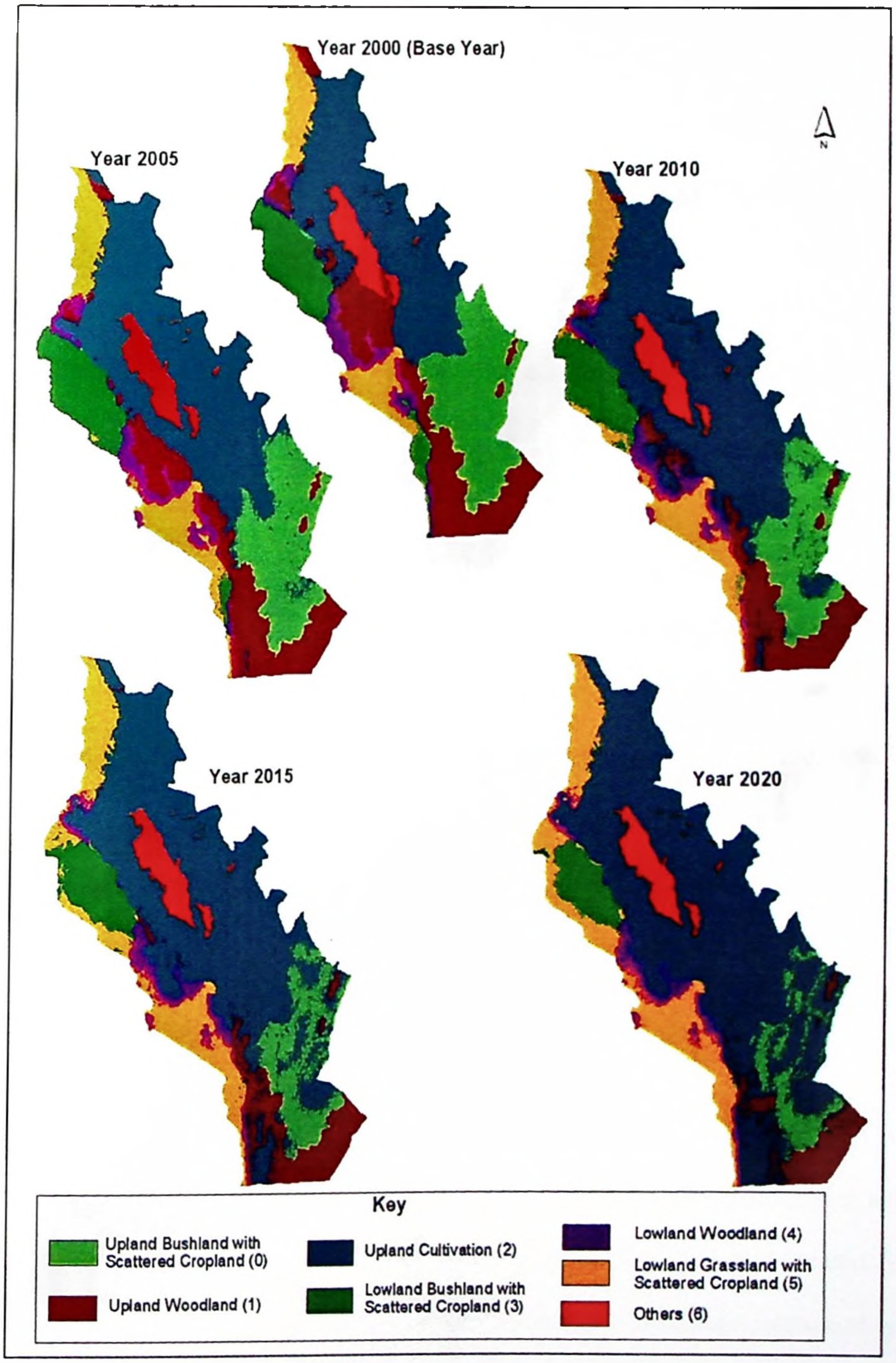

Figure 17: Simulated landscape changes based on the business as usual scenario.

4.5.1 LIM-CLUES simulated landscape changes due to business as usual scenario

The business as usual scenario that assumes the land use and land cover trends between 1990 and 2000 continues, was used to simulate the landscape changes in the study area. Fig. 17 therefore shows the land use and cover maps simulated for years 2005, 2010, 2015 and 2020.

Generally, the simulated results starting from year 2005 to 2020 (Fig. 17) showed that there was mainly an increase in the cultivated land at the expense of the upland woodland and upland bushland with scattered cropland. The results also showed that cultivation continued to expand from its area occupied in the year 2000 to subsequent years towards south eastern side up to the last year of simulation (2020). Encroachment will also start to take place in the upland woodlands located in the southern part of the study area. This is an area where encroachment had taken place by the 2005 and lies at an altitude ranging between 1550 to 1722 m. with varying slopes ranges from 4 to 34 degrees. The results also implied that this area might have been encroached due to its favourable conditions to the Matengo people for the establishment of settlements and new farms including *ngolo* cultivation and slash-and-burn for finger millet due to steepness.

By the year 2020 the simulated results showed that cultivation will be occupying most of the woodland areas in the southern part, except the south east, which is located further away near border to Mozambique. There will also be some remaining patches of upland bushland with scattered cropland in the middle parts of the study area based on the trends of resource utilisation considered under this scenario.

Furthermore, simulated results showed that most of the areas where cultivation will be extended by the year 2020 have relatively less slopes and elevation compared to areas which were under cultivation up to the year 2000. This implied that areas that are expected to be under cultivation in the near future are those that do not necessarily require the use of *ngolo* farming system.

Moreover, simulated results also showed that almost all upland woodlands located in the steep slopes of the Livingstone mountain ranges in Chiwanda, Mtipwili, Mbamba Bay and Lipingo wards in the lowland areas will be cleared for cultivation possibly by using the *ngolo* farming system. Steep slopes and population density will have more influence in increasing the cultivated land. This massive encroachment in the upland woodlands located in the lowland wards imply that there will be chances for land use conflicts between upland and lowland villagers whose villages share the boundaries.

The results also implied that expansion of upland cultivation at the expense of upland woodland land would continued to take place from areas that were closer to existed cultivated land in the year 2002 at higher altitudes towards lower altitude areas. These are areas favourable for *ngolo* cultivation system. Although simulated results showed encroachment will start in some parts of upland woodland areas by 2015, still there will be some remaining stands of upland woodland by the year 2020 along the Livingstone Mountain ranges in the steep slopes of the southern part of the study area. However, if the current trends for woodland utilisation continue, there will be more threats in the future. Similar results were obtained by Nindi (2004) where deforestation due to opening up of new farms in Kitanda (in the Miombo frontiers) village in Mbinga district by decreased the tree cover from over 85% in the year 1984 to less than 20% in the year 2000.

More simulated results for the landscape changes from year 2005 to 2020 based on the business as usual scenario are presented in Fig. 18 and Table 23. It is important to note that the area under upland cultivation will increase to about 160 000 ha by the year 2020. At the sametime upland woodland and upland bushland with scattered cropland will also decrease to less than 20 000 ha by the year 2020. This showed that the area for upland cultivation will increase at the expense of both upland woodland and upland bushland with scattered cropland. This implies that there will be more decrease in the woodland ecosystem and subsequently decrease in the goods and services derived by the communities for their livelihoods.

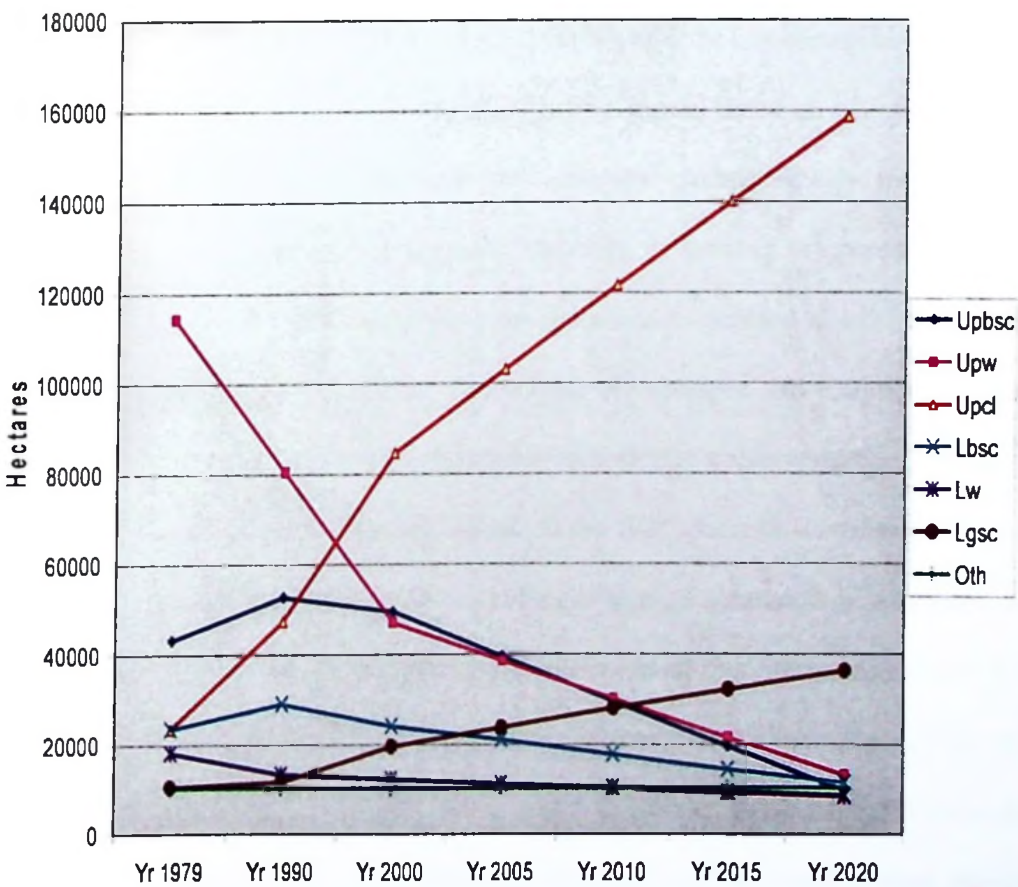

Figure 18: Simulated results for landscape changes from base year (2000) to 2020 based on business as usual scenario.

Table 23: Summarised results on actual and simulated areas of landscape changes in hectares under business as usual scenario from base year 2000

LULC	Baseline 2000	Actual 2005	Simulated 2005	Actual 2010	Simulated 2010	Actual 2015	Simulated 2015	Actual 2020	Simulated 2020
Upbsc	49 561	39 561	39 559	29 561	29 561	19 561	19 561	9 561	9 561
Upw	47 093	38 593	38 596	30 093	30 093	21 593	21 593	13 093	13 093
Upcl	84 627	103 127	103 126	12 1627	121 627	140 127	140 127	158 627	158 627
Lbsc	24 021	20 781	20 937	17 541	17 596	14 301	14 339	11 061	11 200
Lw	12 292	11 372	11 197	10 452	10 292	9 532	9 380	8 612	8 666
Lgsc	19 562	23 722	23 741	27 882	27 987	32 042	32 156	36 202	36 009
Oth	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104
Total	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260

4.5.2 LIM-CLUES simulated landscape changes under policy scenarios

Simulated maps were generated by the LIM-CLUES model based on two different policy scenarios. It was assumed that simulated landscape change results from developed scenarios would support Mbinga District Authority in making informed decisions on land use planning and natural resources management. As pointed out by Yanda (2010) that macro-policies have contributed to the land use changes and consequently on the Miombo ecosystem, it was therefore important to consider implementation of policies in developing the scenarios in this study. Thus, in the first scenario, assumption was made that policies are implemented in order to reduce effects of clearance of woodland in the Livingstone Mountain ranges. This assumption considered that there was need to reduce area that is under cultivation in order to allow regeneration to take place. The second scenario assumed that policies were put in place to restrict anymore cultivation in the remaining upland woodland areas. Instead, cultivation was allowed in non woodland areas. However, it is important to note that both of the policy scenarios were applied in the upland area where serious vegetation clearance was noticed by this study.

4.5.2.1 LIM-CLUES simulated landscape changes based on scenario that targets at reducing the area under upland cultivation

Figure 19 showed that between years 2005 and 2010, the upland bushland with scattered cropland category would be extending upwards in Kingerikiti ward. At the same time (year 2005) upland woodland started to regenerate in the same Kingerikiti ward.

This result implied that Kingeriki ward in the Matengo highlands, which had a least population density of between 48 to 75 people per square kilometre by the year 2000, had more changes of decreasing upland cultivation hence allowing the area of upland bushland with scattered cropland to increase. The results also show that by the year 2015 only a very small area of Kingerikiti ward will still be under upland cultivation whereas simulated results show that there will be no upland cultivation practised in Kingerikiti ward by the year 2020.

It is important to note that people will derive their livelihoods by practising scattered cultivation instead of upland cultivation. By upland cultivation it implies total clearance of natural vegetation whereas scattered cultivation leaves some natural vegetation in the farms. Thus, scattered cultivation will be practised in the upland bushland, whereby its area will increase too at the expense of reduced upland cultivation area.

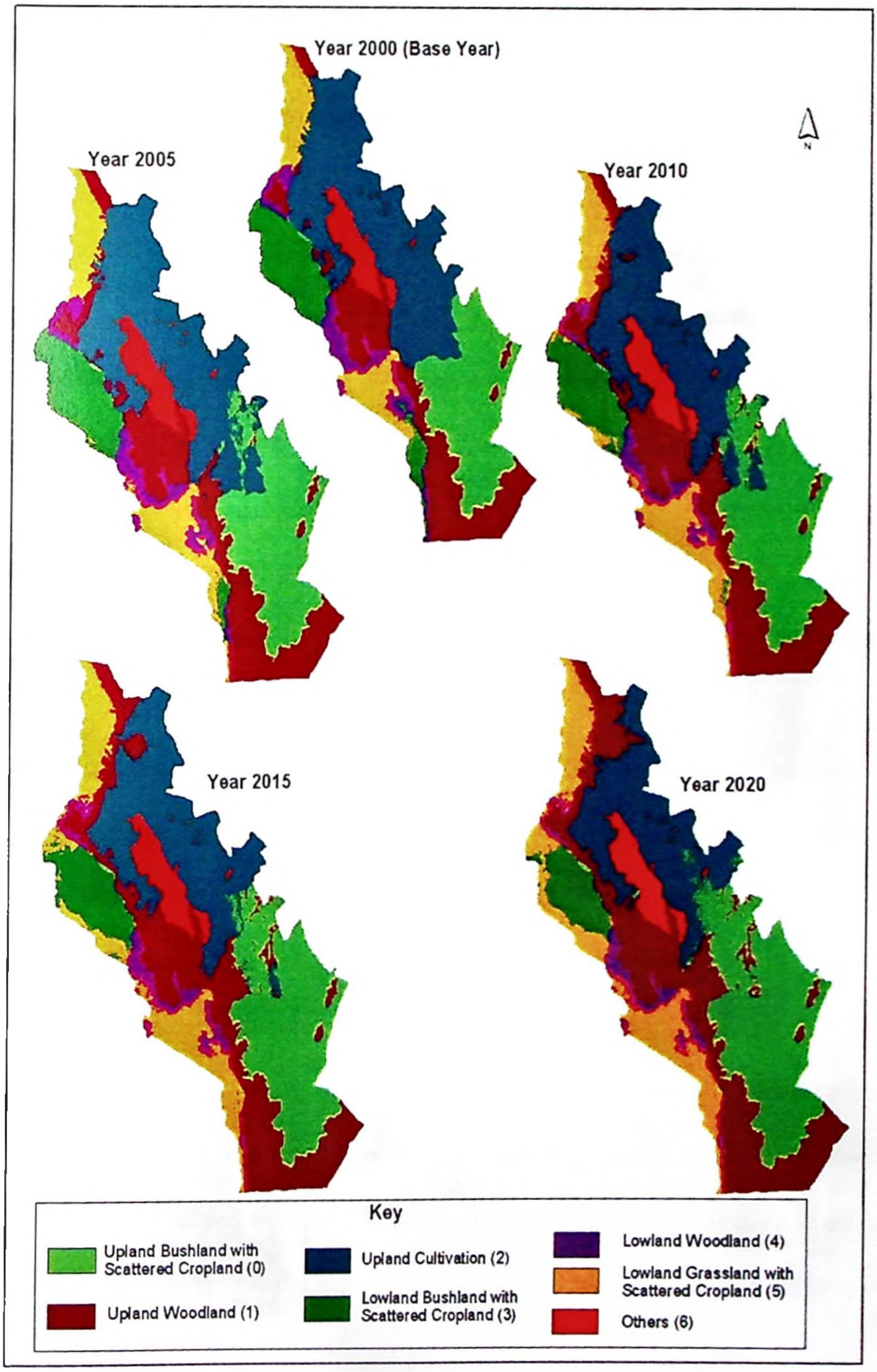

Figure 19: Simulated landscape changes based on policy scenario considering reduction of cultivated land by almost 40% from its base year area.

Simulated landscape change results (Fig. 19) also showed that the distribution of upland woodland will also extend towards southeast of the study area between 2015 and 2020 and will spread along the escarpment of the Livingstone Mountain ranges around middle parts of the study area in Maguu and Langilo wards in the upland area. Although the population densities of both Maguu and Langilo wards ranged between 109 to 161 people/sqkm and Kitura ward 48 to 75 people/sqkm, regeneration of upland woodland along the middle parts, which were mostly occupied by the escarpment, could probably been influenced mainly by the slope. This is because the model results revealed that regeneration of upland woodland will be mainly along the escarpment, which has steep slopes. This is also supported by the fact that most of the remaining woodlands are located in the steep slopes.

Likewise, simulated map (Fig. 19) also showed that distribution of regenerated upland woodland will occupy most of the Ukata ward by the year 2020. This is because most of the areas of Ukata ward lies within an area with altitude ranging between 721-918 m. Also Ukata ward had less population density ranging from 26 to 48 people/sqkm and there was no extensive cultivation during base year (2000). Simulated map for year 2020 therefore show that upland woodland will regenerate and occupy large parts of Ukata ward. This implies that population density and lack of upland cultivation have influenced distribution of upland woodland in this area. Lack of upland cultivation in this area is due to presence of extensive flat areas which are not favourable for *ngolo* cultivation.

The LIM-CLUES model results therefore show that if we intend to allow regeneration of the upland woodland within the Livingstone Mountain ranges, the best option is to restrict cultivation in the steep slopes and other remaining woodland areas. But this does not mean people will be completely restricted to cultivate, instead, government should introduce policies that will require people to cultivate in the upland bushland with scattered cropland in Kingerikiti ward instead of cultivating in upland woodland in steep slopes. This initiative implies that the Matengo people could still migrate to Kingerikiti ward based on factors that it has less population density and there will be an increase in the area of upland bushland based on simulated results from the model. LIM-CLUES results (Fig. 19) show that increase in the area of upland bushland with scattered cropland will allow regeneration of upland woodland hence improve the management of the woodlands within the Livingstone Mountain ranges. However, the government and other stakeholders should play part in assisting communities to establish/strengthening primary societies, provision of farm inputs that can ensure prosperity in coffee, which would facilitate intensification and subsequently slow down landscape changes, hence giving room to regeneration. Table 24 summarises results that show actual and simulated areas of the land use and cover categories based on a policy scenario that considered reduction of cultivated area by almost 40% from its area in the year 2000.

Table 24: Summarised results on actual and simulated areas of landscape changes in hectares under policy scenario that targets at reducing cultivated area

LULC	Baseline 2000	Actual 2005	Simulated 2005	Actual 2010	Simulated 2010	Actual 2015	Simulated 2015	Actual 2020	Simulated 2020
Upbsc	49 561	53 061	53 061	56 561	56 561	60 061	60 061	63 561	63 561
Upw	47 093	52 093	52 093	57 093	57 093	62 093	62 088	67 093	67 093
Upcl	84 627	76 127	76 127	67 627	67 627	59 127	59 132	50 627	50 627
Lbsc	24 021	21 041	21 185	18 061	18 078	15 081	15 181	12 101	12 068
Lw	12 292	11 587	11 404	10 882	10 695	10 177	10 024	9 472	9 343
Lgsc	19 562	23 247	23 286	26 932	27 102	30 617	30 670	34 302	34 464
Oth	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104
Total	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260

4.5.2.2 LIM-CLUES simulated landscape changes based on scenario that targets at maintaining the area under remaining upland woodland

The LIM-CLUES simulated results from this policy scenario show that, once the area for *(upw)* that was available in year 2000 is assumed to be recovered through natural regeneration; the government will have to put in place policies that will require people to undertake *(upcl)* in areas with *(upbsc)*. Starting with year 2005, LIM-CLUES results Fig. 20 showed that *(upcl)* will be extended southwards in Kingerikiti ward.

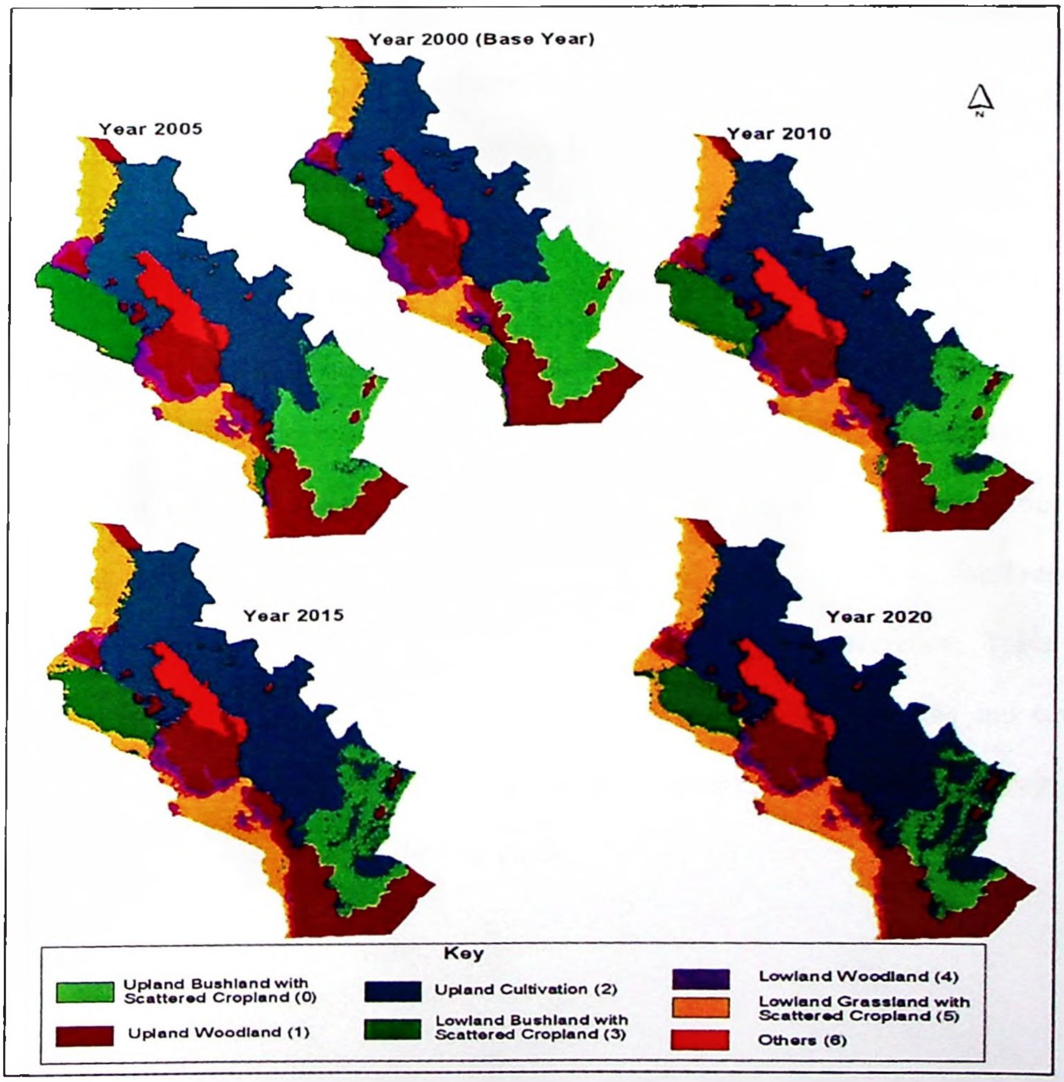

Figure 20: Simulated landscape changes based on policy scenario considering maintaining the area and location of upland woodland as it was in year 2000.

Some encroachment will also start within Tingi ward. By the year 2010, almost all of Kingerikiti ward will be under upland cultivation and more cultivation will be expanded in Tingi ward. Both years 2015 and 2020 show expansion of cultivation in Tingi ward though by the year 2020 there will still be patches of scattered bushland within Tingi ward.

These simulated results (Fig. 20) implied that it is possible to expand *(upcl)* within *(upbsc)* areas in order to allow natural regeneration of *(upw)* in all areas that had woodland by the year 2000. Communities can therefore be assisted and directed to expand, if need arise, upland cultivation in upland bushland with scattered cropland areas. This can be done by using cheaply available Global Positioning Systems (GPS) in order to identify geographical coordinates for locating simulated areas of interest from the different land use and cover categories. The simulated maps can therefore be overlaid with grid lines and coordinates in any of the GIS packages to facilitate their use in the field. In line with implementation of model results for planning purposes, the government and other stakeholders should also encourage and educate communities on tree planting programs, development of economic activities e.g. apiculture, fish keeping that can ensure both livelihood improvement and landscape conservation. Table 25 summarises results that show actual and simulated areas of the land use and cover categories based on a policy scenario that considered maintaining the area and positions of upland woodland as it was in the year 2000.

Table 25: Summary of actual and simulated landscape changes in hectares based on policy scenario that considered maintaining the area and location of upland woodland as it was in year 2000

LULC	Baseline 2000	Actual 2005	Simulated 2005	Actual 2010	Simulated 2010	Actual 2015	Simulated 2015	Actual 2020	Simulated 2020
Upbsc	49 561	41 061	41 061	32 561	32 561	24 061	24 061	15 561	15 561
Upw	47 093	47 093	47 093	47 093	47 093	47 093	47 093	47 093	47 093
Upcl	84 627	93 127	93 127	10 1627	101 627	110 127	110 127	118 627	118 627
Lbsc	24 021	21 041	21 185	18 061	18 078	15 081	15 180	12 101	12 068
Lw	12 292	11 587	11 404	10 882	10 695	10 177	10 016	94 72	9 343
Lgsc	19 562	23 247	23 286	26 932	27 102	30 617	30 679	34 302	34 464
Oth	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104	10 104
Total	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260	247 260

Thus, results from LIM-CLUES model have shown its applicability in supporting decision making under varying scenario conditions. It is therefore important to note that details and other analytical functionalities of the LIM-CLUES model are provided in the User Manual (Appendix 9).

4.6 Testing and Validating the LIM-CLUES Model

In prediction modeling, the most important and the absolutely essential component are testing and validating the predicted results. Without some kind of validation, the prediction model and image are totally useless and have hardly any scientific significance (Chung and Fabbri, 2003). In this case, the area change results between 1990 and 2000 were the basis for the analysis. The time gap of ten years was not considered as a problem due to rapid changes that have taken place in the study area. The Landsat imagery of the year 2006 (Appendix 8) was used to validate the model results.

In order to validate the LIM-CLUES model results therefore, a validation methodology by Kok (2001) was employed. The areas for each land use and cover types were computed and aggregated to determine their administrative unit averages at ward level. The performance of these aggregated results has been examined because the interest was to capture patterns of change and not in detailed grid to grid changes. Quoting Verburg (2000) from his study in Java he pointed out that *"from validation we can conclude that we should not interpret the results of the model on a cell-to-cell basis, as deviation between simulated and observed for individual cells can be considerable. Instead, the model results can be used to explore the pattern of land use change and indicative regions that might become hot-spot of land use change"*. This approach has been adopted in this study.

Six out of seven land use and cover types were therefore used in the model validation. These land use and cover types were upland bushland with scattered cropland, upland woodland, upland cultivation, lowland bushland with scattered cropland, lowland woodland, and lowland grassland with scattered cropland. The seventh land use type, which was not included in the model validation, is *others*. This was excluded because it was held constant in the model. The findings from this study indicated that the model was able to approximate the land use and land cover in the study area. However, just by visual interpretation it is difficult to assess precisely the correct locations of the important and complex patterns of change (Verburg, 2000).

Fig. 21 presents the measured and simulated maps for the year 2006. The correlation for the measured and simulated land use and cover ranged from 0.80 to 0.99.

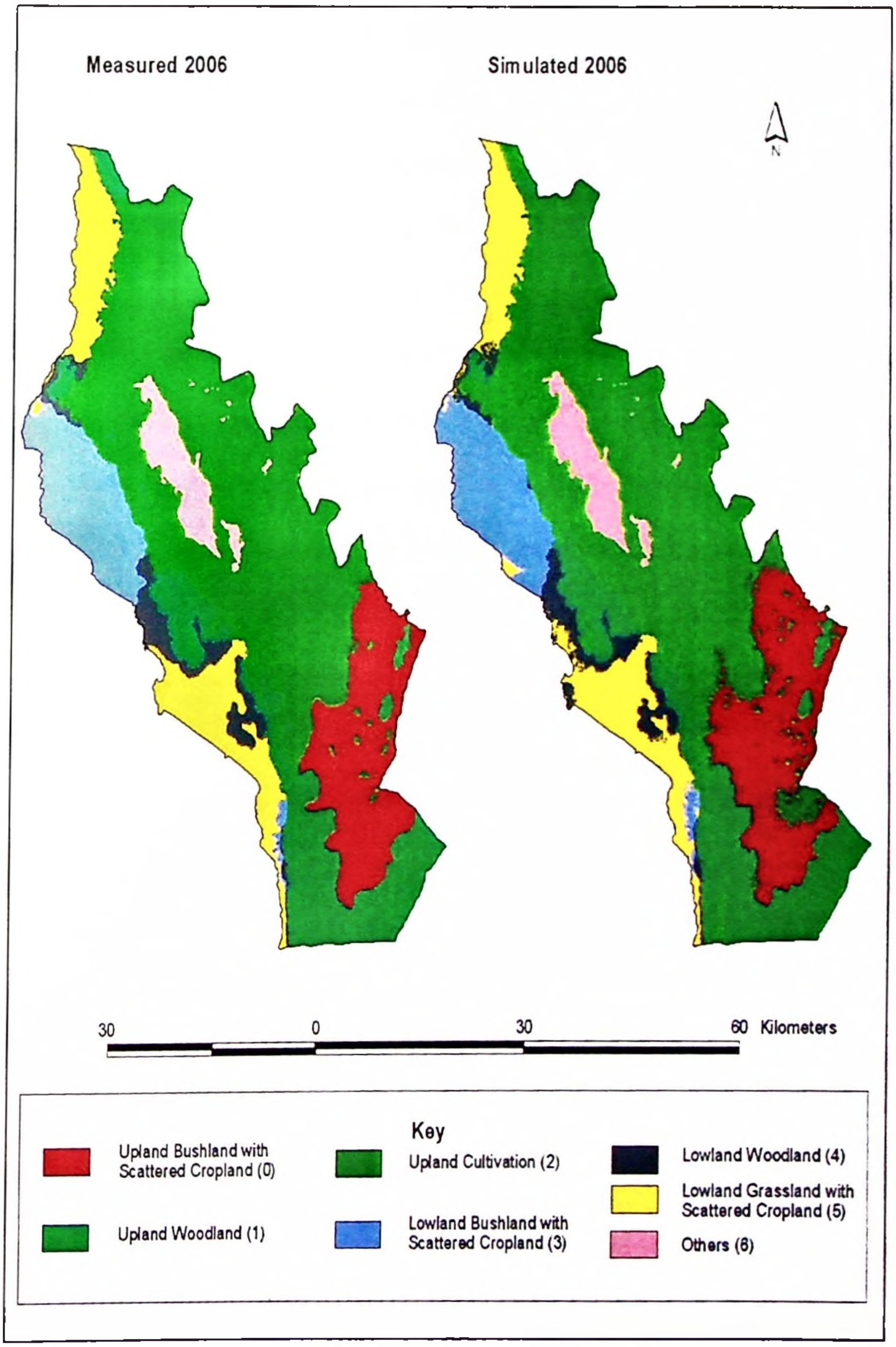

Figure 21: Measured and simulated change in land use and cover types for the year 2006.

Fig. 22(a-d) present the results for model validation. The correlation of the two land use and cover categories of upland bushland with scattered cropland and others were not presented in this study because the upland bushland with scattered cropland category appeared in only two wards of the study area. This situation would have biased the validation results. The other category was held constant therefore its area remained the same throughout the study periods. The lowland grassland with scattered cropland category had the highest correlation of 0.99 between measured and simulated changes in the model whereas upland cultivation and upland woodland had the correlation of 0.97 and 0.80, respectively. The highest correlation of the results can partly be explained by the relatively small changes in the land use and cover during the validation period and possibly the level of accuracy attained in generating the input parameters in the model. The Lowland woodland had the correlation of 0.93.

Similar results were obtained by Kok (2001) whereby the correlation coefficient for pasture and forest were 0.87 and 0.95 in a study conducted in the Northern Atlantic Zone of Costa Rica, using a model developed by CLUES framework. Likewise, validation results by Orékan (2007) from a model developed in Central Benin using the CLUES modeling framework show that correlation coefficients (R^2) for agriculture and forests were 0.750 and 0.748, respectively. The results from these examples therefore show that CLUES modeling framework has been applied in developing different land use and cover prediction models. Moreover, validation results for the case studies in Costa Rica, Benin and those generated by this study have provided reliable accuracy for supporting spatial decision making processes in various applications.

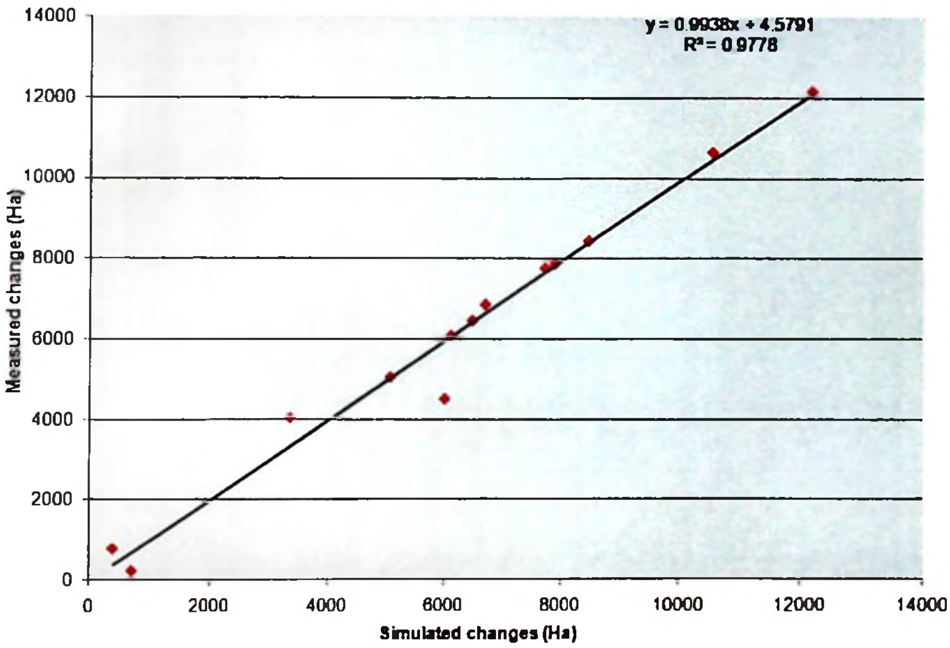

Figure 22(a): Correlation between measured and simulated change results for upland cultivation category.

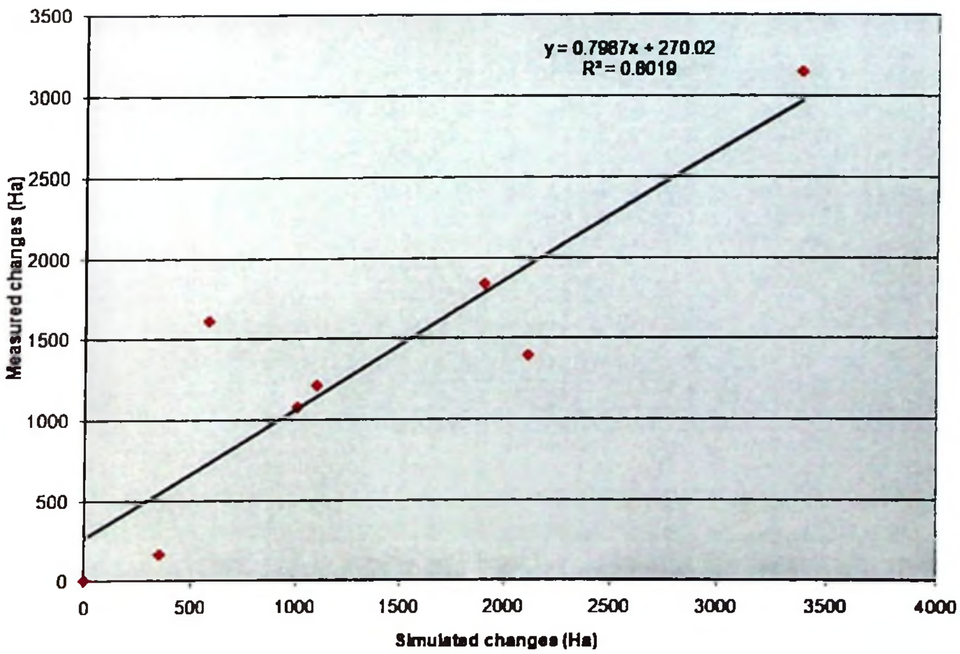

Figure 22(b): Correlation between measured and simulated change results for upland woodland category.

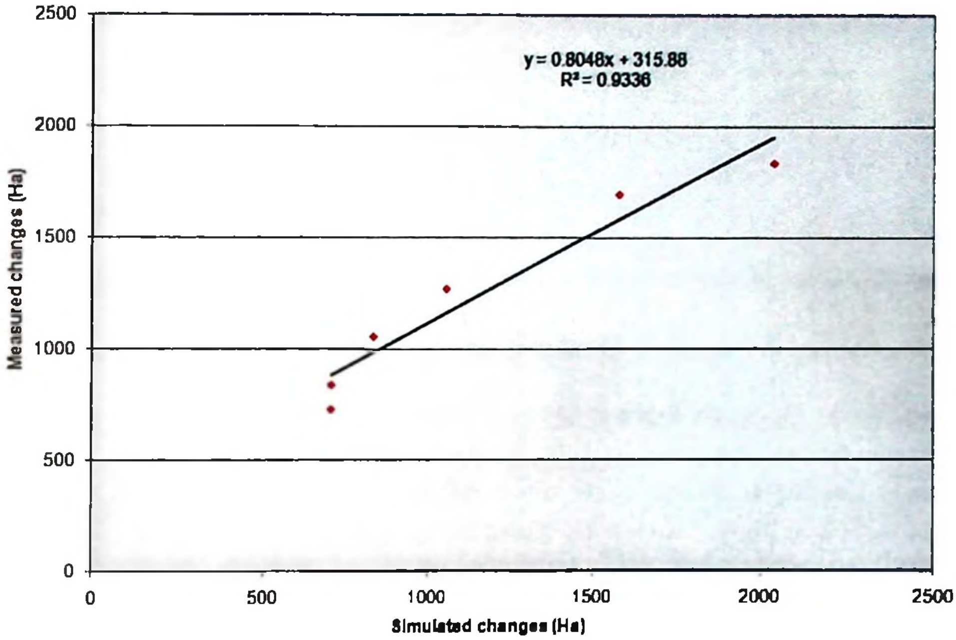

Figure 22(c): Correlation between measured and simulated change results for lowland woodland category.

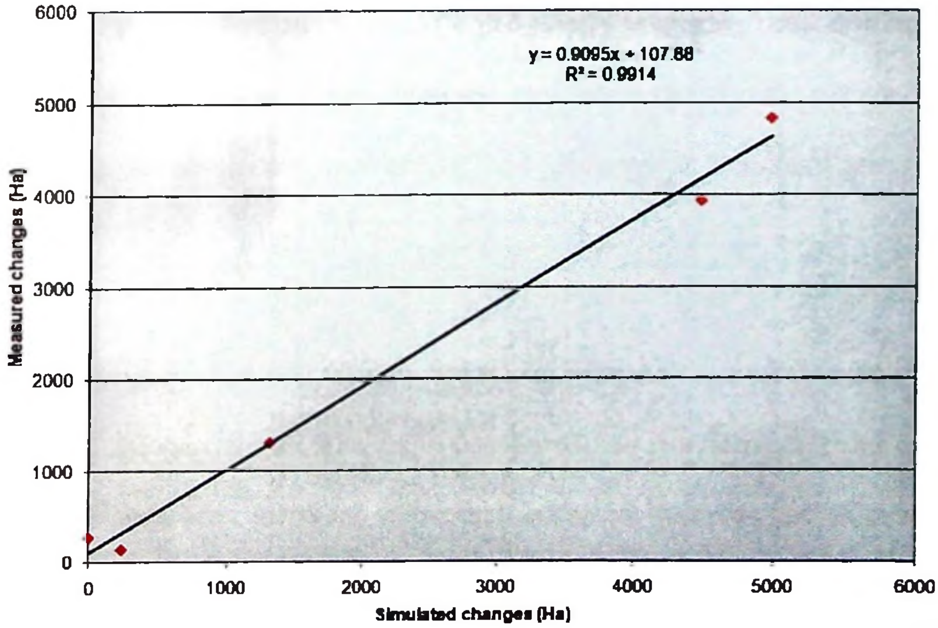

Figure 22(d): Correlation between measured and simulated change results for lowland grassland with scattered cropland.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research work demonstrates the ability of Remote Sensing and GIS in capturing and manipulating the spatial and temporal datasets. Based on evidences from satellite imagery interpretations between study periods (1979 – 1990 and 1990 – 2000), there had been a continuous decline in the area covered by upland woodland closed and upland woodland open in the upland area of the study. The results show that the combined total areas for upland woodland closed and upland woodland open declined whereas that of upland cultivation increased throughout the study periods. The study concludes that decline in the woodland areas were caused by conversion of such areas to either fully cultivated land or to upland bushland with scattered cropland. Thus, driving factors used in this study which were slope, elevation, population density, the distance to the roads and rivers had significant influence in the conversion of woodland areas to cultivated land.

Results therefore show that there had been a lot of human activities in the study area that caused landscape changes. The major conclusion that can be made from the findings is that there have been increases in the area occupied by agro-ecosystem mainly at the expense of woodland ecosystem in both upland and lowland areas of the study. As a result, without appropriate land use management and sustainable agricultural practices, the loss of woodland will continue with associated consequences such as soil erosion, destruction of wetlands and sedimentation of Lake Nyasa resulting from landscape change mainly in the upland area.

This study also concludes that the process of landscape change is the outcome of complex interactions between biophysical and socio-economic factors. All spatial factors used in the modeling (population density, distance to road, distance to river, aspect, elevation, slope) have shown to be influential in landscape changes in the study area. So, land use is more than the artifact of human behavior, for it is closely tied to the physical environment. Understanding land use change in relation to its driving factors provides essential information for land use planning and sustainable management of resources. It is therefore important to integrate biophysical and socio-economic conditions in the analysis of landscape changes. Moreover, the application of remote sensing and GIS techniques have helped in the acquisition of useful information and in the identification of landscape changes, which are the basis for spatial decision-making, on a limited number of biophysical and socio-economic variables.

It is also concluded that the use of *ngolo* farming system in the upland areas enables cultivation to take place in the steep slopes of up to 50 degrees. Application of *ngolo* farming system in the upland area therefore makes slope as a non-limiting factor for upland cultivation in the steep slopes within the study area. However, continue opening up new farms in the steep slopes (where most of the remaining woodlands are located) makes influence landscape changes in the Livingstone Mountain Ranges. In contrast, cultivation is not practiced in steep slopes of the lowland areas because *ngolo* farming system is not part of people's traditional farming system.

The study has shown that the Livingstone Mountain ranges and its adjacent lowland areas provide different ecosystems goods and services to the local communities in the study area. However, consequences of landscape changes including unprecedented strong winds, excessive floods and changes in river regime all have been posing problems to the communities. Identified problem associated with landscape changes include destructions in the infrastructures such as roads and bridges, destruction and drying-up of wetlands and fish breeding, which have significant impacts to the livelihood. It is therefore concluded that landscape changes have implications to the livelihoods of the people in terms of difficulties in accessing goods and services and increased prices of commodities due to transportation problems.

The study also concludes that, coffee production and woodland survival in the upland area of the study are so interlinked. It has been realised that once the economic stability of the Matengo, which entirely depends on coffee becomes unstable, landscape changes becomes serious as it was the case between 1990 and 2000 due to the collapse of their local institution (MBICU). It is therefore concluded that, for the Matengo people coffee is like an engine for supporting their livelihoods whereby when it is broken down the woodlands areas becomes conspicuous tool for its maintenance, hence landscape changes increases.

Through this study, it has also been realised that the application of Boserup's model of agricultural intensification is uncertain in the study area, regardless of increase in population growth over the study periods. Her model can only be applicable in the study area when policies are enhanced or enforced, including the presence of favourable environment such as reliable coffee market and improved infrastructure. The lack of alternative income generating activities and farm inputs make extensive farming in the woodland areas as the only way of supporting livelihoods especially in the upland, instead of agricultural intensification.

Moreover, it is concluded that land use planning and environmental management requires information about the dynamics of land use. A model developed by this study helps to understand these dynamics and has enabled projection of near future land use trajectories, which are important for targeting spatial management decisions. This study has therefore shown that the quality of decisions can be improved by using an integrated systems approach, such as a spatial decision support system. The Spatial Decision Support Systems (SDSS) are designed to help decision-makers solve complex spatial problems. This study has therefore demonstrated usefulness of integrating remote sensing, GIS and modeling tools in order to develop spatial decision support system. It is also concluded that this study has helped to understand the proximate causes of landscape changes in the study area. However, application of policy scenarios in the model can help to understand effectiveness of some underlying factors like influence of policies in landscape changes. It is therefore concluded that the use of LIM-CLUES model could be one of the best options in guiding the implementation of Kilimo Kwanza Initiative for attaining a sustainable land use planning in Mbinga district.

5.2 Contributions of the Study in Knowledge Generation

This study has contributed to knowledge generation in a number of ways:

The developed LIM-CLUES model for the predicting ecosystems vulnerability in the Livingstone mountain ranges and its adjacent lowland area paves way for the informed spatial decision making in natural resources management. It has been a common practice that policies related to management of natural resources are formulated without prior spatial information about future conditions that are based on reliable trends of resources utilization. In most cases by-laws and laws have been enacted mostly based on non-spatial future information. The LIM-CLUES model is therefore a spatial-based decision making supporting system. Through the LIM-CLUES model, the use of different business as usual and policy scenarios enables to accommodate crucial aspects that are necessary in sustainable management of natural resources. The study has illustrated the direct use of spatial technologies (remote sensing and GIS) from their conventional use to planning environment. The study has therefore developed a Spatial Decision Support System (SDSS), LIM-CLUES Model for the Mbinga District Authority for the management of the ecosystems in the Livingstone Mountain ranges and its adjacent lowland area.

This study has demonstrated the integration of biophysical and socio-economic factors in the assessment of landscape changes in a spatial manner. This is evident in the logistic regression analysis whereby the study has integrated the land use and cover categories (as independent variables) with biophysical factors such as slope, elevation, aspect (as dependent variables). By doing so, it has been possible to know the spatial influence of the biophysical factors in the location of the land use and cover categories, which has not been common in most cases. Extraction of the spatial components in a GIS such as land use and cover categories, slopes, aspects, elevation, distances to roads and rivers, and population density and integrating them so that could be accessed in the SPSS for performing statistical analysis is also a valuable contribution of this study.

The results from this study have shown that intensification of agricultural land use is not always a result of increase in population growth as established in Boserup's model. Population growth in a study area resulted to expansion of agricultural land rather than intensification due to existence of other factors that were not part of the variables considered by Boserup in her times and environment.

5.3 Recommendations

In view of the above study conclusion, the following recommendations are suggested:

5.3.1 Policy recommendations

i. The results from this study have shown that upland cultivation will continue in areas with less population density and slopes particularly in Kingerikiti and Tingi wards. It is therefore recommended that communities should be encouraged and facilitated by the local government, NGOs and other stakeholders to practice agro-forestry instead of the common tendency of clear felling all natural trees whenever expanding their farming land. A proper agro-forestry system should therefore be developed to promote tree plantation in the study area.

ii. In order to manage the resources sustainably it is important to apply a holistic approach that considers both upland and lowland areas of the study. This is based on the fact that implications of the landscape changes taking place in the upland area due to natural vegetation clearance through human activities had more effects to the lowland areas in terms of influencing destruction of infrastructures (bridges, roads), wetlands, fish breeding sites and siltation in the Lake Nyasa due to excessive flooding waters. Such destructions had serious implications to the livelihoods of the people. Thus, addressing landscape change issues therefore need to consider the entire study area as a whole.

iii. Based on the study findings that there are no reliable cash crops to support livelihoods of communities in the lowland areas along Lake Nyasa, there is need to conduct a research on cash crops that could be introduced in those areas and also assess the possible markets for such crop(s). Lack of reliable cash crop forces people to rely only on the ecosystem services for their livelihoods. This cause unsustainable utilisation of the natural resources thus increasing landscape changes in the study area.

5.3.2 Suggestions for further study

This study has developed a model for predicting ecosystems vulnerability under landscape changes in the Livingstone Mountain ranges and its adjacent lowland areas. Further research is required to enable lessons of this study be used in other areas with similar agro ecological conditions and environmental problems:

i. Some driving forces such as rainfall and soil types could not be used in this study due to lack of availability or where existing in a form that could be applied in this study. It is therefore suggested that future studies need to consider the use of these variables so as to improve the model.

ii. There is need to conduct researches in order to ascertain the communities' opinion that decrease in fish stocks in Lake Nyasa and rivers in the study area has been influenced by increased landscape changes in the Livingstone Mountain ranges.

iii. Simulated results of landscape changes from this study show that future cultivation in the Livingstone Mountain ranges will be extended in areas with less stepness in the upland area. There is need therefore to research on the future application of *ngolo* farming system especially in areas where upland cultivation will be extended because most of these areas are relatively flat hence do not necessarily need the use of *ngolo* cultivation system.

iv. Feasibility studies on the potentiality of the Lake Nyasa in tourism development need to be carried out to establish ways of supporting livelihoods of the people and as alternative source of income particularly in the lowland area. In this regard, Lake Nyasa has beautiful beaches, small islands, fresh and deep water for diving that can be developed as tourist attractions to support livelihoods of the people. However, improved infrastructure including roads, ports, air strips, hotels and communication need be developed to promote tourism development in the area.

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APPENDICES

Appendix 1: Summary of Different LUCC modeling categories and approaches

Model category	Main characteristic	Modeling approach
Empirical-statistical (Chomitz and Gray, 1996; Veldkamp and Fresco, 1996; Mertens and Lambin et al. 2000)	Identify explicit causes of land-use changes Analyses of possible exogenous contributions to empirically-derived rates of changes Predict the pattern of land-use changes Do not establish a causal relationship Regression models are not spatial and perform poorly outside the study area Can not be used for a wide-range of extrapolations Spatial statistical models combine GIS and multivariate statistical models to predict and display future land-use pattern based on formulated assumptions (scenarios)	Multiple linear regression techniques Spatial statistical (GIS-based) models
Stochastic (Thornton and White *et al.*, 1997; Jones,1998; Wu, 1998)	Stochastically describe processes that move in a sequence of steps through a set of states (i.e. an amount of land covered by various types of land-use) Consist mainly of transition probability models (e.g. Markov chains) Advantage of Markov chain analysis lies in its mathematical and operational simplicity Probabilities of transitions are defined for changes from one land-use category to another Only current land-use information is required Can predict when land-use takes place in the short term under a strict assumption of stationarity of the process Can be used when no information on driving forces and mechanisms of land-use changes is available Other forms: spatial diffusion and Cellular automata models	Transition probability models
Optimization (Kaimowitz and Angelsen, 1998;	Mainly applied in economics Uses a general equilibrium models either at the microeconomic level (farm) or at the macro-economic scale Any parcel of land, given its attributes and its location, is modeled as being used in the way that earns the highest rent. Investigate the influence of various policy measures on land	Linear programming Land rent theory

Model category	**Main characteristic**	**Modeling approach**
Irwin and Geoghegan, 2001)	allocation choices Can not be used for prediction because of unpredictable fluctuations of prices and demand factors, and to the role of noneconomic factors driving changes Other forms: Agent-based and behavioural models	of von Thünen and Ricardo
Dynamic (process-based) simulation (Stephenne and Lambin, 2001)	Patterns of land-cover changes in time and space are depicted by the interaction of biophysical and socio-economic processes. Emphasize the interactions among all components forming a system. Condense and aggregate complex ecosystems into a small number of differential equations in a stylized manner. Simulation models are based on an a priori understanding of the driving forces of changes in a system. Process-based models can be parameterized based on local observations of decision making (difficult to deal with scale issue)	Behavioural models and dynamic simulation models Dynamic spatial simulation models
Integrated/Hybrid (Wassenaar *et al.* 1999)	Combine the best elements of different modeling techniques in ways that are most appropriate in answering specific questions Provide useful insights into complex land-use systems since they are developed within the framework of multidisciplinary research teams	Vary according to combined models

Source: Orekan, 2007

Appendix 2: Questionnaire for household heads

SOKOINE UNIVERSITY OF AGRICULTURE

FACULTY OF AGRICULTURE

DEPARTMENT OF FOREST MENSURATION AND MANAGEMENT

A. Household characteristics

Date.......................

Household member **Residence:** Highland=1 Lowland=2	**Sex** Male =1 Female=2	**Age** (Years)	**Marital status** Single=1 Monogamousl married =2 Polygamous married =3 Divorced=4 Widowed=5 Separated=6 Other (specify)=7	**Relationship to the household head** *Head=1* Spouse=2 Son/Daughter= Relative=4 Un-related=5	**Schooling** Attended before=1 Attending now=2 Young to attend=3 Never attended=4	**Number of years of schooling complete** (if attended or is attending school)	**Occupation** Farmer=1 Fisherman=2 Businessman=3 Employed=4 Other (specify)=5

B. Socio-economic issues

1. What properties do the household posses in the study area?

No.	Property	Tick(✓) property(s) owned	Within village=1 outside village=2	Food crop=1, cash crop=2	heading=1, free range=2, zero grz=3 tethering=4
1	Farmland				
2	Livestock				
3	Private woodlot				
4	Houses				
5	Fishing boat				
6	Bicycles				
7	Businesses (shop,				
8	Others, *Mention*				

2. What are the main sources of income?

Activity Type	Tick Appropriate
▪ Farming (Subsistence)	
▪ commercial farming	
▪ livestock	
▪ trade	
▪ public office	
▪ Charcoal Burning	
▪ artisan skill/service	
(i) brick making	
(ii) capentry	
(iii) Fishing	
(iv) weave mats	
others (specify) …	

3. What problems occur when the main economic activities fail to be undertaken?.....

4. What is the income level per month

a) Less than 50,000 b) 31,000 – 50,000 c) 51,000 – 70,000

d) 71,000 – 90,000 e) 1110,000 – 130,000 f) Above 130,000

5. Expenditure per month

a) Less than 30,000 b) 31,000 – 50,000 c) 51,000 – 70,000

d) 71,000 – 91,000 e) 91,000 – 110,000 f) Above 110,000

C. Farm resource allocation and land tenure

6. Types of crops grown, uses, farm location and cultivation system

Crops	Place of sale a) Home use b) Sell to institutions e.g. schools, etc c) Sell locally d) Sell to other traders e) Others (please specify)	How much income from sale (Tshs)	Location (Within village=1, outside village=2)	Cultivation system a) ridges a^1=mounds, a^2=long ridges b) ngolo c)flat seedbed	Size (acres): <1= a, 1-3=b, 4-6=c, 7-9=d, 10-12=e, 12-14=f, >14=g
root/tuber crops e.g. potatoes, cassava					
Cereals e.g. maize, rice, millet, etc					
Bananas					
Legumes/pulses e.g. beans, g'nuts, etc					
Leafy vegetables					
Tree vegetation e.g. coffee					
Fruit					
Other					

7. List the animals owned by the household

	Home use	Sell locally	Sell to other traders
Cattle			
Goats and sheep			
Poultry			
Chicken			
Guinea fowl			
Ducks			
Turkeys			
Pigs			
Fish			
Other			

8. Under what type of tenure do you own your land (tick appropriately)?

i) customary ii) leasehold iii) freehold iv) rented land v) other (specify)

D. Environmental issues

9. What are the roles of local community in natural resources management?............

10. What do you know about landscape changes?...

11. Are there any problems in the lowland areas caused by activities undertaken in the upland areas?

i) Yes ii) No iii) Do not know

12. If yes, what are the problems?..............................

13. Are there any problems in the upland areas caused by activities undertaken in the lowland areas?

i) Yes ii) No iii) Do not know

14. If yes, what are the problems?..............................

15. Which side is more affected by activities from the other?

i) Lowland areas ii) upland areas iii) Do not know iv) None

16. If the answer is (i) or (ii), how?..............................

E. Community perception on landscape changes

17. How do you see the extent of the landscape changes in upland areas?

i) Very serious ii) Serious iii) Not serious iv) Not affected at all

18. How do you see the extent of the problem in lowland areas?

i) Very serious ii) Serious iii) Not serious iv) Not affected at all

19. How communities have been affected by landscape changes?

No.	Problem	Scores*				
		1	2	3	4	5
1	Income decline					
2	Land use conflicts					
3	Scarcity of land for farming					
4	Scarcity of land for grazing					
5	Scarcity of firewood					
6	Soil erosion					
7	Increased unfertile land					
8	Collapse of infrastructures (roads, bridges)					
9	Drying wetlands					
10	Change in river regime					
11	Siltation of Lake Nyasa (destruction to aquatic environment)					
12	Others, *mention*					

Scores:-1. Very serious, 2. Serious, 3. Moderate, 4. Not serious, 5. Not applicable*

20. Between which period did the problems of landscape changes started

i) 1-5 years ago ii) 5-10 years ago iii) More than 10 years ago iv) No problem

21. What factors influence landscape change?

22. What are the implications of landscape changes on people's livelihood...........

23. Are there any collective efforts among community members to reduce effects of landscape changes?

i) Yes ii) No iii) Do not know

24. If yes, what are the efforts?...

25. Do natural disasters happen?

i) Yes ii) No

26. Types of natural disasters that have occurred in the past 15 years

27. What were the effects caused by natural disasters?..

28. Are there natural resources degradation resulting from landscape changes?

    i) Yes ii) No iii) Do not know

29. If yes, how?...

F. Resource management issues

30. What are the collective efforts among community members to reduce effects of landscape changes?...

31. Name organizations that are dealing with natural resource management?

No	Name of organization	Activities performed in the area	Year started
1			
2			
3			
4			

32. Do you know the activities undertaken by such organizations?

    i) Yes ii) No

33. How these organizations collaborate with local communities?

    i) Awareness creation

    ii) Training

    iii) Providing support (loans, grants)

    iv) Establishing links and networks with other actors

34. Do farmers participate in decision making concerning natural resources use?

    i) Yes ii) No iii) Do not know

35. If yes, how..

36. Have you shifted from what you were doing before as a result of the influence of landscape changes? For example, agriculture to petty business?

i) Yes, from agriculture to petty business

ii) Yes, from petty business to agriculture

iii) Yes, from agriculture to fishing

iv) Yes, from fishing to agriculture

v) Yes, but currently I have nothing to do

vi) Not at all

vii) Others (mention)……………………..

37. What type of farming system were you practicing before?

38. What type of farming system are you practicing now?

    i) Ngolo

    ii) Ridges

    iii) None

    iv) Flat seedbed

    v) Other (mention)………………

39. If different from the previous farming practice, why changed?................

40. If yes, why?...

41. If no, why?...

42. Is there any importance of collective efforts in solving problems of landscape changes?

    i) Yes   ii) No   iii) Do not know

43. If different from the previous farming practises, why changed?

44. If yes, why…………………………………………………

45. If no, why………………………………………………..

Appendix 3: Checklists for FGDs and in-depth interviews

CHECKLIST FOR FOCUS GROUP DISCUSSIONS WITH VILLAGERS

1. What are the main economical activities?
2. Do you have farms outside your village?
3. Why are you farming outside your village?
4. Have there been landscape changes in the past 15 years?
5. Which animals used to be in the forests but are no longer found? Why?
6. Which fish used to be in the lake and rivers but are no longer found? Why?
7. What are the factors influencing/causing landscape changes?
8. What are the implications of landscape changes on people's livelihood?
9. Have the landscape changes caused food shortages, how?
10. Do you experience scarcity of grazing land resulting from landscape changes, how?
11. What are the other problems resulting from landscape changes?
12. Do you experience decrease in income resulting from landscape changes, how?
13. Is the Lake Nyasa potential for tourism to support your income?
14. What is the *ntambo* land use management system?
15. Do you use *ntambo* in you farming practices?
16. What land use management system could suit in the Livingstone Mountains and its lowland areas?
17. Have you experienced natural disasters due to landscape changes?
18. What natural disasters that have occurred in the past 15 years?
19. How did people get affected by such natural disasters?
20. Which side of the land is more affected by such activities-highland or lowland?
21. What are the collective efforts among community members to reduce effects of landscape changes?

22. How many organizations are dealing with natural resources management?
23. Are there any problems caused by activities undertaken in the mountainous areas, how?
24. Are there any problems caused by activities undertaken in the lowland areas, how?
25. What measures have you taken regarding landscape changes?

CHECKLIST FOR FOCUS GROUP DISCUSSIONS WITH VILLAGE GOVERNMENT

1. What is the total population in the village?
2. How many households *(kaya)* in the village?
3. What are the main economic activities for the local communities in this village?
4. Which animals used to be in the forests but are no longer found? Why?
5. Which fish used to be in the lake and rivers but are no longer found? Why?
6. Is the Lake Nyasa potential for tourism developemnt to support community's income?
7. What are the landscape changes observed in the area in the past fifteen (15) ten years?
8. How do community members participate in natural resource management activities?
9. What problems do you experience working with the local community in natural resources management?
10. Are there village members who are farming outside their village?
11. If yes for the above question number 2, why and since when?
12. Are there people from other villages coming to farm in your village? If yes, since when?
13. Why are people coming to farm in your village?
14. What are the conditions of acquiring land in the village?

15. Are your villagers' members of any SACCOS? Mention its name
16. What are control mechanisms available for good land husbandry for in-comers (distant farmers)?

CHECKLIST FOR IN-DEPTH INTERVIEWS WITH DISTRICT NATURAL RESOURCES OFFICER (DNRO)

1. What are the main uses of forest products in the district?
2. Have the availability of forest products being affected due to landscape changes?
3. What is the status of land degradation in the district?
4. What are the factors influencing/causing land degradation in the district?
5. How do you engage local communities in afforestation programmes?
6. Do community members have private woodlots?
7. What are the main landscape changes taking place in the upland areas?
8. What are the main landscape changes taking place in the lowland areas?
9. Is there any impact in the lowland area caused by landscape changes in the upland area?
10. What are implications of landscape changes in the upland and lowland areas?
11. What are the existing natural resources management/conservation projects undertaken in the study area?
12. How do community members engaged in natural resources management programs?
13. How many organizations are dealing with natural resources management?
14. What problems do you experience working with local communities in natural resources management?
15. Is the Lake Nyasa potential for tourism development to support community's income?

CHECKLIST FOR IN-DEPTH INTERVIEWS WITH DISTRICT AGRICULTURAL DEVELOPMENT AND LIVESTOCK OFFICER

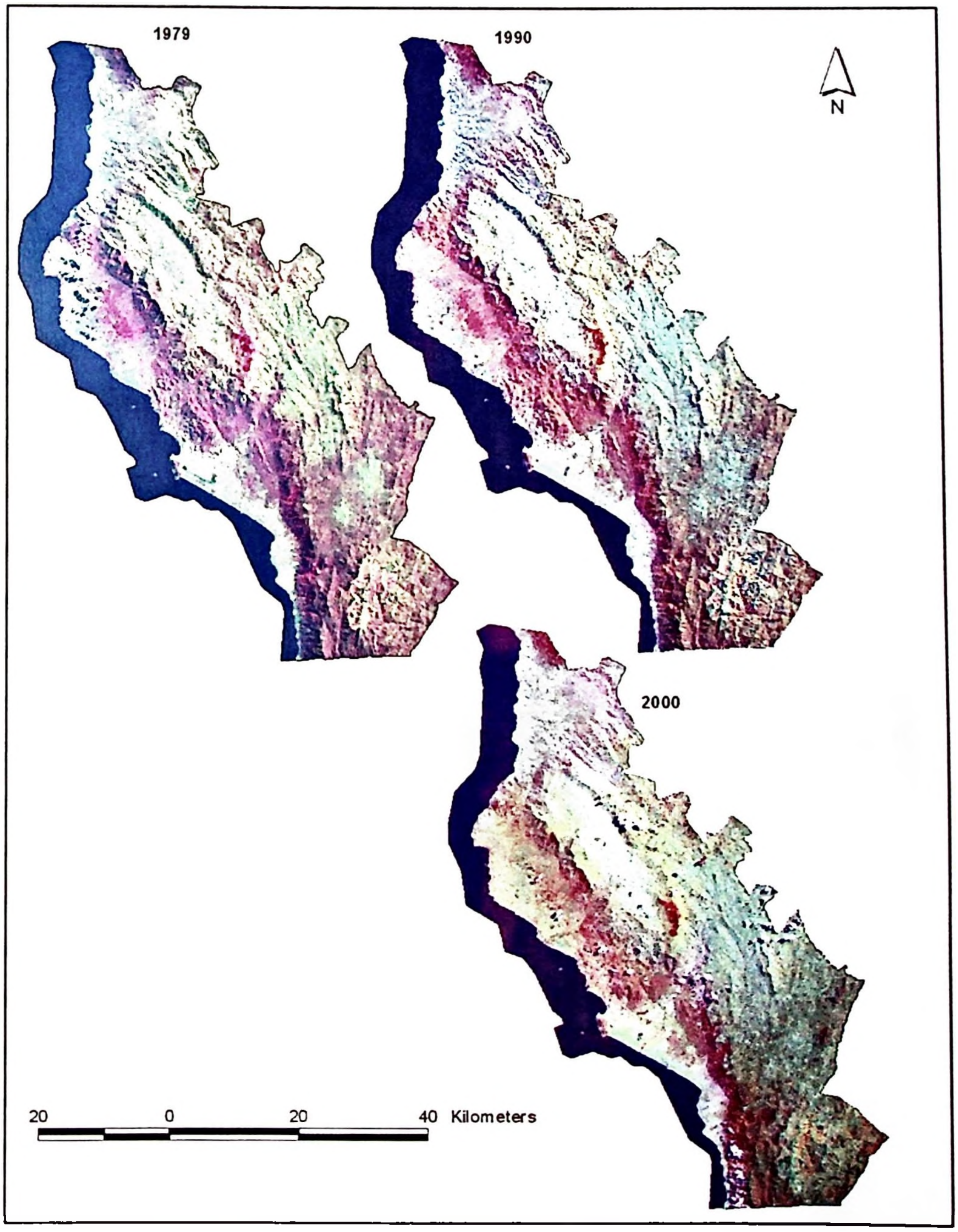
1. What are the main cash and food crops grown in the area?
2. Have the changes in the landscape affected people's livelihood?
3. What are the main economical activities of the local communities in the mountainous and lowland areas
4. Are there different crops introduced in the past ten years in the mountain or lowland areas?
5. Who introduced them?
6. What is the trend of crop harvests in Mountain areas for the past ten years – increased or decreased?
7. What is the trend of crop harvests in lowland areas for the past ten years? Has it increased or decreased?
8. What are the farming systems employed in the district?
9. Are there differences in the farming systems practiced in the mountain and lowland areas?
10. If yes for Q7, are they different between mountainous and lowland areas?
11. How are farming systems related to environmental management and conservation?
12. Do you perceive soil fertility change problems in the area?
13. If yes Q10, has fertility increased or decreased?
14. Are there any types of indigenous knowledge used in the farming systems?
15. Do farmers get subsidies from the government?
16. What land use management system that could suit in the Matengo Highlands?
17. Have there been changes in the prices of crops that affected farmer's income?
18. If farmers experience scarcity of farming land resulting from landscape changes, why?

19. What are the main types of livestock kept by local communities?
20. If farmers experience scarcity of grazing land resulting from landscape Changes, why?
21. If farmers experience decrease in income resulting from landscape changes, how?
22. What are the implications of landscape changes on people's livelihood?
23. What problems do you experience working with local communities in natural resources management in both mountainous and lowland areas?
24. Are there any conflicts between agriculturalist and fishers or others?

CHECKLIST FOR IN-DEPTH INTERVIEWS WITH DISTRICT COOPERATIVES AND MARKETING OFFICER (DCMA)

1. What is the trend of coffee production (increase / decrease) in the past ten (15) years?
2. Have there been changes in the prices of coffee that affected farmer's income? How?
3. Are there any impacts/effects resulting from introduction of trade liberalization of coffee market that brought in private coffee buyers?
4. Do farmers use chemical fertilizers in coffee production?
5. What were the kinds of assistance given to farmers by MBICU during its existence?
6. How do farmers get farming inputs given that MBICU do no longer exist?
7. How coffee farming practise related to environmental management and conservation?
8. Have there been altitudinal changes by farmers towards coffee growing that resulted from changes in coffee prices, how?
9. If yes for Q8, how has such altitude change affected the landscape?

Appendix 4: Landsat scenes of years 1979, 1990 and 2000 used in the study



Appendix 5: Conversion Matrices

Business as usual scenario (Demand1)

1	0	1	0	0	0	0
0	1	1	0	0	0	0
0	0	1	0	0	0	0
0	0	0	1	0	1	0
0	0	0	0	1	1	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

First Policy scenario (Demand2)

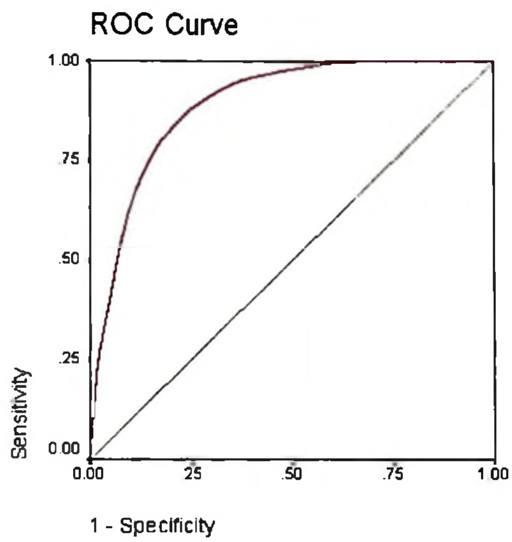
1	0	0	0	0	0	0
0	1	0	0	0	0	0
1	1	1	0	0	0	0
0	0	0	1	0	1	0
0	0	0	0	1	1	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

Second Policy scenario (Demand3)

1	0	0	0	0	0	0
0	1	0	0	0	0	0
1	1	1	0	0	0	0
0	0	0	1	0	1	0
0	0	0	0	1	1	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

Appendix 6: Relative Operating Characteristic Curves (ROC)

Upland bushland with scattered cropland

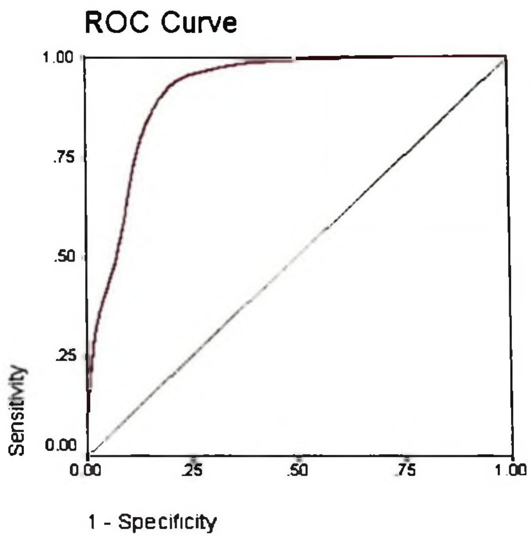


Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.890

Upland cultivation

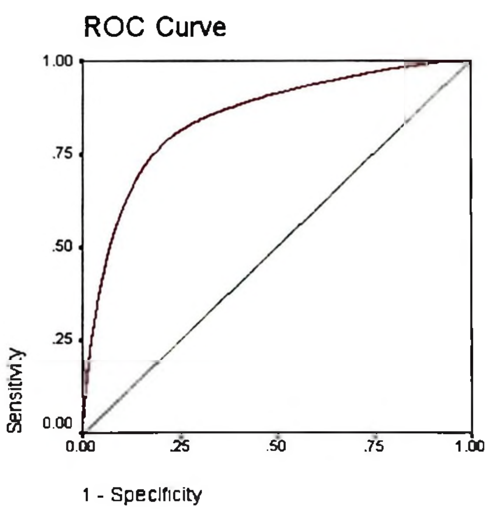


Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.914

Upland woodland

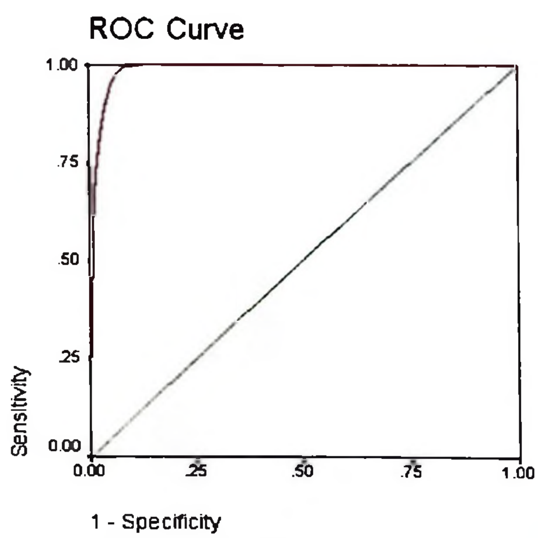


Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.846

Lowland bushland with scattered cropland

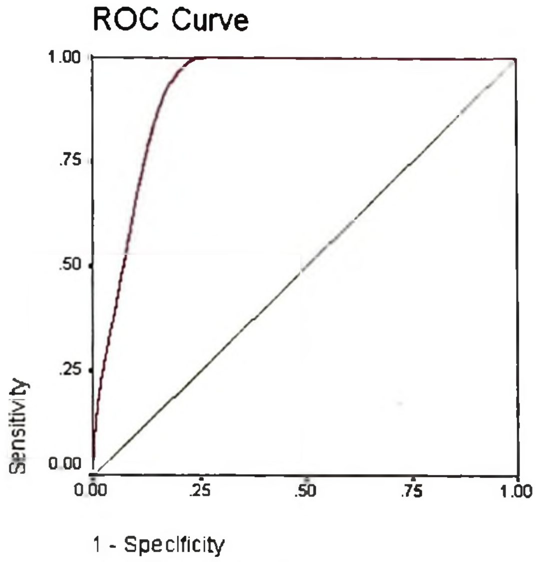


Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.986

Lowland woodland

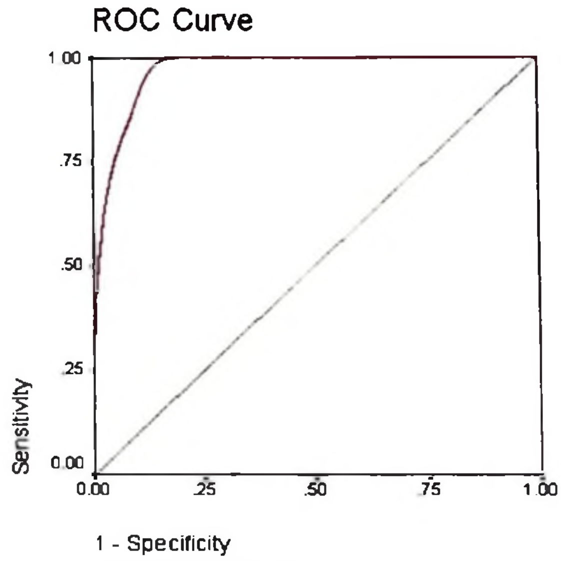


Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.921

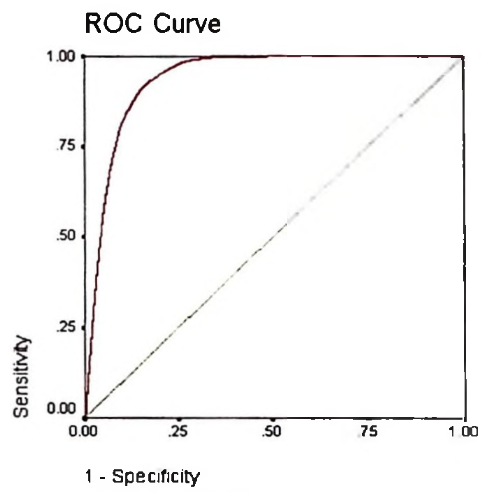
Lowland grassland with scattered cropland



Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.969



Area Under the Curve

Test Result Variable(s): Predicted probability

Area
.937

Others

Appendix 7: Demand Tables

Demand 1 (Business as usual scenario)

49561	47093	84627	24021	12292	19562	10104
47561	45393	88327	23373	12108	20394	10104
45561	43693	92027	22725	11924	21226	10104
43561	41993	95727	22077	11740	22058	10104
41561	40293	99427	21429	11556	22890	10104
39561	38593	103127	20781	11372	23722	10104
37561	36893	106827	20133	11188	24554	10104
35561	35193	110527	19485	11004	25386	10104
33561	33493	114227	18837	10820	26218	10104
31561	31793	117927	18189	10636	27050	10104
29561	30093	121627	17541	10452	27882	10104
27561	28393	125327	16893	10268	28714	10104
25561	26693	129027	16245	10084	29546	10104
23561	24993	132727	15597	9900	30378	10104
21561	23293	136427	14949	9716	31210	10104
19561	21593	140127	14301	9532	32042	10104
17561	19893	143827	13653	9348	32874	10104
15561	18193	147527	13005	9164	33706	10104
13561	16493	151227	12357	8980	34538	10104
11561	14793	154927	11709	8796	35370	10104
9561	13093	158627	11061	8612	36202	10104

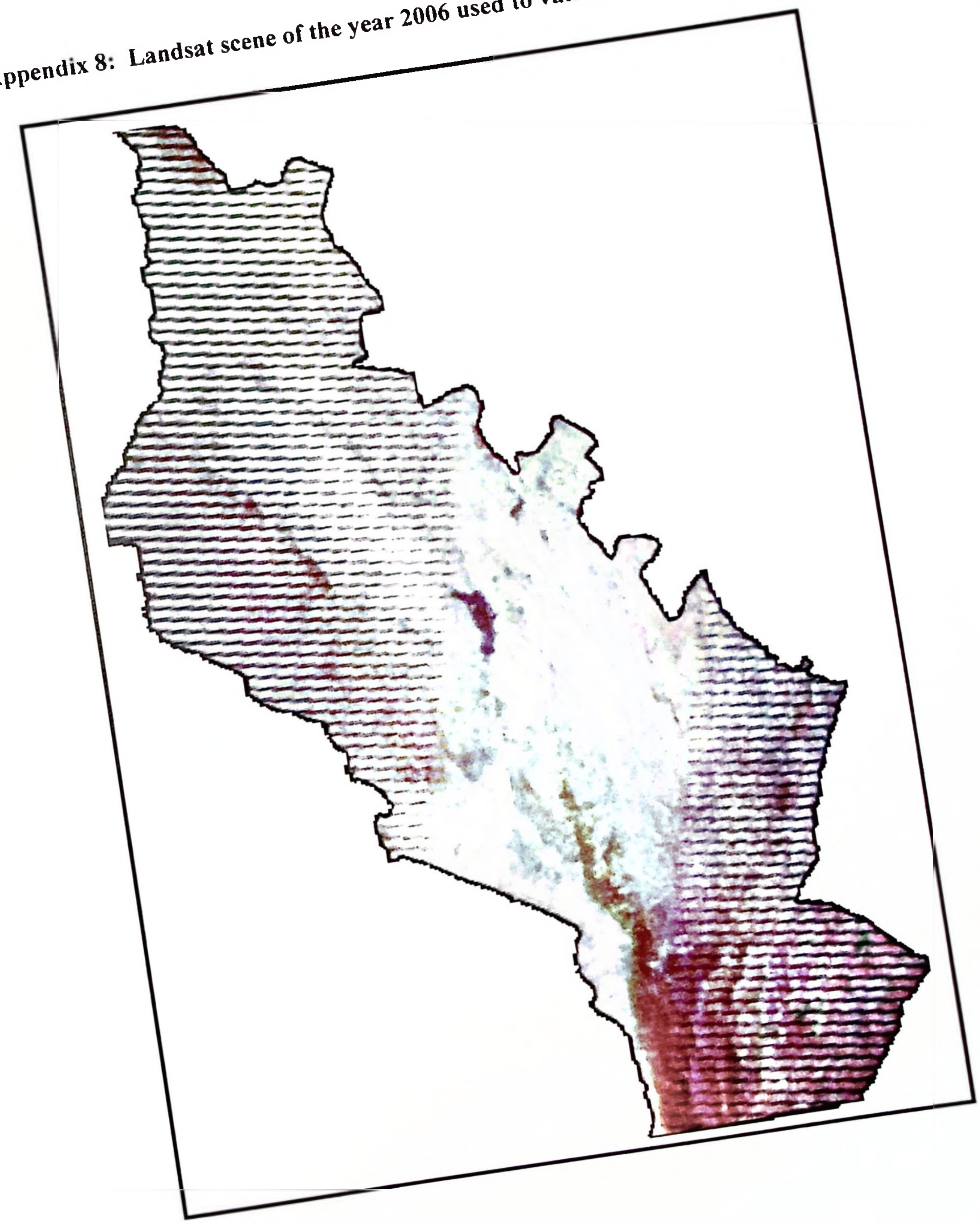
Demand 2 (Policy Scenario)

49561	47093	84627	24021	12292	19562	10104
50261	48093	82927	23425	12151	20299	10104
50961	49093	81227	22829	12010	21036	10104
51661	50093	79527	22233	11869	21773	10104
52361	51093	77827	21637	11728	22510	10104
53061	52093	76127	21041	11587	23247	10104
53761	53093	74427	20445	11446	23984	10104
54461	54093	72727	19849	11305	24721	10104
55161	55093	71027	19253	11164	25458	10104
55861	56093	69327	18657	11023	26195	10104
56561	57093	67627	18061	10882	26932	10104
57261	58093	65927	17465	10741	27669	10104
57961	59093	64227	16869	10600	28406	10104
58661	60093	62527	16273	10459	29143	10104
59361	61093	60827	15677	10318	29880	10104
60061	62093	59127	15081	10177	30617	10104
60761	63093	57427	14485	10036	31354	10104
61461	64093	55727	13889	9895	32091	10104
62161	65093	54027	13293	9754	32828	10104
62861	66093	52327	12697	9613	33565	10104
63561	67093	50627	12101	9472	34302	10104

Demand 3 (Policy Scenario)

49561	47093	84627	24021	12292	19562	10104
47861	47093	86327	23425	12151	20299	10104
46161	47093	88027	22829	12010	21036	10104
44461	47093	89727	22233	11869	21773	10104
42761	47093	91427	21637	11728	22510	10104
41061	47093	93127	21041	11587	23247	10104
39361	47093	94827	20445	11446	23984	10104
37661	47093	96527	19849	11305	24721	10104
35961	47093	98227	19253	11164	25458	10104
34261	47093	99927	18657	11023	26195	10104
32561	47093	101627	18061	10882	26932	10104
30861	47093	103327	17465	10741	27669	10104
29161	47093	105027	16869	10600	28406	10104
27461	47093	106727	16273	10459	29143	10104
25761	47093	108427	15677	10318	29880	10104
24061	47093	110127	15081	10177	30617	10104
22361	47093	111827	14485	10036	31354	10104
20661	47093	113527	13889	9895	32091	10104
18961	47093	115227	13293	9754	32828	10104
17261	47093	116927	12697	9613	33565	10104
15561	47093	118627	12101	9472	34302	10104

Appendix 8: Landsat scene of the year 2006 used to validate the model



Appendix 9: LIM-CLUES Model User Manual

1.0 INTRODUCTION

The Livingstone Mountain (LIM) Conversion of Land Use and its Effects (CLUE) model has been developed specifically for the Livingstone Mountain ranges and its adjacent lowland areas in Mbinga district, Tanzania. Development of the LIM-CLUES was based on the Dyna-CLUES modeling framework. The Dyna-CLUES modeling framework (Veldkamp and Fresco, 1996; Verburg *et al.,* 1999a) is an engine developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modeling of competition between land use types. For details on the CLUES modeling framework, visit www.cluemode.nl. Therefore, different biophysical and socio-economic factors have been used in the development of the LIM-CLUES model. These factors are elevation, slope, aspect, distance to road, distance to river, and population density. In addition, the land use and cover changes were analyzed from Landsat MSS (1979), TM (1990), and ETM+ (2000). The detected land use and cover changes were also used to determine other input parameters for the model. Thus, the analyzed primary, secondary and remotely sensed data enabled to establish input parameters and scenarios used for developing the LIM-CLUES model.

1.1 The Livingstone Mountain Ranges

The Livingstone Mountain Ranges lie between longitude 34°38'E and 35°06'E and latitude 10°30'S and 11°34'S. The Livingstone Mountain ranges stretch from the north-western parts of Mozambique, crossing the border into the southern part of Tanzania. In Tanzania the Livingstone Mountain Ranges stretch further northwards from Mbinga District in Ruvuma Region through Ludewa and Kyela Districts in Iringa and Mbeya regions respectively. For the development of the LIM-CLUES model, only part of the Livingstone mountain ranges in Mbinga district has been considered in the study. In Mbinga District the Livingstone Mountain Ranges cover about 460km^2, comprising about 4% of the total land area of the District. Steep mountain slopes covered with woodlands and tracks of cultivated land characterize the area. The land surrounding the high mountains slopes to the Lake Nyasa, in the lowland area, and is mainly used for agricultural and residential activities. For modeling purpose, the spatial resolution of 100 × 100 meter is used. Six different land use and cover types are distinguished for simulation as shown in the last section (Table 1).

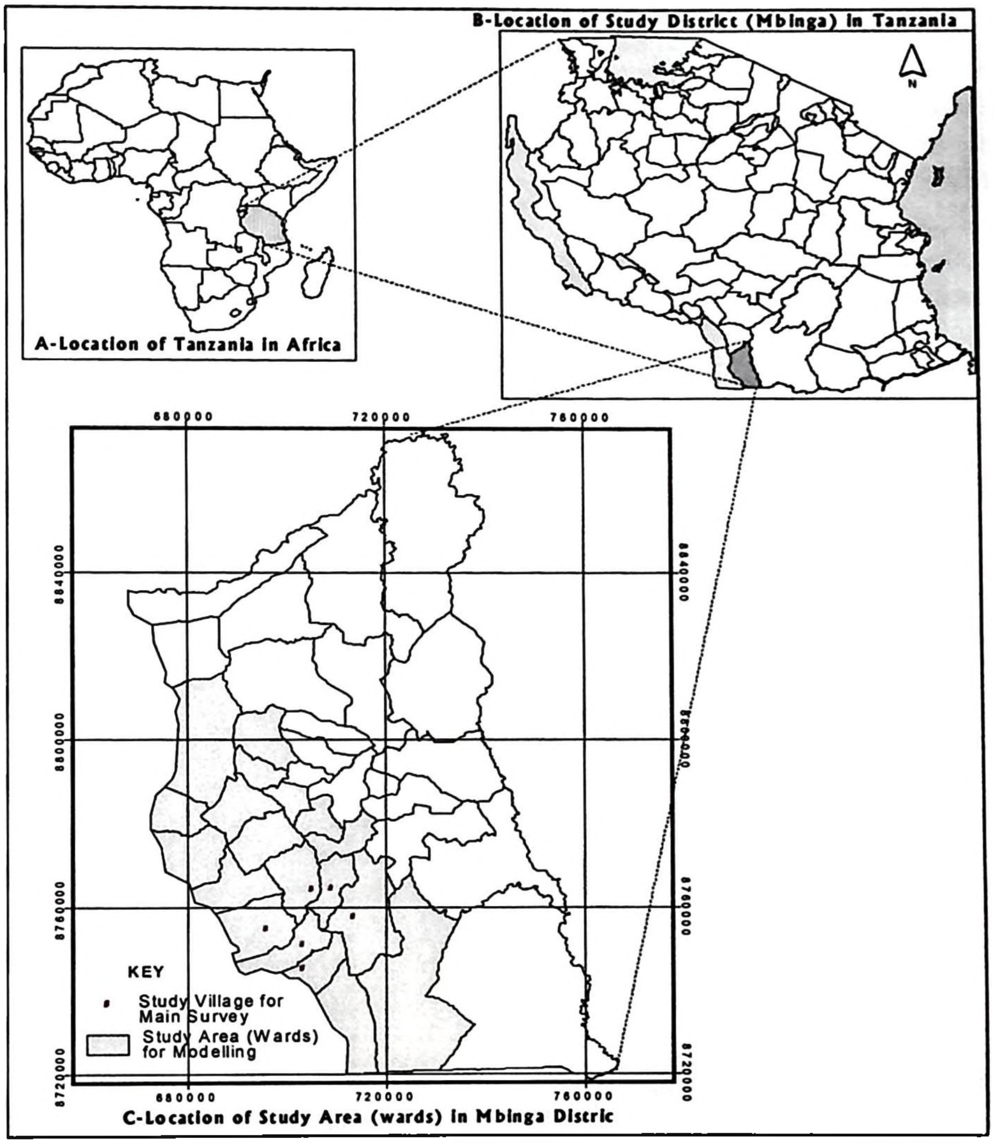


Figure 1: Map showing location of the study area (Livingstone Mountain ranges)

2. SCENARIOS USED TO DEVELOP THE MODEL

Three different scenarios have been used in the development of the LIM-CLUES Model for the period from 2001 to 2020. Therefore, there are three demand or land requirement files (demand1, demand2 and demand3). Four different files with land requirements (demand). The land requirements defined in the three scenarios are as summarized below.

2.1 Business as usual scenario

In this scenario it is assumed that the trends of deforestation and general vegetation clearance observed between 1990 and 2000 will continue until the year 2020. This implies that there will be an increase in the expansion of cultivated land at the expense of woodland and other natural vegetations. This assumption is captured in the land requirement file **demand1**.

2.2 Policy scenario 1

This policy scenario considers that the Mbinga district authority will target at reducing at least half of the area that was under cultivation by the year 2000. Therefore cultivation will be directed in the areas identified as *bushland with scattered cropland* in the land use and cover types used in this study. This policy aims at encouraging people to practice more agro-forest rather than clear felling, hence allowing woodland regeneration to take place in areas previously under cultivation. This scenario is represented in the **demand2** file.

2. 3 Policy scenario 2

This policy scenario is a follow-up of the Urgent Strategy on *Land Conservation and Water Catchments* issued by the Vice President's office in the year 2004. In this scenario therefore, all the areas which were covered by woodland in the year 2000 are intended to be recovered. Most of these areas are located in higher altitudes along steep slopes of the Livingstone Mountain ranges. Basically, these are catchments areas. This scenario is represented in the **demand3** file.

3. INSTALLING LIM-CLUES

The LIM-CLUE model is supplied in a CD or other removable devices. To install LIM-CLUES on your computer, double click the *"autorun"* file from the explorer. The user-interface (Figure 2) should appear on the screen

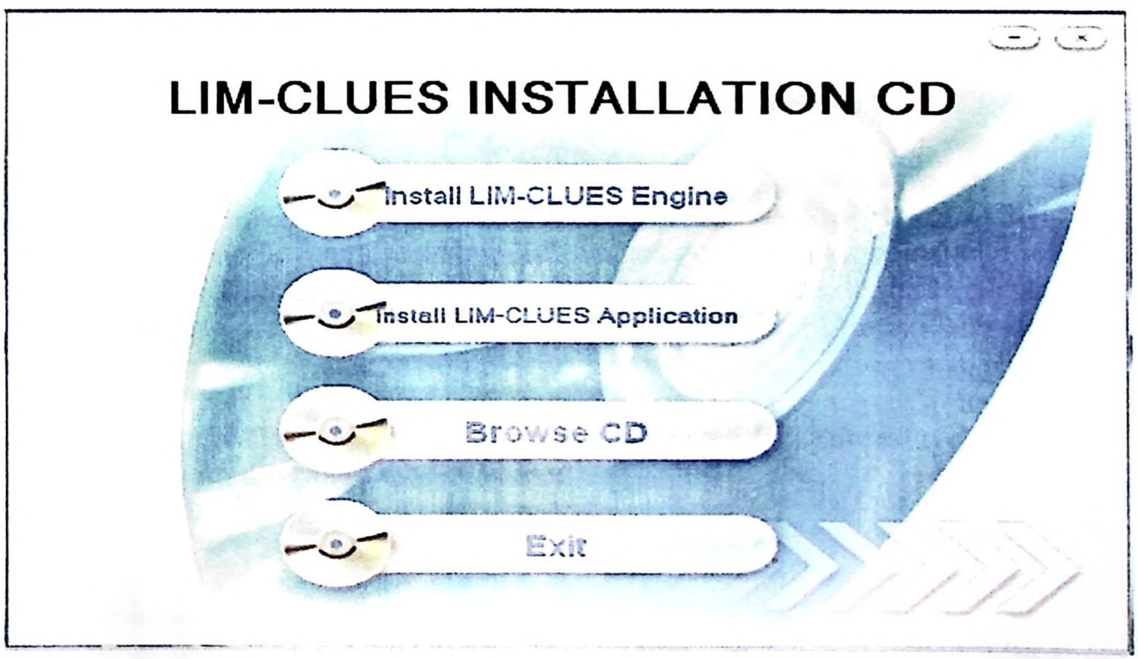


Figure 2: LIM-CLUES Installation interface

It is important to note that LIM-CLUES runs under the Dyna-CLUES engine. Therefore, you first of all install the LIM-CLUES Engine (that implies the Dyna-CLUES modeling framework) and then the LIM-CLUES application. All necessary files will be located in the installation directory you have specified.

LIM-CLUES can be started in two different ways:
Click Start | Programs | LIM-CLUE Model
Open the directory where CLUE-S is installed with explorer and double-click 'LIM -CLUES' LIM_CLUES

The user-interface (Figure 3) should appear on the screen

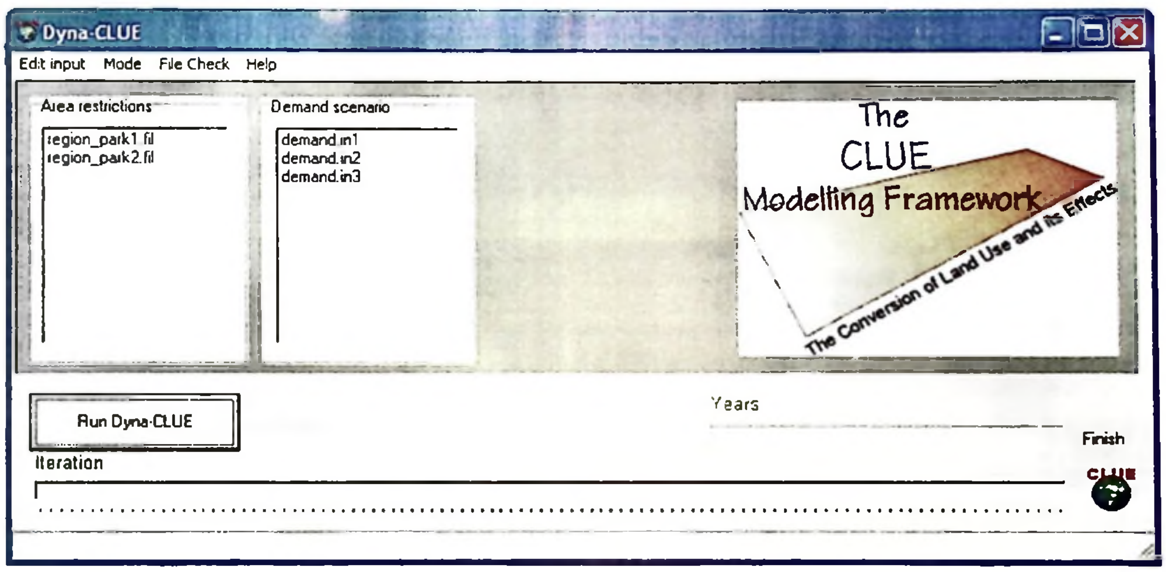


Figure 3: User Interface of the CLUE-S model

4. MAIN FUNCTIONS

Through the user interface, editing of the main parameter file can be done using built-in text editor. It is also possible for the user to choose the scenario conditions. The details of scenarios used in this study are specified in the Makota (2011)[1]. Before start simulating the land use and cover changes one file must be selected from *Area restricted* and *Demand scenario* windows, based on the intended simulation according to specified scenarios. Simulation can be started after making sure that all parameters are set. In order to start simulating the land use and cover changes click the 'Run CLUE-S' button. Simulated results need to be saved to any selected folder, using a selected name. The saved file can be imported in a GIS in order to display the simulated results from the LIM-CLUES Model.

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[1] - Predicting ecosystems vulnerability under landscape changes in Livingstone Mountain ranges of Mbinga district, Tanzania. (2011). PhD Thesis, Sokoine University of Agriculture, Morogoro, Tanzania. 285pp.

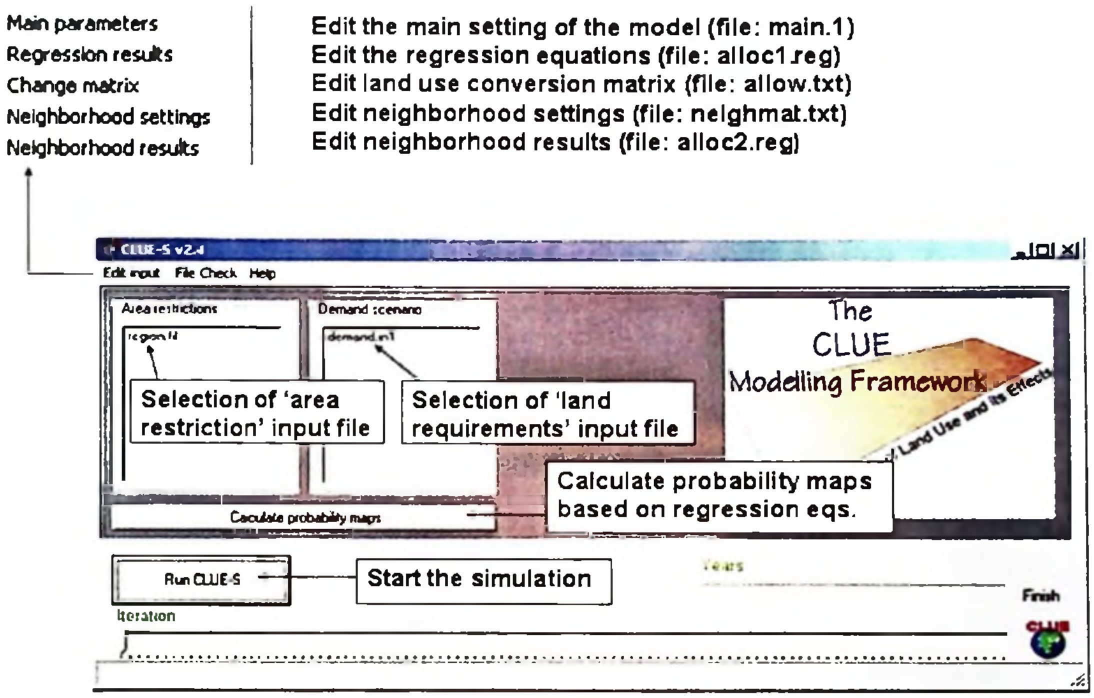

Figure 4: Explanation of the CLUE-S interface

5. START THE SIMULATION

First, select one of the files from *'area restriction'* as an input file. There area 2 different files shown in the restriction area in the LIM-CLUES model. The 'area restriction' file indicates which cells of a rectangular grid are part of the case-study area and can also contain information on the locations that belong to an area with restrictions to land use conversion, e.g. a natural park.

Second, select one file from the demand scenario window. This is a *'land requirements'* (demand) input file. The 'land requirements' file contains the required area of each land use and cover types that need to be simulated for each year. In the LIM-CLUES model there are three different land requirement files (demand) based on the scenarios used in the study.

Selection of area restrictions input file
Selection of land requirements input file
Start the simulations

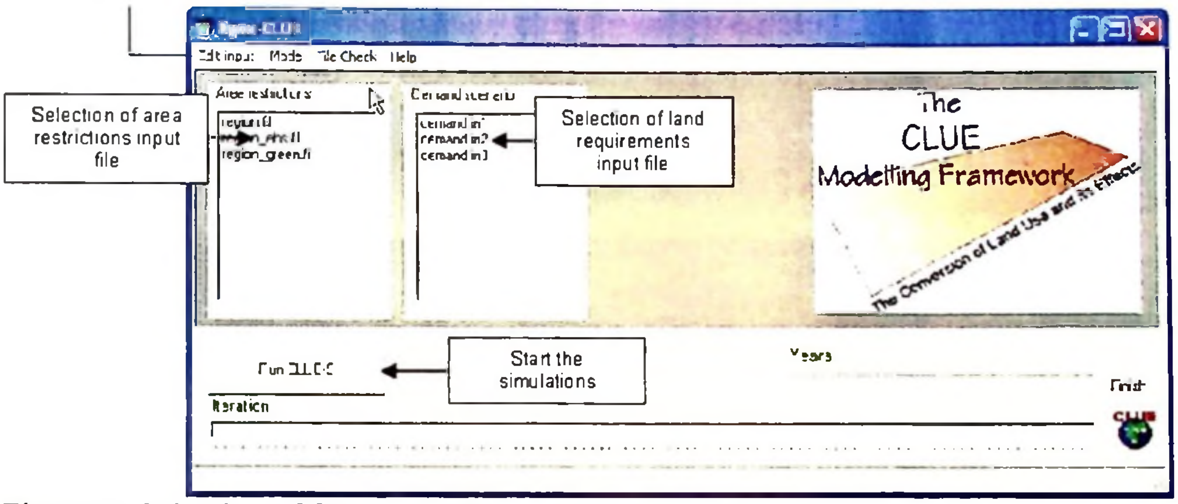

Figure 5: Selection of files to run the model

Next step is to click 'Run CLUES'.
The simulations will now start and the status bars show the progress (Figure 6)

NOTE: The status-bar for the iterative procedure (Figure 6) shows the average difference between the allocated area of the different land use types and the required allocation of the different land use types. The simulation of one year is finished if the allocated area deviates less than the specified maximum allowed deviation. Only when one of the land use types exceeds the specified maximum deviation between allocation and requirements for one of the land use types the iterations will continue and a special indicator will appear on the screen.

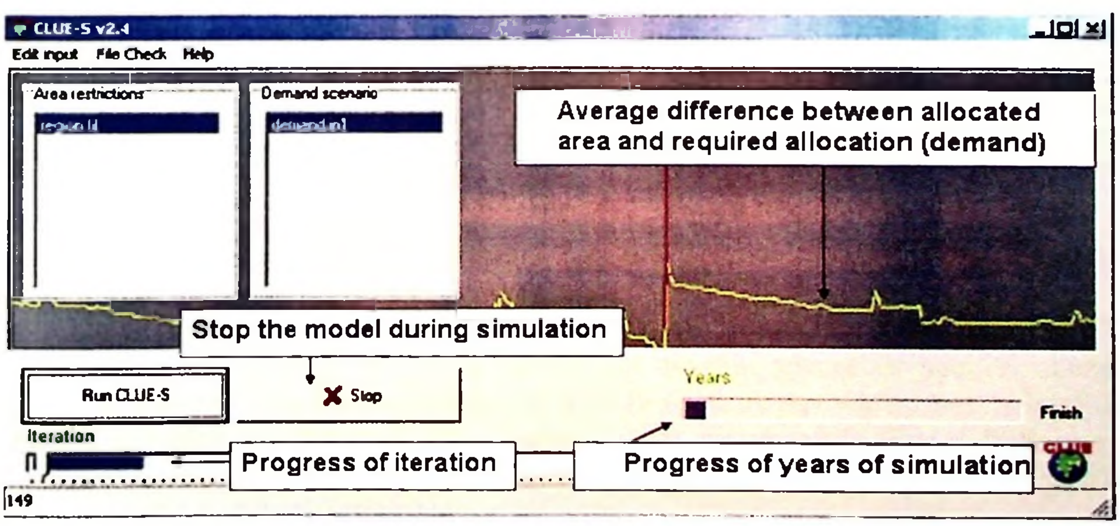

Figure 6: Status of simulated results

6. END OF THE SIMULATION

When all simulations are made successfully the model will display the message 'finished' and a button that gives access to the LOG-file will appear (Figure 7). The log file contains information on the input files and run-time information on the iterations and may be consulted when errors occur or unexpected results are found.

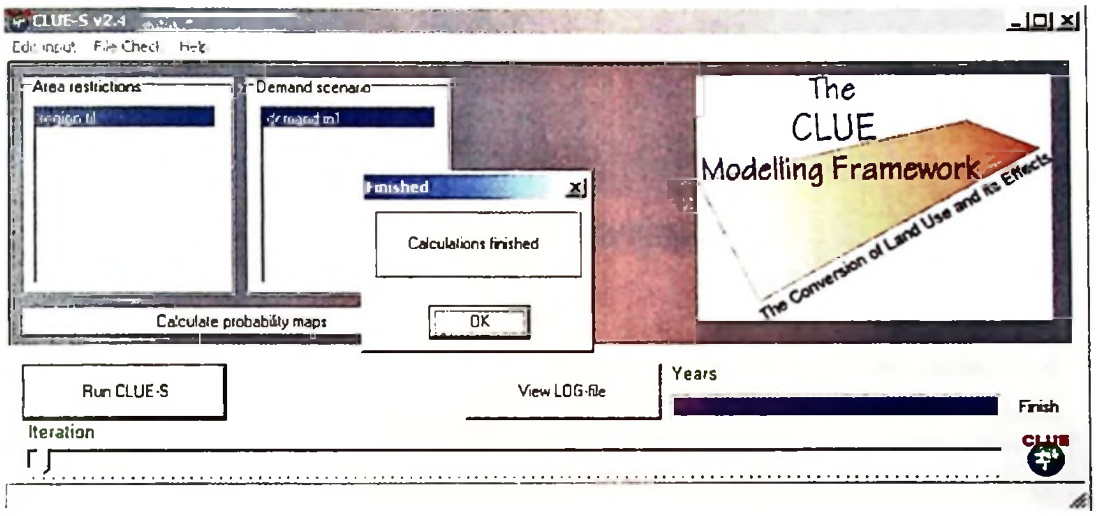

Figure 7: Interface after finishing the simulation

7. DISPLAY OF SIMULATION RESULTS

In order to display simulated results, you have to access them from LIM-CLUES directory. All simulated results are saved in the installation directory that you had specified. A GIS package is therefore needed to display the simulated results. In the LIM-CLUES model, explanations are provided for the ArcView 3.x software.

Use of ArcView 3.x

Start ArcView and make sure that the Spatial Analyst extension is installed and activated: File | Extensions | Check 'Spatial Analyst' | OK

Open a new View by selecting 'Views' from the project window and click the 'New' button.

Import the file with simulation results that you want to display: File | Import Data Source. Select import file type: ASCII Raster | OK.

Select the file with simulation results. Go to the installation directory of LIM-CLUE-S. **Note**: the installation directory should not contain spaces or special characters, since this might disturb the import of ASCII files in ArcView. Set 'List Files of Type:' at 'All Files (*.*)'. The simulation results are stored in files called: cov_all.* where * indicates the year after the start of the simulation. Select the file you want, e.g. cov_all.12 and click 'OK'.

Specify a name and directory where you want to store the resulting grid, e.g., YEAR12.

The program will prompt: 'Cell values as integers?'. Click: 'Yes'.

The program will prompt: 'Add grid as theme to the View?'. Click: 'Yes'.

The result of the simulation can now be seen on the screen and analysed using ArcView (Figure 8).

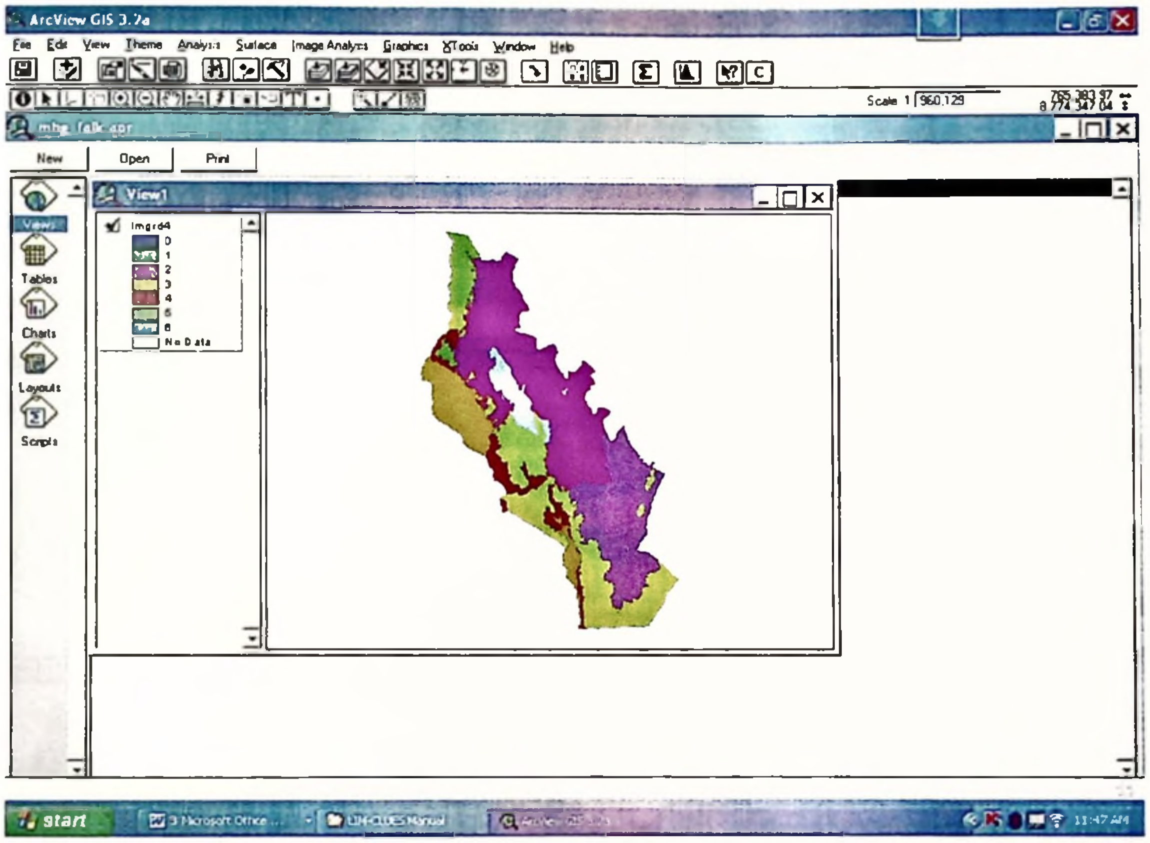

Figure 8: Simulation result displayed in ArcView

It is now possible to change the graphical presentation by changing the colors of the map into color that are easily associated with the different land use type.

Therefore, colors of a simulated map can be changed using the color palette according to how each category is associated to a land use type. Area of each land use and cover type can be displayed by clicking the attribute table botton from the ArcView software. In order to know the name of land use type you need to associate the codes displayed from a simulated map with specific names as shown in the Table 1.

Table 1: Codes used to represent Land use and cover types in the model

Land use type	Code used in the model
Upland bushland with scattered cropland	0
Upland woodland closed	1
Upland cultivation	2
Lowland bushland with scattered cropland	3
Lowland woodland closed	4
Lowland grassland with scattered cropland	5
Others	6

8. IMPLEMENTATION OF THE MODEL BASED ON SCENARIOS

Implementation of the model can be run based on the detailed procedures mentioned above. Therefore, in order to run the model based on scenarios developed, follow the combination of region_park and demand files as explained below.

8.1 Business as usual scenario

In order to run the model for the business as usual scenario, select ***region_park1*** under restricted window and ***demand1*** in the demand scenario window.

8.2 Policy scenario 1

In order to run the model for the policy 1 scenario, select ***region_park1*** under restricted window and ***demand2*** in the demand scenario window.

8.3 Policy scenario 2

In order to run the model for the policy 2 scenario, select ***region_park2*** under restricted window and ***demand3*** in the demand scenario window.

Note

Maps showing years of simulated results are in cov_all.* files, stored in LIM-CLUES installation directory. This symbol * therefore represents number of a respective year of simulation. e.g. cov_all.12, means simulated map for the year 2012.