THE DEVELOPMENT AND APPLICATION OF A COMPREHENSIVE LAND DEGRADATION ASSESSMENT METHOD IN THE MONDULI DISTRICT, TANZANIA

BY

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CONTENTS

	Page
ABSTRACT	II
ACKNOWLEDGEMENTS	III
CONTENTS	V
LIST OF FIGURES	X
LIST OF TABLES	XIII
LIST OF PLATES	XV

Chapter one: Introduction

1.1 General introduction and Rationale behind this study	1
1.2 Land degradation in Tanzania	5
1.3 Aim and objectives of the study	6
1.3.1 Specific objectives	6
1.4 Working hypothesis and structural outline	7
1.4.1 Working hypothesis	7
1.4.2. structural outline	7

CHAPTER TWO: DEFINITIONS, PROCESSES, CAUSES AND CONCEQUENSES OF LAND DEGRADATION; A THEORETICAL OVERVIEW

2.1 An introduction to the concept of land degradation	8
2. 2 Definitions and changing perceptions of land degradation	10
2.3 Land degradation in the context of this research project	12
2.4 Drylands Characteristics	13
2.5 Processes of land degradation	16
2.5.1 Vegetation degradation	17
2.5.2. Soil degradation	21
2.6 Causes of land degradation, an overview	28
2.6.1 Anthropological causes	29
2.6.2 Natural causes	34
2.7 Socio-economic consequences of land degradation	37
2.7.1 On-site adverse effects on crop yields	38
2.7.2 Off-site effects	38
2.7.3 Financial costs of land degradation	39
2.8 Political ecology aspects of land degradation	40
2.9 Summary	43

CHAPTER THREE: LAND DEGRADATION ASSESSMENT METHODS, AN OVERVIEW

3.1 Introduction 46
3.2.Challenges in assessing land degradation 49
3.3 Land degradation indicators 52
3.4 Land degradation assessment methods 52
3.4.1 Methods for assessing climate variability and distribution 55
3.4.2 Soil degradation assessment methods 56
3.5 Remote sensing 62
3.5.1 Application of remote sensing in meteorology 64
3.5.2 Application of remote sensing in vegetation degradation 66
3.5.3 Application of remote sensing in soil degradation 66
3.6 Informed opinion 67
3.6.1 The Global Assessment of Soil Degradation (GLASOD) 68
3.7 Comparative assessment of land degradation assessments 70
3.8 Summary 72

CHAPTER FOUR: RESEARCH STRATEGY

4.1 Introduction 74
4.2 Case study selection 74
4.3 Choice of remote sensing images 75
4.4 Interpretation of remote sensing images 76
4.5 Sampling design 77
4.5.1 Sampling design for environmental data 79
4.5.2 Sampling design for socio-economic data 79
4.6 Data collection 80
4.6.1 Environmental data collection 80
4.6.2 Socio-economic data collection 81
4.7 Data compilation and analysis 82
4.7.1 Landcover/use maps 82
4.7.2 Landcover/use change maps 83
4.7.3 Trend of landcover changes 86
4.7.4 Landcover/use change pattern 88
4.7.5 Determination of land degradation 89
4.8 Conclusion 90

CHAPTER THREE: LAND DEGRADATION AND INTERVENTIONS IN TANZANIA. A HISTORICAL PERSPECTIVE

5.1 Introduction 94
5.2 Land degradation in Tanzania 95
5.2.1 Land degradation: Colonial period up to Independence 96

5.2.2 1960's to late 1970's 100
5.2.3 Period post 1980 104
5.3 Conclusion 111

CHAPTER SIX: BIOPHYSICAL CHARACTERISTICS OF THE STUDY AREA

6.1 Introduction to the study area 115
6.2. Climate 118
6.2. Geomorphology 122
6.2.1 Main terrain units 124
6.2.2 Main geological units 128
6.3 Drainage 129
6.4 Soil types 132
6.5. Semi-natural vegetation 134
6.6. Wildlife 139
6.7 Conclusion 139

CHAPTER SEVEN: SOCIO-ECONOMIC ASPECTS, HISTORICAL AND CURRENT DEVELOPMENTS

7.1 Introduction 141
7.2 History and culture of Maasai 143
7.2.1 Population dynamics in the Maasailand 144
7.2.3 Population changes in the study area 146
7.2.4 Settlements distribution and organization 147
7.3 Livestock keeping 152
7.3.1 Livestock development within the study area 157
7.3 Agricultural activities 160
7.3.1 Crop yields 164
7.4 Water supply 167
7.5 Conclusion 171

CHAPTER EIGHT: LANDCOVER AND LAND USE CHANGES

8.1 Introduction 173
8.2 Landcover/use, 1960's, 1991, 1999 176
8.2.1 Landcover/use, 1960's 176
8.2 2 Landcover/use, 1991 180
8.2.3 Landcover/use, 1999 184
8.3 Landcover/use changes 190
8.3.1 Landcover /use changes, 1960's/1991 190
8.3.2 Landcover/use changes, 1991/1999 203
8.4 Trend of landcover changes, 1960's, 1991 and 1999 211

8.4.1 Overall trend of landcover changes 211
8.4.2 Trend of semi-natural vegetation cover changes, 215
8.5 Analysis of landcover change patterns 220
8.5.1 Semi-natural vegetation cover change pattern 220
8.5.2 Agricultural cover change pattern 231
8.5.3 Gully and bare land change patterns 239
8.6 Discussion 246
8.9 Conclusion 250

CHAPTER NINE: TOWARDS A NEW METHOD OF LAND DEGRADATION ASSESSMENT

9.1 Introduction 252
9.2. Conceptual framework for the method 253
9.2 Determination of semi-natural vegetation degradation processes 254
9.3 Determination of soil degradation processes 260
9.4 Land degradation assessment 261
9.5 Causes of land degradation 264
9.5.1 Anthropological factors 264
9.5.2 Natural causes 266
9.6 Discussion 271
9.7 Conclusion 272

CHAPTER TEN: SYNTHESIS AND CONCLUSIONS

10.1 Introduction 276
10.2 Land degradation; basic concepts and assessment methods 277
10.3 Land degradation in Tanzania 279
10.4 Biophysical characteristics of the study area 279
10.5 Socio-economic dynamics of the area 281
10.6 Landcover/use and landcover/use changes 283
10.7 The new method for land degradation assessment 286
10.8 Land degradation 286
10.9 Causes of land degradation 288
10.10 Limitations 289
10.11 Implications of the findings 291
10.12 Conclusion 293
10.13 Future directions 295

References 297

LIST OF FIGURES

Figure		Page
Figure 2.1	UNESCO natural or semi-natural vegetation typification	19
Figure 2.2	ITC natural or semi-natural vegetation structure typification	19
Figure 2.3	A model of arroyo formation in the American southwest	30
Figure 2.3	Land degradation model	45
Figure 4.2	General approach used in the study	93
Figure 5.1	Administrative regions in Tanzania	95
Figure 6.1	Location of the study area	116
Figure 6.2	The East African rift system, Tanzanian sector (the study area is between Lake Eyasi and Lake Natron)	117
Figure 6.3	Long-term seasonal rainfall distribution at Ardai Rainfall station	120
Figure 6.4	Long-term rainfall variability	121
Figure 6.5	Aridity zones for the study area	123
Figure 6.6	Terrain units and fault lines	125
Figure 6.7	Terrain elevation model	126
Figure 6.8	Main Geological units	130
Figure 6.9	Geomorphology of the study area	131
Figure 6.10	Vegetation structure	136
Figure 6.11	Semi-natural vegetation/use map	138
Figure 7.1	Location of Bomas	149
Figure 7.2	Villages and settlement boundaries	150
Figure 7.3	A typical example of a Boma	151
Figure 7.4	Trend of maize yield	166
Figure 7.5	Estimated maize yield trend (tonnes/ha)	166
Figure 7.6	Main types of water sources	170
Figure 8.1	Main landcover types for the 1960's	178
Figure 8.2	Main semi-natural vegetation types for the 1960's	178
Figure 8.3	Landcover/use map for 1960's	179
Figure 8.4	Main landcover types for 1991	182
Figure 8.5	Main semi-natural vegetation types for 1991	182
Figure 8.6	Landcover/use map, 1991	183
Figure 8.7	Main landcover types for 1999	186
Figure 8.8	Main semi-natural vegetation types for 1999	186
Figure 8.9	Landcover/use map, 1999	188
Figure 8.9b	Restricted land areas	189
Figure 8.10	Location of gullies and bareland	191
Figure 8.11	Main landcover changes between the 1960's and 1991	194

Figure 8.12 Semi-natural vegetation cover changes map, 1960's/1991 196
Figure 8.12b Semi-natural Vegetation cover changes, 1960's/1991 198
Figure 8.13 Agricultural cover changes lands 1960's/1991 198
Figure 8.14 Agricultural changes map1960's/1991 199
Figure 8.15 Water bodies cover changes 60's/91 200
Figure 8.15a Water bodies changes map 60's/91 201
Figure 8.16 Gully and bareland changes map,1960's/1991 202
Figure 8.17 Main landcover changes 1991/1999 204
Figure 8.18 Semi-natural vegetation cover changes map 1991/1999 206
Figure 8.19 Semi-natural vegetation cover changes 207
Figure 8.20 Agricultural cover changes, 1991/1999 209
Figure 8.21 Agriculture cover changes map, 1991/1999 210
Figure 8.22 Bare land and gullies changes 91/99 212
Figure 8.23 Water bodies changes, 91/99 212
Figure 8.24 Bare land and gullies change map, 91/99 213
Figure 8.25 Water bodies change map, 91/99 214
Figure 8.26 Trend of landcover changes, 1960's, 1991 and 1999 215
Figure 8.27 Vegetation cover changes, 1960's/1999 216
Figure 8.28 Generalized semi-natural vegetation cover changes, 1960's, 1991 and 1999 218
Figure 8.29 Generalized map of semi-natural vegetation cover Changes 1960's to 1999 219
Figure 8.31 Semi-natural vegetation cover changes against rainfall distribution 180
Figure 8.31a Semi-natural vegetation cover changes against relief 225
Figure 8.32 Semi-natural vegetation cover changes against geology 227
Figure 8.33 Semi-natural vegetation cover changes against population density 229
Figure 8.34 Semi-natural vegetation cover changes against main economic activities 231
Figure 8.35 Agricultural cover changes against rainfall distribution 233
Figure 8.36 agricultural cover changes against relief 235
Figure 8.37 Agricultural changes against geology 238
Figure 8.38 Agricultural cover changes against population density 240
Figure 8.39 Gully and bare land changes against rainfall distribution 241
Figure 8.40 Gully and bare land changes against relief 242
Figure 8.41 Gully and bare land changes against slope 243
Figure 8.42 Gully and Bare land changes against geology 244
Figure 8.43 Gully and bare land changes against population density 246
Figure 8.44 Gully and bare land changes against socio-economic activities 247

Figure 9.1	Steps followed in developing the assessment method	255
Figure 9.2	Semi-natural vegetation cover change types deemed as undergoing degradation	258
Figure 9.3	Semi-natural vegetation degradation map	259
Figure 9.4	Soil degradation map	262
Figure 9.4	Land degradation map	263
Figure 9.5	Model for land degradation for Monduli District	273

LIST OF TABLES

Table		Page
Table 2.1	Dryland categories	14
Table 2.	Chemical parameters for classification of soil affected soils	26
Table 3.1	Comprehensive list of indicators for land degradation	53
Table 3.2	Detailed list of land degradation indicators that can be used at the community level	54
Table 3.3	A list of land degradation assessment methods	56
Table 3.4	The main satellite systems and their applications	65
Table 3.5	UNEP estimates of the type of land degradation deemed susceptible to desertification	71
Table 4.1	An example of output of landcover changes by direct comparison	83
Table 4.2	An example of generalized cover changes for semi-natural vegetation	84
Table 4.3	An example of vegetation cover changes generated by combining 1960's/1991 and 1991/1999	87
Table 4.4	An example of generalized of generalized trends of semi-natural vegetation covers changes from the 1960's to 1999	88
Table 4.5	Materials used in the research project	92
Table 6.1	Rainfall stations in and around the study area that has been used in the study	119
Table 6.2	Aridity zones in the study area	122
Table 6.3	Types of extrusive igneous rocks	129
Table 6.4	Laboratory results of soil samples from Mto wa Mbu	135
Table 7.1	Population changes in Monduli District	145
Table 7.2	Total population and density per village, 1994 data	147
Table 7.3	Changes in boma organization	153
Table 7.4	Livestock numbers in Arusha Region, 1978- 1995	156
Table 7.5	Livestock numbers in Monduli district, 1978-1984	156
Table 7.6	Livestock changes over time	158
Table 7.7	Reasons for livestock changes	158
Table 7.8	Main economic activities	159
Table 7.9	Current main diet in the study area	160
Table 7.10	maize and beans yield in different agro ecological zones	164
Table 7.11	Trends of areas under maize cultivation and their yields	165
Table 7.12	Main types of water sources and their conditions	169
Table 8.1	Landcover/use, 1960's	177
Table 8.2	1991 landcover/use	181

Table 8.3	Landcover/use, 1999	185
Table 8.4	Landcover/use changes, 1960's/1991	195
Table 8.5	Landcover/use changes, 1991/1999	205
Table 8.6	Landcover changes, 1960's to 1999	215
Table 8.7	The detailed and generalized semi-natural vegetation cover changes in the area from 1960's, 1991 and 1999	217
Table 8.8	Semi-natural vegetation cover changes against rainfall distribution	221
Table 8.9	Semi-natural vegetation cover changes against relief	224
Table 8.10	Semi-natural vegetation changes against geology	226
Table 8.11	Semi-natural vegetation changes against population density	228
Table 8.12	Semi-natural vegetation cover against main economic activity	230
Table 8.13	Agricultural covers changes against rainfall distribution	232
Table 8.14	Agricultural changes against relief	234
Table 8.15	Agricultural changes against geology	237
Table 8.16	Agricultural cover change against population density	239
Table 8.17	Gully and bare land changes against rainfall distribution	241
Table 8.18	Gully and bare land changes against relief	242
Table 8.22	Gully and bare land changes against slope	243
Table 8.19	Gully and bare land changes against geology	244
Table 8.20	Gully and bare land changes against population density	245
Table 8.21	Gully and bare land cover changes against socio-economic activities	246
Table 9.1	Vegetation cover changes deemed as vegetation degradation	257
Table 9.2	Soil degradation	261
Table 9.3	Results of soil sample analysis at three sites with gullies	267
Table 9.4	Landcover changes and land degradation significance classes	275

LIST OF PLATES

Plate		Page
Plate 6.1	Panoramic view of the study area	127
Plate 6.2	Typical grasslands in lake-terraces	137
Plate 6.3	Typical bushland in basement plateau	137
Plate 7.1	Livestock resting at Mto wa Mbu livestock holding ground	161
Plate 7.2	Livestock grazing near Nanja Dam	161
Plate 7.3	Successful field of maize crop, June 1999 (good rainfall year)	168
Plate 7.4	Failed of maize crop at Lendikinya village, June 2000 (poor rainfall year)	168
Plate 8.1	A newly formed gully at Lendikinya village	192
Plate 8.2	A deep gully at Sinon Ngarash village	193
Plate 8.3	A shallow gully at Lashaine village	193
Plate 9.1	Termite grazing area near Duka bovu	270
Plate 9.2	A bareland in Meserani Juu village partly created by termites	270

CHAPTER ONE

1.INTRODUCTION

1.1 General introduction and rationale behind this study

Land degradation in drylands, remains a highly contentious issue. Broadly speaking, land degradation may be defined as undesirable changes in the state of land from productive to unproductive due to natural or human made factors (Interim Secretariat, 1994; Young, 1998). The concept of land degradation is a complex one because it encompasses physical, biological and socio-economic parameters. According to UNEP (1997), land degradation processes can be divided into two main categories, those leading to the removal of vegetation cover and those leading to soil degradation. In the context of this study, the term land degradation is used as defined in the International Convention to Combat Desertification (Interim Secretariat, 1994). In other words, land degradation involves the processes and end results of both semi-natural vegetation and soil degradation due to natural or anthropological factors. UNEP (1997) states that land degradation is one of the world's major socio-economic and environmental problems affecting one billion people in 110 countries worldwide and is prevalent across about 40% of the earth's surface. In Africa, it is estimated that about 320 million ha, or about one quarter of its dry lands, is affected by different types of soil erosion (UNEP, 1997).

The consequences of land degradation are many and varied; for example at a global level, degradation of semi-natural vegetation can lead to an increase in greenhouse gases due to the reduced capacity of carbon storage (Otterman, 1974; Charney, 1975; Hulme and Kelly, 1993). On a local level, on the other hand, semi-natural vegetation degradation not only leads to loss of biodiversity but also to a reduction or loss of protective cover of soil (Sanders, 1986). Soil degradation can lead to a fall in soil productivity due to the removal of nutrients important for plant growth, siltation of dams and lakes and an increase in the frequency and severity of flooding (Pierce and Lal, 1994; Lal, 1998). The socio-economic consequences of land degradation include reductions in food production and income levels and increased conflict among local communities (UNSO, 1992; UNEP, 1997). Land degradation, clearly, is a major environmental problem across vast areas of the earth with significant, if complex, implications for many millions of people.

Despite the fact that land degradation is a global issue, it remains confronted with contentious issues, such as those of definition, causes and assessment. The problem of arriving at a mutually agreed definition arises from continuously changing perceptions on what constitutes land degradation, its causes, processes and manifestations. However, currently it seems that there is a general consensus that land degradation is taken as defined in the International Convention to Combat Desertification (Interim Secretariat 1994; UNEP, 1997; Dregne, 1998).

The causes of land degradation can be due to natural factors, such as tectonic and extreme climate conditions (for example prolonged drought). It can also be due to anthropological factors such as population increase, change of land use activities and overgrazing. However, in dryland areas livestock keeping is often regarded as having a negative effect on rangeland ecosystems (Thomas and Middleton, 1994). Some studies, for example, McCabe (1990), Warren (1994), Behnke and Scoones (1995) suggest, however, that this is not always the case. They argue that traditional livestock keeping strategies are well developed and suited for the drylands, areas of fluctuating moisture and biomass. The problems are only considered to arise when there is an external interference, for example, through improved livestock services or the introduction of agricultural activities.

A number of methods are available to assess land degradation on different scales, from laboratory experiments, field observations, remote sensing and informed opinion on a global level. The use of different kinds of remote sensing images from the global to the detailed local spans several popular methods applied in assessing land degradation. There are a number of constraints associated with assessing land degradation: viz.: no direct correlation between land degradation processes and productivity, unreliable productivity figures, changing paradigms on the characteristics of drylands, conflicting perceptions of land degradation and the difference in emphasis between soil and semi-natural vegetation processes in assessing land degradation. Perhaps the issue of placing a different emphasis on the processes of semi-natural vegetation and soil degradation in land degradation assessment is the most contentious issue and has more serious consequences. This has led to the development of non-comprehensive land degradation assessment methods that focus on particular aspects of land degradation, either soils or semi-natural vegetation.

A clear example of the consequences of variable emphasis can be given using the World Atlas of Desertification (UNEP, 1997). Despite using the definition of land degradation as given in the Convention to Combat Desertification and pointing out that "no consideration of land degradation or desertification is complete without a consideration of vegetation" (p 50), the GLASOD methodology used to produce the desertification atlas focuses only on soil degradation. The main reason for excluding semi-natural vegetation given by UNEP (1997) is its natural variability due to various factors including long-term climate variability. Therefore, it is argued, semi-natural vegetation changes cannot be included in land degradation assessment because it is very difficult to differentiate between changes due to natural and anthropological factors. In addition, the argument goes on that true semi-natural vegetation degradation only occurs when there is soil degradation. Due to the fact that the World Atlas of Desertification does not include semi-natural vegetation, Dregne (1998) gives a different opinion on the value of the World Atlas of Desertification, that, "it is not an atlas of desertification" (p.444) but a very useful atlas of global soil degradation. According to Thomas and Middleton (1994), the inclusion or non-inclusion of semi-natural vegetation in the assessment of land degradation on a global level partly explains the differences in the extent of land degradation figures produced by the United Nations system over the years.

From the definition included in the Convention to Combat Desertification, land degradation, especially at a national or sub-national level, should include both semi-natural vegetation and soil degradation because, at these levels it is possible to carry out ground-truthing (particularly when remote sensing is applied). One of the possible explanations as to why this has not been possible (to combine vegetation and soil degradation) so far is that, traditionally, land degradation assessment by remote sensing has depended on at least two sets of sequential remote sensing images. This approach can certainly determine soil degradation processes or land cover changes in general over the period of interest but cannot determine semi-natural vegetation degradation because it does not offer the possibility of separating changes in semi-natural vegetation due to anthropological and long term-rainfall variability. To some extent, separating changes in semi-natural vegetation due to human factors and rainfall variability can be attained by using more than two sets of remote sensing images synchronized with historical rainfall data. The principle of using remote sensing data together with long-term rainfall variability is not entirely new in differentiating semi-natural vegetation changes due to anthropological long-term rainfall variability. It has been applied in correcting the incorrect concept of the Sahara Desert encroaching by 5.5 km/year between 1958 and 1975 arrived at by Lamprey in 1975 (Thomas and Middleton, 1994; Mainguet, 1994). The moving desert concept has been dismissed by Hellden (1984, in Thomas and Middleton, 1994) who, after including (among other things) long-term rainfall variability, found no evidence of the Sahara desert advacing south at the rate determined by Lamprey. Therefore imperative that if land mitigation efforts are to be realized, reliable and repeatable holistic assessment methods that can be used to accurately assess land degradation should be developed.

1.2 Land degradation in Tanzania

Land degradation is one of the major problems facing Tanzania, even though its true extent has not, as yet, been established. Between 45% and 75% of the country is estimated as degraded in one way or another (NEMC, 1990). As elsewhere, land degradation definitions, causes and assessment have also been contentious issues in Tanzania. The definition of land degradation has changed from one of purely involving soil erosion and overgrazing to one including both semi-natural vegetation and soil degradation processes and their respective consequences. The causes of land degradation in Tanzania over time have been interpreted to include both natural and human factors, even though the emphasis as to the main causes has varied with time and location. However, in many cases, pastoralists have been blamed to a larger degree than other stakeholders as being responsible for land degradation through overgrazing. As elsewhere, a number of methods has been used to assess land degradation in Tanzania, from laboratory experiments to field observation and measurements using two sets of sequential remote sensing images. In Tanzania, there may be an over-estimation as to the extent of land degradation for two reasons. Firstly, the extent of drylands is established through long-term mean values and not by aridity index values. Secondly, when land degradation is assessed using only two sets of remote sensing images without necessarily considering rainfall variability, the landcover changes determined may be due to both rainfall variability and anthropological factors. Therefore, it is quite possible that efforts to control land degradation in Tanzania are partly hampered by the inaccurate assessment of land degradation that ultimately led to inappropriate solutions. To conserve and make better use of natural resources, reliable methods for assessing land degradation are urgently needed in Tanzania and other developing countries because of the scarcity of the resources in these countries. It is to this end this research is directed to the development of a new land degradation assessment methodology that may lead to an attainment of more reliable results of land degradation.

1.3 Aim and objectives of the study

The overall aim of this thesis is to develop a new land degradation assessment methodology that takes into account both soil degradation and vegetation changes due to both anthropological activities and natural causes of land degradation. Long-term rainfall data, remote sensing images, historical maps, together with current biophysical data and historical socio-economic data are used to develop the methodology.

1.3.1 Specific objectives

1.To document and highlight the basic and general concepts of land degradation, causes and assessment methods in East Africa and Tanzania in particular.

2. To describe the historical development of land degradation, causes, assessment and interventions in Tanzania.

3. To determine semi-natural cover changes in the study area-taking cognizance of annual and inter-annual natural variability due to seasonal and long-term rainfall variability.

4. To determine semi-natural vegetation degradation in the study area whilst considering of natural annual and inter-annual changes due to rainfall variability.

5. To determine soil degradation in the area by taking into account soil erosion due to water and chemical deterioration of soils.

6. To determine land degradation in the area based on land degradation processes of both semi-natural vegetation and soil.

7. To identify the main causes of land degradation in the area by taking into account both natural and historical socio-economic factors.

1.4 Working hypothesis and structural outline

In order to contextualise this study, the author proposes the following as a working hypothesis.

1.4.1 Working hypothesis

It is possible to differentiate natural from anthropological causes of land degradation in Monduli District by using three wet-year sequential remote sensing images synchronized against long term rainfall data and historical socio-economic, geological and soil data. It is, in turn, possible to develop a more holistic land degradation assessment methodology by combining both soil and vegetation degradation processes and taking into account both natural and anthropological factors that contribute to land degradation.

1.4.2 Structural outline

The report is divided into four main parts, chapters 1 to 3 provide introduction, rationale to the study, and a background to land degradation in general and land degradation assessment methods. Chapter 4 discusses the research strategy. Chapters 5 to 7 provides land degradation in Tanzania, biophysical and socio-economic data of the study area. Chapter eight and nine provides the analysis on landcover, landcover changes and land degradation. Chapter 10 dwells on the synthesis, discussions, conclusions of the research.

CHAPTER TWO

2. DEFINITIONS, PROCESSES, CAUSES AND CONCEQUENSES OF LAND DEGRADATION; A THEORETICAL OVERVIEW

2.1 An introduction to the concept of land degradation

Land degradation in the broader perspective implies undesirable changes in the state of land from productive to unproductive due to anthropogenic and/or natural factors (Barrow, 1991; Kassas, 1995; Eden, 1996; Young, 1998). The term "land" in this context includes soils, vegetation, water and air, and land degradation is taken to mean a reduction in resource potential, that is the deterioration in the quality of and/or the biological degradation of a resource (Mainguet, 1994; UNEP, 1997). There are many processes that can lead to land degradation; examples include soil loss, vegetation loss, and water and air pollution and these processes are occurring or can occur at any place on the earth's surface (Thomas and Middleton, 1994). However, land degradation has been categorized spatially into two main divisions, that occurring in the humid lands and that occurring in the drylands, also often known as desertification. This issue will be visited later in this chapter. Land degradation, in the context of this research project, refers specifically to land degradation in the drylands, or desertification. According to Lal (1988), Blair *et al.* (1972) and UN (1992, in Thomas and Middleton, 1994), the main reasons for making this categorization are firstly that drylands are regarded as delicate and fragile systems highly susceptible to disturbance and degradation and secondly, many societies in the drylands are vulnerable for a number of political and social reasons. The concept of land degradation is a complex one and takes into account all key components of the environment, including the physical, biological and socio-economic aspects. Moreover, there are continuously changing perceptions as to what constitutes land degradation, its causes, processes and manifestations.

The drylands environment in which land degradation is prevalent is marked by natural climatic variations of alternating wet and dry seasons, of drought, normal and wet years, and this makes the issue even more complex. The terms land degradation, land degradation in drylands and desertification are used here interchangeably. The justification is provided in the discussion below.

The main aim of this chapter is to show the complexity of land degradation, its many and different perceptions, the processes and their conflicting views, the ongoing debates as to what constitutes the main cause, the socio-economic effects and the political ecology aspects of land degradation in developing countries. The complexity of land degradation shown by the many, changing and (at times) conflicting definitions as given by different experts and authorities on land degradation. The situation is made even more complex by conflicting opinions as to the nature and environmental dynamics of the drylands on which land degradation occurs. The many and at times conflicting perspectives as to what land degradation is, is reflected by the different views held by different land degradation actors or agents, from land managers, to government and international institutions. The many processes that may lead to land degradation are reflected by a number of sub-processes within vegetation and soil degradation processes. The conflicting schools of thought as to which constitute the main land degradation processes are reflected by difference in views between physical and human geographers. The main causes of land degradation are analyzed to reflect both anthropological and natural factors and the related conflicting views as to which are the dominant causes of land degradation. The analysis is made by first distinguishing between natural and anthropological factors and second by highlighting the different types of anthropological factors. The biophysical effects are analyzed to include consequences on vegetation and topsoil, socio-economic, (on crop yields), and a discussion made on the difficulties in quantifying the effects of land degradation. Finally, an overall political ecology framework in which land degradation issues are managed in developing countries is analyzed by discussing the key actors and their roles at different levels.

2. 2 Definitions and changing perceptions of land degradation

Desertification or land degradation has over one hundred published definitions (UNEP, 1987; Goudie, 1990). The question of the definition of desertification and land degradation has been extensively discussed, for example, see Blaikie and Brookfield (1987), Mainguet (1994), Thomas and Middleton (1994), Johnson and Lewis (1995) and Agnew and Andrew (1996). According to Mainguet (1994), the main areas of contention concern the causes of land degradation, the mechanisms, manifestations or the indicators, and its impact. As a result of this, there has been a continuous change in the perception of land degradation. To demonstrate the changing perspective it is worth quoting a few definitions from the United Nations (UN) to reflect the changes within the UN itself. This is necessary because the UN is actively involved in land degradation assessment, formulation of mitigation measures and financing of desertification control programs. Therefore a change in the definition could have an influence on policy, assessment methods, mitigation measures and funding.

UN definitions of desertification

1. UNCOD, 1977

> *Desertification is the diminution or destruction of the biological potential of the land that can lead ultimately to desert like conditions. It is an aspect of the wide-spread deterioration of the ecosystems, and has diminished or destroyed, the biological potential, i.e. the plant and the animal production, for multiple use purposes at a time when increased productivity is needed to support populations in quest of development* (Mainguet, 1994, p. 3).

2. FAO/UNEP, 1984

A comprehensive expression of economic and social process as well as those natural and induced ones which destroy the equilibrium of the soil, vegetation, air and water, and the areas subject to edaphic and /or climatic aridity. Continued deterioration leads to a decrease in, or destruction of the biolcgical potential of the land, deterioration of the living conditions and an increase of desert landscape (Thomas and Middleton, 1994, p.9).

3. UN, 1990

Land degradation in arid, semi-arid and dry sub-humid areas resulting mainly from adverse human impact (Thomas and Middleton, 1994,p.10).

4. UN Convention to combat desertification, 1994

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (Interim Secretariat, 1994, p.7).

Thomas and Middleton (1994) provide further elaboration of these definitions. The first definition identifies desertification as both a process and as an end result, the second one defines desertification from the human perspective, and notes the contributory factors and its limits in the arid, semi-arid and the sub-humid areas. The third definition equates desertification with land degradation in the drylands and further remarks that anthropogenic factors are the cause of degradation. The last definition adds natural factors as possible contributors to land degradation. Agnew and Warren (1996), furthermore, point out that different definitions are attached to different stakeholders, and that there is a shift in the emphasis often between those definitions that exclude climatic fluctuations and emphasize mismanagement and those that incorporate climatic variations. The constant evolution of the definition is not unexpected as explained by Blaikie and Brookfield (1987) and Verstrate (1986), who point out that land degradation is a perceptual term, and that there will be a number of definitions in any situation. The land degradation problem will, therefore, be viewed differently by government authorities, aid agencies, technical people and farmers or pastoralists. In addition, Agnew and Warren (1996) emphasize the importance of differentiating between environmental change and an environmental problem. Environmental change concerns any physical change which can be monitored on the earth's surface and an environmental problem concerns the impact of the environment upon people, and vise versa. In other words, not all environmental changes constitute environmental degradation.

2.3 Land degradation in the context of this research project

The 1994 definition of land degradation, as given in the Convention to Combat Desertification, is adopted for the purpose of this review. In the context of the 1994 Convention, land includes soil, vegetation, other living things and the hydrological processes that operate within. Land degradation is taken both as a process and an end result of reduction or loss in the economic or biological productivity of land. The causes of land degradation are taken to be both anthropogenic, manifested in different types of land uses, or in physical and biological processes such as soil and vegetation degradation, as well as natural factors, such as tectonic activities and climatic variations. Finally, land degradation is deemed to focus on the drylands.

2.4 Drylands Characteristics

Having discussed the definitions of land degradation and established that they are many and continuously changing it is now time to consider the characteristics of drylands, the geographical areas where land degradation is normally assumed to take place. The characteristics of the drylands are thoroughly discussed in numerous publications, see examples in UNSO (1992), Behnke *et al.*, (1993), Mainguet (1994), Thomas and Middleton (1994), Sullivan (1996), and UNEP (1997). The most important characteristic is, of course, aridity, which is the lack of available moisture because the moisture input or precipitation is exceeded by moisture losses or evapotransipiration. The aridity of a particular area can be determined by finding the ratio of precipitation (P) to evapotransipiration (PET), that is P/PET. There are a number of ways in which PET can be determined, including a direct measurement or the Penman or Thornthwaite method (UNEP, 1997). Based on the calculations of aridity, four dryland zones are generally recognized. These are: hyperarid, arid, semi-arid and dry sub-humid areas (WMO, 1993; Mainguet, 1994; UNEP, 1997). Table 2.1 shows the dryland areas based on the aridity index, precipitation levels and human activities in each zone. Arid areas are also characterized by climatic variability, which refers to year to year (or shorter) changes in individual climatic parameters around long term mean values (Le Houe'rou, 1996). This gives rise to dry and wet seasons annually, droughts, normal wet years and above average wet years, interannually. It is important to note that "drought" has a number of definitions and the following three commonly agreed types of definitions have been adopted for this research. Agricultural drought refers to moisture deficit for crop requirements, meteorological drought is moisture deficit in relation to mean precipitation, and desiccation refers to decadal scale reduction in moisture availability (UNSO, 1992; WMO, 1993; Mainguet, 1994; UNEP, 1997).

Table 2.1 Dryland categories.

P/PET	Type	Characteristics
< 0.05	hyperarid	very dry areas, very limited human activities
0.2-0.50	arid	200-300 mm/y, pastoralism possible
0.2-0.50	semi-arid	500 to 800 mm/y, pastoralism and sedentary agriculture possible, subject to moisture availability
0.50-65	dry- sub-humid	rainfed agriculture widely practiced.

Source: UNEP, (1992)

Climatic fluctuations can be associated with variations in climatic forcing mechanisms, for example, a change in solar output (Meadows, 1975) or sea - surface temperature and atmospheric circulation changes (WMO, 1993; UNEP, 1997). Soil formation in the drylands is extremely slow and it can take several hundred years before the soils are differentiated into different horizons (Mainguet, 1994). Physical processes, that is water and wind erosion, play a more prominent role in soil formation compared to the more humid areas where biological processes are more dominant. Aridity and climatic variability and other abiotic factors such as temperature, runoff, altitude, slope, drainage, soil and fire has led to the formation of a diverse range of types of vegetation as Harris (1980) has pointed out. Vegetation types found in the drylands vary from the evergreen broadleaf forest through broadleaf forests, woodlands and grasslands, to desert scrub.

The issue of equilibrium versus non-equilibrium is pertinent to the debate. Because climatic variability is an integral part of the drylands, vegetation and soils are adapted to this. The equilibrium, or the balance of the nature model, advocates plant succession leading to climax state vegetation and the population of animals and plants is controlled by biotic to biotic interactions. The non-equilibrium model suggests that such a process cannot be used to explain the ecological dynamics of the drylands (Ellis, *et al.*, 1993; Behnke and Scoones, 1993; Mainguet, 1994; Mills, 1995; Sullivan, 1996; UNEP, 1997). Instead, the non-equilibrium model advocates that the ecological dynamics of the drylands are largely controlled by moisture availability, mainly through precipitation, which is highly variable in space and time. In other words, the population of plants and animals are controlled by abiotic interactions and changes in drylands vegetation and animals are highly correlated to changes in rainfall (Behnke and Scoones; 1993; Ellis, *et al.*, 1993; Mills, 1995; Sullivan; 1996). The basic tenets of the non-equilibrium model, according to Cowling (2000) are:

- Rangeland systems do not have a single equilibrium point, but rather have multiequilibria, or are disequilibrial or nonequilibrial.

- The concept of carrying capacity is of minimal value.

- Pastoralists should not adhere to a single conservative stocking rate.

- Herbivores have a minimal impact on vegetation or reproduction

- Opportunistic strategies give the highest economic retums compared with other strategies.

The non-equilibrium model is challenged by some authorities, for example Illius and O'Connor (1999), who argue that animal numbers are density-dependent and limited by forage availability during the dry season. Also, Coppock (1993) points out that the non-equilibrium model works only in dryland areas that have rainfall of less than 400mm/year (Coppock 1993). Otherwise dryland areas with rainfall between 400 to 800mm/year follow the equilibrium model as supported by a study in the southern Ethiopian rangelands. The main reason for the differences in behaviour is that drylands with low rainfall have a higher frequency of droughts, therefore controlling the biotic environment. Drought in drylands with relatively more rainfall, however, are less frequent, so that biotic-biotic interactions play a more prominent role in controlling the environment. This view is supported by Lykke (2000) and Kuiper and Meadows (2002) who add that even though there is a recovery of vegetation in terms of biomass in good years, the long-term quality of vegetation in terms of species composition might suffer due to the pressure applied by human activities. So, in this context, biotic to biotic interactions still play a key role in the dryland ecosystems.

The debate on drylands being equilibrium or non-equilibrium systems has very serious implications especially in assessing the nature and the extent of land degradation and remedial measures. For example if land degradation is to be assessed using a non-equilibrium model, it means that the assessment methodology applied should be able to separate temporary changes of vegetation due to rainfall variability from permanent changes of vegetation due to human activities. The permanent vegetation changes can then classified as vegetation degradation while temporary vegetation changes may be classified as mere vegetation changes. If the very same area was to be assessed again, but using an equilibrium model, then in principle all vegetation cover changes could be considered as being degraded, and therefore, there would be no need to use a methodology that separates temporal and permanent vegetation changes. This means that the results on nature and the extent of land degradation, and by implication remedial costs, can differ by simply using different conceptual models on the behavior dryland.

2.5 Processes of land degradation

Given the complexities of defining land degradation and the conflicting views on the dynamics of the drylands it is now pertinent to discuss the landcover changes that may lead to the processes of land degradation. According to UNEP (1997), land degradation processes are the mechanisms that lead to the degradation of the land. These can be divided into two main categories, processes leading to the removal of the vegetation cover, and processes leading to soil degradation. Sanders (1986) notes that, normally, two or more of these processes occur together and usually the occurrence of one of the processes leads to the development of one or more of the other processes. Clearly, many such processes are strongly interrelated.

2.5.1 Vegetation degradation

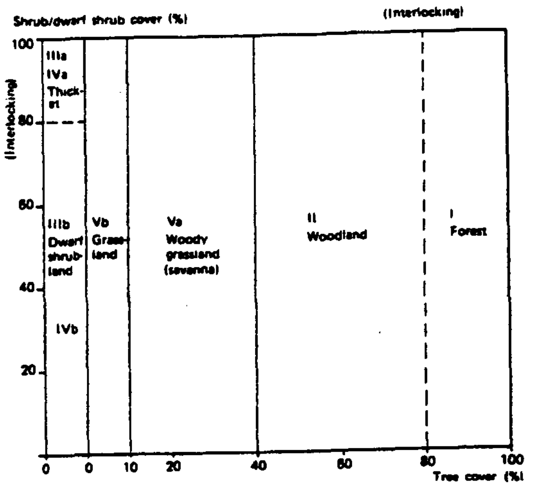
a) Significance of vegetation

In order to fully understand the processes of vegetation degradation it is important to appreciate the significance of vegetation and how it is classified. Vegetation, apart from its basic ecological role as the primary producer of food through photosynthesis, has an environmental, economic, social and agricultural significance in dry areas. Thornes (1995, in UNEP 1997) lists reasons for the significance of vegetation in dry areas. Vegetation not only supports pastoralism, which is a key land use activity in dry areas, but is also an important source of fuelwood energy and soil nutrients. Furthermore, loss of vegetation cover can contribute significantly to soil deterioration by influencing soil erodibility both by water and wind erosion. Lastly, changes in vegetation cover can be used as an indicator of pending changes within the soil system.

b) Vegetation classification

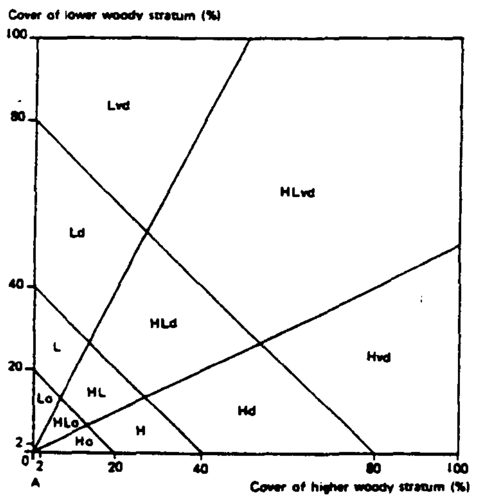
Vegetation can be classified using three main approaches viz. physiognomic, floristic composition (Beard, 1973; Zonneveld, 1988a, 1988b; Kuchler, 1988a, 1988b) and production levels (UNEP, *1997)*. Physiognomic refers to the classification of vegetation according to the dominant life forms or a combination of life forms and structure. Life form is an acquired or adjusted morphological characteristic of a plant that suits the environmental conditions. Examples of life forms based on morphology are trees, shrubs, herbs, bryoids, epiphytes and lianas (Zonneveld, 1988a). Structure refers to the arrangement of layers or strata of different life forms, their height and their density within each layer (Kuchler, 1988b). There are several vegetation classifications based on physiognomy and structure which can be used in exploratory scales, that is for national, continental or global or a reconnaissance or a semi-detailed survey i.e. sub-national level. These include UNESCO and Eiten classification systems which can be used from a national to a global level and a vegetation classification developed by the Institute for Aerospace Survey and Earth Sciences (ITC) which can be used at a local level (Zonneveld, 1988c). The UNESCO classification has five major vegetation types, namely: forest, woodland, woody grassland (savanna), grassland, and dwarf shrubland. The Eiten classification system has six main classes: forest, woodland, scrub woodland, savanna, scrub and plant field. Physiognomy and structure classification in the ITC method is based on airphotos interpretation and field sampling in which the percentage of woody cover in each stratum is determined. The vegetation cover values per vegetation layer are then plotted in two or three dimensional space to classify vegetation structure (Zonneveld, 1988c). Figure 1.1 and 1.2 show UNESCO vegetation categories and an example of vegetation structural classification that can be arrived at using the ITC classification method. The classification of vegetation by floristic composition refers to making classes or groups according to species composition. This can be based on sociological groups, that is groups of plants that show similar distribution, or ecological groups, that is plants appearing in particular environments, or a of combination of both (Whittaker, 1973; Kuchler and Zonneveld, 1988; Zonneveld, 1988b). A number of methods have been developed for floristic analysis and classification, including the quadrat (releve') method, the Kuchlers phytocenological record, line transect, step point and Curtis transect (Kuchler and Zonneveld, 1988).

Figure 2.1 UNESCO natural or semi-natural vegetation classification



Source: Zonneveld, (1988c)

Figure 2.2 ITC natural or semi-natural vegetation structure classification



H = Higher woody stratum dominant
HL = Higher and lower woody stratum dominant
L = Lower woody stratum dominant
A = Absence of woody stratum
O = Open
D = Dense
Vd = Very dense

Source: Zonneveld, (1988c)

The vegetation classification according to production levels, that is the net primary production or biomass, can be made by directly measuring biomass in the field or by estimations using remote sensing by means of the Normalized Difference Vegetation Index (NDVI) (Millington and Townsend 1989; UNEP 1997; Chen, *et al.*,1998; Gibson, 2000). NDVI can be calculated as a ratio of (near-infrared band - red band)/near-infrared band + red band) (Tucker, *et. al.*, 1985). Once vegetation production levels of an area are known, it is possible to categorise the area according to biomass production in kg/ha.

c) Vegetation degradation types

Vegetation degradation can occur due to changes in the structure or the species composition brought about by both human and natural factors. UNSO (1992), UNEP (1997) and many others, point out the main activities that can lead to vegetation change or degradation. This includes agricultural expansion which can lead to the clearance of vegetation and reduction in fallow periods. Fuelwood harvesting and/or collection can lead to changes in vegetation structure and composition. Grazing can lead to the depletion of grasslands due to overgrazing result in bare lands, bush encroachment or an increase of less palatable plant species. Settlement increase and expansion can also lead to a permanent loss of vegetated lands. Sanders (1986) points out that the effect of the removal of the vegetation cover is the exposure of the soil to other processes, which, in turn, may destroy or remove the soil, leaving the area less productive and its productive potential seriously impaired. Barrow (1995) argues that recognizing and assessing vegetation change can be difficult because at times factors normally regarded as contributing to vegetation degradation, such as occasional overgrazing and periodic fire may be necessary for vegetation's long term survival. Without them vegetation may become senile, cease to regenerate and give away to something different. In addition, Barrow (1995) points out, vegetation may vary even within a limited area due to differences in soil, drainage, aspect altitude and history of disturbance.

2.5.2. Soil degradation

Having discussed vegetation degradation, which among other things entails the removal of protective cover of the topsoil, it is pertinent now to discuss the processes leading to soil degradation. According to FAO (1979), Sanders (1986), Barrow (1991), Mabbut (1986), Mainguet (1994) and UNEP (1997), soil degradation can be divided into two main parts, soil erosion and soil deterioration. Soil erosion is the detachment, transportation and deposition of soil particles through the forces of water or wind, while soil deterioration is *in situ* negative chemical or physical change in soil characteristics (UNEP, 1997).

a) Soil erosion

Kirkby (1980), Mainguet (1994) and Morgan (1995) define soil erosion as the physical detachment, transport and deposition of a soil particle. Soil erosion can be of two main types, natural soil erosion, which occurs naturally over the earth's surface, and soil erosion which has been accelerated by human activities. Natural soil erosion is not usually regarded as an environmental problem because it is a standard process in the weathering of rocks and soil formation. A problem arises when there is accelerated soil erosion and the quantity of soil removed is in excess of that which can be replaced naturally. It is, however, often difficult to distinguish between accelerated and natural soil erosion.

Soil erosion depends on the climate, topography, substrate and land use factors. It is a joint result of the *erosivity* (forces that can detach soil from the main soil mass) of the physical agencies such as water or wind, and the *erodibility* (susceptibility of soil to loss of material) of the soil (Mitchell and Bubenzer, 1980; Mainguet, 1994; Lal and Elliot, 1994; Barrow, 1995; Morgan, 1995; UNEP 1997). Properties of wind erosivity include wind velocity, turbulence, frequency of strong winds and duration of windy events, while water erosivity includes raindrop impact velocity, raindrop size, frequency of rainfall events and storm duration.

Examples of soil variables for erodibility include particle size and shape, organic matter content, clay content, cohesiveness, infiltration capacity, moisture content and porosity and permeability. Erodibilty for surface variables include slope angle, vegetation cover density, plant height and shape, leaf/stem fineness, presence of surface crusts and plant orientation (for wind erosion). In practice it means that soils erosion per unit time is greatest during short-duration, high-intensity thunderstorms, and soil erosion is low in soils with higher infiltration rates, higher levels of organic matter and good soil structure. Soil loss due to water erosion increases with the increase in the slope steepness and slope length, and soil erosion potential is higher on the soils with very little vegetation cover or crop residues. There are two main forms of soil erosion: by water and wind.

i) Water erosion

Water erosion occurs when the soil is detached and transported by water. Evans (1980), Mainguet (1994) and Morgan (1995) divide the water erosion process into three stages, viz. physical detachment of soil particles by the impact of raindrops on the soil surface, transport of soil particles by raindrop splash and runoff water and deposition of soil particles. Water erosion can be sub-divided into six types of processes: splash erosion, sheet erosion, rill erosion, gully erosion and piping or tunnel erosion (Holy', 1980; Thornes, 1980; Mainguet, 1994; Morgan, 1995; UNEP; 1997)

- Splash erosion is the detachment and transport of soil particles by raindrop impact and is determined by rainfall kinetic energy. The dislodged particles may, or may not be subsequently removed by surface runoff.

- Sheetwash erosion is the detachment and transportation of soil particles in sloping land by overland flow. The soil particles already loosened by raindrop impact can easily be transported in sheet erosion. Sheetwash removes fine particles of soil and the chemical substances, which bind the soil, therefore changing the on-site and off-site soil texture and soil nutrient contents. The eroded soils become coarse grained with lower nutrient content while the soils enriched with sediments are fine grained and rich in nutrients. Sheetwash is very often inconspicuous and without any visible traces and can be difficult to monitor and therefore may be underestimated.

•Rill erosion occurs when the runoff or overland flow concentrates into many small channels of a few centimeters deep, where larger particles can be detached and transported because of the higher kinetic energy. These channels are called rills when they are small enough not to interfere with field machinery operations. Over time, if not removed, rills can develop into extensive lateral and upslope networks.

•Gully erosion occurs when rills widen to more than 0.3 meters and deepen to more than 0.6meters. Gullies are capable of removing large amounts of soils from the land surface and restricting farming by mechanical means and mobility by motorized means.

•Piping or tunnel erosion occurs when soil is carried away by water through pipes or holes running through the ground due to a number of soil characteristics, such as a high percentage of swelling clays and associated cracking of the soil profile, high cation exchange capacity and soils subjected to marked action of burrowing animals. Piping is always enhanced by reduction in vegetation cover and a loss of internal binding by roots (Gibbs, 1945; Kingsbury 1952; Brown, 1962; Parker, 1965; Heed, 1971; Crouch, 1976; Imeson *et al.*, 1982; Crouch *et al.*, 1986; UNEP, 1997; Beckedahl, 1998).

ii) Wind erosion

Wind erosion is common in areas where vegetation cover is naturally low or has been removed. Wilson and Cooke (1980) and Mainguet (1994) identify three principal means of aeolian transport, viz. suspension, saltation and creeping. Suspension involves the transportation of dust particles, which have a diameter of 60 to 80 μm which can be either organic or mineral in origin. Because of their small size, dust particles can remain suspended in air even when the wind speed has decreased. Saltation occurs when particles between 0.1 and 0.6 mm are lifted almost vertically in successive bounds. Because air speed is reduced to almost zero near the soil surface, the grains fall by means of their own weight along a curved trajectory at an oblique angle to the soil. Creeping takes place when soil particles are too large to be lifted by wind, so they move by rolling along the surface. Creeping results from the direct effect of the wind or from the impact of one-grain falling against another.

b) Soil deterioration

Soil deterioration is sub-divided into chemical and physical deterioration. Chemical deterioration deals mainly with chemical changes in the soil, salinization and/or alkalinization and nutrient loss (Barrow, 1991; Szabolcs, 1998; Rengasamy, 1998). Physical deterioration deals with *in situ* degradation of soils through physical processes, waterlogging, soil crusting and compaction and organic matter reduction (Sanders,1986; UNEP, 1997; Mainguet, 1994).

i) Chemical deterioration

Chemical deterioration involves nutrient depletion and salinization. Nutrient depletion refers to the loss of chemicals essential to plant and other organism growth. Plants require certain types of nutrients such as potassium, nitrogen and phosphorus and other trace elements like boron, zinc and manganese (Gelens, N.D). Nutrient depletion is closely linked to the decline of soil organic matter, because most of the nutrients are derived from dead plant matter (Russell, 1975; FAO, 1983, in Sanders 1986; UNEP, 1997). Organic matter in soil not only supplies the required nutrients but also improves soil structure, water retention capacity and cation exchange capacity (Allison 1973; Barrow, 1991; Morgan, 1995). There are a number of ways in which nutrients can be lost from the soil. These include vegetation loss, shortening of fallow periods, soil erosion and over-cultivation without replenishing nutrients through the use of fertilizers or manure (UNEP, 1997). Nutrients can also be lost through leaching. Leaching is the removal of chemical bases of calcium, potassium, and sodium from the upper horizons of the soil to the lower ones (Nordt, *et. al.*, 1999). Leaching is a naturally occurring process, which does not necessarily lead to degradation unless accelerated by human actions such as irrigation or flooding. Salinization is the accumulation of soluble salts (chlorides, sulfates, and carbonates) at the soil surface (Mainguet, 1994; UNEP, 1997; Rowell, 1994). According to the U.S. D.A. Salinity Laboratory Staff (1954), Abrol, *et al.*, (1988), Rowell (1994) and Mainguet (1994), there are two main types of salt affected soils. Saline soils, which have high levels of NaCl, $NaSO_4$ or other neutral salts, and alkaline or sodic soils which have low levels of total salt but contain alkali salt Na_2CO_3. The U.S.D.A Salinity Laboratory Staff (1954) and Rowell (1994) identified parameters that can be used to differentiate saline from alkaline soils. These are electrical conductivity (EC), which measures total salt, exchangeable sodium percentage (ESP), which is the amount of sodium expressed as a percentage of cation exchange capacity (CEC), and pH. Saline soils have higher levels of EC and lower levels of ESP, while sodic soils have low levels of EC and higher levels of ESP. See Table 2.2 for details.

Salinization or alkalinization can occur naturally, i.e. primary salinization, or can be human induced as secondary salinization (Szabolcs 1976; Metternicht, 1996; Szabolcs, 1998). Primary salinization is normally not regarded as an environmental problem and occurs in many parts of the drylands because evapotransipiration is higher than precipitation, whereas secondary salinization is regarded as a problem because it affects crop production and grazing quality. Sanders (1986), Mainguet (1994), UNEP (1997), and Szabolcs (1998) identify the following as the main factors contributing to secondary salinization.

Table 2.2 Chemical parameters for the classification of salt affected soils

Salt-affected soil	**Chemical indicators**
Saline soils	EC > 4dS/m ESP < 15% pH < 8.5
Alkaline (sodic) soils	EC > 4dS/m ESP > 15% 8.5 <pH< 10
Saline-alkaline (sodic) soils	EC > 4dS/m ESP > 15% pH : variable

Source: USDA salinity laboratory (1954) and Rowell (1994)

•Prolonged use of saline groundwater for irrigation can lead to the development of saline soils because water evaporates during crop production leaving behind salts in the soil. The accumulation of salts in the soil in turn makes the groundwater even more saline because in many cases ground water in the drylands is not recharged as quickly as the water is pumped out.

•Seawater intrusion occurs in freshwater aquifers in cases where irrigation using ground water is located in coastal arid zones. The lowering of the groundwater table due to pumping can create a hydraulic gradient between ground and seawater resulting in seawater intruding into ground water.

•At times, salinization can occur under non-irrigation conditions. Under natural conditions the salts are well distributed in the soil profile. Furthermore, the natural vegetation is usually composed of plants of different growth and rooting habits, drawing their requirements of water and nutrients from different levels, thus keeping the water table relatively low and not providing a chance for salts to concentrate and accumulate on the soil surface. When large areas are cleared by removing the deep-rooted trees, shrubs and perennial grasses and replaced with annual crops, the hydrological cycle is affected. Not only does runoff increase, but also shallow-rooted crops cannot use the deep water and salts, therefore this leads to the rising of the water table, carrying and relocating salts to the soil surface.

ii) Physical deterioration

Soil compaction, sealing and crusting was identified by Barrow (1991), Valentin and Bersson, (1998) and Hakansson and Voorhees, (1998) as a key land degradation process occurring in dry areas. Compaction is the mechanical stress of soil characterized by a decrease in volume and an increase in soil density. Sealing is the reorganization of the surface layer during rainstorm and crusting is the hardening of the surface after the soil had dried out (Barrow, 1991; Valentin and Bresson, 1998; Hakansson and Voorhees, 1998). This occurs when the soil structure is broken down and destroyed because of the use of heavy machinery or the action of concentrated animal hooves. When the soil structure is broken, it means the porous surface in which soil particles are held together in peds is destroyed and, instead, a fine powdery surface is formed. This fine powdery surface develops into a relatively smooth hard surface crust after rain. This process happens when soils are cultivated with implements, such as tractors, or when the soils are very dry; implements tend to shatter the soil and leave the surface material powdery (Barrow, 1991; UNEP, 1997).

Water logging refers to the raising of the water level to the soil surface due either to natural factors, such as flooding or the submergence of the soil by rainwater due to the interference of natural drainage system by human activities. Water logging leads to a severe reduction in the aeration of the soil and the loss of the micro-organisms responsible for the biodegradation of organic material. It can also cause salinization and sodification (Mainguet, 1994; UNEP, 1997;).

Aridification refers to the change of the moisture regime in the soil to a drier one due to the extraction of ground water for irrigation or for a water supply to human settlements. It may also occur when crops that have a high demand for water replace natural vegetation (UNEP 1997).

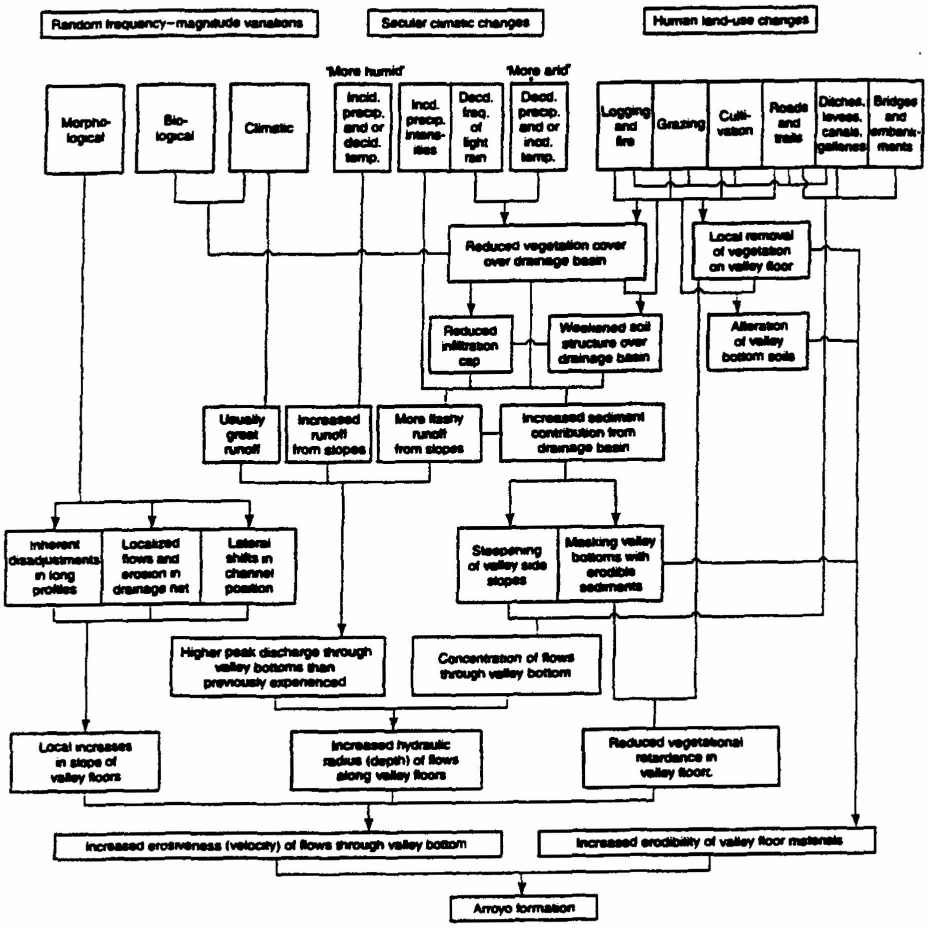
2.6 Causes of land degradation, an overview

Given the complexities in defining land degradation, conflicting views on the dynamics of the drylands and the multiple processes contributing to land degradation, it is now time to look at the possible factors that may cause land degradation. The determination of the causes of land degradation is fraught with difficulties due to the different perceptions of the problem as well as its complexity. According to Kirkby *et al.* (2001) these differences in perception are partly brought about by two conflicting schools of thought, one pessimistic and another one optimistic. The pessimistic school of thought believes that, globally, land degradation is worsening primarily due to human activities and inappropriate technologies (Kasperson *et al.*, 1999). The optimistic school of thought believes that communities at the grassroots level have abilities to reduce the threat and effects of land degradation (Blaikie and Brookfield, 1987a; Adams and Mortimore, 1997). Other factors include the fact that land degradation has not always been seen as a social problem because of the dominance of natural scientist in the UN systems dealing with desertification. (Blaikie and Brookfield, 1987a; Thomas and Middleton, 1994). Governments in Africa have traditionally been advised by foreign experts, who might not necessarily be sufficiently conversant with local conditions and problems concerning land degradation issues. As a result of this no serious attempt has been made to take into account opinions of local communities which may shed light on land degradation causes at the local level (Warren, 1996). In addition, the complexity and differences in parameters, i.e. biophysical, socio-economic and political aspect found in different geographical areas, makes it difficult to generalize the causes of land degradation (Warren, 1993). Barrow (1995) further points out that determining the causes of land degradation is made more difficult by lack of information about the original state of degraded land. The issue is further complicated by changing paradigms on the characteristics of the drylands (UNSO, 1992), and the ongoing debate on whether land degradation is primarily caused by environmental or anthropological factors (Kirkby, *et al.,* 2001). Notwithstanding the above mentioned difficulties, it is now generally agreed that land degradation is caused by multiple factors (Cooke and Reeves, 1976). These multiple factors can be broadly assigned to two groups, natural or anthropogenic (Cooke and Reeves, 1976; Mainguet, 1994; Thomas and Middleton, 1994; Interim Secretariat, 1994; Johnson and Lewis, 1995; Barrow; 1995). The natural factors can be grouped into climatic variability, tectonic activities and inherent soil characteristics. Figure 2.3 shows the model for arroyo formation in the American southwest. It suggests that the formation of gullies has been due to both human activities (e.g. logging, grazing and cultivation), climatic variability (rainfall and temperature change, and local morphological, biological and climatic changes).

2.6.1 Anthropological causes

According to Thomas and Middleton (1994) and Geist and Lambin (2001) the anthropogenic causes of land degradation can be considered on two levels. *Direct* causes are human activities or management strategies that directly affect the environment or the biophysical aspects of the environment, such as over-

Figure 2.3 A model of arroyo formation in the American southwest



Source: Cooke and Reeves (1976)

cultivation and overgrazing. *Indirect* or underlying causes are the social processes such as government policies, international trade, underdevelopment, internationalism, inappropriate technology colonial legacies and population growth that underpin the direct causes of land degradation.

a) Direct causes of land degradation

i) Overgrazing

Traditional livestock keeping systems in drylands for years have been blamed for contributing to degradation (Barrow, 1995; UNEP, 2000). Overgrazing, i.e. excess livestock grazing per unit area, includes both the excess removal of vegetation cover by livestock and trampling. The effects of overgrazing include increased soil erosion by water and wind and the encroachment of unpalatable or noxious shrubs, reduction in frequency of grassland fires which may lead to increase in woody vegetation (Mainguet, 1994; Barrow, 1995; UNEP, 1997). Livestock numbers do seem to have increased in drylands of the developing countries (Arnon, 1981 and UNEP, 2000). For example UNEP (2000) on the state of the environment-Africa argues that in Southern Africa, escalating land degradation has been caused by increased livestock numbers. In some quarters there is a perception that traditional livestock keeping systems and increase in livestock numbers in drylands of the developing countries is apparently due to ignorance and the irresponsible manner of the pastoralists (Khogali, 1983; Cooke, 1983; Slaymaker and Spencer, 1998). This view on irresponsible increase in livestock numbers and poor livestock management strategies has been challenged by a number of scholars including Mortimore (1989), Behnke and Scoones (1993), Thomas and Middleton (1994), Barrow (1995) and Stocking (1996). These authorities argue that livestock populations in drylands normally fluctuate in rhythm with rainfall and vegetation variability. Similarly, the traditional livestock keeping systems tend to maximize the use of ample resources in wet years, and between dry and wet seasons. Therefore the traditional livestock keeping systems tend to increase the possibility of survival livestock in dry seasons and dry years. In addition, some studies have shown that traditional systems are up to ten times more efficient than ranching system (Breman and de Wit, 1983). Lastly, the view of irresponsible manner of the pastoralists being confined to the drylands of the developing countries only is further challenged by the fact that overgrazing has also been occurring in drylands of developed countries such as Australia and America (Thomas and Middleton, 1994; Barrow 1995).

ii) Agricultural expansion

Land degradation is a serious problem in Africa and it is estimated that 500 million hectares of land have been affected by soil degradation since 1950, including as much as 65 per cent of agricultural lands (UNEP/ISRIC 1991; Oldeman, 1994). The expansion of the entire continent's agricultural activities is one of the contributory factors to an increase in soil erosion due to the removal of vegetation cover. Glantz and Orlovsky (1983) and Dregne (1986) identify the cultivation practices that may lead to degradation, including shorter fallow periods that may lead nutrient depletion which is a serious problem in drylands, cultivation in marginal lands, cultivation in poorer soils and improper tillage. This problem is compounded by an increase in the use of mechanized farming, which damages the soil structure, and farming on steeper slopes which are susceptible to erosion (Thomas and Middleton, 1994).

ii) Fuelwood harvesting

Fuelwood remains the main source of domestic energy in many countries of the developing world, as indeed it has for many centuries. However, it is now becoming a problem because of an increase in population, high rates of rural-urban migration and cutting down of living trees (Thomas and Middleton, 1994). The continued reliance on fuelwood as the main source of domestic energy is said to contribute significantly to land degradation, especially around major settlements as vast tracks of vegetation have to be cleared to meet the demands (Barrow, 1991; Mainguet, 1994; Barrow, 1995). The clearance of vegetation further contributes towards making the soil prone to water and wind erosion. Thomas and Middleton, (1994) point out that not all deforestation is due to fuelwood harvesting, due to the fact that woody vegetation is also cleared for other purposes, such as commercial logging. In addition at times areas under fuelwood harvesting may have already been stressed by overgrazing.

b) Indirect causes of land degradation

These are the underlying factors that drive direct causes of land degradation. They include, population increase, economic, policy and institutional, technological and socio-political factors, and natural disasters (Thomas and Middleton.1994; Geist and Lambin, 2001). In many drylands, especially in Africa, there has been rapid population growth of between 2% and 3% per annum (Tarver, 1996). Population increase can lead to an increasing demand on agricultural lands for food production, fuelwood, and the shortening of fallow periods. Human population increase may lead to an increase of livestock numbers, which in turn can lead to a reduction of livestock mobility for various reasons including reduction in grazing areas. However it should be noted that even though the population is frequently cited as one of the causes of degradation, there is no clear connection between population density and land degradation (UNSO, 1992; Mortimore, 1993; Thomas and Middleton, 1994; Geist and Lambin, 2001). Land degradation has been found both in high and low population density areas and in some cases an improvement in land management has occurred with an increase in population density as was the case of the Machakos District in Kenya (Tiffen, *et al.*, 1994). Political economic factors by the international institutions, government or local organization on for example commercialization, urbanization and industrialization may contribute to degradation. An example of government policies that might lead to land degradation include sedentarization of pastoral communities, improvement of animal husbandry and veterinary services, an increase in frequency of bore holes which promote opportunities for grazing, a change from traditional to ranching systems. All these can lead to the concentration of livestock in specific areas and may lead to the breakdown of the mobile traditional grazing systems which in many respects were geared towards coping with climate variability in drylands. Another example is the pressure to produce for the international market which may lead to opening of farms in marginal lands and use of heavy machinery in the fragile soils of drylands that may increase in risk for soil degradation (Barrow, 1991; UNSO, 1992; Thomas and Middleton, 1994). UNSO (1992) and Thomas Middleton (1994) point out other indirect factors such as poverty, which can lead to poor people using the natural resources without conservation measures, in order to survive. Land ownership, which can bring conflict between traditional land ownership and government laws. However, it should not be taken for granted that indirect or structural factors automatically cause degradation because it is difficulties in establishing the link (UNSO 1992).

2.6.2 Natural causes

a) Climate change

There is considerable evidence to suggest that climate, temperature and rainfall change occur on different spatial and time scales due to natural or anthropological factors (Williams and Balling, 1996; Smith; 2001). For example, with regard to temperature changes on a global level, it is widely accepted that the build-up of greenhouse gases particularly carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFC_s) are contributing to global warming (IPCC, 1990; Wigley; 2001). With rainfall changes, using a time scale as an example, it has been established that in Africa Sahel, the annual rainfall during the most recent three decades has been between 20 and 40 percent less than it was from 1931 to 1960 (Hulme and Kelly, 1993). In addition, it has also already been shown that annual and inter-annual rainfall variability is one of the characteristics of dry lands. The effects of climatic changes on land degradation are complex. Williams and Balling (1996) and Smith (2001) point out that global warming due to greenhouse gases will impact on the extent of the drylands and the climatic regime within them. Hulme and Kelly (1993) further add that, because the definition of land degradation is implicitly linked with the assessment of degraded lands, a change in climate will lead to changes in areas assessed as degraded. However, they point out that while climatic change can alter the frequency and severity of drought, it does not necessarily lead to land degradation, unless there is mismanagement of the natural resources. Separating the impacts of climate change from human factors is extremely difficult. The matter is further complicated by the fact that land degradation itself can lead to climatic change, because of increase surface air temperature in degraded lands due to the loss of vegetation cover (Balling, 1991). Vegetation reduction leads to a reduction in atmospheric moisture, which results in an increase in the energy available to heat the air (sensible energy), because less energy is used to heat water (latent energy) (Hulme and Kelly, 1993). Loss of vegetation can also lead to an increase in albedo, i.e. the reflectance from the bare soils and reduction in the potential of the drylands to act as carbon sinks due to the reduced capacity of carbon storage (Otterman, 1974; Charney, 1975; Hulme and Kelly, 1993). Therefore it can be argued that climatic change and variability *per se* is not a cause of land degradation, although it can predispose the landscape, through mismanagement, to deterioration.

b) Geological process

Geological processes can contribute to degradation and in this context it refers to tectonic activities which in a broader sense means earth movements that result in major structural features (Hamblin, 1985, John and Lewis, 1995). In tectonically active areas, for example, the Rift Valley of East Africa, the uplifting and tilting of tectonic blocks is common (McConnel, 1972; Mactyre *et al.*, 1974; Eriksson, 1996). Higher frequencies of earthquakes, as in the Rift Valley, indicate that the area is tectonically active (Iranga, 1991; Hamblin, 1985; Nyamweru, 1996). Summerfield (1991) points out that a relatively minor tilt of a land surface by a fraction of a degree will not only cause pronounced changes in the drainage system but will also increase the potential energy and hence erosional power of running water. Studies by Ericksson (1996) in tectonically active parts of Central Tanzania showed that block uplifting and tilting contributed significantly to higher rates of erosion.

c) Other natural causes

Barrow (1995) points out that there are other natural factors, although not widespread, such as wildlife and termites, which may degrade vegetation to initiate land degradation. Grass-eating termites are abundant and widely distributed throughout the tropics, sub-tropics and semi-arid areas in a variety of vegetation types, including both grasslands and woodlands (Wood and Ohiagu, 1976). Wood (1978) discusses the feeding habits of termites both in terms of the vegetation types they feed on and their feeding dynamics. Wood (1978) further elaborates that termites can feed on living vegetation such as tree trunks, branches or leaves of grasses and herbs, or roots. They can also feed on dead vegetation, such as standing or fallen dead trees and branches, grasses, herbs, dead roots, and plant litter lying on the soil surface. In addition, they can feed on decomposing vegetation, humus and fungus (Wood and Pearce, 1991). Termites construct a system of galleries or runways along which they travel in search for food and other requirements. Many grass-eating termites construct galleries that can extent up to 20 – 25m, eventually terminating in foraging holes from which termites emerge and feed in the open. Damage to pasture by termites and at times complete denudation and acceleration of soil erosion has been reported in various parts of the world, particularly in South Africa (Coaton, 1954), Australia (Ratcliffe, 1952), Nigeria (Wood and Ohiagu, 1976), Kenya (Lepage, 1981) and (Collins, 1982) and in the tropics as a whole (Wood, 1996). Wood and Ohiagu (1976) report that, in Africa, the most abundant and widely distributed species are various species of *Hodotermes*, *Microhodotermes* and *Trivervitermes*.

Based on discussion on the causes of land degradation, it implies that any methodology used in assessing land degradation should be comprehensive enough to take into account, firstly, direct and indirect anthropological factors. That is causes which can be seen directly in the field or through other means such as remote sensing images, and indirect factors, (e.g. population increase and government policies) which cannot directly been seen on the ground and might be affecting a larger area than the location of study. Secondly, it must be able to take into account natural factors both at local level such as soil erodibilty and presence of termites and regional and historical natural factors, such as rainfall variability and tectonic activities.

2.7 Socio-economic consequences of land degradation

Despite conflicting opinions on the causes of land degradation, it has been shown that land degradation can be due both to direct and indirect anthropological and natural factors. The next step then is then to look on the socio-economic consequences of land degradation. However, the literature used in this section pertains more to soil erosion because most of the studies have concentrated on the change of productivity in relation to soil degradation. There are three main types of socio-economic consequences of land degradation; adverse effects on crop yields, financial costs and social impacts (Stocking, 1996; Lal, *et al.*, 2000). These consequences can occur on-site or off-site. Further, the socio-economic consequences can be analyzed as to those pertaining to soil erosion and those due to soil deterioration.

2.7.1 On-site adverse effects on crop yields

The effects of soil erosion on crop yield is documented in a number of publications including, Sanders (1986), Pierce and Lal (1994), Stocking, 1996; Lal (1998), and Lal, *et al.*, (2000). Soil erosion adversely affects crop productivity due to the following; reduction of top soil depth, decrease in soil organic content, reduction of soil nutrients (N and P), reduction in soil available water-holding capacity, reduction of soil aggregate stability, increase in soil density, alteration of clay content. Barrow (1991) Szabolcs (1992) and Mainguet (1994), identify the following as the on site effects of salinization that a have adverse effects on plant growth. The soil structure becomes unstable and compacted, with a decrease in permeability and porosity. Plant growth and biological activity in the soil is weakened and the metabolism between the compounds of the soil and the atmosphere and hydrosphere that would supply the biosphere with nutrients becomes paralyzed. Also, with an increase of soil pH value beyond 9 or 10, the natural vegetation characteristic changes or sometimes completely disappears. Ultimately there are significant changes in the water/soil/ plant balance. Factors that negatively affect crop yield due to soil crusting and compaction are elaborated upon by Valentin and Bersson, (1998), Hakansson and Voorhees, (1998). Crusted and compacted soils tend to increase runoff, decrease the infiltration of the water into the soil to prevent or inhibit plant growth, and to leave the surface bare and subject to other forms of degradation.

2.7.2 Off-site effects

The off-side effects due to soil erosion are as follows. Sediments can be transported and deposited in flat areas, rivers, and irrigation canals, leading to other problems like siltation of dams and lakes and loss of agriculture lands. Water erosion can lead to an increase in frequency and severity of flooding causing damage to property, even loss of life (Sanders, 1986; Pierce and Lal, 1994; Lal, 1998). The off-site impact of wind erosion as identified by Wilson and Cook (1980), Sanders (1986) and Skidmore (1994) can be as follows. The blockage of the transportation infrastructure or the coverage of agricultural lands and settlements by soil that has been blown and then deposited, and damage, or destruction of vegetation growing in adjacent areas by abrasive action of the wind blowing particles.

2.7.3 Financial costs of land degradation

Crosson (1998) defines financial costs of land degradation as the net loss of farm income attributable to erosion. The loss may reflect yields lost due to soil erosion or increased costs due to measures introduced to deal with soil erosion or a combination of the two. Calacicco *et al.* (1989) segregates on-site financial losses into yield and nutrient losses per yield of ton. The yield losses reflect loss of yield due to change physical quality of soil (e.g. rooting depth and water – holding capacity, while nutrient cost represent increased costs of nutrient losses in eroded material that can be replaced by manure or fertilizer. Financial costs can be estimated or calculated on-site or off-site by using different methods from the farm to global level (Crosson, 1998; Lee, *et al.*, 1998; Lal, 1998). According to Lee, *et al.* (1998) the general approach for most methods used in estimating on-site financial losses is based two equation models. The first equation model, which is the Universal Soil Equation Model (USLE) is used to estimate soil losses. The second model, which is a functional relationship between soil loss and crop productivity, is then derived by using the erosion estimates and crop yield data.

A number of research works are available that estimate, at different levels, the financial losses due to soil degradation, example are as follows. Lal, R. (1995) estimated decline of crop yields in Africa due to soil erosion of between 6 to 9 per cent, and if the trend is left to continue it may be 16 percent by 2020. Dregne (1989) estimated that in some parts of Africa yield reduction by as much as 20 percent. Barbier and Bishop (1995) found that cost due to soil degradation and other environmental damages in some African countries ranged between 1 and 17 percent of the Gross National Product. In Zimbabwe it was estimated that, on a per hectare basis commercial arable lands were loosing $20 annually, communal arable $50 rangelands $80 worth of lost nutrients (Stocking, 1996). However, both Stocking (1996) and Lal (1998) caution on the reliability of these estimates because the available data on soil erosion its extent and severity is weak. In addition there is still an on going debate on agronomic impact of soil degradation. This is exemplified by a study in Bukina Faso which showed an occurrence of land degradation at a broader scale using aerial photos, but no widespread reduction of soil quality were identified in the associated field scale study (Gray, 1999).

There is ample of literature on socio- consequences due to soil erosion but not due to vegetation degradation. This might to have been contributed by the school of thought that believes land degradation occurs only when there is soil erosion. It might also be due to the difficulties of quantifying vegetation degradation in monetary terms especially when it is partial change, that is not complete clearance of vegetation. However, it should be possible to quantify rangeland degradation in monetary terms by estimating livestock loss, which might accrue.

2.8 Political ecology aspects of land degradation

Given the broad outline on what is land degradation, its causes and the socio-ecological effects it is now pertinent to look on the forces and actors that influence to a large degree the issues of land degradation. Bryant and Wilson (1998) define political ecology as the political economy of human-environment interruptions. It is a multidisciplinary study of 'politicized environment' that uses social science methods in understanding human processes that can lead to destruction or creation of environment (Blaikie and Brookfield, 1987a; Braynt and Bailey, 1997; Kirby, *et al.*, 2001). Political economy advocates that the environmental change is determined by the relative powers of agents or actors with conflicting agendas, and that the impact of decisions made at global level are felt even in the remotest communities (Blaikie and Brookfield, 1987b; Blaikie and Brookfield, 1987d; Thomas Middleton, 1994; Kirby, *et al.*, 2001). Blaikie and Brookfield (1987c) and Braynt and Bailey (1997) identify the main agents of environmental change at different levels. The first level is the people who work directly on the land also called land managers; these are the farmers and pastoralist. At the second level is the state and its institutions and NGOs who set up policies, development strategies at a state level and below. The third is the global level, which is the highest; it includes the multilateral institutions, such as the UN system, World Bank and the international Monetary Fund. These define and propagate the main social, economic and environmental development paradigms for the rest of the world, and may also provide financing for socio-economic and environmental development programmes. Stocking (1996), includes scientists at Global and state level, as among actors of environmental change, who have their own needs, such as promotion of their subject and their carriers, research money, publication and prestige, and unfortunately they have prejudices too. Dietz (1999) identifies two main modes of political ecological found in the third world; ecoimperialist and ecopopulism also called neopopulism by Blaikie (2000). According to Dietz (1999) the ecoimperialist mode encompasses interests of the first world in which environmental development programmes in developing countries are implemented through ecological modernization framework often under a banner of sustainable development. Ecoimperialist mode is characterized by top-down hierarchical, neo-colonial approach and is normally implemented with and through the compromise of the élites in developing countries, often excluding the dispossessed people (Kirkby *et al.*, 2001). In contrast, ecopopulism mode, emphasizes the capacity of the local people, their strength, competence and land management traditions and abilities to organize and innovate (Dietz, 1999). Ecopopulism uses anthropological and community based-participatory techniques and detailed investigation of ethnoscience and ethnotechnology (Kirby *et al.,* 2001). According to Kirkby *et al.* (2001) and Ruttem *et al.* (1999) ecopopulism has been accused of idealism, to have a naively romantic view of the people of the developing countries, blind to poveties and inequalities and fails to recognize the wishes of the people in developing countries to have access of the lifestyle of the developed world.

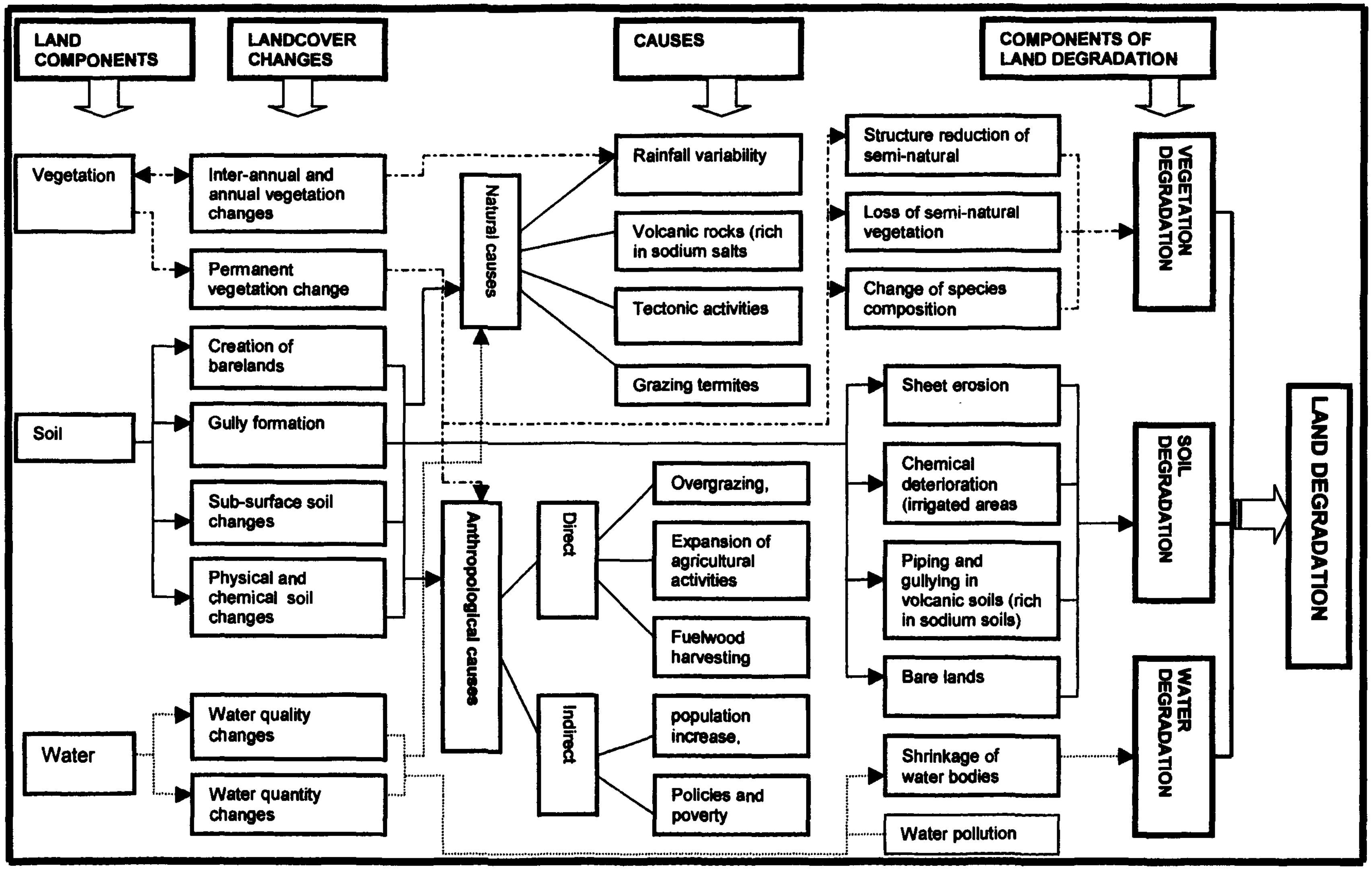
Land degradation issues in the developing countries especially in Africa provide a classical example of ecoimperialist mode (Kirby *et al.*, 2001). According to Blaikie and Brookfield (1987d) land degradation can historically be linked to the interest, of the developed world especially during the colonial era through alienation of large parcels of lands for cash crop farming. This not only displaced local communities from prime areas, but also increased population density and reduced grazing lands, which might have to led to land degradation or increase in risk for land degradation occurrence. The solutions for overcoming land degradation in developing countries, in terms of the nature of the problem, institutions and program, finance and expertise have been initiated and carried out through the eyes of first world. This point is well illustrated in Thomas and Middleton (1994) who elaborate the historical discussions on the nature and extent of land problem by United Nations Conference on desertification (UNCOD), the creation of the institutions to combat desertification, such as United Environmental Program (UNEP) and United Nations Sudano-Sahelian Office (UNSO), programmes to combat desertification such as Plan of Action to Combat desertification (PACD) which was implemented in most of the developing countries. The communities who work directly in the land have been excluded from the whole process and in many cases they have been considered as not capable of formulating strategies for over coming land degradation in their local areas (Blaikie and Brookfield, 1987d; Stocking, 1996). Probably due to this approach desertification in the late 1970's and 1980's was considered as an ecological problem and many of the solutions were geared to overcome the physical symptoms of the desertification, the underlying socio-economic factors were not taken into account (Thomas and Middleton, 1994; Hoffman and Ashwell, 2001).

It is apparent that overcome land degradation in developing countries a genuine participation is required from all key players, land managers, states and international community. In other words a combination of neopopulism and ecoimperialist mode. The United Nations Convention to Combat Desertification (UNCCD) which was adopted in 1994 does seem to combine the two modes through principals of participation, international partnership and coordination, partnership with countries, and special needs, imbedded in the convention (UNCCD, 1995). The principal of participation requires the affected people to be involved in decision-making, design and implementation of the programmes. International partnership and coordination aims at avoiding duplication of efforts and to develop partnership between donors recipients and international organizations. Partnership within countries requires involvement of all stakeholders in desertification control efforts, governments, communities and landholders. The principal of special needs calls for developed countries to give technical, information and financial support to developing countries. The real challenge now is to what extent will these principals be met.

2.9 Summary

The term land degradation has numerous and continuously changing definitions but in general it means undesirable changes in the state of land from productivity to unproductivity. Land degradation may take place anywhere on the earth's surface, however, land degradation in the drylands of the developing countries is categorized as desertification; because these areas are regarded as delicate and its peoples vulnerable. Drylands are characterized by inter-annual and annual climatic variability; consequently socio-economic systems have developed to cope climatic variability. Figure 2.4 is a land degradation model reconstructed by the author based on literature review. It is a multiple hypothesis model of land degradation and is similar to the Cooke and Reeves model (1976) on arroyo formation in the southwest America, in that land degradation is due to a variety of factors. The model has five main components, the land component, landcover changes, causes, land degradation components and land degradation. Land cover changes comprise of temporary or permanent changes of vegetation, soil and water. The causes of landcover changes and land degradation are divided into natural and direct and indirect anthropological factors. Even though not indicated in the model there are conflicting views on whether land degradation is primarily due to climatic changes or to human activities and on whether population and livestock increase enhance land degradation. Also there is an ongoing debate on determining the socio-economic consequences of land degradation which is expressed either as a fall in crop yield or as financial losses. Not reflected in the model, land degradation issues in developing countries are dominated by the ecoimperialist model, that is the perception of land degradation in terms of nature, extent and solutions is dominantly seen from the eyes of the first world. However, the model is unique in a way due to the fact that it incorporates inter-annual and annual vegetation changes due to rainfall variability. The model also differentiates between land cover changes and land degradation. It is the intention of this research to use the Monduli case study to develop a land degradation assessment methodology that will be able to differentiate temporary vegetation cover changes due to rainfall variability from permanent vegetation changes due to mainly human activities. The permanent vegetation cover changes will then be combined with soil degradation to establish the extent of land degradation in the area. The research also intents to come up with a procedure that can be used to establish the main natural and anthropological causes of land degradation in the area.

Figure 2.4 Theoretical conceptual model of land degradation



CHAPTER THREE

3. LAND DEGRADATION ASSESSMENT METHODS, AN OVERVIEW

3.1 Introduction

The definitions, processes, causes, consequences and ecological framework in which land degradation operates in developing countries and the ongoing debates of the same have been covered in Chapter Two. In Chapter Three an attempt is made to explore the methods used in assessing land degradation and their related difficulties. Before going into the details of the methods which are used in assessing land degradation it is important to mention first the basic conditions or characteristics for carrying out a land degradation assessment. Firstly, already discussed, land degradation can occur anywhere on the earth's surface. Therefore, it follows that, depending on the purpose of the assessment, land degradation assessment can be carried out at different levels of scale, from a farm level to global level (FAO, 1979; Stocking, 1987; Blaikie and Brookfieldc, 1987; Foody and Curran, 1994; Burrough, 1997; Dymond, *et al.* , 2001). Young (1976) identifies several levels of scales at which land degradation assessment can be carried out:

- Compilation, this is an assessment based on the compilation of existing surveys, covering the whole world or large regions, at a scale of 1:100 000 or smaller. They are mostly used for qualitative resource inventories. The smallest area that can be delineated in a map is 2500 hectares. (Put different scales as per young)

- Exploratory, this is an assessment also compiled from existing surveys and/or traverses designed to provide information on otherwise unknown regions. The main purpose is to provide qualitative data, which can be used to show the extent of land degradation. Exploratory surveys normally cover the whole country, at a scale of between 1:250 000 to 1: 2 000 000.

- Reconnaissance, this is assessment which involves the assessment of degradation within the regions of a country. The objective is to provide both qualitative and semi-quantitative data, which can be used to identify priority areas for land degradation control. The results are usually shown on maps ranging in scale from 100 000 to 1:500 000. The smallest area that can be delineated on a map at this scale varies from 25 to 625 hectares.

- Semi-detailed surveys, these are normally carried out in areas that have a high priority in terms of land degradation within regions of a country, in order to get more qualitative and quantitative data. The information generated can be used to make a decision on the feasibility of a project in an area. Map scales vary from 1: 25 000 to 1: 100 000. The smallest area that can be delineated on a map of this scale varies from 1.56 to 25 hectares.

- Detailed surveys, these are carried out to generate qualitative and quantitative data needed for project implementation at village or settlement level. Map scales vary from 1:10 000 to 1: 25 000. The smallest area that can be delineated on a map of this scale ranges from 0.25 to 1.56 hectares. At this level even small-scale traditional farms can be mapped.

However, it is important to recognize that scale is a variable; land degradation processes apparent at one scale may not be apparent at another (Foody and Curran, 1994). Therefore inferences drawn from results of land degradation studies at one scale may be incorrect if applied at another scale (Stocking, 1987; Blaikie and Brookfieldc, 1987; Foody and Curran, 1994). Secondly, due to the fact that land degradation involves comparing the past and the present, historical data are required in carrying out land degradation assessment, i.e. the temporal scale, which can vary from one minute to centuries (Blaikie and Brookfield, 1987; Foody and Curran, 1994). Temporal scale enables not only the establishment of the presence of land degradation but also determination of the historical physical and socio-economic factors which may have contributed to land degradation. Thirdly, there is variability in terms of varying rates and varying degrees of severity of occurrence of land degradation processes and, at times, their causal factors. Stocking (1987) gives as an example acidification as one type of land degradation that can occur almost continually and landslides as a type that may occur once in a lifetime. An ideal example of variability of causal factors of land is annual and inter-annual rainfall variations in the drylands. Therefore, in carrying out land degradation assessment, a proper sampling frame has to be formulated so as to take into account both the incremental nature of some slow degradation processes and the more rapid and extreme nature of others.

The main aim of this chapter is to

- Illustrate the basic consideration under which land degradation assessments are carried out.

- Discuss the conceptual and technical complexities in carrying out land degradation assessment as well as land degradation indicators which have been developed to simplify the assessment of land degradation.

- Analyze the different methods, and their limitations, which can be used to assess various land degradation processes and at various spatial scales.

- Define the main overall limitation of the existing methods in the context of this research and propose a way forward.

3.2.Challenges in assessing land degradation

Given the three basic considerations necessary in the assessment of land degradation it is now pertinent to discuss challenges facing the assessment of land degradation. In Chapter Two the ongoing debates were discussed and conflicting opinions regarding land degradation, from the definitions to political ecological aspects. The complexities of land degradation assessment is discussed widely in the land degradation literature, including Stocking (1987), Barrow (1991), Tapson (1993), Behnke and Scoones (1993), Thomas and Middleton (1994) and Dregne (1998). Some of the issues contributing to the complexity are as follows

a) Conflicting perceptions on land degradation

The assessment of land degradation is made more complex due to the many views and the perceptions held by the different actors. This includes the continuous change in definition of land degradation, the causes and impacts. The complexity of land degradation is increased by differences in the interpretation of the outcomes of land degradation between the experts and those working directly on the land, the rural communities (Stocking and Murnagham, 2000). At the community level, the assessment of land degradation is partly linked to the stakeholder's perception of land degradation. Many rural areas are occupied and used by many types of stakeholders, such as pastoralists and farmers who have different views on land degradation. For example, clearing of rangeland for agricultural activities may be regarded as a positive change in landuse by farmers but as land degradation by pastoralists.

b) Difference in emphasis between soil and vegetation degradation processes

The difference in emphasis placed on the two main land degradation processes of soil degradation, e.g. UNEP (1997), and vegetation degradation, e.g. Behnke and Scoones (1993) have an impact on the outcome on land degradation exercises. The outcome of the land degradation exercise for an area may differ simply on the basis of placing different emphasis on either soil or vegetation degradation processes.

c) Changing paradigms regarding the characteristics of drylands

The on-going debate regarding paradigms, especially with respect to equilibrium and non-equilibrium issues, contributes to the uncertainties of land degradation assessment. However, even if the question of paradigms is sorted out, there is a major limitation because it is very difficult to differentiate between permanent, human-induced vegetation changes and vegetation changes due to climate variability (Tucker *et al.*, 1991).

d) Non-automatic correlation between land degradation processes and productivity

Land degradation ultimately refers to the reduction in biological productivity due to various land degradation processes (Behnke and Scoones, 1993; Thomas and Middleton, 1994; Pierce and Lal, 1994). Therefore, land degradation in principle should involve the assessment of degradation processes and their effects on productivity. Although many methods have been developed to assess the actual land degradation processes, for example, soil erosion, few have assessed how soil erosion in turn affects productivity. Stocking (1987), Behnke and Scoones (1993), Thomas and Middleton (1994), Pierce and Lal, (1994) and Dregne (1997) all warn scientists involved in land degradation assessment that there is no automatic correlation between the soil degradation processes e.g. soil erosion and land degradation as measured in terms of loss of productivity. This is due to a number of reasons, including the complexity of the response of plants to soil erosion. For example, Pierce and Lal (1994) point out that the productive capacity of soil varies depending on climate, management and plant genetics in addition to land degradation.

e) Lack of historical and unreliable agricultural productivity figures

Drylands of developing countries lack recorded historical data, such as rainfall records and socio-economic data, which can be used for land degradation assessment. This is simply due to the fact that record keeping is of recent origin. It is also recognized that productivity figures in many developing countries are unreliable and are generalized to wider areas. Therefore, even if it were possible to link degradation processes and productivity, the assessment would still be hampered by unreliable productivity data (Thomas and Middleton, 1994).

f) Difficulties in recognizing some land degradation processes

Barrow (1995) points out that directional changes in vegetation may not always easily be recognized due to the fact, that within a small geographical area, natural change of vegetation can occur simply due to the change of physical factors such as rainfall, topography and aspect. In addition, some factors such as occasional grazing and burning, normally considered as agents of vegetation degradation, may be necessary for regeneration of vegetation. All these factors make it difficult in making a judgement as to which vegetation cover changes can be termed as vegetation degradation and which are merely natural vegetation cover variations. Similarly, for soil degradation, since it is very difficult to recognize and monitor some of the soil degradation processes such as sheetwash erosion as this does not leave obvious landmarks on earth's surface. As a result, even if sheetwash is a major problem in the area it may be underestimated

3.3 Land degradation indicators

Having discussed the challenges in assessing land degradation, it is time to examine land degradation indicators that have been developed to simplify, to some extent, the process of land degradation assessment. Land degradation indicators can be considered in two main groups, biophysical and socio-economic (Berry and Ford 1977; Reining, 1978; Mabbut, 1986; Grainger, 1990; Behnke and Scoones, 1993). Biophysical indicators include changes in climate, vegetation and soils, whereas socio-economic indicators include changes in agriculture and livestock production, human biological parameters, and social processes. It is important to note that the indicators vary in terms of types and level of detail depending on the environmental conditions of the area and the scale or level of study. Generalized land degradation indicators may be used at a global level, while at a community level detailed land degradation indicators may be used. Table 3.1 provides a general list of typical land degradation indicators, while Table 3.2 details visual indicators which can be used at the community level. Mabbut, (1986) and Blaikie and Brookfield, (1987) suggest that indicators can be classified alternatively as either direct or indirect. Direct indicators are obviously those that reveal land degradation directly. Most of the physical indicators are direct indicators; for example, changes in soil depth can easily be related to soil erosion. Socio-economic indicators are, usually at best, indirect indicators of land degradation, for example, the nutritional status of an individual. Nutritional status of an individual may of course can be attributed to many additional factors apart from land degradation

3.4 Land degradation assessment methods

Given the difficulties in assessing land degradation and its indicators, which may simplify the assessment process, it is pertinent now to discuss land degradation assessment methods. Blaikie and Brookfield (1987a), Stocking (1987) and Dregne (1998) explain that land degradation assessment methods can be categorized into two major groupings, *viz.* physical and social

Table 3.1Comprehensive list of indicators for land degradation.

	Type of Indicator
1	***Physical indicators***
	decrease in soil depth decrease in soil organic matter decrease in soil fertility soil crust formation/compaction appearance/increase in frequency/severity of dust/sand storms/dune formation and movement salinization/alkalinization decline in quality/quantity of ground water decline of quality/quantity of surface water increased seasonality of springs and small streams alteration in relative reflectance of land (albedo change)
2	***Biological indicators*** ***(a)vegetation***
	decrease in cover decrease in above-ground biomass decrease in yield alteration of key species distribution and frequency failure of species to successfully reproduce
	(b) animals
	alteration in key species distribution and frequency change in population of domestic animals change in herd composition decline in livestock production decline in livestock yield
3	***Socio-economic indicators***
	change in landuse/water change in settlement pattern change in population (biological) parameters demographic evidence, migration statistics, public information change in social process indicators increased conflict between tribes/groups, marginalization, migration, decrease in incomes, decrease in assets, change in relative dependence on cash crops/subsistence crops.

Source: Reining, (1978) and Kassas, (1987) in Barrow (1991).

Table 3.2 Detailed list of land degradation indicators that can be used at the community level

Visual Indicator	*Types of Soil & Land Degradation*					
	Water Erosion	*Wind Erosion*	*Salinity or Alkalinity*	*Chemical Degradation*	*Physical Degradation*	*Biological Degradation*
Rills	✔	✗	✗	✗	✗	✗
Gullies	✔	✗	✗	✗	✗	✗
Pedestals	✔	✔	✗	✗	✗	✗
Armour layer	✔	✔	✗	✗	✗	✗
Accumulations of soil around clumps of vegetation or upslope of trees, fences or other barriers	✔	✔	✗	✗	✗	✗
Deposits of soil on gentle slopes	✔	✗	✗	✗	✗	✗
Exposed roots or parent material	✔	✔	✗	✗	✗	✗
Muddy water/mudflows during and shortly after storms	✔	✗	✗	✗	✗	✗
Sedimentation in streams and reservoirs	✔	✗	✗	✗	✗	✗
Dust storms/clouds	✗	✔	✗	✗	✗	✗
Sandy layer on soil surface	✗	✔	✗	✗	✗	✗
Parallel furrows in clay soil or ripples in sandy soil	✗	✔	✗	✗	✗	✗
Bare or barren spots	✔	✔	✔	✔	✗	✗
Efflorescence	✗	✗	✔	✗	✗	✗
Soil particles unstable in water	✗	✗	✔	✗	✗	✔
pH	✗	✗	✔	✗	✗	✗
Nutrient deficiency/toxicity symptoms evident on plants	✔	✗	✗	✔	✗	✔
Increased incidence of plant disease/morphological irregularities (e.g. stunting)	✗	✗	✔	✔	✔	✗
Decreasing yields	✔	✔	✔	✔	✔	✔
Changes in vegetation species	✔	✗	✔	✔	✗	✗
Plough pan	✗	✗	✗	✗	✔	✗
Restricted rooting depth	✔	✗	✗	✗	✔	✗
Structural degradation, including compaction	✗	✗	✔	✗	✔	✗
Poor response to fertilisers	✗	✗	✗	✔	✗	✔
Decrease in organic matter (lighter-coloured soils)	✔	✗	✔	✗	✗	✔
Increased sealing, crusting and run-off; reduced soil water	✗	✗	✔	✔	✔	✔
Decrease in number of earthworms/ants and similar	✗	✗	✗	✗	✗	✔

Source: Stocking and Murnaghan (2000)

methods. Physical methods for the assessment of soil and vegetation degradation lie within the realm of the natural science. For simplicity, physical methods can be sub-divided into those used for assessing climate variability and rainfall distribution, and those for assessing vegetation and soil degradation. The second type includes social methods, that is methods to assess the factors underlying land degradation and why adequate measures are not being taken for its control. This lies within the realm of the social scientist. A combination of methods would obviously be preferable, as this would take the inter-multi-disciplinary nature of the problem into account. The following is a more detailed discussion on the physical methods. Determination of rainfall distribution and variability, however, is not a land degradation process *per se* but it is important because it delimits areas that are prone to land degradation i.e. the drylands. The methods that can be used to determine drylands include aridity models and remote sensing (Williams and Balling, 1996; Wigley, 2001). Vegetation degradation can be assessed by use of remote sensing and informed opinion, while soil degradation can be done through reconnaissance methods, runoff erosion plots, field experiments, estimation of suspended load, modeling, remote sensing and informed opinion (FAO, 1993; Mutchler, *et al.*, 1994; Nizeyimana and Petersen, 1998; Gibson, 2000). Note that some of the methods, such as remote sensing and informed opinion, can be used in assessing both vegetation and land degradation, see Table 3.3.

3.4.1 Methods for assessing climate variability and distribution

a) Aridity index models

The ultimate aim of such methods is to demarcate arid zones to highlight dryland areas with a high potential of being degraded. The World Atlas of Desertification (UNEP, 1997) provides the details for calculating aridity. Basically it involves calculating the ratio of precipitation (P) to evapotransipiration (PET) so that an aridity index is determined for different areas. The aridity index is then ranked to produce different types of dryland

Table 3.3 A list of physical land degradation assessment methods

	Parameter/land degradation processes	Method
1	Climate distribution and variability	Aridity modeling Remote sensing
2	Vegetation	Remote sensing Informed opinion
3	Soil	Reconnaissance Runoff erosion plots Field experiments Sediment loads Modeling Remote sensing Informed opinion

as indicated in Table 2.1. The main limitation of the aridity index is that it does not show land degradation *per se* but areas which are susceptible to land degradation. In addition, UNEP (1997) cautions on the correctness of the boundaries of the drylands maps because they are dynamic due to rainfall variations.

3.4.2 Soil degradation assessment methods

a) Reconnaissance methods

These are the methods, according to FAO (1979), Stocking (1987) and Hudson (1993) that can easily and rapidly record observable soil erosion phenomenon in the field. The most common are erosion pins, pedestal development and tree mounds and tree roots. The main advantage of the reconnaissance methods is that they are cheap, simple and can be operated by semi-skilled personnel. Consequently, many measurements can be made which may give more reliable and representative (i.e. believable and usable) results; more so than a single precise measurement from a site which may not be representative (Hudson 1993). Hudson (1993) points out that reconnaissance methods, just like any other field based trials, are prone to interference by local communities for a number of reasons, from plain curiosity to pure vandalism. The solution to this is to encourage local community involvement in the project through awareness campaigns and actual participation in the project it self.

i) Erosion pins

Assessing soil erosion by erosion pins involves driving a pin, also known as a peg, spike, stake or rod, into the soil. The top of the pin then gives the datum from which changes of the soil surface can be made (Stocking, 1987; Hudson, 1993). The pins can be made of iron, wood or any other material, which can not easily decay and is readily available in the local area. A 300mm in length and diameter of 5mm is a typical size of pins used in erosion assessment. Once the pins are installed, measurements of pin heights to determine the changes in soil surface are made regularly for a number of years. However, despite the advantage of convenience, such reconnaissance methods have been criticized by the more technologically minded scientific fraternity (Stocking, 1987)

ii) Pedestals

A pedestal is an isolated soil pillar left standing due to the protection of stone or root when easily eroded material is removed by splash erosion. The erosion in the surrounding area can be considered due to mainly splash rather than surface flow if there is little or no undercutting at the base of the pedestal (Hudson, 1993). It is possible to deduce the approximate depth that has been eroded by measuring the height of the pedestals (Stocking, 1987; Hudson, 1993).

iii) Tree mounds and tree roots

In semi-arid areas it is common for the ground surface under trees to be raised in a gently sloping dome (Hudson, 1993). According to Rapp *et al.* (1973c) the mounds are the result of the tree protecting soil underneath from splash erosion. The rate of soil removal can therefore be determined by measuring the height of the mound and dividing by the age of trees which can be established by counting the tree rings (Stocking, 1987). Using this method in central Tanzania, it was estimated that soil lowering was about 10mm/year (Rapp *et al.*, 1973c). However, Biot (1990) using the same method in Botswana calculated that the rate of denudation was ten to fifteen times greater than by other methods. He argues that the difference in height might be due to differences in bulk density between soils in the mounds and surrounding flat soils. Therefore, Biot (1990) concluded that the mounds might be due to elevation of the local surface rather than erosion of the surrounding surface. This means that evidence from mounds under trees or roots should be treated with caution.

b) Runoff erosion plots and field-scale experiments

Field experiments and erosion plots were first used in the 1940's in the USA because of the difficulties of accurate measurements of the rates of erosion under normal circumstances (Temple and Murray-Rust, 1973; Stocking 1987; Hudson, 1993). The main objective of field-scale experiments and erosion plots is to study basic erosion phases such as surface sealing, aggregate stability, raindrop detachment, splash transport, soil loss (Mutchler *et al.*, 1994). The influence on erosion and runoff is normally determined by using different types of plots in terms of design, size, slope, orientation, soil types, crops and the conservation techniques (Stocking 1987; Hudson, 1993). Hudson (1993) identifies three types of runoff plots that are used for different soil erosion research activities. The micro-plots of one or two square meters are used for a simple comparison of two treatments, for example the difference in surface runoff when grass mulch is applied to newly planted tea bushes. Small-scale plots of about 100m^2 are used for trials of cropping practices, cover effects and crop rotations. Fields plots of about 1 hectare are used for assessing any form of terracing, grazing or livestock management. Generally the information obtained from runoff plots has been intended to be used by the farmers to envisage what might happen if crop and management techniques are changed and to develop soil loss prediction models. The main intention of soil loss prediction models is estimating of soil erosion in agricultural lands.

Stocking (1987), Hudson (1993), Mutchler, *et al.* (1994) and Lal (1994) point out the limitation of field measurements and runoff plots. That is, it is incorrect to take measurements in the laboratory or a small study area and generalize this for the whole district, region, country or even (it has been attempted) up to the global level, due to the large spatial variability of soil and rainfall. Soil erosion rates obtained from runoff plots, when extended to non-experimental areas, grossly over estimate the total sediment leaving the area. The overestimation of sediment occurs due to the fact that in a large area there is both soil movement and deposition, while in the erosion plots there are no depositions of soil particles. Furthermore, Dregne (1998) argues that the majority of the field experiments on soil erosion show how much soil is eroded under different management conditions and only a few relate actual soil loss to soil productivity. Despite the limitations of erosion plots, Hudson (1993) argues that there are still some uses for runoff plots. For example they can be used for demonstrations to show the farmers the seriousness of soil erosion. They can also be used for comparative studies for example to show erosion rates between bareland and vegetation covered land or amount of runoff at the top and bottom of the slope. They can also still be used for developing soil loss prediction models as long as the difficulties in collecting sufficient, accurate and reliable data are overcome.

c) Sediment load measurement

Soil erosion in catchments can be estimated by measuring sediment movement in rivers and streams or by measuring sediments deposited in water bodies, such as lakes and dams (Hudson, 1993). According to Hudson (1993) taking such measurements is time consuming and expensive, and the accuracy of the measurements is likely to be poor. However, such measurements are useful in making comparisons of sediment movement in different streams or at different times of the year, or between watersheds under different landuses. Such an approach was used by the 1973, Dar es Salaam/Uppsala Universities Soil Erosion Studies (DUSER project) in studying soil erosion in the Morogoro, Dodoma and Arusha Regions (Rapp, *et al.*, 1973b). In the Morogoro Region, a natural upper water catchment area of the Morogoro River was used to measure soil and runoff losses. This catchment was used because it was representative of the Ulugurus in terms of terrain and land use and it had regular recordings of precipitation and stream flow (Rapp, *et al.*, 1973a). The measurements of soil and runoff loss were based on the sampling and analysis of suspended sediment load in the Morogoro River during the three rainy seasons of 1969, 1970 and 1971. This was supported by land use mapping and the recording of existing erosional features such as sheet wash, rilling or landslide scars recorded by repeated transects on the ground. Soil profile descriptions and soil sampling were performed in transect lines on slopes and on ridges to valley bottoms. Finally, a detailed land use map was made using ground data and historical and recent airphotos (Rapp, *et al.*, 1973a).

Rapp *et al.* (1973c) explain that, in the Dodoma Region (which is a semi-arid area), soil erosion studies were based on reservoir sedimentation located in four small catchment areas. Small artificial impoundments store part of the sediment eroded from the catchment. The volume of sediment deposited in the dams was determined during the dry season; this was then compared with earlier surveys and the volumes of the interim sedimentation determined. In addition, inventories were made mainly as line transects from the bottom of the hill to the hilltop by use of airphotos interpretation and field studies. The observations made included vegetation cover, soil, land use and different forms of erosion and sedimentation. The reliability of field measurements, for example, by measuring sediment yields from river basins, is questioned because of the continuous variations in the frequency and magnitude of sediment concentration exhibited by most rivers (Walling, 1994). Hudson (1993) identifies three possible sources of error in measuring sediment yield. Firstly, there may be significant eroded material not reaching the river because the material is deposited before it reaches the river. Secondly, in a large catchment area, the eroded material may be deposited, and then eroded again, and then deposited, and this reworking can be repeated a number of times. Therefore a sample of sediment could include material which was originally eroded many years ago. Thirdly, sediment in rivers could include material from areas with different delivery ratios, such as collapsing gullies, cultivated areas and forested areas, so that the measure integrates erosion access under wide range of environmental conditions.

d) Soil loss prediction models

The Universal Soil Loss Equation (USLE) is a soil erosion model designed to predict the long-term average of soil losses in runoff from specified areas of cropping and management systems. The application of this estimate is to allow farmers to select a combination of land use, cropping practice and soil conservation, which will keep will keep soil loss down to acceptable level (Wischmeier, 1976; Wischmeier and Smith; 1978; FAO, 1979). It was developed in the USA from experiments conducted predominantly in the mid-west United States using at the order of 10000 plot years, on a specific range of crops, soil, farming practices and climate (Hudson, 1993).

The equation is represented in the following format (Wischmeire, 1976)

$$A = R \times K \times L \times S \times C \times P$$

Where A = computed soil loss

R= rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover management factor

P = supporting management factor

The USLE has been widely used in the USA and has enabled farmers and conservationists to make an informed prediction of the consequences of the changed land use. The main criticism with USLE is that it has been inappropriately used in other countries without making the necessary adjustments, including the use of local data (Wischmeier, 1976). Hudson (1993) argues that at times the USLE has unfairly criticized functions, which it was not developed for. For example, USLE was not intended to predict sediment yield from a catchment, or predict soil loss from a single storm because the factors used in the equation are all long term averages, predict soil loss outside its own data range (e.g. for slope up to 16%), be used as a precise research tool to study the processes of erosion, treat it as a mathematical factor which could be used to solve one of the input factors, such as solving for K. In 1985 it was decided by the U.S. Department of Agriculture (USDA) to revise the USLE to incorporate additional research and technology developed since the original inception of the equation. This has led to the development of a Revised USLE (RUSLE) even though the basic structure of the equation has been maintained (Renard, *et al.*, 1994). Other attempts to develop empirical models, using local plot data, have been done in Zimbabwe and Australia (Elwell and Stocking, 1982; Hudson, 1993). The empirical model which was developed in Zimbabwe for Southern Africa, is called the Soil Loss Estimator for Southern Africa (SLEMSA) (Elwell and Stocking, 1982).

3.5 Remote sensing

Unlike other methods discussed thus far, remote sensing can be used to assess all the main types of land degradation processes including climate variability. There are a number of satellite systems which are operational, including the meteorological satellites, Earth Resources Technology Satellite (ERTS) also known as Landsat, SPOT satellite, Japanese Earth Resources

Satellite (JERS), Indian Remote Sensing satellite (IRS), RADARSAT and many others (Cracknell, 1994; Gibson, 2000). Remote sensing systems can be classified in a number of different ways. Gibson (2000) identifies three main principles, which can be used to classify remote sensing systems, classification according to the source of energy, operating height and spatial resolution. Based on the energy source, two types of remote sensing systems can be identified, passive and active. Passive remote sensing images use the sun as the source of electromagnetic radiation. The radiation from the sun is reflected by the earth surface and the sensors on the satellite system measure the amount of energy that is reflected. An active remote sensing system carries it own energy source on board. The energy is beamed to the earth and the energy that is reflected back to the system is recorded. Using the operating height three main categories of satellite sensors can be identified, and are as follows. The first group is the sensors carried by aircraft, flying at a height of 500m to 20km above the earth's surface, most of the aerial mapping is done in this group. The second group is sensors that are carried by spacecraft and satellite operating at a distance of between 250 to 1000km from the earth, also known as low orbiting satellite systems. Included in this group are the earth resources satellite, polar orbiting meteorological satellites, orbiting space station and Space Shuttle. The last group is the very high-altitude satellites, which operate 36000 km above the earth. Included in this category are the Geostationary meteorological satellites such as Meteosat. Using spatial resolution classification two types satellite sensors can be identified, these are low and medium sensors. Low spatial sensors have resolutions over 1 Km, included in this category are the Meteosat and NOAA AVHRR. While medium sensors have spatial resolution of less than 100m.

Remotely sensed imagery, is one of the most important and common tools used in monitoring meteorological and landcover changes (FAO, 1979; Tucker, 1985; Barret, *et al.*, 1986; Aronoff, 1989; 1986; Zonneveld, 1988(c); Nizeyimana and Petersen 1998, Gibson, 2000; Dymond, *et al.*, 2001). The determination of landcover and landcover changes using passive remote sensors is based on the contrast of reflectance values measured from a few upper millimeters of the earth's surface (Nizeyimana and Petersen, 1998). Each landcover type, for example vegetation, soils and water bodies, has unique spectral reflectance characteristics that can not only be used for their identification but also for changes within them. The soil spectral reflectance characteristic, as an example, is a function of the chemical and mineralogical composition (Curan, 1985), while the vegetation spectral reflectance characteristic is influenced by plant tissue, especially green leaves, and the structure of vegetation (Zonneveld, 1988d; Gibson 2000). Gibson, 2000 explains that for the active sensor systems, i.e. radar, the major factors controlling signatures are the roughness of the surface, slope of the target and the depression angle. Radar systems can operate day and night and have the capability of penetrating the clouds. In all satellite systems the identification of features in the satellite images is based on tone, texture and spatial relationships and context. The recent satellite sensors and images are designed to cater for several different applications both in meteorological and environmental studies (Gibson 2000). Table 3.4 shows the main satellite systems and their major applications. The application of remote sensing in land degradation falls within three main areas; climate dynamics, vegetation degradation and soil degradation.

3.5.1 Application of remote sensing in meteorology

The dominant satellite images used in meteorological applications are those derived from low spatial resolution sensors, i.e. Meteosat and NOAA AVHRR, even though medium resolution, including Radar images, are also applied when the need arises. According to Gibson (2000) the meteorological applications include a number of activities. Firstly, determination of cloud cover and weather forecasting. This is done by determining the amount of cloud, pattern and type. The satellite-derived information can then be combined with conventional weather station records to enable cloud base to be determined and rainfall amount and spatial extent to be estimated. Secondly, atmospheric monitoring and climate change, including drought and rainfall monitoring. The UN/FAO has developed a system called ARTEMIS

Table 3.4 The main satellite systems and their applications

Satellite/sensor	Spatial resolution	Environmental application
Meteosat	2km	Water, Biomass, clouds, meteorology, heat/temperature
NOAA AVHRR	1km	Water, plant vigour, plant species, biomass, vegetation, meteorological, landuse
Landsat MSS	80m	Water, plant vigour, plant species, biomass, vegetation, landuse
Landsat TM	30m	Water, plant vigour, vegetation, rock types, moisture, meteorology, biomass, clouds, heat/temperature, soils, landuse
SPOT 1, 2, 3 XS	20m	Water, plant vigour, biomass, vegetation, soils, meteorological, landuse
SPOT 4, XS	20m	Water, plant vigour, soils, meteorological, landuse

Adapted from Gibson, (2000)

(African Real Time Environmental Monitoring System) which routinely produces maps of rainfall estimates for 2.4 km squares for the African continent using Meteosat data. These maps are based on the analysis of cloud patterns and temperature change within the troposphere. Thirdly, storm event analysis in which cyclones can be seen and tracked by analyzing a series of low spatial satellite images. The monitoring of oceans and water bodies can be facilitated through the analysis of Sea Surface Temperature (SST), produced by processing thermal infrared data of NOAA AVHRR. The SST maps can be used to locate thermal pollution, warm ocean currents, shoals of fish and algal blooms

3.5.2 Application of remote sensing in vegetation degradation

The medium resolution satellite images include Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and are most widely applied in vegetation degradation studies. Vegetation degradation assessment using satellite imagery can be conducted using two main approaches, *viz.* those that are strictly based on digital processing and classification, and those that rely on visual interpretation of false colour composites (Nizeyimana and Petersen, 1998). The determination of vegetation degradation can be done by the use of single fixed time or sequential remote sensing images. The main limitation with this approach is that it does not take into consideration the vegetation changes that may occur due to rainfall variability, which is of course an established phenomenon in the drylands. The implication of not taking natural vegetation variability into account is that the extent of vegetation degradation may either be over-estimated, by for example comparing a current wet year and past dry year, or under-estimated, by comparing a current dry year against a past wet year. The interpretation or classification of remote sensing images is usually supplemented by ground-truthing. Apart from the medium resolution images, the low-resolution remote sensing images such as NOAA AVHRR, can also be used for land degradation studies. NOAA AVHRR can be used to calculate vegetation index, which is a measurement of vegetation greenness or health, also used as one of the key tool of environmental monitoring (Gibson, 2000). Global vegetation dynamics maps composed from Normalized Difference Vegetation Index (NDVI) are now regularly available and can be downloaded from the Internet. In a much more recent development radar images have also been used in studying vegetation degradation and on crop growth (Gibson 2000).

3.5.3 Application of remote sensing in soil degradation

Low-resolution images such as the TM and SPOT have been used in geological and soil mapping and land degradation (Gibson, 2000). The most important soil variables used to indicate soil degradation are soil moisture, texture, iron oxide, roughness and crusting (Curan, 1985; Cierniewski and Courault, 1993). Soil degradation feature such as barelands, bareland and saline soils can easily be detected in remote sensing images (Metternicht, 1996; Nizeyimana and Petersen, 1998). Just as in vegetation degradation assessment, studies in soil degradation by using remote sensing images can be done by digital processing and interpretation, visual interpretation or based on interpretation of radiance parameters (Nizeyimana and Petersen, 1998; Chen *et al.*, 1998). Raina *et al.* (1993) identified areas in Rajasthan in India that were undergoing water erosion, salinization or a combination of the two by using differences in tone and color in a false color composite of TM image.

There are a number of limitations related to the application of remote sensing in land degradation studies. Abel and Stocking (1987) point out some of the limitations of remote sensing especially in the context of biomass calculations. These are estimates and can only be made during the wet season, because there is little or no green matter in the dry season. Sensors cannot distinguish between the canopies of woody vegetation and herbaceous material when vegetation is sparse and background reflectance can prevent an accurate estimation of vegetation. Dregne (1998) and Gibson (2000) identify further remote sensing limitations, including low resolution especially in semi-detailed surveys, short time frame of records (most of the satellite images are available from the early 1980's only), and the difficulty of discriminating between different plant communities. In addition, the use of remote sensing images can be costly and time consuming, require local knowledge of the area, an experienced technician, and intensive fieldwork (Nizeyimana and Petersen, 1998; Gibson, 2000)

3.6 Informed opinion

Due to the difficulties of collecting and analyzing data at the global level, the informed opinion method has been used to estimate the extent of land degradation at the global level. According to Dregne (1989, 1998), the informed opinion method involves a number of steps. Firstly, there is the collection of available relevant data on land degradation such as available maps of soils, vegetation, geology and topography. Secondly, getting information and data from local experts and using an expert computer system to compile data on land degradation processes and their effects in different areas and finally, a series of group discussions with experts and consultants to draw conclusions and eventually produce degradation maps. In order to be useful, this methodology has to be well structured and controlled and is normally applied when rapid assessment is required for large areas. It has been applied in assessing the global extent of both human induced soil degradation and rangeland degradation (Dregne, 1986; Oldeman and van Lynden, 1998). The following is an example of the application of informed opinion in assessing soil degradation at the Global level.

3.6.1 The Global Assessment of Soil Degradation (GLASOD)

The Global Assessment of Soil Degradation (GLASOD), is an example of a broad survey procedure for human induced soil degradation (Stocking, 1987; Oldeman, 1994; Oldeman and van Lynden, 1998) GLASOD uses soil data stored at the UNEP Global Information System Database (GRID) and Geographical Information System (GIS) technology which allows easy manipulation of the spatial and non-spatial data (UNEP,1992). At the global level GLASOD methodology divides the land into 383 physiographic units also called mapping units or polygons. These are land areas of similar physical characteristics. GLASOD methodology identifies four types of land degradation, water erosion, wind erosion, chemical deterioration and physical deterioration of soils. Each type of degradation is divided into subtypes, and are as follows.

Water erosion (loss of top soil and terrain deformation)
Wind erosion, (loss of top soil, terrain deformation, overblowing),
Chemical deterioration, (salinization, nutrient and organic matter loss, acidification and pollution)

Physical deterioration, (compaction, sealing and crusting, waterlogging, and subsidence of organic soils).

For each mapping unit the type of land degradation is assessed by taking into account the extent and degree of land degradation of each subtype. The extent of degradation is based on five categories, they are, infrequent (up to 5%), common (6 - 10%), frequent (11- 25%), very frequent (26 - 50%), dominant (>50%). The degree of degradation is based on five categories, they are, none, light, moderate, strong, and extreme. Each of the subtypes has its own explanation of the terminology used to express the degree of degradation. For example, for water erosion, *light* means part of the top soil has been removed for soils exceeding 50 cm, shallow rills with spacing of 20 - 50 may be present, perennial plant cover is over 70%. The overall severity of degradation on each land unit is obtained by combining the extent and degree of degradation. Four classes of degradation are arrived at, light, moderate, strong, extreme. These five classes of degradation severity are linked to agriculture productivity. For example, *light* means the land unit has somewhat reduced agriculture productivity, but is still suitable for use in the local farming system. It needs only minor modifications in the management system for full productivity.

GLASOD methodology has a number of limitations including variation of scales at different locations of the earth, which is 1:15 million at the equator, 1:10 at 48^0 longitude and 1:5 at 70^0 longitude (Oldeman and van Lynden, 1998). Another limitation as cited by Thomas (1993), Oldeman and van Lynden (1998) and Dregne (1998) is the low accuracy of numerical data contained due to the fact that it is based on the interpretation from a range of sources and interpreted by a large number of people and also due to the small scale of the map. It can therefore, be argued that the data contained in the GLASOD are essentially qualitative interpretation of the nature and extent of soil degradation. Oldeman and van Lynden (1998) further cite that due to the cartographic limitation only two types of land degradation can be indicated per mapping unit even if the land unit could have more soil degradation types. Dregne (1998) despite the limitation of GLASOD highlights its advantages, that it can be used to provide generalized ideas of the extent, severity and location of soil degradation. Also due to the fact that it is well structured it could be used to assess other types of land degradation including vegetation degradation.

3.7 Comparative assessment of land degradation assessments

Having reviewed a number of land degradation assessment methods it is time now to examine how some of these methods, have been applied, specifically at the global level. Three land degradation assessments that were carried out in 1977, 1984 and 1992 all done within the UNEP framework but by different expert who used different approaches are used for this comparative assessment (Thomas and Middleton, 1994). The 1977 assessment was done for the 1977 United Nations Conference to Combat Desertification, while the 1984 assessment was part of the first General Assessment Progress (GAP) of Plan of Action to Combat Desertification (PACD), and the 1992 was the second GAP (GAPII). The results of the three assessments are indicated in Table 3.5. The table shows variation in the extent of the drylands and also decrease in land degradation between 1977 and 1984 and increase of land degradation between 1984 and 1992. Changes in the extent of the drylands and extent of land degradation can partly be explained by comparing the overall land degradation assessment approach, classification criteria of the desertification status, areas deemed to be drylands at different assessment periods, and time-scale for data used in the assessment. First and foremost, even though in principle all three assessments were based on informed opinion, the differences in the extent of degradation can partly still be explained by the differences in levels of consultation carried between three assessments. The 1977 and 1984 assessments were based on consultation with fewer experts than the 1992 assessment which was a combination of soil degradation based on GLASOD methodology and vegetation degradation

Table 3.5 UNEP estimates of type of land degradation deemed susceptible to desertification

	1977 UNCOD	1984 GAP	1992 GAPII
Climatic zone susceptible to desertification	Arid, semi-arid and sub-humid	Arid, semi-arid and sub-humid	Arid, semi-arid and dry sub-humid
Total dryland susceptible to desertification (million hectares)	5281	4409	5172
Percentage of susceptible drylands affected by desertification	75	79	70
Total area of susceptible drylands affected by desertification	3970	3475	3592

Source Thomas and Middleton, 1994

assessed by the International Centre for Arid and Semi-arid Land Studies (ICASALS) (Mabbutt, 1984; Thomas and Middleton 1994). It can therefore be said that the initial assessments were much more subjective than later ones because they were based on fewer experts and also not on a clearly structured assessment method. Even though all three assessments do recognize land degradation as being due to both vegetation and soil degradation, the second explanation on the differences on the extent of land degradation can be due to the criteria used for estimating the degree of land degradation. All assessments have different levels of degrees of degradation i.e. none, moderate, high and very high, but criteria for determining the degree are different for each assessment. Thomas and Middleton (1994) argue that the 1977 assessment was an estimation of desertification hazard rather that actual occurrence. The 1984, assessment, which was based on Mabbutt's (1984) work, the degree of degradation takes into account both agricultural and rangelands. The degree of deterioration of agricultural lands is based on fall in crop productivity by percent (e.g. moderate = losses of up to 25%) and the degree of deterioration of the rangelands is tied with fall in carrying capacity. However, in the 1992 assessment, a qualitative criteria, instead of quantitative as applied in 1984, was used to assess the status of soil degradation (e.g. slight = some what reduced agricultural productivity) (Oldeman and van Lynden, 1998). Thirdly, the differences can be explained by the criteria used in the determination of the drylands. According to Thomas and Middleton (1994) the 1977 and 1984, assessments considered arid, semi-arid and sub-humid as drylands, while the 1992 assessment considered only dry sub-humid together with arid and semi-arid as the drylands. Lastly, the data set used for 1992 assessment were confined between the 1951 and 1980 , but there was no fixed time frame for 1977 and 1984 assessments.

3.8 Summary

Three main characteristics or properties or requirements apply to any land degradation assessment activity and are as follows. That is land degradation can be conducted at various spatial and temporal scales due to the fact that it occurs at various levels of scale and it involves comparing the past and the present. Unfortunately, land degradation inferences drawn from one level of spatial scale cannot easily be transferred to another level and also recorded historical data relevant to land degradation are scarce in the drylands of the developing countries. Due to the variability in occurrence of land degradations processes e.g. fast and slow and at times periodical occurrence of causal factors e.g. rainfall variability, the sampling framework for data to be used in land degradation assessments must take into account these variations. There are a number of constraints in the assessment of land degradation, including many and constantly changing definitions, difference in emphasis between vegetation and soil degradation, changing paradigms on the nature of the drylands, difficulties in recognizing some of the land degradation processes, non-automatic link between land degradation processes and agricultural productivity and scarcity of historical and production figures. As a result of the difficulties in assessing land degradation physical and socio-economic indicators have been developed that can be used to assess land degradation at various spatial scales. The methods for assessing land degradation can be put into three main categories; i.e. for assessing climatic variability, vegetation and soil degradation. Climatic variability though not a land degradation process may enhance land degradation, can be determined by the use of climatic models and low-resolution satellite images. The methods for assessing vegetation degradation include informed opinion for global and regional assessments and medium and low spatial resolution satellite images. Soil degradation can be assessed using a range of methods from reconnaissance methods, erosion plots, soil models, informed opinion and remote sensing. Each method used in assessing land degradation has its own limitation. For example, the accuracy of reconnaissance methods is low, results of soil erosion plots can not easily be transferred to large areas, the assessment of sediment loads is not reliable due to continuous variation in frequency and magnitude of sediments concentration, soil degradation models cannot be used universally unless modifications are made to take into context local conditions. Other limitations include low reliability of land degradation estimates determined through informed opinion and the high technical knowledge required interpreting remote sensing. These limitations are broadly reflected in non-consistence comparative assessment of land degradation results carried out between 1977 and 1992. However, the most limiting factors for land degradation in the context of this research is the segmented nature of the methods used in assessing land degradation and non consideration of natural changes of vegetation due to rainfall variability. This research, by using remote sensing images synchronized against long term rainfall data, will attempt to develop a holistic method of land degradation assessment that will take into account both soil and vegetation degradation processes, but will exclude natural variability of vegetation.

CHAPTER FOUR

4 RESEARCH STRATEGY

4.1 Introduction

The aim of this chapter is to discuss the strategies and methods used in carrying out this research. The research strategy is divided into seven main components: case study selection, choice of remote sensing images, interpretation of remote sensing images, sampling design, data collection and data compilation and analysis. An extensive literature review was carried out with the overall aim of understanding the basic concepts and contradictions of land degradation. The conceptual aspects of land degradation that were covered include the many and changing definitions of land degradation, the characteristics of the drylands and the on-going debate on whether they are equilibrium or non-equilibrium, land degradation processes, for both vegetation and soil, natural and anthropological causes of land degradation, consequences of land degradation, both physical and socio-economic aspects, the political aspects of land degradation in the developing countries and the assessment of land degradation methods. The literature review on land degradation can be divided into three levels, the general aspects, land degradation in Tanzania, and land degradation aspects specific to the study area. Various types of literature, published and unpublished material from Tanzania and elsewhere were used for this research.

4.2 Case study selection

The selection of the case study was done after the preliminary review of literature. The southern part of Monduli District in Arusha Region was chosen as the case study area for the following reasons:

- It is a typical dryland area in Tanzania originally occupied by pastoralists

- It is widely accepted, and frequently referred to in the literature as undergoing land degradation

- Provides a significant degree of background data due to the fact that a number of studies have been conducted there in the past

- It is an appropriate test site of the various factors involved in land degradation since the early 1960's, because a number of socio-economic changes including population changes and agricultural development at both small and large scale have occurred in the area

- There is an on-going development program, at least partly aimed at addressing the inventory and management of natural resources. This, to a significant degree, further facilitated data collection in the area

4.3 Choice of remote sensing images

Once the case study area was selected, the processes of choosing the relevant remote sensing images commenced. The selection of the remote sensing images is based on a consideration of three elements, *viz.*, the type, timing and number of images. A Thematic Mapper image, which is of a medium spatial resolution, was chosen and used in this research for three reasons. Firstly, it is one of the images commonly used in the study of vegetation and soil degradation (Gibson, 2000). Secondly, at a resolution of 30m it is possible to identify a cluster of small-scale farms found in the area, and which are an integral part for this research. Thirdly, it is more economical to purchase a TM image than, for example a SPOT image, (which is also a medium resolution imagery) even though the SPOT image could have provided higher quality spatial results. The timing of remote sensing images, 1991 and 1998 is based on long-term rainfall records. The principle idea behind the strategy was to determine cover changes by using data from wet years only, so as to reduce the influence, in so far as this is possible, of vegetation cover changes that may be due to rainfall variability. Therefore, both the 1991 and 1998 were determined as" wet" years using rainfall records from 24 rainfall stations. The rainfall stations were all within or in proximity of the study area, and with the length of records ranging from 7 to 62 years. . In addition to these satellite images, the 1965 topographical maps, which were compiled using airphotos taken between 1957 and 1963 during the dry seasons, mainly in January, February, March or August, have been included to produce a third landcover map. From a long-term rainfall variability perspective, the 1960's map is a composite of the wet and dry years of the late 1950's and early 1960's. The idea of using two sets and one set of topographical maps is to produce three sets of landcover maps which can then be used to determine not only landcover changes but also vegetation changes due to rainfall variability. In addition, a number of aerial photographs were used to make a much more detailed analysis of landcover on the slopes of Monduli Mountain.

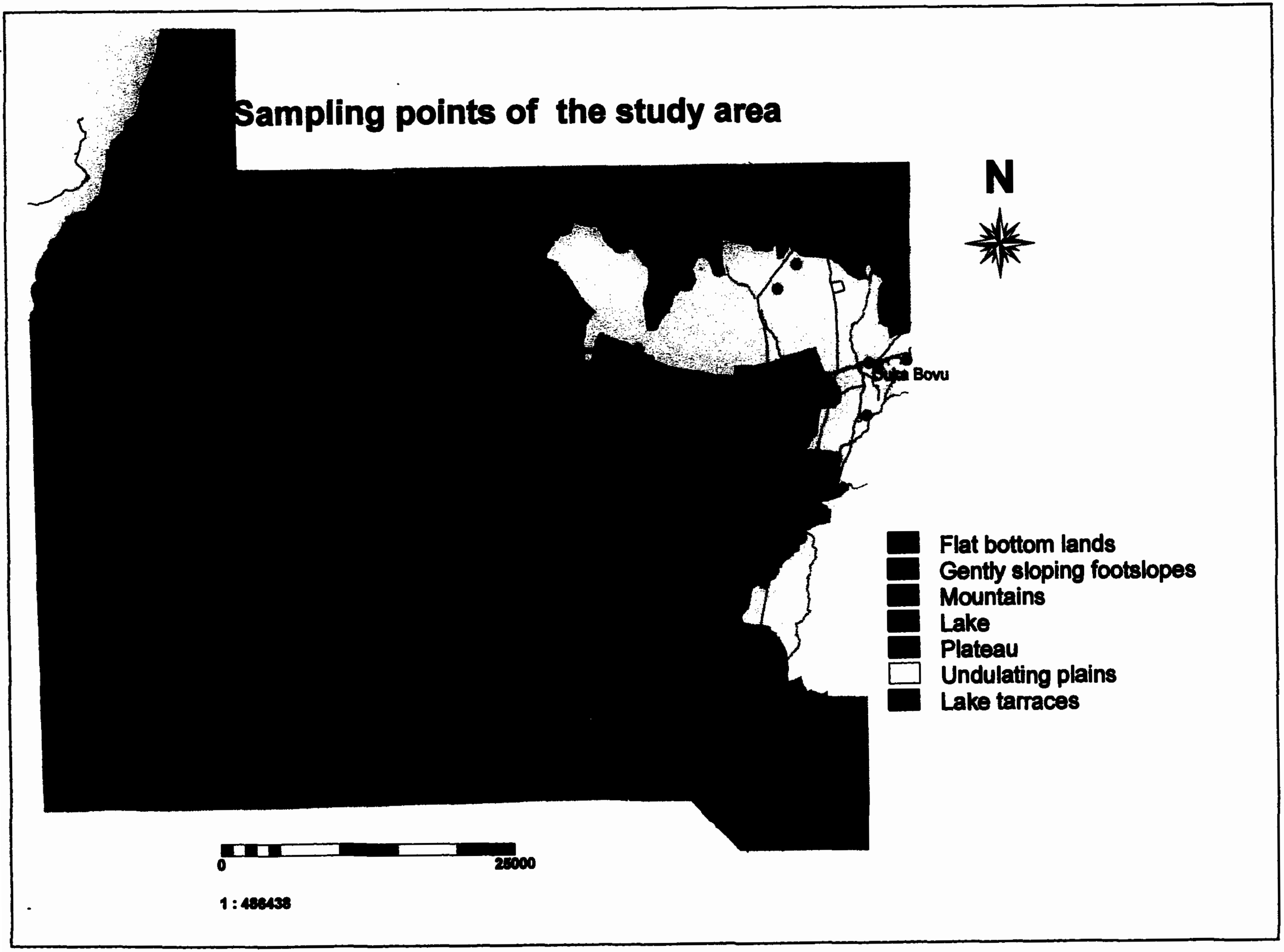
4.4 Interpretation of remote sensing images

Having identified and secured the remote sensing images, the next stage was to carry out an interpretation of the images. The interpretation of the satellite image was done by visual means using hard copy of geo-referenced TM images at a scale of 1:100 000. At this scale, the basic elements required for landcover monitoring, such as hydrology, major landforms, vegetation types, settlements and infrastructure, can easily be identified. Ryd'en (1997) elaborates that visual interpretation has other advantages including provision of a fast and accurate way of extracting major physiographic units, drainage networks and landuse comparable to that of thematic and topographical maps of equivalent scale, and that the human brain is indispensable to the processes of identifying and deducting surface and sub-surface features. Finally, local workers can easily use the method, as it requires less technical inputs in terms of computer facilities and technical skills. The interpretation of the imagery was done in three stages, namely pre-fieldwork, fieldwork and post fieldwork. The pre-field work stage involved the demarcation of polygons based on colour, texture and pattern. The field phase involved verification of landcover types as identified in the polygons by visiting all the sampling sites, (the sampling design is elaborated in the next section). At each sample site the ground truthing was performed relating the imagery characteristics and biophysical data on the ground using the International Institute for Aerospace Survey and Earth Sciences (ITC) data collection sheet (appendix 4.1) and the pre prepared vegetation structure diagram. The data collected during the fieldwork were then used to produce the final landcover map of the area in the post-field work stage.

4.5 Sampling design

The 1998 satellite image was used as the basis for selecting the sampling points, as it was the most up to date. The principle used in designing the sampling framework was that the selected sample sites should represent all landcover types found in the different terrain units in the study area. This means that for example, if grasslands were found in the mountainous areas, undulating plains and plateaus then a sample of grassland was selected in each terrain unit to represent the grassland cover found in each of the three terrain units. The process of pinpointing the exact sampling points was carried out as follows. Polygons were demarcated on the 1998 TM false colour image using differences in color, pattern and texture on the image. Polygons with the same texture and colour were assumed to be of the same type of landcover. In each main terrain unit, the different types of polygons were identified and sites that were accessible and representing each type of polygon were identified as sampling points. Figure 4.1 shows the sampling sites for the study area.

Figure 4.1 sampling sites for the study area



4.5.1 Sampling design for environmental data

The sampling of environmental data was conducted using the standard ITC data collection sheet (Appendix 4.1). The ITC standard data collection sheet can be divided into three main parts.

- Part one is for recording the physical details of the of the sample site including the name of the area, observers, date, sample size and details of the terrain.

- Part two is for recording soil data ,such as horizon, soil depth, texture, colour, mottling, pH, stoniness and erosion indicators.

- Part three is for recording landcover/use. The landcover aspects includes the recording of different types of vegetation based on structure (tree, shrub and herb layers) and dominant species, litter cover and bare soil and the coverage in percentage of each cover type. The land use aspects include type of land use such as agricultural fields and grazing areas and the management aspects.

4.5.2 Sampling design for socio-economic data

The socio-economic data were obtained through a prepared questionnaire (Appendix 4.2). Unlike the physical data, which had to be obtained within the boundaries of the sample plot, the questionnaire was meant to obtain data from the nearest village or villages to the sample site. The socio-economic data that were collected using the questionnaire included social components such as the size of the family and population movements, the main economic activities and the main environmental problems as perceived by the villagers. The socio-economic data were obtained from three main sources: village leaders, villagers, guides from each division who accompanied the survey team within their areas and some district officers who were part of the team.

4.6 Data collection

The collection of socio-economic and environmental data was undertaken in three main phases: pre-field, field and post-field. The pre-field phase activities, which started in February 1998, included a preliminary literature review, a preliminary site visit and acquisition of study materials and equipment (rainfall data, remote sensing images, topographical and geological maps and a GIS). This was done both at the University College of Lands and Architectural Studies (UCLAS) and at the University of Cape Town (UCT). The main fieldwork was conducted in July and August 1999, involved collection of both environmental and socio-economic data by sampling and collection of data at the district and regional offices. The post-field work phase was carried out from the end of 1999 to 2002, and focused more on literature collection, review and analysis both at the UCLAS and at UCT.

4.6.1 Environmental data collection

The collected environmental data can be put into two main groups, namely permanent and variable. The permanent environmental data includes geology, fault lines, topography, and drainage. Geological information and fault lines were compiled from early 1960's geological maps, while the topographical data and drainage lines were extracted from 1960's and 1980's topographical maps of scale 1:50000. The variable environmental data used in the study include precipitation, semi-natural vegetation, landuses, water bodies, infrastructure and settlements. These were obtained from various sources, including, the Meteorological Department in Dar es Salaam for rainfall data, satellite imagery, the 1960's topographical and the 1999 fieldwork for landcover/use types. The physical data collection on sampling sites was done by using the ITC standard data sheet in which the four main types of data were recorded, i.e. the physical details of the site, soil data, and landcover/use. The location of the site was determined by means of a hand held Geographical Positioning System (GPS). On each sample site, soil auguring was carried out with a hand held auger to obtain soil data as indicated on the data sheet. The pH, color and texture of each soil horizon were all determined at the site by using a field soil testing kit. However, some soil samples from gully and irrigated areas were transported to the University of Dar es Salaam chemistry laboratory for further analysis on the chemical properties of the soils that can contribute to salinity or sodicity. The classification of different types of semi natural vegetation by structure was done use of pre-prepared vegetation structure graph. The size of sample varied from 2m x 2m for areas with homogeneous cover types to 20m x 20m for areas with heterogeneous cover types. The logic behind the variation of sample size is that in a homogeneous landcover all required parameters can be collected within a small area, while, a larger sampling area is necessary for a heterogeneous cover so as to maximize the collection varied types of parameters in sampling unit.

4.6.2 Socio-economic data collection

The socio-economic data collected and used in the research can be put into three main groups, demographic data, livestock keeping and agricultural and water supply service data. Demographic data includes history and culture of the Maasai people, which was obtained through a literature review supplemented by data from the questionnaire and interviews with elders and district officers. Data on livestock keeping was based on a literature review and participatory data collection and evaluation of the communities reports, which were conducted by the Monduli Development Program (MDP). Similarly, livestock keeping and agricultural data was also gathered through a literature review and supplemented by information gathered through the questionnaire. Data on water supply services were compiled by using remote sensing images, 1960's maps, interviews and a questionnaire. Data collection using a questionnaire was conducted during the ground truthing period in which a total of 45 questionnaires were administered. Due to the fact that sampling points were based on biophysical and not socio-economic parameters it is reasonable to say that data collected through the questionnaire might not represent the socio-economic conditions in all villages. However, combined data from literature reviews and from the questionnaire give a reliable indication of socio-economic conditions in the study area.

4.7 Data compilation and analysis

Once the data collection exercise was completed, the next step was the compilation and the analysis of data. The compilation and analysis of data undertaken with the data categorised broadly into environmental and socio-economic data. The environmental data were compiled and analyzed through a number of steps, from the digitizing to production of a land degradation map using the Integrated Land and Water Information System (ILWIS) GIS. The outputs of environmental data included landcover/use maps, landcover/change maps, trend of landcover changes maps, landcover/use change patterns and land degradation map. The socio-economic data were analyzed by using the MSACCESS database.

4.7.1 Landcover/use maps

A total of three landcover/use maps were compiled, *viz.* for the 1960's, 1991 and 1999 using the 1960's, 1991 and 1998 satellite and topographical maps respectively. The preparation of the landcover maps was accomplished through a number of steps. The first stage was interpretation of the satellite images and digitization of all environmental parameters such as the contour and drainage lines, settlements and infrastructure, different types of semi-natural vegetation, bareland, geology and fault lines. The landcover maps were then produced by combining the respective vegetation cover maps with drainage, infrastructure, and settlement maps. In each landcover/use map there are four main categories of landcover types, i.e. various types of vegetation, parcels of agriculture lands, bareland and gullies, and water bodies. The 1960's cover map has at total of 11 landcover units, the 1991 has 21 cover units and 1999 has 30 landcover units.

4.7.2 Landcover/use change maps

The determination of the cover changes was carried out after the compilation of the three landcover maps was completed. Land cover changes have been compiled by initially comparing the 1960's landcover map with the 1991, and then the 1991 cover map with 1999. The compilation of the change maps was carried out in two stages. Stage one comprised a direct comparison of cover types was made between 1960's and 1991 and 1991 and 1999. This gave an output which indicated the old and new landcovers as shown in Table.4.1. For example in land unit one, the landcover changed from grassland in the 1960's to agriculture lands in 1991.

Table 4.1 An example of output of landcover changes by direct comparison

Land unit	**1960's landcover**	**1991 landcover**	**1960/1991 landcover changes**
1	Grassland	Agricultural fields	Grassland/agriculture
2	Agricultural fields	Bushland	Agriculture/bushland
3	Bushland	Wooded bushland	Bushland/wooded bushland
4	Woodland	Bushed woodland	Woodland/bushed woodland

However, the direct comparison of cover types generated so many types of cover changes (more that 150 for 1960/1991) that it was difficult to work with these permutations. Therefore it was necessary to generalize so as to have fewer types of cover changes that could easily be analyzed. In stage two, an analysis was made to identify a system that could be used to categorize the cover changes in each of the main cover type into broader or general groups. This led to the development of a set of guidelines that were used to generalize the cover changes for each of the main cover types. For example, the basis for generalization of semi-natural vegetation cover changes was on whether the particular cover change has led to the loss of vegetation, regeneration of vegetation, vegetation structural improvement or structural loss (see Table 4.2). In land unit one for example, areas that were grasslands in the 1960's were used as agricultural lands in 1991. Therefore, effectively there was a loss of vegetation cover in unit one between the 1960's and 1991. In unit two there was vegetation regeneration because agricultural lands reverted

Table 4.2 An example of generalized cover changes for semi-natural vegetation

Land unit	**1960/1991 landcover changes**	**Generalized cover changes**
1	Grassland/agriculture	Vegetation loss
2	Agriculture/bushland	Vegetation regeneration
3	Bushland/wooded bushland	Structural improvement
4	Woodland/bushed woodland	Structural reduction

back to semi-natural vegetation (bushland). The following is an outcome of the generalized cover changes for each of the main cover type;

- Semi-natural vegetation cover

  Generalized cover changes: vegetation regeneration, i.e. the establishment of vegetation in a previously non-vegetated area; vegetation loss, that is the disappearance of vegetation from previously vegetated area, structural improvement; i.e. an increase in woody vegetation in an area; and structural loss, i.e. a decrease of woody vegetation in an area.

- Agriculture

  Generalized cover changes: agricultural loss, in which agricultural lands changed to other cover types, and agricultural expansion in which non-agricultural areas become agricultural lands.

- Gully and bare land

  Generalized cover changes, bare land and gully formation, in which new bare land and gullies are formed, and bare land and gully recovery, in which bare land and gullies are transformed into other cover types.

- Water bodies

  Generalized cover changes, shrinkage or expansion. Shrinkage implies a reduction in the size of the water body, and expansion implies an increase.

In complex units, for example, in a complex of fields and grassland, a partial loss of vegetation occurred when grassland cover changed to gullies but without any change in field cover. Partial change is applicable to all cover types.

4.7.3 Trend of landcover changes

After establishing the landcover changes between the 1960's and 1991 and 1991 and 1999, the next stage was to determine the trend of landcover changes from the 1960's to 1999. The purpose of determining the trend of landcover changes was to establish the dynamics of the cover changes in relation to rainfall variability and human activities on the assumption that the non-equilibrium model applies to the study area. The logic behind this is that, since the area is a dryland assumed to be operating as a non-equilibrium system, it therefore follows that vegetation cover changes will be both due to rainfall variability and anthropological activities. The challenge is then to differentiate landcover changes brought about by rainfall variability and anthropological activities. This challenge was overcome by the use of three "wet" years landcover maps (instead of traditional two) due to the fact that it is possible to identify areas that have continuously lost vegetation from the 1960's to 1999 and areas that have lost and regained vegetation between the three years. Areas, which continuously lost vegetation, were predominantly subjected to human activities that led to vegetation loss. While areas that lost and regained vegetation were less subjected to human activities that led to permanent vegetation loss, therefore vegetation changes in such areas was assumed as being due to rainfall variability. Rainfall variability was identified as the main factor in areas that had loss/reduction and regain in vegetation due to the fact that there were differences in the amount of rainfall between the three "wet" years. The 1999 was the wettest followed by 1964 and least of all was 1991. Theoretically this means if that all other things remain the same, processes that may lead to a reduction of vegetation structure would be more dominant between the 1960's and 1991 because it is a change from a "wet" year to a less "wet" year. While processes that may enhance vegetation structure would be more dominant between 1991 and 1999 because it is a change from a less "wet" year to a much more "wet" year

The trend of landcover changes were investigated in three stages, stage one was carried out by comparing the extent of the coverage of each of the four main landcover types for the 1960's, 1991 and 1999. Secondly, and more important, the establishment of the overall changes (that is without considering the locality of change), and specific (that is in each land unit) dynamics of semi-natural vegetation changes. The overall semi-natural vegetation dynamics were established by comparing areas that lost or regained vegetation in one way or the other between the 1960's/1991 and 1991/1999. The specific vegetation dynamics in each land unit were established by comparing landcover changes between the 1960's/1991 and 1991/1999. Table 4.3 is an example of types of the vegetation changes generated by the combination of the two landcover change maps. In land unit 1, for example that there was vegetation regeneration between the 1960's and 1991 and structural improvement between 1991 and 1999.

Table 4.3 An example of vegetation cover changes generated by combining 1960's/1991 and 1991/1999

Land unit	**Vegetation cover changes, 1960's/1991 and**	**Vegetation cover changes 1991/1999**	**Trend of vegetation cover changes 1960's to 1999**
1	Vegetation regeneration	structure improvement	Vegetation regeneration/structure improvement
2	Structure reduction	structure improvement	Structure reduction/structure improvement
3	Structure reduction	vegetation loss	Structure reduction/vegetation loss

Similarly, for unit 2, in the 1960's/1991 there was structural reduction followed by structural improvement between 1991/1999. The third stage was then to consolidate the 37 types of trends of semi-natural vegetation determined in stage two into general groups which could indicate vegetation dynamics in each land unit in simple terms such as decrease, increase or no change of vegetation between 1960's to 1999. Table 4.4 is an example of two types of trends of vegetation cover changes. Type one showed an increase vegetation between 1960's and 1991 and decrease in vegetation between 1991 and 1999, type two showed a decrease in vegetation between the 1960's and 1991 and increase in vegetation between 1991 and 1999.

4.7.4 Landcover/use change pattern

Once the trend of landcover changes was determined, the next stage was to establish the pattern of landcover changes. The main purpose of determining the patterns of landcover changes was to try to establish both the natural and socio-economic factors involved in landcover/use changes.

Table 4.4 Example of generalized trends of semi-natural vegetation covers changes from 1960's to 1999

Type 1	**Increased/decreased**
	Vegetation regeneration/vegetation loss Vegetation regeneration/structure loss Structure improvement/vegetation loss
Type two	**Decreased/increased**
	Structure reduction/vegetation regeneration Vegetation loss/vegetation regeneration Structure reduction/structure improvement

The pattern of landcover changes was established by comparing the landcover changes, for both 1960's/1991 and 1991/1999, against physical and socio-economic parameters. The physical and socio-economic parameters that were used to analyze the patterns are geology, relief, population density, agricultural and livestock keeping. Using STATISTICA program version 5.5, a statistical analysis was carried out in order to establish the statistical evidence of the relationship between the different types of cover change and physical and socio-economic parameters.

4.7.5 Determination of land degradation

Land degradation in the study area was determined based on the degradation processes of semi-natural vegetation and soil. There are number of steps which were followed in assessing land degradation.

- The first step involved the determination of vegetation and soil degradation processes by using landcover changes data. Based on the trends of landcover changes some of the semi-natural vegetation cover changes were classified as degradation. The main criterion used to make this categorization was the loss or decrease in vegetation without recovery, either between the 1960's and 1991, or between 1991 and 1999 (despite the high amount of rainfall between 1991 and 1999). Similarly, based on the cover changes from 1960's to 1999 all areas that were identified as barelands, gullies or subjected to chemical deterioration were considered as undergoing soil degradation.

- Step two involved the preparation of semi-natural vegetation and soil degradation maps based on the already identified vegetation and soil degradation processes.

- Step three was the preparation of land degradation map using the semi-natural and soil degradation maps.

- The last step was the determination of the natural and anthropological causes of land degradation partly based on the statistical analysis made on the patterns of landcover changes.

4.8 Conclusion

The research design has been established so as to meet the overall aim of developing a land degradation assessment that will be able to distinguish between natural and anthropological vegetation changes through the use of three sets of landcover maps synchronized against long term rainfall variability, determine both soil and vegetation degradation processes, holistically assess land degradation as due to both natural and anthropological factors. In this regard;

- The exploration of the literature was such that it included all the basic elements of land degradation, such as definitions, dryland characteristics, processes, causes, consequences political ecological aspects and assessment of land degradation.

- The selection of the case study area was made in such a way that it reflected a typical dryland area of Tanzania faced with land degradation problems and that has historical biophysical and socio-economic data to facilitate the research.

- The choice of remote sensing images in terms of types, timing and numbers, and of historical maps, is based on long term rainfall data with the ultimate aim of using them for separating natural and anthropological vegetation changes.

- The interpretation of the remote sensing has been done by visual means due to the fact that it is rapid and accurate and can easily be used by workers in developing countries as it requires less technical inputs.

- The basic principle used in the design of the sampling framework was that a sample was to be taken for every type of landcover found in the different terrain units. The selection of sampling points was based on the 1998 TM image, which insured that up date biophysical and socio-economic data was collected.

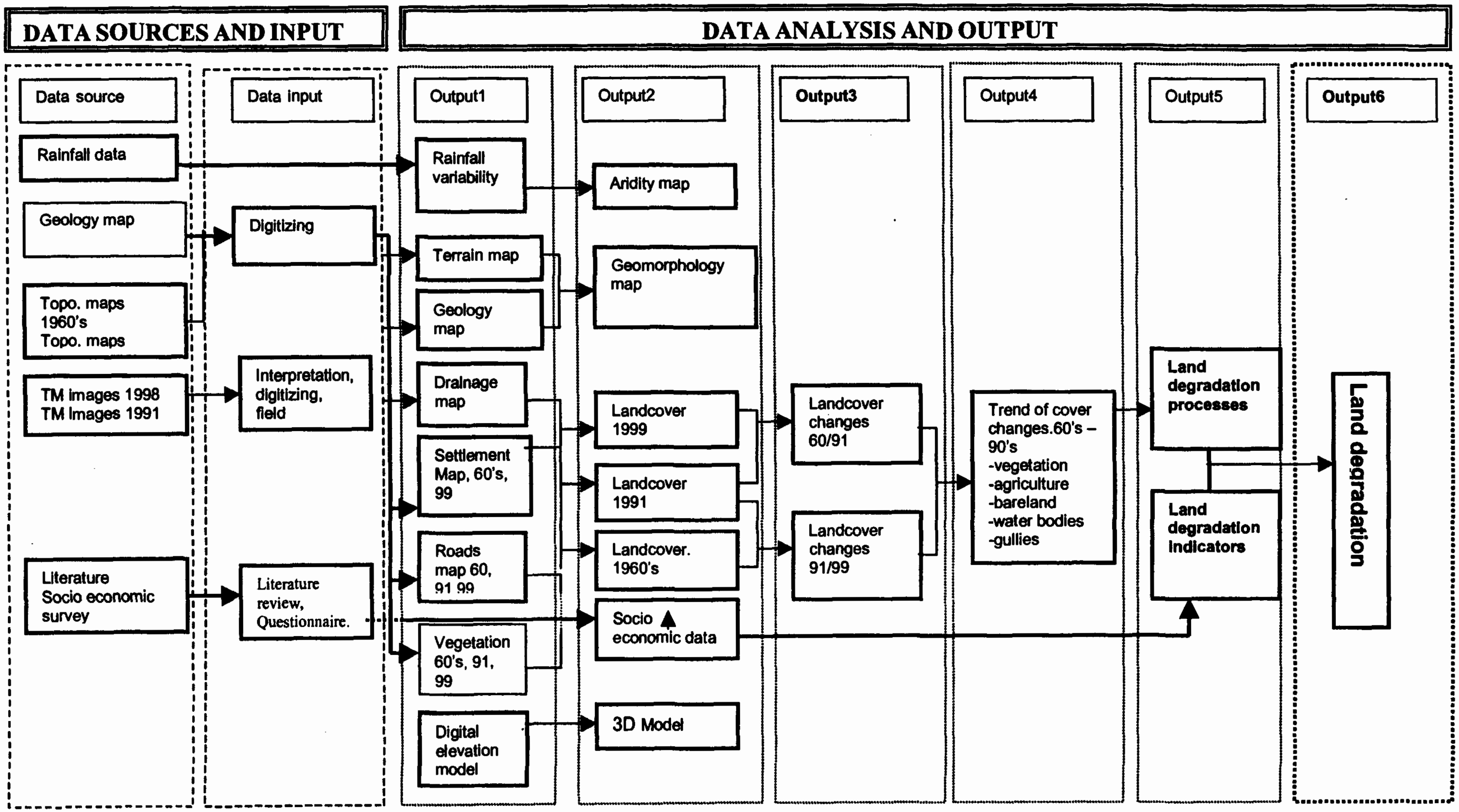
- The collection of biophysical and socio-economic data was done in three main phases, pre-field work, mostly literature review and collection of materials and equipment, at UCLAS and UCT, fieldwork, biophysical and socio-economic data in Monduli and post-fieldwork, mostly literature review at the UCLAS and UCT.

- The data analysis and compilation was done through a number of steps and using various types of materials and equipment (Table 4.5 and Figure 4.2). Starting with digitization, production of different layers of maps, the compilation of three landcover maps for the 1960's, 1991 and 1999, production of change maps and, finally, land degradation maps. All these steps were followed so that land degradation could be assessed as being due to both vegetation and soil degradation, and caused by natural and anthropological factors.

Table 4.5 Materials used in the research project

Type of material	Details	Use
Rainfall data	-24 rainfall stations -Length of record 62 to 7 years	Determination of aridity index and rainfall variability
Remote sensing data	-TM imagery, 15th June 1998 (end of wet season) -TM imagery, 15th September 1991 (dry season) scale 1:100000	Landcover maps 1991 and 1999.
	-Airphotos, 31st January 1962, scale 1:30000 -Airphotos, 20th December 1982, scale 1:80000	Detailed landcover/use for small part of the study area.
Maps	1960's topographical maps 1960's field maps for landcover verification.	Terrain, drainage and 1960's landcover/use map
	1960's geological maps	Geology and fault lines
Socio-economic data	Population dynamics, livestock, agricultural activities and water services	Anthropological factors for land degradation and indicators of land degradation

Figure 4.2 General approach used in the study



CHAPTER FIVE

5. LAND DEGRADATION AND INTERVENTIONS IN TANZANIA. A HISTORICAL PERSPECTIVE

5.1 Introduction

Tanzania is located in East Africa and lies between latitude $1^0 - 12^0$ South and longitude $30^0 - 40^0$ East. According to NEMC (1990), Tanzania has a total area of 942,000 km^2, of which 61,500 km^2 consists of water bodies. Figure 5.1 shows the administrative regions in Tanzania. The population of Tanzania currently stands at about 30 million and this is growing at a rate of 2.8% per annum (D. E., 1998). Traditional agriculture and livestock-keeping remain the main economic activities of the majority of people in Tanzania and this emphasizes the importance of sound information regarding the problems of land degradation. There are no reliable data on the extent of drylands in Tanzania, although three-quarters of the country receives less than 1000mm of rainfall per annum (NEMC, 1990). The figures on the extent of the drylands differ from report to report. For example, the second draft report, the National Action Program to Combat Desertification in Tanzania, prepared by the Division of Environment in 1998 gives a figure of 61% being drylands. Darkoh, (1985), on the other hand, gives a figure of 45 to 75%, and Peberdy (1969), cites 60 to 70%. These differences may be due to different precipitation thresholds used to estimate or calculate the extent of the drylands. For example, the Division of Environment (1998) classifies all areas receiving between 400mm – 800mm/year as drylands, NEMC (1990) uses 400mm – 750mm/year and Darkoh (1997) uses 200mm – 800mm/year. It is important to note that, even though methodological details used to estimate the extent of dryland in Tanzania are not always clear, it seems that estimates are usually based on mean annual rainfall and not on aridity.

Figure 5.1 Administrative regions in Tanzania

Source: NEMC (1990)

5.2 Land degradation in Tanzania

Land degradation is undoubtedly one of the key problems acknowledged to be facing Tanzania, but there are inadequate data at the national level to ascertain the types, extent, causes and rate of land degradation (Darkoh, 1985; Division of Environment, 1998). In several reports, for example UNSO (1990) and the

Division of Environment (1998) the extent of land degradation is merely regarded as the equivalent of the extent of the drylands. The regions regarded as most severely affected are Shinyanga, Arusha, Singida, Mara, Dodoma, Iringa, and some parts of Kilimanjaro, Tanga, Morogoro and Tabora (Figure 5.1). Land degradation is not necessarily only a recent problem in Tanzania, since it has been recorded from the beginning of this century (Gillman, 1930). Nevertheless, the type, extent, causes, remedies and perceptions of land degradation in Tanzania, as elsewhere, has been has been changed with time. In Tanzania these changes can be recognized as belonging to three main phases, *viz.:* a) the colonial period, b) the early days of independence, i.e. 1960's to late 70's, and c) the 1980's to date.

5.2.1 Land degradation: Colonial period up to Independence

The history of land degradation in Tanzania (then Tanganyika) during this period is well documented in a number of writings including Berry and Townshend (1973), Rapp *et al.* (1973a, b, c), Temple and Murray-Rust (1973), Temple (1973), Murray –Rust, (1973), Christiansson, (1973) and Darkoh, (1987). The conventional terms used to express the idea of land degradation during this period were 'soil erosion' and 'overgrazing'. The term land degradation itself did not appear in the literature at all at this time and is first identified in late 1970's. Soil erosion and overgrazing are, however, used as synonyms for the term for this period. Land degradation during this period can be divided into three main phases. Firstly, prior to the 1930's, the government appeared to pay little attention to issues of land degradation. 1930 to 1940 marked a period in which the Government of Tanzania first recognized land degradation as a problem and subsequently by initiated land degradation control measures. From the 1940's to mid -1950's, large-scale land degradation control schemes were established.

a) Types, extent and causes of land degradation

According to Gillman (1930), soil erosion was already a problem in Tanzania earlier in 20th century but was concentrated mainly in densely populated semi-arid areas with tilt-block topography and loose shallow granitic soils, in particular in Central Tanzania. The areas most affected included parts of Dodoma, Singida and the Shinyanga Regions (Figure 5.1). These are areas where the local population practised both livestock keeping and agriculture. However, pure pastoralist areas, such as the Maasailand, did not experience soil erosion because the shortage of water supplies acted generally as a safeguard against overstocking. Berry and Townshend (1973) explain that the government's serious concern over soil erosion started in 1929 when Mr. E.H. Harrison, who had an interest in soil erosion, was appointed Director of Agriculture. He decided to make soil conservation a priority, probably in part due to the fact that soil erosion was gaining prominence elsewhere in scientific circles arising out of the dust bowl issue in the USA (Berry and Townshend, 1973). Subsequently, according to Berry and Townshend (1973) in 1929, a conference was held in Dodoma, which culminated in the establishment of an Advisory Committee on soil erosion. In 1931, the committee identified the densely populated mountainous areas of Uluguru, Kilimanjaro, Pare and Usambara, together with the overstocked semi-arid pastoral areas of Central Tanganyika, such as Usukuma and Maasailand, as areas with the most serious soil erosion problems. The main causes of soil erosion were understood to be agriculture and steep topography in the hilly areas. The committee initially identified the main causes of soil erosion in the pastoral areas as being overgrazing and the burning of the vegetation, especially in the Northern Mbulu District. However, at a meeting in 1936, the committee was informed that the main cause of degradation in the Central Province was incorrect cultivation and overstocking methods (Berry and Townshend, 1973).

b) Land degradation assessment and control methods

Berry and Townshend (1973) elaborate on government policy and practice in the 1930's and early 1940's and note that it was aimed at persuading people through their local authorities to adopt improved land use methods to control soil erosion. This approach was followed because there were no funds to carry out large scale schemes to control soil erosion. As a result of this, a number of demonstration plots were set up in the mountain areas of Kilimanjaro, Usambaras, Pares and Mount Meru in order to convince the native authorities as to the benefits of improved land uses (Berry and Townshend, 1973). In addition, experiments were carried out at agricultural research stations throughout the country to measure soil and water loss from the land under different types of vegetation cover. They also measured yields of coffee and cotton under different management systems and attempted to find out which were the most suitable pastures for use in the Central Province. These studies continued up to 1950's (Berry and Townshend, 1973). Berry and Townshend (1973) and Darkoh (1987) point out that, in the 1940's, in Central Province, thousands of miles of contour banks were constructed by the local people under the supervision of the Department of Agriculture and extension staff to prevent soil loss. In addition, a number of areas were set aside for controlled grazing experiments which included, among other things, depopulation and destocking. In 1944, a comprehensive development scheme was drawn up to cover the period 1947 to 1956. 1.5 million sterling was allocated to a number of agricultural schemes covering 68,500 sq. miles and affecting two million people; the soil conservation service was established in 1945 (Berry and Townshend 1973). The two main projects initiated were the Sukumaland resettlement and the Kolo rehabilitation. The main objectives of both projects were to educate people on improved methods of land use and to resettle the excess population and livestock in new areas in order to control soil erosion. The other smaller schemes were in Maasailand and Mbulu District. In the Mbulu District, the main objective was to control the tsetse fly by bush-clearing in the surrounding settled areas, and cattle culling to reduce stock densities. In Maasailand, meanwhile, the objective was the provision of better water supplies in order to improve livestock distribution by using wet season forage over a much longer period. Two other major schemes were planned for Uluguru and Usambara mountain areas and seven other small schemes were planned in different parts of the country (Berry and Townshend, 1973).

All the schemes were subject to sets of rules and orders, without necessarily taking into account local traditions and technologies. Therefore, the policy of the government after 1944 can be said to be one of direct action, manifested through schemes which had developed systematic orders and rules (Berry and Townshend; 1973; Darkoh, 1987). For a number of reasons, as documented by Berry and Townshend (1973) the success of the soil erosion control schemes was, nevertheless, limited. Firstly, there was a shortage of trained personpower and secondly, the climate, especially in the semi arid areas resulted in conservation structures being washed away during heavy downpours. This meant that the local people were always repairing the conservation structures instead of building new ones. Thirdly, the rules and orders built into the schemes challenged the peasant's economic security. Fourthly, there was a lack of appropriate planning in the early stages of the projects. As a result, there was a negative reaction against the schemes and it became a political issue used against the government. By 1958, government efforts had stopped and the local people started demolishing the conservation structures (Berry and Townshend, 1973; Darkoh, 1987). Apart from large scale schemes carried out during this period, a number of studies concerning water balance in water catchments were carried out by East Africa Agriculture from 1956 onwards in all three East African countries: Tanzania, Kenya and Uganda (Pereira, 1962). In addition, the soil conservation service attempted to review soil erosion in Tanganyika between 1951 and 1952 (Berry and Townshend, 1973).

3.2.2 1960's to late 1970's

At this juncture, the term land degradation was still being used in the context of soil erosion and overgrazing. This period can be viewed as one of relatively low profile in terms of government efforts in respect of conservation issues, especially in the early years of independence. There are two possible reasons why the government took a low profile during this time. Firstly, conservation programmes were used as a political weapon against the colonial government. TANU, the then ruling party after independence had, prior to independence, used conservation schemes to stir up sentiment against the colonial government (Cliffe, 1964; 1991; Darkoh, 1987), so it was not easy to reactivate the programs quickly after independence. Secondly, the new government was busy consolidating its political and economic powers (Darkoh, 1987; Muheto, 1995). However, in the late 1960's, the government began to acknowledge the importance of the proper use of land in the country. This is reflected in the Arusha Declaration of 1967, which declared Tanzania to follow the socialist path of development (Nyerere, 1974). The Arusha Declaration emphasized that land was the basis of human life and that all Tanzanians should view it as a valuable investment for future development (Nyerere, 1974). The second five year development plan, 1969- 1974, also advocated proper land use (Darkoh, 1987).

Even though the government took a low profile on environmental issues, key events relevant to land degradation occurred during this period. Examples of such events include the Ujamaa villagisation, which led to the formation of the Ujamaa villages. The formation of the Ujamaa villages had an impact on the utilization of the natural resources in rural areas because of the change of the settlement pattern from dispersed traditional settlements to concentrated settlements (Kiunsi, 1994). In fact, events like this are likely to continue to influence the issues around land degradation in Tanzania for many years to come. During this period an important research on erosion problems in Tanzania was carried out through the Dar es Salaam/Uppsala (DUSER) project between 1968 and 1972 (Rapp *et al.*, 1973a). The main objective of the DUSER project was to obtain reliable data on the types, extent and rates of soil erosion and sedimentation. This was necessary because until this time there had been no consensus on the severity and economic consequences of soil erosion. The research was confined to the semi-arid areas of Central Tanzania and Arusha, and the mountain areas of Uluguru in the Morogoro Region, which generally have reliable and heavy rainfall.

a) Types, extent and causes of land degradation

Erosion was clearly a serious problem in both mountainous and semi-arid areas at this time. According to the findings of Rapp *et al.* (1973a), Christiansson, (1973), Rapp *et al.* (1973b), Temple (1973), Temple and Murray–Rust (1973) and Rapp *et al.* (1973c), the main types of soil erosion in the mountainous areas were rainsplash, sheet erosion, rill erosion and episodic landslides. In semiarid areas, however, soil erosion types differed from one location to another as follows. In the Dodoma District, splash and sheet erosion were prominent, whereas in the Kondoa District, which is in the rift valley and its topography partly determined by fault lines, extensive sheet and gully erosion prevailed. In the Singida Region, sheet erosion and wind erosion in gently undulating plains was common, while splash, sheet and gully erosion dominated in slopes along the fault lines. West of Arusha Town, splash, sheet and gully erosion were the dominant forms of erosion evident (Murray-Rust, 1973). The findings also revealed that hilly areas had lower rates of soil erosion than the semi-arid areas which are, in general, more gently sloping. The calculated average annual soil erosion between 1966 and 1970 in the Morogoro river catchment was 0.26mm/year, which is equivalent to a sediment yield of 390 tons/km^2 (Rapp, *et al.*, 1973b). Soil erosion measurement using erosion plots from mountainous areas showed the annual soil loss to vary from 24mm to 83mm/year (Rapp, *et al.*, 1973b). Soil loss measurements using water reservoirs in the Dodoma

District, a semi arid area, varied from 0.2 to 0.73mm/year corresponding to a sediment yield of between 195m^3 to 729m^3/year (Rapp, *et al.*, 1973c). Soil loss on erosion plots with grass cover at the Mpwapwa research station in the Dodoma Region was, on average, eight times more than similar but wetter plots at Tengeru station in Arusha (a mountainous area), while for maize plots, the erosion rates were ten times greater (Temple, 1973).

In all case studies human activities, i.e. cultivation and livestock keeping, were considered to be the main factors triggering soil erosion. However, studies in Dodoma and Kondoa did show that some gullies had been stable since the 1940's (Christiansson, 1973). This meant that recent human activities did not contribute to the formation of the gullies, but that they were more likely formed as a result of uplift caused by tectonic activity (Christiansson, 1973). In Arusha, in the Kisongo area, historical reasons including the movement of the Arusha people from the fertile soils east of Mount Meru to the marginal Maasailands contributed to soil erosion (Murray-Rust, 1973). This is because the Arusha people are both farmers and livestock-keepers, and after moving in to the marginal areas they continued with the same activities and this increased pressure on the land, hence contributing to soil erosion (Murray-Rust, 1973). In 1973, probably as a consequence of the DUSER research, the Kondoa soil conservation project (HADO) was started with the main aim of rehabilitating 125,000 hectares of badly eroded land through improved farming methods, afforestation and destocking. In 1979, a by-law was passed prohibiting grazing in the project area and, as a result, 90,000 head of cattle from 19 villages were removed from the project area (Muheto, 1995).

The formation of the Ujamaa villages influenced the use of natural resources in the rural areas. Villagisation involved moving villagers from their traditional settlements to communal villages where it proved easier to provide social services and carry out joint economic activities. The main problem as far as land degradation is concerned was that no resource assessment was carried out in the locations of the new communal villages. This led, in many cases, to the degradation of land in the communal villages and the surrounding areas (Missana and Nyaki, n.d.; Schuler, 1991; Kiunsi, 1994). For example, ILO (1982), Mzava (1989) and MLNT (1989) all cite the progressive disappearance of woody vegetation from the populated village centres, especially in Dodoma, Singida, Shinyanga, Arusha and Tabora Regions. In 1977, the government prepared a paper highlighting what was now called the desertification problem in Tanzania, especially in the semi-arid areas of Tanzania. This paper was presented to the 1977 UNCOD meeting in Nairobi (United Republic of Tanzania, 1977).

b) Land degradation assessment and control methods

A number of approaches were used to assess land degradation in mountainous and semi-arid areas. In mountainous areas, the measurement of soil and runoff losses of a river catchment was through field studies by sampling and analyzing sediment load in the river (Rapp *et al.*, 1973b). The characteristic of the catchment in terms of landcover/use including erosion features was determined by the use of airphotos followed by a field check (Rapp *et al.*, 1973b; Temple and Murray - Rust, 1973). Data from field studies were supplemented by data obtained from small experimental plots on soil erosion and sedimentation, which were carried out at Mfumbwe, Eastern Uluguru (Temple and Murray-Rust, 1973). In semi-arid areas, three main approaches were used. Firstly, the reservoir sedimentation survey involved the determination of sediment volume deposited in reservoirs in four catchments in Dodoma District. Again, just as in the mountainous areas, the landcover/use (including erosion features) was determined by the use of airphoto interpretation and field check. The same approach was used to study soil erosion problems in a grazing area north west of Arusha Town (Murray-Rust 1973). Secondly, in Kondoa, field studies using sequential airphotos and field check at the district level were used to determine landcover/use including soil erosion (Christiansson, 1973). Lastly, in the Singida District, field studies were carried out using only 1960 air photos and a field check (Christiansson, 1973).

5.2.3 Period post 1980

This period is marked not only by increased government efforts to solve environmental problems in general, but also by increased involvement of the international community in environmental management in Tanzania. This is reflected by the introduction of new policies, institutions, plans, projects, public awareness and increased funding especially from the international community. This period is also marked by the continuous changing of key players in leadership in issues of land degradation management from, initially, the Ministry of Agriculture to Division of Forestry to the National Environmental Management (NEMC) Council to the (now) Division of Environment (DE). A number of projects and programmes such as "Land and Water" in certain districts of the Iringa Region (HIMA), Shinyanga Land and Water Conservation project (HASHI), and Man-land Interrelations in Semi-arid Tanzania (MALISATA) were implemented to mitigate land degradation (Muheto 1995; Kikula, 1996). MALISATA was a continuation of HADO in Kondoa District. It was also during this period, especially in the mid 1990s, that the initial stages of the expansion of the land degradation concept occurred in Tanzania to include not only soil and vegetation degradation but also socio-economic aspects of land degradation and productivity.

a) Types, extent and causes of land degradation

This period is marked by varying opinions as to the nature and extent of land degradation in Tanzania but also a realization that it is location- specific, that is, the types of land degradation and their causes differ from one location to another (Kikula, *et al.*, 1991). In the early eighties, the government perceived deforestation as the main land degradation issue and a figure of 400,000 hectares of forestland disappearing annually was commonly quoted (Missana and Nyaki, N.D; Lema, 1990; Kiunsi, 1994). In the 1990's, the government, through NPACD, changed its stance on the nature of land degradation, clearly stating that desertification was the major environmental problem in the semi-arid areas of Tanzania. Desertification, as defined by NPACD at that time was seen as a process of enhanced deterioration in the symbiotic Nature-Man production system which had reached a high degree of adaptation to the arid and semi-arid conditions, through a long interaction between human societies and their environments (NEMC, 1990). This view was supported by research done by the Institute of the Resource Assessment (IRA), in Sukumaland, in the early 90's which showed that, apart from deforestation, overgrazing and soil erosion were the main land degradation problems in the area (Kikula, *et al.*, 1991). Also, research in the MALISATA project in the mid-1990's showed that soil erosion was still the main environmental problem in the Kondoa District, Central Tanzania (Shishira and Payton, 1996; Christiansson, 1996). This period is also marked by the broadening of the concept to include not only the effects of land degradation processes on soil properties but also on soil productivity as well as socio-economic aspects. For example, Shishira and Payton (1996) realized that farmers had ceased cultivating ferric lixisols on pediment mid-slopes because of the decline in soil productivity and that there had been changes in the soil quality in low-lying areas due to soil and sediment deposition. Mbegu (1996) shows that there was an increase in crop yields in the Kondoa area, from 200 to 300 kg harvested before the HADO project to 600 and 1000 kg from one acre (0.4 ha) after the HADO project, attributed mainly to the recovery of the soils. Back'eus *et al.* (1996) discussed changes in vegetation productivity in formerly eroded areas in terms of both structure and floristic changes as a result of the HADO project. Mohamed (1996) and Loiske (1996) discuss some socio-economic aspects relevant to land degradation at the village level in Kondoa and Hanang

Districts. These include farm sizes, farm layout, farm implements, use of organic fertilizers, labour input land tenure and indigenous knowledge of the local people on land degradation issues. Dejene *et al.* (1997) arrived at the following conclusions for farmers in the Kondoa District, *viz.* firstly, farmers were indeed aware of the land degradation taking place in their surroundings, based mainly on the perception and interpretation of the indicators regarding conditions of their crops and pastures and secondly, that there is a wealth of indigenous knowledge to be tapped in developing plant species indicators closely linked to soil erosion, decline in soil fertility or degradation of the pasture.

During this period there has been a general consensus that a combination of anthropogenic and natural factors cause land degradation. Nevertheless the emphasis as to the main cause changes from time to time and also differs from one place to another. For example, in the early 1980's, the main reason for deforestation was thought to be the cutting of the trees for fuelwood requirements, but by the mid- 1980s, it was realized that agriculture was probably the main cause of deforestation (Lema, 1990; Kiunsi, 1994; Missana and Nyaki, N.D.). Kikula, *et at.* (1991) emphasize that land degradation in Sukumaland was caused both by farming and livestock activities. NEMC (1990) in the National Plan of Action to Combat Desertification, argues that extensive grazing practised by pastoralists is not considered as a significant agent of land degradation, as long as there is no external interference, for example through the introduction of farming activities. In the Kondoa District, according to Shishira and Payton (1996), and Erickson (1996) soil erosion has been divided into two episodes: recent erosion is triggered by human activities while historically tectonic activities were important. NEMC (1990), Kikula, *et al.* (1991) and Christiansson (1996) all agree on the importance of including historical factors in fully understanding land degradation in Tanzania. Examples of historical factors include projects for the eradication of the tsetse fly by clearing woodland as was done in different parts of the country, the introduction of cash crops such as cotton, which led to the clearance of vast areas of vegetated land (Kikula, *et al.*, 1991). Others included the increase in demand for food supply during the First World War as was the case in Kondoa Town that served as a granary first for the Germans and later for the British, where marginal lands were cultivated to provide food for soldiers (Christiansson, 1996)

b) Land degradation assessment and control methods

A number of methods mostly involved in assessing land degradation processes rather than their consequences were used to assess land degradation on differing scales. For example, in the early eighties, when it was considered that deforestation was the main form of land degradation due to fuelwood consumption, a fuelwood per capita consumption of $1.0m^3$ was used to calculate the demand for fuelwood per year (NEMC 1990). This was then translated into the amount of vegetation per hectare removed per year (Kiunsi, 1994). Later, when this approach was abandoned, field studies based on remote sensing and field check were predominantly used. For example, many of the MALISATA studies in the Kondoa District and other land degradation studies in the Arusha Region and elsewhere used field studies based on remote sensing (Kiunsi, 1993; NEMC, 1993; Ericksson, 1996; Shishira and Payton, 1996; Back'eus *et al.*, 1996; Yanda, 1996). Both aerial photographs and satellite images especially SPOT and TM images were utilised in a number of projects. Land degradation or, at times land cover changes, were determined by comparing sequential remotely sensed images. No consideration was given to landcover changes due to inter-annual climatic variables or image seasonality. This, in many cases, led to all landcover changes that were determined as being classified as land degradation. On the positive side, socio- economic aspects were included in some surveys (Shishira and Payton, 1996; Mohamed, 1996; Yanda, 1996; Dejen *et al.*, 1997) and an attempt was made to determine the effect of long term rainfall variability on land degradation (Ngana, 1996). A few studies also included changes in land productivity due to land degradation (Shishira and Payton, 1996). The recently proposed National Action Program to Combat Desertification was prepared by informed opinion method. Different scales have been used to assess land degradation during this period. For example, the extent of land degradation or the extent of deforestation as it was in the early 1980's was assesed at the national level (Kaale, 1983; Kiunsi, 1984; Vice President's Office, 1999). Many of the other assessments were carried out either at the district (e.g. MALISATA) project or sub-district level, (e.g. baseline mapping for monitoring of desertification in Tanzania (NEMC, 1993; Kikula, 1996). Also during this period a number of institutions, policies and plans were introduced or created to mitigate land degradation. The details of each are as follows:

i) Building institutions of land degradation control

After realizing that Tanzania was faced with many environmental problems cutting across all sectors, the government decided to make a new institutional arrangement to enable a more holistic management of environmental issues. In 1983 and 1984 the government established The National Environmental Management Council (NEMC) and the Land Use Commission (LUC) respectively. NEMC was given a wide range of tasks and powers including advising government on all matters related to the environment, coordinating activities of all parties concerned with environmental issues, promoting environmental research and education and initiating and even conducting projects in environmental management. The function the LUC had was to be the principal advisory organ of the government on all matters related to land use planning, with the conservation of land resources being the overriding principle (Muheto, 1995; NEMC, 1990). In 1985, the UN General Assembly endorsed the eligibility of Tanzania to receive assistance through the United Nations Sudano-Sahelian Office (UNSO). As a result, in 1986, a Drought and Desertification Control Unit was established in the National Environmental Management Council (NEMC, 1990) while, at the same time, the UNSO undertook a review of past and current activities to curb the depletion of the natural resources in Tanzania.

In 1990, the government established the Division of the Environment (DE) in the Ministry of Natural Resources and Tourism. The main function of DE was to deal with environmental policies, laws and overall planning. In principle, DE is supposed to work closely with NEMC through the setting of overall policy, law and planning frameworks, while NEMC does the actual groundwork. In order to give a higher profile to environmental issues the government moved both NEMC and the Division of the Environment to the Vice- President's Office. It was expected that this would facilitate faster communication between the Division of the Environment and the other Ministries regarding environmental issues. In addition to institutional policy and legal strengthening at the national level, other activities took place aimed at enhancing environmental protection. These included the establishment of an Environmental Information Centre (under NEMC) and regular broadcasting of radio programs on environmental issues. These two strategies were proposed in the earlier National Plan of Action to Combat Desertification prepared in 1990 by NEMC. The Tanzania Natural Resources Information Centre (TANRIC) was also established under the Institute of Resource Assessment. TANRIC is, in essence, the main natural resources data bank. In 1996, TANRIC, in collaboration with the Ministry of Lands, produced the first land use map of Tanzania on a scale of 1:250,000.

ii) Policies geared to control land degradation

During this period, the government formulated a number of policies all geared in one way or other to enhance environmental management and protection. Several national policies relevant to land degradation have thus far been introduced: The National Environmental Policy was introduced in 1997 with one of its broad objectives to control degradation of land, water, vegetation and air. It was also used as a base in formulating sector policies relevant to environmental issues (Vice President's Office, 1997). The Agricultural Policy was introduced in 1993 and, among other things, advocated soil conservation through various means. The 1998 Livestock Policy advocates the improvement and conservation of grazing lands. The Energy Policy (1992) has, as one of its central objectives, the minimizing of woodfuel consumption through the development of alternative energy sources. The 1997 Forest Policy is in part aimed at ensuring ecosystem stability through the conservation of forest biodiversity, water catchment areas and soil fertility (MNRT, 1998). The 1995 Land Policy advocates sustainable land development and an increase in land tenure security to the rural population by giving rural settlements certificate of land ownership. Other policies geared at enhancing environmental protection include Water Policy, Wildlife Policy, Tourism Policy, Industrial Policy and Mining Policy (D.E., 1998; MEM, 1997). In 1997, the government ratified the international Convention to Combat Desertification. This means that, starting in 1997, land degradation strategies in Tanzania will use the guidelines as set out in the Convention to Combat Desertification.

iii) Mitigation plans for land degradation

In the 1980's the Prime Minister's Office produced zonal land use plans covering the Lake zone, the *Uhuru* corridor zone, and the Central and Northern Zones. One of the main objectives of these plans was to try to control land degradation through physical planning. In 1983, a five-year national village afforestation plan was produced which set out, among other things, the number of trees to be planted in each district (Kaale, 1983). The belief that forests were disappearing because of domestic energy needs led to a nationwide campaign of afforestation and the utilization of improved charcoal stoves, kilns and the use of biogas (Kaale, 1982). Kiunsi (1994) outlines the performance of this afforestation programme which, through the campaign to plant more trees, proved to be of only limited success. For example, between 1973 and 1978, the target was to plant 129,000 ha per year, but only 6,437 ha were actually planted. By 1986, only 12,440 ha were planted annually compared with the expected target of 200,000 ha per year (Kiunsi, 1994). There were many reasons for this poor performance, including the non-availability of seedlings, poor survival rates, (because the woodlots were normally allocated in poor soils) and the low level of incentives for the villagers to plant the trees because of the long maturing period. However, there was some success in the use of improved cooking stoves, for example many of the urban (as opposed to rural) dwellers have freely adopted the improved stoves.

In 1989, the Division Forestry of the Ministry of Natural Recources and Tourism prepared the Tropical Forest Action Plan (TFAP) covering the period 1990/91-2007/8. Its main aim was to improve the forestry sector through projects geared to control land degradation. Relevant projects include forest management, bio-energy, people's participation, forest research and ecosystem conservation (MTNRE, 1989). Its performance to date is difficult to assess, but it seems the proposed projects were not as well funded as had been expected. In 1990, the National Plan of Action to Combat Desertification (NPACD) was prepared by NEMC with the assistance of UNSO (NEMC, 1990). NPACD identifies areas most affected by desertification and the possible causes as well as outlining projects for controlling desertification. In 1994 and 1995, NEMC finalized the National Environmental Action Plan (NEAP) and the National Conservation Strategy for Sustainable Development (NCSSD) respectively. NEAP and NCSSD are similar documents in many respects (Muheto, 1995). Both the NCSSD and NEAP acknowledge the TFAP and the NPACD as integral parts of their strategies. The NCSSP co-ordinates both the sectoral, i.e. (horizontal) and the vertical, from the district to the national level. They both propose a number of cross-sectoral interventions to be used in areas undergoing land degradation, although the methodologies for identifying the areas undergoing land degradation are not discussed. In 1995, the Division of the Environment commenced the preparation of a new National Action Program to Combat Desertification (NAPCD) using the methodology proposed in the convention. This was finalized in 1999 and it outlines the status of desertification, as well as institutional, policy and legal frameworks for combating desertification in Tanzania

5.3 Conclusion

Land degradation is not a new and recent phenomenon in Tanzania. It is recorded to have been occurring in the drylands and in the mountainous area of high rainfall as early as the 1900's. To date the extent of drylands in Tanzania is debatable, but it comprises between 45% and 75% of the country. The terminology and perception over land degradation has changed over time. From the early 1900 to late the 1970's soil erosion and overgrazing were terms used to express land degradation and in the early 1980's it was expressed as deforestation. Starting in the early 1990's the term land degradation was used to include both vegetation degradation and soil erosion processes. From the early 1900's to date there is a consensus that it is due to both human activities, such as agricultural and livestock-keeping activities, and natural factors such as tectonic processes. However the emphasis as to which is the main cause changes with time and location. For example, from the 1900's to 1960's it was either agricultural and/or livestock-keeping activities and tectonic activities, whereas in early 1980's it was mainly fuelwood harvesting and in the 1990's both agricultural, livestock and tectonic activities are believed to have contributed to land degradation. Assessment methods have varied over time, from erosional plots and simple observations focusing mainly on land degradation processes, used before and in the early days of independence, to remote sensing and field investigations in recent years, focusing both on degradation processes and their consequences. The basic solutions for controlling land degradation have remained more or less the same, with varying emphasis of time and location. These solutions include destocking, depopulation, and the construction of physical barriers to control soil erosion, afforestation, and awareness creation on land degradation among local people. In recent years a great deal of emphasis has been put on structural changes, both in terms of institutions, policies and programmes dealing with land degradation. There are a number of limitations with regard to approaches that have been used to assess and mitigate land degradation in Tanzania, *viz.*

- The confusion of the extent of dry lands in Tanzania is probably due to the use of mean annual rainfall data instead of aridity. The proper use of a measure of aridity is essential for establishing the appropriate extent of land degradation in Tanzania.

- In assessing land degradation vegetation and soil degradation process have been treated separately. This can yield an incorrect impression on the extent of degradation because the same area can be effected by both processes.

- Inter-annual or seasonal vegetation structural changes due to rainfall variability are not normally taken into account in assessing land degradation. This can lead to its recognition as vegetation degradation of changes that are purely due to rainfall variability.

- Most land degradation assessments did not take into account wind erosion or physical and chemical deterioration of soils. Non-inclusion of these processes might give the wrong impression on the extent of land degradation in Tanzania.

- Consequences of land degradation have not been fully taken into account because land degradation indicators have not been used appropriately.

The following chapter will introduce the study area and discuss its biophysical characteristics.

CHAPTER SIX

6. BIOPHYSICAL CHARACTERISTICS OF THE STUDY AREA

6.1 Introduction to the study area

Given the background of land degradation in Tanzania, it is now pertinent to discuss the biophysical characteristics of the study area. The study area (Figure 6.1) is located in the southern part of Monduli District, in the Arusha Region of northeast Tanzania. The study area is bordered by volcanic Monduli and Lepurko Mountains in the north, Lake Manyara and Mbulu District in the west, Lolkisale and village in the south and Arumeru District in the east. For many years the Maasai people, traditionally pastoralists, occupied this area. It is an important area for wildlife conservation, since most of it is divided into game controlled areas and it is also bordered by Manyara and Tarangire National Parks and the Ngorongoro Conservation Area. It is an area typical of the drylands of the Rift Valley and is commonly cited as having serious land degradation problems in terms of overgrazing and soil erosion (MDC,1997). A number of significant environmental and socio-economic changes are taking place in the area including population increase and change in landcover and land use. The most significant land use changes in recent years are the increase in agricultural activities through both small and large-scale farming. The physical characteristics of the area, especially terrain, geology and soils, are strongly influenced by tectonic activities and volcanism. These activities are relatively more active in the area because of its position in the Rift Valley. According to Iranga (1992), the East African rift system represents the most extensive active zone of continental rifting on the globe. Figure 6.2 shows the East African rift system, Tanzania section. The terrain, geology and soils have, in turn, indirectly influenced rainfall distribution, vegetation types and wildlife of the area (MDC, 1997).

Figure 6.1 Location of the study area

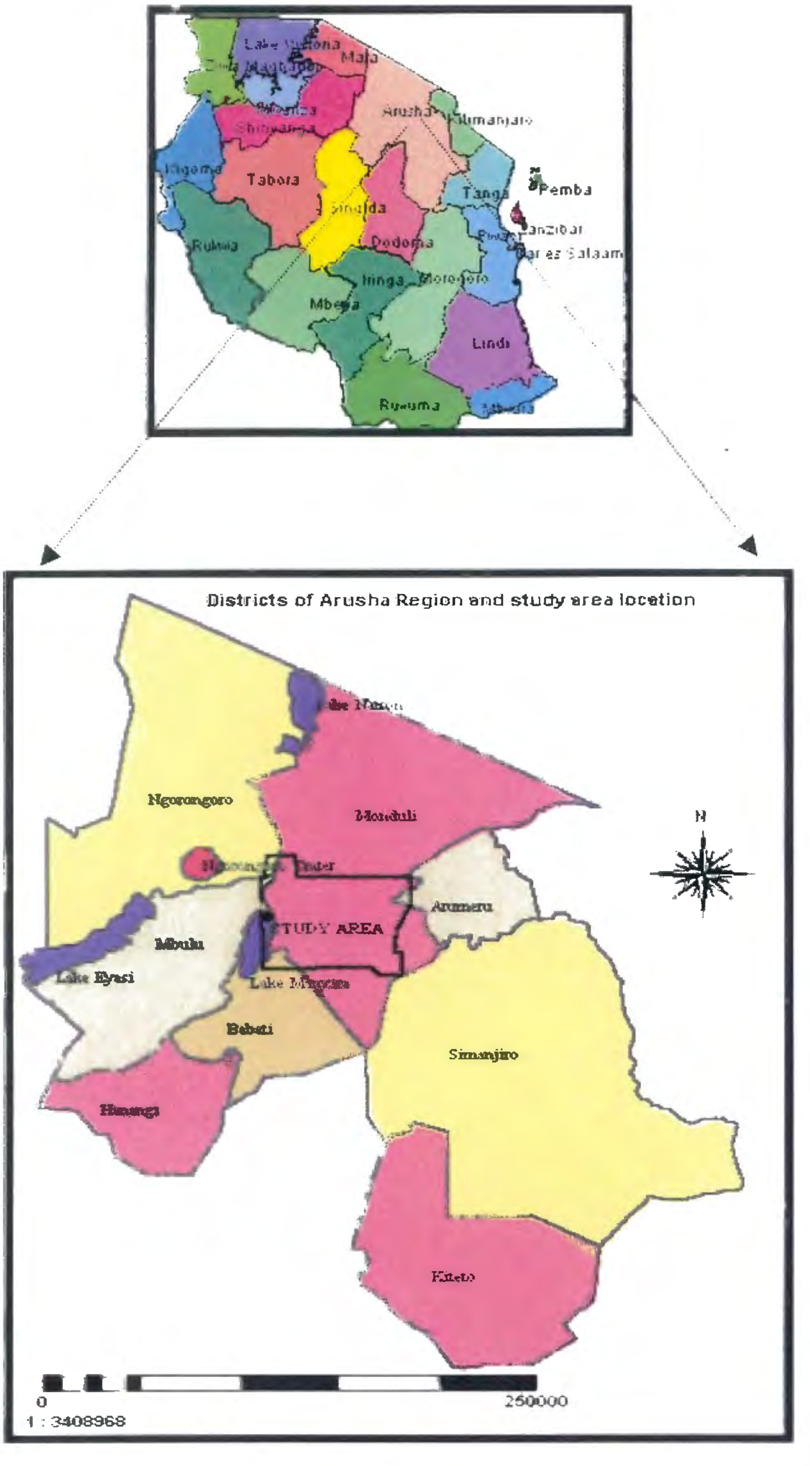
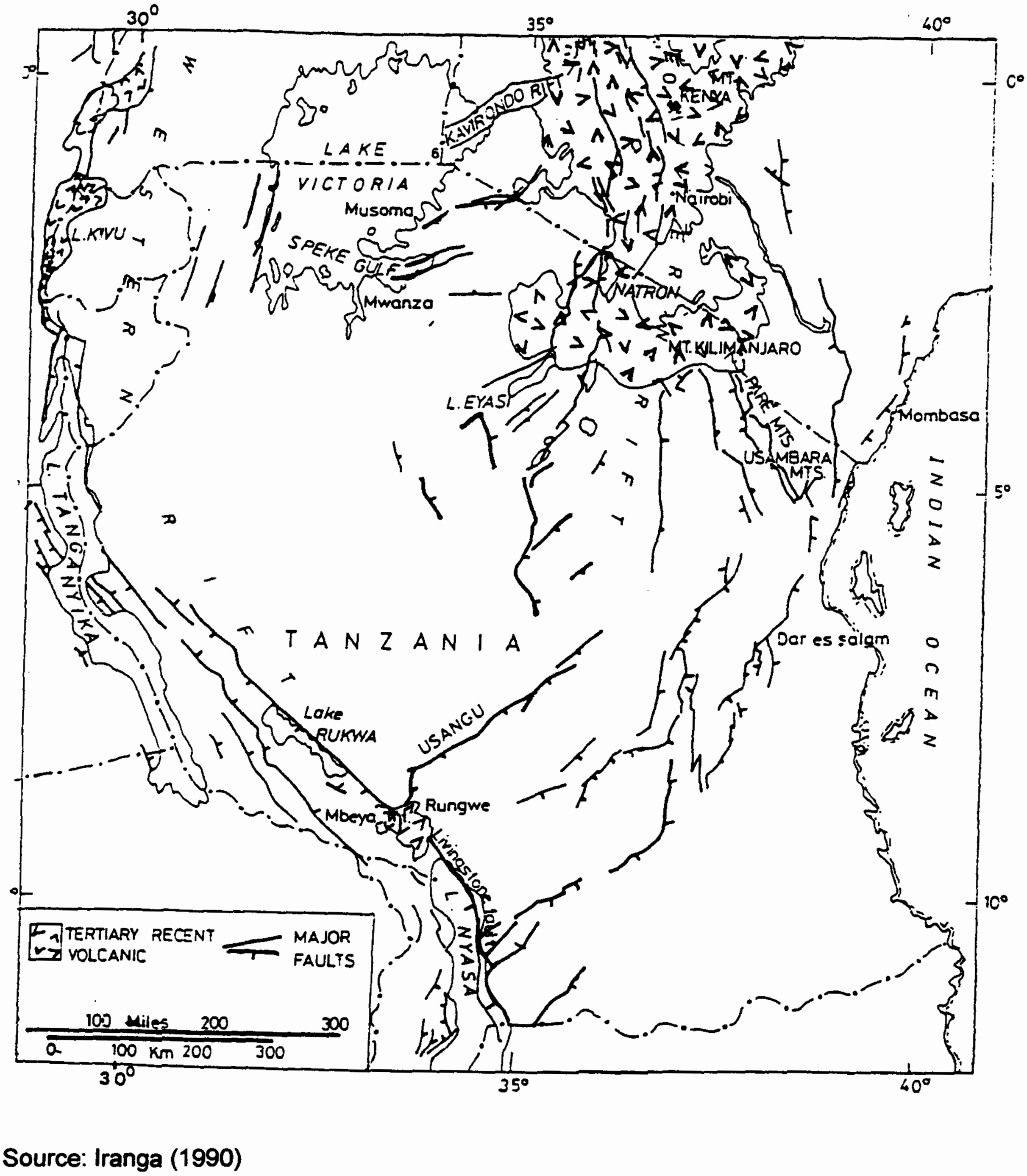


Figure 6.2 The East African rift system, Tanzanian sector (the study area is between Lake Eyasi and Lake Natron)



Source: Iranga (1990)

The aim of this chapter is to highlight the biophysical characteristics that can be used to not only categorize the study area as a dryland but also to highlight why some parts of the case study area are more prone to land degradation. The following will be specifically analyzed and discussed,

- Annual rainfall distribution and inter-annual rainfall in the context of dryland charateristicts.

- Geomorphological characteristics in terms of relief and geology and to what extent they relate to soil erodibility.

- Drainage in terms of rivers, lakes and dams and how they change either annual or inter-annually in relation to rainfall variability.

- Soil charateristicts especially texture and chemical properties in relation to geology of the area and erodibility.

- Vegetation types and distribution and their uses for both human population, livestock and wildlife.

- Wildlife type, distribution and changes over time to show the importance of the area for wildlife conservation.

6.2. Climate

Having discussed the general background of the study area and the main aims of this chapter, it is time to analyze climate variability but limited to rainfall only. Annual rainfall totals vary from 600mm in the rift valley plains and in the lowlands and plateaus in the central and southeastern parts of the study area to about 1000mm/year in mountainous areas. Table 6.1 shows the rainfall stations used in the study. A low amount of rainfall, that is between 600 to 700mm per year, is found mainly in the lowlands and plains around Lake Manyara, southeastern and central parts of the area. High amounts above 700mm per year are found mainly around the Monduli Mountain, the plateaus, Lossimingori and Lepurko Mountains and in the footslopes. This categorization of rainfall into low and high is based on the perception of the local people and district officers in the area.

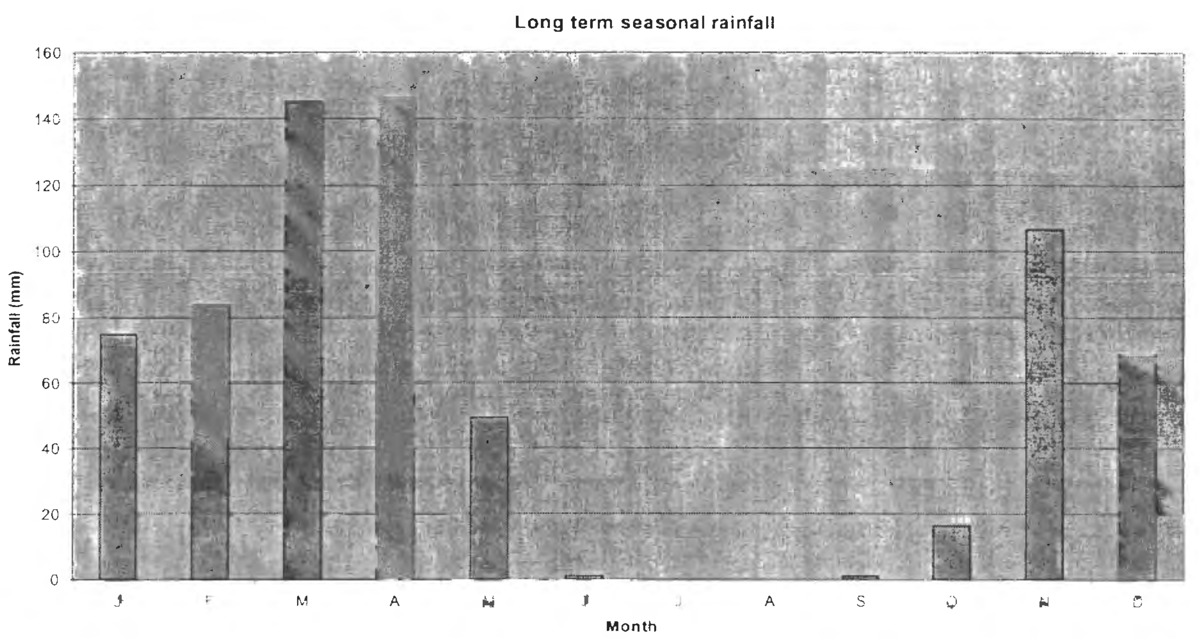
Table 6.1 Rainfall stations in and around the study area that have been used in the study

Name of the station	Data length(years)	Station No	Long term average
Arusha Air Field	23:1973-1992	9336033	818.2
Monduli District	62:1934-1994	9336014	812.0
Mbulumbulu Pr.sch.	50:1942-1991	9335024	760.0
Kongoni estate	51:1941-1991	9335020	816.0
Ardai Ranch	16:1977-1995	933643	648.7
Oldvai Camp	20:1964-1986	923505	472.9
Endulen	35:1946-1995	933513	1048.3
Mto wa Mbu	10:1958-1973	933532	564.7
Loiborsoit	23:1946-1969	933621	534.5
Tarosero	32:1946-1977	933607	867.4
Loliondo	52:1946-1998	923500	886.9
Longido	15:1946-1960	923600	510.0
Kia	27:1972-1998	9337115	546.5
Ndamakia Es, Oldean*	33		941.8
Karatu*	29		893.8
Bergfrieden Es,Oldean*	29		1016.0
Rhode's Es Oldean*	31		1005.8
Mto wa Mbu*	7		683.3
Mto wa Mbu, treasury*	7		579.1
Ngorongoro Dist Office*	7		983.0
Mbulu Boma*	52		840.7
Olmotonyi Forest Station	17:1975 - 1996	933600	796.1
Imani Estate Oljoro	18: 1976 -1996	933659	715.2
Oljoro National Service	17: 1975 -1995	933646	493.9

Source: Directorate of Meteorology and Mwalyosi and Yanda
* = Mwalyosi and Yanda (dates and station numbers not indicated)

The annual rainfall distribution is characterized by distinct rainy and dry seasons. Four climatic seasons can broadly be identified as follows. A short rainy period extending from November to December, a short and hot period from January to March, a long rainy season from March to mid-May and a long cold dry season from May to October (MDC, 1997). Figure 6.3 shows the annual rainfall variability or seasons using long term rainfall data from the Ardai station (Table 6.1), a typical dry station. Drought occurrence is a common phenomenon in the area as reflected by inter-annual rainfall variability. Figure 6.4 shows the long-term rainfall variability of the dry and wet years from mid 1940's to date. There have been six drought periods: 1948-1950, 1953-1956, 1964-1967, 1973-1976 1983- 87 and 1991-1994. This analysis of wet and dry years tallies with drought records kept at the district office (MDC, 1997). It should be noted that climate analysis has been limited to rainfall only due to the non-availability of records of other climate parameters such as temperature and wind.

Figure 6.3 Long-term seasonal rainfall distribution at the Ardai rainfall station

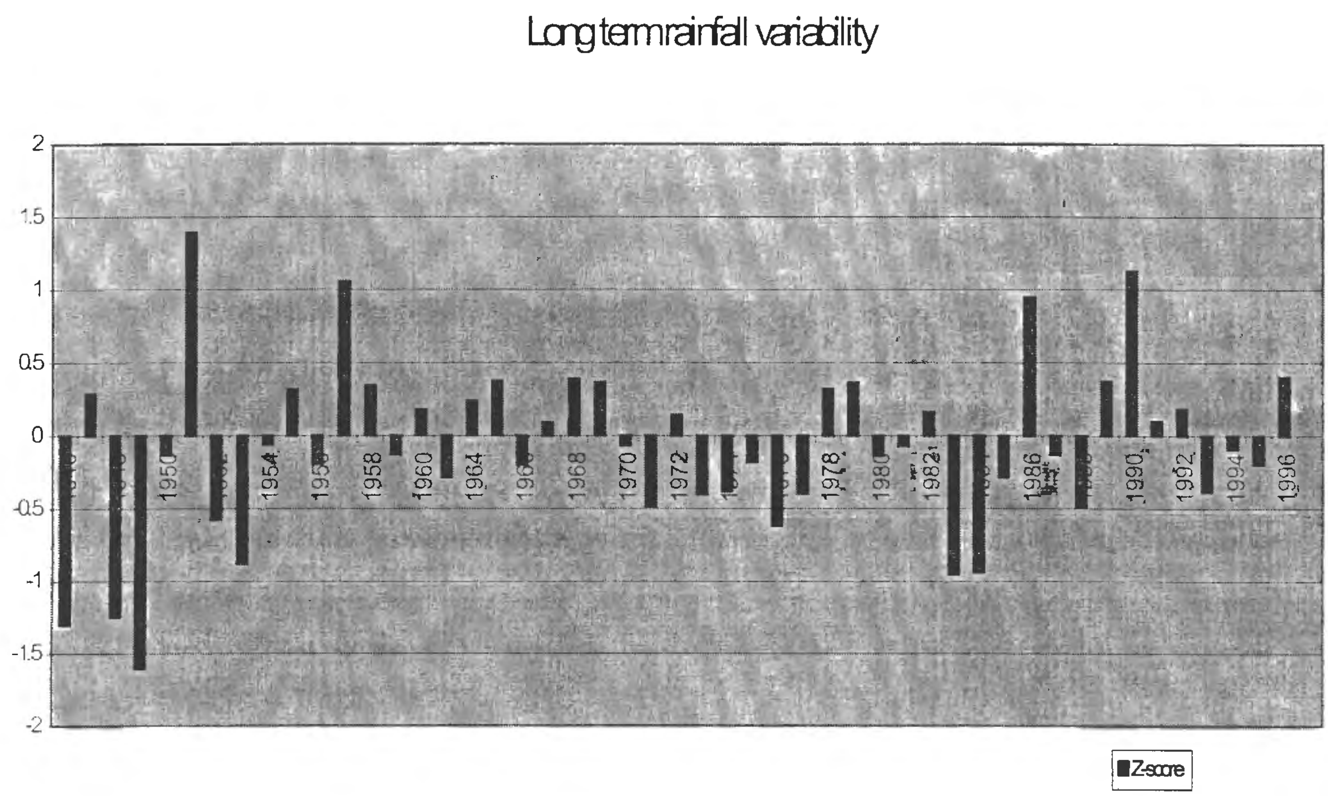


The aridity index has been calculated by finding the ratio of annual rainfall to potential evapotransipiration. In the absence of measured values of evapotransipiration for the area, evapotransipiration values have been calculated by using Woodshed's formula (Sombroek, 1982). The more rigorous methods for calculating PET such as Penman or Thornthwaite methods were similarly not used due to lack of adequate data. So the aridity zones calculated by using Woodshed's formula should be taken as indicative and is as follows.

$$PET = 2422 - 0358h$$

Where h = height in meters

Figure 6.4 Long-term rainfall variability



The aridity index in the area ranges from 0.3 to 0.52. Based on types of aridity zones as given by UNEP (1992), and perceptions of the local technical experts in the district, the area can be divided into two main agro- ecological zones, *viz.:* semi-arid and sub-humid. The semi-arid zone is further divided into "dry" (semi-arid 1), found mainly in the plains and plateaus and "wet" (semi-arid 2), found mainly on slopes and footslopes, and to a lesser degree in undulating plains and plateaus. The dry sub-humid zone is found in upland areas. Table 6.2 and Figure 6.5 show details of the various aridity zones. Note that figures 6.5 to 6.11 were all produced from original satellite images and maps.

Table 6.2 Aridity zones in the study area

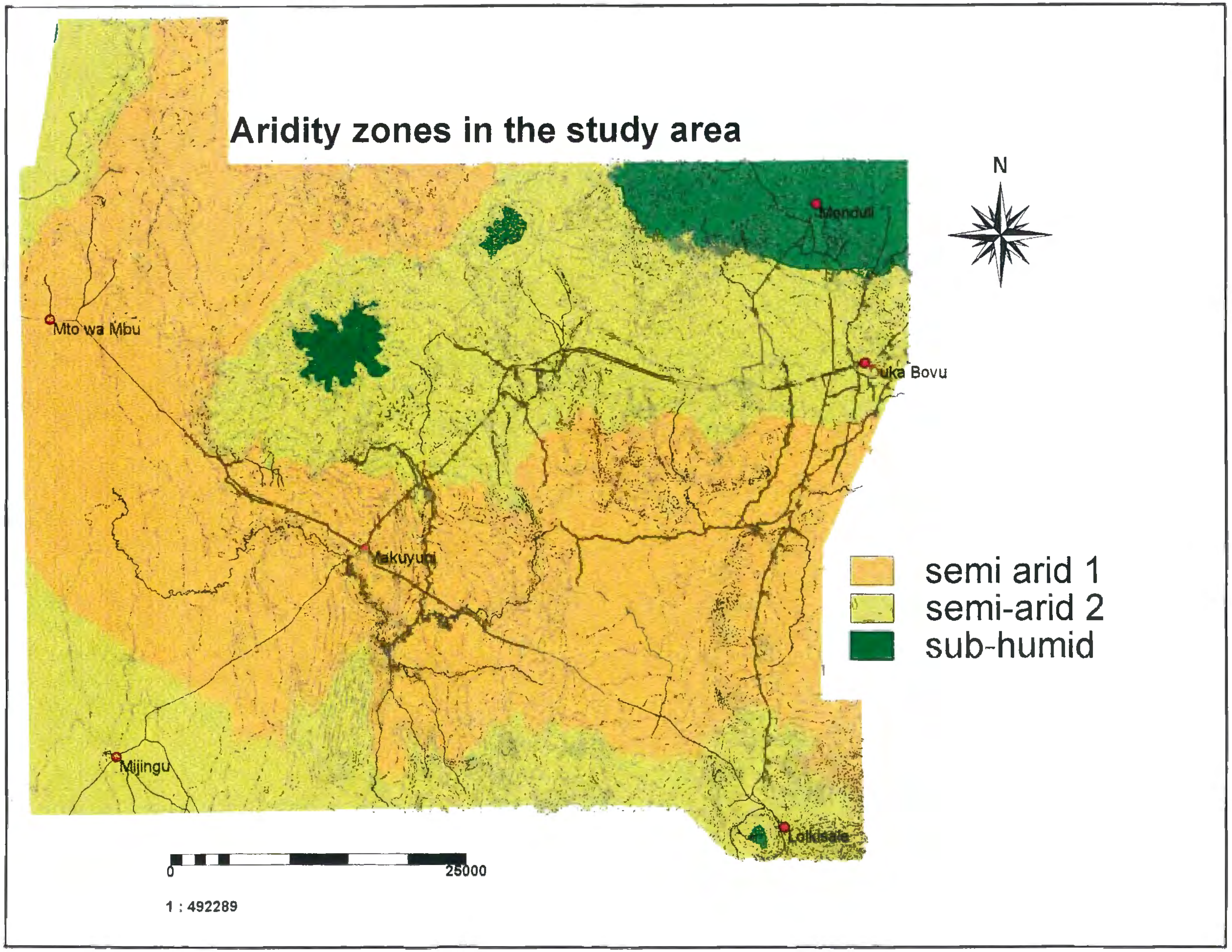
P/PET	aridity zone
0.3 – 0.35	semi arid 1
0.35 – 0.4	semi arid 2
0.4 - 0.51	Dry sub-humid

Source: Calculated from rainfall data using Woodshed's formula

6.3 Geomorphology

The geomorphology of the area is strongly related to faulting and volcanism associated with the formation of the rift valley (Dawson and Pickering, 1964; McConnel, 1972). The rift valley has formed due to earth movements associated with plate tectonics and continental rift which have spilt the earth's crust into tectonic blocks, while at the same time uplifting some and down-warping other blocks (Dixey, 1946; Macintyre, *et al.*, 1974; Hamblin, 1985). The formation of the present landscape can be ascribed to three main phases (Dawson and Pickering, 1964). The first phase during the Precambrian period was the modification of the ancient basement rocks by weathering and tectonic movements that made the landscape generally flatter (Jones, 1964; MDP, 1997). This was followed during the Neogene by the modification of the landscape through the period of volcanic activities (Jones 1964). There are major volcanic cones in and around the study area, such as Kitumbeine, Monduli, Gelai, Lashaine, and Oldonyo

Figure 6.5 Aridity zones for the study area



Lengai and Oldonyo Elorori (MDC, 1997). The most recent phase involved modification of landscape sedimentation and deposition of loose material in the plains and footslopes of volcanic mountains, which also occurred during the Neogene period (Jones, 1964). The study area is a zone of major weakness in the crust of the earth. because it is located in the rift valley, thus prone to seismic activities (Ollier, 1981; Hamblin, 1985). This is evidenced by the high frequency of tremors occurring in the area, the local appearance of cracks in the earth's surface and the presence of the active volcano of Oldonyo Lengai which last erupted in 1940 (Dawson, 1964; Iranga, 1990; MDC, 1997; Erickson 1998).

6.2.1 Main terrain units

Topographically, the area can be divided into three main units, the lowlands, undulating plains and mountainous areas. The lowlands occupy the western part of the area bordering Lake Manyara and also cut across the study area in a narrow strip from west to east, rising from 900m to 1200m above mean sea level (amsl). The lowlands can be divided into two, the Lake Manyara beds rising to a maximum of 1000m and floodplain areas rising to a maximum of between 1000m and 1200m amsl. The undulating plains are between the bottom lands and the footslopes, rising from 1200m above sea level to 1400m. The volcanic mountainous area located in the north of the study area includes Monduli, Lepurko and the Lossimingori Mountains which rise to more than 2000 m amsl, whereas their foothills rise to a maximum of between 1400m to 1800m amsl. Figure 6.6 shows terrain units and the fault lines of the study area and Figure 6.7 shows the terrain elevation model for the area.

Based on studies carried out by Dawson and Pickering (1964), Pickering (1965), Orridge (1965), Jones, (1978), and Wilkinson *et al.* (1983), the area can be said to be strongly dissected by a number of fault lines. In the north-east and in the

Figure 6.6 Terrain units and fault lines

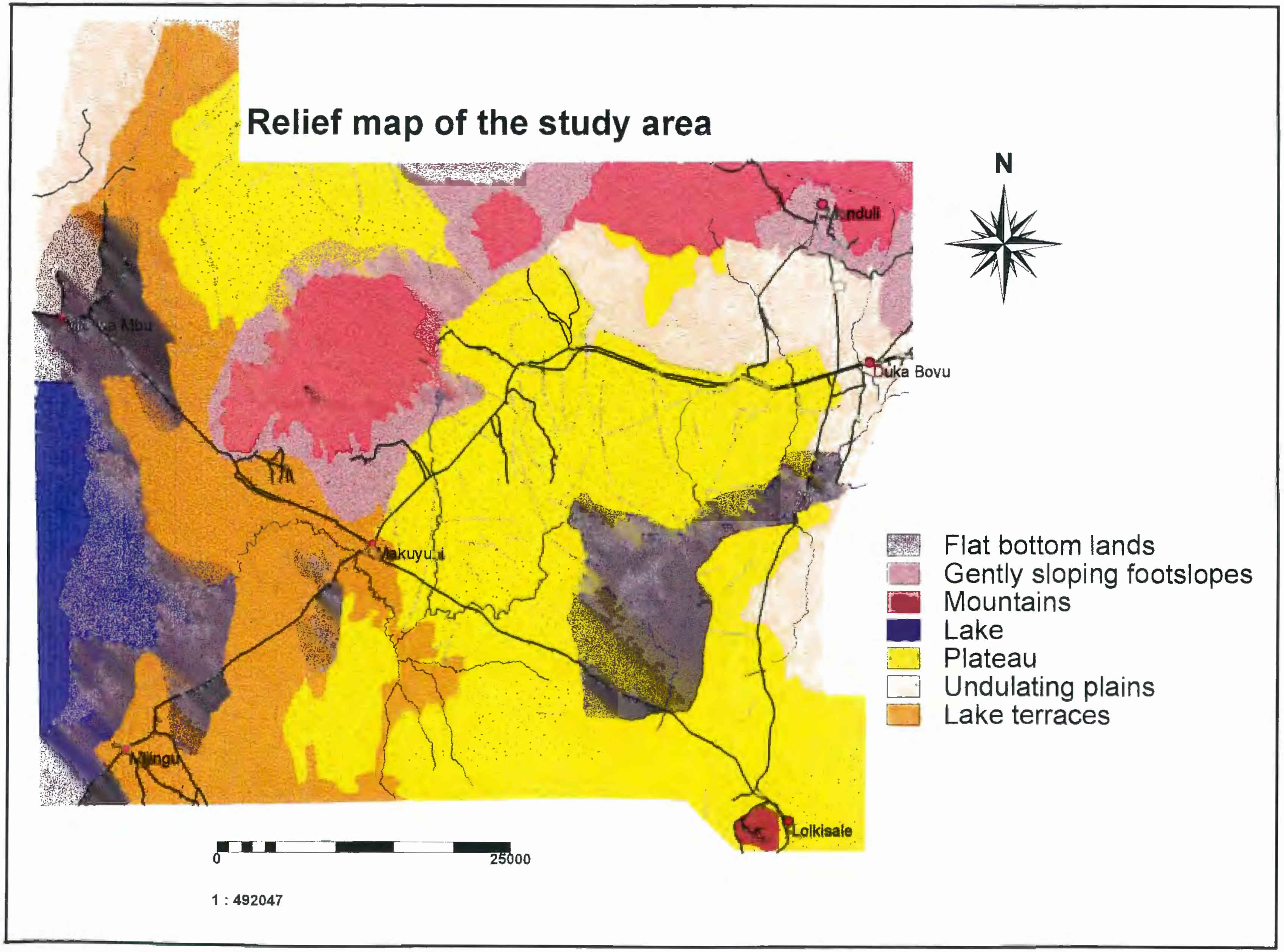


Figure 6.7 Terrain elevation model

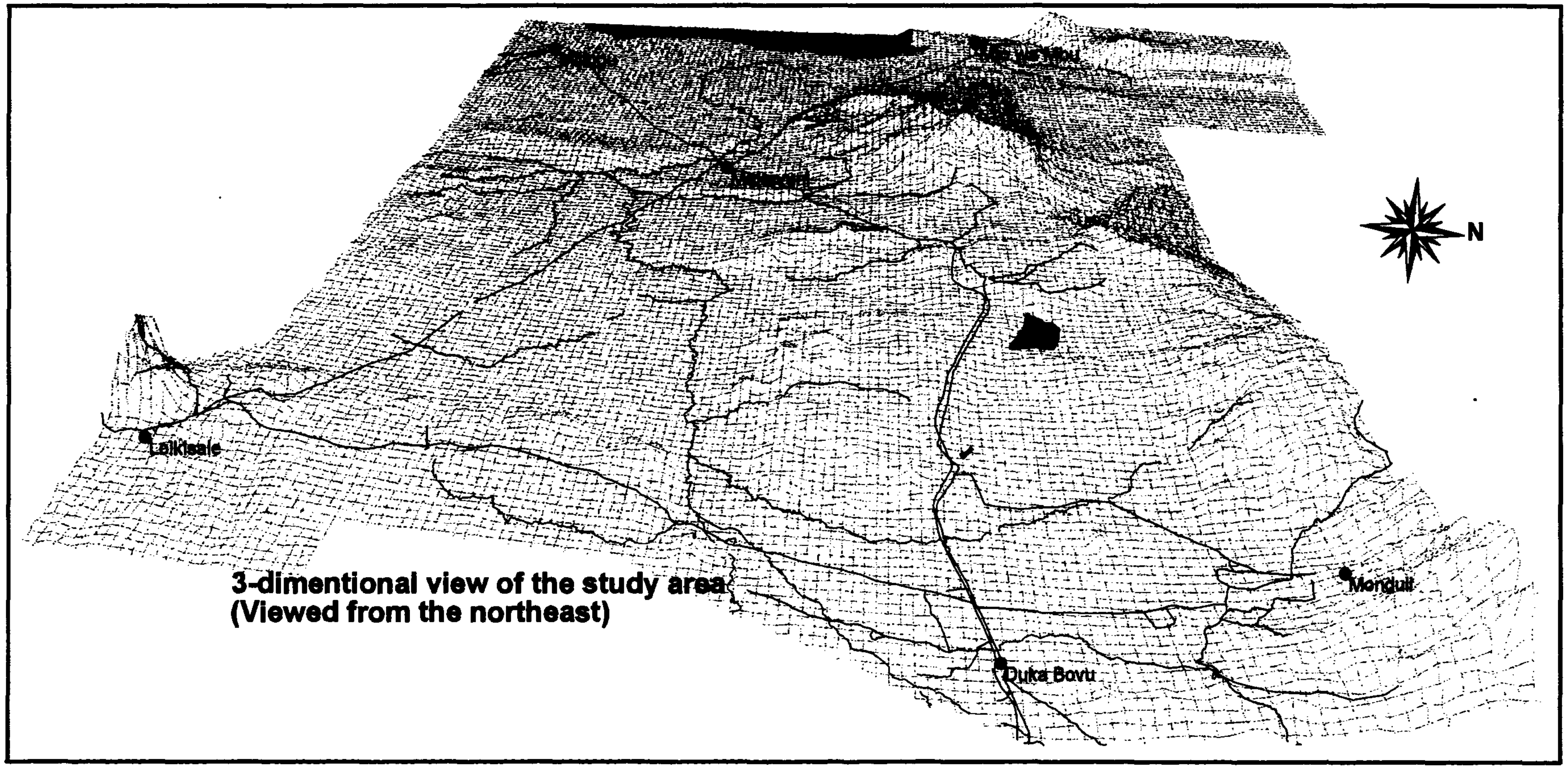


Plate 6.1 Panoramic view of the study area, taken from the slopes of Monduli Mountain, facing southwest direction

central part of the study area, fault lines run roughly in a NW-SE direction. In the southern part, fault lines run in the N-S direction and in the west the fault lines run in a NNE-SSW direction forming the boundary of the Gregory rift valley. According to Gillman (1930) and Eriksson (1998), the tilted areas in Tanzania have been found to be more prone to soil erosion. Faulting at times can lead to an increase in erosion hazard in an area due to deposition of unconsolidated materials that can easily be transported by water on fault scarps (Berry, 1990). For example soil materials deposited along fault scarps in Singida and Kondoa districts have been found to be easily eroded away (Christiansson, 1973). In the study area, unconsolidated black and grey soils have been deposited on fault scarps north and west of Monduli Town (Dawson and Pickering, 1964)

6.2.2 Main geological units

Three main geological units are found in the area, namely volcanic, sedimentary and basement units. Volcanic rocks cover a large part of the study area. According to Decker and Decker (1998), different types of volcanic rocks, such as basalt, andesite, dacite and rhyolite are classified according to their silica (SiO_2) content. Table 6.3 shows the volcanic rock types and their silica content. Rocks that contain more silica also contain more sodium and potassium and less iron, calcium and magnesium. Studies have indicated that volcanic activities along the continental rift systems, as in rift valleys, take the form of quiet eruptions of basaltic magma (Ollier, 1981; Hamblin, 1985). However, studies in Kenya and northern Tanzania, where the case study is located, indicate the presence of strongly alkaline and mildly magmatic series (Baker, *et al.*, 1972; Ollier, 1981). The alkaline volcanic rocks found in northern Tanzania include nephelinites, phonolites, trachytes and carbonatites (Dawson, 1964; Dawson and Powell, 1969; Baker, *et al.*, 1972). The volcanic rocks underlie the mountains and most of the undulating plains and are divided into young and old extrusives.

The former covers the Lossimingori and Lepurko Mountains and the latter Monduli Mountain (Dawson and Pickering, 1964).

Table 6.3 Types of extrusive igneous rocks

Range of silica content	rock type
45% - 54%	basalt
54% - 62%	andesite
62% - 70%	dacite
70% – 78%	rhyolite

Source: Decker and Decker (1998)

Lake Manyara sediments are found in the Western part of the study area, bordering Lake Manyara. The southern part of the area including Lolkisale Mountain and its surrounding areas is covered by a basement system (Dawson and Pickering, (1964). Figure 6.8 and 6.9 show the main geological and geomorphological units of the study area, respectively.

6.3 Drainage

From the theoretical perspective the drainage of an area is normally linked to both climatic and geomorphological conditions of the area. Similarly in the study area, the drainage conditions have been strongly influenced by rifting and volcanism in terms of both river drainage patterns and drainage basins. The largest water body in the area is Lake Manyara, which is located on the floor of the rift valley. The size of the lake varies depending on rainfall, surface runoff and discharge from rivers; it has a maximum depth of 2 m and is brackish (Mwalyosi, 1991; MDC, 1997). Lake Manyara receives its water from several ephemeral rivers, including the Makuyuni, its main source of runoff, originating in

Figure 6.8 Main Geological units

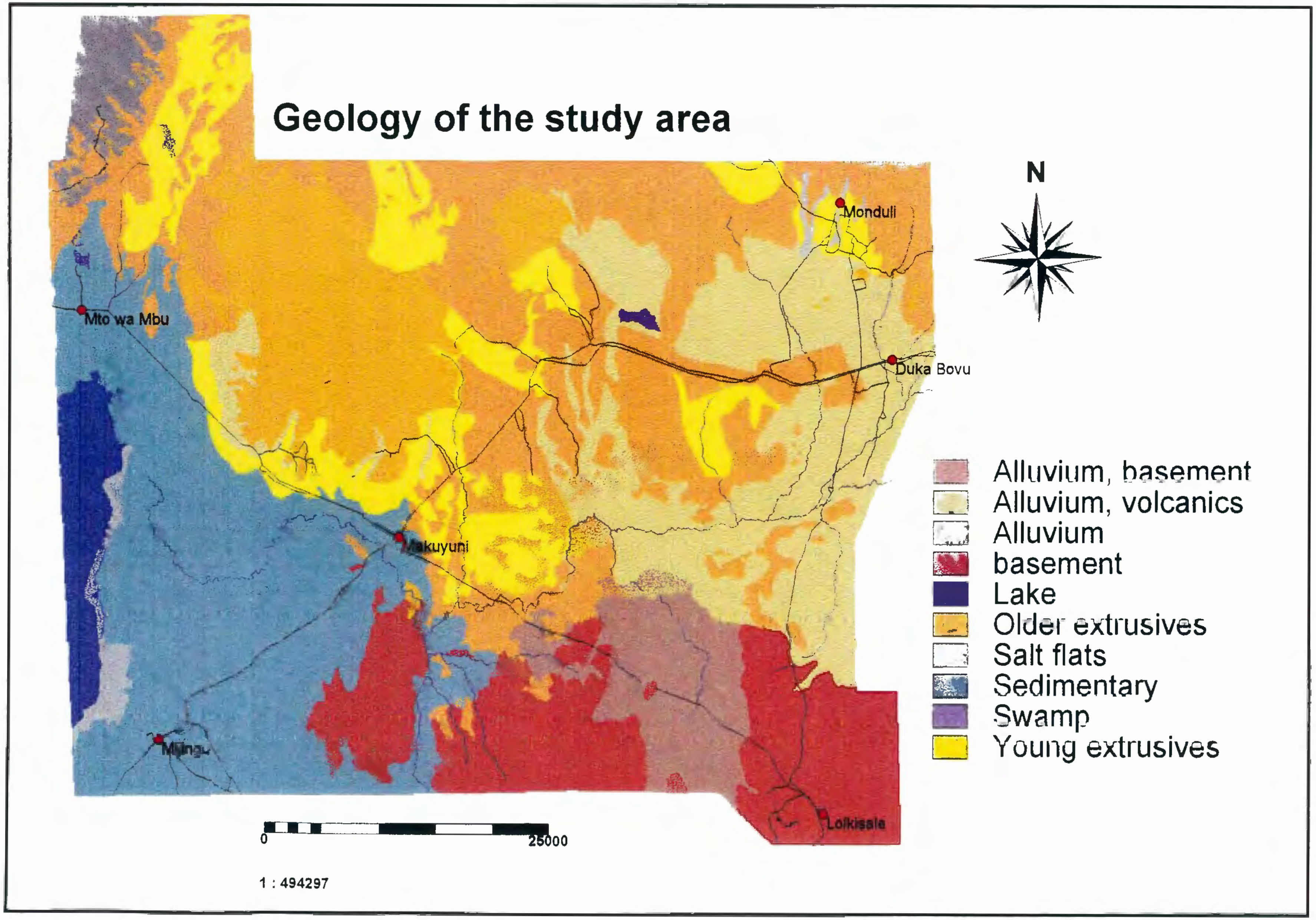
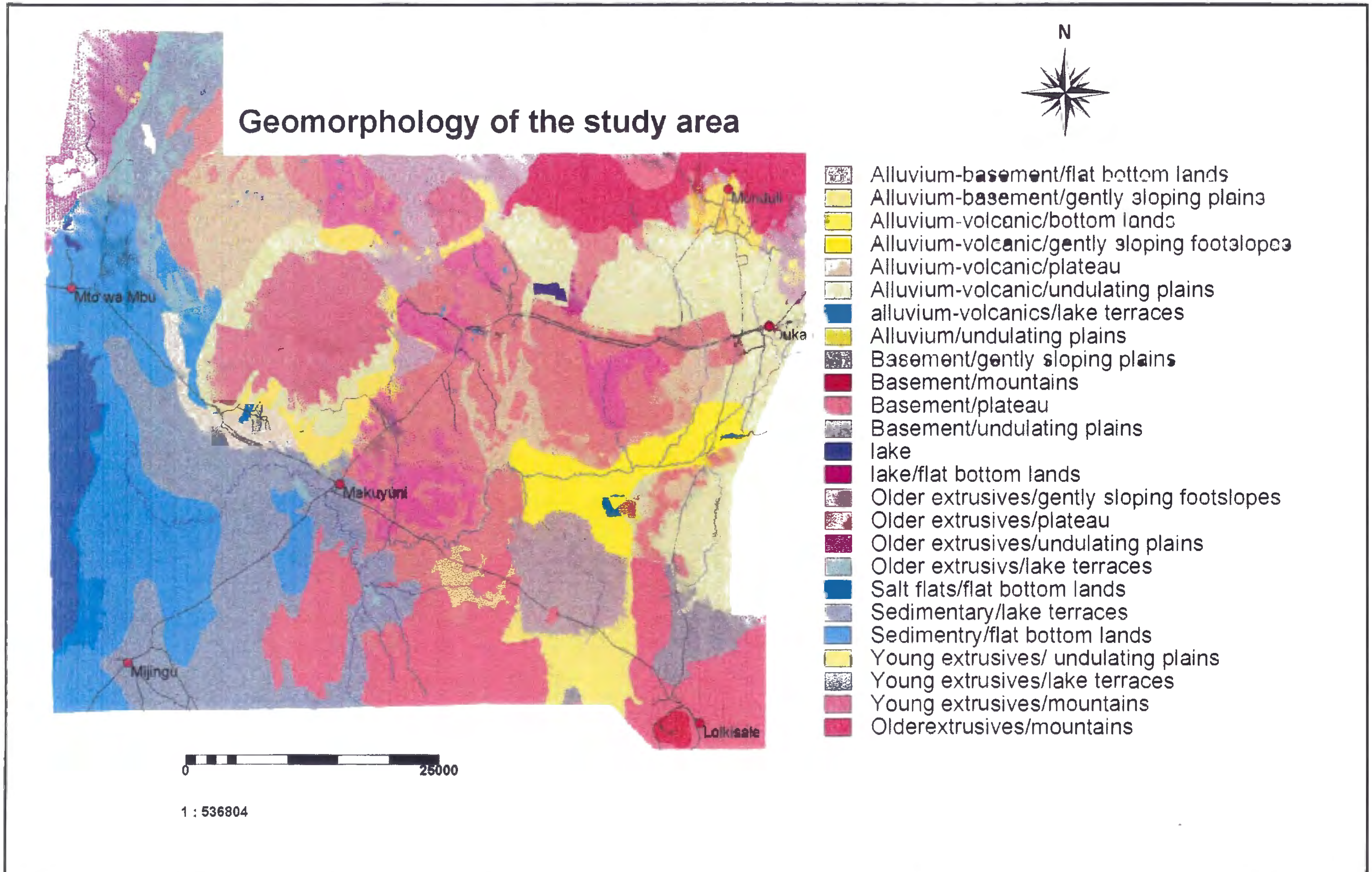


Figure 6.9 Geomorphology of the study area



the volcanic hills in the north, whereas other rivers originate from the basement hills in the south. The rivers from the volcanic hills in the north flow initially in a southerly direction and the rivers from the south initially flow to the north or northeast before turning west to drain into Lake Manyara. The lake also receives water from the perennial Rivers Simba, Kirurumo and Mto wa Mbu, originating from the relatively humid Ngorongoro highland forest outside the study area (MDC, 1997). Studies carried out by IRA (1989) showed that the Simba, Mto wa Mbu, Kirurumo and Makuyuni Rivers discharge a total of 231 x 10^6 m^3/annum and that water quality in Mto wa Mbu and Makuyuni is saline and alkaline respectively (Mwalyosi and Yanda 1989).

6.4 Soil types

The soil types found in the study area are partly related to the already discussed characteristics of geology, relief, climate and drainage of the area. According to Presant, (1974), National Soil Service, (1987) and personal observations, the following main soil types can be identified in the area. Lithosols are shallow soils found on the steep slopes at the edges of fault scarps and plateaus or mountain slopes. Their characteristics in terms of texture, depth, colour and pH vary considerably, depending on the parent material and position in the landscape. Alluvial soils are found in watercourses and adjacent flood plains. They are poorly drained soils recently deposited, with pH values usually exceeding 7.5 and with abundant free $CaCO_3$ and other salts. Calcimorphic soils are found mainly in areas west of Monduli Town on the gentle slopes between the lowlands and the uplands, but in areas receiving rainfall of not more than 600mm/year. These are soils derived from ash or reworked pyroclastic materials and are characterized by the presence of large quantities of soluble $CaCO_3$ at a depth or near the surface. They have high pH values and high quantities of exchangeable bases. They are relatively deep soils, exceeding 60cm and have silt clay or clay textures. Vertisols are most extensive in poorly drained basins and the lowlands between Monduli and Makuyuni and Monduli and Lolkisale. They are black, dark gray or brown soils, derived from alluvial clays and have high contents of clay that readily swell when wet and shrink when dry. When dry, they form surface cracks, sometimes, up to a few centimeters wide. They have high exchangeable base concentrations. Vertisols that occupy poorly drained depressions are saline. Soil texture is clay to heavy clay with moderate soil depth of up to 50 cm. Eutrophic brown soils occupy high elevation areas receiving a rainfall of more than 600 mm/year, such as parts of the Monduli Mountain and some uplifted plateaus near Makuyuni. These are dark brown soils, usually with ABC horizons, and are derived mainly from ash or modified ash materials; they are relatively permeable and well drained. They have clay loam or clay textures with increasing clay content with depth. pH values range from slightly acid at the surface to moderately alkaline with depth and have high exchangeable bases. Mineral hydromorphic soils are alluvial in origin; they are found between Kisongo and Monduli town. These soils are brown or gray in colour, with textures ranging from silty clay to clay; they are associated with poor drainage. Like vertisols, they expand when wet and shrink when dry, even though their cracks are not as wide as in the case of vertisols. Free carbonate usually commences below the surface and the soils are moderately alkaline with a high degree of base saturation. Compared to the rest of the study area, no detailed data on soils is available in the southern and western part because there has not been a comprehensive soil survey in these areas. In the basement system, in the southern part of the study area, the dominant soil types are sandy clay loams, sandy loams and loams of moderate depth. The colour of soil ranges from grey-brown, red brown to brown and pH value ranges from 6.5 to 7. Soils found in the sedimentary system of the Manyara plains are brown-gray and brown clay to the silt clay texture of a very shallow depth of less than 30 cm. The pH of these soils ranges from slightly acidic to neutral. According to Mabugo (1980), Nyanda (1989) and Braun (1990) the Mto wa Mbu area in the Manyara plains, where irrigation activities have been carried out has the following soil types: clay-loam soils covering most of the southern and central parts, clay soils in the north east and sand-loamy and clay-loam found on the slopes of the Rift valley escarpment. Deep soils are found in the central parts of the Mto wa Mbu area where the main rivers pass and shallow soils are found in peripheral areas in both the east and west. Based on a number of studies that have been carried out in Mto wa Mbu since the early 1980's, large parts of soils in the area can be classified as having a high amount of salts. For example, Mabugo (1980) found that all 20 soil samples taken in the area were either alkaline or saline-alkaline. Rambau and Kweka (1994) in the study based on 80 soil samples found that 35% of the samples had high amounts of salts. 75% of salt affected soils were sodic in nature and the other 25% were saline-alkaline. These had high amounts of ESP ranging from 22% to 61% and low electrical conductivity ranging from 0.31 to 6 mS/cm. Similar results (Table 6.4) on the nature of salts affecting soils in the Mto wa Mbu area were obtained from 10 samples taken in 1999 by the author. As already indicated in Chapter Two that EC is a measure of the total salt in the soil while ESP is a measure of the proportion of sodium cations on the exchange complex. This means that these soils have low amounts of salts and high amounts of sodium, hence are sodic (see Table 2.2). The fact that Mto wa Mbu has many sodic soils (i.e. high ESP) is a reflection of the locally-poor drainage and from crystalline and high sodium rocks (e.g. at Karatu) around (Braun, 1990; Sanyu Consultants Inc. and Japan Engineering Consultants Co, 1995; Ndyetabula, 1995) These types of soils can be prone to degradation because their structure can become unstable and compacted with weakened plant growth and biological activities (Barrow, 1991; Szabolcs, 1992; Mainguet, 1994 and UNEP, 1994).

6.5. Semi-natural vegetation

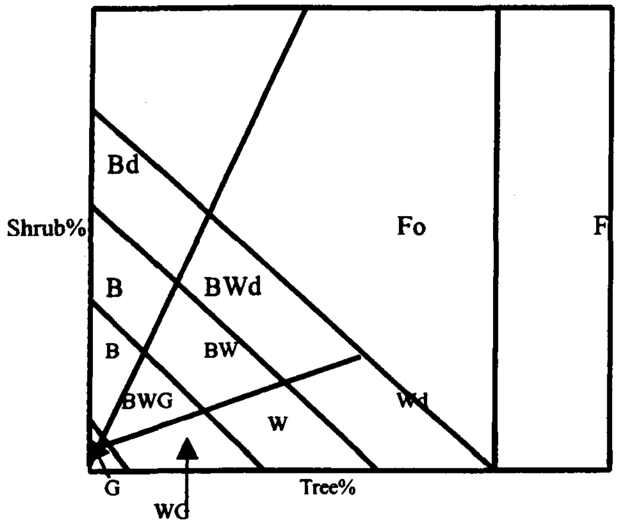
Having discussed the physical aspects of the study area and how they relate to each other each other it is now time to analyze and discuss the vegetation types

Table 6.4 Laboratory results of soil samples from Mto wa Mbu

	Exchangeable bases (me/100g)							
					EC MS/cm	pH	ESP %	Type
	Na	K	Ca	Mg				
1	9.39	7.15	55.2	22.4	0.31	9.17	94	sodic
2	33.91	11.74	50.75	19.15	1.05	9.97	116	sodic
3	42.o3	13.40	36.67	14.24	1.62	10.20	106	sodic
4	2.69	5.06	60.5	17.51	0.14	8.53	86	sodic
5	0.75	4.34	34.11	14.86	0.10	7.64	54	sodic
6	1.61	7.27	63.72	19.80	0.14	8.40	92	sodic
7	3.99	11.35	53.35	17.33	0.24	8.80	86	sodic
8	9.37	5.99	66.54	15.53	0.22	9.14	97	sodic
9	6.54	7.06	59.5	22.91	0.3	9.01	96	sodic
10	0.69	4.06	38.06	17.43	0.15	7.85	60	sodic

found in the area. Vegetation classification in the study area is based on vegetation structure as shown in Figure 6.10. The vegetation structure diagram was derived from aerial photographs by the author in 1992 and was used to determine landcover changes north of the present study area in the Monduli District in 1993 (Kiunsi, 1993). The diagram shows a number of vegetation types categorized according to percentage coverage of tree and shrubs per unit area. The system has been developed using airphotos from the study area and data gathered during field checking. Three main groups of vegetation can be identified in the area, *viz.:* grasslands, bushy and woody vegetation. Table 6.5 and Figure 6.11 shows details of different vegetation types and their coverage Grasslands include grasslands proper, bushed grassland and wooded grassland and occupy almost 60% of the area. They are found in almost all terrain units but are more dominant in the flat bottomlands, lake terraces and in the undulating Ardai plains. Grasslands are also found in the plateaus, especially in the north

Figure 6.10 Vegetation structure



F = Forest
Fo = Open forest
BWd = Bushed woodland, dense
Wd = Bushland, dense
W = Woodland
BW = Bushed woodland
B = Bushland
BWG = Bushed wooded grassland
WG = Wooded grassland
BG = Bushed grassland
G = Grassland

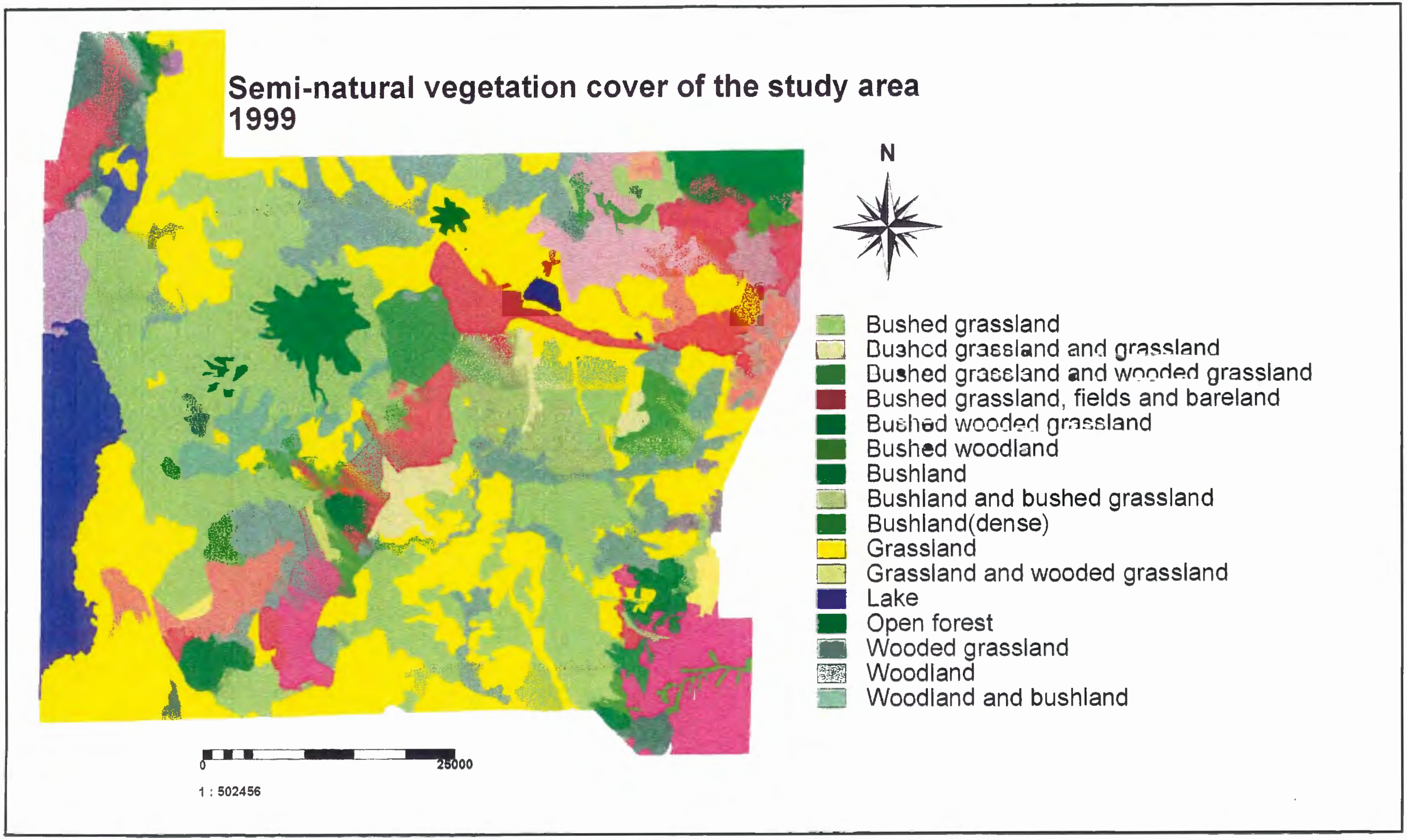
Source: Kiunsi, (1993)

and central part of the study area (Figure 6.11). Bushy vegetation, which includes complexes of bushland and bushed grassland, bushed woodland, bushed wooded grassland and bushland, covers about 9% of the study area. Woody vegetation is found mostly in lake-terraces and in the plateaus representing some 6% of the study area and is found mainly in the mountainous areas and in footslopes. Plate 4.2 and 4.3 show typical grassland and bushland in the area. The common woody species in the protected forest include, *Bersum absyssinica, Cassipourea malosama, Noxia simplicifelia, Podocarpus milanjiana, Olea* and *Albizzia species,* while the common woody vegetation in plains and plateaus include different species of *Acacia, Commifora africana and Balanites egyptiaca.* The dominant herbaceous genera are *Aristida, Pennisetum, Panicum, Eragrostis Cenchrus, Chloris and Sporobolus.*

Plate 6.2 Typical grasslands in lake terraces, on the background is the rift valley escarpment

Plate 6.3 Typical bushland in basement plateau

Figure 6.11 Semi-natural vegetation map (only vegetation cover types indicated in legend)



6.6. Wildlife

The study area is rich in wildlife and with exception of the built-up areas is classified as a Game Controlled Area (GCA). Both resident and migratory wildlife are found in the area. Examples of resident wildlife include impala, bushbuck, hippo, dikdik and several species of cat; while the migratory wildlife species include wildebeest, zebra, gazelle, elephant, ostrich and eland (Mwalyosi, 1991; MDC 1997). There are no reliable population data on the various species but the migratory types are most abundant and are located mostly on the plains. Migratory wildlife, as the name implies, move seasonally to different grazing locations in wet and dry periods. There are three main wildlife corridors used by wildlife for seasonal migration: Lolkisale, the Manyara ranch or Jangwani corridor and Selela. These corridors facilitate seasonal movement of wildlife between the study area and surrounding conservation areas

6.7 Conclusion

The study area is a typical dryland area dominated by a semi-arid type of climate and has a rainfall ranging from 600mm to less than 1000mm/y. It is tectonically active due to its location in the rift valley. Tectonic activities have strongly influenced the topography as exemplified by the presence of volcanic mountains and scarps. Many areas are covered with the volcanic alkaline shallow soils, of clay or silty clay texture. Grasslands and bushed grasslands are the dominant semi-natural vegetation in the area. Bushy and woody vegetation cover only a small part of the area, mostly in the mountains. The area is an important habitat for wildlife as most of it is designated game controlled area and it is also surrounded by a number of National Parks. It facilitates the functioning of the wildlife ecological system in the Maasai plains by acting as a wildlife dispersal area during the wet season and connecting a number of conservation areas through its wildlife corridors. The study area is likely to be more prone to land degradation than other drylands in Tanzania due to poor drainage in the bottomlands a contributory factor to primary salinization; and high content of sodium in volcanic rocks which makes the soils vulnerable to erosion.

CHAPTER SEVEN

7. SOCIO-ECONOMIC ASPECTS, HISTORICAL AND CURRENT DEVELOPMENTS

7.1 Introduction

Understanding the long term use or misuse of natural resources necessitates the analysis of the socio-economic aspects of the society that are directly linked to the utilization of the natural resources. The aspects which have been considered for analysis in the study area are the Maasai culture, population dynamics, economic activities and water supply. However, the compilation and analysis of the socio-economic data has been limited by a number of factors. Firstly, the study area is not a uniquely defined administrative or ecological area, it is a part of larger unit, making it difficult to obtain long term data specific to the area. Secondly, changes in administrative boundaries, both at the district and village level, have been made several times, so that the tracking of population changes becomes more difficult. Thirdly, changes in population composition from a more or less pure Maasai to a mixed population of Maasai and non-Maasai have occurred, creating some difficulties in comparing current and past populations as in the past, population data on Maasai were given separately. Fourthly, current population data for the area are based on estimates because no recent official population census has been carried out. Lastly, the high mobility of pastoral societies lowers the reliability of population information because of the difficulties of getting accurate data on the ground. Due to the lack of adequate data specific to the area, especially regarding population and livestock, data covering the whole of Maasailand and the Monduli District have been used to gain an impression of the population dynamics in the study area. This chapter is organised in such a way that each theme starts with a general description followed by descriptions specific to the study area. The general description is based on secondary sources, while socio-economic data specific to the study area is based on both secondary sources and on a questionnaire conducted during ground truthing.

The main aim of this chapter is an attempt to show how the Maasai people were culturally and economically organized in the use of the natural resources and how changes in population and economic activities in modern times are impinging on the landcover/use of the area. Specifically this chapter will attempt to:

- Highlight the history and cultural of the Maasai in the context of their organization and use of the natural resources.

- Analyze the demographic and settlement changes and the effect of these changes on the use of the natural resources in the area.

- Highlight and discuss traditional livestock strategies in relation to rainfall vegetation variability and how these strategies are collapsing due to socio-economic changes.

- Document and discuss the increase in agricultural activities, both small and large scale, and ascertain how they are impacting on livestock keeping and wildlife management activities.

- To show and discuss the extent of water services in the area and the inter-annual and annual variability of water and how they effect both livestock and agricultural activities.

7.2 The history and culture of the Maasai

The history and culture of the Maasai has been discussed by a number of writers, including Fosbrooke (1948, 1956), Gulliver (1969), and Talbot (1971). Maasai are considered to be Nilo-Hamitic people, traditionally semi-nomadic pastoralists and warriors. According to Fosbrooke, (1948) it is believed that 400 years ago the Maasai occupied the lowlands of northwest Kenya. They subsequently moved south and by 1800 a few Maasai had moved to the present locations in Tanzania. Talbot (1971) further elaborates that, by 1880, the Maasai had reached their peak in terms of maximum land holdings, occupying about 210,000 km^2, cattle number and power. By around 1890, a series of disasters including the rinderpest epizootic, smallpox epidemic, severe drought and famine struck the Maasai population and both livestock and people perished in numbers. Some of the Maasai sought refuge in largely agricultural tribes in the surrounding areas; some, like the Waarusha people, still maintain that way of life. By the end of the 19th century the number of Maasai people and their livestock were greatly reduced. When the German settlers arrived in East Africa in the late 1880's, they found the relatively few Maasai concentrated south of Arusha and Moshi. After the Second World War there was a steady increase in population and livestock numbers due to increased rangeland development programmes in Maasailand. Therefore, it can be argued that historical fluctuations of human population and livestock numbers in Maasailand have been controlled by both biotic and abiotic factors, i.e. moisture availability and disease.

The Maasai are loosely bound by a confederate social system of a common pattern of institutions, values and attitudes (Gulliver, 1969; Talbot, 1971). The Maasai social structure, which is well documented in MDC (1997), is based on stratification by male age sets. Each age set has its own internal leadership, which enforces collective will, and the two older age sets hold power in the community. Each ecological locality or community has its leader whose role is resource allocation and planning of landuse. Livestock, particularly cattle, have traditionally formed the social and economic base of the Maasai. Livestock not only provided wealth but prestige and security. The Maasai have traditionally lived in temporary villages, popularly known as "boma", consisting of a circular fence with a number of huts in between enclosing a cattle enclosure at the centre. Traditionally, Maasai villages have been mobile, with the location of the village primarily being determined by water availability, forage and security requirements. In the broader context it can be deduced that both social organization and the economic system were geared to make the maximum use of the natural resources in drylands that vary in space and time, depending on moisture availability. This was attained because social organization had in-built mechanisms for decision making on resource utilization, while temporary bomas and livestock ownership facilitated mobility from one location to another depending on the availability of natural resources.

7.2.1 Population dynamics in Maasailand

From an historical perspective, the total Maasai population in both Kenya and Tanzania was estimated to be around 45,000 in the 1800's, about 50,000 in the 1920's; 107,000 in 1948 and 117,000 by 1961 (Fosbrooke, 1948; Simon, 1962; Talbot, 1971). Recent long-term population dynamics at the district level for both the Maasai and non-Maasai is elaborated in MDC (1997). The Monduli district population was 22,290 in 1948 and by 1995 it had increased to 141,896 growing at 3.8% compared to the national annual growth rate of 2.8%. Table 7.1 gives the details of the total population and the growth rates of the district from 1948 to 1995. The population growth rate of between 3.8% to 4.5% per annum is higher than the national average of 2.8% to 3.5% per annum (Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha, 1999).

Table 7.1 Population changes in the Monduli District

Year	Total population	Annual growth (%)
1948	22,290	
1957	25,250	1.4
1967	37,747	4.1
1978	68,906	4.3
1988	109,006	4.5
1995	141,896	3.8

Source: MDC (1997)

The main cause of the higher growth rate is immigration, especially generated by people from the surrounding densely populated highlands who came to the more sparsely populated less fertile lowlands, and also from labourers who come from other regions to work on large-scale farms. There has been an increase in population density over time, prior to the arrival of European colonialists in East Africa, the population density of the Maasai in both Kenya and Tanzania was estimated to be 0.2 people per km^2, and by 1961 it had increased to 1.3 (Talbot, 1971). More recent population density at the district level, as given by the 1999 Arusha Regional economic and social development profile, Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999) in 1988 and 1996, was 7.7 and 10.0 people per km^2, respectively. Even though there has been an increase in population density in the Monduli District, it is still low compared to the national average density, which stands at 21 per km^2. There has also been a change in population composition due to immigration and the encroachment of former purely Maasai pastoral lands by the Waarusha. They, like the Maasai, are Maa speaking and their social and cultural aspects are similar except that the Waarusha are agro-pastoralists. They occupied the fertile footslopes of Mount Meru, but in recent years, starting in the early 1960's, due to the pressure of population there, they have expanded and occupied the drier Maasailand

(Murrary-Rust, 1973). Partly as a result of this expansion, it is estimated that, currently in the district, only about 40% of the population are Maasai, 20% are Waarusha and the rest belong to tribes from other parts found mainly in urban areas (MDC, 1997). The steady increase in population numbers and population density in recent years has been attained by external intervention through improved social services and food supply in drought years (MDP, 1995). This means that Maasailand is no longer a closed system and that the direct impact of rainfall variability on population dynamics has to a large extent been reduced.

7.2.3 Population changes in the study area

There are no recent and reliable population statistics for the study area because the last population census in Tanzania was carried out in 1988 (Bureau of Statistics, 1991). The most recent statistics are based on surveys carried out by water consultants in 1994 (Groundwater survey, 1994; Sanyu Consultants, 1995). Table 7.2 gives the total population for the 1988 and 1994 as well as the population density for the later date for each village. The 1994 survey indicates that about 70% of the population in the Monduli District live within the confines of the study area (Groundwater Survey; Sanyu Consultants, 1995). It also shows that between 1988 and 1994 the population increased by 100% from about 50000 to 100000. This is mainly due to the fact that the chief settlements in the District, together with the greater part of the economic activities of farming and tourism, are located in the study area. It is important to note that new villages were created or the adjustment of village boundaries were made between 1988 and 1994. The data for villages or settlements reflect that higher populations both in terms of number and density are found either in areas of higher agricultural potential, or with a higher level of business activity, or that are used as administrative centres.

Table 7.2 Total population and density per village, 1994 data

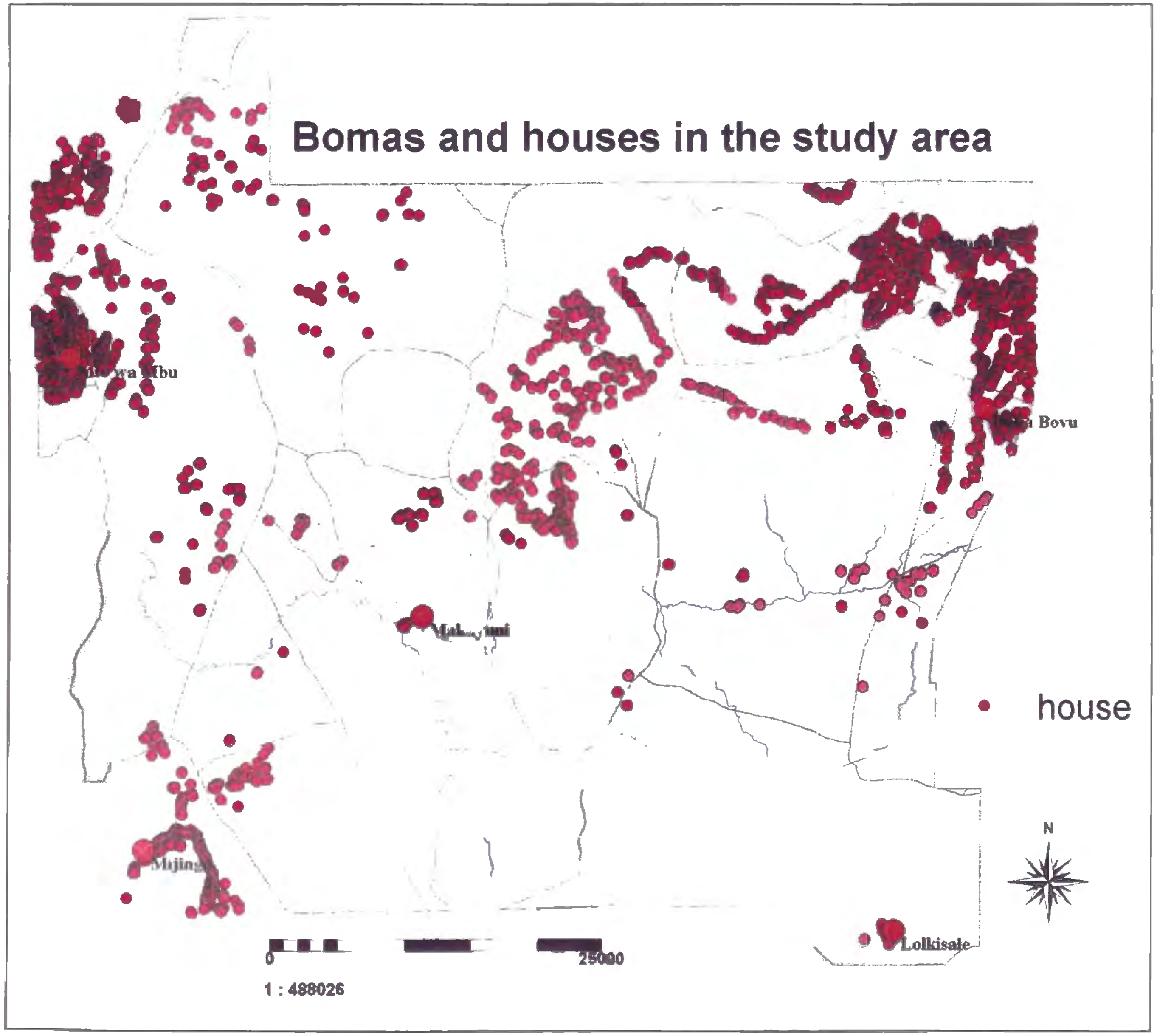
S/N	Village name	Population 1988	Population 1994	Population density, 1994
1.	Lolkisale	3154	4455	7.3
2.	Meserani Chini		2125	14.3
3.	Mswakini	1885	2210	20.8
4.	Makuyuni	4665	7724	17.7
5.	Esilalei-Losrwa	2324	1205	3.0
6.	Mto wa Mbu	10179	21137	361
7.	Selela	1907	3318	6.4
8.	Monduli Town	4243	18210	607.0
9	Lossimingori		1557	10.7
10.	Mbuyuni	2922	2620	13.7
11.	Lepurko	4794	3041	15.7
12.	Lendikinya	4817	2512	19.9
13.	Arkatan	1540	1712	29.5
14.	Meserani Juu	2342	3339	41.6
15.	Mlimani	2137	4404	298.4
16.	Lashaine		3450	105.3
17.	Sinon-Ngarash	2027	12663	781.7
18	Emairete	3843	3641	10.1
Total		**50872**	**103727**	

Source: Bureau of Statistics (1991); Groundwater Survey (Tanzania) Ltd. (1994); Sanyu Consultants Inc. and Japan Engineering Consultants Co. Ltd (1995)

7.2.4 Settlement distribution and organization

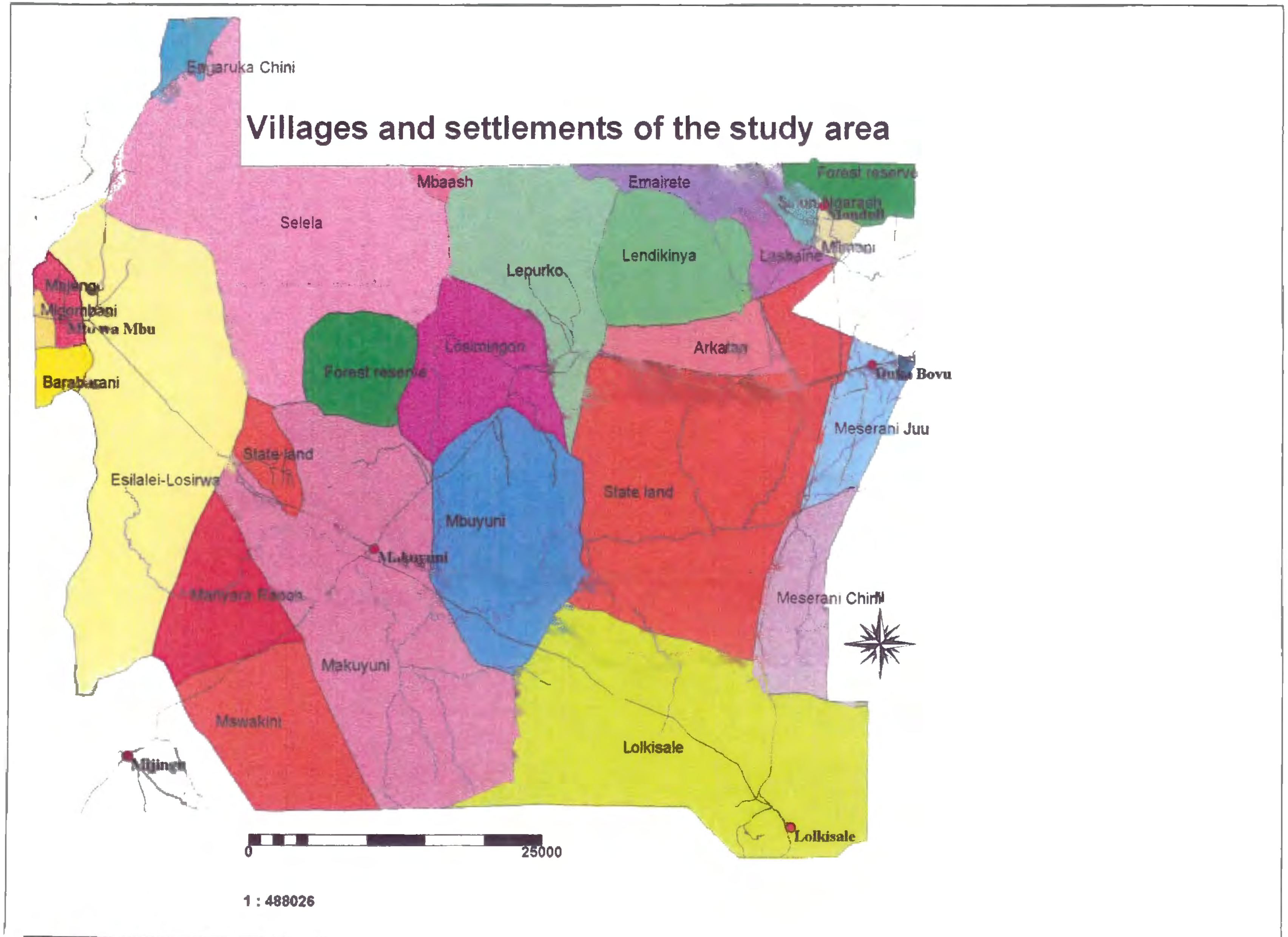
In this section it will be shown that changes in settlement distribution and organization in the area are partly linked to the changes in population density. There were no village boundaries as such before the 1960's; the settlement distribution was determined more or less by distribution of bomas. Figure 7.1 shows the location of bomas, based on the 1960's topographical sheets. The bomas were concentrated mainly in particular locations, e.g. on the slopes of mountains and in and around Mto wa Mbu and Mijingu. This sort of arrangement ensured that vast areas were left open for grazing. All these locations had a reliable water supply and/or good pastures. Even though the majority of villages still live in bomas except in the main settlements, village boundaries are now in place. Figure 7.2 shows the boundaries of the villages and main settlements in the area. For example, the largest settlement is Mto wa Mbu because of its irrigation, commercialism and tourism. Most of the people are immigrants from the surrounding highly populated rural areas within and outside the Arusha Region (Braun, 1990). Second in size is Monduli Town, located on the slopes of the Monduli Mountain. It is the district headquarters, has high agricultural activities and is a commercial centre. All villages surrounding Monduli Town, such as Sinon–Ngarash and Mlimani have relatively high populations. Other villages with high populations include the Makuyuni and Lolkisale villages; both have farming and other agricultural related activities. Figure 7.3 shows a typical example sketched from one of the bomas belonging to Mzee, "the old man ", Oltetia in Lolkisale village. The boma consists of seven households, of which four belong to the old man and his four wives. Each wife has a separate hut for herself and the younger children. The other three households belong to Oltetia's older sons and their families. The outer ring of the boma consists of a number of huts for living, storage, cooking and keeping goats, all joined by a fence. The inner ring consists of a fence and is used as a cattle enclosure. This type of boma arrangement, where many households concentrate in one location, not only ensures the security of the Maasai and their livestock but minimizes areas to be used for habitation, thus freeing large areas for grazing. There has been a change in both settlements and the size of bomas. Even though (due to their small size), it was not possible to map the location of bomas for 1999 using hard copy satellite images it can be said based on field observations areas of high concentration of bomas have remained the same. Though there has been an increase in the number of bomas they are much more scattered all over the area.

Figure 7.1 Location of Bomas



Source: 1960's topographical maps

Figure 7.2 Villages and settlement boundaries



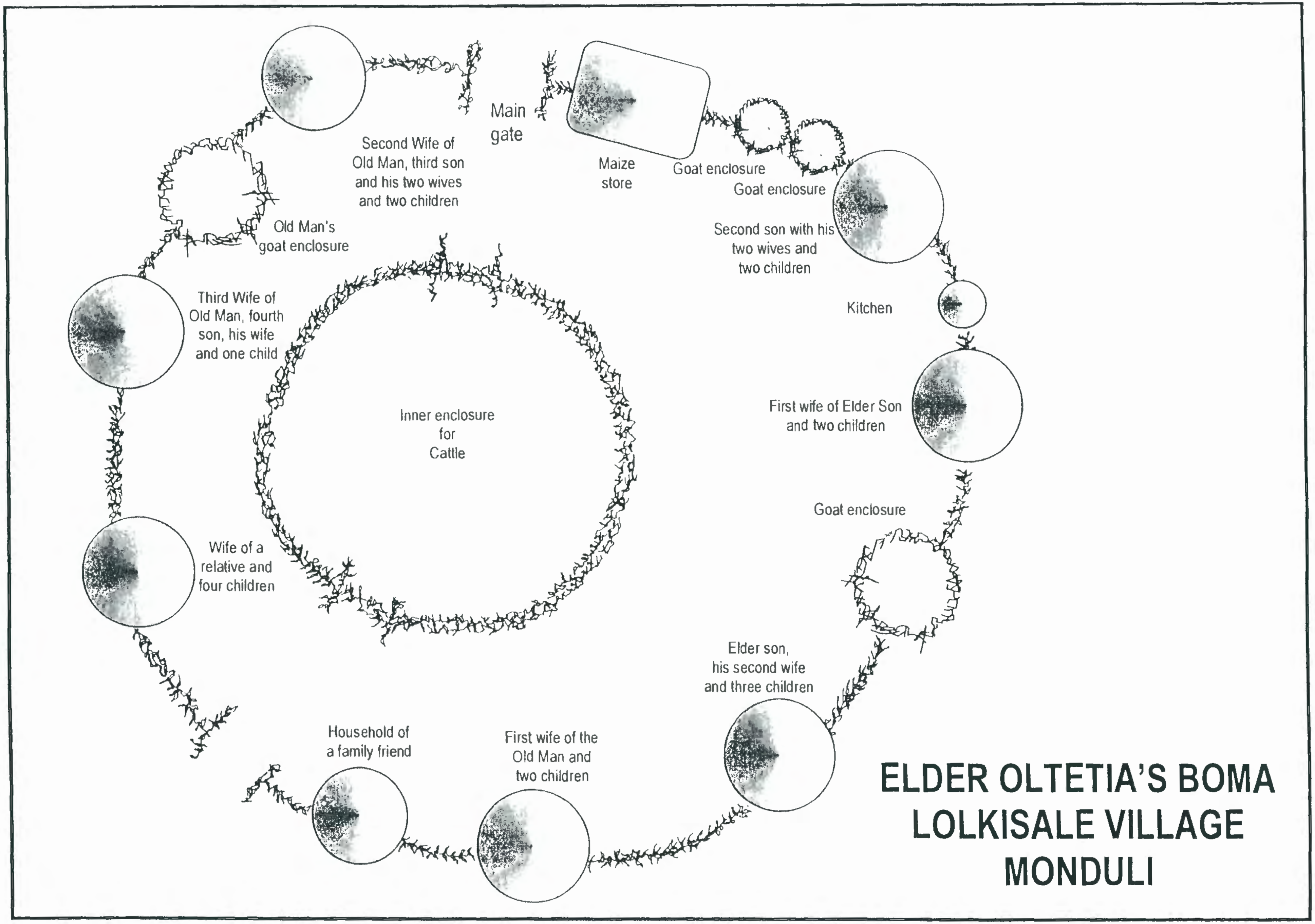


Figure 7.3 A typical example of a Boma

However all bomas that were in lands now held by the government or large-scale farms were removed to other locations. For example, during the mid-1970's, bomas between the Nangungu and Lashaine hills were removed to make way for a government institution. Most of the villagers moved further north on to the footslopes of the Monduli Mountain. At the same time the social survey carried out as part of this study shows that the traditional set-up of bomas is changing in terms of size and location. 40% of the respondents believe that the bomas are becoming dispersed and/or scattered, 40% note the size of bomas is decreasing, that is that the number of households per boma are becoming lesser (Table 7.3). The main reasons given for this change, based on discussions with the villagers and district officers, are the population increase and a desire for each household to hold land. Young Maasai or Waarusha families are breaking away early from their parents to start their own bomas, and in this way hold their own land. This change in bomas is likely to have a negative effect on the traditional livestock management system because it restricts mobility that is an essential element in the Maasai pastoral system. In addition, based on discussions with villagers and district officers, there is general consensus that the power of traditional leaders seems to be deteriorating because new administrative structures such as village governments have been put in place to control the use of natural resources.

7.3 Livestock-keeping

Having discussed the population dynamics in the area and seen that there is a rapid increase of population in recent years, is now time to discuss livestock keeping strategies and changes of the same in the recent past. Historically, the Maasai have been pure pastoralists of the semi-nomadic kind, and livestock keeping plays a central economic and social role in their lives. Gulliver (1969) and Talbot (1971) elaborate the historical importance of livestock keeping in the Maasai socio-economic system. Livestock provide milk, meat and blood, the traditional food of Maasai, as they do not routinely eat farm produce except in the case of older men and women.

Table 7.3 Changes in boma organization

S/N	Response	No of respondents	%
1.	Bomas are becoming larger	0	0
2.	Bomas are becoming smaller	18	40
3.	No change	2	5
4.	Dispersed/or scattered	18	40
5.	No response	7	15
	Total	**45**	**100**

Source: Socio-economic survey (1999)

In addition, livestock is used as a form of capital for most economic transactions, provides the cow dung used in plastering huts, provides security against drought and diseases, are used in cultural functions such as rituals, marriages and circumcisions and in carrying loads. The Maasai did have, and still have to some extent, an elaborate grazing system, which enables their livestock to survive during the dry seasons. In order to get fodder and water all year round, livestock are moved to lands in various climatic zones during the wet and dry seasons, for example, areas at higher elevations that is footslopes and highlands are used as dry season grazing areas. Wetlands are used as dry season pastures; and the lowlands, which also includes salt licks, are used as wet season pastures (MDC, 1997). Although fences are not used, each group of Maasai has recognized grazing areas for wet and dry seasons, and the elders controlled the movement of the livestock (Talbot, 1971).

There are no reliable current data and past trends of livestock numbers are difficult to assess, but it is known that livestock numbers have been fluctuating in the whole of Maasailand due to drought and disease. However, based on data from a number of authors writings, such as Gulliver (1969), Talbot (1971) and MDC (1997) there is a general trend toward livestock decline in the whole of Maasailand, including the study area. Gulliver (1969) and Talbot (1971) give historical trends of livestock changes up to the early 1960's. The maximum livestock holdings are said to have occurred around 1880 at the peak of the Maasai holding of land and power. Around 1890, there was a decline both in livestock numbers and human population due to the rinderpest epidemic which coincided with severe drought and famine. By the end of the 19th century Maasai and their livestock were greatly reduced in numbers and were widely scattered. After the Second World War, a number of projects to improve livestock management, such as veterinary services, water and discouraging of cattle-raiding practices, were carried out in Maasai areas by the government of the day. This led to an increase in livestock numbers, reaching a peak by 1960. Apart from sheep and goats it is estimated that there were about 13 cattle for each Maasai at this time (Gulliver, 1969). Drought and famine struck Maasailand again in 1960/1961, once again reducing the livestock numbers. Talbot (1971) emphasizes that, apart from the scarcity of water and forage, diseases such as foot and mouth, pleurolneumonia, east coast fever, trypanosomiasis and rinderpest have always caused significant losses to Maasai livestock.

More recent livestock development activities and trends in the Arusha Region, Monduli District and the study area in particular are documented in office records of the 1970's, MDC, (1997), and Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999). According to the 1970's notes and records held at the Monduli District office, another attempt was made in the 1970's to improve livestock management in the Monduli District by starting cooperative ranches through the Maasai Range Development Commission. A number of cooperative ranches were established throughout Maasailand and were provided with an infrastructure, such as veterinary centres, dams, dips, permanent crushes, heavy construction equipment and training of veterinary officers and assistants. During this period, livestock services were at their peak and were provided free of charge. The project ended in 1980 and most of the infrastructure is now dilapidated. Data from Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999) shows that in recent years there has been a steady decline of livestock especially cattle. Tables 7.4 and 7.5 show livestock changes in the Arusha Region and Monduli District respectively. At the regional level, livestock have decreased from 4.6 million in 1978 to 3.8 million in 1995. There has been a general decline in cattle from 2 million to 1.5 million, while a general increase of goats from 1.4 million to 1.6 million. At the district level, there was an overall decrease of livestock by about 100000 between 1978 and 1984. However, caution must be exercised in interpreting livestock data to take into consideration the long-term livestock fluctuations in relation to rainfall variability, (see Figure 6.4.). 1978 was a wet year preceded by four dry years, therefore the livestock numbers may have just started recovering after a period of drought. Both 1984 and 1995 were drought years, therefore there is a possibility the livestock numbers were exceptionally low at that time. The regional authorities have given two main reasons for the decrease in livestock numbers at the district and regional level. Firstly, the increase of disease in recent years due to a decline in veterinary services in the region because the government has ceased providing livestock services and drugs to pastoralists (MDC, 1997). As an example, the Arusha Region has some 254 dips but only eight are now operational and, in the Monduli District, only one is operational out of 33 dips (Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha, 1999). Secondly, a number of Maasai have moved their livestock to regions where their rangelands are still in a better condition. For example, livestock in the Rukwa Region had increased by 2% from 4820000 in 1984 to 490000 in 1994 Morogoro Region by 527% from 531 to 3334000 and the Dodoma Region by 12% from 1712000 to 1925000. (Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha, 1999).

Table 7.4 Livestock numbers in Arusha Region, 1978-1995

Type	1978	1984	1995
Cattle	2026292	1855880	1447589
Goats	1495593	1231014	1648473
Sheep	1056699	758467	722168
Total	**4578584**	**3845361**	**3818230**

Source: Tume ya Mipango na ofisi ya Mkuu wa Mkoa, Arusha (1999)

Table 7.5 Livestock numbers in Monduli district, 1978-1984

Type	1978	1984
Cattle	334981	300639
Goats	272376	233421
Sheep	187905	164893
Total	**795262**	**698953**

Source: Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999)

It is worth noting that movement of livestock by the Maasai to other regions has led to fighting in some cases between the Maasai and the farming communities in the new areas. For example, the widely reported killings between the Maasai and farming communities in Kilosa District, Morogoro Region in December 2000 (Guardian 14/12/2000, 4/2/2001). The calf survival rates in the district have declined from between 65 and 80% in the 1960's and late 1970's to about 52% in the 1990's (Talbot, 1971; MDC, 1997) This partly indicates that health conditions of livestock in the district and study area are deteriorating with time.

7.3.1 Livestock development within the study area

The previous section gave an overall livestock keeping in the district, this section focuses on livestock activities within the study area only. The most recent survey of livestock data specific to the study area was conducted by the Groundwater Survey in 1994. It gives livestock numbers by that date as follows, cattle: 76086; sheep: 33223 and donkeys: 3245. Despite the changes that have occurred in Maasailand in general and the study area in particular since early the 1960's, the basic social system has remained more or less the same. For example, even though the mobility of Maasai has been reduced and they have now permanent village boundaries, the mobility of livestock within and outside the village boundaries is still maintained (MDC, 1997). Mobility of livestock is regulated by village elders who determine areas and watering points to be used in different seasons or areas that can be used by livestock keepers from other villages on request (MDP, 1998a 1998b, 1998c). The 1999 socio-economic survey shows that villages in the slopes of the Monduli Mountain graze their livestock in the wet season within the footslopes of the mountain, and in the dry season they move their livestock to higher elevations. Livestock in the Selela village, which is in the rift valley plains, graze in the plains during the wet season and are moved to the wetlands at the foot of the rift valley escarpment during the dry season for watering and forage. Livestock in the Lolkisale and Mswakini villages graze within their areas during both dry and wet seasons because they normally have excess forage. The 1999 socio-economic survey in the study area supports the view of general decline in livestock numbers, in which 71% of respondents said that there has been a decline of livestock both in total livestock numbers and in the size of the livestock herd. In addition 9% of the respondents said there had been an increase in small stock (goats and sheep) in relation to cattle (Table 7.6). The respondents attributed 33% of livestock decline to disease and water, 29% to just disease and 18% water scarcity (Table 7.7). The shortage of grazing land was rarely mentioned.

Table 7.6 Livestock changes over time

S/N	Response	No of respondents	%
1.	Increased	5	11
2.	Decreased	32	71
3.	More shoats than cattle	4	9
4.	No change	0	0
5.	No response	4	9
Total		**45**	**100**

Source: Socio-economic survey (1999)

Even though livestock keeping activities are still an important social and economic activity, a number of changes in recent years have occurred, altering the traditional method. The main changes are reflected in a number of sources including MDC (1993, 1997), Zwart, (1995) and 1999/2000 fieldwork. Firstly, the area is no longer purely occupied by the Maasai, but by other ethnic groups including the agro-pastoralist Waarusha who have moved from the fertile slopes

Table 7.7 Reasons for livestock changes

S/N	Response	No of respondents	%
1.	Disease	13	29
2.	Water scarcity and disease	15	33
3.	Water scarcity	8	18
4.	Water scarcity, disease and shortage of grazing lands	3	7
5.	Shortage of grazing lands	1	2
6.	No response	5	11
Total		**45**	**100**

Source: Socio-economic survey (1999)

of Mount Meru. Secondly, the majority of the Maasai are currently engaged in *both* livestock and agricultural activities. The 1999 socio-economic survey showed that 92% of the villagers are engaged, at different levels, both in livestock keeping and agriculture (Table 7.8). Thirdly, the mobility of the pastoralists is very important for the survival of the livestock, which has been restricted because some of the traditional grazing lands have been used up for agriculture or by government institutions. Fourthly, from the social survey, 60% of the residents interviewed said that there has been a change in the Maasai diet from purely livestock products of milk, blood and meat to include grain produce mainly beans and maize (Table 7.9). The main reason given for this change is the low output of milk and other products due to the low number of livestock kept per family and also the poor production of milk per beast. Lastly, the introduction of administrative boundaries, either at village, district, regional or national level has also contributed to limiting the free movement of livestock.

Table 7.8 Main economic activities

S/N	Response	No of respondents	%
1.	Pastoralist	1	2
2.	Agriculturist	1	2
3.	Agro-pastoralist	41	92
4.	Others	2	4
Total		**45**	**100**

Source: socio-economic survey (1999)

These changes, together with the steady decline of livestock in Maasailand even in good rainfall years, may indicate the beginning of the collapse of the Maasai pastoral system as it has been known. This is due to the competition between livestock keeping and other land use activities and the restriction in mobility. Plates 7.1 and 7.2 show livestock resting at the Mto wa Mbu livestock holding ground and livestock grazing near the Nanja dam respectively.

Table 7.9 Current main diet in the study area

S/N	Response	No Of respondents	%
1.	Milk and meat	0	0
2.	Milk, meat and food grains	44	98
3	No response	1	2
Total		45	100

Source: socio-economic survey (1999)

7.3 Agricultural activities

Given the dynamics of changes in livestock keeping activities it is now pertinent to discuss the agricultural activities in the area. Discussion and the analysis of agricultural activities are limited to the study area due to the fact that agricultural activities in the Monduli District are to a large degree are confined within the study area. The Monduli District has traditionally been used for grazing, but this is no longer the case, as in recent years crop farming activities have been on the increase. Three main types of farming activities can be identified in the district and the study area: agro-pastoralism, large-scale farming and small-scale irrigation activities. The history and development of agricultural activities in the Monduli District have been carefully studied by DLO, The Winand Staring Center for Integrated Land, Soil and Water Research of Netherlands, who used, among other source MSS and TM images at a scale of 1: 250000 from 1976 to1988 (Oosterom, 1995). The Madhivan group established the first medium-sized and large-scale farming in the southeast of Lossimingori (Rasha Rasha estate) in the 1930's. Later, during World War Two, a wheat farm was opened on the Ardai plains, using Italian prisoners of war as forced labor. After this large-scale farms by retired foreign soldiers expanded in the south and southeast slopes of Monduli, Lepurko and the Lossimingori Mountains.

Plate 7.1 Livestock resting at Mto wa the Mbu livestock holding ground (in the background is the rift valley escarpment)

Plate 7.2 Livestock grazing near Nanja Dam

The main crops grown were coffee and wheat near Monduli, and maize, beans and sorghum near Lossimingori and Lepurko. Between 1950 and 1960, medium-size farms were established south-east of Makuyuni by Tanzanian immigrants from Arusha, Mto wa Mbu and Monduli. The main crops grown were maize and beans. At about the same time, medium-sized farms, growing barley, maize, beans and Irish potatoes, were also opened on the northwest slopes of Mount Kilimanjaro. In the late 1960's and early 1970's the first large scale farms owned by private companies growing seed beans, maize, sorghum and sunflower were established northeast of Lolkisale. In the late 1980's to middle 1990's, large estate farms growing seed beans and maize, owned by both foreign and Tanzanian companies, were opened to the west and south-west of Lolkisale. These newly opened up areas were controlled by the Tanzania Military until 1988, prior to which agricultural activity was not allowed. Today about 50% of the Makuyuni village and 25% of the Lolkisale and Moita villages are leased to large-scale farms. The size of large-scale farms varies from less than 100 ha to more than 100000 ha. For example farms owned by international companies have on average more than 80 000 ha per company (for example the Rift Valley Seed Co. has about 154 305 ha), and companies owned by Tanzanians have between 80 to 800 ha. However, it should be noted that it is difficult to get accurate data on large-scale farms for the following reasons. Firstly, not all leased farms are officially registered. Secondly, the gauging of the farms is inaccurate because no proper survey has been conducted for many of the farms. Thirdly, many leased land areas are not or are only partially cultivated because they are kept for speculative investments or the owners do not have the necessary capital needed to invest in the farms. Therefore their boundaries can not be seen clearly on the ground or by remote sensing. On the other hand, small-scale agriculture was started by forest workers in the 1950's on northwest slopes of Mount Kilimanjaro, south of Monduli Mountain and south-west of the Meru Mountain by the Waarusha and Waameru. Major expansion of small-scale agricultural took place between 1970 and 1980. This coincided with the establishment of Ujamaa villages

(Oosterom, 1995; Monduli, 1997). The expansion of agriculture activities in the drylands between Moita Kiloriti and Meserani Chini, mainly by the Waarusha and Waameru, occurred between 1980 and 1990. From the late 1980's to middle 1990's agricultural expansion occurred in the dry marginal areas north and west of Monduli town mainly by the Waarusha. It was also during this period that the Maasai living between Sinonik and Mairowa attempted agricultural activities. Currently, all villagers interviewed during the social economic survey excluding those living in Mto wa Mbu and Monduli Towns, said they were engaged both in agricultural and livestock keeping activities or agro-pastoralism at different levels. Two main categories of agro-pastoralists could be identified, those who consider crop production as their main enterprise for subsistence food production and for cash income, and those who consider livestock keeping as their main enterprise and farming as their subsidiary activity. Most of the true agro-pastoralists were Waarusha, and had farm sizes of between 2 – 10 ha and herds of between 10 –30 cattle (MDP, 1997). Many of the Maasai engaged in agricultural activities belong to the second category. Beans and maize are still the main crops grown by the majority of agro-pastoralists, and a number of the farmers use tractors or cattle plough to cultivate their farms. Pure agro-pastoralists appear in higher frequency in relatively wet areas (like footslopes, and plateaus and also on the eastern side of the study area close to Mount Meru; where they originally came from), but are fewer in the much drier northwestern plains in the rift valley.

Small-scale irrigation started at Mto wa Mbu after the Second World War (Yanda and Mohamed, 1989; Braun, 1990). The Mto wa Mbu settlement is located in the flood plain of the eastern arm of the great Rift Valley. The settlement is crossed by a number of perennial rivers which are used for irrigation, including Kirurumo, Simba and Mto wa Mbu. The main crops grown are bananas, maize, paddy rice, millet and vegetables. A major expansion of irrigation activities occurred during the formation of the Ujamaa villages. Based on records at the irrigation office and earlier studies such as Braun (1990), the average size of irrigation plots ranges from 0.5 to 2 ha. According to Braun (1990) and from the 1999 survey, the total area used for both irrigation and rain-fed agriculture in the Mto wa Mbu area has increased from 452 ha in 1980, to 1081 ha in 1985 and then to 4680 ha in 1998. The areas which are currently used for irrigation activities in the Mto wa Mbu village and to a limited extent at Selela village were previously used as dry season and watering points for both Maasai livestock and wildlife (Monduli, 1997)

7.3.1 Crop yields

Long term reliable data on crop yields in the district in general and in the study in particular area is scarce. However, the MDC (1997) gives average yields for maize and beans in the semi arid area and semi-humid lands as shown in Table 7.10. As expected, yields are higher in semi-humid lands, for both maize and beans, than in the semi-arid areas. Estimates on crop yield of the main crops at the regional and district level are indicated by Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha, (1999). Table 7.11 shows areas under maize production and yields in different years. In general, if the 1985/86 season is ignored, the amount of land under maize farming is increasing with time, probably due to an increase in the population engaged in farming activities.

Table 7.10 Maize and beans yield in different agro-ecological zones

Climatical zone	**Yield**	
	Maize	Beans
Semi-arid lands	500-1250	250-750
Semi-humid lands	1750-2500	500-1000

Source MDC (1997)

Despite the fact that there is a general increase in land under maize cultivation, the amount of land used each year fluctuates depending on the rainfall conditions. Both Table 7.11 and Figure 7.4 show similar patterns of increase and fluctuation of maize yield over time. It is difficult to point out the exact causes of the fluctuations of maize due to limited data, but the possibility that rainfall variability is one of the factors cannot be ruled out. The probable explanation for this anomaly is that there may have been an improvement in agricultural management. Figure 7.5 taken together with Table 7.11 shows the maize yield in tonnes/ha fluctuating over time.

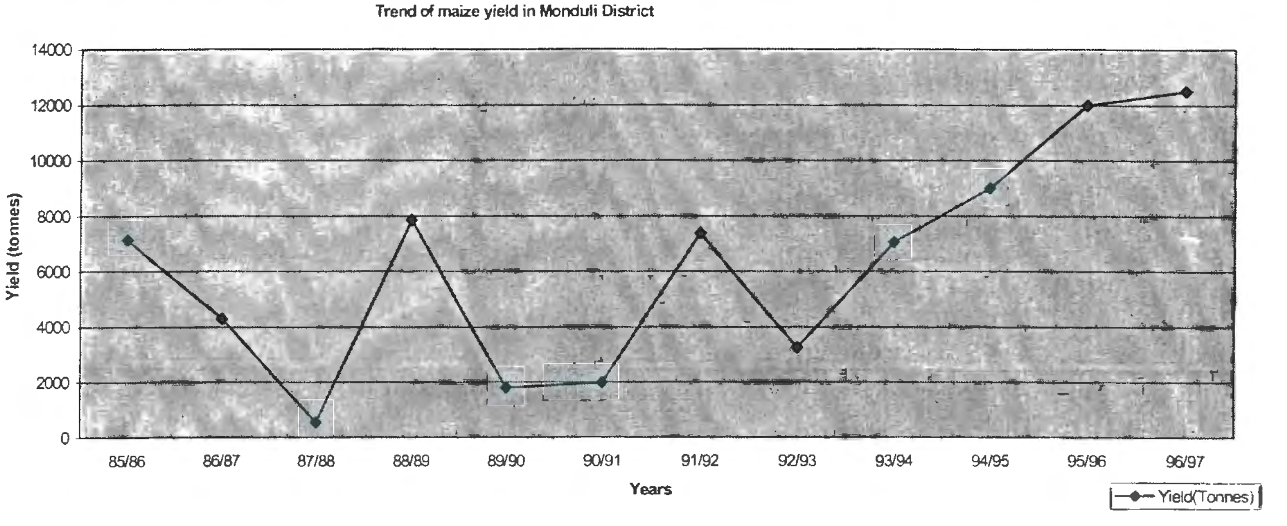
Table 7.11 Trends of areas under maize cultivation and their yields

Year	Area (ha)	Yield(tonnes)	Yield (tonnes/ha)	Annual rainfall
85/86	4800	7140	1.5	641
86/87	2830	4290	1.5	886
87/88	3130	560	0.2	668
88/89	3170	7860	2.5	557
89/90	3940	1790	0.5	843
90/91	3310	1990	0.6	874
91/92	4920	7380	1.5	753
92/93	3600	3250	0.9	760
93/94	4700	7060	1.5	590
94/95	3600	9000	2.5	675
95/96	4800	12000	2.5	660
96/97	5000	12500	2.5	754

Source: Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999)

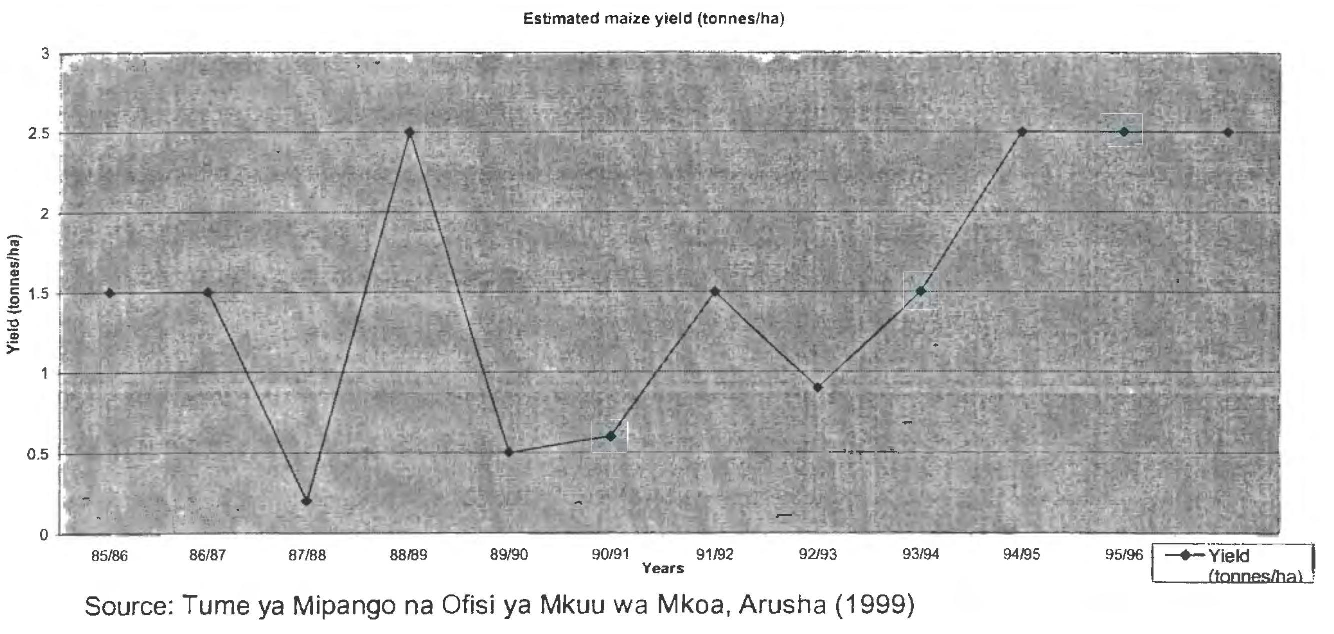
Initially, maize yields/ha fluctuated, but after 1994 there was a steady increase in yield per hectare. This can be due to, as already pointed out, improvement in agricultural management. The fluctuation of maize production at the district level is supported to some extent by the 1999 socio-economic survey, which indicates that 60% of the respondents have seen changes on crop yields over time. Only 24% indicated that crop yields were falling, while 74% could not tell, as there was great variability from year to year.

Figure 7.4 Trend of maize yield



Source: Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999)

Figure 7.5 Estimated maize yield trend (tonnes/ha)



Source: Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha (1999)

55% of the respondents pointed out rainfall changes as the main reason for change in crop yields, and only 15% saw a combination of rainfall and fall in soil fertility as the main cause. Plate 7.3 shows a successful field of maize crop in June 1999 (good rainfall year) in the Lendikinya village while Plate 7.4 shows crop failure of maize field in the same village, in June 2000, a poor rainfall year.

7.4 Water supply

Water service levels directly affect the utilization of natural resources in the area. This is due not only to the area being dryland but also to the main economic activities of agriculture and livestock keeping depending directly on the water supply through precipitation. This means for example, that in high rainfall years there are good pasture conditions and there is a good water supply for human beings, livestock and wildlife. The opposite is true in the case of poor rainfall conditions. The main types of water sources in the area are; small-scale dams, boreholes, springs and piped water. Small-scale dams and shallow wells are the commonest source of water and are used in almost all villages. Piped water supply is limited only to Monduli Town, Mto wa Mbu and the Tanzania Military Academy. Water from boreholes is used in the Makuyuni and Mswakini villages only, while spring water is used in the Lolkisale village, Monduli Town and Mto wa Mbu. Shallow wells are found in almost all villages. Table 7.12 and Figure 7.6 show the main types of sources of water together with their condition and location respectively. There is a marked annual and inter-annual water supply variability in the area. During the rainfall season, there is an adequate water supply as it can be obtained from seasonal rivers, ponds and boreholes. However, in dry the season, there is a scarcity of water as seasonal rivers, ponds and most of the boreholes dry. During the dry season residents resort to using water from dams or piped water at Monduli Town or at the Duka Bovu settlement or from the deep borehole at Makuyuni

Plate 7.3 Successful field of maize crop, June 1999 (good rainfall year)

Plate 7.4 Failed of maize crop at Lendikinya village, June 2000 (poor rainfall year)

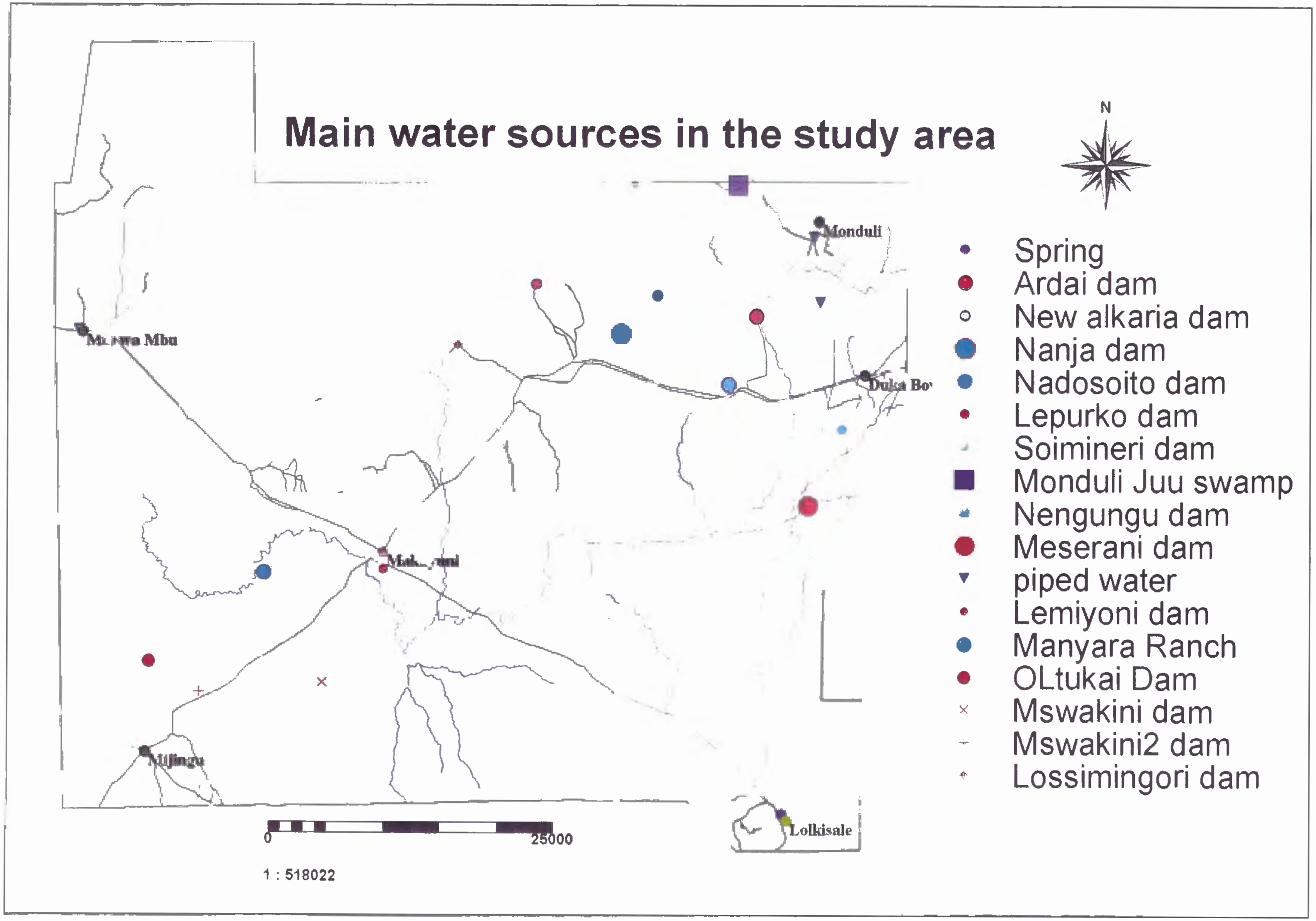
village. When there is an acute scarcity of water, livestock are normally moved away to other areas that have water. At these times arrangements are made for some villages to be supplied with water by trucks from Arusha Town. Inter-annual variability of the water supply is directly linked to the inter-annual rainfall variability. In wet years the dams can have enough water until the next rainy season, while in dry years the dams dry half way through the dry season. Overall, it appears that there is a fall of water supply services due the non-functioning of a number of the large dams (see Table 7.12).

Table 7.12 Main types of water sources and their conditions

Name of the village	**Name of the dam**	**Storage capacity $1000m^3$**	**remarks**
Lashaine	Ardai	113	not working
Lendikinya	New Alkaria	142	working
Arkatan	Nanja	2678	working
	Nadosoito	362	working
Lossimingori	Lossimingori	81	not working
Meserani Juu	Nengungu	101	working
Mbuyuni	Mbuyuni	102	not working
Makuyuni	Lemiyoni	16	not working
Manyara ranch	Manyara ranch	?	working
Oltukai	Oltukai	264	not working
Mswakini	Mswakini-1	45	not working
	Mswakini –2	21	not working
Emairete	Monduli Juu	271	livestock only
	Emairete	15	working
Lepruko	Lepruko	169	not working
Makuyuni	Soimineri	69	not working
Meserani Chini	Meserani	750	not working

Source: Sanyu Consultants Inc. and Japan Engineering Consultants Co (1995)

Figure 7.6 Main types of water sources



Silting and breaching are the main factors attributed to this (Sanyu Consultants Inc. and Japan Engineering Consultants Co, 1995; Groundwater Survey, 1994). Silting is due to soil erosion as a number of silted dams were located within areas undergoing soil erosion, while breaching can partly be caused by the high content of sodium salts which makes the soils more erodible.

7.5 Conclusion

The study area is part of a large area that has traditionally been occupied by the Maasai people who are considered to be semi-nomadic pastoralists and warriors. Their social organization has been based on the stratification of communities using male age sets, and the two senior age sets were considered as the leaders who made decisions on the use of natural resources. Milk, blood and meat all products of livestock, have been the traditional food of Maasai. The Maasai population numbers has been fluctuating due to disease, famine and drought. Livestock keeping has been the main social and economic activity of the Maasai and large areas were used as rangelands. To ensure the availability of forage and water all year around, they moved their livestock to different ecological areas in wet and dry seasons. As with the human population, livestock numbers fluctuated due to disease and drought. Beginning in the early 1970s, a number of social and economic changes occurred in the area. The area is no longer exclusively occupied by Maasai, but also by other social groups from within and outside the region, who are either farmers or agro-pastoralists. Also, in recent years, there has been an increase in large-scale farming by international and local companies, and an increase in irrigation at Mto wa Mbu. The population and population density has increased mainly due to immigration. A number of consequences have arisen due to recent socio-economic changes in the area. Foremost it has led to a reduction of prime grazing areas and livestock mobility, as most of the farms were initially located in areas with good pastures. It has also influenced the Maasai people to become agro-pastoralists, and has led to a gradual change in the Maasai diet. This implies a shift in the use of natural resources from periodical use facilitated through mobility to permanence through agricultural activities. The current socio-economic changes that are taking place in the study area are likely to lead to the breakdown of traditional systems in natural recourse utilization and an acceleration in land degradation.

The following chapter will discuss and analyze landcover, landcover changes and patterns of landcover changes in the study area.

CHAPTER EIGHT

8. LANDCOVER AND LAND USE CHANGES

8.1 Introduction

Having discussed the biophysical and socio-economic aspects of the study area it is pertinent now to analyze and discuss the landcover/use changes in the study area from the1960's to 1999. The main objectives of this chapter are to:

- Describe and analyze the landcover/use for the study area for the years of the 1960's, 1991 and 1999.
- Determine and analyze the landcover/use changes for both periods of the 1960's/ 1991 and 1991/1999.
- Establish the trend of landcover changes from the 1960's to 1999 by combining landcover changes of the 1960's/1991 and 1991/1999.
- Distinguish changes in semi-natural vegetation due to rainfall variability from changes due to anthropological activities.
- Establish the pattern of the main types of cover changes in relation to physical and socio-economic factors.
- Determine, for both soil and vegetation, landcover changes that may be identified as processes of land degradation.

This is a key chapter central to the thesis along with Chapter 9. The chapter has four main sections. Section one deals with landcover/use situation for the years of the 1960's, 1991 and 1999. The section starts with description and analysis of the landcover/use of the 1960's, 1991 and 1999. The landcover/use for the three years are discussed and presented using three different formats, i.e. maps, tables and histograms. The maps show the spatial coverage of each landcover, while the tables contain the spatial coverage and land uses of each type of landcover. For each year there are two histograms, one shows only the main cover types, and the other shows the coverage of semi-natural vegetation. For the year 1999, two extra maps were added, one shows the restricted areas for pastoral activities, and the other indicates the gullies and bare lands. There are four main categories of landcover found in all three years as follows; a) various types of semi-natural vegetation, b) agricultural lands, c) gullies and bare lands and d) water bodies. An analysis in terms of location and use has been made for each of the main landcovers.

Section two dwells on landcover changes both between the 1960's and 1991, and 1991 and 1999, and was based on landcover information generated in section one. As already indicated in Chapter Four on research strategies, direct comparison of landcover maps generates so many cover changes that it was difficult to comprehend, a factor that led to the generalization of cover changes for the two periods. Therefore, cover changes presented in this section are generalized landcover changes. These landcover changes have again been presented using maps, tables and histograms. There is a table for each period of change, i.e. the 1960's/1991 and 1991/1999 showing the generalized cover changes in hectares for each of the main cover type. This table is supported by a histogram which shows the overall cover changes for the period of 1960's/1991 and 1991/1999. Separate landcover change maps and histograms were prepared for each of the main types of landcover (semi-natural vegetation, agriculture, gullies and bare land and water bodies) for earlier and later periods. The change maps, tables and histograms for each main landcover type are supported by an analysis in terms of the location of change areas and discussion as to the likely factors contributing to the changes.

The third section explores the trends of landcover changes from the 1960's to 1999, which were generated by combining the change maps of the 1960's/1991 and 1991/1999. This section can be divided into three sub-sections; sub-section one is on the overall trend of the main cover changes and is presented in both tabular and histogram format. The table and the histogram both show the overall trend of all cover types from 1960's to 1999. Sub-section two focuses on overall and specific (i.e. within each land unit) trends of different types of semi-natural vegetation and again is presented in a tabular, map and histogram format. The specific trends of different types of semi-natural vegetation show the vegetation cover changes in each land unit for both periods of the 1960's/1991 and 1991/1999. The trends of vegetation cover changes in each unit were reclassified into groups in such a way that they reflected the dynamics of cover changes in terms of increase, decrease or no change in vegetation for the whole period. Therefore, the final output is a map supported by a table and a histogram shows nine different types of vegetation dynamics that occurred in the different land units. The nine types of vegetation dynamics are: no change/decreased (no change = no change in vegetation between the 1960's/1991, decreased = vegetation decrease in 1991/1999 period), increased/no change, increased/increased, decreased/ decreased, no change/increased, increased/decreased, decreased/no change, no change, decreased/increased. The final section is on analysis of patterns of landcover changes against physical and socio-economic factors. It is the section that attempts to show the factors contributing to landcover changes. The physical factors considered include rainfall distribution, relief, geology, and slope, while the socio-economic parameters were population density and the main economic activities. A separate analysis is made for each of the main cover types of vegetation, agriculture, gullies and bare land and water bodies. In this section the results are presented using only tables and histograms.

Comparing landcover changes using the wet years of 1999 and 1991 and a composite of wet and dry years of the 1960's poses a serious limitation because of the inherent landcover variability associated with moisture availability which obviously differs between the wet and dry years. This problem is further compounded by differences in seasons, which are the end of the wet season for 1999 and the dry seasons for 1991 and the 1960's maps. To derive a reasonable comparison of land cover changes over time, then, certain adjustments ought to be made on the landcover/use maps so that they appear as if constructed under similar rainfall regime conditions, in terms of wet or dry years, or seasons that are dry or rainy. Adjustments were made for 1991 cover maps to overcome the differences in seasons between 1991 and 1999. No adjustments were made for the 1960's cover maps, in part because airphotos are not as sensitive as satellite images to changes in grassland colour from green to brownish when dry. In addition, field maps used for ground-truthing did not have any land demarcated as bare land, meaning that, either there was indeed no bare land, even in the dry season, or that areas which appeared as bare land were incorrectly mapped as grassland.

8.2. Landcover/use, 1960's, 1991 and 1999

This section describes and analyzes the three landcover maps for the 1960's, 1991 and 1999. The section starts with the description and analysis of the 1960's landcover/use, followed by the 1991, and finally the 1999 landcover/uses.

8.2.1 Landcover/use, 1960's

In the late 1950's and early 1960's, about 87% of the area was covered by several different types of semi-natural vegetation, as opposed to agricultural or water body. Table 8.1 and Figures 8.1, 8.2 and 8.3 show the 1960's

Table 8.1 Landcover/use, 1960's

	Cover type	Area (ha)	% of total area	% of cover	Landuse (Remarks)
A	*Vegetation*				Mostly rangelands for livestock and wildlife Game controlled areas Protected forests in mountains
1	Bushland (dense)	5674	1.4	1.6	
2	Open forest	6500	1.6	1.8	
3	Woodland	10056	2.5	2.8	
4	Bushland	13411	3.3	3.7	
5	Bushed woodland	47929	11.9	13.1	
6	Bushed grassland	105826	26.2	29.0	
7	grassland	176041	43.6	48.2	
	Sub total	**365437**	**90.6**	**100.0**	
B	*Agriculture*				Subsistence farming, maize and beans Commercial farming, coffee plantations
1	Small scale farming	104	0.0		
2	Large scale farming	4714	1.2		
	Sub total	**4818**	**1.2**		
C	***Water bodies and wetlands***				Domestic and livestock watering.
1	Dam	17.2	0.0		
2	Lake	9507	2.4		
	Swamp	4092	1.0		
	Sub total	**13616.2**	**3.4**		
D	***No data***	**19669**	**4.9**		
	Overall total	**403340**	**100.0**		

landcover/use in spatial and quantitative terms. The dominant natural and semi-natural vegetation types were grasslands and bushed grasslands, which covered 41% and 26% of the vegetated area respectively. Woody vegetation covered 21%, of the area of which 12% was bushed woodland, 3% bushlands, 3% woodland, 2% open forest and 1% dense bushlands. Bushed woodland was mostly found in the southern part of the study area. Floodplains, swamps and salt flats, found mostly in lake terraces and low lying areas, covered about 7% of the area. Agricultural lands, mainly large-scale farming concentrated on the slopes of the Monduli, Lepurko and Lossimingori Mountains, covered about 1% of the total area. There were very few small-scale farms, occupying about 100 ha found in and around the Meserani Juu village. Water bodies, mainly Lake Manyara, covered about 2% of the area. In the late fifties and early sixties the area was predominantly used as a rangeland by both livestock and wildlife. Crop production was confined to large-scale farming activities. Apart from the large-scale farms, all land in the area was held in the public domain.

Figure 8.1 Main landcover types for the 1960's

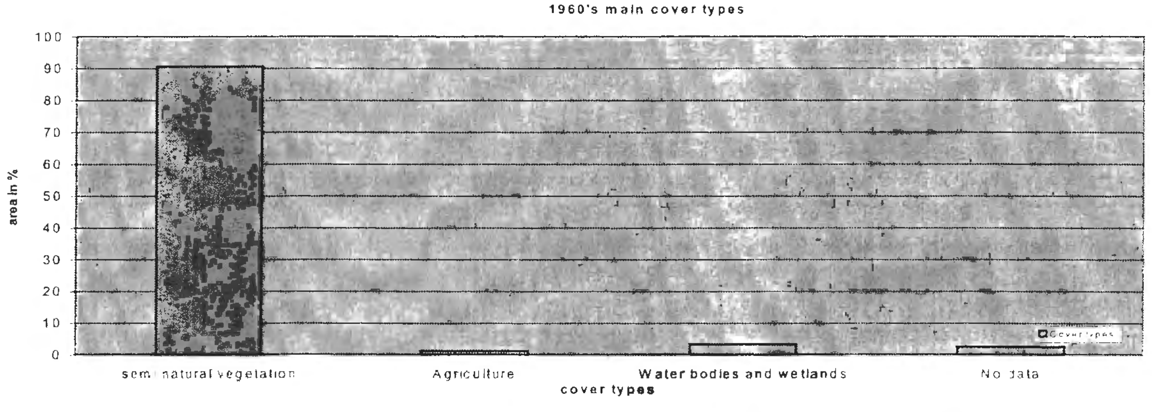


Figure 8.2 Main semi-natural vegetation types for the 1960's

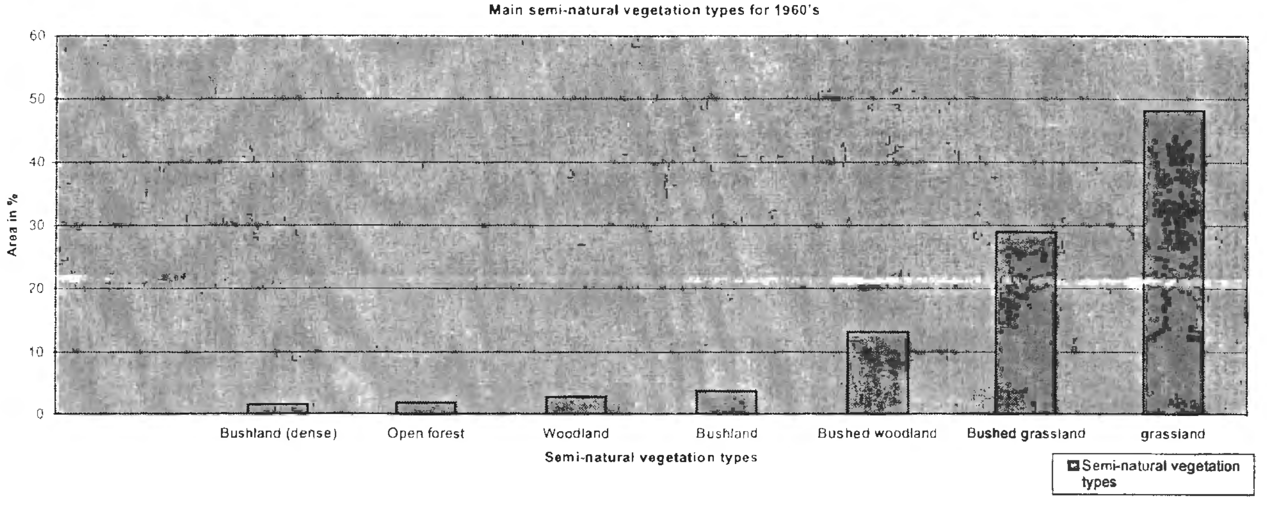
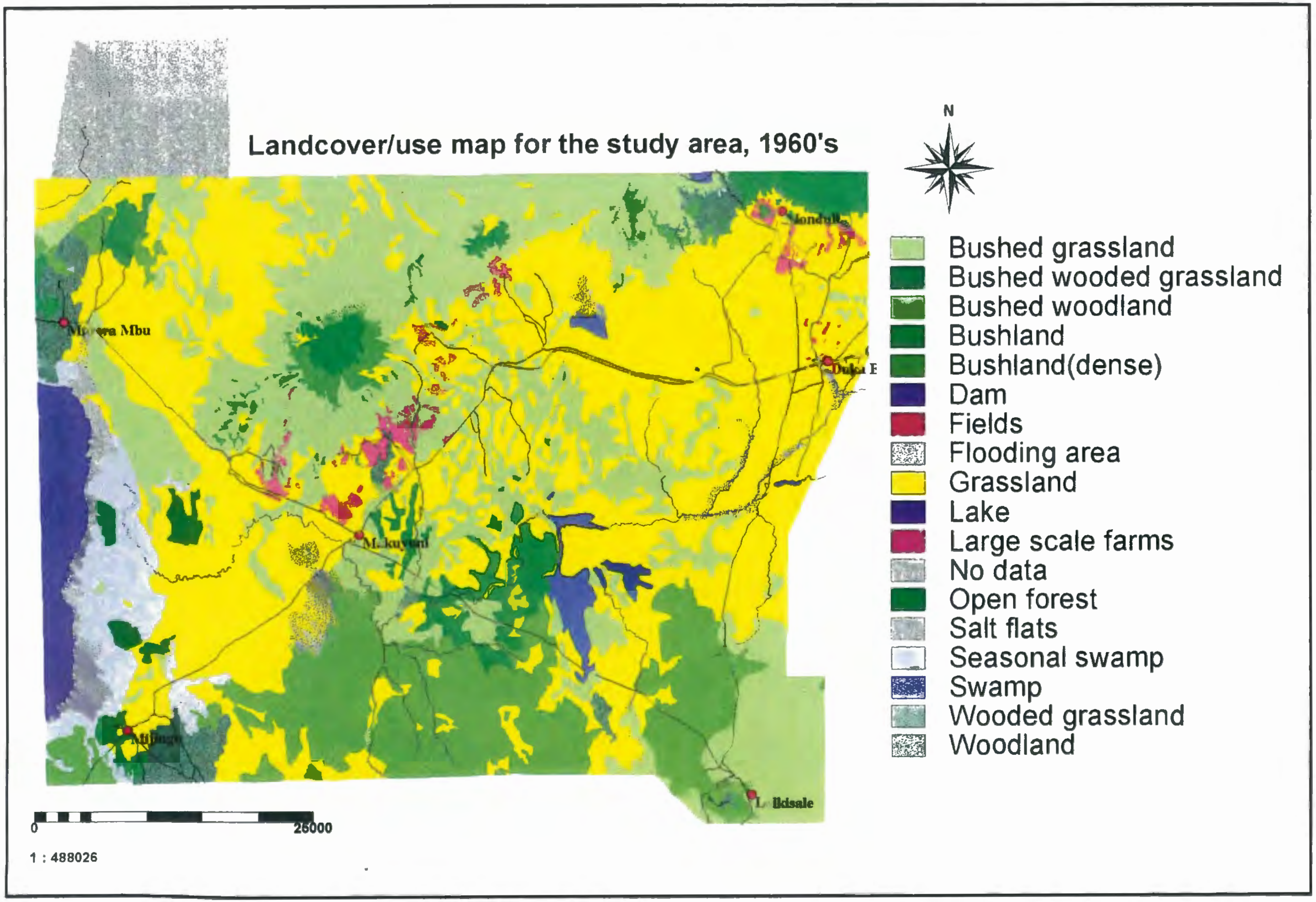


Figure 8.3 Landcover/use map for 1960's



8.2.2 Landcover/use, 1991

Direct interpretation of the 1991 satellite image shows the predominant landcover as being different types of semi-natural vegetation, mostly grassland and bushed grassland, which covered about 289200 ha (72%) of the area, followed by agricultural lands, occupying about 81700 ha (20%), bareland and gullies 17100 ha (4%) and water bodies 12000 ha (3%). Table 8.2 and Figures 8.4, 8.5 and 8.6 show the details of 1991 landcover/use. However, because the 1991 landcover/use map was derived from a dry season TM image, during this time of the year large areas of grasslands appear as dry. Consequently it becomes very difficult to differentiate between grasslands and bare land in false colour satellite images, as most of the dry grasslands appear as barelands. Those areas which appear as barelands in satellite images especially on undulating plains and plateau areas, are probably grasslands and would have appeared as such if the image were taken in the wet season or just at the end of the wet season. Therefore an adjustment has been made, to change areas that appear as bare land in September TM image to appear as grasslands. Nevertheless, such an adjustment could lead to an underestimate of areas that were truly barelands in 1991, since no field check at the time was possible to verify landcover/use types. After this adjustment was made, all the figures on landcover types remained the same except for semi-natural vegetation which increased to 305600 ha (76%) and bareland and gullies were reduced to 600 ha (0.2%). Grasslands and bushed grasslands were still the dominant vegetation cover types, occupying 78% of the semi-natural vegetated land. Most of the semi-natural vegetated areas were used as rangeland for both livestock and wildlife. This was followed by crop production activities practised in small and large-scale farming and in traditional irrigation farms.

Table 8.2 1991 landcover/use

	Cover type	Area (ha)	% of total area	% of cover	landuse (Remarks)
A	**Type of vegetation**				
1	Bushed grassland and grassland	1377	0.3	0.5	Livestock and wildlife grazing
3	Bushland (dense)	1737	0.4	0.6	State land, Manyara ranch
4	Bushland	2565	0.6	0.8	Dormant large-scale, protected
5	Bushed woodland	2929	0.7	1.0	forest areas
6	Woodland	3936	1.0	1.3	Settlements areas, source of
7	Wooded grassland	8850	2.2	2.9	fuelwood and traditional medicines
8	Open forest	8141	2.0	2.7	Game controlled areas and hunting
9	*Wooded grassland*	15455	3.8	5.1	blocks
10	*Bushed wooded grassland*	23244	5.8	7.6	
11	*Bushed grassland*	75426	18.7	24.7	
12	*Grassland*	161972	40.1	53.0	
	Total	**305632**	**75.7**	**100.0**	
B	**Agriculture**				
	Small scale farming				
1	Built-up area grasslands and fields	354	0.1		
2	Wooded grassland and fields	2608	0.6		Subsistence maize and beans
3	Bushed grassland and fields	10006	2.5		cultivation
4	Fields	23017	5.7		Residential areas
5	Fields and grassland	24339	6.0		
	Sub total	**60324**	**14.9**		
6	Large scale farming	**18124**	4.5		Commercial and subsistence seed
3	Irrigation	**3255**	0.8		beans, maize, maize, paddy and
	Total	**81703**	**20.2**		vegetation cultivation.
C	**Bare land and gullies**				
1	Bareland and gullies	479	0.1		Residential areas and grazing
2	Built-up area and bareland	148	0.0		areas for calves
	Total	**627**	**0.2**		Livestock tracks
D	**Water bodies and wetlands**				
1	Lake	11263	2.8		Domestic water sources, livestock
2	Dam	704	0.2		watering areas, dry season
	Sub total	**11967**	3.0		grazing areas
	Overall total	**403879**	**100.0**		

Figure 8.4 Main landcover types for 1991

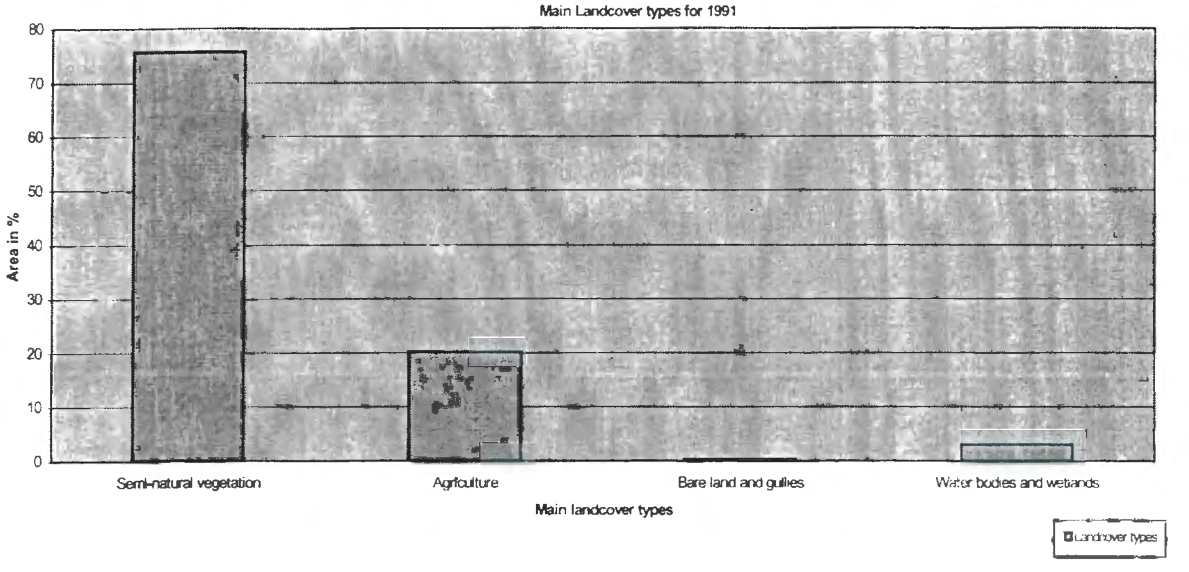


Figure 8.5 Main semi-natural vegetation types for 1991

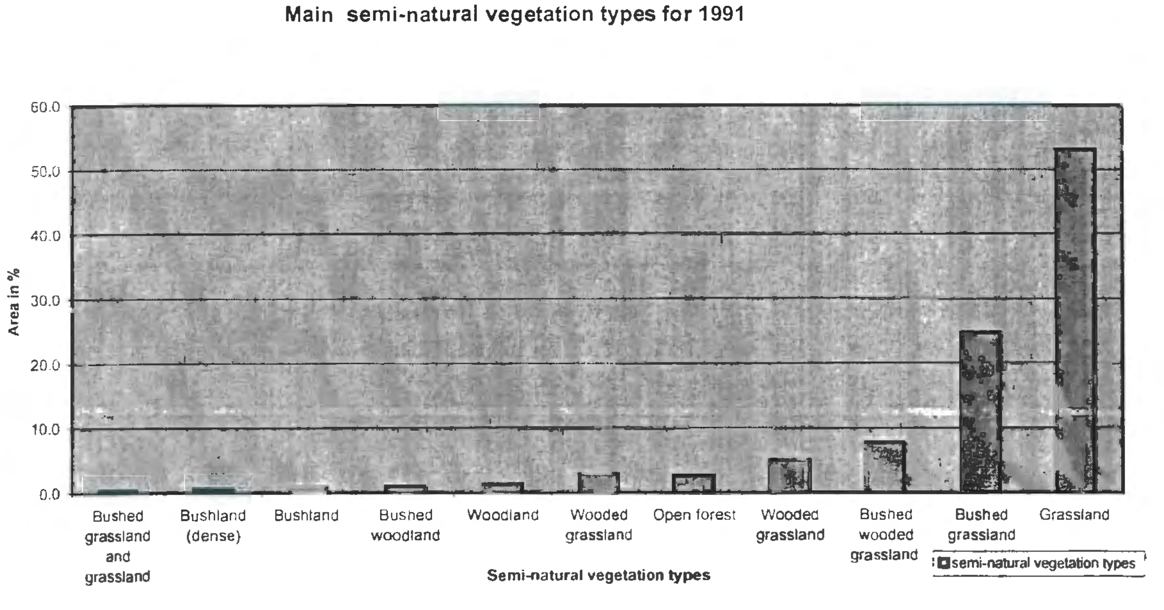
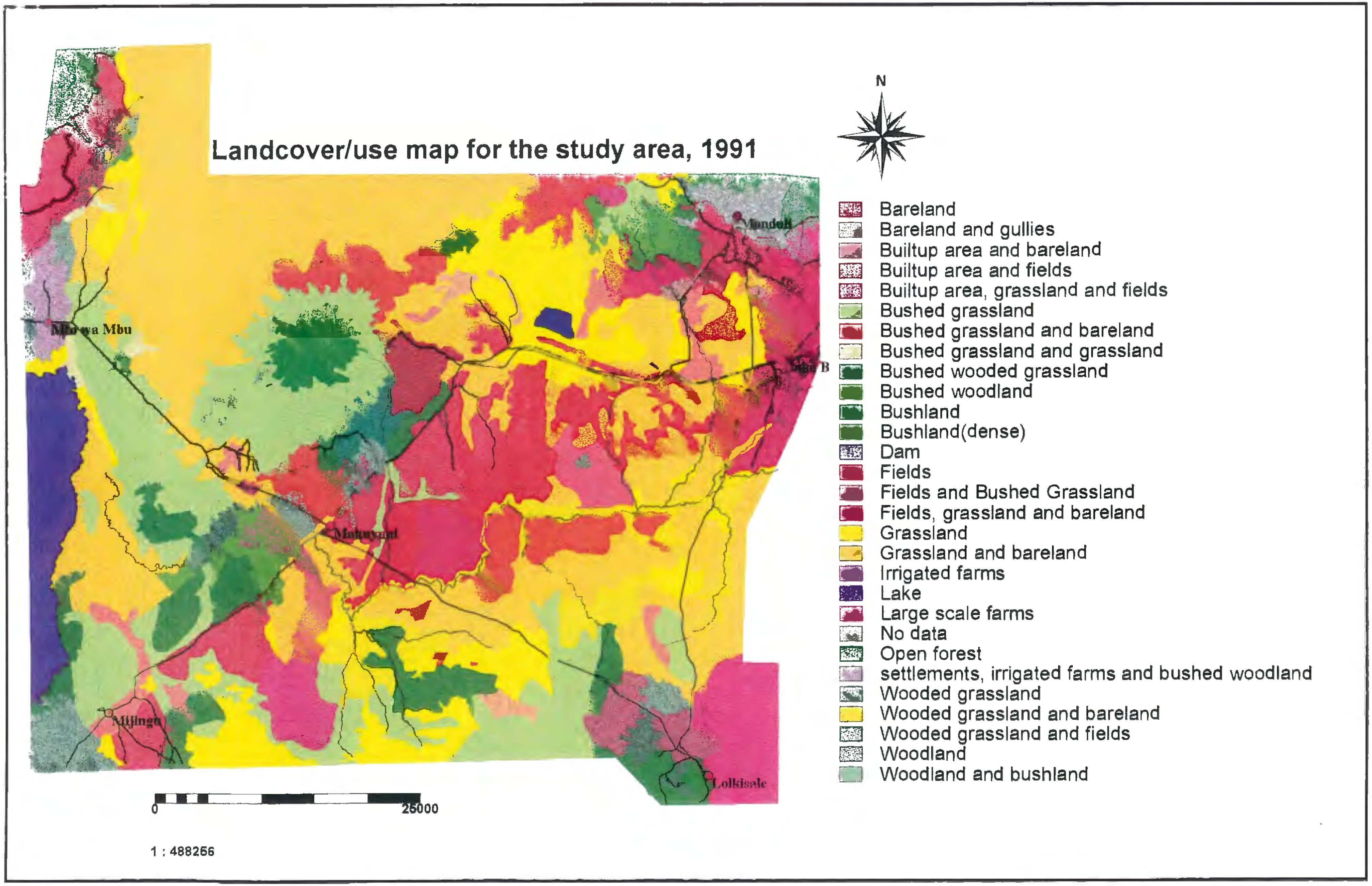


Figure 8.6 Landcover/use map, 1991



8.2.3 Landcover/use, 1999

Four main types of landcover were found in the area, including semi-natural vegetation, agricultural land, bare land and water bodies. Areas occupied by semi-natural vegetation occupied about 301300 ha or 75% of the total area, agricultural land 70100 ha or 17%, bare land and gullies 11800 ha or 3%, and water bodies occupy about 19600 ha or 5% of the total area. Table 8.3 and Figures 8.7, 8.8 and 8.9 show the details of both the 1999 landcover and landuse of the area. Both people and wildlife use lands occupied by semi-natural vegetation for a number of activities. They provide forage for both wildlife and livestock, are used in building new bomas and settlements; harvested products from vegetated lands are used as building materials and as domestic fuelwood. Such areas are cleared to open new agricultural lands in relation to both small and large-scale farming. In addition, both the Maasai and Waarusha use a number of medicinal plants for treating various human and livestock diseases and which they obtain within the area (Ibrahim, 1997). Other landuse activities include the protection and hunting of wildlife instituted through game controlled areas and hunting blocks respectively. Professional hunting companies, who bring in tourists for hunting expeditions, own the hunting blocks. Rainfed agricultural lands are used to grow food or cash crops during the rainy season, the details of which have been explained in the preceding chapter seven. After harvesting, especially on small-scale farms, crop remnants are used as a source of fodder for livestock. However, owners of large-scale farms do not allow livestock to graze on their properties following harvest in order to avoid soil erosion and compaction, unless such livestock belong to the farmer. In irrigated lands, where farming activities are carried out throughout the year, no grazing is allowed although crop remnants are usually cut and sold to livestock keepers during the dry season.

However, not all vegetated land is available to be used freely by the inhabitants of the area (Figure 8.9b). About 48200 ha were taken up by the military in the

Table 8.3 Landcover/use, 1999

	Cover type	Area (ha)	% of total area	% of a cover	land/use (Remarks)
A	**Vegetation**				
1	Bushland	584	0.1	0.2	Livestock and wildlife
2	Grassland and wooded grassland	638	0.2	0.2	grazing.
3	Bushland (dense)	1342	0.3	0.4	State land
4	Woodland	3992	1.0	1.3	Manyara ranch
5	Bushed grassland and grassland	5371	1.3	1.8	Dormant large-scale and
6	Bushed grassland and wooded grassland	5415	1.3	1.8	small scale farms
7	Woodland and bushland	5948	1.5	2.0	Protected forest areas
8	Bushed wooded grassland	7545	1.9	2.5	Settlements
8	Bushed woodland	9216	2.3	3.1	Source of fuelwood and
9	Bushland and bushed grassland	9923	2.5	3.3	traditional medicines
10	Open forest	12884	3.2	4.3	Game controlled areas
11	Wooded grassland	34908	8.7	11.6	Hunting blocks
12	Bushed grassland	100179	24.9	33.2	
13	Grassland	103393	25.7	34.3	
	Total	**301338**	**74.8**	**100.0**	
B	**Agriculture**				
	Small scale farming				
1	Built-up area grasslands and fields	742	0.2		Subsistence maize and
2	Bushed grassland and fields	1879	0.5		beans cultivation
3	Bushed grassland, wooded grassland and fields	2917	0.7		Residential areas
4	Built-up area and fields	3482	0.9		
5	Fields and grasslands	11973	3.0		
6	Fields	21453	5.3		
	Sub total	**42446**	**10.5**		
	Large scale farming				
1	Large scale farming and grasslands	1826	0.5		Commercial Seed beans
2	Large scale farms	20583	5.1		and maize and maize
	Sub total	**22409**	**5.6**		cultivation.
	Irrigation				
1	Irrigated farms	516	0.1		Subsistence and
2	Built-up area and irrigated farms	4680	1.2		commercial cultivation
	Sub total	**5196**	1.3		of bananas, beans, rice
	Total	**70051**	**17.4**		vegetables and maize
C	**Bareland and gullies**				
1	Bareland and gullies	152	0.0		Badlands or
2	Fields and gullies	2374	0.6		grazing areas for calves
3	Grassland and gullies	2392	0.6		Livestock tracks
4	Fields, grassland and gullies	6854	1.7		
	Total	**11772**	**2.9**		
D	Water bodies				
	Dam	87	0.0		Domestic water
	Swamp	1911	0.5		sources, livestock
	Lake	17612	4.4		watering areas, dry
	Total	**19610**	4.9		season grazing areas
	Overall total	402771	100.0		

Figure 8.7 Main landcover types for 1999

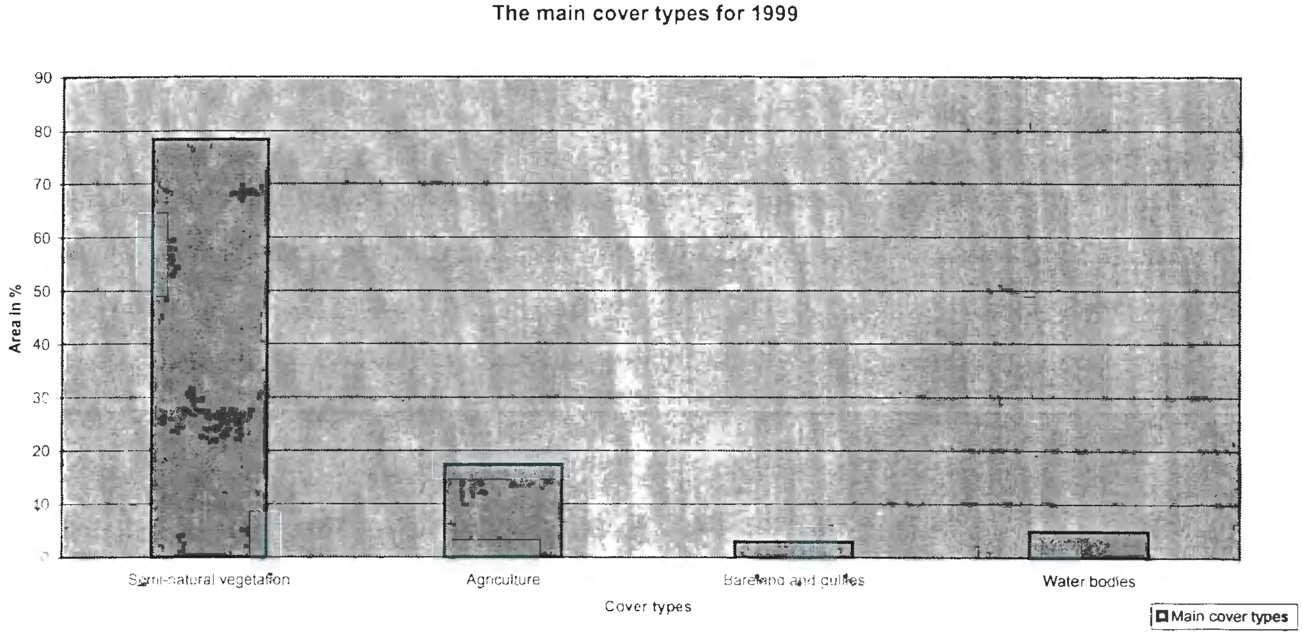
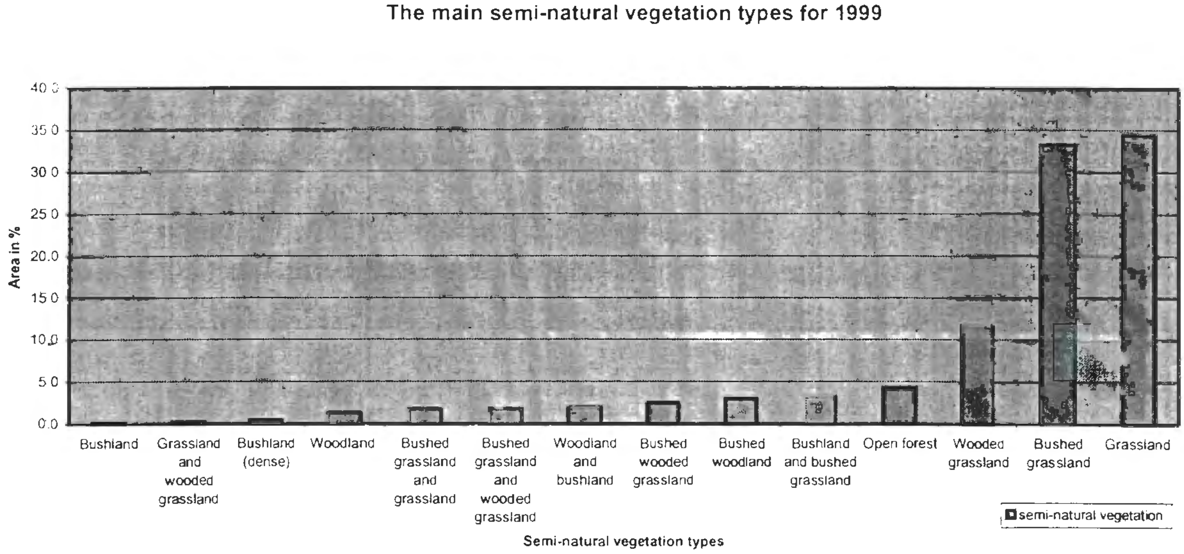


Figure 8.8 Main semi-natural vegetation types for 1999



mid-seventies to be used by military activities. Villagers are not allowed to construct in these areas or carry out farming activities, but they are allowed to use the associated rangelands with certain restrictions. On the 18200 ha that belong to the Manyara State ranch, villagers are not allowed access, even though ranching activities have long since ceased. About 8376 ha belong to large-scale estates which are hardly cultivated. These estates occupy the slopes of the Lossimingori Mountain; villagers in the vicinity of these estates are strictly not allowed to graze their livestock within these areas. About 15000 ha northwest of the Lolkisale Mountain are dormant medium-scale surveyed estate farms. Villagers are not allowed to farm or build bomas within the dormant estates, although they are allowed to graze their livestock. In addition, there are some restrictions that have been put on the use of protected forests of Monduli, Lossimingori and Lepurko, especially on the harvesting of woody vegetation, even though villagers are allowed to graze their livestock.

Gullies are found in the cracking soil of high clay content mainly on the footslopes and on the undulating plains of Monduli Mountain. In terms of depth and width the size of the gullies in footslopes and undulating plains differs with the topographical position. Gullies in higher elevations and steep slopes are relatively deep with steep sidewalls. For example, gullies in the Sinon-Ngarash village are very deep, at times up to 10 m, and have a width of between 10 to 15m with sidewalls of 45^0 or more. The depth and steepness of gully sidewalls decreases, and width increases as one moves south towards the undulating plains. At the Lashaine village, for example, gullies have a maximum depth of about 5m and a width of 20m to more than 25m. In the Lendikinya village, the gullies become much shallower and narrower, eventually fusing into the Makuyuni River at the Arkatani village just before crossing the escarpment. Bare lands and gullies covering an area of about 1700 ha are found in undulating plains around Meserani Juu village. This area has become bare partly because of overgrazing due to the large numbers of livestock passing through the area from the adjacent Arumeru District to grazing areas, within and beyond the study

Figure 8.9 Landcover/use map, 1999

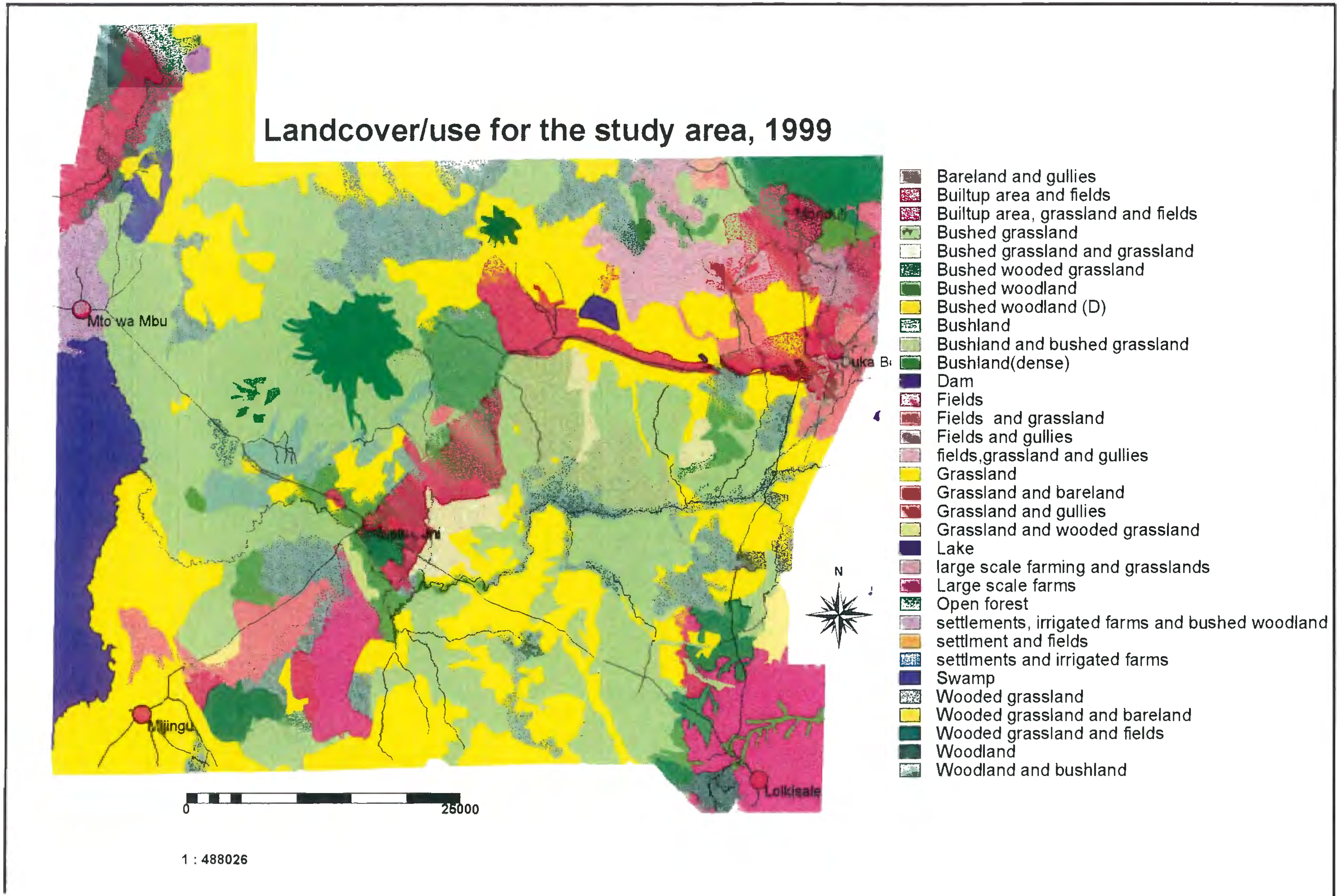
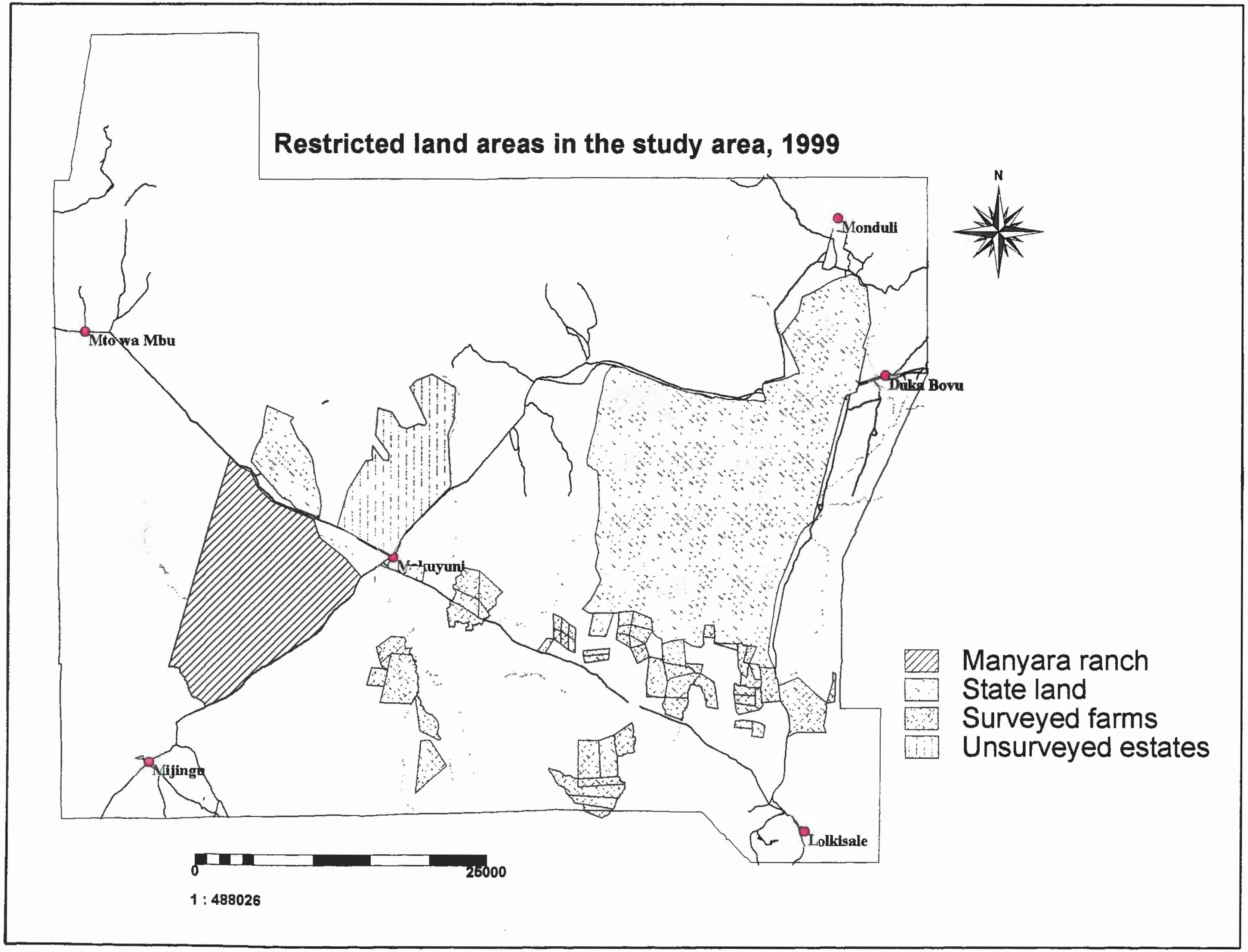


Figure 8.9b Restricted land areas



area, and also due to a large number of livestock being brought to the weekly market at the village. Another contributory factor that renders the area bare land is the presence of termites that forage mainly dry herbaceous material. This has been ascertained through field observation, discussions with local residents and earlier reports which were made available by the Institute of Resource Assessment in the early 1990's (NEMC 1990). Figure 8.10 shows the locations of gullies and bare land for the study area. Plate 8.1, 8.2 and 8.3 show gullies at Lendikinya, Sinon-Ngarash and the Lashaine village respectively. Land use activities in badly gullied areas are limited to use as livestock movement routes. However, areas that can still support the growth of some grass cover are used as grazing areas for young goat and sheep during the dry season. Water bodies, of which the Lake Manyara is the largest, cover about 17700 ha or 4.3% of the area. Water bodies are used as a source of water by human beings, livestock and wildlife. Lake Manyara, which is saline, is used to a limited extent for fishing activities in the part of the lake that is not part of Lake Manyara National Park.

8.3 Landcover/use changes

Having analyzed the landcover/use for the 1960's, 1991 and 1999, this section explores the landcover changes which occurred between the years. The analysis starts with the determination of cover changes between the 1960's and 1991, followed by cover changes between 1991 and 1999.

8.3.1 Landcover /use changes, 1960's/1991

There were a number of changes in all categories of cover types during this period (Figure 8.11). The most prominent change has been a loss of vegetation due to the increase in farming activities.

Figure 8.10 Location of gullies and bareland

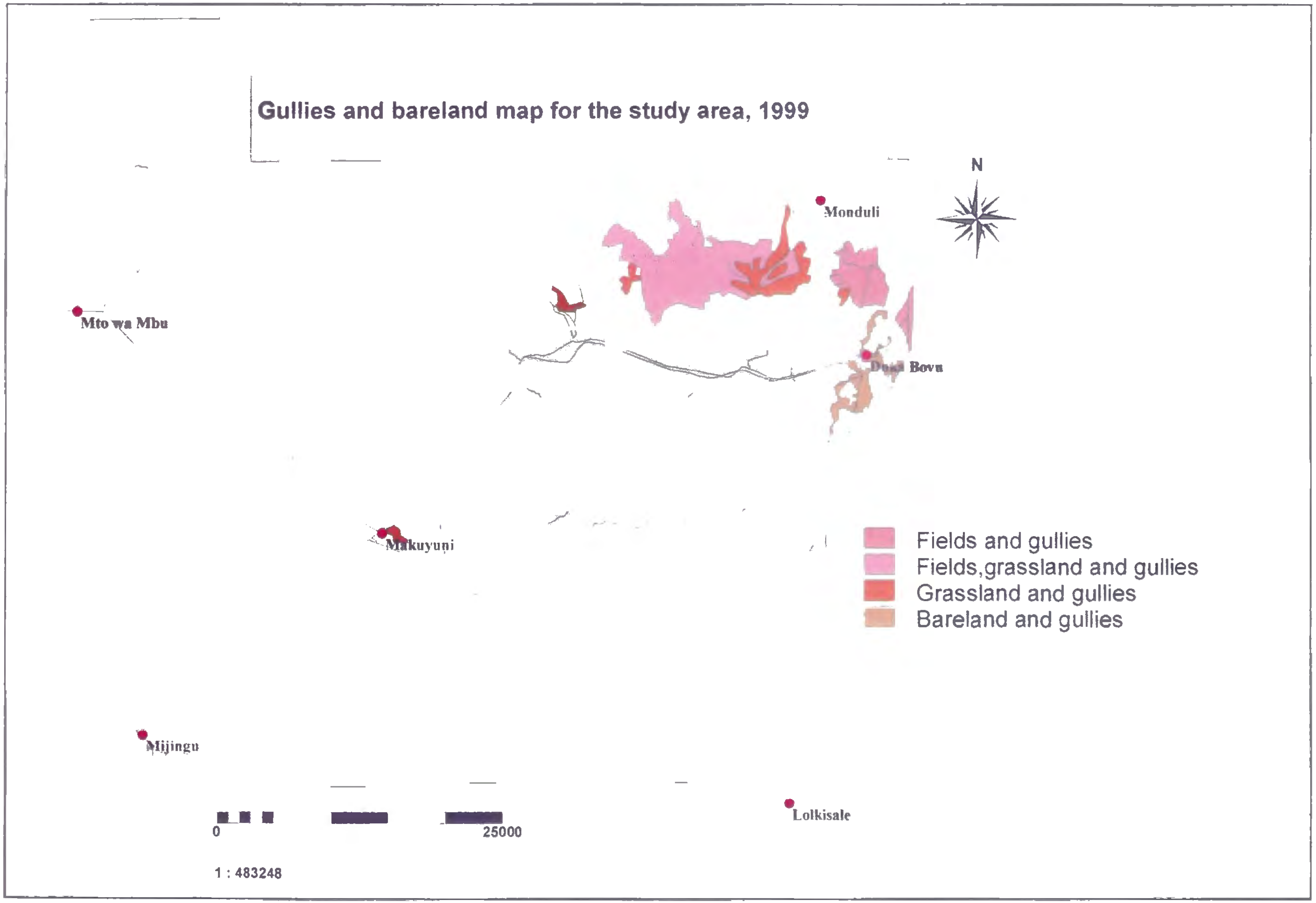


Plate 8.1 A newly formed gully at Lendikinya village

During this period, semi-natural vegetated land decreased by about 56000 ha, from 365400 ha in the 1960's to 305600 ha in 1991(15%) (Table 8.4 and Figure 8.12). At the same time, agricultural lands increased from about 4900 ha to 81700 ha, (1602%), and bareland and gullies increased by about 630 (100%). However there was a decrease of water bodies by about 2600 ha (19%).

a) Vegetation cover changes

The main cover change within the semi-natural vegetation system was structural reduction in which there was a loss of woody vegetation in about 23% of the vegetated area. Loss of woody vegetation occurred mainly to the north of the

Plate 8.2 A deep gully at Sinon Ngarash village

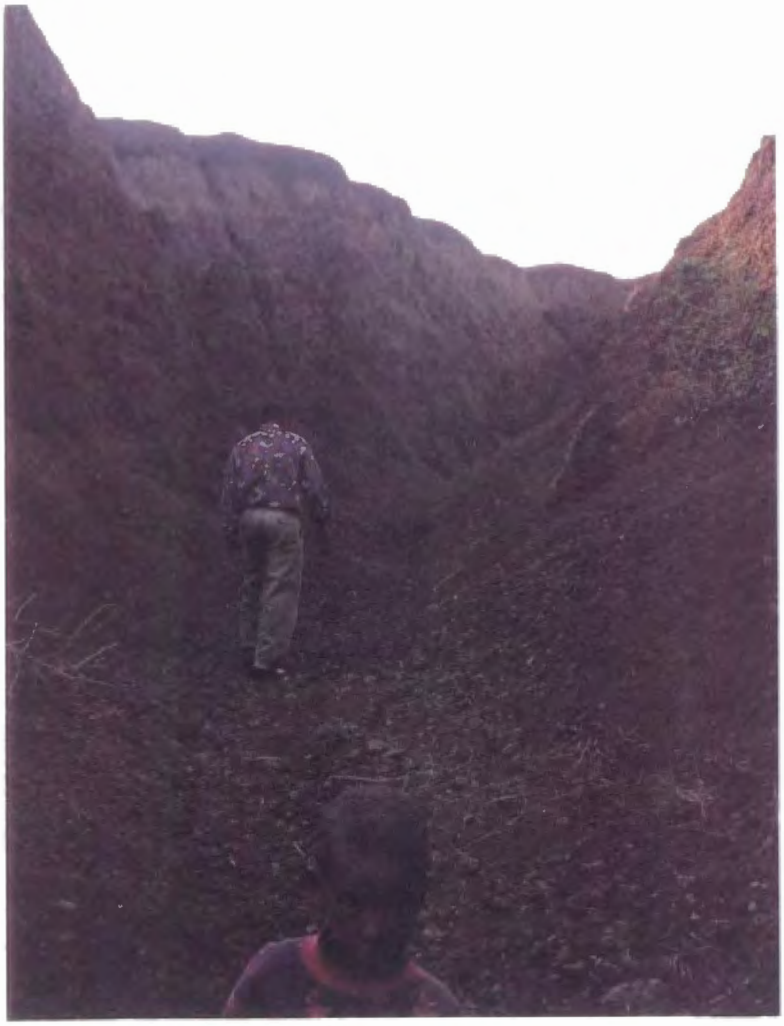
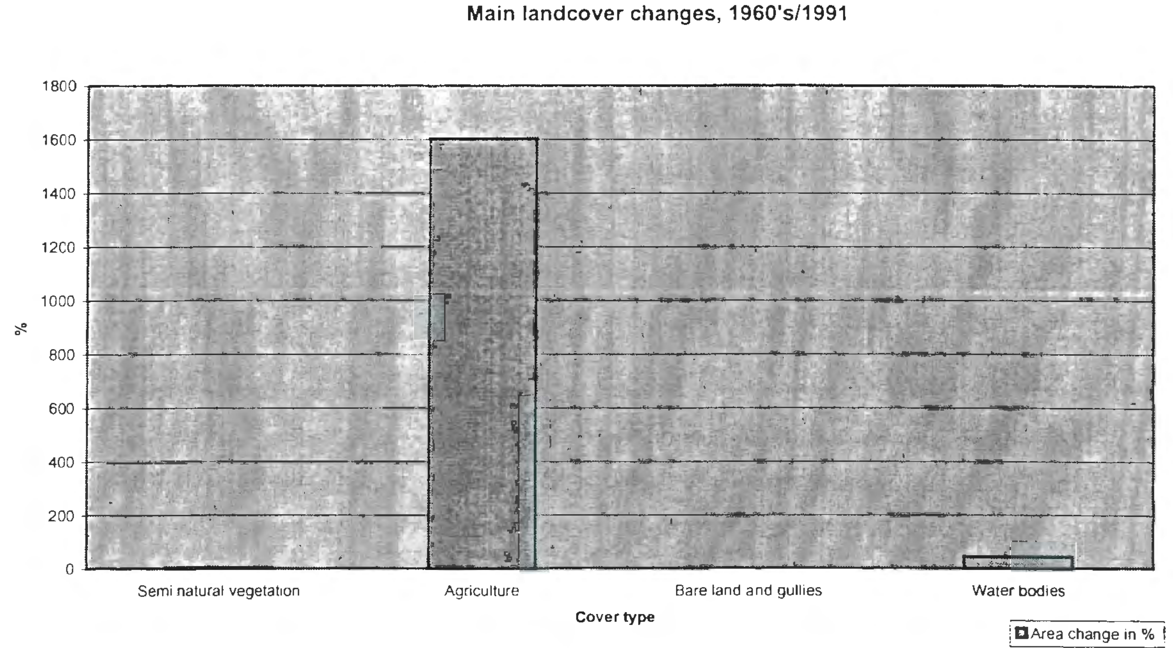


Plate 8.3 A shallow gully at Lashaine village

Figure 8.11 Main landcover changes between the 1960's and 1991



Source Table 8.1 landcover, 1960's and 8..2 landcover, 1991

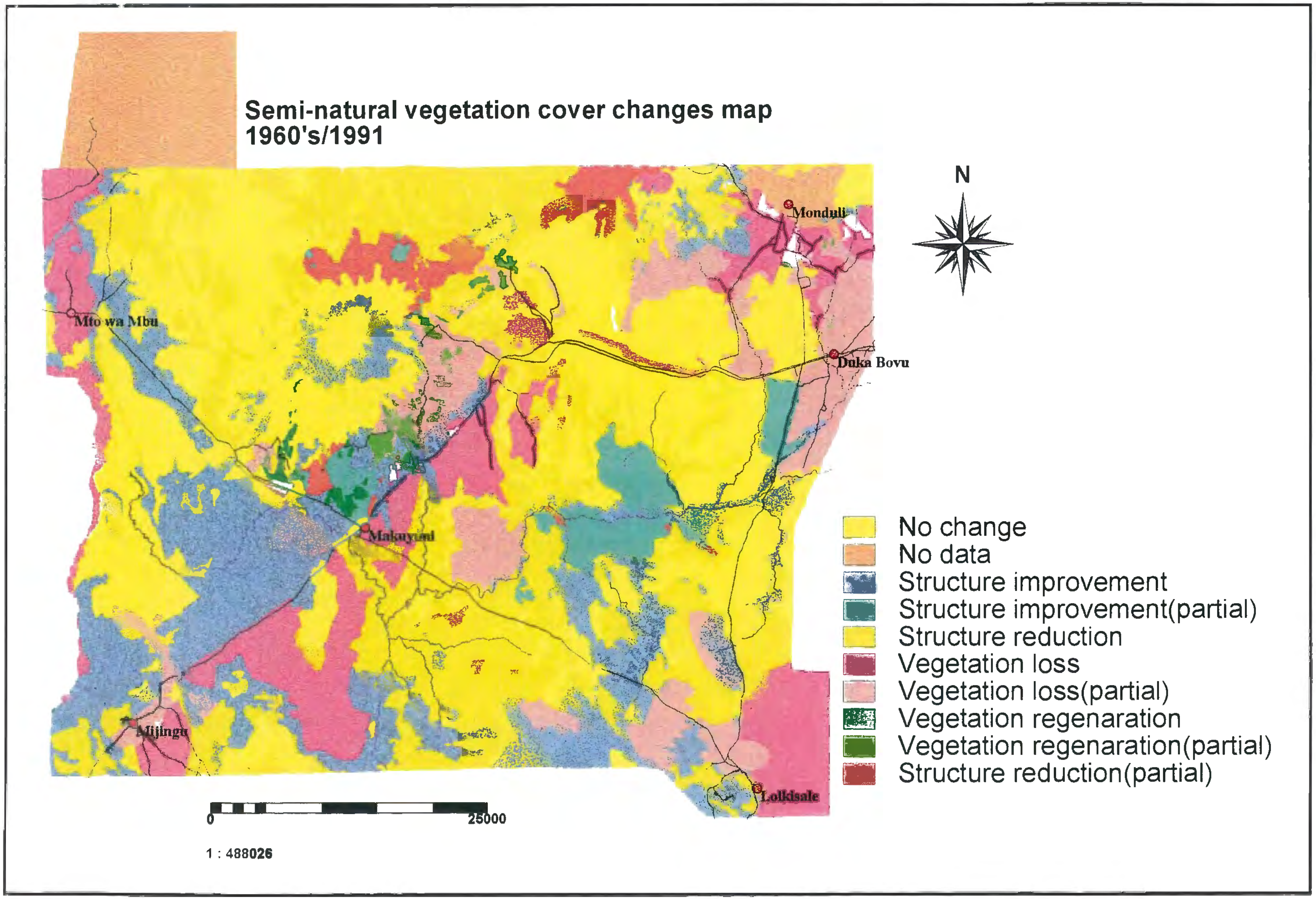
Lossimingori Mountain where bushed grassland changed to grassland. In the southern part of the area, bushed woodland changed to bushed wooded grassland or to grassland, or bushland changed to bushed grassland. Structural improvement or increase in woody vegetation occurred in 18% of vegetated land. This took place in a number of locations including the unused Lake Manyara ranch, where, grassland changed to bushed grassland. In the southwest and south of the area grasslands changed to bushed grassland, or grasslands to wooded grasslands, or bushed woodland to woodland. Structural improvements took place in areas that were not used for agriculture or were not under high grazing pressure like the Manyara ranch and the south and southwestern areas. Complete and partial loss of vegetation occurred in 12% and 9% of vegetated land respectively. Most of the vegetation was cleared to open small and large

Table 8.4 Landcover/use changes, 1960's/1991

A	*Vegetation (changes)*	**Area (ha)**	
1	Vegetation regeneration	1566	0.4
2	Vegetation regeneration (partial)	1923	0.5
3	Structure reduction (partial)	8914	2.4
4	Structure improvement (partial)	12193	3.3
5	Vegetation loss (partial)	33924	9.2
6	Vegetation loss	44632	12.1
7	Structure improvement	69330	18.7
8	Structure reduction	86219	23.3
9	No change	111544	30.1
	Total	**370245**	**100.0**
B	***Agricultural changes***		
1	No change	992	1.2
2	Agricultural loss	1552	1.9
3	Agricultural loss (partial)	1922	2.3
4	Agriculture expansion (partial)	36631	44.6
5	Agriculture expansion	41033	50.0
	Total	**82130**	**100.0**
C	***Gully and bareland changes***		
1	Gully formation	**630**	**100**
D	***Water bodies***		
1	Dam shrinkage	4	0.0
2	Lake shrinkage	9	0.1
3	Dam expansion	196	1.6
4	Swamp expansion	1109	8.8
5	Lake expansion	1993	15.9
6	No change	9255	73.7
	Total	**12566**	**100.0**

scale farming, mainly along the main road from Lake Manyara to Arusha, on the slopes of the Monduli Mountain and Ardai plains, in the south and south-east of the area. Vegetation regeneration took place in about 1% of the vegetated area, mainly in former large-scale farms found on the slopes of the Lossimingori Mountain. There were no changes in about 28% of the vegetated land, mainly

Figure 8.12 Semi-natural vegetation cover changes map, 1960's/1991



grasslands in lake beds, central and north-western plateau areas, and in undulating plains including parts of the Ardai plains. Other vegetation types that did not change include the bushed grasslands on the slopes of the Lossimingori Mountain and in the Lake Manyara terraces and protected open forests in Monduli, Lossimingori, Lepurko and the Lolkisale Mountains. Figure 8.12b shows the quantitative semi-natural vegetation cover changes between the 1960's and the 1991 period.

b) Agricultural cover changes

Two main types of agricultural changes occurred during this period: agriculture expansion and agriculture loss. Agricultural expansion was the dominant direction of change, in which about 41000 ha became new agricultural lands. Out of these, 2300 ha (56%) were small-scale farms and about 18100 ha (44%) were large-scale. In addition, about 36600 ha were partially converted to agricultural lands. Agricultural expansion occurred mainly along the road from Mbulu and Babati District to Arusha town in which grasslands or bushlands, especially in and around the Mbuyuni village, Ardai and the undulating plains changed to small-scale farms. In the south of the area in and around the Lolkisale village and also in the southwest, bushed grasslands or grasslands or wooded grasslands were converted to large-scale farms. A loss of agricultural land occurred mainly on the slopes of the Lossimingori Mountain, in which about 1900 ha were totally converted and 1600 ha were partially converted to either bushed grasslands or wooded grasslands and fields. No changes worth comment took place in the agricultural lands in and around Monduli Town. Figure 8.13 and 8.14 show the quantitative and spatial extent of agricultural changes between the 1960's and 1991.

Figure 8.12b Semi-natural Vegetation cover changes, 1960's/1991

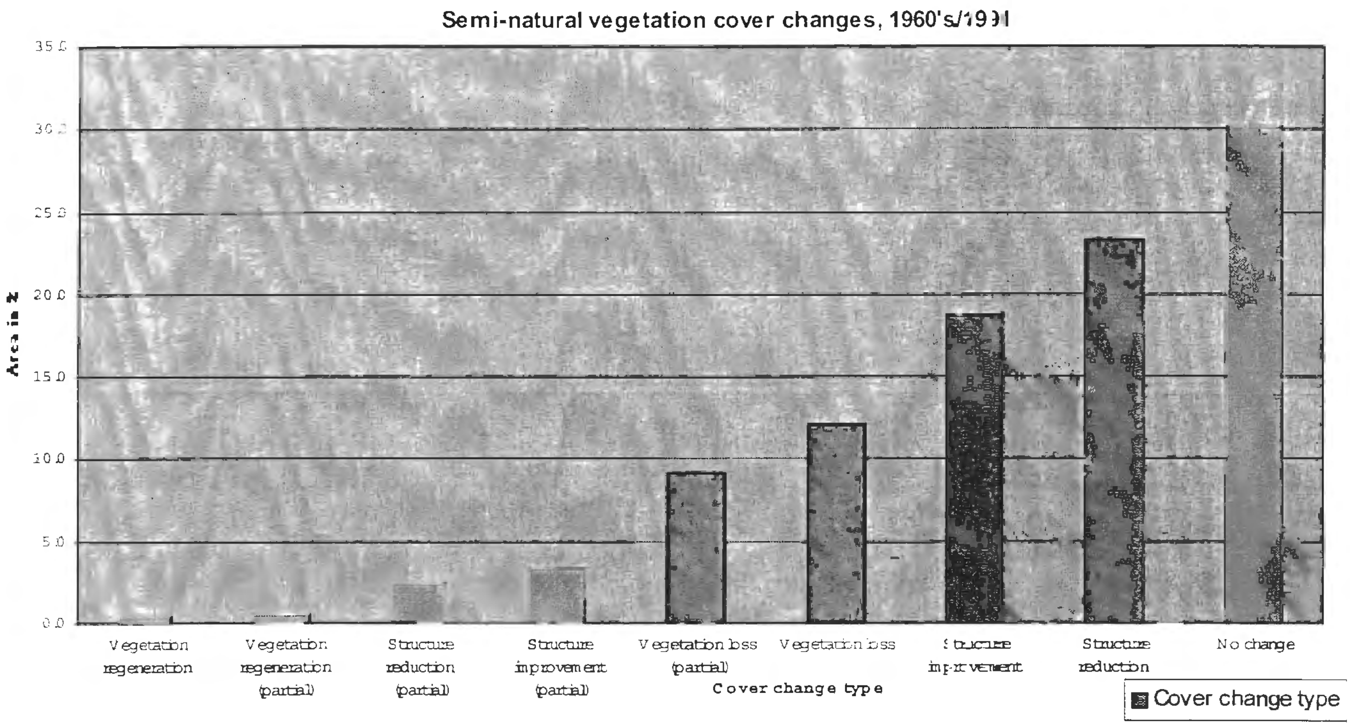


Figure 13 Agricultural lands cover changes 1960's/1991

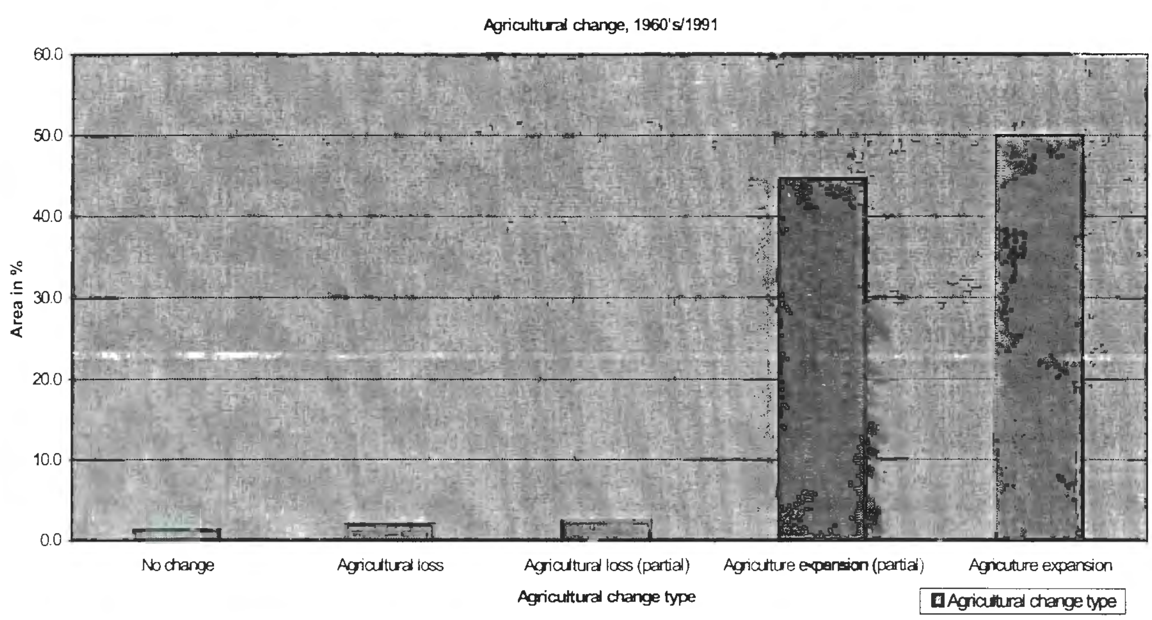


Figure 8.14 Agricultural changes map1960's/1991

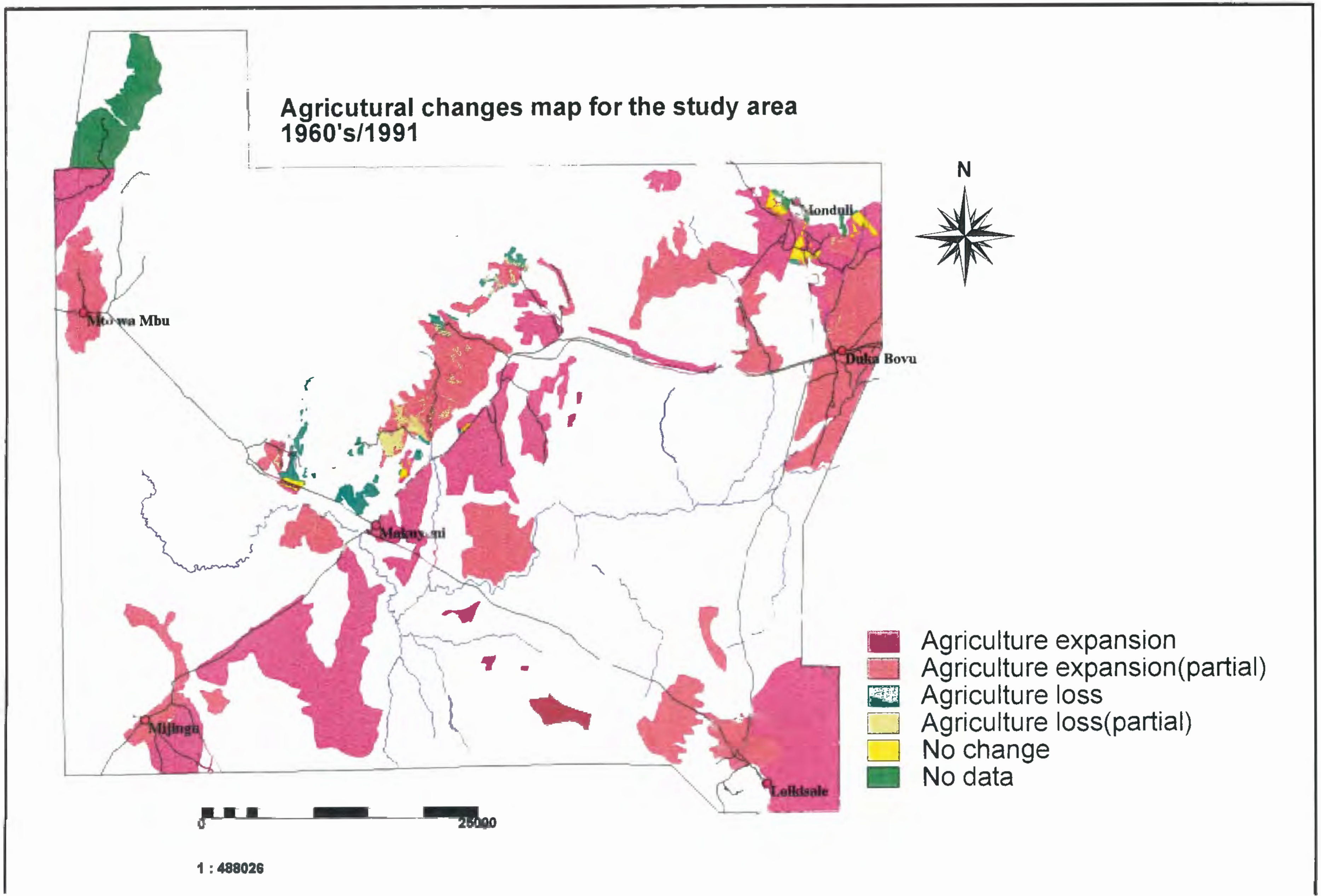


Figure 8.15(a) Water bodies changes map 60's/91

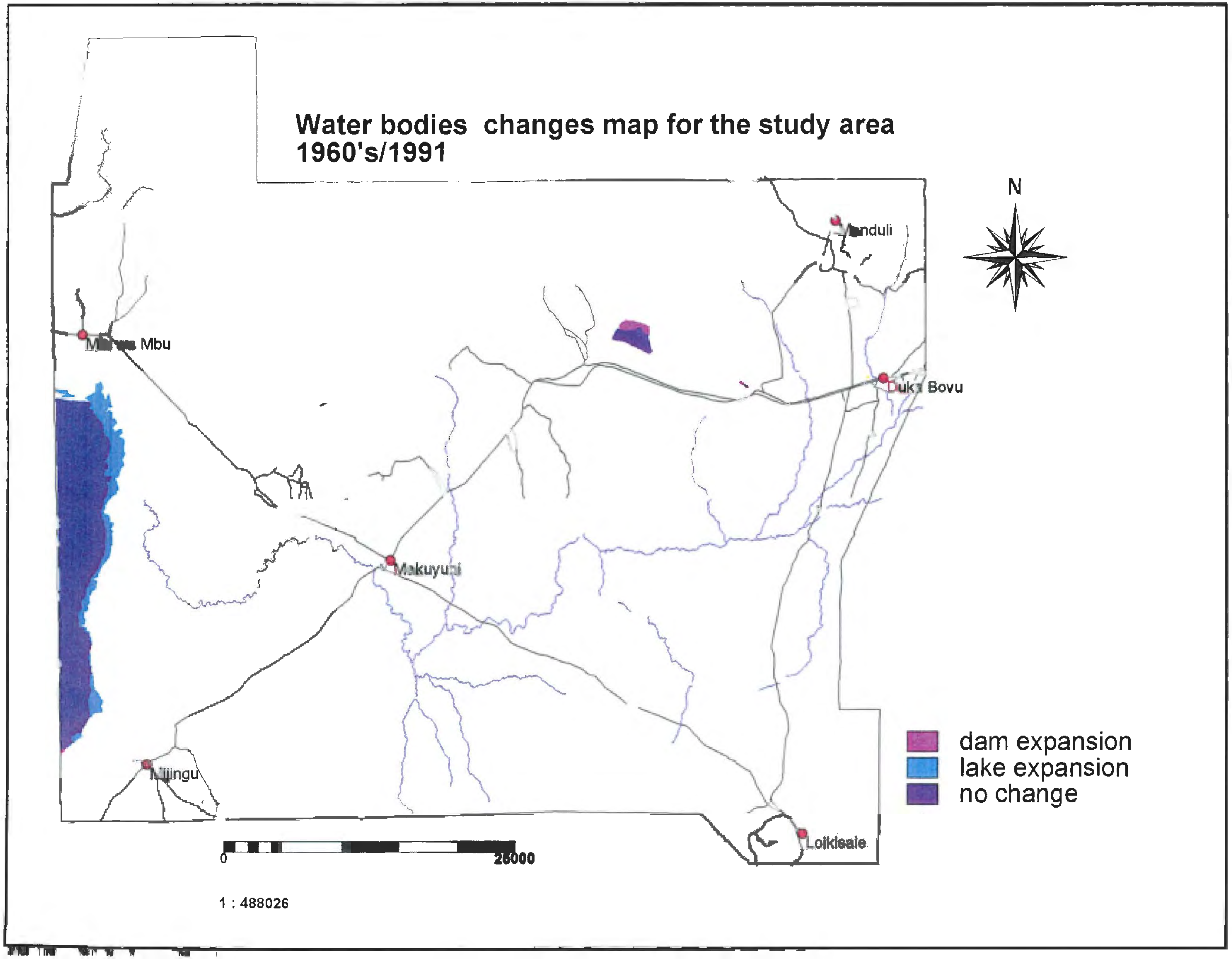
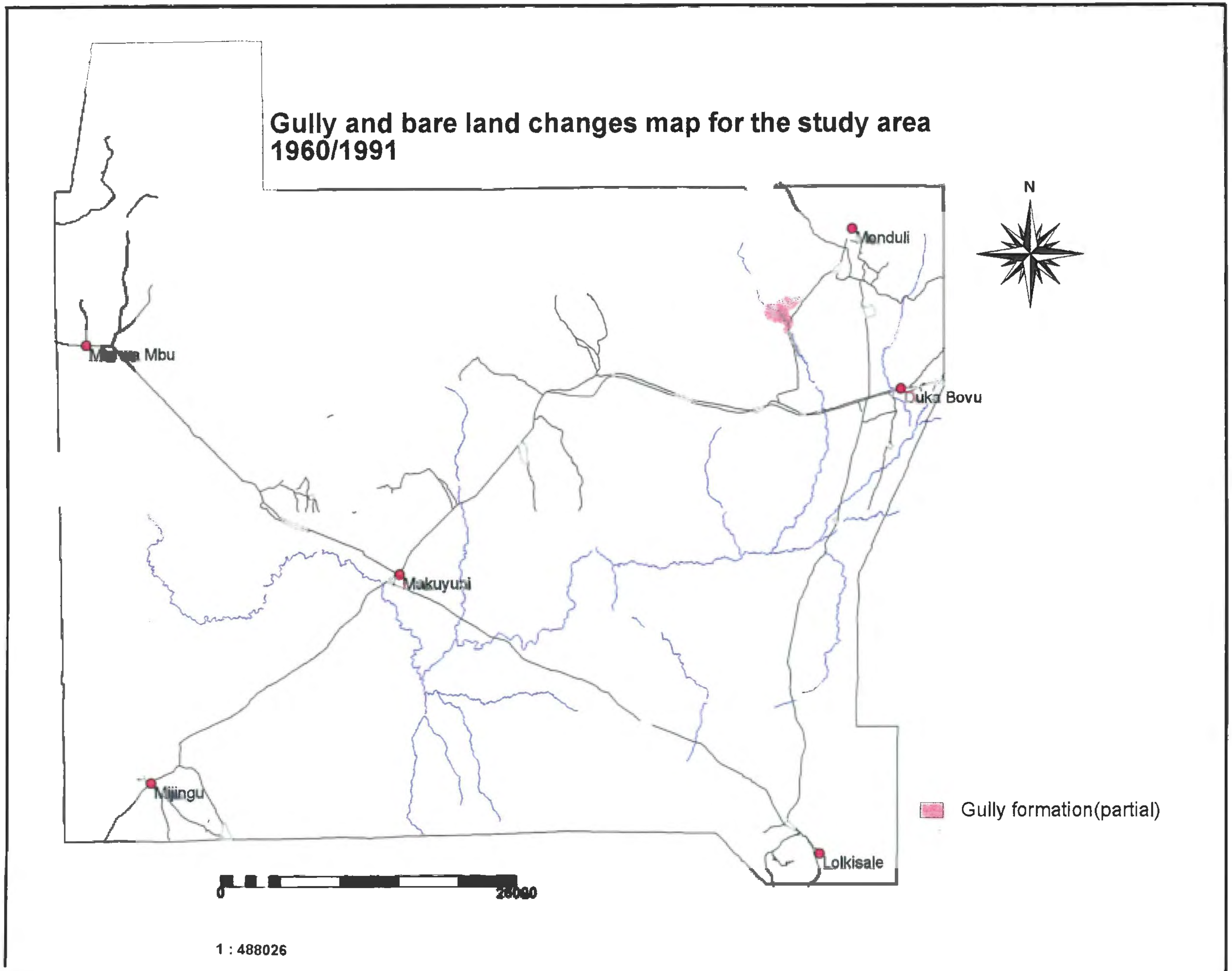


Figure 8.16 Gully and bareland changes map, 1960's/1991



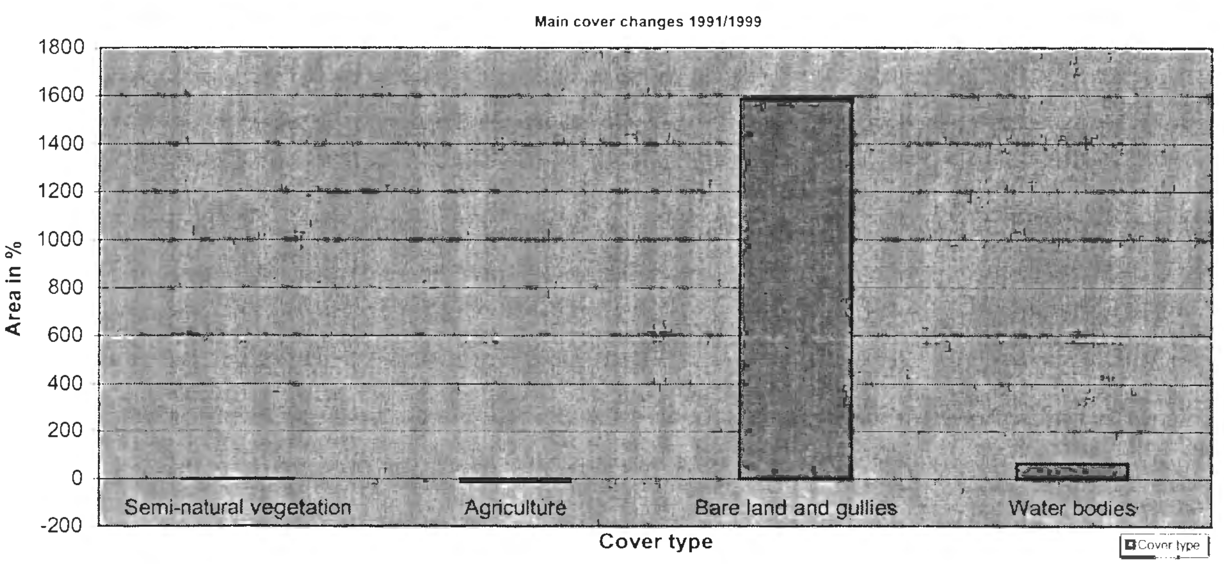
8.3.2 Landcover/use changes, 1991/1999

Changes in landcover and use continued to occur in all the main categories of cover types, although at a different rate compared with the 1960's/1991 changes. The following are overall cover changes between 1991 and 1999. Semi-natural vegetation cover decreased from 305600 ha in 1991 to 301 300 ha in 1999 (1.4%), while areas that could be mapped as agricultural lands decreased from 81700 ha to 70100 (14%). However, one should be cautious in interpreting agricultural figures because in reality there has been an increase in farming areas during this period. The area under farming appears less in 1999 than was expected due to the timing of satellite images used in mapping the landcover/use. The use of the end of the wet season satellite image meant that only areas cultivated during that season could be identified as agricultural lands, at least from hard copy image. Other agricultural areas that were not cultivated appeared as semi-natural vegetation in satellite sensor images due to the fact that, at the end of the wet season, fallow lands were still covered by green semi-natural vegetation. In addition there was a general increase in biomass due to a higher than average of rainfall in 1998 and 1999, (El Nino) making the uncultivated farms even more to difficult detect. In 1991, the dry season image was used, making it easier for the satellite images to record not only farms cultivated in that year but also fallow farms because, by then, there was no semi-natural vegetation obscuring old farm patterns. In other words, 1991 represents more or less all farming areas, fallow and non-fallow, while the 1999 image represents farms that were cultivated in that year only. During this period there was a major change in bare land and gullies with an increase of less than 700 ha to about 11800 ha (1585%). This again should be treated with caution because of the differences in seasonality of the images used. Bare land and gullies could not be mapped with accuracy in 1991 because in the dry season it is much more difficult to differentiate permanently bare land and gullies from seasonally bare lands or grasslands since many areas are already bare or have dry semi-natural vegetation. Bare land and gullies were mapped with greater precision in 1999 because, at the end of the wet season, permanently bare lands and gullies did not have green vegetation while the rest did. During this period there was again an increase in the water bodies, mainly Lake Manyara, from 11900 ha to 19600 (65%). Figure 8.17 shows the general landcover changes between 1991 and 1999.

a) Semi-natural vegetation cover changes

The main change in semi-natural vegetation cover during this period was structural improvement in which about 107000 ha (30%) of vegetated land increase in woody vegetation (Table 8.5 Figure 8.18 and 8.19). The dominant changes were from grassland to bushed grassland or wooded grassland and in some cases bushed grassland to wooded grassland. This occurred in the plateau area north of the Lossimingori Mountain, lake terraces and on state land.

Figure 8.17 Main landcover changes 1991/1999



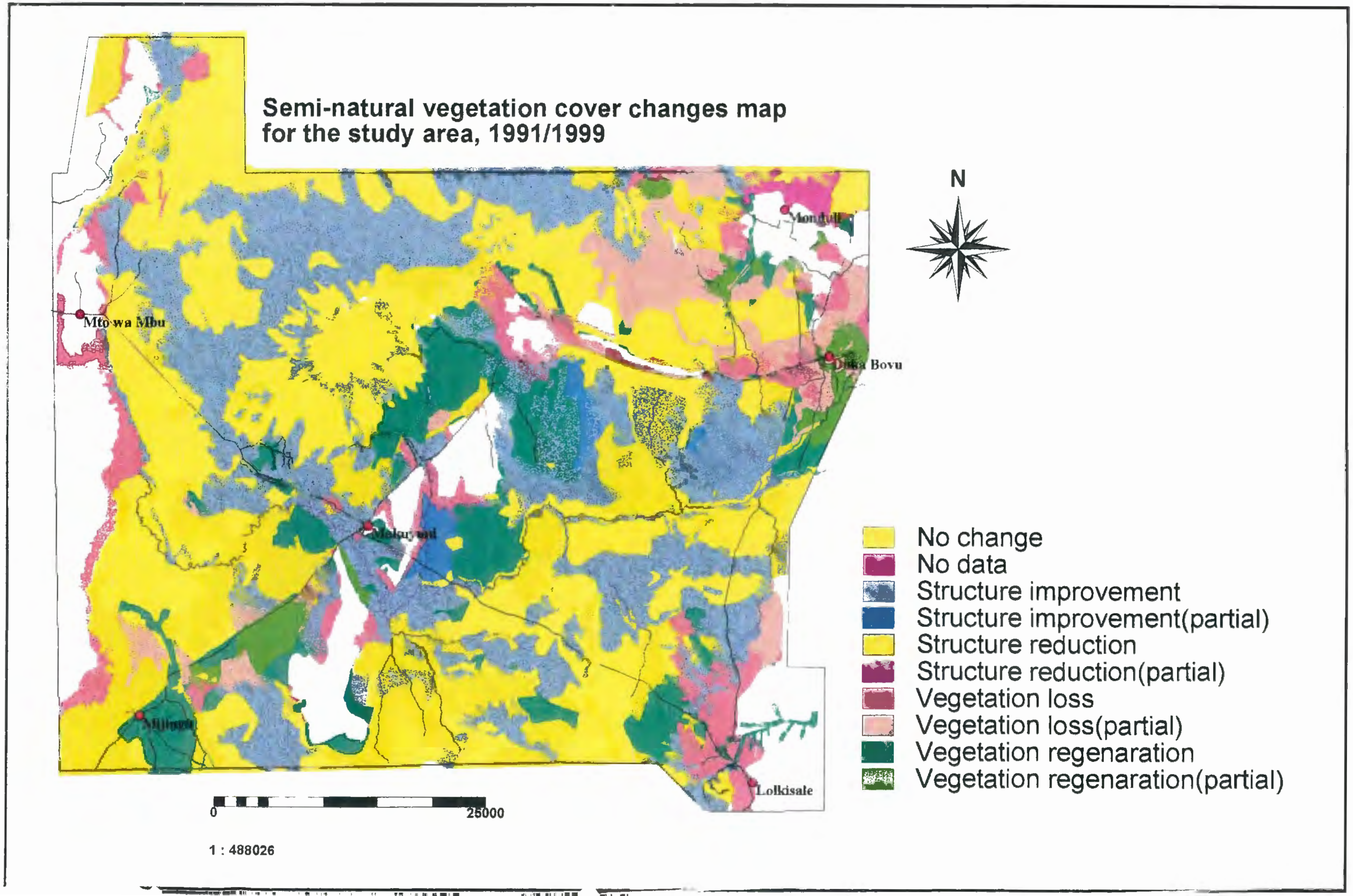
Source Table 8. 2 and 8. 3

Table 8.5 Landcover/use changes, 1991/1999

A	*Vegetation changes*	Area (ha)	% of the area
1	Structure improvement (partial)	3490	1.0
2	Vegetation regeneration (partial)	7505	2.1
3	Vegetation loss (partial)	20282	5.6
4	Vegetation loss	27168	7.5
5	Vegetation regeneration	31087	8.6
6	Structure reduction	50240	13.9
7	Structure improvement	106728	29.5
8	No change	114843	31.8
	Total	**361343**	**100**
B	*Agriculture changes*		
1	Agriculture loss (partial)	10720	10.4
2	Agriculture expansion (partial)	15950	15.5
3	Agriculture expansion	15993	15.6
4	No change	28959	28.2
5	Agriculture loss	31034	30.2
	Total	**102656**	**100.0**
C	*Gully and bare land changes*		
1	No change	488	4.0
2	Gully formation (partial)	11722	96.0
	Total	**12210**	**100.0**
D	*Surface water and wetlands changes*		
1	Dam Shrinkage	21	0.1
2	Dam expansion	111	0.6
3	Swamp expansion	318	1.7
4	Lake expansion	4691	25.3
5	No change	13412	72.3
	Total	**18553**	**100.0**

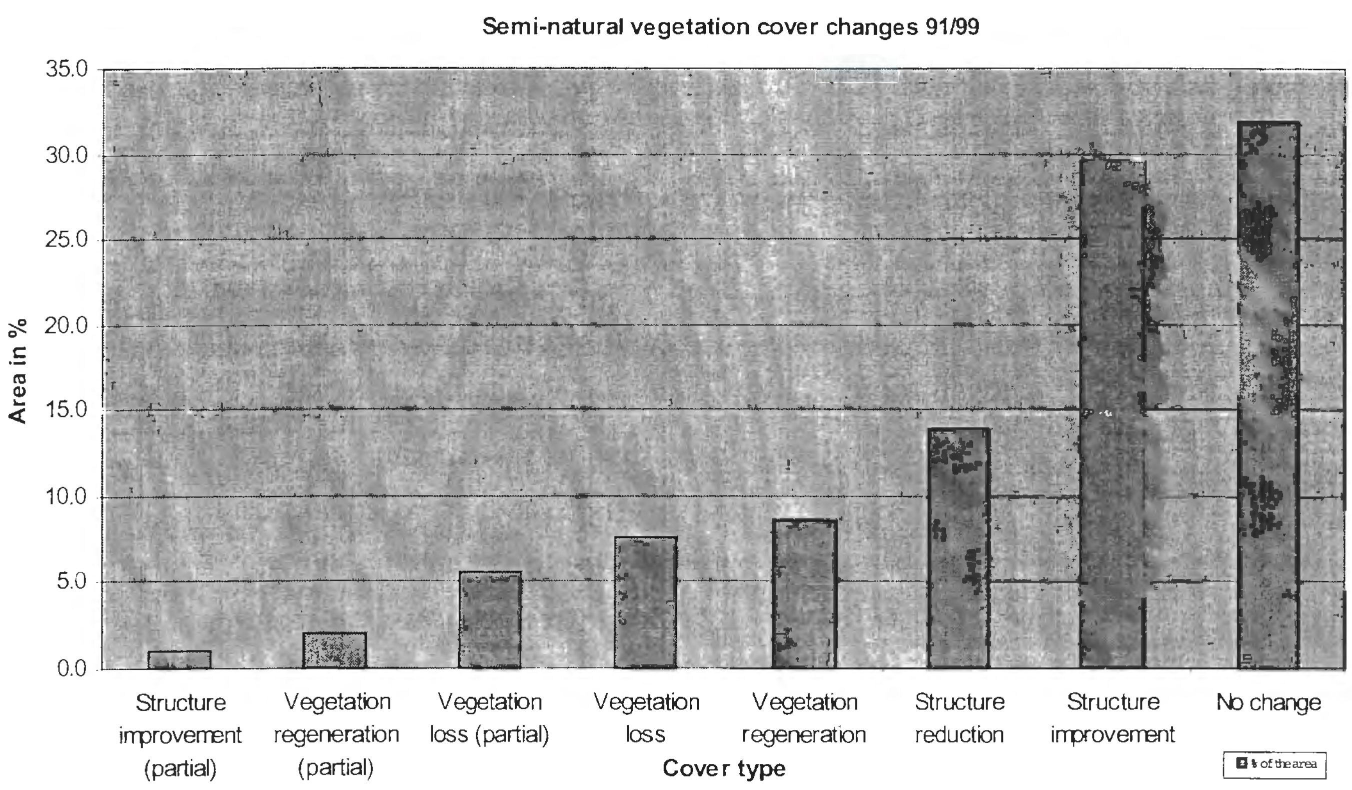
The second most important change was structural reduction, in which about 50200 ha (14%) of the vegetated area lost its woody vegetation. This mainly resulted in changes from bushed grassland or bushed woodland to grassland, and in some cases bushed wooded grassland to bushed grassland. Most of these changes occurred in the Manyara ranch, Mijingu area and southern parts of the Makuyuni village. Regeneration of semi-natural vegetation took place on

Figure 8.18 Semi-natural vegetation cover changes map, 1991/1999



the slopes of the Lossimingori Mountain, south of the Mbuyuni village, around the Mijingu area, Lake Manyara ranch and in the Lolkisale village. During this period about 31100 ha (9%), changed predominantly from fields to grasslands or from a combination of fields and semi-natural vegetation to semi-natural vegetation. A loss of 27200 ha (8%) of semi-natural vegetation occurred in Arkatani, Lepurko the Lossimingori villages in areas adjacent to the main road and on undulating plains in and around Meserani Juu and the Lolkisale village, in which grasslands or a combination of grasslands and fields or wooded grassland and woodland, were converted to agricultural lands. Semi-natural vegetation, mainly grasslands and bushed woodlands was also lost in the lake terraces due to the expansion of Lake Manyara. Less pronounced semi-natural vegetation cover changes, including partial regeneration of about 7500 ha (2%), and partial structural improvement of about 3500 ha (1%), occurred in Mswakini and south of Mbuyuni and Makuyuni villages respectively.

Figure 8.19 Semi-natural vegetation cover changes

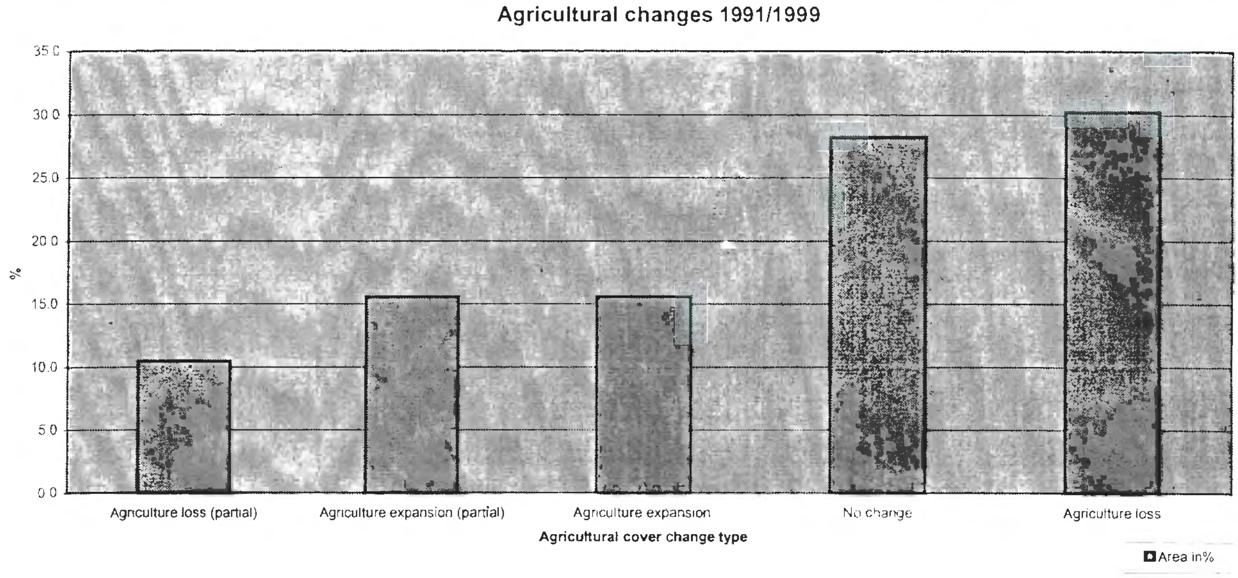


Partial regeneration of the semi-natural vegetation was due to the conversion of fields to a combination of fields and grasslands. Meanwhile, partial structural improvement occurred due to a change of grassland to bushed grassland and grassland. Roughly one-third of the vegetation cover types remained the same between 1991 and 1999. Cover types not changing included bushed grassland and grasslands found in the Lake Manyara terraces, Ardai plains and plateaus areas northwest of the Lolkisale Mountain. Others include the protected open forest in the mountains and bushed grasslands on the slopes of the Lossimingori Mountain.

b) Agricultural changes

The main change in agricultural lands during this period was the loss of agricultural lands in which about 31000 ha (30%) of farms complexes and different types of semi-natural vegetation, mostly bushed grassland or grassland, reverted back to bushed grasslands or grasslands and wooded grassland (see Figure 8.20). These changes occurred mainly on the slopes of the Lossimingori Mountain, Mijingu area, the Manyara ranch, south-east of the Makuyuni village, south of the Mbuyuni village, the Meserani Juu village and north-west of the Lolkisale Mountain. An increase of a total 16000 ha (16%) in agricultural lands, in both small and large-scale farming, occurred in different villages during this period. Farm expansion took place in Lolkisale the village, where wooded grasslands were cleared for large-scale farms, in the Arkatani, Lepurko and Lossimingori villages, where grasslands were cleared for small-scale farming. Partial agricultural expansion occurred in the Lolkisale and Ardai plains, where a total of about 16000 ha (16%) of grasslands or bushed grassland were converted to a complex of either fields and gullies or fields and built-up areas. Meanwhile partial agricultural loss occurred, mainly in the Mswakini village and on the Ardai plains, where a total 10700 ha (10%) of either fields or grassland and fields were converted to a complex of fields and grassland or fields, grassland and gullies. A

Figure 8.20 Agricultural cover changes, 1991/1999

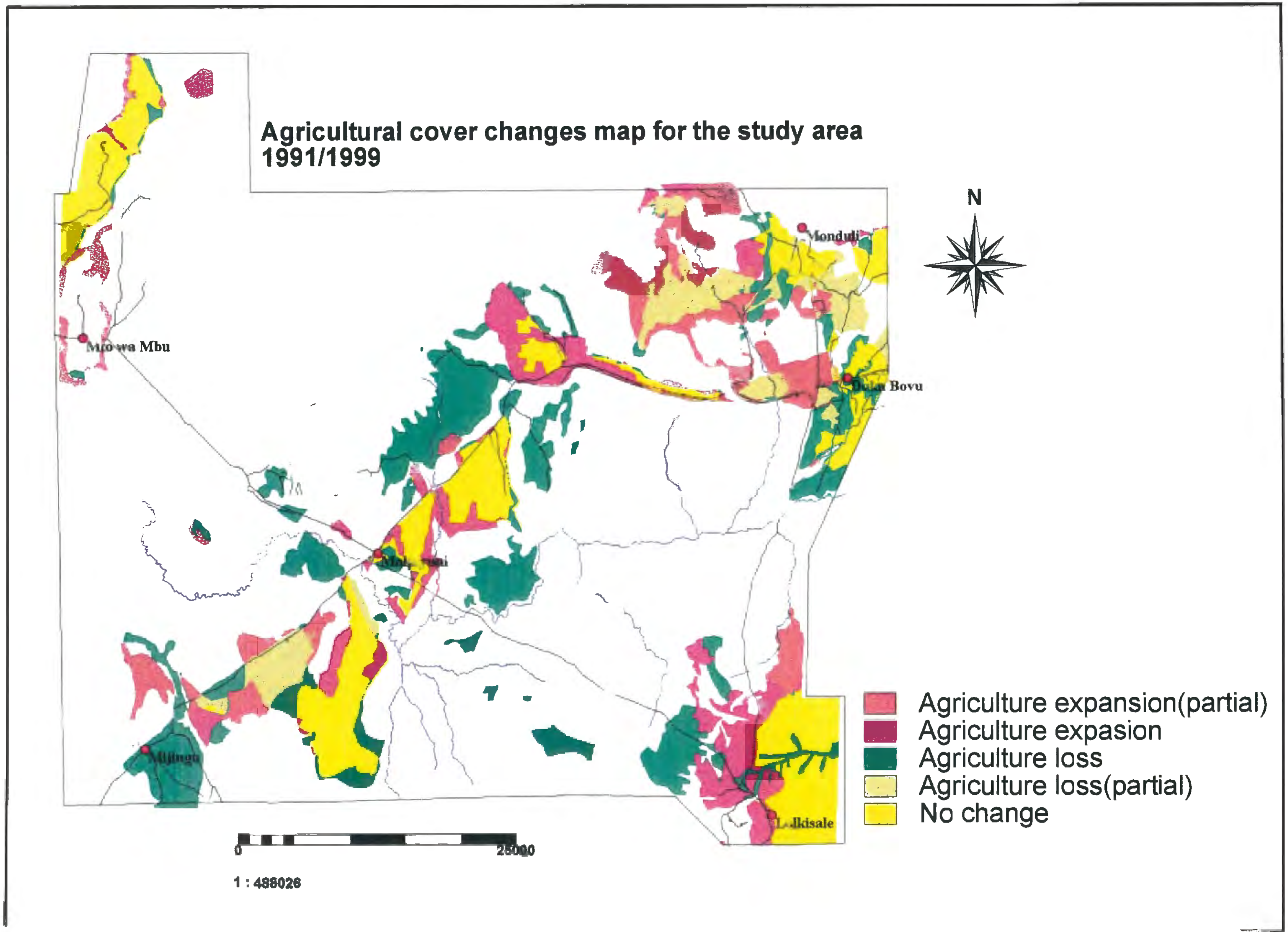


total of 29000 ha (28%) of agricultural lands remained as agricultural lands, mostly in the large-scale farms located in the Mswakini and Lolkisale villages, and on the slopes of the Monduli Mountain; others were fields located in the main settlements of Makuyuni, Mbuyuni and on the Ardai plains. Figure 8.21 shows the details of spatial agricultural changes between 1991 and 1999 respectively.

c) Gully, bare land and water bodies changes

This period is marked by a drastic increase in bareland and gullies, in which 11700 ha (96%) of fields complexes, bareland and gullies were created from grasslands or bushed grassland or complexes of grassland and fields. Gully and bareland developments were confined mainly to the slopes of the Monduli Mountain, the Ardai plains and the undulating plains in the Meserani Juu village. Only about 500 ha (4%) of bareland and gullies remained unchanged in the area. The main change in water bodies was the expansion of Lake Manyara, which an

Figure 8.21 Agriculture cover changes map, 1991/1999



increased in size by 4700 ha (25%). Other minor changes included the expansion of the Nanja dam and Selela swamp, which expanded by 2% and 1% respectively. Figures 8.22, 8.23, 8.24 and 8.25 show water bodies change, bare land and gully change map and water bodies change map respectively.

8.4 Trend of landcover changes, 1960's, 1991 and 1999

Given the land cover changes for the periods of between the 1960's/1991and 1991/1999, this section will now attempt to establish the trend of cover changes from the 1960's to 1999. The trend of landcover changes from the 1960's to 1999 was determined by comparing the landcover changes of periods between 1960/1991 and 1991/1999, or in other words by comparing the three sets of landcover maps of the 1960's, 1991 and 1999 respectively. The trend of landcover changes was done in two stages. Stage one was on the overall changes of the main cover types, and stage two focused on overall changes and changes within each land unit for the different types of semi-natural vegetation.

8.4.1 Overall trend of landcover changes

Overall there has been a general decline of semi-natural vegetation and a corresponding increase of agriculture, barelands and gullies between 1960 and 1999 (Table 8.6 and Figure 8.26). The total area covered by semi-natural vegetation has decreased from 91% in the 1960's to 76% in 1991 and 75% in 1999. Meanwhile, agricultural areas increased from 1% in the 1960's to 20% in 1991 and decreased to 17% in 1999. Bare lands increased from nil in the 1960's to 0.2% in 1991 and 3% in 1999. Water bodies increased from 3% in the 1960's and 1991 to 5% in 1999.

Figure 8.22 Bare land and gullies changes 91/99

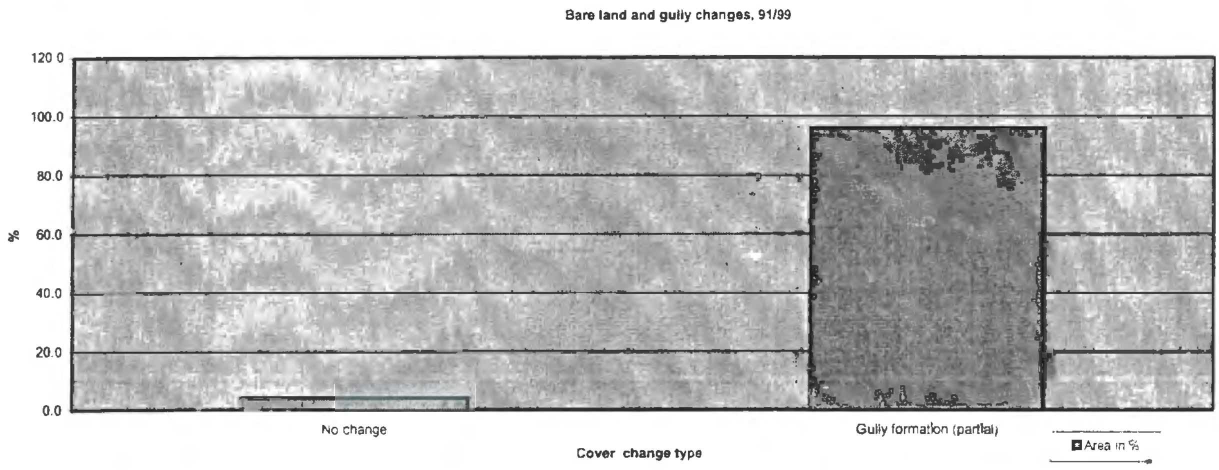


Figure 8.23 Water bodies changes, 91/99

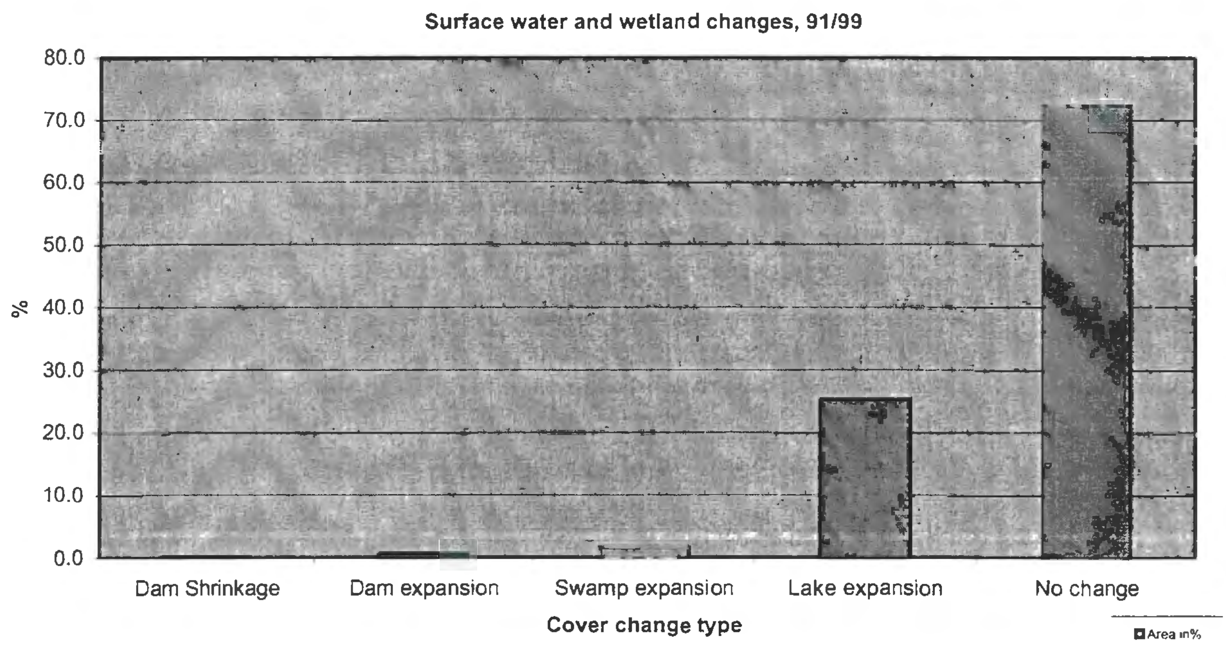


Figure 8.24 Bare land and gullies change map, 91/99

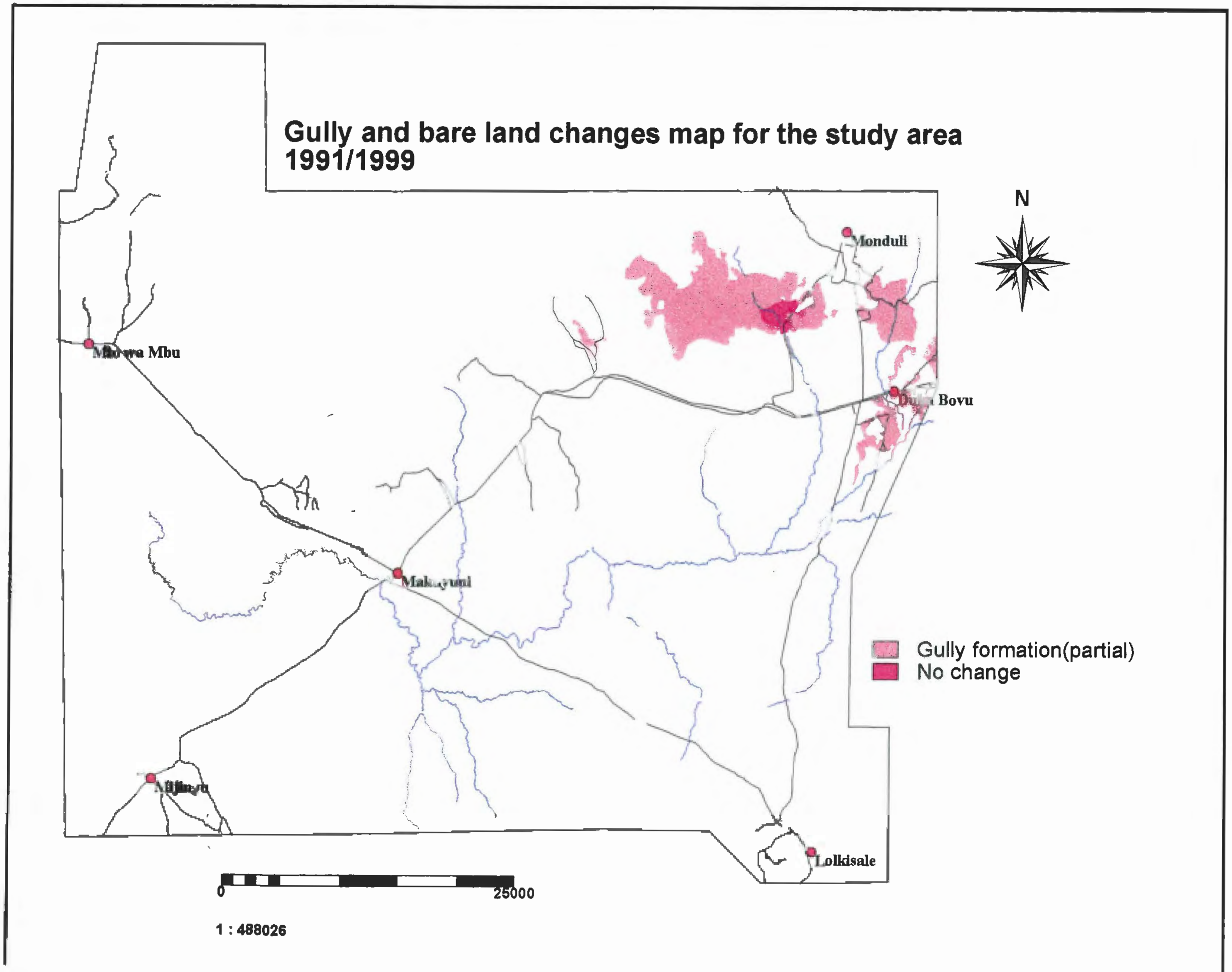


Figure 8.25 Water bodies change map, 91/99

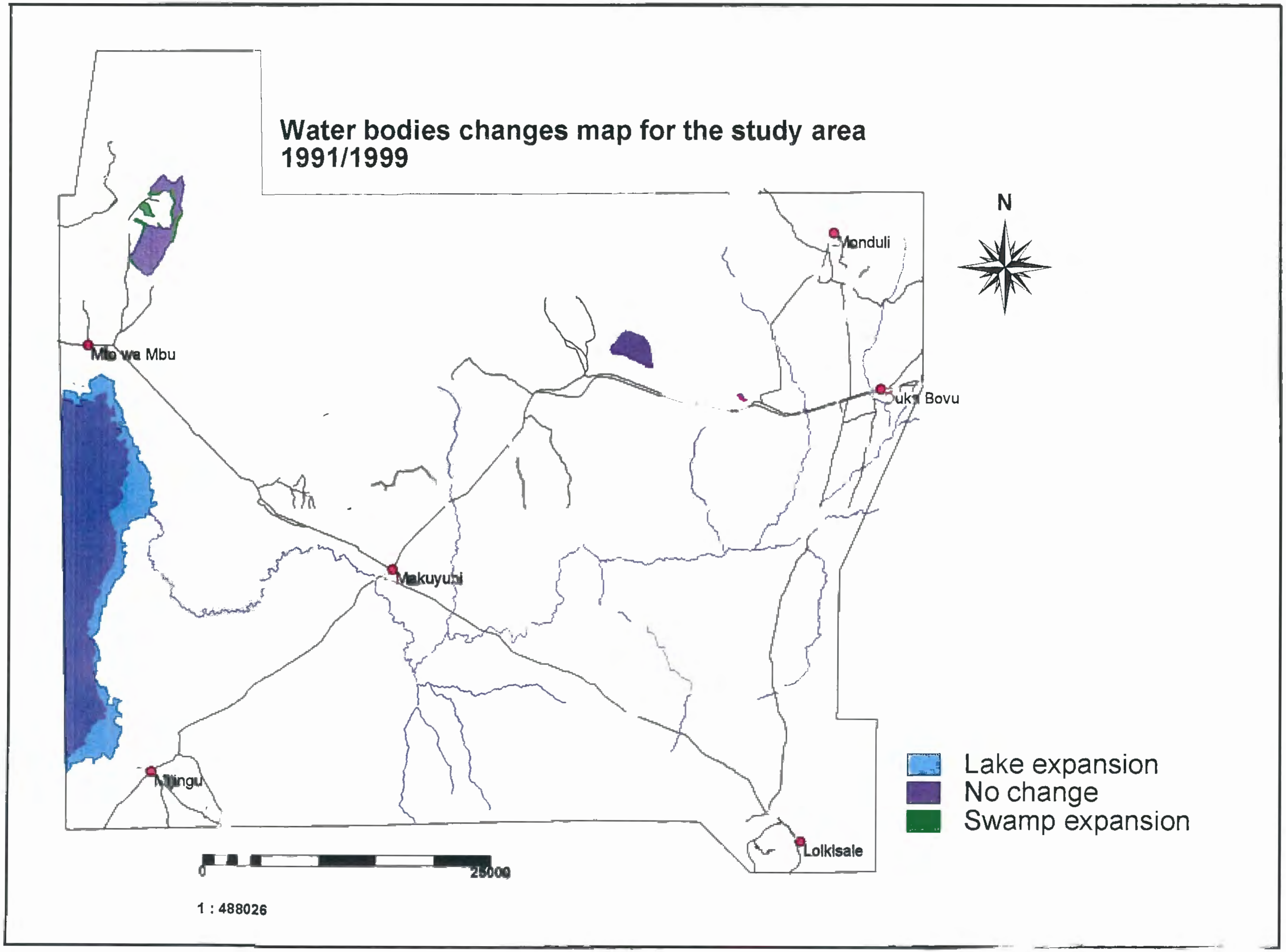
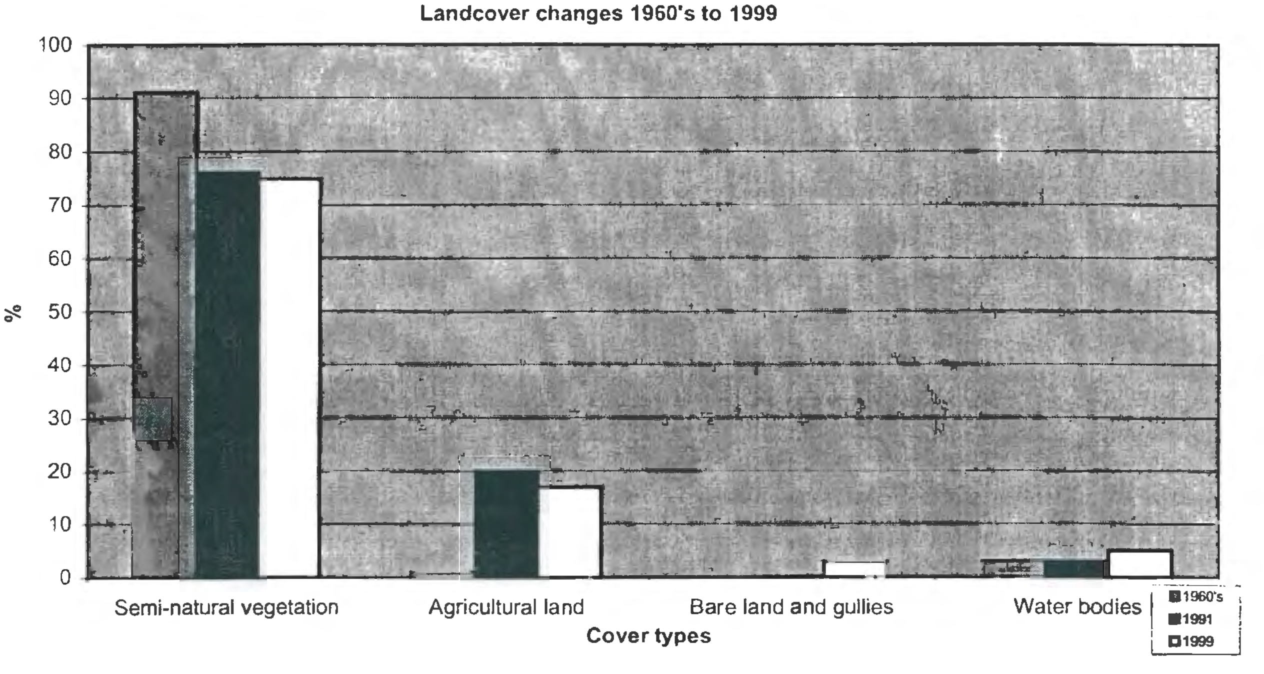


Table 8.6 Landcover changes, 1960's to 1999

	Type of cover	1960's		1991		1999	
		Area (ha)	%	Area (ha)	%	Area(ha)	%
1	Semi-natural vegetation	365437	91	305632	76	301338	74.8
2	Agricultural land	4818	1	81703	20	70051	17
3	Bare land and gullies			627	0.2	11772	3
4	Water bodies	13616	3	11967	3	19610	5

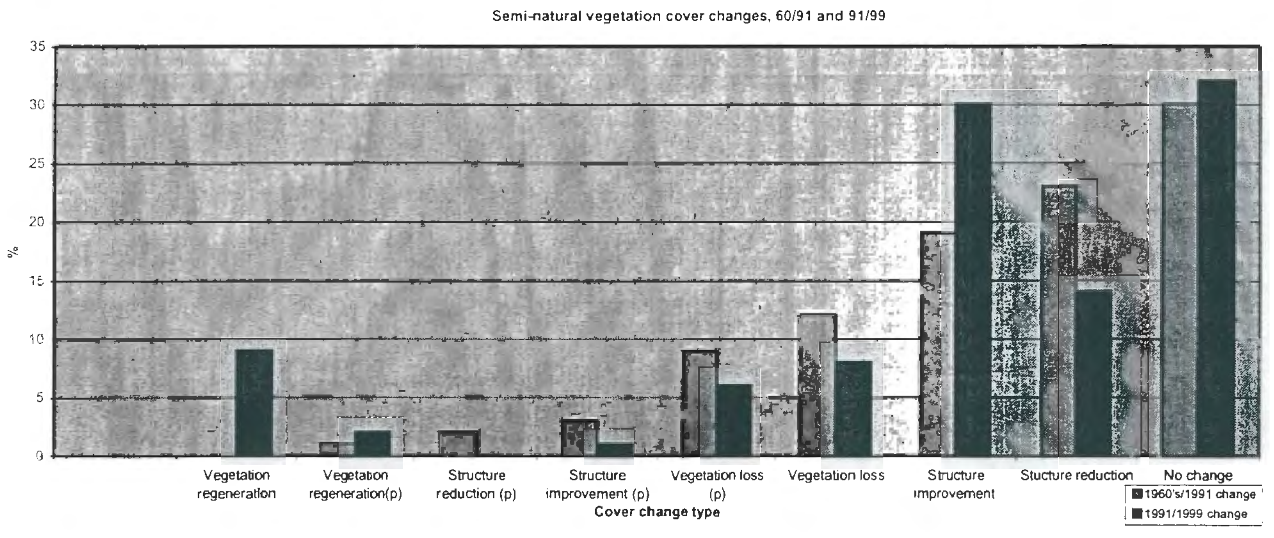
Figure 8.26 Trend in landcover changes, 1960's, 1991 and 1999



8.4.2 Trend of semi-natural vegetation cover changes

The overall changes in semi-natural vegetation cover between the1960's, 1991 and 1999 can be examined from two perspectives. One is to compare the types of cover changes that occurred between 1960's/1991 and 1991/1999in general without considering their locality. This gives a general picture on the nature of changes in terms of depletion or recovery of semi-natural vegetation in each period of investigation. This comparison indicates the types of cover changes that lead to vegetation depletion, such as vegetation loss and structural reduction were dominant between the 1960's and 1991 (Figure 8.27). Meanwhile, types of cover changes that lead to the recovery of semi-natural vegetation, such as vegetation regeneration and structural improvement, were more prevalent during the 1991 to 1999 period. The second means of considering semi-natural

Figure 8.27 Vegetation cover changes, 1960's/1999



vegetation cover changes is to determine types of semi-natural vegetation cover changes that had occurred in each land unit from the 1960's to 1991 to 1999, i.e. a spatial analysis. The 1960's, 1991 and 1999 trend map of semi-natural changes has been generated by combining the 1960's/1991 and 1991/1999 change maps. A total of 37 types of vegetation changes occurred in different land units between the two periods. To get clear impression on the trends of vegetation cover changes in each land unit the 37 types of vegetation changes were recategorized into broader groups based on the nature of change in terms of increase, decrease or no change. For example, a decrease/increase, decrease-means a depletion of semi-natural vegetation, vegetation loss or structural reduction, between 1960's and 1991. An increase means a recovery in semi-natural vegetation in that particular land unit (in terms of vegetation regeneration or structural improvement), between the 1991 and 1999. Table 8.7

Table 8.7 The detailed and generalized semi-natural vegetation cover changes in the area from the 1960's, 1991 and 1999

	Type of vegetation changes	Area (ha)	Area %
A	**no change /decreased**		
1	No change/structure reduction	1289	0.4
2	No change / vegetation loss (p)	6007	1.6
3	No change / vegetation loss	7547	2.1
	Sub total	***14843***	***4.1***
B	**increased/no change**		
4	Structure improvement (p) / no change	2953	0.8
5	Structure improvement / no change	18318	5.0
	Sub total	***21271***	***5.8***
C	**increased/increased**		
6	Vegetation regeneration/structure improvement	758	0.2
7	Vegetation regeneration (p)/vegetation regeneration	1567	0.4
8	Structure improvement (p) /structure improvement	3457	0.9
9	Structure improvement/structure improvement	15605	4.3
	Sub total	***21387***	***5.9***
D	**decreased/decreased**		
10	Vegetation loss(p)/vegetation loss (p)	1332	0.4
11	Structure reduction (p)/ structure reduction	2107	0.6
12	Structure reduction /vegetation loss (p)	2879	0.8
13	Structure reduction / vegetation loss	5910	1.6
14	Vegetation loss (p) /vegetation loss	6673	1.8
15	Structure reduction (p) / structure reduction	13051	3.6
	Sub total	***31952***	***8.8***
E	**no change/increased**		
16	No change/structure improvement	1013	0.3
17	No change / structure improvement	39919	10.9
	Sub total	***40932***	***11.2***
F	**increased/decreased**		
18	Vegetation regeneration/vegetation loss	161	0.0
19	Vegetation regeneration/structure reduction	350	0.1
20	Structure improvement/ vegetation loss (p)	3965	1.1
21	Structure improvement (p) / structure reduction	5679	1.6
22	Structure improvement / vegetation loss	6351	1.7
23	Structure improvement / structure reduction	24933	6.8
	Sub total	***41439***	***11.4***
G	**decreased/no change**		
24	Structure reduction(p)/no change	782	0.2
25	Vegetation loss (p) / no change	3524	1.0
26	Structure reduction / no change	20250	5.6
27	Vegetation loss/ no change	27698	7.6
	Sub total	***52254***	***14.3***
H	**No change**		
28	No change	***54803***	**15.0**
I	**decreased/increased**		
	Structure reduction/vegetation regeneration	337	0.1
29	Structure reduction/structure improvement (p)	2368	0.6
30	Vegetation loss(p)/vegetation improvement(p)	2410	0.7
31	Vegetation loss(p) / vegetation regeneration (p)	2585	0.7
32	Vegetation loss (p) / vegetation regeneration	2629	0.7
33	Vegetation loss/vegetation regeneration (p)	4492	1.2
34	Structure reduction (p)/ structure improvement	5751	1.6
35	Vegetation loss / vegetation regeneration	9832	2.7
36	Vegetation loss (p) / vegetation regeneration	14378	3.9
37	Structure reduction / structure improvement	41172	11.3
	Sub total	***85954***	***23.6***
	Overall total	**364835**	**100.0**

and figure 8.28 and 8.29 show the following, between the 1960's and 1999, about 24% of the area had a decrease/increase in semi-natural vegetation, 15% of the area had no change in semi-natural vegetation, 14% decreased/no change, 11% increased /decreased, 11% no change/ increased, 9% decreased/decreased, 6% increase/increased, 6% increase/no change and 4% no change/decreased. Further, Table 8.7 also shows that land units in 50% of the area have undergone two types of semi-natural vegetation cover changes from the 1960's to 1999, while land units in 35% of the area underwent only one type of cover change, and land units in 15% of the area did not change at all. However these figures should be treated with caution because they are generalized. Their importance lies in reflecting the dynamics of the semi-natural vegetation cover in each unit.

Figure 8.28 Generalized semi-natural vegetation cover changes, 1960's, 1991 and 1999

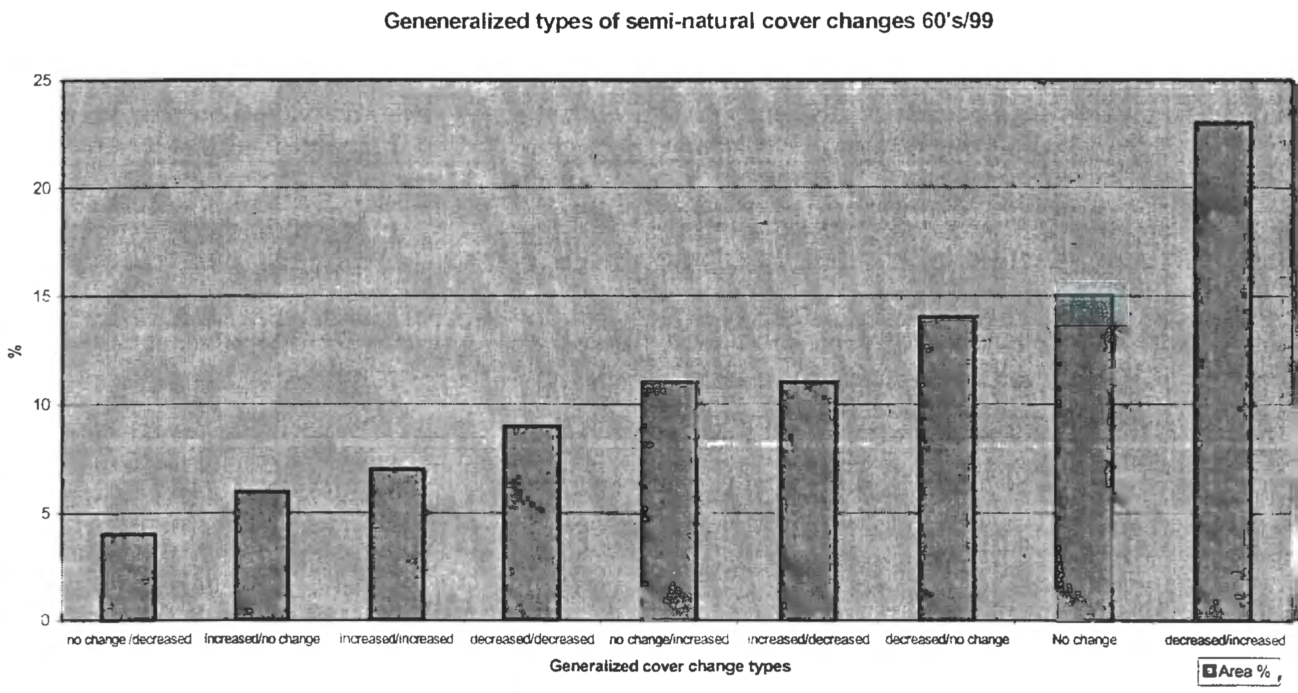
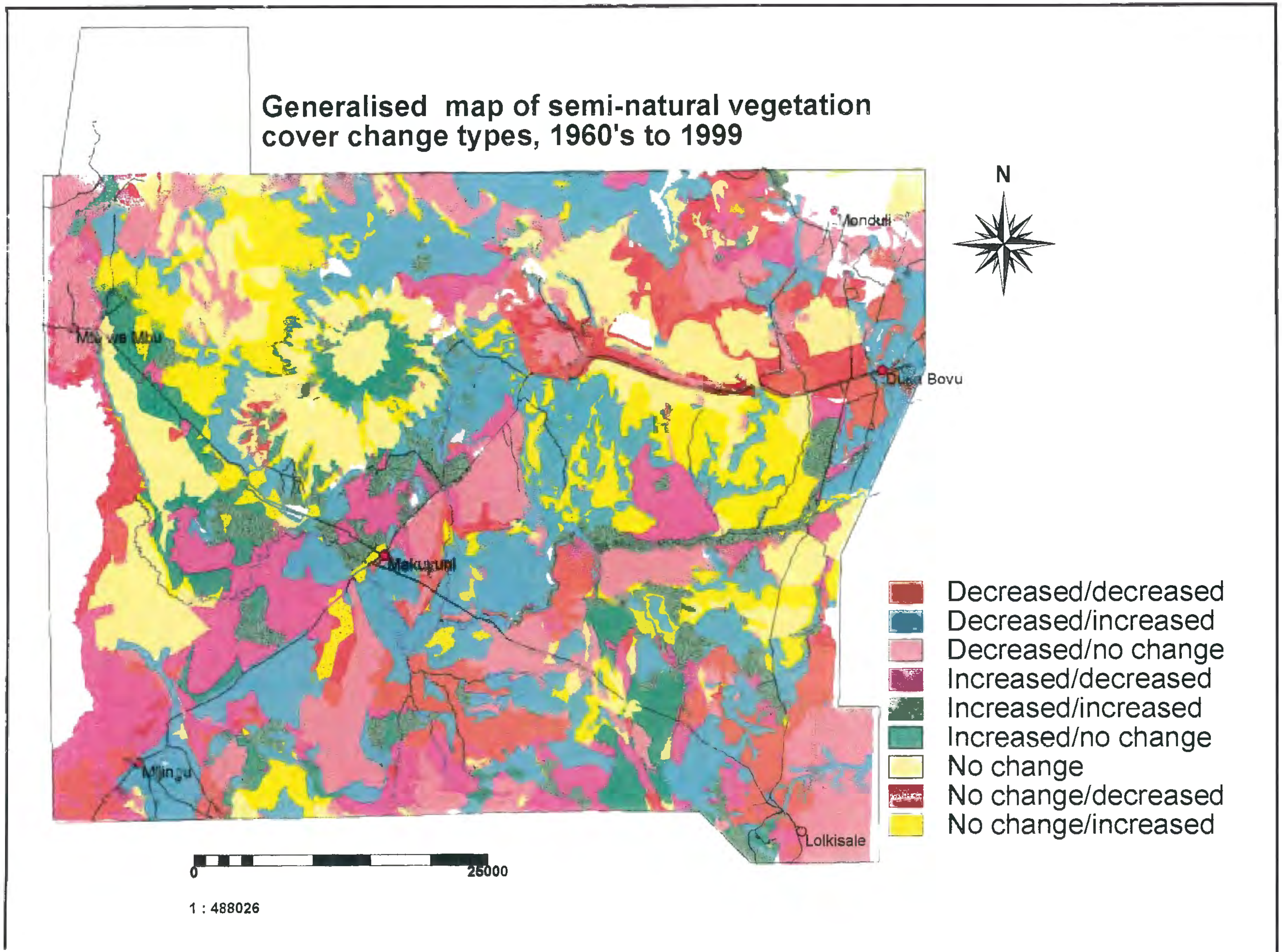


Figure 8.29 Generalized map of semi-natural vegetation cover change types, 1960's to 1999



8.5 Analysis of landcover change patterns

The last section dwelt on the trends of landcover from the 1960's to 1999, this section will attempt to link the various types of cover changes to the physical and socio-economic factors within the study area. Patterns of landcover changes were analyzed by comparing cover change maps of semi-natural vegetation, agricultural and bare land and gullies against physical and socio-economic parameters. The physical parameters that were considered are: rainfall distribution, geology, relief and slope, while the socio-economic parameters were population density and main economic activities. The analysis of each type of landcover changes shows a pattern linking cover changes and natural and/or human factors in the area. For example, semi-natural vegetation changes occurred in volcanic plateaus and sedimentary lowlands of medium and high rainfall. Gully and bare land changes took place in volcanic soils in areas practising agro-pastoralism. Agricultural changes also occurred in plateau areas of low population density. In order to get a statistical evidence between cover changes and physical and socio-economic parameters a chi-square statistic and contingency tables analysis was made on all cover changes, except for a few. Appendix 8.1 gives the summary of the statistical analysis. The following offers an analysis of the pattern for change of each cover type.

8.5.1 Semi-natural vegetation cover change pattern

The physical and socio-economic parameters that were used to analyze the patterns of change for semi-natural vegetation are rainfall distribution, geology, relief, population density and main socio-economic activities. The considered physical parameters directly or indirectly influence plant growth, therefore the types semi-natural vegetation. For example, higher rainfall areas are normally associated with high biomass and the opposite is the case for the low rainfall areas. At the same time the socio-economic parameters taken into account influence the mode in which semi-natural vegetation is utilized. As an example agricultural areas are associated with the clearing of semi-natural vegetation for crop production, while this is not carried out in pure pastoral areas.

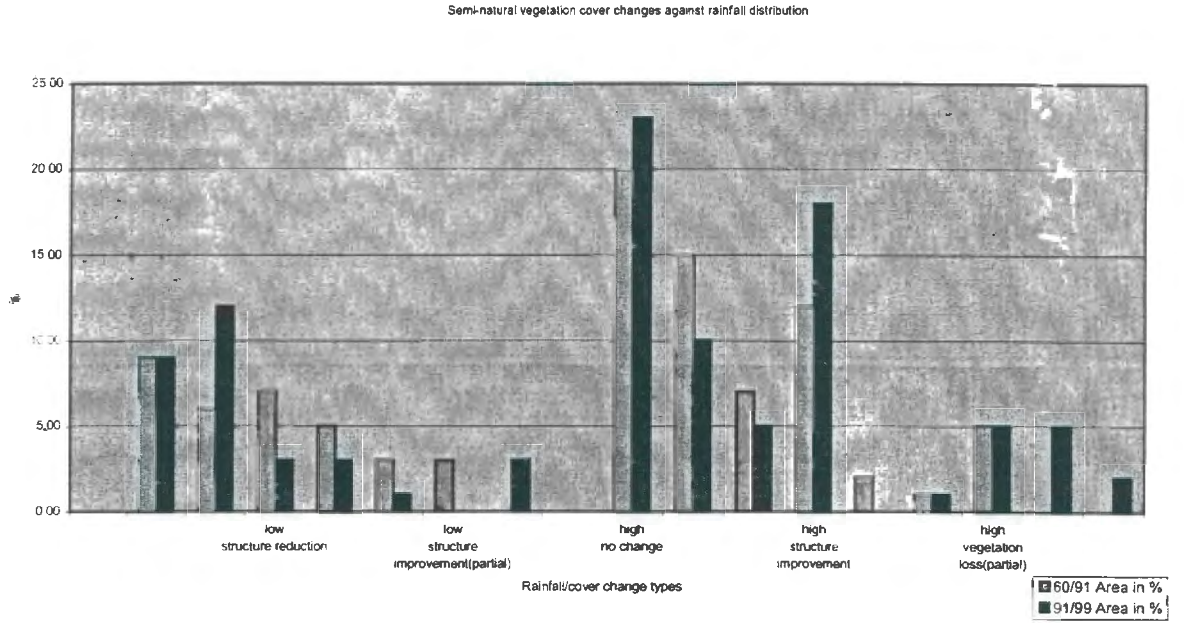
a) Changes in semi-natural vegetation cover against rainfall distribution

In Chapter six rainfall distribution in the area is categorized into low: <700 mm/year and high: >700 mm/year. Semi-natural vegetation cover changes occurred in areas with medium rainfall followed by low rainfall areas for the whole duration of the investigation (Table 8.8 and Figure 8.31).

Table 8.8 Semi-natural vegetation Changes cover against rainfall distribution

	Cover change type	Rainfall amount	60/91		91/99	
			No of Pixels	Area in %	No of Pixels	Area in %
1	**no change**	low	35703	9	32143.5	9
2	structure improvement	low	23802	6	42858	12
3	structure reduction	low	27769	7	10714.5	3
4	vegetation loss	low	19835	5	10714.5	3
5	vegetation loss (partial)	low	11901	3	3571.5	1
6	Structure improvement(partial)	low	11901	3	0	0
7	Vegetation regeneration	low	0	0	10714.5	3
	Sub total of vegetation cover change	**low**	95208	**24**	**78573**	**22**
8	**no change**	**high**	79340	**20**	82144.5	**23**
9	structure reduction	high	59505	15	35715	10
10	vegetation loss	high	27769	7	17857.5	5
11	structure improvement	high	47604	12	64287	18
12	structure reduction (partial)	high	7934	2	0	0
13	structure improvement (partial)	high	3967	1	3571.5	1
14	vegetation loss (partial)	high	19835	5	17857.5	5
15	vegetation regeneration	high	0	0	17857.5	5
16	vegetation regeneration (partial)	high	0	0	7143	2
.	**Sub total of cover change**	**high**	**166614**	**42**	**164289**	**46**
17	No data		19835	5	0	0
	Overall total		**396700**	**100**	**357150**	**100**

Figure 8.31 Semi-natural vegetation cover changes against rainfall distribution



In the 60's/91 period about 42% and 24% of semi-natural vegetation cover changes occurred in high and low rainfall areas respectively, while for the 91/99 period it was 46% in high rainfall areas and 22% in low rainfall areas. A statistical evidence for a relationship between semi-natural vegetation cover change and rainfall distribution at the 95% confidence limit explain the relationship. The dominant types of cover change in the 60's/91 period were structural reduction of 15% and 7% in high and low rainfall areas respectively. This was followed by a structural improvement of 12% in high and 6% in low rainfall areas. During the 91/99 period, the main type of cover change was a structural improvement of 18% high and 12% in low rainfall areas. This was followed by a structural reduction of 10%, vegetation regeneration of 5%, a vegetation loss of 5% and a partial vegetation loss of 5%, all in high rainfall areas. Meanwhile, in low rainfall areas, major cover changes were a structural reduction of 7%, a structural improvement of 6% and a vegetation loss of 5%. Even though high areas were experienced the highest levels of changes of semi-natural vegetation, they also retained higher levels of unchanged semi-natural vegetation cover.

b) Changes in semi-natural vegetation cover against relief

There are seven relief types in the area (Figure 6.6): flat bottom lands, gently sloping footslopes, gently sloping plains, mountains, lake terraces, plateau and undulating plains. To simplify the analysis the seven relief types were reclassified into five relief types i.e. mountains, footslopes, plains, plateaus and flatlands. Semi-natural vegetation changes occurred in all terrain units in the 1960/1991 and 1991/1999 periods. However, the most affected geomorphic types were the plateau areas 25% and 24% in the 60/91 and 91/99 periods respectively, followed by 21% in the flat lands both for the 60/91 and 23% for the 91/99 periods. Chi-squared statistics showed statistical evidence for a relationship between semi-natural vegetation cover change and relief at the 95% confidence limit. The dominant types of cover change in the 60's/91 period were structural reduction, 11%, followed by a vegetation loss 6% in plateau areas and 6% structure improvement in the flat bottomlands. A structural improvement of 12% and 6% in these areas in the 1991/1999 period was the major types of cover changes. Table 8.9 and Figure 8.32 show the details of semi-natural vegetation changes in relation to relief. However, despite the fact that plateau and bottom flat lands had most cover changes, they still had larger areas of semi-natural vegetation. 8% of the plateau areas did not change in the 60/91 and 91/99 periods, while in the flat bottomland it was 6% and 7% respectively.

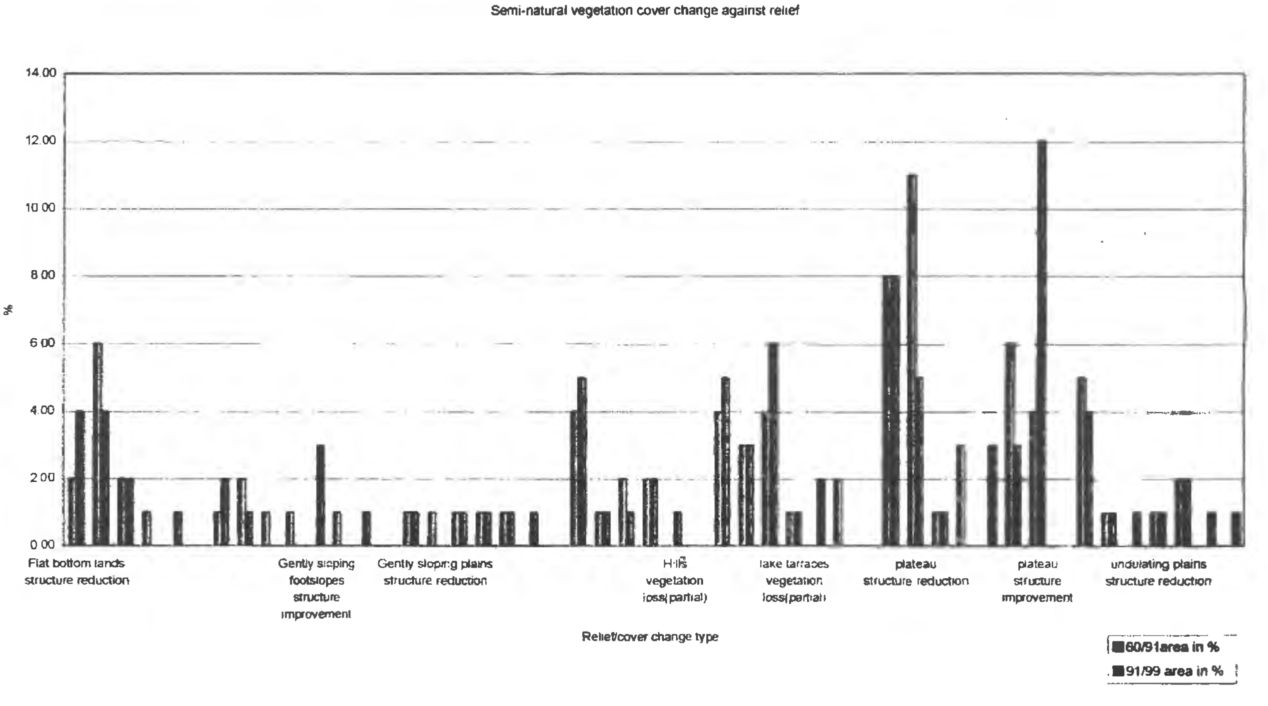
c) Changes in semi-natural vegetation cover against geology

The main geological units in the area are indicated in Figure 6.8; and are as follows: alluvium basement, alluvium volcanic, basement, black and gray volcanic

Table 8.9 Semi-natural vegetation cover changes against relief

	Cover change type	Relief	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	flat bottom lands	**23802**	6	25000.5	7
2	structure reduction	flat bottom lands	7934	2	14286	4
3	structure improvement	flat bottom lands	23802	6	14286	4
4	vegetation loss	flat bottom lands	7934	2	7143	2
5	structure improvement (partial)	flat bottom lands	3967	1	0	0
6	vegetation regeneration	flat bottom lands	0	0	3571.5	1
	Sub total of cover change		**43637**	**11**	**39286.5**	**11**
7	**no change**	Gently sloping footslopes	3967	1	7143	2
8	structure reduction	Gently sloping footslopes	7934	2	3571.5	1
9	structure reduction (partial)	Gently sloping footslopes	3967	1	0	0
10	vegetation loss	Gently sloping footslopes	3967	1	0	0
11	structure improvement	Gently sloping footslopes	0	0	10714.5	3
12	vegetation loss (partial)	Gently sloping footslopes	3967	1	0	0
13	vegetation regeneration	Gently sloping footslopes	0	0	3571.5	1
	Sub total of cover change		**19835**	**5**	**17857.5**	**5**
14	**no change**	**Gently sloping plains**	3967	1	3571.5	1
15	structure reduction	Gently sloping plains	3967	1	0	0
16	vegetation loss (partial)	Gently sloping plains	3967	1	3571.5	1
17	structure improvement	Gently sloping plains	3967	1	3571.5	1
18	vegetation loss	Gently sloping plains	3967	1	3571.5	1
19	vegetation regeneration	Gently sloping plains	0	0	3571.5	1
	Sub total of cover changes		**15868**	**4**	**14286**	**4**
20	**no change**	**Mountains**	15868	4	17857.5	5
21	structure reduction (partial)	Mountains	3967	1	3571.5	1
22	structure reduction	Mountains	7934	2	3571.5	1
23	structure improvement	Mountains	7934	2	7143	2
24	vegetation loss (partial)	Mountains	0	0	3571.5	1
	Sub total of cover changes		**19835**	**5**	**17857.5**	**5**
25	**no change**	**lake terraces**	15868	4	17857.5	5
26	structure reduction	lake terraces	11901	3	10714.5	3
27	structure improvement	lake terraces	15868	4	21429	6
28	vegetation loss (partial)	lake terraces	3967	1	3571.5	1
29	vegetation regeneration	lake terraces	0	0	7143	2
30	vegetation loss	lake terraces	7934	2	0	0
	Sub total of cover changes		**39670**	**10**	**42858**	**12**
31	**no change**	plateau	**31736**	**8**	**28572**	**8**
32	structure reduction	plateau	43637	11	17857.5	5
33	structure improvement (partial)	plateau	3967	1	3571.5	1
34	vegetation loss (partial)	plateau	11901	3	0	0
35	vegetation regeneration	plateau	0	0	10714.5	3
36	vegetation loss	plateau	23802	6	10714.5	3
37	structure improvement	plateau	15868	4	42858	12
	Sub total of cover changes		**99175**	**25**	**85716**	**24**
38	no change	**undulating plains**	**19835**	**5**	**14286**	**4**
39	vegetation loss	undulating plains	3967	1	3571.5	1
40	structure improvement	undulating plains	0	0	3571.5	1
41	structure reduction	undulating plains	3967	1	3571.5	1
42	vegetation loss (partial)	undulating plains	7934	2	7143	2
43	vegetation regeneration	undulating plains	0	0	3571.5	1
44	vegetation regeneration (partial)	undulating plains	0	0	3571.5	1
	Sub total of cover changes		**15868**	**4**	**25000.5**	**7**
45	No data		27769	7	0	0

Figure 8.31a Semi-natural vegetation changes cover against relief

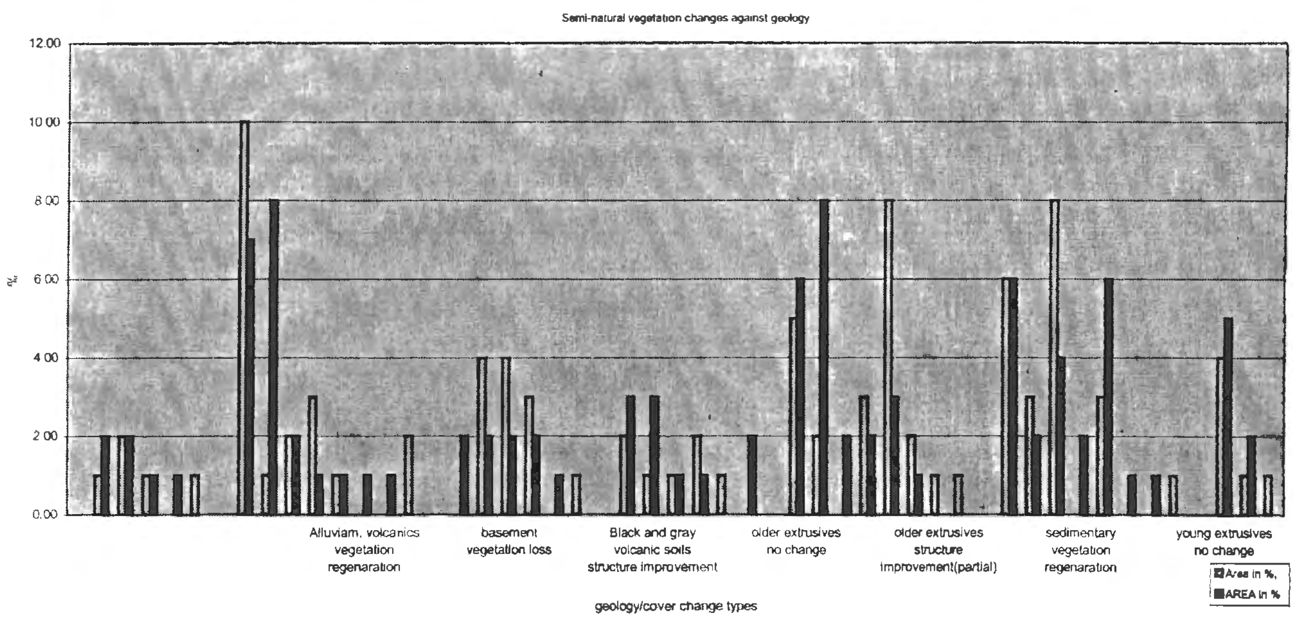


soils, older extrusive, sedimentary and young extrusive. To simplify the analysis the geology of the area was regrouped into three main types of volcanic, basement and sedimentary. Changes of semi-natural vegetation cover have taken place in all geological units but at different levels. For example, 39% of semi-natural vegetation cover changes between 1960's/1991 occurred in volcanics 15% in sedimentary and 16% in basement substrates. Meanwhile, between 91/99 the major cover changes occurred not only in volcanics 30% and sedimentary 16%, but also 11% in basements (Table 8.10 and Figure 8.32). Chi-squared statistics showed statistical evidence for a relationship between semi-natural vegetation cover change and geology at the 95% confidence limit. The predominant type of cover changes in 60/91 were 8% in structural reduction and structure improvement respectively, which occurred in older extrusives and sedimentary areas. These were followed by 4% of each of vegetation loss and

Table 8.10 Semi-natural vegetation changes against geology

	Cover change type	Geology	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**Alluvium, Basement**	3966.61	1	7143	2
2	structure improvement	Alluvium, Basement	7933.22	2	7143	2
3	structure reduction	Alluvium, Basement	3966.61	1	3571.5	1
4	vegetation regeneration	Alluvium, Basement	0	0	3571.5	1
5	vegetation loss (partial)	Alluvium, Basement	3966.61	1	0	0
	Sub total of cover changes		**15866.44**	**4**	**14286**	**4**
6	**no change**	**Alluvium, Volcanics**	**39666.1**	**10**	**25000.5**	**7**
7	structure improvement	Alluvium, Volcanics	3966.61	1	28572	8
8	vegetation loss (partial)	Alluvium, Volcanics	7933.22	2	7143	2
9	structure reduction	Alluvium, Volcanics	11899.83	3	3571.5	1
10	vegetation loss	Alluvium, Volcanics	3966.61	1	3571.5	1
11	vegetation regeneration	Alluvium, Volcanics	0	0	3571.5	1
12	vegetation regeneration (partial)	Alluvium, Volcanics	0	0	3571.5	1
13	structure improvement (partial)	Alluvium, Volcanics	7933.22	2	0	0
	Sub total of cover changes		35699.49	**9**	50001	**14**
14	**no change**	**Basement**	0	0	7143	2
15	structure reduction	Basement	15866.44	4	7143	2
16	vegetation loss	Basement	15866.44	4	7143	2
17	structure improvement	Basement	11899.83	3	7143	2
18	vegetation regeneration	Basement	0	0	3571.5	1
19	vegetation loss (partial)	Basement	3966.61	1	0	0
	Sub total of cover changes		**47599.32**	**12**	**25000.5**	**7**
20	**no change**	**Black and gray volcanic soils**	7933.22	2	**10714.5**	3
21	structure improvement	Black and gray volcanic soils	3966.61	1	10714.5	3
22	vegetation loss	Black and gray volcanic soils	3966.61	1	3571.5	1
23	structure reduction	Black and gray volcanic soils	7933.22	2	3571.5	1
24	vegetation loss (partial)	Black and gray volcanic soils	3966.61	1	0	0
25	vegetation regeneration	Black and gray volcanic soils	0	0	7143	2
	Sub total of cover changes		**19833.05**	**5**	25000.5	7
26	**no change**	**older extrusive**	**19833.05**	**5**	21429	6
27	structure improvement	older extrusive	7933.22	2	28572	8
28	vegetation regeneration	older extrusive	0	0	7143	2
29	vegetation loss	older extrusive	11899.83	3	7143	2
30	structure reduction	older extrusive	31732.88	8	10714.5	3
31	vegetation loss (partial)	older extrusive	7933.22	2	3571.5	1
32	structure improvement (partial)	older extrusive	3966.61	1	0	0
33	structure reduction (partial)	older extrusive	3966.61	1	0	0
	Sub total of cover changes		**67432.37**	**17**	**57144**	16
34	**no change**	sedimentary	23799.66	6	21429	6
35	vegetation loss	sedimentary	11899.83	3	7143	2
36	structure improvement	sedimentary	31732.88	8	14286	4
37	vegetation regeneration	sedimentary	0	0	7143	2
38	structure reduction	sedimentary	11899.83	3	21429	6
39	vegetation loss (partial)	sedimentary	0	0	3571.5	1
40	vegetation regeneration (partial)	sedimentary	0	0	3571.5	1
41	vegetation loss (partial)	sedimentary	3966.61	1	0	0
	Sub total of cover changes		**59499.15**	**15**	**57144**	**16**
42	**no change**	young extrusives	15866.44	4	17857.5	5
43	structure improvement	young extrusives	3966.61	1	7143	2
44	structure reduction	young extrusives	3966.61	1	0	0
	Sub total of cover changes		**7933.22**	**2**	7143	2
	No data		31732.88	8	10714.5	3
	Total			**100**		**100**

Figure 8.32 Semi-natural vegetation changes cover against geology



structural reduction in the basement system. In 91/99, the major type of cover changes were a structural improvement of 8% in older extrusives and alluvium volcanics and structural reduction in the sedimentary system. The geological units that had large areas of unchanged semi-natural vegetation were alluvium volcanics of 10% and 7% for 60/91 and 91/99 respectively, followed by sedimentary areas of 6%, for both these periods.

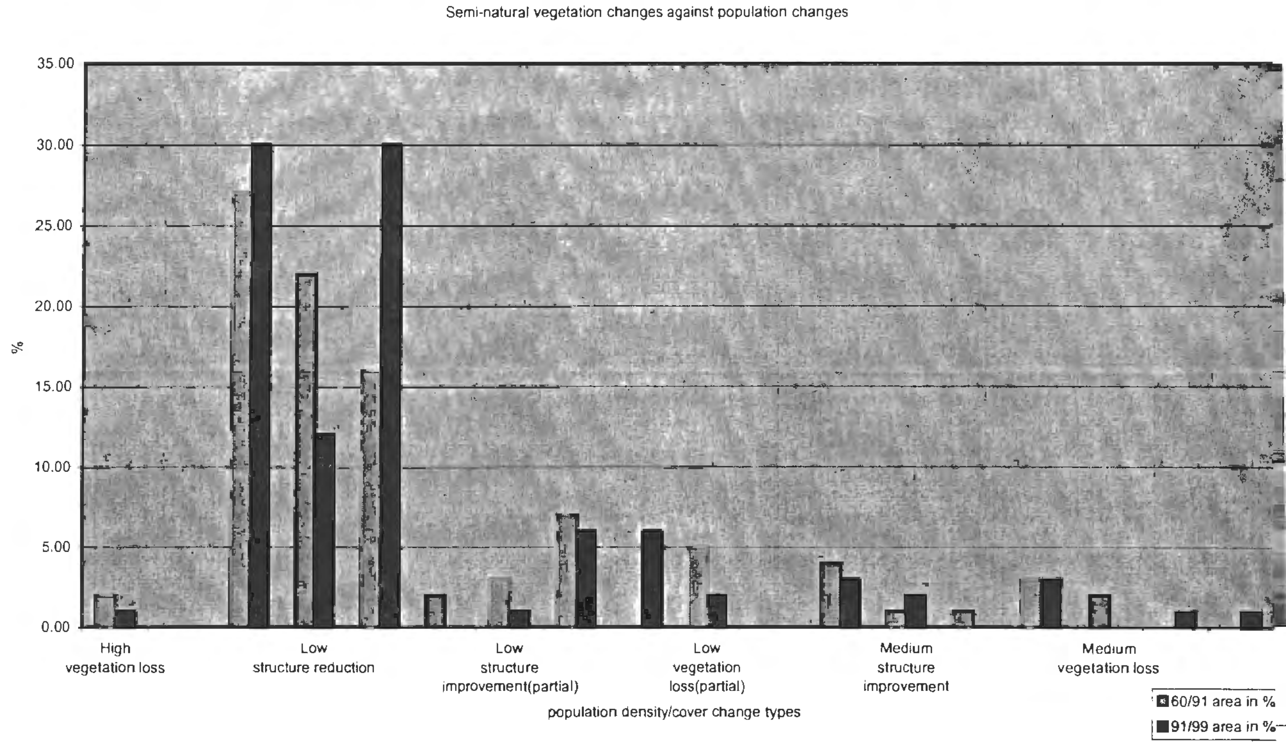
d) Changes in semi-natural vegetation against population density

The population density of the area was categorized into three units, *viz.*: low: < 15 persons/km^2, medium: 15 >100 persons/km^2 and high: more than 100 persons /km^2. Details of population density in the area are shown in Table 5.2. The main cover changes of semi-natural vegetation, 56%, took place in low-density areas in 1960/91 and 57% in 91/99. A statistical evidence for a relationship between semi-natural vegetation cover change and population density at the 95% confidence limit explain the relationship. A structure reduction of 22% followed by a structure improvement of 16% and a vegetation loss 7% were the dominant types of cover change in the 60/91 period. The opposite occurred in the 91/99 period, in which a structural improvement of 30% was dominant, followed by a structural reduction of 12% and vegetation loss and regeneration of 6% each, in low density areas. Low-density areas still retain large areas of unchanged semi-natural vegetation for both periods 27% and 30% respectively. Table 8.11 and Figure 8.33 show the details of the relevant cover changes. Low density areas

Table 8.11 Semi-natural vegetation changes against population density

	Cover change types	**Population density**	**60/91**		**91/99**	
			No of pixels	*Area in %*	*No of pixels*	*Area in %*
1	vegetation loss	**High**	**7215.26**	**2**	**3311.29**	**1**
	sub total for cover changes	High	**7215.26**	**2**	**3311.29**	**1**
2	**no change**	**Low**	**97406.01**	**27**	**99338.7**	**30**
3	structure reduction	Low	79367.86	22	39735.48	12
4	structure improvement	Low	57722.08	16	99338.7	30
5	structure reduction (partial)	Low	7215.26	2	0	0
6	structure improvement (partial)	Low	10822.89	3	3311.29	1
7	vegetation loss	Low	25253.41	7	19867.74	6
8	vegetation regeneration	Low	0	0	19867.74	6
9	vegetation regeneration (partial)	Low	3607.63	1	0	0
10	vegetation loss (partial)	Low	18038.15	5	6622.58	2
	sub total for cover changes		**202027.28**	**56**	**188743.53**	**57**
11	**no change**	**Medium**	**14430.52**	**4**	**9933.87**	**3**
12	structure improvement	Medium	3607.63	1	6622.58	2
13	tructure reduction	Medium	3607.63	1	0	0
14	vegetation loss (partial)	Medium	10822.89	**3**	9933.87	3
15	vegetation loss	Medium	7215.26	2	0	0
16	vegetation regeneration (partial)	Medium	0	0	3311.29	1
17	vegetation regeneration	Medium	0	0	3311.29	1
	sub total for cover changes		**25253.41**	**7**	**23179.03**	**7**
18	No data		14430.52	4	6622.58	2
	Total		**360763**	**100**	**331129**	**100**

Figure 8.33 Changes in semi-natural vegetation cover against population density



were subjected to higher rates of change in semi-natural vegetation because new agricultural lands were opened in these villages located in low-density areas. Example of such villages include Lolkisale, Makuyuni, Mswakini and Mbuyuni.

e) Changes in semi-natural vegetation cover against main economic activities

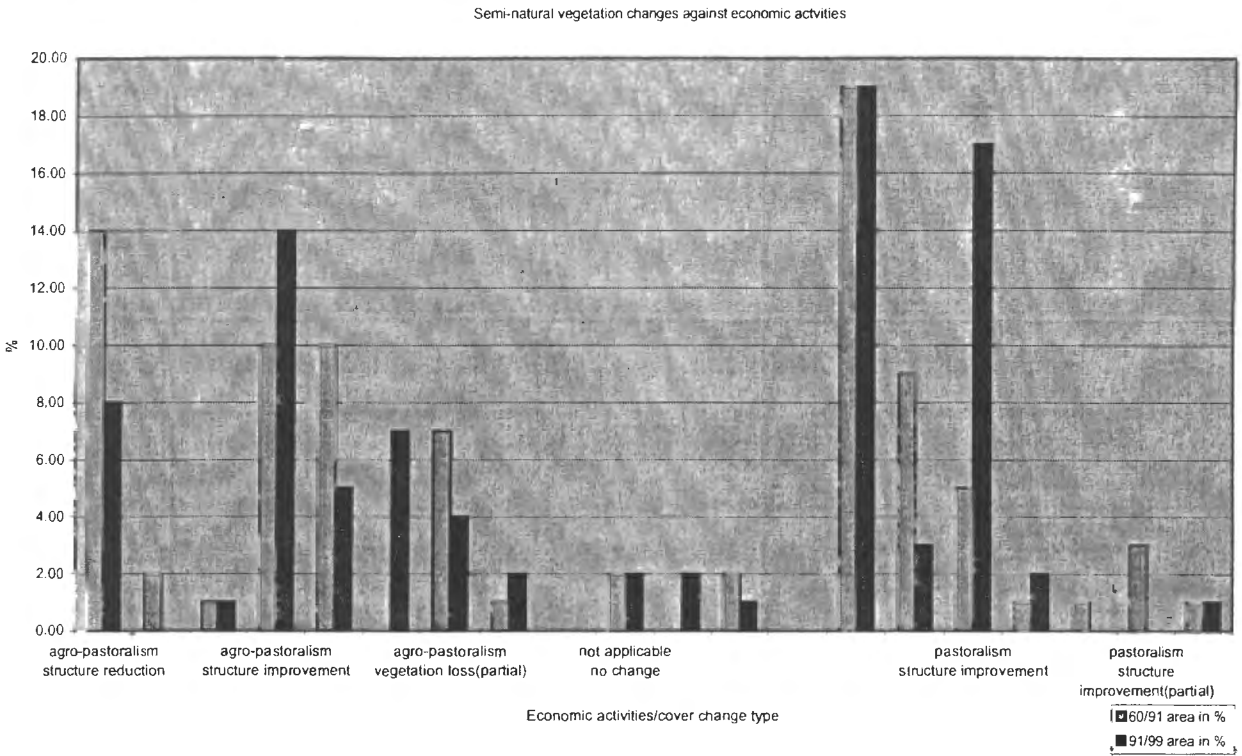
The villages in the study area were divided into two categories: agro-pastoralism for those practising both livestock keeping and farming, and pastoralism for those predominantly practicing livestock keeping. A third, minor, category is the Manyara Ranch that is currently not used either for farming or pastoralism (noted as "not applicable" in the Table 8.12). Agro-pastoralism areas were subjected more to cover changes of semi-natural vegetation than pastoral areas 45%

Table 8.12 Semi-natural vegetation changes cover against main economic activity

	Cover change type	Economic activity	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**agro-pastoralism**	**43291.56**	**12**	**39735.48**	**12**
2	structure reduction	agro-pastoralism	50506.82	14	26490.32	8
3	structure reduction (partial)	agro-pastoralism	7215.26	2	0	0
4	structure improvement (partial)	agro-pastoralism	3607.63	1	3311.29	1
5	structure improvement	agro-pastoralism	36076.3	10	46358.06	14
6	vegetation loss	agro-pastoralism	36076.3	10	16556.45	5
7	vegetation regeneration	agro-pastoralism	0	0	23179.03	7
8	vegetation loss (partial)	agro-pastoralism	25253.41	7	13245.16	4
9	vegetation regeneration (partial)	agro-pastoralism	3607.63	1	6622.58	2
	sub total for cover changes		**162343.35**	**45**	**135762.89**	**41**
10	**no change**	**not applicable**	**7215.26**	**2**	**6622.58**	**2**
11	structure reduction	not applicable	0	0	6622.58	2
12	structure improvement	not applicable	7215.26	2	3311.29	1
	sub total for cover changes		**7215.26**	**2**	**9933.87**	**3**
13	**no change**	pastoralism	**68544.97**	**19**	**62914.51**	**19**
14	structure reduction	pastoralism	32468.67	9	9933.87	3
15	structure improvement	pastoralism	18038.15	5	56291.93	17
16	vegetation loss	pastoralism	3607.63	1	6622.58	2
17	structure reduction (partial)	pastoralism	3607.63	1	0	0
18	structure improvement (partial)	pastoralism	10822.89	3	0	0
19	vegetation loss (partial)	pastoralism	3607.63	1	3311.29	1
	sub total for cover changes		**72152.6**	**20**	**76159.67**	**23**
	Total		**360763**	**100**	**331129**	**100**

between 60/91 and 41% between 91/99. A statistical evidence for a relationship between semi-natural vegetation cover change and socio-economic activities at the 95% confidence limit explain the relationship. In the agro-pastoral areas the major types of cover changes in the 1960 to 1991 period were 14% structural reduction, followed by 10% structural improvement and a vegetation loss of 10%. Similarly during this period, main types of cover changes in pastoral areas were 9% structural reduction and 5% structure improvement. Between 91/99 the main types of cover changes in agro-pastoral areas were 14% structural improvement followed by 8% structural reduction and 7% vegetation regeneration, while in

Figure 8.34 Semi-natural vegetation cover changes against main economic activities



pastoral areas, a structural improvement of 17% was dominant type of the cover change in the 91/99. Pastoral areas had larger areas of semi-natural vegetation, which remained unchanged at 19%, for both the 91/91 and 91/99 periods.

8.5.2 Agricultural cover pattern

Changes in agricultural patterns were analyzed against rainfall distribution, relief, geology and population density. The agricultural cover change pattern is very similar to semi-natural vegetation change patterns, which occurred in villages with marked development activities. Therefore, geological, terrain units, or rainfall areas where these villages are located are subjected to higher rates of agricultural changes. Rainfall variability again seems to play its role where the

1991/1999 period is marked by loss of agricultural lands due to timing of the satellite image which meant only farms cultivated in 1998 could be seen, or large areas were deliberately left fallow because of the higher rainfall in 1998/1999.

a) Changes in agricultural cover against rainfall distribution

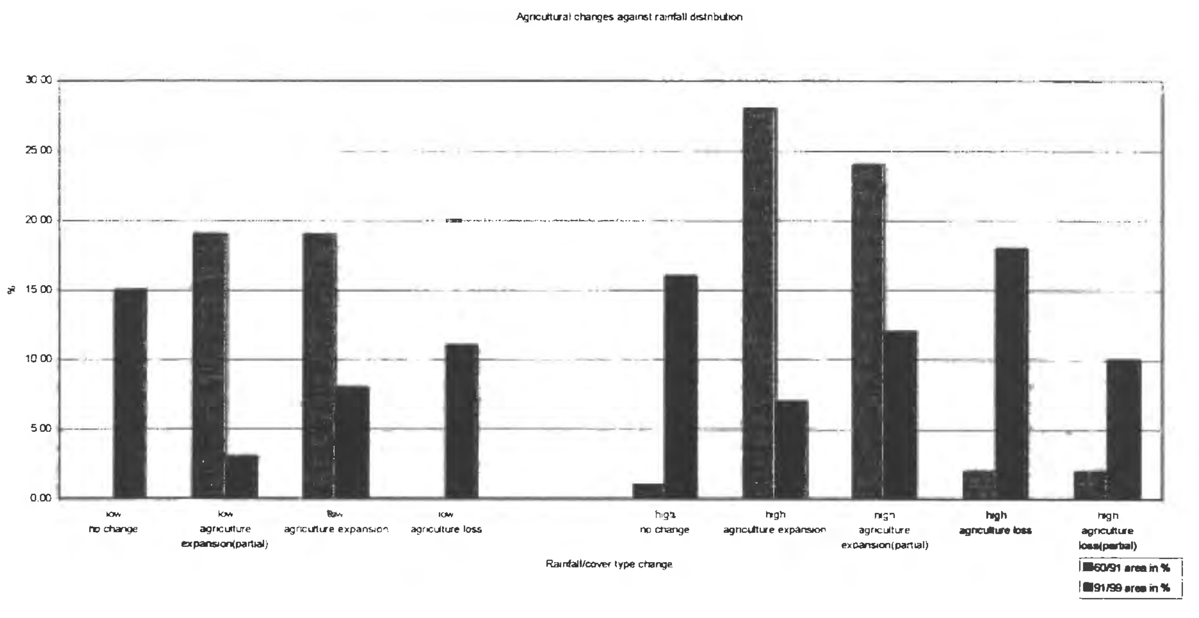
During the entire period of investigation, agricultural cover changes were more active in high rainfall areas, i.e. 56% and 47% for 60/91 and 91/99 respectively. In low rainfall areas during the same period, agricultural cover changes constituted 38% and 22% respectively. Table 8.13 and Figure 8.35 show the details of cover changes in relation to rainfall distribution. Chi-squared statistics showed statistical evidence for a relationship between agricultural cover change and rainfall distribution at the 95% confidence limit. The main types of agricultural cover changes in the 60/91 period were 28% agricultural expansion, followed by partial agricultural expansion of 24% in high rainfall areas. Meanwhile, in the 91/99 period in the same zone of high rainfall, dominant cover

Table 8.13 Changes in agricultural cover against rainfall distribution

	Cover change type	Rainfall	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**Low**	0	**0**	**16368.3**	**15**
2	agriculture expansion (partial)	Low	16518.79	19	3273.66	3
3	agriculture expansion	Low	16518.79	19	8729.76	8
4	agriculture loss	Low	0	0	12003.42	11
	sub total for cover changes		**33037.58**	**38**	**24006.84**	**22**
5	**no change**	**High**	**869.41**	**1**	**17459.52**	**16**
6	agriculture expansion	High	24343.48	28	7638.54	7
7	agriculture expansion(partial)	High	20865.84	24	13094.64	12
8	agriculture loss (partial)	High	1738.82	2	19641.96	18
	sub total for cover changes		0	**0**	**10912.2**	**10**
	no data		4347.05	5	51287.34	47
	Total		**86941**	**100**	**109122**	**100**

changes were 18% agricultural loss, and a partial agricultural expansion of 12%. In low rainfall areas, agricultural expansion of 19% and partial agricultural expansion of 19% were the major cover changes in the period of 60/91, while the dominant types of cover changes for the 91/99 period in the low rainfall areas were 11% agricultural loss and 8% agricultural expansion. Both in high and low rainfall zones about 16% and 15% of the area respectively, continued to be used for agricultural activities between 91/99.

Figure 8.35 Agricultural cover changes against rainfall distribution



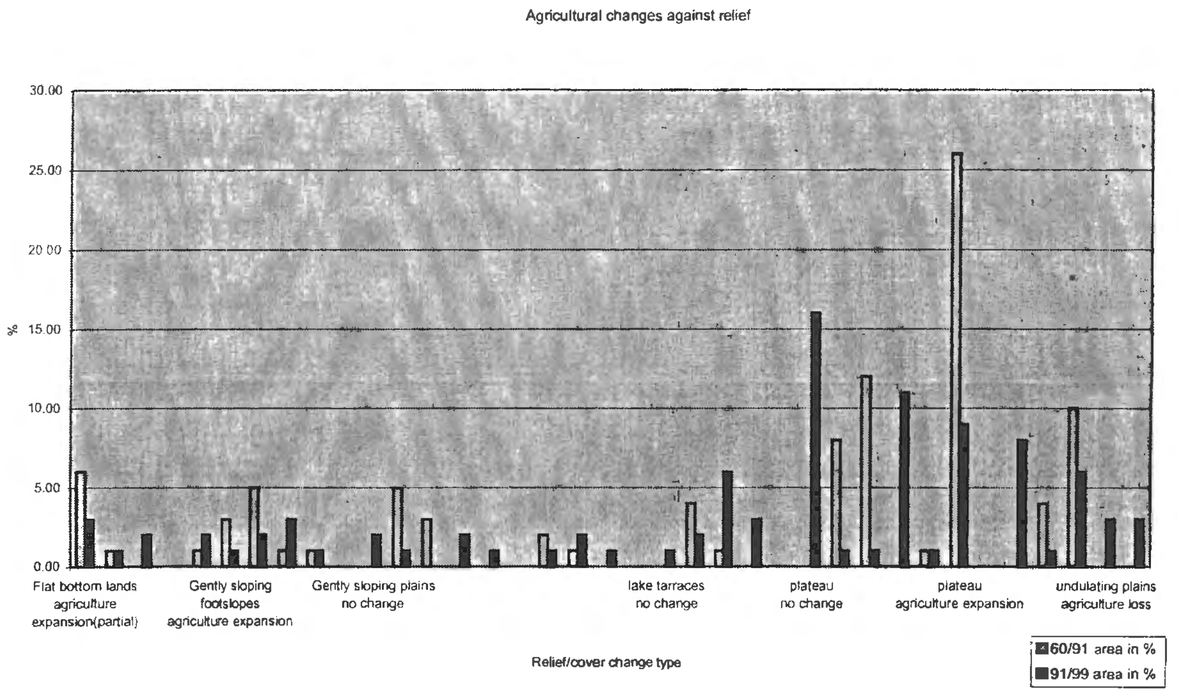
b) Changes in agricultural cover against relief

Most of the agricultural changes between the 60's/91 and 91/99 occurred in the plateau areas, undulating plains and gently sloping footslopes. Table 8.14 and Figure 8.36 show the details of agricultural cover changes. The least affected areas were the in mountains. Chi-squared statistics showed statistical evidence for a relationship between agricultural cover change and relief at the 95%.

Table 8.14 Agricultural changes against relief

	Cover change type	Relief	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**Flat bottom lands**	**0**	0	**3273.03**	3
2	agriculture expansion (partial)	Flat bottom lands	5216.4	6	3273.03	3
3	agriculture expansion	Flat bottom lands	869.4	1	1091.01	1
4	agriculture loss	Flat bottom lands	0	0	2182.02	2
	sub total for cover changes		**6085.8**	7	**6546.06**	6
5	**no change**	**Gently sloping slopes**	**869.4**	1	**2182.02**	2
6	agriculture expansion	Gently sloping slopes	2608.2	3	1091.01	1
7	agriculture expansion (partial)	Gently sloping slopes	4347	5	2182.02	2
8	agriculture loss	Gently sloping slopes	869.4	1	3273.03	3
9	agriculture loss (partial)	Gently sloping slopes	869.4	1	1091.01	1
	sub total for cover changes		**8694**	10	**7637.07**	7
10	**no change**	**gently sloping plains**	**0**	0	**2182.02**	2
11	agriculture expansion (partial)	gently sloping plains	4347	5	1091 01	1
12	agriculture expansion	gently sloping plains	2608.2	3	0	0
13	agriculture loss	gently sloping plains	0	0	2182.02	2
14	agriculture loss (partial)	gently sloping plains	0	0	1091.01	1
	sub total for cover changes		**6955.2**	8	**4364.04**	4
15	**no change**	**Mountains**	**1738.8**	2	**1091.01**	1
16	agriculture expansion (partial)	Mountains	869.4	1	2182.02	2
17	agriculture loss (partial)	Mountains	0	0	1091.01	1
	sub total for cover changes		**2608.2**	3	**4364.04**	4
18	**no change**	**lake terraces**	**0**	0	**1091.01**	1
19	agriculture expansion (partial)	lake terraces	**3477.6**	4	**2182.02**	2
20	agriculture loss	lake terraces	**869.4**	1	**6546.06**	6
21	agriculture loss (partial)	lake terraces	**0**	0	**3273.03**	3
22	agriculture expansion	lake terraces	**6955.2**	8	**1091.01**	1
	sub total for cover changes		**11302.2**	13	**13092.12**	12
23	**no changes**	**plateau**	**0**	0	**17456.16**	16
24	agriculture expansion (partial)	plateau	10432.8	12	1091.01	1
25	agriculture loss	plateau	0	0	12001.11	11
26	agriculture loss (partial)	plateau	869.4	1	1091.01	1
27	agriculture expansion	plateau	22604.4	26	9819.09	9
	sub total for cover changes		**33906.6**	39	**24002.22**	22
28	**no change**	**undulating plains**	**0**	0	**8728.08**	8
29	agriculture expansion	undulating plains	3477.6	4	1091.01	1
30	agriculture expansion (partial)	undulating plains	8694	10	6546.06	6
31	agriculture loss	undulating plains	0	0	3273.03	3
32	agriculture loss (partial)	undulating plains	0	0	3273.03	3
	sub total for cover changes		**12171.6**	14	**14183.13**	13
	No data		4347	5	0	
	Total		**86940**	**100**	**109101**	**100**

Figure 8.36 Agricultural cover changes against relief



confidence limit. Between the 60's/91, 39% of agricultural cover changes took place in plateau areas, which was reduced to 22% over the 91/99 period. Meanwhile, in the plains about 22% and 17% agricultural cover changes took place in the period of 60's/91 and 91/99 respectively, compared to 20% and 18% in flat land areas for the same periods of time. Substantially reduced agricultural cover change occurred on the gently sloping footslopes, being 10% and 7% for the 60's/91 and the 91/99 periods respectively. Between 60'/91 the dominant agricultural cover change types were 26% agricultural expansion which took place in the plateau areas, and 8% lake terraces. Others include of a partial agricultural expansion of 12% in plateaus, 10% undulating plains and 5% gently sloping footslopes. During the 91/99 period, the dominant type of agricultural change was an agriculture loss 11% on plateaus and 6% lake terraces. Other types of agricultural change included 9% agricultural expansion on the plateaus and 6% partial agricultural expansion in the undulating plains. Between 91/99, 16% and 8% of agricultural lands continued to be used for the same purpose in plateaus and undulating plains respectively.

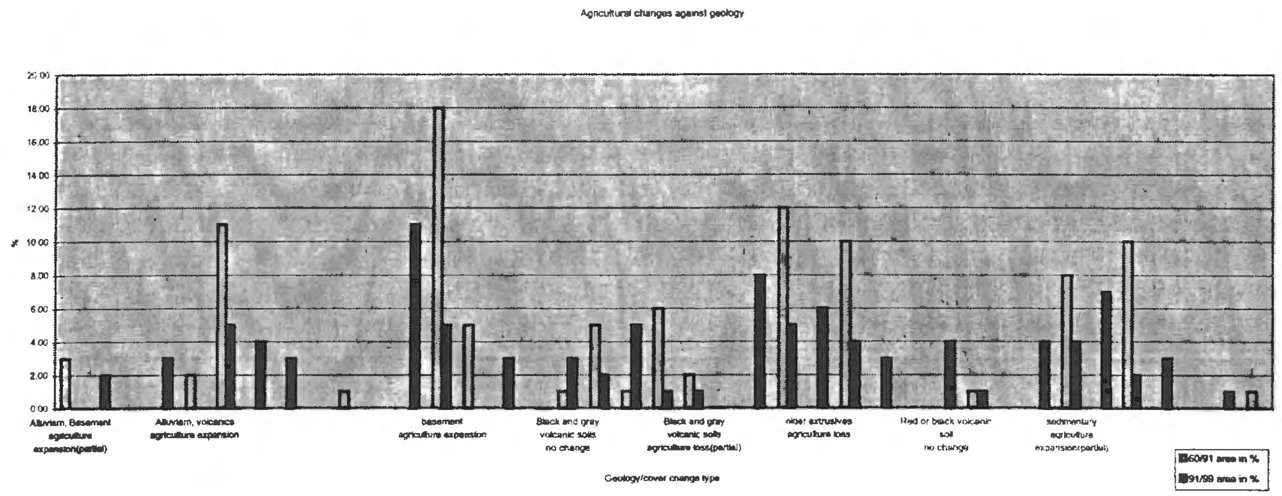
c) Changes in agricultural cover against geology

Agricultural changes in relation to geology were mostly concentrated in the basement, volcanics followed by basement areas for both periods. The highest percentage, being 53% of agricultural change between 60'/91 took place in volcanic areas, followed by 26% in basement and 18% in the sedimentary areas. During the 91/99 period, most of the agricultural changes continued to occur in volcanic areas 41%, followed by the sedimentary areas 16%, and 10% in areas with basement soils. Chi-squared statistics showed statistical evidence for a relationship between agricultural cover change and geology at the 95% confidence limit. The dominant type of agricultural change during the 60's/91 period was agricultural expansion being 19% in volcanics, 18% in basement areas, and 10% in sedimentary areas. Partial agricultural expansion of 18% occurred in volcanics, 8% in both basements and sedimentary areas. Loss of agricultural land was the dominant type of agricultural changes during the 91/99 period in which 7%, and 11% of agricultural lands were converted to other cover types in sedimentary areas and volcanic soils, respectively. Geological areas that had largely unchanged agricultural areas were 11% basement and 8% volcanics. Table 8.15 and Figure 8.37 show the cover changes in relation to geology.

Table 8.15 Agricultural changes against geology

	Cover change type	Geology	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	agriculture expansion (partial)	Alluvium, Basement	2508.99	3	0	0
2	agriculture loss	Alluvium, Basement	0	0	2182.04	2
	sub total of cover changes		**2508.99**	**3**	**2182.04**	**2**
3	**no change**	**Alluvium, volcanics**	**0**	**0**	**3273.06**	**3**
4	agriculture expansion	Alluvium, volcanics	1672.66	2	0	0
5	agriculture expansion (partial)	Alluvium, volcanics	9199.63	11	5455.1	5
6	agriculture loss	Alluvium, volcanics	0	0	4364.08	4
7	agriculture loss (partial)	Alluvium, volcanics	0	0	3273.06	3
	sub total of cover changes		**10872.3**	**13**	**13092.24**	**12**
8	**agriculture expansion**	**Alluvium**	836.33	1	0	0
	sub total of cover changes		**836.33**	**1**	**0**	**0**
9	**no change**	**basement**	**0**	**0**	**12001.22**	**11**
10	agriculture expansion	basement	15053.9	18	5455.1	5
11	agriculture expansion (partial)	basement	4181.65	5	0	0
12	agriculture loss	basement	0	0	3273.06	3
	sub total fo cover changes		**19235.6**	**23**	**8728.16**	**8**
13	**no change**	**Black and gray volcanic soils**	836.33	1	3273.06	3
14	agriculture expansion	Black and gray volcanic soils	4181.65	5	2182.04	2
15	agriculture loss	Black and gray volcanic soils	836.33	1	5455.1	5
16	agriculture expansion (partial)	Black and gray volcanic soils	5017.98	6	1091.02	1
17	agriculture loss (partial)	Black and gray volcanic soils	1672.66	2	1091.02	1
	sub total of cover changes		**11708.6**	**14**	**9819.18**	**9**
18	**no change**	**older extrusives**	0	0	8728.16	8
19	agriculture expansion	older extrusives	10036	12	5455.1	5
20	agriculture loss	older extrusives	0	0	6546.12	6
21	agriculture expansion (partial)	older extrusives	8363.3	10	4364.08	4
22	agriculture loss (partial)	older extrusives	0	0	3273.06	3
	sub total of cover changes		**18399.3**	**22**	**19638.36**	**18**
23	**no change**	**Red or Black volcanic soil**	0	0	4364.08	4
24	agriculture expansion	Red or Black volcanic soil	836.33	1	1091.02	1
	sub total of cover changes		**836.33**	**1**	**1091.02**	**1**
25	**no change**	**sedimentary**	**0**	**0**	**4364.08**	**4**
26	agriculture expansion (partial)	sedimentary	6690.64	8	4364.08	4
27	agriculture loss	sedimentary	0	0	7637.14	7
28	agriculture expansion (partial)	sedimentary	8363.3	10	2182.04	2
29	agriculture loss (partial)	sedimentary	0	0	3273.06	3
	sub total of cover changes		**15053.9**	**18**	**17456.32**	**16**
30	**agriculture loss**	**young exclusives**	**0**	**0**	**1091.02**	**1**
31	agriculture expansion	young exclusives	836.33	1	0	0
	sub total of cover changes		**836.33**	**1**	**1091.02**	**1**
	No data		2508.99	3	0	
	Total		**83633**	**100**	**109102**	**100**

Figure 8.37 Agricultural changes against geology



d) Changes in agricultural cover against population density

A large proportion of the agricultural cover changes took place in low-density areas followed by medium density areas in both periods of the 60's/91 and 91/99. (Table 8.16 and Figure 8.38). This is not surprising because low-density areas were characterized by large unoccupied parcels of land. During the 60's/91 period, 68% of changes in agricultural lands occurred in the low lands, reduced to 48% in the 91/99 period. 23% of agricultural changes took place in medium density areas and again reduced to 18% during the 91/99 period. Chi-squared statistics showed statistical evidence for a relationship between agricultural cover change and population density at the 95% confidence limit. The main types of agricultural changes in former period were agricultural expansion: 35% in low-density areas and 10% in medium density areas; followed by partial agricultural expansion: 28% in low-density areas and 13% in medium density areas. During the 91/99 period, the dominant types of agricultural cover change was agricultural loss; 23% in low-density areas and partial agricultural loss and expansion 6% for each respectively, in medium density areas.

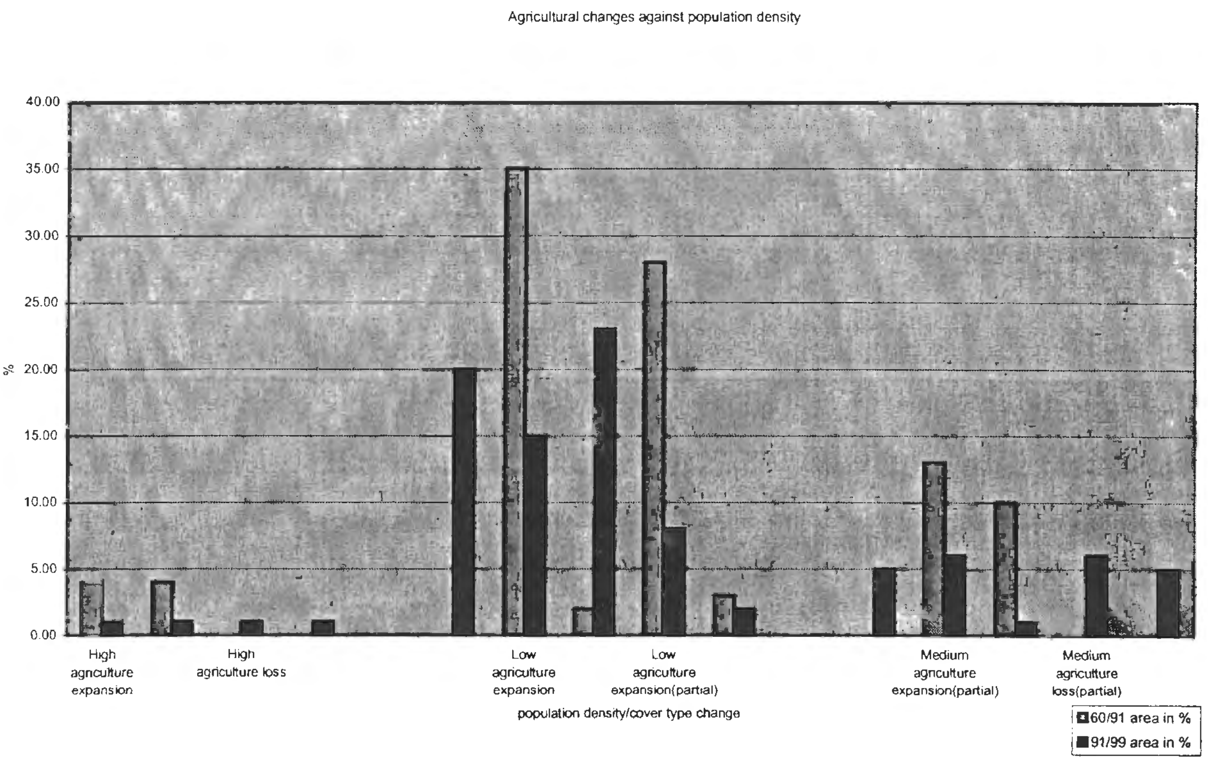
Table 8.16 Agricultural cover change against population density

	Cover change type	Population density	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**High**	921.45	1	3500.55	5
2	agriculture expansion	High	3685.8	4	700.11	1
3	agriculture expansion (partial)	High	3685.8	4	700.11	1
4	agriculture loss	High	0	0	700.11	1
5	agriculture loss (partial)	High	0	0	700.11	1
	sub total of cover changes		**7371.6**	**8**	**2800.44**	**4**
6	**no change**	**Low**	0	0	**14002.2**	**20**
7	agriculture expansion	Low	32250.75	35	10501.65	15
8	agriculture loss	Low	1842.9	2	16102.53	23
9	agriculture loss (partial)	Low	2764.35	3	5600.88	8
	agriculture expansion (partial0	Low	25800.6	28	1400.22	2
	sub total of cover changes		**62658.6**	**68**	**33605.28**	**48**
10	**no change**	**Medium**	**0**	**0**	**3500.55**	**5**
11	agriculture expansion (partial0	Medium	11978.85	13	4200.66	6
12	agriculture expansion	Medium	9214.5	10	700.11	1
13	agriculture loss (partial)	Medium	0	0	4200.66	6
14	agriculture loss	Medium	0	0	3500.55	5
	sub total of cover changes		**21193.35**	**23**	**12601.98**	**18**
	Total		**92145**	**100**	**70011**	**100**

8.5.3 Gully and bare land change patterns

In analyzing patterns of gully and bare land changes in the area, similar parameters as applied in other cover changes have been used but with the addition of a slope factor. Gully and bare land cover changes have occurred in medium rainfall areas, both in undulating and gently sloping plains, in flat and sloping areas. Statistical analysis of the relationship between gully change and the physical and socio-economic parameters during the 1960's/1991 could not be carried out because only one type of change (partial formation) occurred during this period. Similarly, the relationship between gully change and geology during 1991/1991 could not be analyzed because all gully change occurred in volcanic soils.

Figure 6.38 Agriculture cover changes against population density



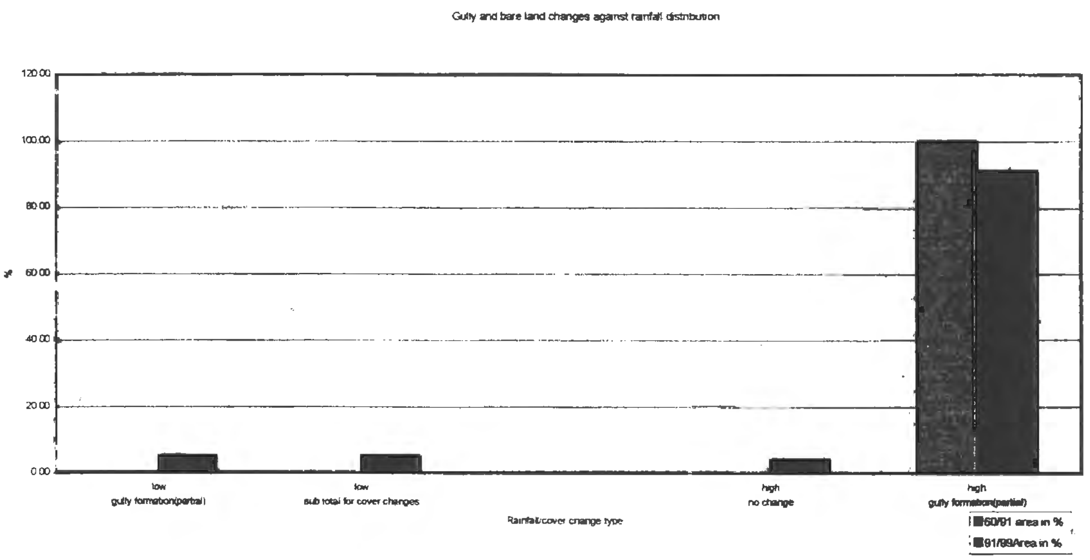
a) Changes in gully and bare land against rainfall distribution

Bare land and gully changes were confined to high rainfall areas for both periods of 60's/91 and 91/99. The former period, 100% of bare land and gully changes occurred in high rainfall areas. This changed to 91% in high rainfall areas and 5% in low rainfall areas during the 91/99 period. Based only on 1991/1999 gully changes the Chi-squared statistics showed statistical evidence for a relationship between gully cover change and rainfall distribution at the 95% confidence limit. Table 8.17 and Figure 8.39 show the bare land and gully changes in relation to rainfall distribution.

Table 8.17 Gully and bare land changes against rainfall distribution

	Cover change type	Rainfall	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	gully formation (partial)	low	0	0	600	5
	sub total for cover changes	**low**	**0**	**0**	**600**	**5**
2	no change	high	0	0	480	4
3	gully formation (partial)	high	496	100	1092	91
	Total for cover changes		**496**	**100**	**12000**	**91**

Figure 8.39 Gully and bare land changes against rainfall distribution



b) Changes in gully and bare land against relief

During the 60's/91 period, gully and bare land were confined to plains only. However, there was a change in the 91/99 period gully and bare land formation of which 7% also took place in mountains, 10% in footslopes and gully development in plains was reduced to 81% (Table 8.18 and figure 8.40). Again based only on the 1991/1999 gully changes statistical evidence for a relationship between gully formation and relief describe the relationship.

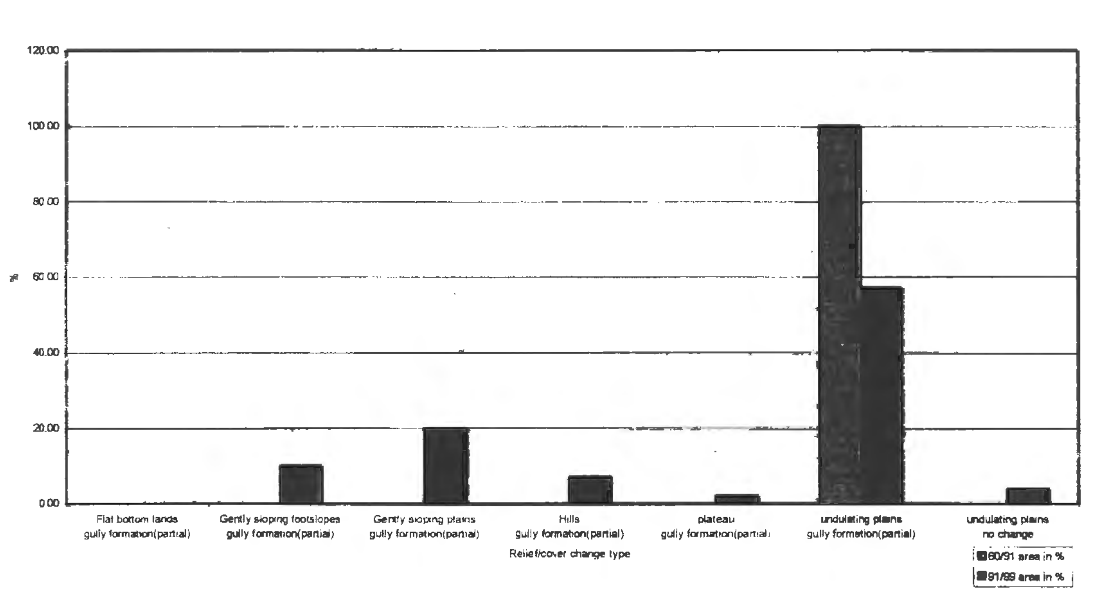
c) Changes in gully and bare land against slope

Using the digital elevation model, the area was divided into three general categories of slopes, viz. Flat, slope % < 2, sloping, slope % 2-7, very steep, slope % > 7. Gully and bare land cover changes have been occurring in both flat

Table 8.18 Gully and bare land changes against relief

	Cover change type	Relief	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	gully formation (partial	flat bottom lands	0	0	0	0
2	gully formation (partial	gently sloping footslopes	0	0	1200	10
3	gully formation (partial	gently sloping plains	0	0	2400	20
4	gully formation (partial	mountains	0	0	840	7
5	gully formation (partial	plateau	0	0	240	2
6	gully formation (partial	undulating plains	496	100	6845	57
7	no change	undulating plains	0	0	480	4
	Total				12005	100

Figure 8.40 Gully and bare land changes against relief

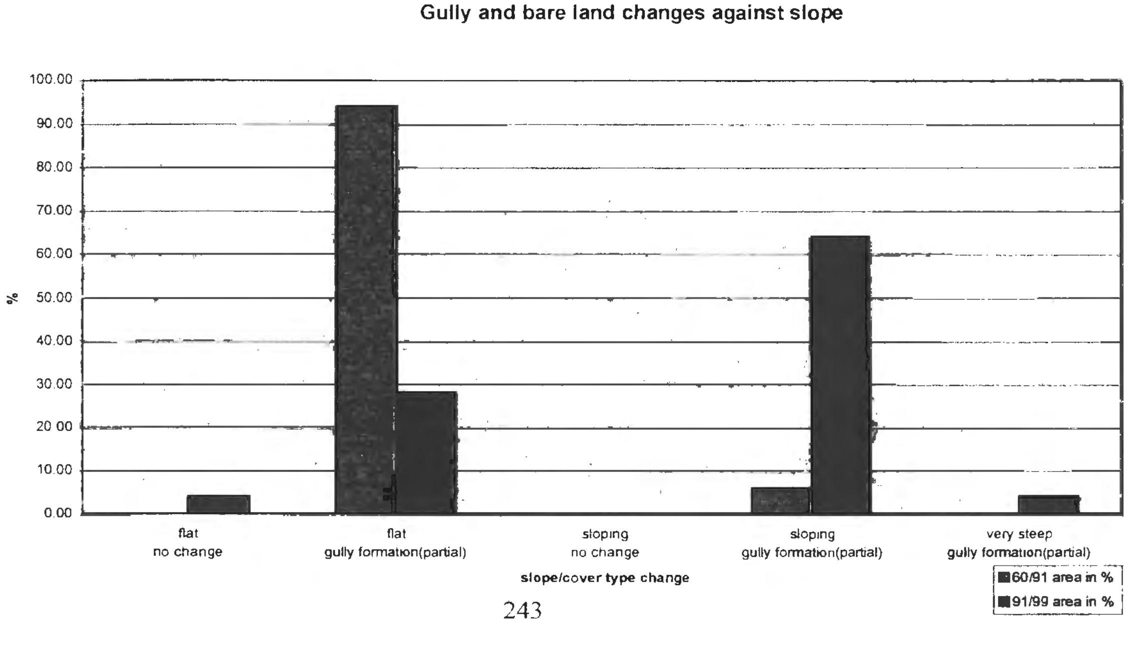


areas and sloping areas for the whole period, from the 1960's to 1999. However, the nature of change differed between the two periods of interest. Gully and bare land changes of 94% were more or less concentrated in flat lands in the 1960's /1991 period. The opposite happened in the 91/99 period, in which 64% gully and bare land changes occurred in sloping areas as compared to 28% in the flat areas (Table 8.22 and Figure 8.41). The Chi-squared statistics based only on 1991/1999 gully changes showed statistical evidence for a relationship between gully cover change and slope at the 95% confidence limit.

Table 8.22 Gully and bare land changes against slope

	Cover change type	Slope type	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**flat**	**0**	**0**	**480.36**	**4**
2	gully formation (partial)	flat	466.24	94	3362.52	28
3	no change	sloping	0	0	0	0
4	gully formation (partial)	sloping	29.76	6	7685.76	64
5	gully formation (partial)	very steep	0	0	480.36	4
	Total		**496**	**100**	**12009**	**100**

Figure 8.41 Gully and bare land changes against slope



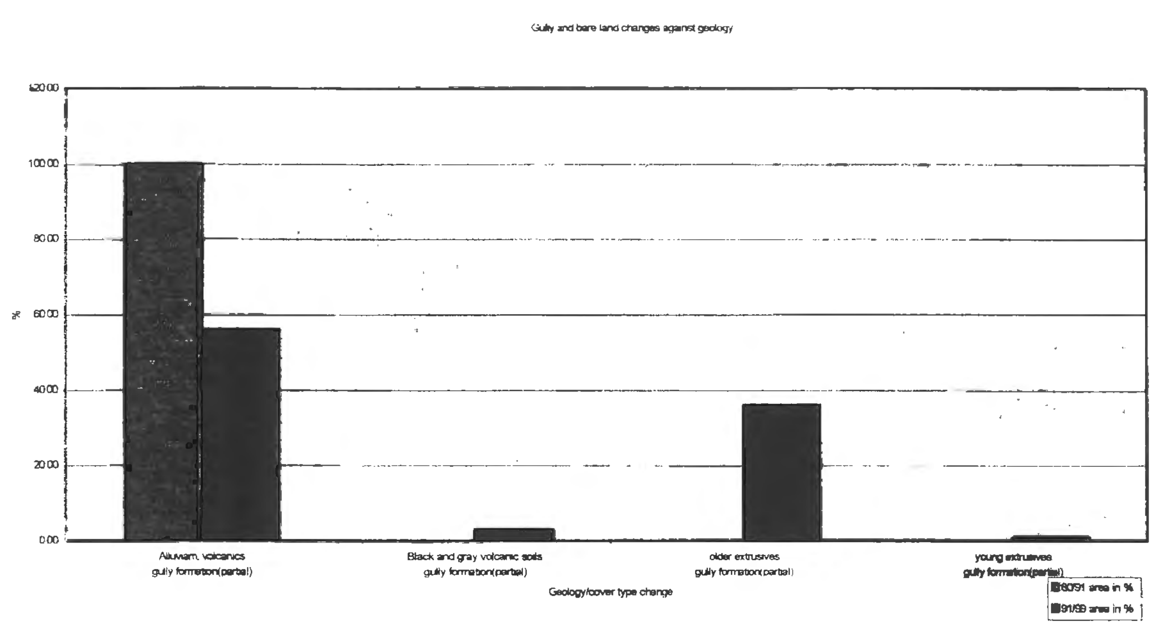
d) Changes in gulfy and bare land s against geology

Gully and bare land changes exclusively occurred in alluvial volcanics in the 60's/91 period. During 91/99 gully and bare land changes appeared in other geological units but were of volcanic origin. For example, 56% still appeared in alluviam volcanics, 36% in older extrusives and 3% in black and gray volcanic soils (Table 8.19 and Figure 8.42).

Table 8.19 Gully and bare land changes against geology

	cover type change	geology	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**Alluvium, volcanic**	0	0	480	**4**
2	gully formation (partial)	Alluvium, volcanic	496	100	6725	56
3	gully formation (partial)	Black and gray volcanic soils	0	0	360	3
4	gully formation (partial)	older extrusives	0	0	4323	36
5	gully formation (partial)	young extrusives	0	0	120	1
	Total		**496**	**100**	**12008**	**100**

Figure 8.42 Gully and bare land changes against geology



e) Changes in gully and bare land against population density

Gully and bare land changes have occurred in all three types of population density, even though the extent has varied between the two periods of interest. In the 60/91 period, more gullies were formed in high-density areas 55% followed by medium density areas of 35% and 10% in low -density areas. This scenario changed in the 91/99 period in which 80% of the gullies were formed in medium density areas. The Chi-squared statistics based only on 1991/1999 gully changes showed statistical evidence for a relationship between gully cover change and population density at the 95% confidence limit. Table 8.20 and Figure 8.43 show the details of gully and bare land cover changes in relation to population density.

Table 8.20 Gully and bare land changes against population density

	cover change type	Population density	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	no change	high	0		291.84	3
2	gully formation (partial)	high	272.8	55	778.24	8
3	no change	low	0	0	97.28	1
4	gully formation (partial)	low	49.6	10	680.96	7
5	no change	medium	0	0	97.28	1
6	gully formation (partial)	medium	173.6	35	7782.4	80
	Total		496	100	9728	100

f) Changes in gully and bare land against socio-economic activities

For both periods of 60'/91 and 91/99 gully and bare land changes have been occurring to a very large degree in agro-pastoral areas than in pastoral areas. Approximately 90% of partial gully formation in agro-pastoral areas occurred in each of the two periods of investigation (Table 8.21 and Figure 8.44). The Chi-squared statistics based only on 1991/1999 gully changes showed statistical evidence for a relationship between gully cover change and socio-economic activities at the 95% confidence limit.

Figure 8.43 Gully and bare land changes against population density

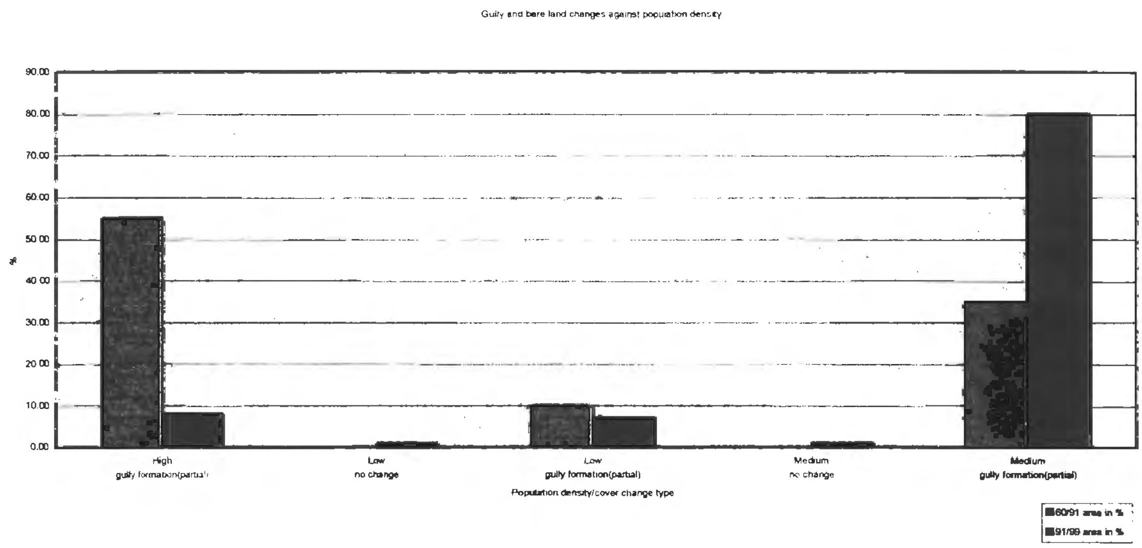
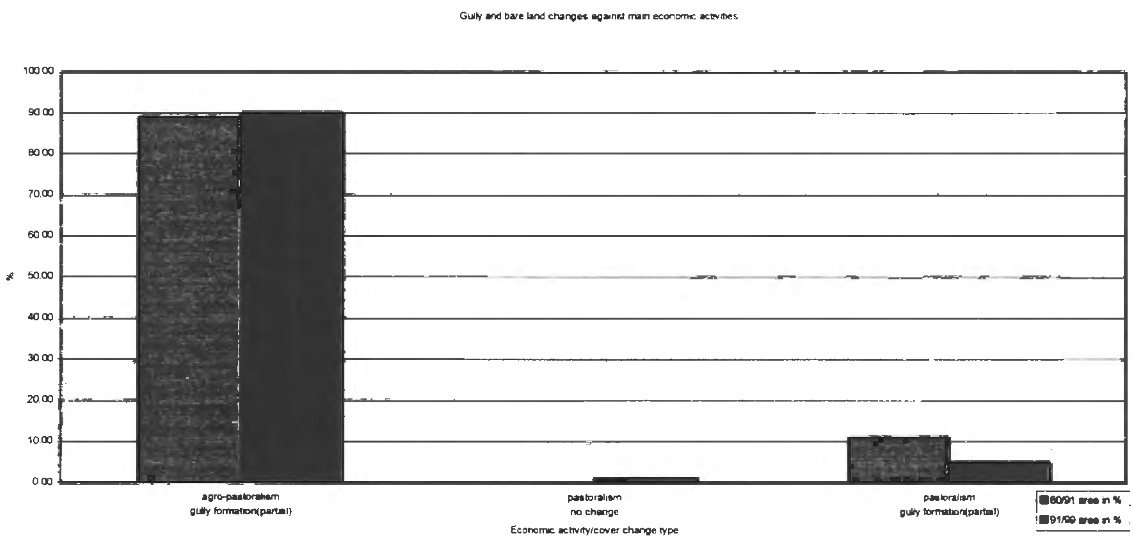


Table 8.21 Gully and bare land cover changes against socio-economic activities

	cover change type	socio-economic activity	60/91		91/99	
			No of pixels	Area in %	No of pixels	Area in %
1	**no change**	**agro-pastoralism**	**0**	**0**	**389.12**	**4**
2	gully formation (partial)	agro-pastoralism	441.44	89	8755.2	90
3	no change	pastoralism	**0**	0	**97.28**	1
4	gully formation (partial)	pastoralism	**54.56**	**11**	**486.4**	**5**
	Total		**496**	**100**	**9728**	**100**

Figure 8.44 Gully and bare land changes against socio-economic activities



8.6 Discussion

Semi-natural vegetation cover changes have occurred significantly in higher rainfall areas on volcanic and basement plateaus, in low density and agro-pastoral areas than in other locations. This could be due to a number of reasons, including differences in vegetation types found in low and higher rainfall areas. Higher rainfall areas have more woody vegetation i.e. 25% in the 1960,s, 15% in 1991 and 20% in 1999 compared to 9%, 4% and 13% in low rainfall areas for the same periods. As a result of these differences, changes in woody vegetation due to natural or anthropological causes are more easily detectable than changes in non-woody vegetation. In addition, the utilization of semi-natural vegetation in higher rainfall areas is much higher because higher rainfall and more diverse and rich semi-natural vegetation has attracted more human activities and wildlife due to higher productivity. The semi-natural vegetation changes are predominant on volcanic and basement plateaus and sedimentary bottom lands because these geomorphic units still have vast rangeland areas and unutilized privately owned lands. Furthermore, in these geomorphic units, changes in semi-natural vegetation are exacerbated by the presence of a number of settlements, such as Makuyuni, Mbuyuni, Mto wa Mbu engaged in agro-pastoral activities. The predominance of semi-natural vegetation changes in low population density areas is due to the fact that low density areas still have large areas of semi-natural vegetation that change annually or inter-annually due to rainfall variability. In addition, new agricultural activities are carried out in these areas because of availability of land. The changes in semi-natural vegetation are predominant in agro-pastoral areas because in agro-pastoral areas vegetation changes are due to both natural variability of semi–natural vegetation and human factors (especially agricultural activities), while in pastoral areas it is mainly due to natural variability only. There is a clear pattern that semi-natural vegetation cover types that lead to semi-natural vegetation depletion dominated in 60/91, and those that lead to the recovery of vegetation dominated in 91/99 due to differences in the amounts of rainfall between 1964, 1991 and 1999. The amount of rainfall in 1964 was higher than in 1991, therefore the vigour of vegetation in 1991 was less than in 1964, while, 1999 had higher amounts of rainfall than 1991, hence more vigour.

An analysis of patterns of agricultural changes shows that it has occurred predominantly in high rainfall areas, in volcanic and basement plateaus, in sedimentary lake terraces and in areas that have low population density. Further more, the pattern of agricultural changes shows that the period between the 1960's and 1991 was dominated by agricultural expansion and the 1991/1999 period was dominated by a loss of agricultural lands. Agricultural activities occur predominantly in higher rainfall areas because these areas are more suitable for agricultural activities due to greater moisture availability and productivity. These geomorphic units with higher levels of agricultural activities also have higher rainfall amounts so that a number of agro-pastoral settlements and large-scale farms are found in these units. There is a marked increase in agricultural land between the 1960's and 1991 because this is a period in which a new phase of agricultural activities, the development of both small and large-scale farms, commenced in the area. The 1991/1999 period is marked by a loss of agricultural land because of the timing of the 1999-satellite image at the end of the wet season and very high amounts of rainfall in that year. This entailed that in general only farms cultivated in that year could be identified as farms, since fallow agricultural lands tended to be covered by semi-natural vegetation. Consequently they were mapped as semi-natural vegetation. Gully and bare land changes have occurred in high rainfall areas of undulating or gently sloping plains or footslopes of volcanic origin. These areas are characterized by high and medium density settlements that are occupied by agro-pastoralists. Gully and bare land changes occur in higher-rainfall areas because the available moisture is adequate to initiate the processes of soil erosion in terms of detachment and transportation of soil particles. Gully and bare land changes occur in volcanic soils because they are highly erodible due to the high content of sodium salts found. The occurrence of gullies and bare land in high population density areas engaged in agro-pastoral activities is due to the high pressure put on the land by the removal of vegetation cover and the high intensity of land use (in terms of settlements, tracks and farms). These factors have accelerated soil erosion in the area.

Based on the analysis of patterns of landcover changes in the area, five key points can be identified as conforming to current literature on landcover changes in the drylands, *viz*.

- The establishment of the natural variability of semi-natural vegetation in the area due to inter-annual rainfall changes conforms with the notion of variability of semi-natural vegetation in drylands as advocated in the literature (UNSO, 1992; Behnke *et al*., 1993; Sullivan, 1996; Kuiper and Meadows, 2002).

- The demonstration that agricultural activities are on the increase in the area tallies with findings from other publications that in general agricultural activities are on the increase in the drylands (Kikula, 1991; Kiunsi, 1994; Mohamed, 1996).

- The findings that soil erosion in the area is more prominent in high density population and agro-pastoral areas supports the view that soil erosion is likely more to occur in areas practising both farming activities and livestock keeping than in pure pastoral areas (Gillman, 1930; Berry and Townshend, 1973)

- The fact that gullies and bare land are concentrated in soils derived from volcanic rocks that have a high content of sodium salts supports the notion that these soils are more prone to soil erosion (U.S. Salinity Laboratory Staff, 1954; Parker 1965, Heed, 1971; Rowell,1954).

- The finding that landcover changes in the area are much higher in areas practising agro-pastoralism than in pastoral areas supports the view that landcover changes in the drylands are due to both natural variability of semi-natural vegetation and human activities (Behnke *et al.*, 1993, UNEP, 1997).

9.9 Conclusion

The dominant landcover for the study area is different types of semi-natural vegetation, mainly grasslands and bushed grassland used as rangeland for both livestock and wildlife. However, there has been a significant landcover/use changes in the area, especially starting from the 1960's. The main cover changes include a reduction in semi-natural vegetation and an increase in agricultural lands, and in bare land and gullies. Landcover changes in the area are due to both rainfall variability changes and human factors. From the 1960's to 1999, two major types of cover changes were identified as occurring in different land units in the area. Land units that lost and recovered their semi-natural vegetation and land units that progressively lost their semi-natural vegetation. Inter-annual rainfall variability was the main contributing factor in land units that had reduction and recovery of semi-natural vegetation, while anthropological factors are largely associated with land units that progressively lost their semi-natural vegetation. A permanent loss of semi-natural vegetation has occurred in areas of high rainfall and settlements that are practising agro-pastoralism, while a minimum change in semi-natural vegetation has occurred in low rainfall areas where villages still predominantly practise pastoralism. Gully and bare land changes have occurred predominantly in volcanic soils under high population density and settlements that are practising agro-pastoralism. The following chapter will assess the land degradation in the study area based on the landcover changed identified in this chapter.

CHAPTER NINE

9. TOWARDS A NEW METHOD OF LAND DEGRADATION ASSESSMENT

9.1 Introduction

Given the described trends in landcover changes, it is now necessary to assess land degradation in the Monduli District by using data on cover changes generated in the last chapter. The overall aim of this research is to develop a new holistic land degradation assessment methodology that takes into account both soil and degradation vegetation and considers both natural, and anthropological factors as possible contributory variables to land degradation. Attempts to develop a holistic method for assessing land degradation have been constrained by two major factors, that is, the difficulties involved in separating natural and human induced vegetation changes and too much emphasis being put on the anthropological factors as the main causes of land degradation. As a result, traditional farmers and pastoralists in Tanzania and elsewhere are blamed for causing land degradation and in many cases without investigating the possible natural factors that might also contribute to land degradation. This research, therefore, has attempted to develop a methodology that can separate natural and human induced vegetation changes and can also take into account both anthropological and natural factors for land degradation. The concepts, definitions and varying opinions of land degradation have been presented in Chapter Two. As indicated earlier, the 1994 definition of land degradation as given in the Convention to Combat Desertification has been adopted for this research. This definition recognizes that soil vegetation and water regimes can all undergo degradation. Land degradation is taken to include both land degradation processes e.g. different forms of soil and vegetation degradation, and the end *result* of such processes, that is a reduction or loss in economic or biological productivity of land (Interim Secretariat, 1994). The development of the new land degradation assessment method is based on this definition. However, due to lack of data on reduction or loss in economic or biological productivity in the study area, land degradation assessment was carried out only with reference to physical and biological processes of land degradation processes.

The aim of this chapter is, firstly, to present the overall conceptual framework the method and the steps used in developing the methodology. Secondly, it presents and discusses land degradation assessment results in the Monduli District.

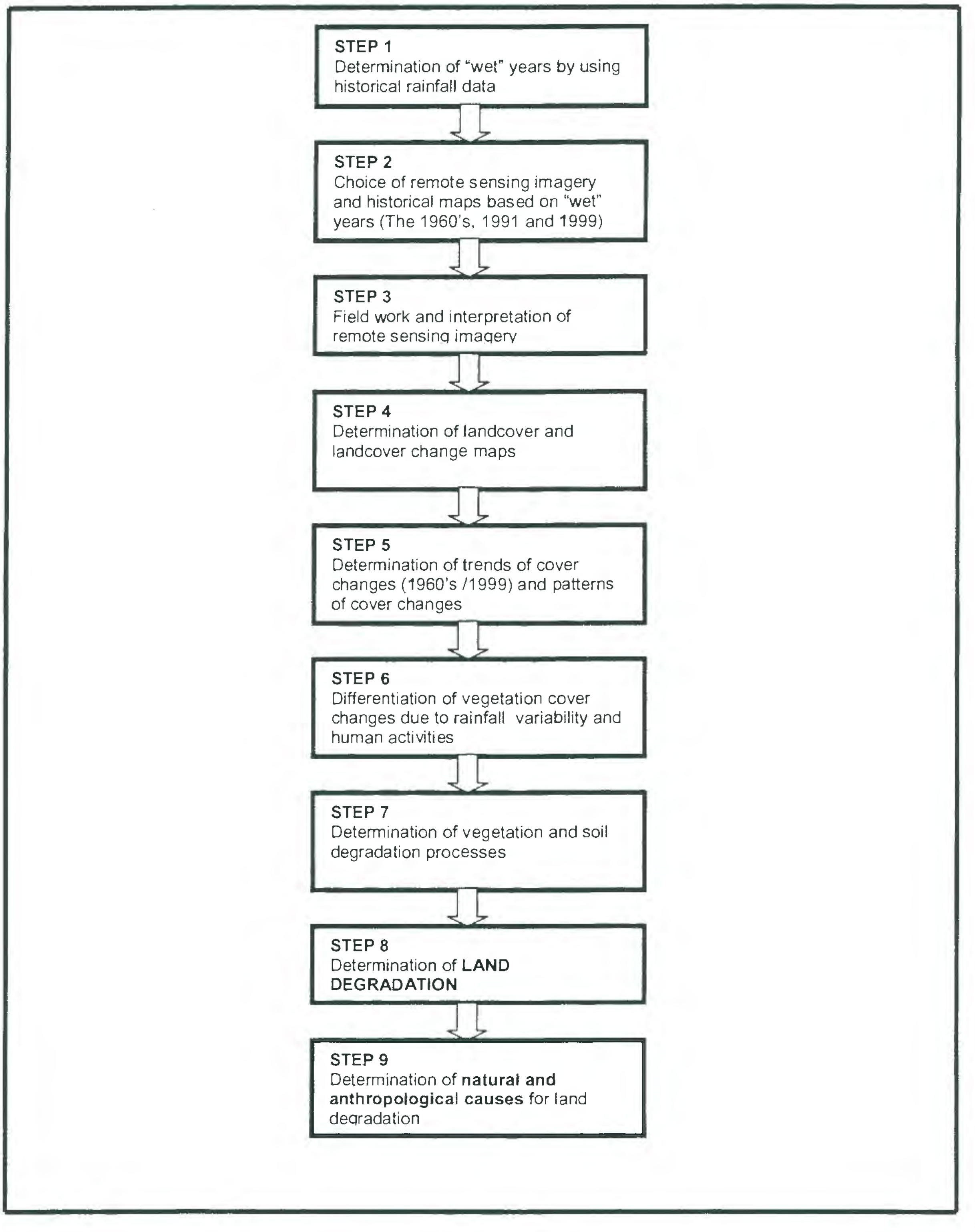
9.2. Conceptual framework for the method

The conceptual framework assumes a non-equilibrium model operates in the drylands. Therefore vegetation changes in the drylands are determined by both rainfall variability and anthropological factors. The new method for land degradation assessment is based on three principles. The first principle is that holistic land degradation assessment should take account both of soil and vegetation degradation. The difficult task of separating natural variability of vegetation from that which is human induced was overcome by using three "wet" years landcover maps. The logic behind using "wet" years was to reduce as much as possible the vegetation cover changes that might have occurred purely due to the differences in rainfall amount. The differentiation of vegetation variability due to natural and anthropological factors was attained by determining the trend of vegetation changes in the three landcover maps. Two types of vegetation trends were determined, namely areas that continuously lost vegetation from the 1960's to 1999 and areas that lost and recovered vegetation between the three years. Human activities, such as farming and settlements, were more apparent in areas that continuously lost vegetation, and therefore it can be said that the cover changes in these areas were due to human activities. Human activities were less apparent in areas that lost and regained vegetation, therefore it was assumed that vegetation cover changes in such areas were due to rainfall variability. The second principle is that land degradation may be assessed as a process and/or as an end result. Land degradation assessment in the study area was assessed as a process by taking into account vegetation and soil degradation processes. Areas that continuously lost vegetation from the 1960's to 1999 were considered as undergoing vegetation degradation processes. Similarly, areas that were subjected to water erosion or chemical deterioration were considered as undergoing soil degradation processes. The last principle is that both natural and anthropological factors should be considered as possible factors contributing to land degradation. This was achieved by taking account of both bio-physical and socio-economic factors such as geology, rainfall, presence of termites and the main economic activities. The development of the land degradation assessment method was accomplished through a number of steps starting with the determination of the wet years through to determination of land degradation. Figure 9.1 gives a summary of the steps followed in the development of this method.

9.2 Determination of semi-natural vegetation degradation processes

Semi-natural vegetation degradation, as previously discussed in Chapter Two, includes changes in the vegetation structure, a complete loss of vegetation, a change in plant species and biomass changes. Semi-natural vegetation changes in the area from the 1960's to 1999 have already been identified in Table 8.7 and Figure 8.29. Some of these semi-natural vegetation changes can be categorized as vegetation degradation. The main criterion used to make this categorization is the loss or decrease in vegetation without recovery, either between the 1960's

Figure 9.1 Steps followed in developing the assessment method



and 1991 or between1991 and 1999, despite high amounts of rainfall in 1991 and 1999. The following groups of semi-natural vegetation cover changes can be deemed to have undergone vegetation degradation. Group One includes those that did not change cover between the 60's/1991 but experienced a decrease in cover between 1991/99 (no change/decreased). Group Two includes those that experienced a decrease in vegetation cover both between the 60's/91 and 91/99 (decreased/decreased). Group Three includes those that experienced increased vegetation cover between the 60's/91 and a decrease in cover between 91/99 (increased/decreased), and Group Four had a decrease in vegetation cover between the 60's/91 and no change in cover between 91/99 (decreased/no change). However, two exceptions were made to the general criteria. Firstly, vegetation loss due to changes of water bodies specifically, Lake Manyara, was not considered as vegetation degradation because it was assumed that changes in water bodies were due purely to rainfall variability. This is a reasonable assumption and was made because no other data were collected that would have supported other factors (such as siltation) for changes in water bodies. Secondly, the category of increased/decreased land parcels that had improved vegetation structure in the 1960's/1991 but had structural reduction in 1991/1999 was not considered as vegetation degradation provided that the new structure was not at a lower level than the original one. For example, if the vegetation structure in the 1960's was bushed grassland, then between the 1960's/1991 it changed to bushed wooded grassland, then it reverted back to bushed grassland between 1991/1999, this was not considered as vegetation degradation because bushed grassland was the original structure in the 1960's. All other groups of vegetation cover changes had the following changes between 60/91 and 91/99: increased/increased, increased/no change, no change/increased, decreased/increased and no change/no change. These were not considered as vegetation degradation either because there was an improvement in vegetation in both periods or there was no change throughout the period. The four types of semi-natural vegetation changes deemed to be undergoing degradation processes have been regrouped into three types, that of vegetation loss, structure reduction and partial vegetation loss, as shown in Table 9.1 and Figure 9.2 and 9.3. About 117800 ha, or about 38% of semi-natural vegetation changes

Tables 9.1 Vegetation cover changes deemed as vegetation degradation

	Type of vegetation degradation process	Area (ha)	Area %
A	**vegetation loss(partial)**		
1	Vegetation loss(p)/vegetation loss (p)	1332	1.1
2	Structure reduction /vegetation loss (p)	2879	2.4
3	Structure improvement/ vegetation loss (p)	3965	3.4
4	Vegetation loss (p) / no change	3524	3.0
5	no change/vegetation loss(p)	6007	5.1
	sub total	**17707**	**15.0**
B	**structure reduction**		
6	Vegetation regeneration/structure reduction	350	0.3
7	Structure reduction(p)/no change	782	0.7
8	No change/structure reduction	1289	1.1
9	Structure improvement (p) / structure reduction	1679	1.4
10	Structure reduction (p)/ structure reduction	2107	1.8
11	Structure improvement / structure reduction	9274	7.9
12	Structure reduction (p) / structure reduction	13051	11.1
13	Structure reduction / no change	20250	17.2
	sub total	**48782**	**41.4**
C	**vegetation loss**		
14	vegetation regeneration/vegetation loss	161	0.1
15	structure reduction /vegetation loss	5910	5.0
16	structure improvement/ vegetation loss	6351	5.4
17	Vegetation loss (p) /vegetation loss	6673	5.7
18	No change / vegetation loss	6547	5.6
19	Vegetation loss/ no change	25658	21.8
	sub total	**51300**	**43.6**
	Overall total	**117789**	**100.0**

from the 1960's to 1999, equivalent to 29% of the total area, is subjected to semi-natural vegetation degradation processes. The main cover changes contributing to degradation are loss of semi-natural vegetation accounting for 44% and structure reduction, 41%, and partial semi-natural vegetation loss, 14%. It is important to note that, while no systematic data were collected on vegetation degradation using changes in species composition, the 1997 Monduli District Council Report points out that changes in species composition, especially in areas with a high concentration of livestock, such as cattle routes and around the Makuyuni settlement do occur. The report notes that there is a shift from common grass species, such as *Heteropogon, Hyparrhenia* and *Themeda spp.* to *Aristida* and *Sporobolus.* The district livestock and wildlife officers believe that

Figure 9.2 Semi-natural vegetation cover change types deemed as undergoing degradation

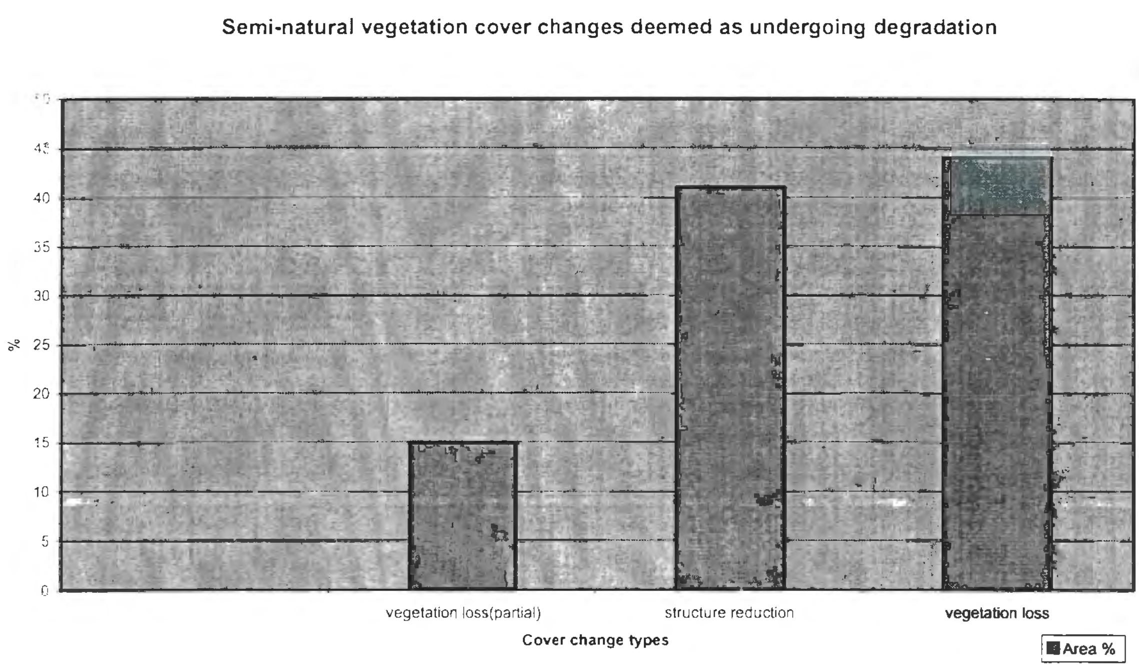
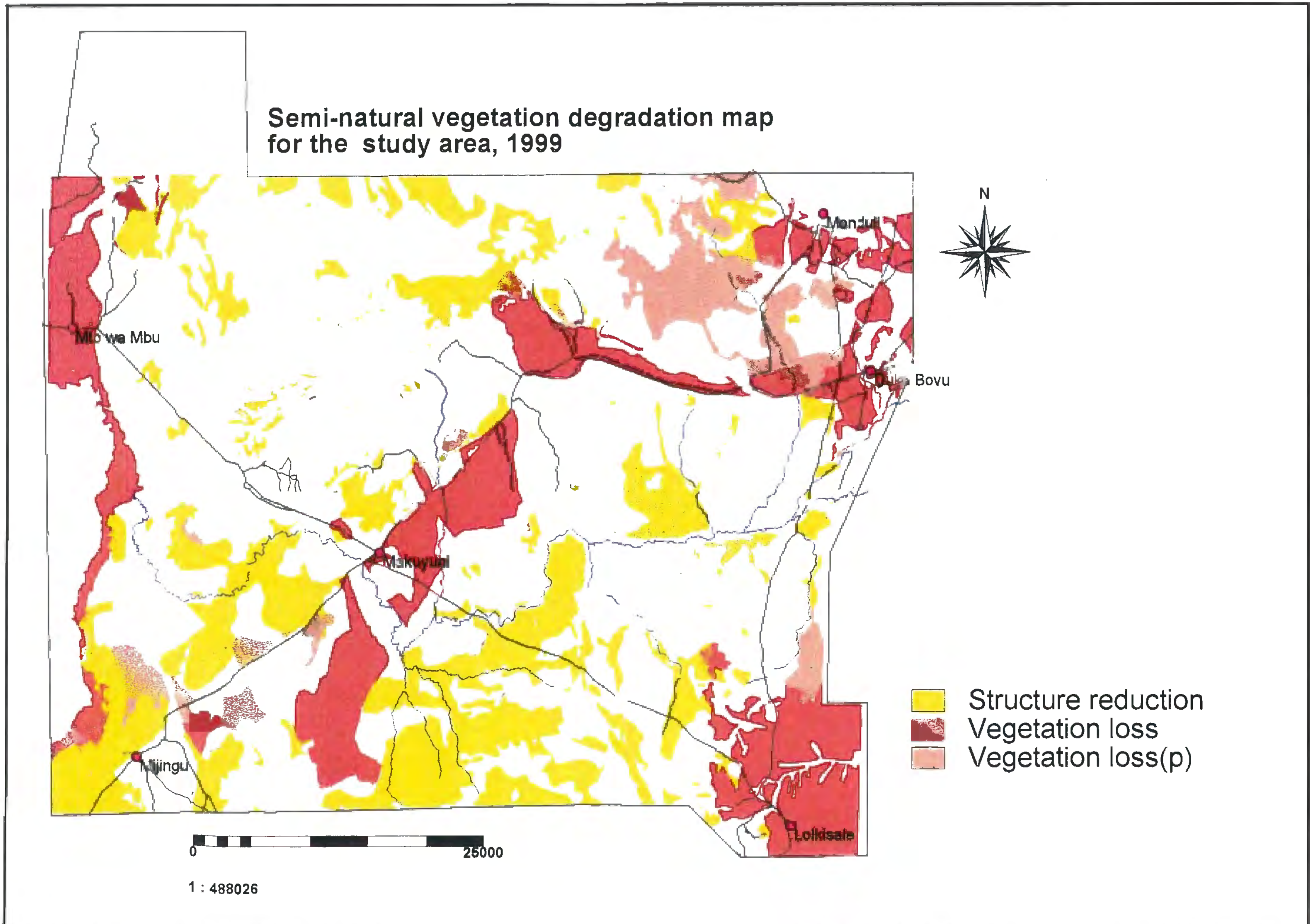


Figure 9.3 Semi-natural vegetation degradation map



there is an apparent general change in the composition of vegetation, not only due to the exploitation by communities in the area but also to the reduction in numbers and mobility of wildlife in the area.

9.3 Determination of soil degradation processes

Soil degradation, as discussed in Chapter Two, includes various types of soil erosion due to water and wind action, and various forms of soil deterioration. The assessment of soil degradation in the area is based on the results of this study, supplemented by results from other studies. The evidence of soil erosion is likely to be that of accelerated soil erosion since no soil erosion features could be identified from the early 1960's aerial photography. Therefore all observed soil erosion processes in the area are taken to be soil degradation. Soil degradation in the area is due to three main processes, *viz.* water erosion, both surface and sub-surface; soil deterioration, mainly chemical and physical; and wind erosion. About 18700 ha, or 5% of the area, is under various types of soil degradation. This figure does not include soil degradation due to wind and physical deterioration because of the lack of quantitative data. Surface and sub-surface soil degradation occur in the form of gullies, sheet erosion and piping found predominantly on the footslopes of the Monduli Mountain, Ardai plains, and accounts for 72% of the degraded soils. Chemical degradation, mainly sodicity (Table 6.4), which accounts for 28% of degraded soils, is found in Mto wa Mbu and the Selela villages and the Manyara lake terraces. Table 9.2 and Figure 9.4 show the main forms of soil degradation in the area. Other areas where gully sheet and rill erosion was found, but not mapped, are along the Arusha-Babati main road and around the Makuyuni settlement where sheet and rill erosion is active, even though no systematic data were collected for wind erosion and physical deterioration of soils. Wind erosion is a common problem not only on large-scale farms which do not have wind breaks but also in other areas that become bare during the dry season (MDC, 1997). Physical deterioration in the form of sealing and crusting is found on bare lands, while soil compaction is found in cattle and motor tracks and also on large-scale farms.

Table 9.2 Soil degradation

	Type of soil degradation	area (ha)	% of the area
1	sheet erosion and gullies	1557	8.3
2	gullies and fields	2432	13.0
3	gullies and grassland	2442	13.1
4	chemical deterioration	5244	28.0
5	gullies, fields and grassland	7023	37.6
	Total	**18698**	**100.0**

9.4 Land degradation assessment

The land degradation assessment was conducted by combining areas undergoing vegetation or soil degradation processes. A total of 116900 ha, i.e. 29% of the total area, was found to be subject to one or more of the three forms of land degradation processes. These are: combined vegetation and soil degradation, covering 8270 ha i.e. 7% of the degraded area, partial vegetation and soil degradation 8660 ha, 8%, and vegetation degradation, 99750 ha, 85%. Soil degradation on large-scale farms due to compaction was not included in these calculations because not enough data were collected to warrant mapping. Therefore the extent of land degradation in the area is probably an under-representation. The area subjected to land degradation due to combined semi-natural vegetation and soil degradation is equal in size to the areas under semi-natural vegetation degradation. This means that all areas subjected to soil degradation have also undergone semi-natural vegetation degradation, but not all areas under semi-natural vegetation degradation were subjected to soil degradation. Figure 9.5 shows the land degradation map based on vegetation and soil degradation processes.

Figure 9.4 Soil degradation map

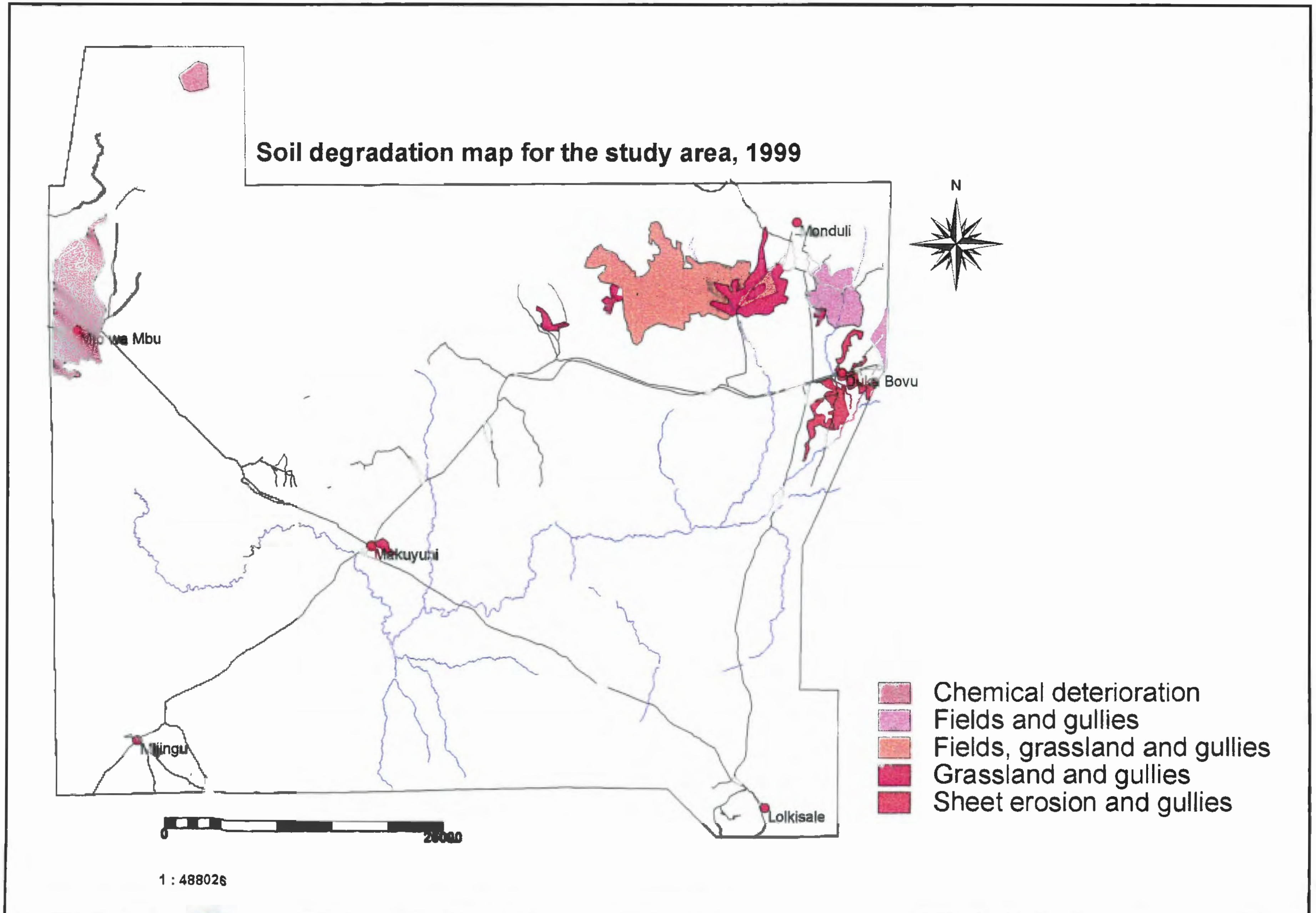
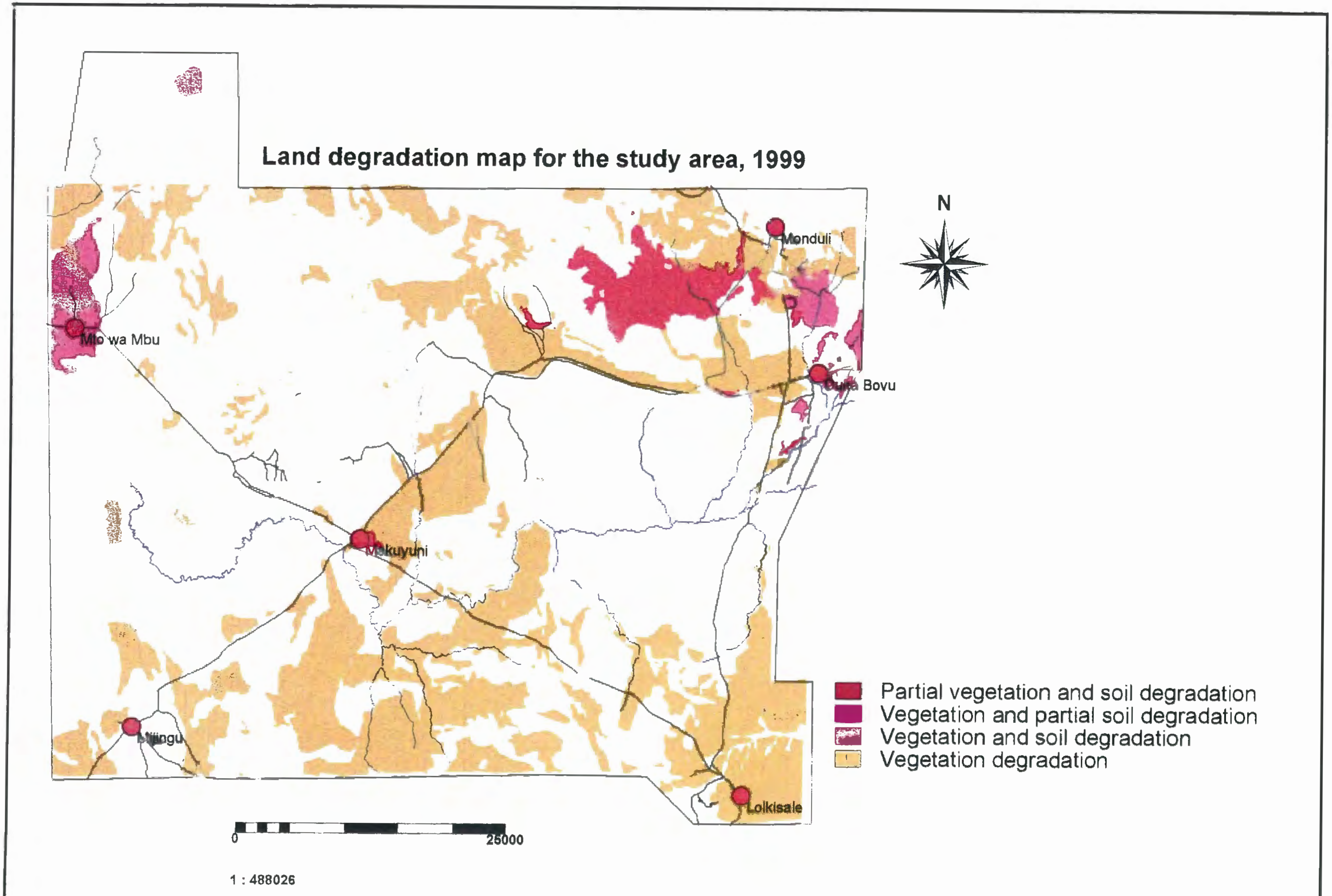


Figure 9.5 Land degradation map



9.5 Causes of land degradation

Having identified the extent of land degradation in the area by combining both vegetation and soil degradation processes, it is now time to analyze the possible factors contributing to land degradation. The development of land degradation in the study area may be attributed to both natural and anthropological factors. As discussed in Chapter Two, anthropological factors may be divided into direct and indirect. Direct factors include overgrazing, expansion of agricultural activities and fuelwood harvesting, while indirect factors may include population increase, development policies and poverty. Examples of natural factors that may enhance land degradation include rainfall variability, sodic soils, tectonic activities and the presence of grazing termites.

9.5.1 Anthropological factors

For simplicity, the anthropological factors leading to land degradation were placed in two main categories those leading to vegetation degradation and the those contributing to soil degradation. The possible **direct** factors that led to semi-natural vegetation degradation are increase in farming activities and fuelwood harvesting. Table 9.1 shows the two main types of vegetation degradation processes as being vegetation loss and reduction in vegetation structure. In Chapter Eight it was shown that vegetation loss from the 1960's to 199 was mainly through an increase in farming activities in different parts of the study area. Vegetation loss has occurred in all land units engaged in farming activities irrespective of other biophysical characteristics. This includes villages located in low or high rainfall areas, such as those found in Monduli footslopes and Ardai plains. Other examples include villages that are located in low rainfall areas such as Lolkisale, Makuyuni, Mbuyuni, Lepurko, Mswakini, Lendikinya, Lossimingori, Arkatani, and the Sinon-Ngarash villages that lost semi-natural vegetation primarily due to opening of small and large-scale farms. Vegetation degradation in other parts of Lolkisale, Makuyuni, Mbuyuni and the Lepurko villages is, however, mainly due to structural changes. The main reason for structural changes in these was associated with fallowing practice, when farms are left fallow or unused for some time, semi-natural vegetation recovers, although not to its original state. Partial loss of vegetation occurred mainly in Lendikinya, Meserani Juu, Lashaine villages and in some parts of state land also due to agricultural activities and the development of gullies and barelands. The second likely contributing factor was fuelwood harvesting by the villagers for domestic requirements within the proximity of these vegetated areas (Monduli District council, 1997). Charcoal making was common in the eighties and early nineties in the southern part of the study area. In the north, reduction of woody vegetation occurred because the former Lekeni ranch was located in the area in the eighties. Direct factors that may have contributed to soil erosion include the removal of semi-natural vegetation mainly due to the expansion of agricultural activities, construction of unlined water drainage channels in the main roads and the use of heavy machinery on large-scale farms which leads to soil compaction.

The possible **indirect** causes for land degradation include increase in population and government policies which has led to the loss of extensive areas of pastoral lands to private companies, individuals and the state. In Chapter Seven it was shown that the population in the district has increased from about 22,000 in 1948 to about 142,000 in 1995. The increase in population has certainly led to an increased pressure on land due to increased human activities and also change in land use activities. The land uses have changed from the purely pastoral system to agro-pastoralism. This had has a number of repercussions, including the reduction of mobility, the change of settlement from sparse to concentrated, and the change of size of boma from large to smaller. For example, the reallocation of villagers from state land to the slopes of Monduli Mountain in the mid-seventies led not only to an increase in the population but also to a change of landuse activities on the slopes. All these factors have led to the removal of semi-natural vegetation in the area due to increased agricultural activities and the creation of livestock or motor tracks, hence the increased probability of land degradation. This argument is supported by findings in Chapter Eight, which *show* that gully and bare land development occurred in both high and medium density areas and in agro-pastoral areas.

9.5.2 Natural causes

Soil degradation processes in the area were categorized into two major types, water erosion and chemical deterioration. The possible causes of water erosion which was sub-divided into surface and sub-surface soil degradation, include high erodibility of volcanic soils, presence of grazing termites in some locations and tectonic activities. The possible factors contributing to chemical deterioration include poor drainage and rocks with high sodium content.

a) High erodibility of volcanic soils

It has already been demonstrated in Chapter Eight that gully and bare land development had occurred in terrain units of volcanic origin. It was also shown in Chapter Six that volcanic rocks found in the area have high contents of sodium, which makes the derived soils vulnerable to gullying and piping. This argument was supported by results of soil samples taken from sites where most gullies are located in the Sinon-Ngarash, Lashaine and Emairete villages. Table 9.3 shows that all topsoils have electrical conductivity values (EC) of less than 4, exchangeable sodium percentages (ESP) above 15% and pH between8 <10. These results show that that soils in the three sites with gullies are sodic in accordance with the United States Department of Agriculture (1954) and Rowell (1994) (see Table.2.1)

Table 9.3 Results of soil sample analysis at three sites with gullies

Village name	Exchangeable base me/100g				ESP%	EC	pH ds/m
	Ca	Mg	K	Na			
Lashaine	50.53	5.85	3.118	3.118	63.3	2.0	9.5
Ngarash	12.56	3.91	1.533	1.93	19.93	0.6	7.78
Emairete	39.91	3.352	0.877	0.106	44.25	1.3	8.09

Source: Based on soil samples taken in June 2000

Based on field observations and discussions with villagers and local district staff, the following conclusions can be drawn on the nature and processes of soil erosion in the area. It appears that most of the gullies have been formed in high clay or silt clay content cracking soils, along cattle routes and motor tracks and in former water courses. It is also clear that the gullies were formed initially underground by pipe formation and result from the collapse of the pipes. This is due to the fact that, in locations of newly formed gullies, there are no indications of surface erosion in the immediate surrounding areas. Gullies seem to arise from nowhere; the earth simply caves in. Plate 9.1 shows a newly formed gully in the Lendikinya village in a former track. Note the intact herbaceous cover on the edges of the gully where there were no signs of surface erosion at all. In addition, pipes or holes created by sub-surface erosion can be seen in areas already undergoing soil erosion. Similarly, on the upper footslopes where there is thick vegetation of the protected forest on Monduli Mountain, one can suddenly fall through to an underground pipe after stepping on seemingly secure ground. It seems that sub-surface erosion is taking place even in the upper slopes covered by thick vegetation. However, the thick vegetation, including roots, protects the surface holding it together even when the sub-surface soil has been washed away. Therefore, the likely gully forming process taking place in the area is as follows:

During rainstorms, rainwater passes quickly to the sub-surface soil, especially in *tracks* where there is poor vegetation cover. The sub-surface flow is initiated by easily dispersing and transporting soil particles in sodic soils. In this way, sub-surface pipes are formed, but due to torrential seasonal rainfall the topsoils cave in, forming gullies. After the formation of gullies, surface soil erosion is initiated because of the creation of a steep hydraulic gradient (Brown 1962). This partly explains why older gullies are surrounded by barelands primarily due to surface erosion.

The soil erosion phenomenon occurring commonly in the area is well documented in the literature. Beckedahl (1998) investigated the sub-surface erosion phenomena in South Africa. Crouch (1976) discusses the necessary conditions for sub-surface erosion, which include seasonal rainfall, high summer temperatures, soil cracks, reduced vegetation cover and the existence of a hydraulic gradient within a dispersible soil layer. Kingsbury (1952), Parker (1965) and Imeson *et al.* (1982) elaborate on the importance of soil cracks on the formation of tunnels. The characteristic of sodium-rich soil and their role in the formation of sub-surface tunnels is well explained by Brown (1962), Heed (1971) and Crouch *et al.* (1986). Therefore, the likely factors for tunnel erosion in the area include the nature of the soils, which are rich in clay content, that swell when wet and shrink when dry, thereby forming cracks. Cracking soils allows the rapid entry of water in sub-surface soil and consequently promotes the sub-surface water flow (Gibbs, 1945). Sodic soils are prone to soil erosion because they are easily dispersible when exposed to free water (Brown, 1962; Heed, 1971). The decrease of vegetation cover due to increased farming activities and overgrazing makes the soils more vulnerable to erosion because of the lack of protective cover. This is especially acute in cattle and motor tracks where compaction of the topsoil by livestock or motorcars makes the soils even more vulnerable to erosion.

b) Presence of termites in some locations

Bare lands and gullies covering an area of about 1700 ha were found on the undulating plains around the Meserani Juu village. Based on field observations, discussions with the district officers and villagers and NEMC (1990') report, the area is bare due to both overgrazing and the presence of termites that forage mainly dry herbaceous material. The termites were collected and preliminary identified in the University of Dar es Salaam's, Zoology Department as belonging to *Termitidae* family. From observations and discussion with the local residents and district staff, it was found that the termites at Meserani Juu village are subterranean termites and come out to feed during dry seasons only, commencing in mid-June and proceeding to the end of February/March. During the dry season they collect all the food they need and store this in their galleries to be used in the wet season (Wood, 1978). They feed at night, early mornings and late evenings, when the temperatures are lower (Wood and Ohiagu, 1976; Wood, 1978). They feed on dry grass, including grass that cannot be grazed by livestock because it is unpalatable. Semi-circular bare patches can be observed in locations where termite grazing has occurred. These circular areas at times coalesce, to create continuous stretches of bare lands which can even be seen in the satellite imagery. The local residents in the area point out that termites are primarily responsible for the creation of barelands, due to the fact that they forage all the grass, leaving the land bare, and at times consume even the tussocks, which are responsible for the regrowth of herbaceous plants. The villagers furthermore argue that livestock normally leave remnants of vegetation, and do not graze land completely bare. Plate 9.1 shows an area currently being grazed by termites; the foreground shows an area already grazed, while the background shows an area not grazed by termites as yet. Plate 9.2 shows an area that has become completely bare and, according to the local residents, it is primarily due to grass-eating termites. The area is also subjected to surface erosion processes such as gully and sheet erosion and no semi-natural vegetation can grow in the area even during the rainy season. Grass-eating

Plate 9.1 Termite grazing area near Duka bovu

Plate 9.2 Bare land in the Meserani Juu village partly created by termites

termites are neither new nor confined to the study area. The reader is referred to Chapter Two in this regard.

c) High sodium content rocks and poor drainage

The high levels of sodicity in the irrigated lands of Mto wa Mbu is due to natural and human factors. The soils have higher levels partly because the parent volcanic rocks in the area and those deposited from uplands are rich in sodium as previously discussed in Chapter Six. Other natural factors that may enhance sodicity in the area are the low and flat topography and the semi-arid conditions. According to Szabolcs (1998) and Rengasamy (1998) topographical and rainfall conditions found in the Mto wa Mbu village can lead to primary salinization or alkalization. The poor irrigation methods including poor drainage channels as indicated in Chapter Three, further exacerbates the alkalinity in the area.

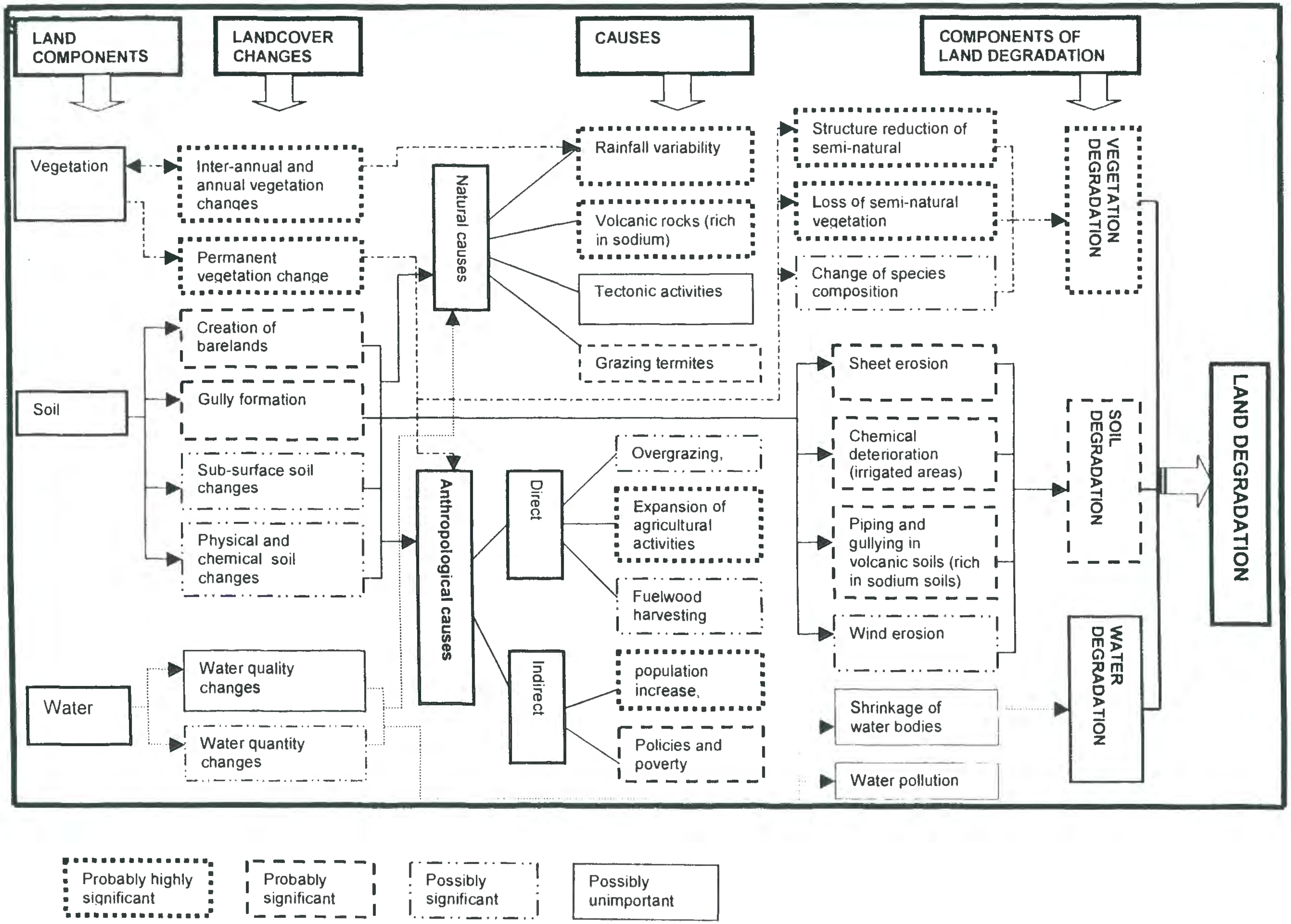
9.6 Discussion

The land degradation assessment method that has been applied in the study area has attempted to fulfill the basic elements required for holistic assessment of land degradation. Firstly, the method has made an attempt to separate vegetation changes due to natural variability from vegetation changes that can be termed as undergoing land degradation. A natural vegetation change due to rainfall variability is one of the key characteristics of drylands (UNSO, 1992; Barrow, 1995; Sullivan, 1996). One of the challenges facing land degradation assessment that has arisen due to natural variability of vegetation is the difficult in separating natural vegetation changes from the vegetation changes due to human activities (Agnew and Warren, 1996; UNEP, 1997; Dregne, 1998). The land degradation assessment method developed in this research has attempted to overcome this problem. Secondly, the method has assessed land degradation as per most currently acceptable definitions within the UN system (UNCCD, *1995*; UNEP, 1997). The current definition of land degradation within the UN system among other things takes into account both vegetation and soil degradation processes as components of land degradation. This new land degradation assessment method has managed to combine both vegetation and soil degradation processes. Thirdly, the method takes into account both anthropological and natural factors as possible causes of land degradation, which is one of the necessary requirements for comprehensive assessment of land degradation. The findings show that both natural and anthropological factors contribute to land degradation in the study area and accords with the causes cited in the literature as contributing to land degradation in drylands. Direct and indirect causes normally cited as contributing to land degradation in the literature and which were also found as factors in the study area include, change in land use, overgrazing, fuelwood harvesting, increase in population, government policies and international market forces (UNSO, 1992; Mainguet, 1994; Thomas and Middleton, 1994; Interim Secretariat, 1994). Natural factors cited in the literature as possible contributors of land degradation, which were also identified in the study area include, inherent soil erodiblity due to high sodium content in soil (Brown, 1962; Heed, 1971; Beckedahl, 1998) and the presence of grazing termites (Wood and Pearce, 1991, Wood, 1978). However it should be noted that termites generally are noted for their enhancement of soil properties (Lobry de Bruyn, *et. al.*, 1990) and not for land degradation.

9.7 Conclusion

A holistic land degradation assessment has been carried out in the study area by not only considering vegetation and soil degradation processes but also considering both natural and anthropological factors as contributors to land degradation. Figure 9.6 shows the model of land degradation in the study area. The model is divided into five main parts, land components, cover changes,

Figure 9.6 Model of land degradation for Monduli District



causes of cover changes, land degradation components and land degradation. The landcover components are taken as mere cover changes, which were observed or recorded in the area. They include inter-annual and permanent changes of vegetation, which led to the exposure of soils, gully development, and changes in soil sub-surface. The differentiation between inter-annual and permanent vegetation change was attained by the use of three sequential landcover maps synchronized against long term rainfall data. Other cover changes are changes in physical and chemical properties of soil and changes in water quality and quantity. Land cover changes were categorized into four groups: probably highly significant, probably significant, possibly significant and possibly unimportant based on quantitative data (Table 9.4). Landcover changes occurred extensively are marked probably highly significant while landcover changes that were likely to have occurred but there was not enough data to prove the change, are marked as "possibly significant". The identified landcover changes were then translated into vegetation and soil degradation processes. For example, permanent vegetation change was translated into vegetation structural reduction, complete loss of vegetation and changes in species composition. Soil cover changes were translated into soil degradation processes of sheet erosion, chemical deterioration, gullying and piping and wind erosion. Changes in water bodies were translated into shrinkage of water bodies. The land degradation processes are classified according to their significance using the same principles as in case of landcover changes. Both anthropological and natural factors were considered as possible causes for landcover changes and land degradation. Natural factors contributing to changes in the area are rainfall variability, volcanic rocks with high sodium content, tectonic activities and presence of grazing termites. While direct anthropological factors contributing to land degradation include overgrazing, expansion of agricultural activities and fuelwood harvesting. The indirect factors include population increase, government policies on land and poverty. Again the causes of land degradation were classified into four significance classes. However, the significance classes

Table 9.4 Landcover changes and land degradation significance classes

No	Landcover change	Area (ha)	Significance class	Land degradation	Area (ha)	Significance class
1	**Inter-annual**	247,046	Probably highly significant	**Loss of vegetation**	135496	Probably highly significant
2	**Permanent**	117789	Probably highly significant	**Vegetation structure reduction**	48782	Probably highly significant
3	**Gully and bare land**	13454	Probably significant	**Change of species composition**	No data	Possibly significant
4	**Chemical physical deterioration**	Incomplete data	Possibly significant	**Sheet erosion**	1557	Probably significant
5	**Sub-surface soil changes**	Incomplete data	Possibly significant	**Chemical deterioration**	5244	Probably significant
6				**Piping and gullying**	11897	Probably significant
7				**Wind erosion**	No data	Possibly significant
8				**Shrinkage of water bodies**	Incomplete data	Possibly unimportant
9				**Water pollution**	No data	Possibly unimportant

Source: Table 8.7, 9.1 and 9.2

were based on both statistical relationship derived from pattern analysis and spatial extent of each type of land degradation.

CHAPTER TEN

10. SYNTHESIS AND CONCLUSIONS

10.1 Introduction

Land degradation is a serious global issue, and a difficult problem to solve. It is associated with great complexities and it is especially important that be addressed in developing countries. Any efforts to do so are partly hampered by difficulties in correctly assessing the extent and causes of land degradation. Overall, these difficulties are brought about by different perceptions on the nature, causes and assessment of land degradation. Examples of the difficulties brought about by these varying perceptions are the different emphases put on semi-natural vegetation and soil degradation, and the varying assessment methods, for example those based on the land degradation process and those based on the end results of degradation. Efforts to overcome land degradation will be limited unless the extent and the driving forces of land degradation in local environments are understood so that appropriate mitigation measures can be identified and applied. This is more critical in developing countries where the judicious use of resources is more urgent. The overall aim of this thesis was to develop a new land degradation assessment methodology that takes into account both soil degradation and vegetation changes due to both anthropological activities and natural causes of land degradation. The specific objectives of the study included:

- Highlighting the general concepts of land degradation, causes and assessment methods in East Africa, and historical development of land degradation in Tanzania.

- Determining semi-natural vegetation cover changes and degradation in the study area whilst considering long term rainfall variability.

- Determining soil degradation in the area by taking into account soil erosion due to water and chemical deterioration of soils.

- Determining land degradation in the area based on land degradation processes of both semi-natural vegetation and soil.

- Identifying the main causes of land degradation in the area by taking into account both natural and historical socio-economic factors.

The research project, based on an assessment of land degradation in the Monduli study area, has highlighted some issues which hopefully can be used to improve methodologies used in addressing land degradation in Tanzania in particular and elsewhere. The following are the main findings of the research.

10.2 Land degradation; basic concepts, and assessment methods

Land degradation is a complex concept, but in a broader perspective it implies undesirable changes of land from productive to unproductive. The drylands environment in which land degradation is prevalent is marked by natural climatic variations of alternating wet and dry seasons, of drought, normal and wet years. There are continuously changing perceptions as to what constitutes land degradation, its causes, processes and manifestations. In general land degradation processes can be divided into two main categories; processes leading to the removal of the vegetation cover, and processes leading to soil degradation. Vegetation degradation can occur due to changes in the structure or species composition, while soil degradation can occur due to water or wind removing soil, and physical or chemical deterioration of soil. The determination of the causes of land degradation is fraught with difficulties due to the different perceptions of the problem as well as its complexity. It is generally agreed that land degradation is caused by multiple factors, both anthropological and natural. Anthropological factors may be divided into direct e.g. expansion of agricultural activities and fuelwood collection, and indirect factors such as population increase and government policies. Examples of natural factors that may lead to land degradation include climate variability, tectonic activities and inherent soil characteristics. The socio-economic consequences of land degradation may be categorized as on-site and off-site. The on-site effects include adverse change in crop yields, and examples of off-site effects include, siltation of water bodies and loss of agricultural lands. From the political ecological perspective, causes leading to land degradation can be linked to both external and internal socio-economic factors. In addition the current perceptions on land degradation and strategies for overcoming land degradation are to a large extent ideas and models borrowed from the developed world.

The methods for assessing land degradation may be divided into physical methods and social methods. Physical methods are used to assess climate, vegetation and soil, while social methods are used to assess factors contributing to land degradation. Examples of the methods which can be used to determine climate variability include aridity models and remote sensing. Vegetation degradation can be assessed by use of remote sensing and informed opinion, while soil degradation can be done through reconnaissance methods, runoff erosion plots, field experiments, estimation of suspended load, modeling, remote sensing and informed opinion. Each of the listed methods has its advantages and disadvantage in respect to land degradation.

10.3 Land degradation in Tanzania

Land degradation is not a recent problem in Tanzania, it has been recorded from the beginning of the 20th century. The regions regarded as most severely affected are Shinyanga, Arusha, Singida, Mara, Dodoma, Iringa, and some parts of Kilimanjaro, Tanga, Morogoro and Tabora. However, the type, extent, causes, remedies and perceptions of land degradation in Tanzania, as elsewhere, have been changing with time. The conventional terms used to express the idea of land degradation from the early 1900's up to late the 1970's were 'soil erosion' and 'overgrazing'. It is only after the late 1970's that the term land degradation was used in Tanzania. Both anthropological and natural factors have been cited as the main causes of land degradation, even though the emphasis as to the dominant cause of land degradation have been changing over time and from location to location. Over time, the solutions for combating land degradation include destocking, depopulation, and the construction of physical barriers to control soil erosion, afforestation, and awareness creation on land degradation among local people. However in recent years a great deal of emphasis has been put on structural changes, both in terms of institutions, policies and programmes dealing with land degradation.

10.4 Biophysical characteristics of the study area

The study area is a typical dryland located within the rift valley system and, except for the mountainous areas, the whole of the study area is classified as semi-arid. The area is characterized by a recurrence of droughts with an average rainfall of between 600 to 700mm/year. Volcanic rocks, covering mainly the mountains, part of the plateau and the undulating plains, dominate the geology of the area. Sedimentary and basement rocks are found in lake-terraces in the west and in and around the Lolkisale Mountain in the south. Depending on parent material and topographic conditions, soils found in the area vary considerably. Shallow to deep silty clays are found in footslopes of the volcanic mountains and undulating plains. These soils normally have a high sodium content derived from volcanic parent materials. Soils found on the sedimentary Manyara plains are shallow clay or silty clay soils, while in the southern part of the area, sandy clay loam and loam of moderate depth can be found. Grassland and bushed grasslands are the dominant semi-natural vegetation types found in all terrain units except in the mountains where open forests and dense bushland are found.

A comparison of biophysical characteristics of the study area to the rest of the drylands in the country is difficult to make due to the differences in methodology used to determine aridity in the study area compared to the rest of the country. The determination of drylands in Tanzania was carried out using long term mean rainfall data, while in the study area aridity zones were based on the aridity index derived by Woodshed's formula (Sombroek, *et al.*, 1992). It should be noted that the determination of aridity in the study area by the use of the Woodshed's formula does not fully comply with ideal methods of determining aridity by use of measured values of evapotransipiration. However, based on the long-term mean rainfall data, the study area is generally classified as belonging to a much drier zone than other drylands in Tanzania (NEMC, 1990). Consequently, based on biophysical data alone, it can be inferred that the area is likely to be more vulnerable to land degradation than other drylands due to the following reasons. Foremost, the fact that it belongs to a much drier rainfall regime means that the frequency of droughts may be higher than in drylands with relatively higher rainfall (Coppock, 1993). Secondly, the rate of soil erosion may be higher due to possible earth movements related to tectonic activity. Thirdly, the problem of alkalization/salinization in the area may be enhanced by aridity and topography (bottomlands) especially around Mto wa Mbu. Lastly, the presence of sodium in soils renders them more erodible. The biophysical characteristics of the area, if compared to the general literature on drylands, except for its location in a tectonically active area and the presence of soils rich in sodium salts, can be said to be that of a typical dryland.

10.5 Socio-economic dynamics of the area

The socio-economic dynamics of the area can be looked at from two perspectives, generally, covering the whole of the Maasai area, and specifically, covering only the study area itself. From a general perspective, the study area is part of a large Maasai area that once covered the southern and northern parts of Kenya and Tanzania respectively. The Maasai people are historically considered to be semi-nomadic pastoralists and warriors who had exclusively occupied Maasailand. The dryland conditions in the area caused the Maasai to develop an elaborate grazing system to cope with the differing availability of forage and water supplies due to annual and inter-annual rainfall variability. The mobility of livestock depended on the availability of forage, water and security. This was facilitated by strong leadership in each locality that determined resource use and planning, for example by allocating areas that could be used for grazing and watering in different seasons of the year. From an historical perspective, both human population and livestock numbers in Maasailand have been fluctuating markedly due to drought and disease.

However, in the case study area, socio-economic conditions started to change in the 1930's. These included population, economic activities, administrative structures and settlement patterns. There has been a steady increase in population and a change in population composition due to the migration of the non-Maasai people from surrounding areas and from other parts of the country. This has occurred, either because of population pressure in the surrounding areas or employment opportunities on large-scale farms found within the study area. Economic activities have changed from being mainly livestock keeping to agricultural activities. The latter has occurred because most of the immigrants are traditionally agro-pastoralists and also due to the establishment of large-scale farms. Slowly the Maasai people are becoming agro-pastoralists for a number of reasons, including being influenced by immigrants, a desire to own a piece of land permanently, and also because livestock can no longer meet the Maasai people's food requirements. Even though there are no hard data, it appears that there is a change in livestock, both in numbers and composition, coupled with an increase in the agricultural activities.

The contributing reasons given for changes in livestock include the reduction of grazing areas, a decrease in veterinary services and migration of livestock to regions with better rangelands. The increase of population and agro-pastoral activities have led to changes in settlement patterns, from semi-permanent to permanent, and to changes in boma sizes from large to smaller to facilitate land holdings and farming activities. Private ownership of land by individuals or the government has led to loss of grazing lands previously used by the Maasai people. The introduction of village governments in the area means that the natural resources in the localities are no longer exclusively controlled by traditional leaders. This, in some ways, has contributed to the erosion of the powers of traditional leaders who, for many years, played such an important role in the management of natural resources.

Changes in socio-economic activities are not confined to the study area, and they also occur in other rural areas in Tanzania and Kenya that were previously used by pastoralists only. However, the rate of change and its consequences may be considered as unique compared with other drylands in Tanzania for a number of reasons. Firstly, agro-pastoral activities in the area are relatively recent compared to other drylands in Tanzania that have been traditionally occupied by sedentary populations who practice both cultivation and livestock keeping. Therefore, in other places it is possible that sedentary communities, over time, have developed methodologies that combine livestock keeping and agricultural activities, which do not necessarily lead to environmental degradation. Secondly, the changes in the socio-economic factors, i.e. population and socio-economic activities may be accelerated due to the proximity of the study area to a high population pressure zone, the Arumeru District, and the opening of large-scale farms and irrigation activities at Mto wa Mbu. Thirdly, private ownership of large portions of the area has probably increased pressure on the remaining rangelands. Consequently, due its socio-economic background being pastoral and the rapid change in socio-economic factors, the study area is likely be more vulnerable to land degradation compared to other dryland areas in Tanzania. The socio-economic changes that are taking place in the study area concur well with the general literature on socio-economic changes in drylands. However, socio-economic changes in the area may represent an extreme case due to the fact that it is a change from one extreme economic system of pastoralism to another extreme economic system, that of agro-pastoralism and large scale farming. The study area also presents as an example of the influence of international markets on socio-economic changes at a local level as illustrated by seed beans farming on large-scale farms.

10.6 Landcover/use and landcover/use changes

Landcover types and their respective changes have been compiled and analyzed using three sets of sequential wet years landcover/use maps (the 1960's, 1991 and 1999) based on long term rainfall variability. Seasonality adjustment was made for the 1991 landcover map in order to be able to compare landcover changes based on the same season. The idea of using three sets of sequential landcover maps of wet years was to try to minimize semi-natural vegetation changes due to rainfall variability and to differentiate the areas undergoing semi-natural vegetation changes due to rainfall variability and due to anthropological factors. The results show that semi-natural vegetation was and is still the dominant cover type, even though its proportion has been declining in relation to agricultural lands, gully and bare lands and water bodies. Structural changes in semi-natural vegetation partly show a correlation to rainfall variability. This is evidenced by the domination of cover types that lead to a decline of semi-natural vegetation between 1964 (the "wetter" year) and 1991 (a less "wet" year). The opposite occurred between 1991 (a less "wet" year) and 1999 (a "wetter" year). Using the three sets of landcover maps, three types of semi-natural vegetation cover changes were identified as occurring in different land units in the area between the 1960's and 1999: land units which had overall loss or reduction of semi-natural vegetation between the 1960's and 1999, those that had loss/reduction and recovery and those in which there was no change. It is assumed that the overall loss of semi-natural vegetation is due to anthropological factors while loss and recovery in some land units is taken as the natural dynamics of vegetation due to rainfall variability.

The analysis of change patterns of semi-natural vegetation shows that cover changes predominantly took place in and around villages practising agro-pastoralism, or in areas with large scale or irrigation farms. Many of them are located on volcanic or sedimentary plateaus, bottomlands or lake-terraces of medium or low rainfall. Semi-natural vegetation changes in these areas have been attributed to both human activities, such as agriculture and fuelwood harvesting, and rainfall variability. Agricultural cover changes occurred to a large degree in villages with low population density that still had vast rangelands. It took place in plateaus, undulating plains or lake-terraces in high or low rainfall areas. Gully and bare land changes occurred in volcanic soils found on undulating or gently sloping plains, both in flat or sloping areas.

A direct comparison of the findings on landcover changes in the area with the rest of the country is complex, primarily due to the differences in the methodology used in determining these changes in the area and the rest of the country. The methodology used in the study area was based on the basic principle of identifying and separating landcover changes due to natural variability and anthropological factors. This was attained using three sets of "wet" years landcover maps which were identified by the use of long term rainfall records, whereas the determination of landcover changes in Tanzania is traditionally through two sets of landcover maps (Christiansson, 1973; NEMC, 1993; Shishira and Payton 1996; Eriksson, 1998). There is no evidence which suggests that the choice of the timing for the two sets of landcover maps used is based on long term rainfall variability and seasonality. In addition, the methodology applied in the study area also allows for the identification and differentiation between a number of cover change categories within a specific cover. For example, under semi-natural vegetation cover, the categories, which have been identified are vegetation loss/regeneration, and structural changes (increase/decrease), whereas in the methodologies used in Tanzania, no differentiation is made for the different categories within a specific cover change. For example, semi-natural cover changes are termed deforestation or overgrazing (Berry and Townshend, 1973; NEMC, 1990; Kikula, *et al.*, 1991). Notwithstanding the differences in output, the findings of the decline in semi-natural vegetation and the increase in agricultural lands concurs well with the general cover changes in the drylands of Tanzania (NEMC, 1990; Vice Presidents Office, 1990; Kiunsi, 1994). The driving forces for changes to combined pastoralism and agricultural activities and formation of permanent settlements in the study area are very similar to what has occurred elsewhere in Tanzania. Berry and Townshend (1973), MLNT (1989) and Kiunsi (1994) all cite the depletion of semi-natural vegetation in drylands of Tanzania as being due to both farming and livestock keeping activities. However, this study has added rainfall variability as an extra factor in semi-natural vegetation changes. It should be noted that the general literature on land degradation recognizes natural variability of semi-natural vegetation due to annual and inter-annual changes of rainfall. However, in Tanzania rainfall variability is not normally included as a factor when land degradation assessment is carried out. In addition, the findings of the research support the view that there is minimal permanent change of semi-natural vegetation in areas that are still predominantly used by pastoralists (Gillman, 1930).

10.7 The new method for land degradation assessment

The development of the new land degradation assessment method is based on three principles. Firstly, both soil and vegetation degradation have been taken into account. Secondly, land degradation area has been assessed using only soil and vegetation degradation processes. Thirdly, in determining the causes of land degradation in the area both anthropological and natural factors were taken into account. The developing of the method was carried out through a number of steps, starting with the selection of remote sensing imagery and historical maps synchronized against historical rainfall data. This was followed by preparation of three landcover maps based on the fieldwork and interpretation of imagery. Other steps included the determination of landcover changes and determination of trend of cover changes from the 1960's to 1999. The last three steps were determination of vegetation changes due to anthropological and rainfall variability, determination of vegetation and soil degradation processes, determination of land degradation and determination of causes of land degradation.

10.8 Land degradation

Land degradation assessment in the area was assesed using the new method. Based on this method areas that had overall loss/reduction of vegetation between the 1960's and 1999 were considered as being degraded i.e. 38% of the total semi-natural cover changes. All other land units, which lost and recovered their semi-natural vegetation, were not considered as being degraded. About 5% of the total area was mapped as experiencing various types of soil degradation: viz. gully, sheet erosion and the chemical deterioration of the soil. Other types that could not be mapped are wind erosion and soil compaction. Land degradation assessment based on combined semi-natural vegetation and soil degradation processes show about 29% of the study area as having undergone land degradation.

A direct comparison of land degradation in the area to the rest of the country is difficult because of the differences in the methodology used in assessing land degradation in the study area and those normally used in Tanzania. The fundamental difference is that, firstly, in the study area natural variability of vegetation due to rainfall changes was differentiated from vegetation changes due to human activities, while currently applied land degradation assessment methods in Tanzania do not differentiate between the two types of vegetation changes. Secondly, both semi-natural vegetation and soil degradation processes were considered in determining the extent of land degradation in the area. Land degradation assessment methods in Tanzania treat separately the processes of semi-natural and soil degradation (Rapp, *et al.*, 1973a; Kikula, 1996 and Yanda, 1996). Notwithstanding the differences in methodologies, in general the processes of land degradation occurring in the area with respect to both soil and semi-natural vegetation are similar to other drylands in Tanzania, such as the central regions or in the Sukumaland (Rapp *et al.*, 1973c; Kikula *et al.*, 1991; Kikula, 1996). However, some land degradation processes, such as piping and sodicity that occur in the study area are not normally mentioned in land degradation literature in Tanzania. The probable reason for this is that they have simply not been investigated. The general literature recognizes the different types of land degradation processes found in the area and the importance of combining the land degradation processes of semi-natural vegetation and soil and their end results. However, the stumbling block has been lack of methodologies that can separate semi-natural variability from natural variability and the different perceptions as to what real constitutes land degradation (vegetation and soils) held by different schools of thought (UNEP, 1997; Dregne, 1998).

10.9 Causes of land degradation

Land degradation in the study area is due to both direct and indirect anthropological and natural factors. The most significant direct anthropological factor is the expansion of agricultural activities, which is the leading cause for the reduction of semi-natural vegetation. Other direct factors include fuelwood harvesting and overgrazing which also, to some extent, contribute to a reduction in semi-natural vegetation. The most significant indirect anthropological factor is population increase due to both immigration and natural growth of the Maasai people. Population increase has led to a number of repercussions, for example, change in land use activities from purely pastoral to agro-pastoral, and a reduction in the mobility of the people in the area. The change of land use activities has led to a direct loss of semi-natural vegetation and hence a loss of grazing lands, while the reduction in mobility of the pastoral people can increase land degradation because of the loss of recovery time for natural resources, especially semi-natural vegetation. Other indirect anthropological causes include government development polices that have led to significant amount of rangeland area being turned into private large-scale farms or being used exclusively by government institutions. Private ownership and government acquisition of large pieces of land are partly responsible for the change in settlement patterns that have led to the concentration of settlements and their related activities in soil erosion prone areas, on volcanic footslopes and undulating plains. Other policy issues that may have contributed to the increase in land degradation in the area include the introduction of a local government system in the area in the form of village governments. Village governments may have contributed to the undermining of the powers of the Maasai traditional leaders, who in one way or the other contributed to the adherence of traditional livestock keeping systems. The most significant natural factor contributing to land degradation is the geology of the area which has volcanic rocks of a high sodium content that have contributed to gullying and piping. At Mto wa Mbu the alkalization and salinization is made worse by the presence of volcanic rocks of high sodium, aridity and lowland topography. Other natural factors that may have enhanced sheet erosion in some locations in the study area include the presence of termites that graze on grass, leaving the earth bare, thereby creating ideal conditions for other soil degradation processes to commence. The anthropological factors (population increase, change of settlement pattern, expansion of agricultural lands and fuelwood harvesting) for land degradation in the area are similar to elsewhere in the drylands in Tanzania (NEMC, 1990; Kikula, *et al.*, 1991; Shishira and Payton, 1996). The study also supports the view that land degradation in the drylands is enhanced when there is an interference in the traditional livestock keeping practices either through change in land use activities or administrative structures (Gillman, 1930; MDC, 1997). The literature on causes of land degradation in Tanzania supports the view that natural factors can contribute to land degradation. The commonly mentioned natural factors are drought, steep topography and tectonic activities (Christiansson, 1973; NEMC, 1990; Eriksson, 1996). High levels of sodium in soils and the presence of termites as contributing factors to land degradation are not mentioned as a factor in other drylands in Tanzania. Except for termites, the causes of land degradation in the study area are well reflected in the general literature of land degradation.

10.10 Limitations

In executing the research, a number of limitations were encountered right from data collection to the assessment of land degradation, *viz.:*

- Reliability of biophysical data, especially rain data is limited due to unequal distribution of rainfall stations. Rainfall stations are concentrated in areas of higher rainfall where agricultural activities are possible and very few rainfall stations are found in much drier areas where only pastoralism is practised. In addition, a number of stations have ceased to operate in recent years.

- The reliability of socio-economic data is limited because most of the data used covers a larger area than the study area. There is also a lack of updated and reliable data on population, livestock and agricultural production.

- The accuracy in compilation and interpretation of landcover and landcover changes may have been affected by the following limiting factors. Foremost, semi-natural vegetation cover analysis considers only the structural aspects and not plant species. Secondly, difficulties associated with the interpretation of structural classes from satellite images may have affected semi-natural vegetation types in the 1991 and 1999 maps. Thirdly, landcover and landcover changes might have been affected by the comparison of the composite map of the 1960's with the non-composite map of 1991 and 1999. Fourthly, there are difficulties in the identification of fallow agricultural lands in satellite images from semi-natural vegetated lands. Lastly, the use of satellite images of different seasons for 1991 and 1999 that necessitated making adjustments so that they appear as belonging to the same season might have led to an underestimation of bare lands for 1991.

- The non-inclusion of wind and the physical deterioration of the soils made the assessment less comprehensive even though its is known that they occur in the area.

- The statistical analysis which could have supported the arguments put forward for landcover change patterns was constrained due to limited socio-economic and rainfall data.

- The time lag between the 1960's, 1991 and 1999 may mask complex cover changes that could have occurred in between these periods. A shorter time interval may have given a more reliable landcover dynamics in the study area.

10.11 Implications of the findings

The findings of this research project can be used to improve land degradation assessment in the drylands of Tanzania, or elsewhere for that matter, as follows:

- In order to minimize the effects of semi-natural vegetation cover changes due to rainfall variability, a comparison of landcover changes should always be made between years of similar moisture regime, i.e. wet and wet years and not wet and dry years. Long term rainfall data can be used to determine wet years that can, in tum, be used for comparing landcover/use changes. The inclusion of long term rainfall variability in monitoring land cover changes should not be a very difficult task because long-term rainfall data are readily available from govemment meteorological departments. However, care should be taken that apart from comparing landcovers between wet years, it should also be the same season. This is due to the fact that in the drylands, to a large degree, herbaceous vegetation becomes dry during the dry season thus changing in colour from green to brown. As a result of this change in colour it becomes difficult to differentiate between grassland and bare land, especially when hard copy false colour imagery is used. Therefore, areas that are in reality grassland may appear as bare land if recorded during the dry season. The most suitable period for the comparison of land cover changes is the end of the wet season because it is much easier to differentiate vegetated areas from permanently non-vegetated areas. In situations where it is not possible to obtain satellite images of the same season, then necessary adjustments should be made so that outputs in the form of cover maps appear as if they are of the same season.

- To overcome the difficult task of separating semi-natural vegetation changes due to rainfall variability and anthropological factors, three sets, instead of two landcover maps, selected by using long term rainfall variability, should be used in determining land degradation. This again is a possibility which does not require great resources because of the availability of historical maps and different types of remote sensing images in Tanzania and elsewhere. The task of compiling and analyzing three sets of landcover maps can be made easier by the application of GIS.

- In order to assess land degradation as defined in the International Convention to Combat Desertification, land degradation assessment in Tanzania and elsewhere should include both processes and their end results. Land degradation processes can be extracted from landcover maps and their respective attribute data, while the end results can be obtained socio-economically in the form of land degradation indicators.

- Determination of the main causes of land degradation in different areas in Tanzania can be improved on by investigating both natural and human causes. The data sources already in existence can be used again, for example, natural factors, rainfall data and geological and soil maps, while for anthropological factors both historical and current socio-economic data can be used.

10.12 Conclusion

Based on the general aims and objectives of this project it can be concluded that:

1. Land degradation, which is an undesirable change of land from productive to unproductive due to natural or anthropological factors, is one of the most serious global environmental problems occurring in the world's drylands. Due to its complexity in that it encompasses both biophysical and socio-economic aspects of the environment, it is frequently associated with changes in opinions as to its definition, causes and assessment.

2. Land degradation has been recorded as occurring in Tanzania since the early 1900's in the drylands and mountainous areas. The terminology used to express land degradation in Tanzania, its causes, assessment and remedies, have changed with time. For example, in the early 1900's to 1960's, land degradation was known as soil erosion or overgrazing, in the 1970's to 1980's, it was deforestation, and in the 1990's, it was known as land degradation and included both semi-natural vegetation and soil degradation. The causes for land degradation have been identified as varying from overgrazing, to agricultural activities and fuelwood harvesting. A number of methods have been applied to assess land degradation in Tanzania, varying from erosion plot measurements and field observations to the use of remote sensing. The remedies applied to land degradation have varied from destocking, improved agricultural methods, afforestation, building of physical barriers to the control of soil erosion and the formulation of special institutions to deal with land degradation. Efforts to control degradation in Tanzania have been confronted by limitations such as the use of mean values in determining drylands, non-consideration of soil chemical deterioration, and a separate assessment of semi-natural vegetation and soil degradation processes. Socio-economic factors have also been underplayed.

3. The study area is typical of other drylands in the country in terms of aridity and socio-economic changes that are occurring in the area. However, it is probably more vulnerable than other drylands because of the volcanic soils that have a high sodium content.

4. Semi-natural vegetation changes in the study area have been determined in consideration with long term rainfall variability by using "wet" year satellite images for 1991 and 1999 and the 1960's composite map.

5. A new comprehensive land degradation assessment method has been developed and applied in the Monduli District. This method took into account both vegetation and soil degradation processes and considered both natural and anthropological factors as possible agents of land degradation.

6. In assessing landcover changes in the study area, annual and inter-annual rainfall variability was taken into account. This was attained by first adjusting the 1991-cover map to appear as the same season for 1999, and using three sets of sequential cover maps. This facilitated in separating cover changes due to rainfall variability and anthropological factors. It was established that natural variability of vegetation followed by permanent vegetation changes were the most significant cover changes.

7. Soil degradation mapping was confined to water erosion and chemical deterioration due to the fact that these two parameters could easily be recorded from satellite images and field checking, or through field measurements. Other types of soil degradation, which are equally important in the study area but could not be measured, are wind erosion and physical soil deterioration.

8. Land degradation assessment in the study area was determined by using degradation processes of semi-natural vegetation and soil in which about

29% of the area was deemed as degraded. The results showed that vegetation degradation due to structural changes and vegetation loss was the dominant land degradation type

9. Both anthropological and natural factors were determined as contributing to land degradation in the area. The significant natural factors contributing to land degradation include high erodibility soils of high sodium content, while the significant direct anthropological factors are increase in agricultural activities. The significant Indirect anthropological factors include population increase and government development policies, which in turn has led to changes in landuse activities, loss of authority of the traditional Maasai elders and changes in settlement patterns and boma sizes.

10.13 Future directions

1. The study area was located in a tectonically active area. More studies should be conducted to establish the influence of tectonic activities, especially with reference to block tilting and the erodibility of soils deposited on fault scarps. The relationship between block tilting and a higher rate of soil erosion has been established in other block-tilted areas in Tanzania.

2. In the study area termites have been identified as contributing to land degradation. More research can be undertaken to identify the species and environmental conditions, especially overgrazing and climate, that lead to termites becoming a menace to the environment. There is a perception among Monduli District Natural Officers that termites only become a menace when overgrazing occurs in low rainfall areas.

3. More research can be undertaken to establish the appropriate timing of satellite images to be used for land degradation assessment to capture semi-

natural vegetation, agricultural lands and bareland and gullies. In this research project there has been some limitation purely because of the timing of the imagery. For example, the 1999 imagery at the end of the wet season captured semi-natural vegetation and bareland and gullies but could not capture farms that were not cultivated that year because they were masked by vegetation due to high amounts of rainfall. Meanwhile, the 1991 dry season imagery captured all agricultural lands, but it was difficult to differentiate between bare land and dry grassland.

4. The research project used three sets of landcover maps, one composite and two from satellite images, to differentiate landcover changes due to anthropological and natural factors. The validity of this methodology can be tested and improved by using more than three sets of TM or SPOT satellite images all based on the same season. The natural variability of semi-natural vegetation can further be confirmed by the use of NOAA/AVHRR satellite images.

REFERENCES:

Abel, N and Stocking, M. (1987) A rapid method for assessing rates of soil erosion from rangelands: an example from Botswana. *Journal of Range Management*, **40(5):** 460-466.

Abrol, I. P., Yadav, J. S. P. and Massoud, F. I. (1988) Salt affected soils and their management. FAO *Soils Bulletin* **39**.

Adams, W. M. and Mortimore, M. J. (1997) Agricultural intensification and flexibility in the Nigerian Sahel. *The Geographical Joumal*, 163: 150-160.

Agnew, C. and Andrew, W. (1996) A framework for tackling drought and land degradation. *Joumal of Arid Environments* **33**: 309 – 320.

Allison, F. E. (1973) *Soil organic matter and its role in crop pro*duction. Elsevier, New York.

Aronoff, S. (1989) *Geographic information systems: a management perception.* WDL Publications, Ottawa.

Arnon, I (1981) *Modemizing agriculture in developing countries: resources, potentials and problems.* John Wiley, Chichester.

Backeus, I., Rulangaranga, Z. K. and Skoglund, J. (1996) The dynamic interrelationship between vegetation and environment on the formerly eroded Kondoa hills. In: Christiansson, C. and. Kikula, I (Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania*, **Report No 13**, Regional Soil Conservation Unit, SIDA, Nairobi, 54-63

Baker, B. H., Mohr, P. and Williams, L. A. J. (1972) Geology of eastem rift system of Africa. *Geological Society America,* special paper 136.

Balling, R. C. (1991) Impact of desertification on regional and global warming. *Bulletin of American Meteorological Society* **72**: 232-34.

Barbier, E. B., and Bishop, J. J. (1995) Economic values and incentives affecting soil and water conservation in Developing countries. *Journal of Soil and Water Conservation* **50**: 133-137.

Barret, E. C and Hamilton M .G. (1986) Potentialities and problems of the satellite remote sensing with special reference to arid and semi-arid regions. *Climatic Change* **9**: 167 - 186.

Barrow, C. J. (1991) *Land degradation: development and breakdown of terrestrial environments.* Cambridge University Press, Cambridge.

Barow, C. J. (1995) *Developing the environment; problems and management.* Longman Scientific and Technical, Harlow.

Beard, J. S. (1973) The physiognomic approach. In: Whittaker, R. H. (Ed) *Ordination and classification of communities.* Dr. W. Junk b.v, The Hague, 355-386.

Beckedahl, H. R. (1998) *Subsurface soil erosion phenomena in South Africa.* Unpublished Ph.D. thesis. University of Natal, Department of Geography.

Behnke, R. J. and Scoones, I. (1993) Rethinking range ecology: implications for rangeland management in Africa. In: Behnke, R. J., Scoones, I. and Kerven, C. (Eds) *Range ecology at disequilibrium. New models of natural variability and pastoral adaptations in African savannas.* Overseas Development Institute, London, 1-30.

Berry, E. M. (1990) Soil catena development on fault scarps of different ages, eastern escarpment of the Sierra Nevada, California. *Geomorphology* **3**: 333-350.

Berry, I. and Townshend, J. (1973) Soil conservation policies in semi -arid regions of Tanzania, a historical perspective. In: Rapp, A., Berry, L. and Temple, P.H. (Eds), *Studies of soil erosion and sedimentation in Tanzania*, BRALUP Research **Monograph 1**, University of Dar es Salaam, 241-253.

Biot, Y. (1990) The use of tree mounds as benchmarks of previous land surface in a semi-arid tree savanna, Botswana. In Thornes, J. B. (Ed), *Vegetation and erosion.* John Wiley, New York, 437-450.

Blaikie, P. and Brookfield, H. (1987a) Defining and debating the problem. In: Blaikie, P. and Brookfield, H (Eds) *Land degradation and society.* Routledge, London.

Blaikie, P. and Brookfield, H. (1987b) Approaches to the study of land degradation. In: Blaikie, P. and Brookfield, H (Eds) *Land degradation and society.* Routledge, London

Blaikie, P. and Brookfield, H. (1987c) Decision making in land management. In: Blaikie, P. and Brookfield, H (Eds) *Land degradation and society.* Routledge, London

Blaikie, P. and Brookfield, H. (1987d) Colonialism, development and degradation. In: Blaikie, P. and Brookfield, H (Eds) *Land degradation and society.* Routledge, London

Blaikie, P.(2000) Development, post-, anti- and populist: a critical review. *Environmental Planning*, A **32**: 1033-1050.,

Braun, R. (1990) Environmental impact assessment of Mto wa Mbu irrigation and flood control project. A document prepared for the Environmental, Energy and Human Settlements (PID/E), International Labor Office (ILO), United Nations.

Breman, H. and de Wit, C.T. (1983) Rangeland productivity and exploitation in the Sahel. *Sience* **221**: 1341-1347.

Brown, G. W. (1962) Piping erosion in Colorado. *Journal of Soil Water and Conservation* **7**: 220 –222.

Bryant, R. L and Bailey, S. (1997) *Third World political ecology.* Routledge, London

Bryant, R. L. and Wilson, G. A. (1998) Rethinking of political ecology. *Progress in Human Geography* **22**: 321-343.

Bureau of Statistics (1991) Population census; regional profile. Presidents Office, Planning Commission, Dar es Salaam.

Burrough, P. A. (1997) Geo-information needs: effects of scale. *ITC Journal* **3/4**: 235-236.

Charney, J. G. (1975) Dynamics of deserts and drought in Sahel. *Quarterly Journal of the Royal Meteorological Society* **101**: 193-202.

Chen, Z., Christopher, D. E. and David P. G. (1998) Vegetation change detection using high spectral resolution vegetation indices. In: Lunetta, R. S. and Elvidge, C. D. (Eds), Remote *sensing change detection: environmental monitoring methods and applications.* Ann Arbor Press, Michigan, 137-161.

Christiansson, C. (1973) Notes on morphology and soil erosion in Kondoa and Singida district. In: Rapp, A., Berry, L and Temple, P.H. (Eds), *Studies of soil erosion and sedimentation in Tanzania,* BRALUP Research **Monograph 1** University of Dar es salaam, 319-324.

Christiansson, C. (1996) Linking landscapes and societies: Glimpses from on-going studies in "Man-land interrelations" Research Program. In: Christiansson, C. and Kikula, I. (Eds). *Changing Environments: research on man-land interrelations in semi -arid Tanzania,* Report No 13, Regional Soil Conservation Unit, SIDA, Nairobi, 4-6.

Cierniewski, J. and Courault, D. (1993) Bi-directional reflectance of bare soil surfaces in the visible and near-infrared range. *Remote Sensing Review* **7**: 321-339.

Cliffe, L. (1964) *Nationalism and the reaction to agriculture improvement in Tanganyika during enforced colonial period.* Makerere University, Kampala (Mimeo).

Coaton, W. G. H. (1954) Veld reclamation and harvester termite control. *Farming in Southem Africa* **29**: 243 – 248.

Colacicco, D. T., Osborn, T. and Alt, K. (1989) Economic damage from soil erosion. *Journal of Soil and WaterConservation* **44**: 35-39.

Collins, N. M. (1982) The interaction and impact of domestic stock and termites in a Kenyan rangeland. In: Breed, M. D., Michener, C. D, and Evans, H. E (Eds). *Biology of social insects.* Westemview Press, Boulder, Colorado, 80-84.

Cooke, R. U and Reeves, R. W. (1976) Arroyos and environmental change in the America southwest. Oxford University Press, Oxford.

Cooke, H. J. (1983) The struggle environmental degradation – Botswana's experience. *Desertification Control Bulletin* **8**:9-15.

Coppock, D. L. (1993) Vegetation and pastoral dynamics in the Southern Ethiopian rangelands: implications for theory and management. In: Behnke, R. J., Scoones, I. and Kerven, C. (Eds) *Range ecology at disequilibrium. New models of natural variability and pastoral adaptations in African savannas.* Overseas Development Institute, London, 42-61

Cowling, R. M. (2000) Challenges to the 'new' rangeland science. *Trends in Ecology and Evolution* **3**: 303-304.

Cracknell, A. P. (1994) Remote sensing and the determination of geophysical parameters for input to Global models. In: Foody, G. and Curran, P. (Eds) *Environmental remote sensing from Regional to Global scales.* John Wiley, 167-180.

Crouch, R. J. (1976) Field tunnel erosion- a review. *Journal of soil conservation New South Wales* **32**: 98-111

Crouch, R. J., McGarity, J. W. and Storrier, R. R. (1986) Tunnel formation processes in the Riverina area of New South Wales, Australia. *Earth Surface Processes and Landforms* **11**: 157-168.

Curan, P. J. (1985) *Principles of remote sensing.* Longman Scientific, London.

Darkoh, B. K. (1996) Environmental problems in Kenyan arid and semi-arid lands. In: Eden, M. J. and Parry, J. T. (Eds) *Land degradation in the tropics, environmental and policy issues.* The Commonwealth Foundation, London, 126-143.

Darkoh, M. B. K. (1987) Review, Combating desertification in the arid and semi arid lands of Tanzania. *Journal of Arid Environments* **12**: 87-99.

Dawson, J. B. (1964) Carbonatic volcanic ashes in northern Tanganyika. *Bullettin of Volcanology* **T 27**: 81-92.

Dawson, J.B. and Pickering, R. (1964) Monduli; Quarter degree sheet No. 54. Ministry of industry, Mineral Resources and Power, Dar es Salaam.

Decker, R. and Decker, B., (1998) *Volcanoes.* Third edition. W.H. Freeman and Company, New York.

Dejene, A., Shishira, E. K, Yanda, P.Z. and Johnsen, F. H (1997) *Land degradation in Tanzania: perception from the village.* World Bank Technical paper No 370, Washington.

Dietz, T (1999) Political environmental geography of the tropics. *Development* **76**: 179-188.

Division of Environment (1998) A background document for the National Action Program to Combat Desertification in Tanzania. A second draft, Vice President's Office, Dar es Salaam.

Division of Environment (n.d.) Project on the preparation of the National Action Program to Combat Desertification. An outline paper. Ministry of Natural Resources and Tourism, Dar es Salaam.

Dixey, F. (1946) Erosion and tectonics in the East African Rift System. *Geological Society of London Quarterly Journal* **102**: 339-338.

Dregne, H. E. (1986) Desertification of arid lands. In: El-baz F. and Hassan M. H. A. (Eds) *Physics of desertification.* Dordrecht, Nijhoff.

Dregne, H. E. (1989) Informed opinion: filling the soil erosion data gap. *Journal of Soil and Water Conservation* **44:** 303-305

Dregne, H. E. (1989) Erosion and soil productivity in Africa. *Journal of Soil and Water Conservation*, **44:** 33-305.

Dregne, H. E. (1998) Desertification assessment In: Lal, R., Blum, W. H., Valentine, C. and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press, New York, 441-458

Dymond, J. R. B'egue, A. and Loseen, D. (2001) Monitoring land at regional and national scales and the role of remote sensing. *International Journal of Applied Earth observation and Geoinformation* **3/2**: 162-175.

Eden, M. J. (1996) Land degradation: environmental, social and policy issues. In: Eden, M. J. and Parry, J. T. (Eds) *Land degradation in the tropics: environmental and policy issues.* The Commonwealth Foundation, London, 3-18.

Ellis, J. E., Coughenour, B. M. and Swift, D. M. (1993) Climate variability, ecosystem stability and the implications for range and livestock development. In: Behnke, R. J., Scoones, I. and Kerven, C. (Eds) *Range ecology at disequilibrium. New models of natural variability and pastoral adaptations in African savannas.* Overseas Development Institute, London, 31-41

Elwell, H. A. and Stocking, M. A. (1982) Developing a simple yet practical method of soil estimation. *Tropical Agriculture*, 59: 43-48.

Eriksson, M.G. (1996) Effects of tectonic activity on landform evolution in Kondoa Irangi hills, Central Tanzania. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi-arid Tanzania* **Report No 13**. Regional Soil Conservation Unit, SIDA, Nairobi, 23-31.

Eriksson, M.G. (1998) *Landscape and soil erosion history in Central Tanzania: a study based on lacustrine, colluvial and alluvial deposits.* Ph.D. dissertation No. 12. The Department of Physical Geography, Stockholm University, Sweden

Evans, R. (1980) Mechanisms of water erosion and their spatial and temporal controls: an empirical viewpoint. In: Kirkby, M, J. and Morgan, R. P. C. (Eds) *Soil erosion.* John Wiley, Chichester, 109-128.

FAO (1979) *Provisional methodology for soil degradation assessment.* FAO, Rome.

Foody, G. M. and Curran, P. J. (1994) Scale and environmental remote sensing. In: Foody, G. and Curran, P. (Eds) *Environmental remote sensing from Regional to Global scales.* John Wiley, 223-232.

Fosbrooke, H. A. (1948) An administration survey of the Masai social system. *Tanganyika Notes and Records* **26**: 1-50, Nairobi.

Fosbrooke, H. A. (1956) The Masai age groups system as guide to tribal chronology. *African Studies* **15 (4)**: 188-206.

Gelens, H. F. (ND) Introduction to soil science. Unpublished teaching resource manual. ITC, Netherlands.

Gibbs, H. S. (1945) Tunnel-gully erosion on the Wither Hills, Marlborough. *New Zealand Journal of Science and Technology* **27 (2)** 135 –145.

Gibson, P. J. (2000) *Introductory remote sensing: principles and concepts.* Routledge, London.

Gillman, C. (1930) Notes on soil erosion in East Africa. Gillman papers, Hans Cory collection, University of Dar es Salaam.

Glantz, M. H. , Orlovsky, N. S. (1983) Desertification: A review of the concept. *Desertification Control Bulletin*, **9**: 15-22.

Goudie, A. S. (1990) *Techniques for desert reclamation.* John Wiley, Chichester.

Government of the Republic of Kenya, UNEP and Royal Netherlands Government (1997) *National land degradation assessment and mapping of Kenya.* U.N., Nairobi.

Grainger, A. (1990) *The threatening desert.* Earthscan Publications Ltd., London.

Gray, L. C. (1999) Is Land being degraded?. A multi-scale investigation of landscape change in southwestern Burkina Faso. *Land degradation and Development* **10**: 329-343.

Groundwater Survey (1994) Village water sources assessment of Monduli District. Monduli District Development Program. Arusha Region

Gulliver, P. H. (1969) The conservative commitment in northern Tanzania, the Arusha and Masai. In Gulliver, P. H. (Ed) *Tradition and transition in East Africa.* Routledge and Kegan Paul, London, 223 –242.

Hakansson, I. and Voorhees, W. B. (1998) In: Lal, R., Blum, W. H., Valentine, C., and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press, New York, 167-178

Hamblin, W. K. (1985) *The earth's dynamic systems. A textbook in physical geology.* Fifth edition. Collier Macmillan Publishers, London.

Hanan, N. P., Prevost, Y., Diouf, A. and Diallo, O. (1991) Assessment of desertification around deep wells in the Sahel, using satellite imagery. *Journal of Applied Ecology* **28**: 173-186.

Harris, D. R. (1980) Tropical savanna environments, definition, distribution, diversity and development. In Harris, D. R. (Ed). *Human ecology in savanna environments.* Academic Press, London, 3-30.

Heed B. H. (1971) Characteristics and processes of soil piping in gullies. *Forest Service Research Paper* **Rm-68**.

Hudson, N. W. (1993) *Field measurements of soil erosion and runoff.* FAO, Rome

Hoffman, T. and Ashwell, A. (2001) *Nature divided: land degradation in South Africa.* University of Cape Town Press, Cape Town.

Holy', M (1980) *Erosion and environment.* Pergamon Press, Oxford

Hulme, M. and Kelly, M. (1993) Exploring the links between desertification and climate change. *Environment* **35**: 5-11 and 39-45.

Ibrahim, F. N. (1997) The current status of knowledge and actual usage of medical plants among the Maasai, of Naberera, Northern Tanzania in Ibrahim, F., Ndalanga, D., and Ruppert, H. (Eds). *Coping with resource scarcity, case studies from Tanzania and Sudan.* Naturwissenschaftliche Gesellschaft Bayreuth e.V.

Illius, A. W. and O'Connor, T. G. (1999) On the relevance of nonequilibrium concepts to arid and semi-arid grazing systems. *Ecological Applications* **9**: 798-813.

ILO (1982) *Basic needs in danger, a basic needs oriented development strategy for Tanzania.* International Labour Office Jobs, Skills Programme for Africa, Addis Ababa.

Imeson, A. C., Kwaad, F. J. P. M. and Verstraten, J.M. (1982) The relationship of soil physical and chemical properties to the development of badlands in Morocco. In: Bryan, R. and Yair, A. (Eds). *Badland geomorphology and piping,* Geo books, Norwich 47-70.

Interim Secretariat (1994) *United Nations Convention to Control Desertification.* Interim Secretariat, Geneva.

IPCC (Intergovernmental Panel on Climate Change) **(1990)** *Climate change: the IPCC scientific assessment.* Cambridge University Press, Cambridge.

Iranga, M. D. (1991) Seismicity of Tanzania: distribution in time, space, magnitude, and strain release, *Tectonophysics* **209**: 313-320.

Jenks, C. (1977) *Historical consideration of environmental dynamics in the Identification of dryland degradation in the Northern Damaraland.* Unpublished Mphil thesis. University of Cape Town, South Africa.

Johnson, D. L. and Lewis, L. A. (1995) *Land degradation: creation and destruction.* Blackwell, Oxford.

Jones, H. (1964) Makuyuni; Quarter degree sheet No 70. Ministry of Water, Energy and Minerals, Dar es Salaam.

Kaale, B. K. (1982) Afforestation for energy supply and charcoal production in Tanzania. A country paper prepared for the Commonwealth Science Council/Africa Energy Programme/IDRC Workshop on wood-charcoal production and utilization, Nairobi.

Kaale, B. K. (1983) Tanzania five year National village afforestation plan, 1982/83 – 1986/87. Ministry of Natural Resources and Tourism, Dar es Salaam.

Kassas, M. (1987) Drought and desertification. *Land Use Policy* **4(4)**: 389-400.

Kassas, M. (1995) Desertification: a general review. *Journal of Arid Environments* **30**: 115-128.

Kikula, I. S. (1996) Perspectives of the research programme on man-land interrelations in semi-arid Tanzania. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania*, Report No 13, Regional Soil Conservation Unit, SIDA, Nairobi, 1-3.

Kikula, I. S., Shishira, E. K and Maganga, F. P (1991) Development in land degradation in Sukumaland. Institute of Resource Assessment Research Paper **No 30.**

Kingsbury, J. W. (1952) Pothole erosion on the western part of Mlokai Island, Territory of Hawaii. *Journal of Soil and Water Conservation* **7**: 197-198

Kirkby, M., J. (1980) The problem. In: Kirkby, M, J. and Morgan, R., P., C. (Eds) *Soil erosion*, John Wiley, Chichester, 1-16.

Kirby, J., O'Keefe, P. O. and Howorth, C. (2001) Introduction: rethinking environment and development in Africa and Asia. Land Degradation and Development, **12**: 195-203.

Kiunsi, R. (1984) *Woodland management policies in villages in Tanzania.* Unpublished M.A. thesis. Institute of Planning Studies, Nottingham University, U.K.

Kiunsi, R. (1993) *Landcover changes in Longido Game Controlled area and their possible effects on the functioning of the Amboseli Biosphere Reserve.* Unpublished MSc thesis. International Institute for Aerospace Survey and Earth Sciences (ITC), Netherlands.

Kiunsi, R. (1994) *Vegetation loss in rural settlements: Causes and the remedies, with examples from Tanzania.* Dar es Salaam University Press, Dar es Salaam.

Khogali, M. M. (1983) The grazing resources of Sudan. In: Bee, O. J. (Ed) *Natural resources in tropical countries.* Singapore University Press, Singapore, 389-398.

Kuchler, A. W. and Zonneveld, I.S. (1988) Floristic analysis of vegetation. In: Kuchler, A., W. and Zonneveld, I., S. (Eds). *Vegetation mapping,* Kluwer Academic Press, London, 51-66.

Kuchler, A., W. (1988a) Physiognomic and structure analysis of vegetation. In: Kuchler, A. W. and Zonneveld, I. S. (Eds). *Vegetation mapping.* Kluwer Academic Press, London, 37-50

Kuchler, A., W. (1988b) Classification of vegetation. In: Kuchler, A. W. and Zonneveld, I. S. (Eds) *Vegetation mapping.* Kluwer Academic Press, London.

Kuiper, S. M. and Meadows, M. E (2002) Sustainability of livestock farming in the communal lands of southern Namibia. *Land degradation and Development* **13**: 1-15.

Lal, R and Elliot, W. (1994) Erodibility and erosivity: In: Lal, R. (Ed) *Soil erosion, research methods.* Soil and Water Conservation Society, Ankeny, 181-210.

Lal, R. (1988) Soil degradation and future of agriculture in sub-Sahara Africa. *Journal of Soil and Water Conservation* **43**: 444-451.

Lal, R. (1994) Soil erosion by wind and water: problems and prospects. In Lal, R. (Ed) *Soil erosion, research methods.* Soil and Water Conservation Society, Ankeny, 1-10.

Lal, R. (1998) Agronomic impact of soil degradation. In: Lal, R., Blum, W. H., Valentine, C. and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press, New York, 459-474.

Lal, R, Ahmadi, M., Bajracharya, R. M. (2000) Erosional impacts on soil properties and corn yield on alfisols in central Ohio. *Land Degradation and Development* **11**: 575-585

Lamprey, H. (1975) The integrated project on arid lands. *Nature and resources* **14**: 2-11.

Le Houerou, H. N. (1996) Climate change, drought and desertification. *Journal of Arid Environments* **34**: 133-185.

Lema, A. J. (1990) An assessment of the process of desertification in Tanzania. A paper presented at a workshop on environmental education for desertification control, Organized by NEMC, Arusha,Tanzania.

Lepage, M. (1981) The impact of foraging populations of *Macrotermes michaelseni* (Isoptera, Macroterminitinae) on semi arid-ecosystems (Kajiado

Kenya) in foraging activity and factors determining it. *Insectes Sociaux* **28**: 309-320.

Lobry de Bruyn, L. A. and Conacher, A. J. (1990) The role of termites and ants in soil modification: a review. *Australian Joumal of soil Research* **28**: 55-93.

Loiske, V-M. (1996) Socio-economic aspects of land management in Giting village. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi-arid Tanzania*, **Report No 13**. Regional Soil Conservation Unit, SIDA, Nairobi, 113-120.

Lykke, A. N. (2000) Refining the ecological aspects of disequilibrium theories for Africa's pastoral drylands. *Desertification Control Bulletin* **36**: 23–33.

Mabbutt, J. A. (1984) A new Global assessment of the status and trends of desertification. *Environmental Conservation Control Bulletin* **11**: 103-113.

Mabbutt, J. A. (1986) Desertification indicators. *Climatic Change* **9**: 113 - 122.

Mabugo, D. (1980) *Irrigation advancement in Tanzania: Mto wa Mbu irrigation scheme*. Unpublished MSc thesis, University of Dar es Salaam.

MacCabe, J.T. (1990) Turkana pastoralism: a case against the tragedy of the commons. *Human Ecology* **18**: 81-103.

Macintyre, R. M., Mitchel, J. G. and Dawson, J. B. (1974) Age fault movements of the Tanzanian sector of the East African Rift System. *Nature* **247**: 354-356.

Mainguet, M. (1994) *Desertification*. Spinger-Verlag, Berlin.

Mbegu, A. C. (1996) The problems of soil conservation and rehabilitation lesson from HADO project. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania,* **Report No 13**. Regional Soil Conservation Unit, SIDA, Nairobi, 147-157.

McConnell, R. B. (1972) Geological development of the rift valley system of Eastern Africa. *Geological Society of American Bulletin* **83**: 2549-2572.

Meadows, A. J. (1975) A hundred years of controversy over sunspots and weather. *Nature* **256**: 95 – 97.

Metternicht, G. I. (1996) *Detecting and monitoring land degradation features and processes in the Cochabamba valleys, Bolivia, a synergistic approach.* Ph.D. thesis. **Publication no 36** ITC, Netherlands.

Millington, A., and Townsend, J. (1989) *Biomass assessment: SADCC Member States.* Earthscan publications LTD, London.

Mills, J. A., (1995) *The resilience of the African arid/semi-arid rangeland to grazing pressure.* Unpublished Mphil thesis, University of Cambridge.

Ministry of Energy and Minerals (MEM) (1997) The mineral policy of Tanzania. United Republic of Tanzania, Dar es Salaam.

Ministry of Lands, Housing and Urban Development (1995) National Land Policy, United Republic of Tanzania, Dar es Salaam

Ministry of Natural Resources and Tourism (MNRT) (1989) Tropical Action Plan. United Republic of Tanzania, Dar es Salaam.

Ministry of Natural Resources and Tourism (MNRT) (1998) National forest policy. United Republic of Tanzania, Dar es Salaam.

Misana, S. B. and Nyaki, F. R. (n.d.) Relationship between population increase and deforestation. A paper presented in population and environment workshop at The University of Dar es Salaam.

Mitchell, J. K. and Bubenzer, G. D. (1980) Soil loss estimation. In: Kirkby, M. J. and Morgan, R. P. C. (Eds). *Soil erosion,* John Wiley, Chichester, 17-62.

Mohamed, S. A. (1996) Farming systems and land tenure in Haubi village of Kondoa eroded area. In: Christiansson, C. and Kikula, I.(Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania,* **Report No 13**, Regional Soil Conservation Unit, SIDA, Nairobi, 77-83.

Monduli District Council (1993) Monduli District: An agro-economic survey of the Maasai. Monduli District Council, Arusha.

Monduli District Council (1997) *Planning for a better environment in Monduli District.* Netherlands Economic Institute, The Hague

Monduli District Council (1998a) Report on data collection and participatory evaluation of projects in Esilalei village. Monduli District, Arusha.

Monduli District Council (1998b) Report on participatory data collection and evaluation of community based projects in Lolkisale village. Monduli District, Arusha.

Monduli District Council (1998c) Report on participatory data collection and evaluation of community based projects in Selela village. Monduli District, Arusha.

Morgan, R. P. C. (1995) *Soil erosion and conservation.* Longman, Harlow.

Mortimore, M. (1993) Population growth and land degradation. *GeoJournal* **31**: 15-21.

Muheto, R.N (1995) The status of desertification, past and present interventions in Tanzania. A paper presented at the National Workshop on awareness of intemational convention to combat desertification, Dar es Salaam.

Murrary-Rust, D. H. (1973) Soil erosion and reservoir sedimentation in *a* grazing area West of Arusha, Northem Tanzania. In: Rapp, A., Berry, L. Temple, P.H. (Eds), *Studies of soil erosion and sedimentation in Tanzania*, BRALUP Research **Monograph 1** University of Dar es salaam 325-343.

Murray-Rust, D. H. (1973) Soil erosion and reservoir sedimentation in a grazing area west of Arusha, Northem Tanzania. In: Rapp, A., Berry, L., Temple, P. H. (Eds), *Studies of soil erosion and sedimentation in Tanzania*, BRALUP reset monograph No 1, University of Dar es salaam, 325-343.

Mutchler, C. E., Murphree, C. E. and McGregor, K. C. (1994) Laboratory and field plots for erosion research. In: Lal, R (Ed). *Soil erosion, research methods.* Soil and water Conservation Society, Ankeny, 11-37.

Mwalyosi, R. B. B. (1991) Integrated resource management strategy for lake Manyara catchment basin. Institute of Resource Assessment, University of Dar es Salaam. Research paper No 28.

Mwalyosi, R. B. B. And Yanda, P. Z., (1989) *Water potentials in the Lake Manyara catchment basin.* Institute of Resource Assessment, University of Dar es Salaam. Research paper No 20.

National Soil Service, (1987) Soils of the Lolkisale farms (Maasai District, Arusha Region). Their suitability and management requirements for the cultivation of seed beans, wheat and barley. TARO- Agriculture Research Institute, Mlingano Tanga, Tanzania.

Ndyetabula, P. K G. (1995) *The use of soil information in Tanzania.* Ph.D. thesis. The school of Development Studies , University of East Anglia, United Kingdom.

NEMC (1993) Baseline mapping for monitoring of desertification in Monduli area, Arusha, Tanzania. National Environmental Management Council, Dar es Salaam.

NEMC, (1990) National Plan of Action to Combat Desertification in Tanzania. United Republic of Tanzania, Dar es Salaam.

Ngana, J. O. (1996) Climate and hydrology of Kondoa Eroded Area. **In:** Christiansson, C. and Kikula, I.(Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania,* **Report No 13**, Regional Soil Conservation Unit, SIDA, Nairobi, 15-22.

Nyamweru, C. K. (1996) The African rift system. In: Adams, W. M., Goudie, A. S. and Orme, A. R. (Eds), *The physical geography of Africa.* Oxford University Press, Oxford.

Nizeyimana, E. and Petersen, G.W. (1998) Remote sensing application to soil degradation assessments. In: Lal, R., Blum, W. H., Valentine, C. and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press, New York, 393-405.

Nordt, L. C., Wilding, L. P. and Drees, L. R. (1999) Pedogenic carbonate transformations in leaching soil systems: implications for the global Carbon cycle.

In: Lal, R., Kimble, J. M., Eswaran, H. and Stewart, B. A. (Eds) *Global climate change and pedogenic carbonates.* Lewis Publishers, London, 43-64.

Nyerere J (1974) *Ujamaa essays on socialism.* Oxford University Press, Oxford.

Oldeman, L. R. (1994) Global extent of soil degradation. In: Greenland, D. J. and Szabolcs (Eds) *Soil resilience and sustainable land use.* CAB international, Wallingford, 99-118.

Oldeman, L R.. and van Lynden, G. W. J. (1998) Revisiting the GLASOD methodology. In: Lal, R., Blum, W. H., Valentine, C., and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC press New York, 423-440.

Ollier, C. D. (1981) *Tectonics and landforms.* Longman Group Limited. New York.

Oosterom, A. P. (1995) Note on trend analysis landcover/landuse changes Monduli District. A brief communication to Monduli District Council authorities. DLO, Winand Staring Center, Netherlands.

Orridge, G.R. (1963) Mbulu: Quarter degree sheet No. 69. Ministry industry, Mineral resources and Power, Dar es Salaam.

Otterman, J. (1974) Baring high-albedo soils by overgrazing: a hypothesized desertification mechanism. *Science*, 186: 131-33.

Parker, G. G. (1965) Piping, a geomorphic agent in landform development of the drylands. *International Association of Science and Hydrology* **65**: 103 – 113.

Peberdy, J. R. (1969) Rangeland. In: Morgan, W. T. W. (Ed). *East Africa: its peoples and resources.* Oxford University Press, Nairobi, 153-176.

Pereira, H. C. (1962) Grazing Control in semi-arid ranchland. The research project. *East Africa Agricultural and Forestry Journal,* Special Issue, 42-46.

Pickering, R. (1965) Ngorongoro Quarter degree sheet No 55. Ministry of Industry, Mineral resources and Power, Dar es Salaam.

Pierce, F. J. and Lal, R. (1994) Monitoring the impact of soil erosion on crop productivity. In Lal, R (Ed) *Soil erosion, research methods.* Soil and water Conservation Society, Ankeny, 235-263.

Presant, E. W. (1974) Report on the soils of selected areas near Arusha and Monduli Tanzania, for the agronomic research project (wheat). Canadian International Development Agency, Ottawa.

Raina, P. Joshi, D.C. and Kolarkar (1993) Mapping of soil by using remote sensing on alluvial plain, Rajasthan, India. *Arid Soil Research and Rehabilitation* 7:145-161.

Rapp, A., Axelson, V., Berry, L. and Murray - Rust, D. H. (1973a) Soil erosion and sediment transport in Morogoro river catchment. In: Rapp, A., Berry, L. and Temple, P. *Studies of soil erosion and sedimentation in Tanzania.* BRALUP research **Monograph No 1**, University of Dar es Salaam, 125-155.

Rapp, A., Berry, L. and Temple, P. H. (1973b) Soil erosion and sedimentation in Tanzania. In: Rapp, A., Berry, L., Temple, P. H. (Eds), *Studies of soil erosion and sedimentation in Tanzania,* BRALUP **research monograph No 1**, University of Dar es Salaam, 105-109.

Rapp, A., Murray-Rust, D. H., Christiansson, C. and Berry, L. (1973c) Soil erosion and sedimentation in four catchments near Dodoma, Tanzania. In: Rapp, A., Berry, L., Temple, P. H. (Eds), *Studies of soil erosion and* *sedimentation in Tanzania*, BRALUP research **monograph No 1**, University of Dar es Salaam, 255-318.

Ratcliffe, F. N. Gay, F. J. and Greaves, T. (1952) Australian termites: the biology, recognition and biological importance of the common species. CSIRO, Melbourne.

Reining, P. (Ed) (1978) *Handbook on Desertification indicators* (Based on Science Association's 1976 Nairobi seminar on desertification). American Association for Advancement of Science. Washington DC

Renard, K. G., Laflen, J. M. , Foster, G. R. and McCool (1994) The Revised Universal Soil Loss Equation. In Lal, R. (Ed) *Soil erosion, research methods.* Soil and Water Conservation Society, Ankeny, 105-124.

Rengasamy, P. (1998) Sodic soils. In: Lal, R., Blum, W. H., Valentine, C., and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press, New York, 265-277.

Rowell, D. L. (1994) *Soil science: methods and applications.* Addison Wesley Longman, Edinburgh.

Russell, W. (1975) *Soil conditions and plant growth.* 10th edition. Longman, London.

Ruttem, L.M. ,Borgerhoff, M. M. (1999) Are Eeat Africans pastoralists truly conservationist ?. *Current Anthropology* **40**: 621-652.

Ryd'en, A. (1997) Approaches to practical remote sensing for environmental studies. Experiences from a case study in Swaziland and southern Mozambique. *ITC Journal* **2**: 136-145.

Sanders, D. W. (1986) Desertification process and impact in rainfed agriculture regions. *Climatic Change* **9**: 33 -42.

Sanyu Consultants Inc. and Japan Engineering Consultants Co. (1995) The feasibility study of Monduli Town and surrounding area water supply in Arusha Region. Draft final report for Japan International Cooperation Agency (JICA) and Arusha Regional Development Directorate, The United Republic of Tanzania.

Schuler, U. (1991) Environmental impacts of increasing population densities in Tanzania rural settlements. An occasional paper, Geography Department. University of Dar es Salaam.

Shishira, E. K. and Payton, R. W. (1996) The causes and effects of accelerated soil erosion and sedimentation in Kondoa eroded area: evidence from lake Haubi basin, Kondoa District, Tanzania. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania*, **Report No 13**, Regional Soil Conservation Unit, SIDA, Nairobi, 32-45.

Skidmore, E. L. (1994) Wind erosion. In: Lal, R (Ed) *Soil erosion, research methods.* Soil and water Conservation Society, Ankeny, 265-293.

Slaymaker, O. and Spencer, T. (1998) *Physical geography and Global environmental change.* Pearson Education Limited. Harlow.

Smith, J. (2001) Understanding the science and impacts of changes in Global and regional climate. In: Claussen, E. (Ed), *Climate change*, 1-5.

Simon, N. M. (1962) *Between the sunlight and the thunder; the wildlife of Kenya.* Collins, London.

Sombroek, W.G., Braun, H. M. H. and van der Pouw, B.J.A. (1992) *Exploratory soil map and agro-ecological map of Kenya,* Scale 1:1000,000. Kenya Soil Survey, Nairobi.

Stocking, M. (1987) Measuring Land Degradation. In: Blaikie, P. and Brookfield (1987) *Land degradation and society.* Routledge, London, 49-63.

Stocking, M. (1996) Soil erosion. In: Adams, W. M., Goudie, A. S. and Orme, A. R. (Eds). *The physical geography of Africa.* Oxford University Press, Oxford.

Stocking, M. and Murnaghan, N (2000) Handbook for the field assessment of land degradation. Earthscap Publications Ltd.,London.

Sullivan, S. (1996) Towards a non-equilibrium ecology: perspectives from an arid Land. *Journal of Biogeography* **23**: 1-5.

Summerfield, M. A. (1991) *Global geomorphology.* Longman, Essex.

Szabolcs, I. (1976) Present and potential salt affected soils. FAO *Soils Bulletin* **31**: 9-13.

Szabolcs, I. (1992) Salinization of soil and water and its relation to desertification. *Desertification Control Bulletin* **21**:32-37.

Szabolcs, I. (1998) Salt build-up as a factor of soil degradation. In: Lal, R., Blum, W. H., Valentine, C., and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC press, New York, 253-277.

Talbot, L. M. (1971) Ecological aspects of aid programs in East Africa, with particular reference to rangelands. *Bulletin of Ecological Research Committee.* 13 NFR, Stockholm.

Tapson, D. (1993) Biological sustainability in pastoral systems: the Kwazulu case. In: Behnke, R. J., Scoones, I. and Kerven, C. (Eds) *Range ecology at disequilibrium. New models of natural variability and pastoral adaptations in African savannas.* Overseas Development Institute, London, 118-135.

Tarver, J. D. (1996) *The demography of Africa.* Praeger, London.

Temple, P. and Murray-Rust, D. H. (1973) Sheet-wash measurements on erosion plots at Mfumbwe, Eastern Uluguru Mountains, Tanzania. In: Rapp, A., Berry, L. Temple, P.H. (Eds), *Studies of soil erosion and sedimentation in Tanzania*, BRALUP Research **Monograph 1**, University of Dar es Salaam, 195-202.

Temple, P. H. (1973) Measurement of runoff and soil erosion at erosion plots scale, with particular reference to Tanzania. In: Rapp, A., Berry, L. Temple, P.H. (Eds), *Studies of soil erosion and sedimentation in Tanzania*, BRALUP research **monograph 1**, University of Dar es Salaam, 203-220.

Thomas, D.S.G. (1993) Sandstorm in a teacup?. Understanding desertification *Geographical Journal* **159** (3):318-331.

Thomas, D.S.G. and Middleton, N. J (1994) *Desertification exploding the myth*, John Wiley, Chichester

Thomas, D. S. G. (1997) Science and the desertification debate. *Journal of Arid Environments* **37**: 599 - 608.

Thornes, J., B. (1980) Erosional processes of running water and their spatial and temporal controls: a theoretical viewpoint. In: Kirkby, M. J. and Morgan, R., P. C. (Eds), *Soil erosion.* John Wiley, Chichester, 129-182.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994) *More people, less erosion, environmental recovery in Kenya*. John Wiley, Chichester.

Tucker, C. J. and Bhaskar J. C. (1987) Satellite remote sensing of drought conditions. *Remote Sensing of Environment* **23**: 243-251.

Tucker, C. J., Dregne, H. and Newcomb, W. (1991) Expansion and contraction of the Sahara Desert from 1980 to 1990. *Science* **253**: 299-301.

Tucker, C. J., Vanpraet, C. L., Sharman, M.J. and Van Ittersum, G. (1985) Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980-1984. *Remote Sensing of Environment* **17**: 233-249.

Tume ya Mipango na Ofisi ya Mkuu wa Mkoa, Arusha, (1999) Hali ya uchumi na maendeleo ya jamii, Mkoa wa Arusha. Dar es Salaam.

U.S Salinity Laboratory Staff (1954) *Diagnosis and improvement of saline and alkali soils*. (Ed) Richards, L. A. U.S.A. Department of Agriculture handbook.

UNCCD (1995) *United Nations Convention to Combat Desertification in those countries experiencing seriously drought and/or desertification particularly in Africa*. UNEP, Geneva.

UNEP/ISRIC (1991) *World map of the status of Human-induced soil degradation (GLASOD)* An explanatory note, second revised edition (Eds Oldeman, L. R., Hakkeling, R. T. and Sombroek, W. G. UNEP, Nairobi and ISRIC, Wageningen.

UNEP (1997) *World Atlas of Desertification*. Edward Amold, London.

UNEP (2000) *GEO-2000; Global environmental outlook*. Earthscan Publications, London.

United Republic of Tanzania (1977) The threat of desertification in central Tanzania. A technical paper prepared for the UN Conference on Desertification, Dar es Salaam.

UNSO, (1992) *Assessment of desertification and drought in the Sudano-Sahelian Region,* 1985-1991. UNSO, New York.

Valentin, C. and Bresson, L. M. (1998) Soil crusting. In: Lal, R., Blum, W. H., Valentine, C. and Stewart, B. A. (Eds). *Methods for assessment of soil degradation.* CRC Press New York, 89-107.

Verstraete, M. M. (1986) Defining desertification: a review. *Climatic Change,* **9**: 5 -18

Vice President's Office (1999) Proposed National Action Programme to Combat Desertification. United Republic of Tanzania, Dar es Salaam.

Vise President's office (1997) Environmental Policy. United Republic of Tanzania, Dar es Salaam

Warren, A. (1993) Desertification as a Global environmental issue. GeoJournal, **31**: 11-13.

Warren, A. (1995) Changing understandings of African pastoralism and the nature of environmental paradigms. *Transactions of the Institute of British Geographers* **20**: 193-203.

Wigley, T. M.L. (2001) The science of climate change. In: Claussen, E. (Ed), *Climate change,* 6-24.

Whittaker, R. H. (1973) Approaches to classifying vegetation. In Whittaker, R. H. (Ed). *Ordination and classification of communities.* Dr. W. Junk b.v. The Hague, 323-354.

Wilkinson, P., Downie, C. Cattermole, P. J. (1983) Arusha: Quarter degree sheet No. 55. Government of United Republic of Tanzania, Dar es Salaam.

Walling, D. E (1994) Measuring sediment yield from river basins. In Lal, R. (Ed) *Soil erosion, research methods.* Soil and Water Conservation Society, Ankeny, 39-80.

Williams, M. A. J. and Balling, R. C. (1996) *Interactions between desertification and climate.* Edward Arnold, London.

Wilson, S. J. and Cooke, R. U. (1980) Wind erosion. In: Kirkby, M, J. and Morgan, R. P. C. (Eds). *Soil erosion.* John Wiley, Chichester, 217-252.

Wischmeier, W. H. (1976) Use and misuse of the Universal Soil Loss Equation. *Journal of Soil and Water Conservation* **31**: 5-9.

Wischmeier, W. H. (1976) Use and misuse of the Universal Soil Loss Equation. *Journal of Soil and Water Conservation* **31 (1):** 5-9.

Wischmeier, W. H. and Smith, D. D. (1978) Predicting rainfall erosion losses: a guide to conservation planning. *Agriculture Handbook* **No 537**, USA, Department of Agriculture, Washington, DC.

WMO. (1993) *Climate variations, drought and desertification.* WMO No. 653. Switzerland.

Wood, T. G. (1978) Food and feeding habits of termites. In: Brian, M. V. (Ed.). *Production of ecology of ants and termites.* Cambridge University Press, Cambridge, 55-80.

Wood, T. G. (1996) The agricultural importance of termites in Tropics. *Agricultural Zoology Reviews* **7**: 117-155.

Wood, T. G. and Pearce, M. J. (1991) Termites in Africa: the environmental impact of control measures and damage to crops, trees, rangeland and rural buildings. *Sociobiology* **19**: 221-234.

Wood, T. G., and Ohiagu, C. E. (1976) A preliminary assessment of the signifcance of grass-eating termtes (Isoptera) in pestures in Northern Nigeria. *Samaru Agricultural Newsletter* **18**: 22-30

Yanda, P. Z. (1989) *Salinity and water logging, causes and effects on crop yields in Mto wa Mbu irrigation scheme, Arusha.* Unpublished MSc, Agricultural University of Norway.

Yanda, P. Z. (1996) Soil erosion and the fate of Ntomoko/Mwisanga water supply scheme in Kondoa District, Central Tanzania. In: Christiansson, C. and Kikula, I. (Eds). *Changing environments: research on man-land interrelations in semi -arid Tanzania*, **Report No 13**, Regional Soil Conservation Unit, SIDA, Nairobi, 46-53.

Yanda, P. Z. and Mohamed, S.A. (1989) The environmental impact study of the Mto wa Mbu irrigation project. A reconnaissance survey. Institute of Resource Assessment, University of Dar es Salaam.

Young, A. (1976) *Tropical soils and soil survey.* Cambridge University Press, Cambridge.

Young, A. (1998) *Land resources: now and for the future.* Cambridge University Press, Cambridge.

Zonneveld, I. S. (1988d) Reflection, absorption and transmission of light and infrared radiation through plant tissues. In Kuchler, A.W. and Zonneveld, I. S. (Eds). *Vegetation mapping.* Kluwer Academic Press, London, 223-231.

Zonneveld, I. S. (1988a) Composition and structure of vegetation. In: Kuchler, A. W. and Zonneveld, I. S. *Vegetation mapping.* Kluwer Academic Press, London, 25-35.

Zonneveld, I. S. (1988b) Establishing a floristic classification. In: Kuchler, A., W. and Zonneveld, I. S. (Eds) *Vegetation mapping.* Kluwer Academic Press, London, 81-88.

Zonneveld, I. S. (1988c) The ITC method of mapping natural and semi natural vegetation with appendix at A. H. M. and W. v. Wijngaarden. In: Kuchler, A., W. and Zonneveld, I., S. (Eds). *Vegetation mapping.* Kluwer Academic Press, London, 401-426.

Zwart, G., (1995) Monduli District: a socio-economic baseline study. Monduli District Program. Arusha.

Appendix 4.1 ITC data collection sheet

ITC SUMMARIZED RELEVÉ SHEET

ITC Rural and Land Ecology Survey

AREA		DATE	NO.
OBSERVERS		FINAL CLASSIFICATION – LAND UNIT	
PRELIMINARY LAND UNIT	SIZE SAMPLE . x . m	ALTITUDE m	LANDFORM
– TERRAIN –			SOIL
TERRAIN UNIT / LANDFORM			VEGETATION STRUCTURE COMPOSITION
TOPOGRAPHIC POSITION WITHIN MAPPING UNIT	SKETCH:		
SLOPE STEEPNESS (%)			LAND USE AGRICULTURE

– SOIL –

HORIZON No. (/symbol)	DEPTH (cm)	TEXTURE	COLOUR	MOTTLING (Size, amount, colour)	PH	STONINESS (Shape, size, amount)	REMARKS (Erosion, hydrology)
						GROUNDWATER DEPTH (cm)	

– LANDCOVER / LAND USE –

STRUCTURAL LAYER	HEIGHT	COVER (%)	DOMINANT SPECIES (1 or 2)
TREE LAYER	m		
SHRUB LAYER	m		
HERB LAYER	cm		

LITTER COVER (%)	LAND USE –
BARE SOIL (%)	TYPE:
PRELIMINARY COVER CLASSIFICATION –	FIELD SIZE:
STRUCTURE:	FIELD SHAPE:
COMPOSITION:	REMARKS:-

PLANT SPECIES LIST RELEVÉ NO. . .

PLANT CODE	SPECIES	COVER (see scale)	

SCALE FOR COVER ESTIMATIO

R = rare
p = few
a = abundant
m = many
} < 5%

1 = 5 - 15 %   6 = 55-65
2 = 15 - 25 %   7 = 65-75
3 = 25 - 35 %   8 = 75-85
4 = 35 - 45 %   9 = 85-95
5 = 45 - 55 %   10 = 95-100

OBSERVATIONS/INTERVIEWS ON MANAGEMENT ASPECTS

ANIMALS
LIVESTOCK
Type
Number
WILDLIFE
Type
Number

SEMI NATURAL VEG.
burning
fuelwood collectio
grazing traces
watering points
droppings/Foot mark
tracks.

CROPS
Type of crops
Yeild/ha
Input use.

Appendix 4.2 The questionnaire used in the study area

Questionnaire for Monduli study area

1.Name of the interviewer...

Date...

2. No of the questionnaire...

□

Name of the location...

A. Social aspects

1. No of people in the Boma

   Males...

   Females...

   Children...

2. When did you come to the present location?

1.	<5 years ago	[ ]
2.	5 years ago	[ ]
3.	10 years	[ ]
4.	15	[ ]
5.	> 20 years	[ ]

3. Where did you come from?

(i)	Within Monduli area	[ ]
(ii)	outside Monduli area	[ ]

   If outside where

   ...

   ...

□

4. Reasons for coming to the present location

(i)	New pasture lands	[ ]
(ii)	Agricultural lands	[ ]
(iii)	Others	[}

B. Main economic activities

5. What are your main economic activities?
   - (i) Pure patoralist [ ]
   - (ii) Agriculturist [ ]
   - (iii) Agro-pastoralist [ ]
   - (iv) Others [ ]

6. (a) If agriculralist, since when did you become an agriculturist
   - (i) < 5 years ago [ ]
   - (ii) 5 years ago [ ]
   - (iii) 20 years ago [ ]
   - (iv) 15 years ago [ ]
   - (v) > 20 years ago [ ]

   (b) If agro-pastoralist, since when did you become an agro-pastoralist
   - (i) < 5 years ago [ ]
   - (ii) 5 years ago [ ]
   - (iii) 20 years ago [ ]
   - (iv) 15 years ago [ ]
   - (v) > 20 years ago [ ]

7. What reasons made you to become an

   (a) agriculturalist
   - (1) ...
   - (2) ...
   - (3) ...
   - (4) ...

   (b) agro-pastoralist
   - (1)
   - (2) ...
   - (3) ...
   - (4) ...

8. **If agro-pastoralist or agriculturist, what type of crops are grown**

(a) Maize [ ]

(b) Beans [ ]

(c) Others [ ]

9. What is the size of the farm?

(i) < acre [ ]

(ii) 1 to 3 acres [ ]

(iii) > 5 acres [ ]

10. Do you use farm inputs in your farm?

(1) Yes [ ]

(2) No [ ]

11. If yes what type of farm inputs

(i) Agro-chemicals [ ]

(ii) Manure [ ]

11. (b) If agro chemicals

Fertilisers [ ]

Pesticide [ ]

12. What is the average production of crops in your farm?

[ ]

[ ]

[ ]

13. Has the production of crops changed with time?

(1) Yes [ ]

(2) No [ ]

14. If yes has it

(1) Increased [ ]

(2) No [ ]

15. What do you think are the reasons for change?

(i) Rainfall [ ]

(ii) Fall in soil fertility [ ]
(iii) Others [ ]

C. Diet

16. What is your main diet currently?
    (i) Milk [ ]
    (ii) Meat [ ]
    (iii) Food grains [ ]
    (iv) Others [ ]

17. Has there been change of diet over time
    (i) Yes [ ]
    (ii) No [ ]

18. If Yes, what are the changes
    ...
    ...

D 19. Livestock keeping

20. How many livestock to you have?
    Cows [ ]
    Shoats [ ]

21. What changes have occurred to your livestock over time?
    (i) increased [ ]
    (ii) decreased [ ]
    (iii) more shoats than cows [ ]

22. What are the reasons for changes?
    (i) Diseases [ ]
    (ii) Water availability [ ]
    (iii) Shortage of grazing land [ ]

23. Where do you graze your livestock during?
    (i) Dry season [ ]

(ii) Wet season [ ]

24. (i) Have there been changes of grazing location over time

Yes [ ]

No [ ]

25. If yes, what changes has taken place for

(a) wet season areas

...

...

...

(b) Dry season areas

...

...

...

25. What are reasons for changes

...

...

...

26. Where are your watering points?

(a) Wet season –

(b) Dry season –

27. Type of watering facility

Dam [ ]

River [ ]

Well [ ]

Others [ ]

28. What are the main problems associated with water?

- ~~Quality~~ Quantity [ ]
- Quality [ ]
- Silting of dams [ ]
- Distance to watering points [ ]
- Others [ ]

38. What do you think are the main environmental problems in your areas?

Wildlife [ ]

Vegetation loss [ ]

Loss of grazing lands [ ]

Soil erosion [ ]

Water [ ]

Social/economic facilities [ ]

E. Small scale irrigation

1. What type of crops are growing

maize [ ]

beans [ ]

banana [ ]

others [ ]

2. What is the size of your farm?

....

3. What is the production of your crops/acre

Maize [ ]

Beans [ ]

Banana [ ]

Others [ ]

Do you use any farm inputs?

(I) Fertilizers [ ]

(ii) Pesticides [ ]

(iii) Manure [ ]

4. How often per week do you get water

(i)...............

5. How do you manage water in your farm

....

....

6. What are the main problems you are facing.

i)	fall of productivity	[ ]
ii)	salinisation	[ ]
iii)	water scarcity	[ ]
iv)	water borne diseases	[ ]
v)	conflict with pastoralists	[ ]
vi)	conflict with wildlife	[ ]
vii)	others	[ ]

Appendix 8.1

Statistical summary for pattern analysis

No	Type of analysis	Pearson chi-square	df	p
1	Semi-natural vegetation/rainfall 1960's/1991	19557.08	8	0.0000
2	Semi-natural vegetation/rainfall 1991/1999	9792.877	7	0.0000
3	Semi-natural vegetation/relief 1960/1991	119280.0	32	0.0000
4	Semi-natural vegetation/relief 1991/1999	80238.73	28	0.0000
5	Semi-natural vegetation/geology 1960's/1991	84488.42	16	0.0000
6	Semi-natural vegetation/geology 1991/1999	37266.44	14	0.0000
7	Semi-natural vegetation/population density 1960's/1991	53549.83	16	0.0000
8	Semi-natural vegetation/population density 1991/1999	82542.44	14	0.0000
9	Semi-natural vegetation/economic activities 1960's/1991	67840.51	8	0.0000
10	Semi-natural vegetation/economic activities 1960's/1991	47339.88	7	0.0000
11	Agricultural cover/rainfall 1960's/1991	27759.74	16	0.0000
12	Agricultural cover/rainfall 1991/1999	11570.41	4	0.0000
13	Agricultural cover/rainfall/relief 1960's/1991	27759.74	16	0.0000
14	Agricultural cover/rainfall/relief 1991/1999	34591.92	16	0.0000
15	Agricultural cover/geology 1960's/1991	7081.908	8	0.0000
16	Agricultural cover/geology 1991/1999	14737.50	8	0.0000
17	Agricultural cover/population density 1960's/1991	4211.323	8	0.0000
18	Agricultural cover/population density 1991/1999	19958.55	8	0.0000
19	Gully and bare land/rainfall 1991/1999	27.61564	1	0.0000
20	Gully and bare land/relief 1991/1999	119.4695	4	0.0000
21	Gully and bare land/slope 1991/1999	963.7479	2	0.0000
22	Gully and bare land/ population density 1991/1999	1085.295	2	0.0000