# A COMPARATIVE STUDY OF LANDSLIDES AND GEOHAZARD MITIGATION IN NORTHERN AND CENTRAL MALAWI

By

**Golden Gadinala Ashan Chizimba Msilimba**

**Thesis Submitted for the Degree**
**Doctor of Philosophy,**
**Faculty of Agricultural and Natural Sciences,**
**Department of Geography,**
**University of the Free State**

**November, 2007**

**Promoter: Professor Peter J. Holmes**

# FRONTISPIECE

Landslides play a major role in the development of hill slopes. They cause habitat degradation, derange drainage systems, alter drainage path ways, destroy riparian vegetation, bank erosion, accelerate meander development and loss of scenic beauty of mountain environments. Landslides threaten people, their property and livelihood sources. Degraded marginal lands are clearly observed as can be seen in this photograph, taken at the Ntchenachena study area in the Rumphi District of Northern Malawi.

## DECLARATION

I declare that this thesis is a product of my own independent work and has not previously been submitted for the award of a similar or related degree in any other university. All sources of information used have been correctly referenced, and any other assistance rendered has been fully acknowledged. I furthermore cede copyright of the thesis in favour of the University of the Free State

Signature:

**Author:** **…………………………………………..** **Date: …………………………**
**Golden Gadinala Ashan Chizimba Msilimba**

## ABSTRACT

In 2003, a number of landslides occurred in the Ntchenachena and the Chiweta Areas of the Rumphi District in Northern Malawi, and in the Livilivi/Mvai Catchments of Ntcheu District in Central Malawi. The landslide events caused significant damage to crops, farmland, livestock and infrastructure. Worse still, they caused the death of four people. The high density of landslides occurrences suggested instability of the slopes of these areas.

In light of these landslides, this study set out to assess the slope stability status of the areas. The study addressed landslide mapping and classification of observed events; assessment of the causes and contributing factors; assessment of the socio-economic and environmental impacts of the events; exploration of traditional knowledge, beliefs and peoples perceptions surrounding landslides; determination of the coping strategies; and development of mitigations to landslides as geo-hazards.

This study involved a landslide inventory of all observed events. The physical characteristics of the terrain influencing slope instability were measured. The characteristics recorded included slope length, angles, aspect and altitude, and channel dimensions. Landslides were classified based on the type of movement, degree of stabilisation, and age, and materials involved in the movement. Soil samples were collected, using core and clod sampling methods and were tested for plastic limit, liquid limit, plasticity index, bulk density, hydraulic conductivity, aggregate stability, and particle sizes. Structural rock weaknesses were also measured. Vegetation data was collected, using the quadrant method and was analysed for average diameters at stump and breast height, canopy cover, and height. Questionnaires/surveys were used to assess local knowledge and perceptions towards landslides. A SPSS statistical package was used to analyse both social and physical data.

It was found that 131 landslides had occurred of which 98 were in the Rumphi District, Northern Malawi and 33 occurred in the Ntcheu District, Central Malawi. The variations were observed to be due to the degree of disturbance of the physical environment. The Ntchenachena Area, with the highest density (88), was under cultivation and the afro-montane vegetation had been completely destroyed. The deepest channels were observed in the Ntchenachena Area, partly because of the deep chemical weathering of the basement. In contrast, the rest of the areas had thin soils. Slope aspect and type were found to be of little significance in the occurrence and spatial distribution of the events.

The analysis of data suggested that the events were caused by liquefaction of sand and silt fractions due to high and prolonged precipitation. The evidence from the Chiweta and the Mvai Areas suggests that high cleft water pressure between rock and soil masses might have caused some failures. However, destruction of vegetation, cultivation on marginal lands, high slope angle, weathering of the basement, and slope cutting contributed to the instability.

The study also noted that the Ntchenachena, the Mvai and the Livilivi Areas largely require soft solutions to the landslide problem. These include afforestation, proper siting of houses, and restricting settlement activities in danger-prone areas. Income generating activities to reduce poverty, community participation in natural resources management and public awareness and outreach programmes are highly recommended. The Chiweta Area requires urgent major engineering works such as construction of embankments, cable nets, wire meshes, improving drainage and plugging. Stabilisation and rehabilitation of river banks is also recommended to minimize bank collapse and flooding. Integration of traditional knowledge into the existing scientific body knowledge is critical to a better understanding of the mechanisms that generate landslides

Further work needs to be carried out in areas of willingness to relocate to safer ground; change in production system; geological analysis of the Chiweta beds;

hydro-geological assessment of the areas; development of landslides predictive models for Malawi; and the development of a landslide early warning system.

**Msilimba Golden G.C**
**University of the Free State**
**November, 2007**

**Keywords**

Malawi; Landslides; Geohazard; Mitigation; Assessment; Traditional Knowledge; Gender; Rockfalls; Debris flows; Rotational; Translational.

# OPSOMMING

In 2003 het ‘n aantal grondstortings voorgekom in die Ntchenachena en Chiweta gebiede van die Rumphi distrik in noord Malawi, en in die Livilivi/Mvai opvanggebiede van die Ntcheu distrik in sentraal Malawi. Die grondstortings het merkbare skade aan gewasse, landbougrond, lewende hawe en infrastruktuur aangerig. Erger nog, dit het die dood van vier persone veroorsaak. Die hoë digtheid van die voorkoms van grondstortings dui op die onstabiliteit van hange in hierdie gebeide aan.

In die lig van hierdie grondstortings is hierdie studie daarop gerig om die stabiliteit van die hange in die gebiede te bepaal. In die studie word grondstortings gekarteer en waargenome gebeurtenisse geklassifiseer; oorsake en bydraende faktore word evalueer; sosio-ekonomiese en omgewingsimpakte van die gebeure word evalueer; tradisionele kennis, gelowe en mense se persepsies aangaande grondstortings word ondersoek; hanteringstrategieë word bepaal en versagting van grondstortings as gevare word ontwikkel.

Hierdie studie sluit ‘n inventaris van alle waargenome grondstortings in. Die terrein se fisiese eienskappe wat hang onstabiliteit beïnvloed het, is gemeet. Die eienskappe wat aangeteken is, sluit in hanglengte, helling, aspekte en hoogte, en kanaal dimensies. Grondstortings is geklassifiseer op grond van die tipe beweging, die graad van stabilisering, ouderdom en die materiaal betrokke in die storting. Grondmonsters is versamel deur van kern- en kluitmonster metodes gebruik te maak en is getoets vir plastisiteitsgrens, vloeigrens, plastisiteitsindeks, bulkdigtheid, hidrouliese geleidingsvermoë, aggregaatstabiliteit en partikelgrootte. Strukturele rotsswakhede is ook gemeet. Plantegroeidata is versamel deur gebruik te maak van die kwadrant metode. Dit is ontleed vir gemiddelde deursnitte

op stomp- en borshoogte, kroonbedekking en -hoogte. Vraeslyste/opnames is gebruik om plaaslike kennis en opvattings oor grondstortings te bepaal. ‘n SPSS statistiese pakket is gebruik om beide die sosiale en fisiese data te verwerk.

Daar is bevind dat 131 grondstortings plaasgevind het, waarvan 98 in die Rumphi distrik, noord Malawi, en 33 in die Ntcheu distrik, sentraal Malawi, plaasgevind het. Die variasies word toegeskryf aan die graad van versteuring van die fisiese ongewing. Die Ntchenachena area, met die hoogste digtheid (88), was onder verbouiing en die afro-montane plantegroei is totaal vernietig. Die diepste slote is in die Ntchenachena area waargeneem, deels as gevolg van die diep chemiese verwering van die bodem. In teenstelling daarmee het die res van die gebied dun grond gehad. Daar is bevind dat hange en hulle aard weinig bydra tot die voorkoms en ruimtelike verspreiding van insidente.

Die analise van data het aangedui dat die insidente veroorsaak is deur die vloeibaarmaking van sand en silt fraksies as gevolg van hoë en langdurige neerslae. Die aanduiding uit die Chiweta en die Mvai areas is dat hoë kloofwaterdruk tussen rots- en grondmassas sommige grondstortings kon veroorsaak het. Nietemin, die vernietiging van plantegroei, verbouiing op marginale landerye, hoë hangehllings, verwering van die basis en hellinginsnyding het tot onstabiliteit bygedra.

Tydens die studie is ook opgemerk dat die Ntchenachena, die Mvai en die Livilivi areas grotendeels haalbare oplossings vir die grondstortingsprobleem vereis. Dit sluit in bosaanplanting, behoorlike plasing van huise en ‘n verbod op nedersettingsaktiwiteite in moontlike gevaarsones. Inkomste-genererende aktiwiteite om armoede te

verminder, gemeenskapsdeelname in natuurlike hulpbronbestuur en openbare bewustheids- en uitreikprogramme word sterk aanbeveel. Die Chiweta gebied benodig dringende grootskaalse ingenieurswerke soos die konstruksie van walle, kabelnette, draad netwerk, verbetering van die dreinering en bepropping. Stabilisasie en rehabilitasie van rivieroewers word ook aanbeveel om oewerinstorting en oorstroming tot die minimum te beperk. Die integrasie van tradisionele kennis en bestaande wetenskaplike kennis is krities om 'n beter begrip te vorm van die meganismes wat grondstortings veroorsaak.

Verdere werk behoort gedoen te word op verskuiwing na veiliger terrein (in gebiede waar daar gewilligheid bestaan); verandering in die produksiesisteem; geologiese analise van die Chiweta lae; hidrogeologiese assessering van die gebiede; ontwikkeling van grondstortingsvoorspellingsmodelle vir Malawi; en die ontwikkeling van 'n vroeë waarskuwingsisteem vir grondstortings.

**Msilimba Golden G.C.**
**Universiteit van die Vrystaat**
**November, 2007**

**Sleutelwoorde**

Malawi; Grondstortings; Geogevaar; Versagting; Skatting; Tradisionele (Inheemse) Kennis; Gender; Rotsstortings; Puin Afloop; Translasie.

# DEDICATION

To the late Major G.A Chizimba (RTD), the late Mrs Eveles Nyalongwe Chizimba, the late Professor Dan Chimwenje, and Professor Peter J. Holmes

***For your contributions towards my academic achievements***

# ACKNOWLEDGEMENTS

I would like to express my sincere thanks to all the people who assisted me to complete this thesis. In particular, my supervisor, Professor Peter Holmes of the University of the Free State, for the guidance he offered in the course of shaping this work. You were always available for me when I needed your help. More importantly, your efforts in persuading the University of the Free State to support me financially when there was no hope of getting tuition are appreciated. I thank the University of the Free State for this financial support.

I would like to extend my gratitude to Mr Ignasio Malizani Jimu, Ms Tobeka Mehlomakhulu, and Professor Gustav Visser for assisting in the designing and editing of questionnaires. Although this was a tiresome exercise, you assisted without any charge at any time. You also encouraged me when my hopes were shattered due to funding problems.

I am indebted to Mr E. Nguluwe of the Forestry Department for the assistance in carrying out the vegetation survey. I appreciated your patience and resilience in those rugged terrains of the Ntchenachena, the Chiweta and the Mvai/Livilivi areas. You were a source of encouragement to the entire research team.

My special thanks go to Mr P. Jambo and Mr K.A. Tchuwa for your assistance in mapping landslide events in those hostile environments. I also acknowledge your assistance in GIS and the production of images.

I would like to sincerely thank Mr P. Sonjera of Bvumbwe Agricultural Research Station for your assistance in soil sampling. The exercise required patience and perseverance. I still remember how you managed climbing the spurs of the Ntchenachena and the Chiweta areas, with soil samples and sampling equipment on your back when most of the team members had given up. Thanks for assisting in laboratory tests which was a long and tedious process. Through determination the goal was achieved.

I am very grateful to Messrs J. Gondwe, J. Kushe, A. Kayange and M. Kalingwenje and Ms A. Chaona who assisted in the social survey. This exercise required patience and understanding of the respondents. You did a good job. I wish also to thank all the respondents, including the villagers, district commissioners, and officials of the Department of Geological Survey. Without their cooperation, this study would not have been possible.

Special thanks go to Messrs Arts Luwanda, H. Chisale and P. Kubwalo and Ms Chinkwita-Phiri for remarkable guidance in statistical analyses of the questionniares and soil data. To Mrs F. Mkandawire, Mrs M. Kumwenda and Mr A. Tembo, thanks for the secretarial services offered when I was stuck.

My colleagues in the Geography Department at the Universities of Mzuzu and the Free State were very supportive and encouraging. In particular, Mr R.T. Ghambi Head of Department, Mzuzu University who fought hard to secure partial funding for me from the Staff Development Committee. Special thanks to Dr C. Barker of the University of the Free State for the moral support and encouragement.

I appreciate the patience, help and encouragement of Mrs Liesel Cronje. Special thanks for translating the abstract and keywords into Afrikaans; God bless you abundantly.

I am very grateful to Waternet for providing research funds, University of the Free State for providing tuition, and Mzuzu University for meeting some of the living and traveling expenses during the study period. More importantly, I would like to thank the Late Professor D. Chimwenje, Deputy Vice Chancellor, Mzuzu University, for his personal support towards this programme. I wish he had lived to witness the completion of this study. May his soul rest in eternal peace.

My very special thanks go to the “great” driver Mr Timothy Ngwira. Despite being sick in the course of the study you forged ahead till the last day. You proved to

us all that determination and commitment are great virtues. To the porters both in Ntcheu and Rumphi Districts, I appreciated your support. You led us to where landslides occurred.

To friends, thanks for the moral support and encouragement. Special appreciation to Dr A.W. Msiska of the University of Livingstonia, and Mr B. Molande of Chancellor College for proof-reading the final draft.

To Richard Ngalu and Gift Chingwalu for the technical support rendered anytime. Your talent is greatly appreciated.

Finally, untold love and thanks go to Aida, Elias, Foster, Ellen, Potpher, Delia, Lovely, Victoria, Loudon, Harold, Kings, Benard, and Edwin, who in their unique ways have made this work possible.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## ABBREVIATIONS AND ACRONYMS

CC : Canopy Cover
CURE : Conservation Unit for the Rehabilitation of the Environment
Dbh : Diameter at Breast Height
DEM : Digital Elevation Model
Dsh : Diameter Stump Height
ETM : Earth Elevation Model
FGD : Focus Group Discussion
FRIM : Forestry Research Institute of Malawi
GoM : Government of Malawi
GPS : Global Positioning System
GTZ : German Technical Cooperation
H : Height
IGAs : Income Generating Activities
ITCZ : Inter Tropical Convergence Zone
M1 : Main Road
MASAF: Malawi Social Action Fund
MEET : Malawi Environmental Endowment Trust
MWD : Mean Weight Diameter
NEAP : National Environmental Action Plan
NEP : National Environmental Policy
NGOs : Non Governmental Organisations
NRA : National Roads Authority
NSO : National Statistical Office
VBCA : Vunguvungu Banga Catchment Areas

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Landslides are defined as the mass movement of rocks, debris or earth along a sliding plane. They are characterised by almost permanent contact between the moving masses and sliding plane (Butler, 1976; Crozier, 1984; and Smith, 1996). Landslides cause substantial economic, human and environmental losses throughout the world. Examples of devastating landslides at a global scale include the 1972 Calabria landslide in Italy, the 1970 Hauscaran landslide in Peru (McCall, 1992), the 1966 Aberfan landslide in Wales, and the 1985 Armero landslide in Colombia (Alexander, 1993). It is estimated that in 1998, 180,000 avalanches, landslides, and debris flow in different scales occurred in China, estimated at 3 billion dollars worth of direct economic losses (Huabin et al., 2005).

In Africa, landslides are not new phenomena. They have been reported in Cameroon, Kenya, Uganda, Rwanda, Tanzania, and Ethiopia (Rapp et al., 1972; Ngecu and Ichang'i, 1989; Moeyersons, 1988, 1989a and b; Davies, 1996; Westerberg and Christiansson, 1998; Ayalew, 1999; Ngecu and Mathu, 1999; Westerberg, 1999; Inganga et al., 2001; Muwanga et al., 2001; Nyssen et al., 2003; and Knapen et al., 2006). Although the East African highlands are a very heterogeneous region in terms of physiography, geomorphology and rainfall (Knapen et al., 2006), they have a high vulnerability to slope instability in common. The high annual rainfall, high weathering rates, deforestation and slope material with a low shear resistance or high clay content are often considered the main preconditions for landslides (Knapen et al., 2006).

A number of landslide events have occurred in Malawi and the causes are similar to those in the East African region (Cheyo, 1999; Mwenelupembe, 1999; and Msilimba and Holmes, 2005). Examples include the 1946 Zomba Mountain landslide (Cheyo, 1999), the 1991 Phalombe Landslide (Poschinger et al., 1998) and the 1997 Banga Landslide (Msilimba, 2002; and Msilimba and Holmes, 2005). A summary of known landslides that have occurred in Malawi from 1946 to 2000 is given by Msilimba (2002), Msilimba and Holmes (2005) and in **Table 4.1 p.66.**

Literature reveals that landslide studies have been carried out extensively in the southern parts of Malawi (Gondwe et al., 1991; Poschinger et al., 1998; Cheyo, 1999; Mwenelupembe, 1999; and Manda, 1999). Little has been done in Central and Northern Malawi, except for studies carried out by Dolozi and Kaufulu in 1992, and Msilimba in 2002 in Central and Northern Malawi, respectively (Dolozi and Kaufulu, 1992; Msilimba, 2002 and Msilimba and Holmes, 2005). However, it should be noted that most of the landslides which occurred in Southern Malawi caused substantial damage to property and deaths of people.

Recently, a number of landslides have occurred in the Ntchenachena and the Chiweta areas (Northern Malawi), and in the Mvai and the Livilivi areas (Central Malawi). Reports from local radio stations and newspapers indicate that landslides are a common phenomena in these areas. Some events have caused significant loss of property and life. This could be an indication of increasing instability and yet little is known about preparatory and triggering factors, and the severity of old landslides. Therefore, a detailed research work and susceptibility mapping was required to determine landslide hazards and appropriate mitigation measures that can be devised to prevent further occurrences or minimize the impacts. It was also imperative to study how people perceive these events and cope with them.

## 1.2 Aims of the Study

It is extremely important to recognise the reasons that make an area susceptible to sliding and to acknowledge factors that trigger the movement of the rock or soil mass movement. This helps the researcher to arrive at a precise and correct diagnosis of effective remedial measures. The variety of landslide types reflects the diversity of factors which are responsible for their origin. The diversity causes a complexity in describing the factors and their relationships (Zoruba and Mencl, 1969; Crozier, 1984, 1986 and 1989; and Coch, 1995).

Therefore, this study was aimed at identifying and assessing the contribution of various causal factors such as structural weaknesses in rock/soil mass, changes in water content, changes and effect of ground water regime, weathering of slope forming materials, changes in land use, topography and vegetation cover change towards the occurrence of landslides. The study aimed to determine the inter-relationship between these factors. It also aimed at establishing how human interventions have modified landslide magnitude, frequency and geographical distribution.

Although climate change is a generally considered factor in landslide occurrence and its changes in time and space, the study did not envestigate is role/importance due to limited data and lack of equipment. However, Elnino triggered landslides have been reported within the East African Region (Ngecu and Mathu 1999).

Against the determined causes and their relationships, the study aimed at developing mitigation measures, which, if implemented, would reduce the vulnerability of communities to landslides by increasing their resilience to shocks. These measures were to be put in place with reference to traditional knowledge and beliefs surrounding the occurrence of landslides.

## 1.3 Specific Objectives of the Study

The specific objectives of the study were to: (1) map observable individual landslide events in the study areas, (2) determine the extent and channel morphology of these landslide events, (3) determine the factors that contributed and caused these landslide events, (4) determine the slope stability status for the study areas, (5) assess the socio-economic and environmental impact of the landslide events in the study areas, (6) assess local peoples' knowledge and perceptions surrounding the occurrence of landslides, (7) assessing gender perceptios surrounding landslide occurrences and (8) propose landslide mitigation measures.

## 1.4 Rationale of the Study

The geo-hazards assessment of landslides in the Ntchenachena and Chiweta areas in Rumphi District of Northern Malawi and the Mvai/Livilivi catchments in Ntcheu District of Central Malawi has never been studied. Little is known about factors contributing to the instability and the risk posed to settlements and infrastructure by landslides. Therefore, this study is a detailed contribution to studies in landslide occurrences in Northern and Central Malawi, and a contribution to the restricted knowledge on landslides in the entire East African region.

This study was a comparative study to generate information which may be useful in the analysis of causes and mitigation measures of landslides throughout the country. As shown in **Section 1.1**, previous landslide studies concentrated on landslides in Southern Malawi. It was imperative to study landslides in Northern and Central Malawi, considering the variations in climate and physiography of Malawi (Linceham, 1972; and Agnew and Stubbs, 1972).

In the study areas, landslides either claimed human lives or damaged property, or infrastructure. Continued instability put human life and property in great danger. There was, therefore, an urgent need to investigate the causes of the landslides in order to formulate an informed basis for minimising or preventing further losses. Through the identification of the causes, the study would form the basis of landslide hazard management for the study areas.

In Malawi, this research is the first comparison of landslide occurrences and a follow-up attempt to classify the events. The research was also based on a simple methodology developed and modified for a developing country. This methodology could form the basis for teaching slope stability problems at tertiary level in Malawi as one way that makes the study of practical use.

According to the available international literature, the research is the first of its kind to incorporate traditional knowledge and beliefs in the understanding of landslides. It is also the first attempt to assess gendered perceptions towards landslides in Malawi. In that respect, the research is an important step towards the incorporation of traditional knowledge into the scientific understanding of landslide mechanisms of generation while bearing in mind gender-based perceptions. This would bring a better understanding of the complex relationship between humans, the physical environment, and the occurrence of landslides.

### 1.5 Significance of the Study

The study is significant in a number of ways. Firstly, the study has generated information on landslide occurrences which will be used for comparative purposes. The study also fills in critical gap since landslide studies have been concentrated in Southern Malawi and very little work has been done in Northern and Central Malawi (Msilimba, 2002; and

Msilimba and Holmes, 2005). Northern and Central Malawi are in different physiographic and climatic zones and the underlying causes of the events could also be different.

Secondly, the information generated is of academic value. In current landslide literature little is known about landslides in Northern and Central Malawi except for Manyani Hill Landslide (Dolozi and Kaufulu, 1992); and the 1997 Banga Landslide (Msilimba, 2002; and Msilimba and Holmes, 2005). In most cases, researchers make much reference to international landslides at the expense of local case studies. In the long run, interested and affected parties fail to appreciate the extent of the problem in their own geographic setting.

Thirdly, the study has generated information which may be used in the decision-making process to mitigate landslide occurrences. Various government departments could make use of the information, thereby being in a position to check and control the landslides. For example, the Department of Relief and Disaster Management could use the information in the preparation of landslide disaster management plans which could reduce or avoid losses from landslides by ensuring prompt assistance to the victims, and achieve rapid and effective recovery. The information may help in the development of an early warning system. The Department of Lands and Physical Planning could use the information to determine best sites for human settlements. The National Roads Authority (NRA) could use the information in the stabilisation of unstable slopes on the Chiweta beds where the M1 Road to Karonga passes through.

Fourthly, the study could assist the local people in the affected areas to understand better how stable or unstable their physical environments are. They may be well informed of danger-prone areas and risks posed by landslides. This study will provide information on how human activities have contributed to instability of the slopes. In the long run, the local people may appreciate the problem and be more willing to rehabilitate unstable hill slopes or vacate danger-prone areas.

Finally, the information generated would also help various stakeholders in the rehabilitation of affected areas, especially Non-Governmental Organisations (NGOs) working in the affected areas. For example, NGOs like the Conservation Unit for the Rehabilitation of the Environment (CURE), and Malawi Environment Endowment Trust

(MEET) may use the information to rehabilitate the Ntchenachena hills and the Mvai/Livilivi catchments. This could result in the shift of NGOs focus from providing food handouts to implementing environmental protection and management.

## 1.6 Theoretical Basis of the Study

Understanding the complexity of the occurrence of landslides requires the use of integrated methodologies, involving measurement of biophysical parameters and social studies. Both scientific and local knowledge that provides a more holistic understanding of slope stability problems needs to be documented and integrated.

This research follows a political ecology approach and core theory (Bartley and Bergesen, 1977; Blaikie, 1985; Worgu, 2000; and Kema, 2005). This approach emphasises a multi-scale approach to environmental-development analyses, considering scales of analysis from local land user to global institutions (Blaikie, 1985). It also focuses on cultural construction of the environment, and treats the environmental problems as a social problem, requiring negotiation of values and knowledge (Peets and Watts, 1996; and Blaikie, 1985).

Natural scientists have been criticised for viewing environmental degradation as solely an environmental and not a social problem (Blaikie, 1985). This has stimulated interest in the development of a social ecological perspective to enable a more informed understanding of the causes of environmental degradation. Essentially, physical and socio/economic systems have to be analytically integrated in slope stability analysis (Msilimba, 2002). The socio-economic system is important and ignoring it leads to technocratic and physical examination of slope stability problems. An explanatory model developed by Blaikie (1987) isolates several social issues that are being investigated in this study, including characteristics of land users, land tenure and attributes of land users. The model recognises land users as decision makers that can relate use of the physical environment to wider attributes of production and survival strategies. The importance of integrating scientific and local knowledge, and gender and the environment is discussed in detail in **Sections 3.9** and **3.10**.

## 1.7 Organisation of the Thesis

This thesis has been organized in three thematic areas. The first theme revolves around landslides mapping, classification, and impacts. The second theme assesses natural and anthropogenic factors contributing to instability, and triggering landslides. The last theme is the question of traditional knowledge and peoples' perception on the occurrence of landslides, and their coping strategies. These themes are presented in ten chapters.

Chapter One provides background information to the study and describes the problem, rationale, objectives and the significance of the study. Chapter Two presents the geography of Malawi and the characteristics of the study areas. Chapter Three provides a literature review of landslides: definition, classification, mechanisms, causes, consequences, and environmental impacts. Chapter Four addresses landslide studies in Malawi. Chapter Five describes the materials and methods used in the study, including soil sample tests, sampling techniques, data collection and analysis. It also describes various GIS operations and social survey methods. Chapter Six provides the results of landslide mapping, classification, channel morphology, and the impacts of landslides. Chapter Seven discusses the causes and contributing factors to landslides. Chapter Eight provides results of the social survey, and discusses traditional knowledge, perceptions, and coping strategies. It also addresses socio-economic and environmental impacts of the landslides. Chapter Nine provides an analysis of landslide studies in Malawi and mitigation measures for landslide geo-hazards in the study areas, and Chapter Ten provides major conclusions of the study. It highlights areas for further study.

# CHAPTER TWO

# GEOGRAPHY OF MALAWI AND THE STUDY AREAS

This Chapter describes the geography of Malawi in general and the study areas in particular. It also provides information on physical and socio-economic characteristics, which would help the reader to understand their contribution to either slope instability or vulnerability of societies to landslides in the subsequent sections. The first part of the Chapter outlines the general geography of Malawi while the second addresses the characteristics of the study areas.

## 2.1 Geography of Malawi

### 2.1.1 Location

Malawi is situated in east-central Africa between latitudes $9^{0}22'$ S and $17^{0}08'$ S and between longitudes $32^{0}40'$ E and $35^{0}55'$ E (GoM, 1985). It is approximately 860 km in length from north to south, and 250 km wide at its broadest point. Malawi covers an area of approximately 119,000km$^2$. Twenty-eight percent of the land is in the North, thirty-eight percent in the Centre and thirty- four percent in the South. Surface waters, principally Lakes Malawi, Chilwa, and Malombe account for 24,000 km$^2$. Lake Malawi is 570 km in length and up 90 km in width. Malawi is bordered on the north and northeast by Tanzania; on the east, south and southwest by Mozambique; and on the north and northwest by Zambia (**Figures 2.1a and 2.1b;** Carter and Bennet, 1973). Altitude varies greatly from 50m above the sea level in the Lower Shire to 2,600m above sea level on the Nyika Plateau in the North, and above 3000m above sea level on the Mulanje Peak in the South (GoM, 1985).

### 2.1.2 Physiography

Malawi is a country of varied relief, ranging in altitude from a little over 30m above sea level to the extreme south to 3000m on the Mulanje Mountains (GoM, 1985). Pike and Rimmington (1965) have distinguished three major physiographic divisions namely, the Shire Valley and the Lake Malawi Littoral (below about 500m); the medium plateau areas, such as the Shire Highlands and the extensive tertiary plains of the Central Region and the Mzimba Area, which are normally between 1,200m and 1,400m above sea level, but which range from about 600 to 1,500m; and thirdly, the highland areas above 1,500m (**Figure 2.1a**; Carter and Bennet, 1973).

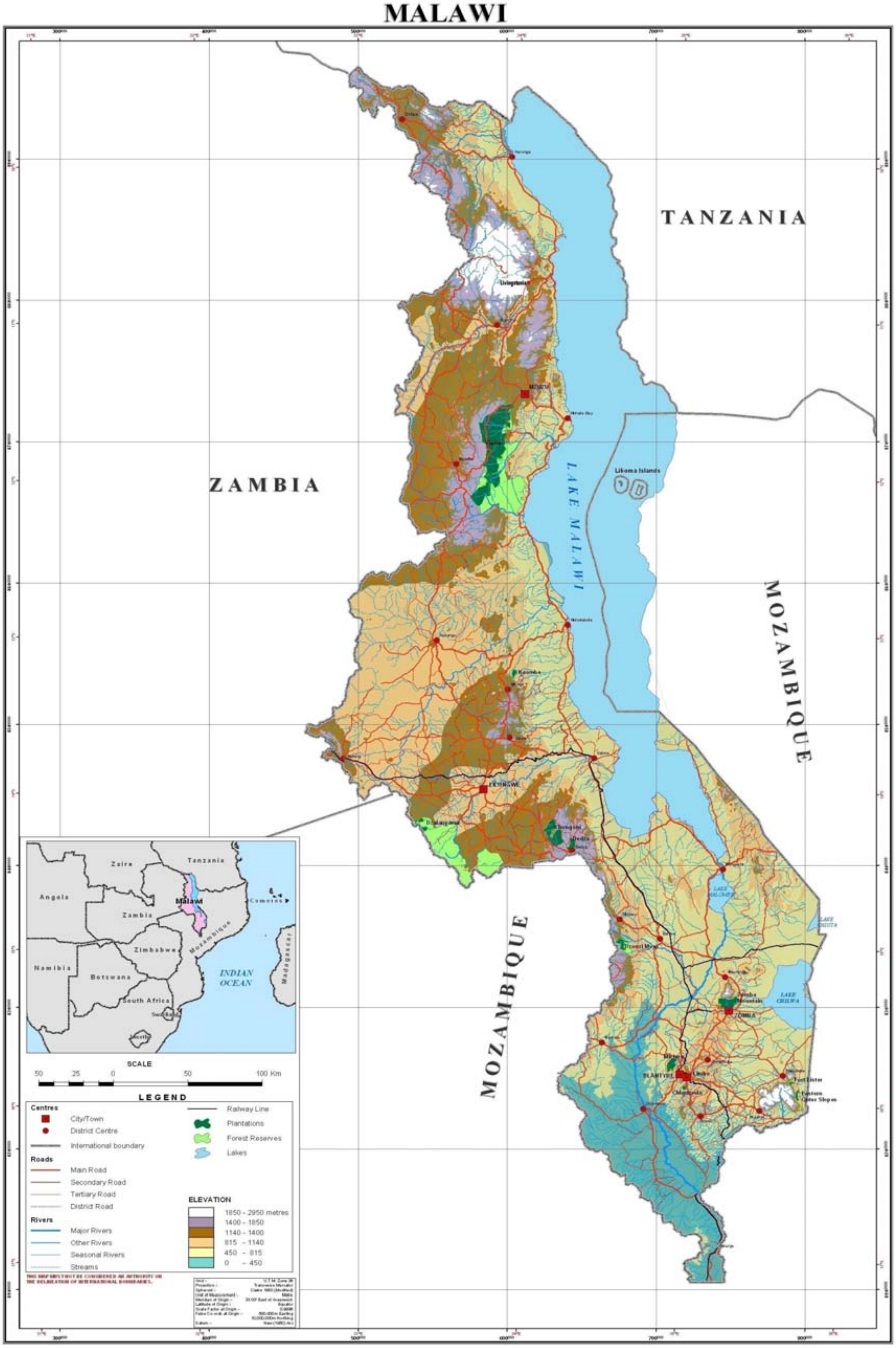


Figure 2.1a**: The Physiography of the country.**
**Source: GoM (1985).**

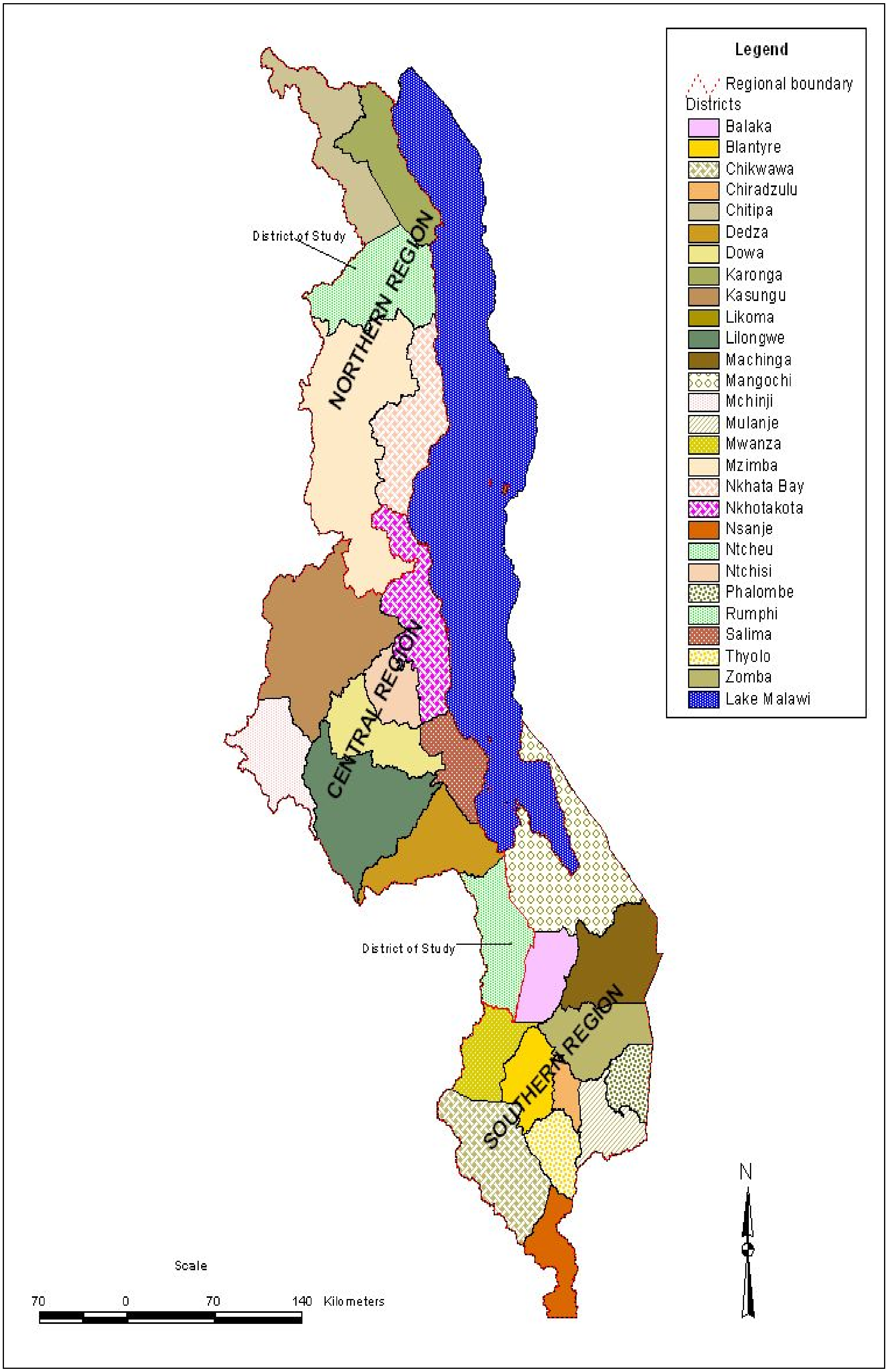


Figure 2.1b: **Map of Malawi showing Ntcheu and Rumphi Districts**

To these divisions, may be added the strongly dissected country of the Rift Valley scarp zone which ranges in altitude between approximately 500 and 1,200m, and separates the Shire Valley and the Lake Malawi Littoral from the medium plateau and highlands (Carter and Bennet, 1973).

The Malawi Rift Valley forms part of the East African Rift System (Dixey, 1956). It extends along the length of the country, and forms its most prominent features. The northern two thirds of the Rift are occupied by Lake Malawi which has an average elevation of 474m above the sea level (**Figure 2.1b**). To the west of the lake, the land surface consists of a number of variable dissected plateaus, rising between 1,200m and 2,500m above sea level, and is tilted towards the west. In Southern Malawi, the course of the Shire River delineates the southward extension of the Rift Valley which is flanked by higher ground, usually in the range of 500m to 1,300m. Surmounting this higher ground are isolated massifs such as Mulanje and Zomba mountains (Pike and Rimmington, 1965; and Carter and Bennet, 1973).

### 2.1.3 Geomorphological Development of the Country

The geomorphological development of the country is considered in terms of five principal erosion cycles and associated epeirogenic movements and faulting (Dixey, 1926; and Lister, 1967). Surfaces produced during the oldest recognised cycles namely, the Gondwana and Post-Gondwana cycles of Jurassic to the Mid-Cretaceous Age, are now restricted to the highest plateaus, though rarely as resurrected (fossil) land surfaces at the basal contacts of Cretaceous sediments (Agnew and Stubbs, 1972). Gondwana surface is displayed on the Nyika Plateau, exhibiting Post-Jurassic tilting which caused the general altitude of the surface to increase northwards across the Plateau. The Post-Gondwana erosion cycle is far more widespread in Malawi than is the older Gondwana (Lister, 1967). It occurs as broad, shallow valley-heads eroded the Gondwana surface on the Nyika Plateau, and as dissected plain on the Vipya Plateau. The summit levels of inselbergs of the Lilongwe Plain, the Kirk Range, Zomba, Dedza, and Mulanje mountains are assigned to the Post-Gondwana erosion cycle. The African (Late-Cretaceous to Early-Miocene) and Post-African (Late-Miocene to Pliocene) surfaces are more widespread. The African surface is characterised by extensive plains surmounted by scattered inselbergs and is best developed in the Central Region. The Post-African cycle tends to be better developed at lower altitudes, but it also modifies the African surface, particularly in the Rift Valley fault scarp where composite African and Post-African landscapes are recognised (Carter and Bennet, 1973). Quaternary erosion cycle is represented by both erosional features and lowland deposition (Agnew and Stubbs, 1972). Pleistocene to Recent deposits forms littoral plains margining the major lakes. Quaternary erosion is active along the Rift Valley escarpments and the rim may be notched by the active thrust of the new cycle. Quaternary surfaces of both erosional and depositional nature are usually of only limited extent and are confined to the floor and sides of the Rift Valley.

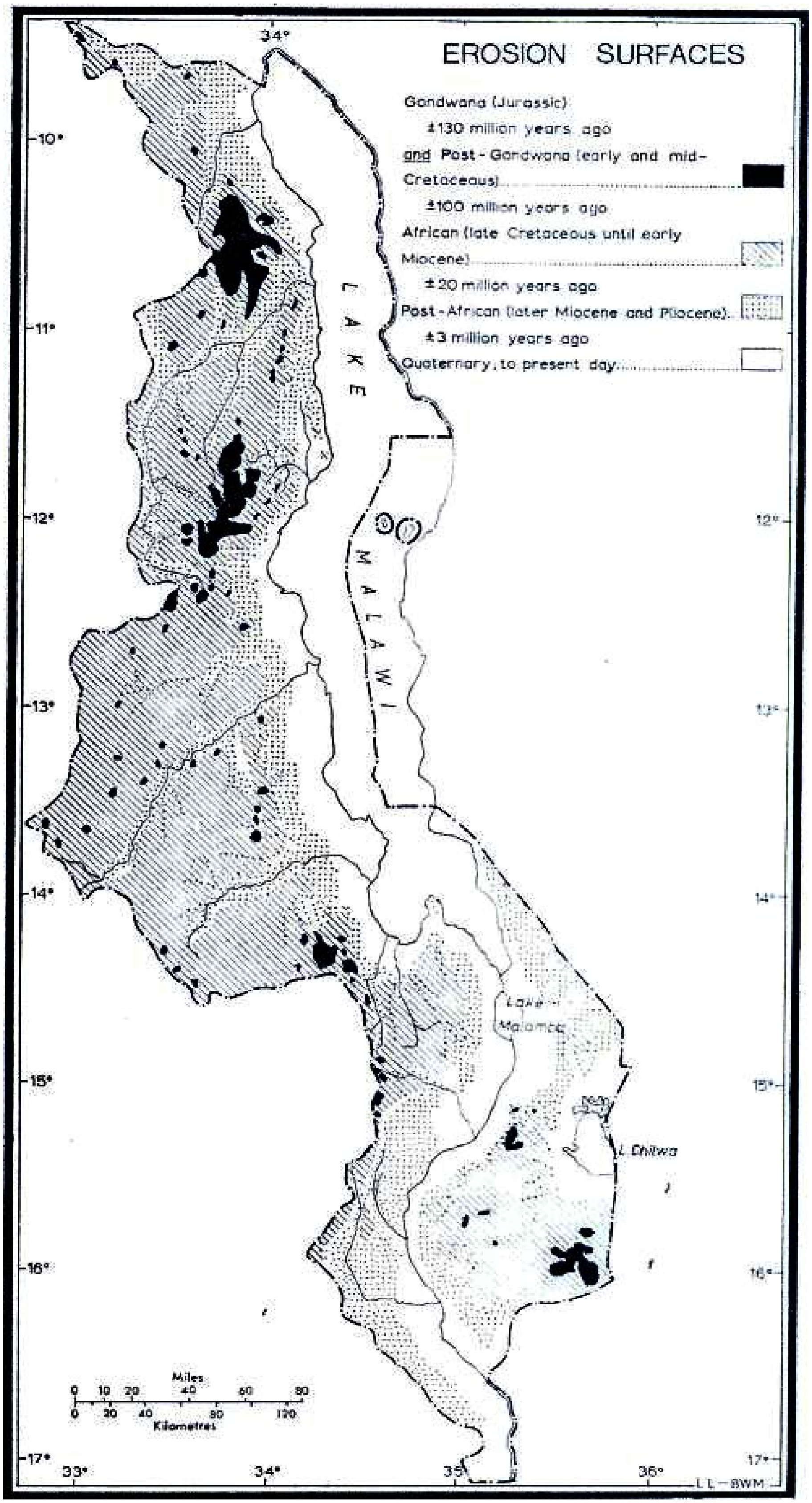


Figure 2.2: **Erosion surfaces of Malawi.**
**Source: Agnew . and Stubbs, (1972).**

### 2.1.4 Geology

The greater part of Malawi is underlain by crystalline rocks of Pre-Cambrian to Lower-Palaeozoic Age which are referred to the Malawi Basement Complex (**Figure 2.3**; Carter and Bennet, 1973). At various localities in the north and south of the country, these rocks are overlain from Permo-Triassic to Quaternary. Intrusive rocks of Upper-Jurassic to Lower-Cretaceous Age, assigned to the Chilwa Alkaline Province, occur widely throughout southern Malawi, and form a distinctive feature of the local geology. Large tracts of plains are covered by various superficial deposits (Agnew and Stubbs, 1972).

The basement complex has undergone a prolonged structural and metamorphic history. The Post-Basement Complex development of the country was dominated by epeirogenic movements, faulting and the formation of the Malawi Rift Valley (Agnew and Stubbs, 1972).

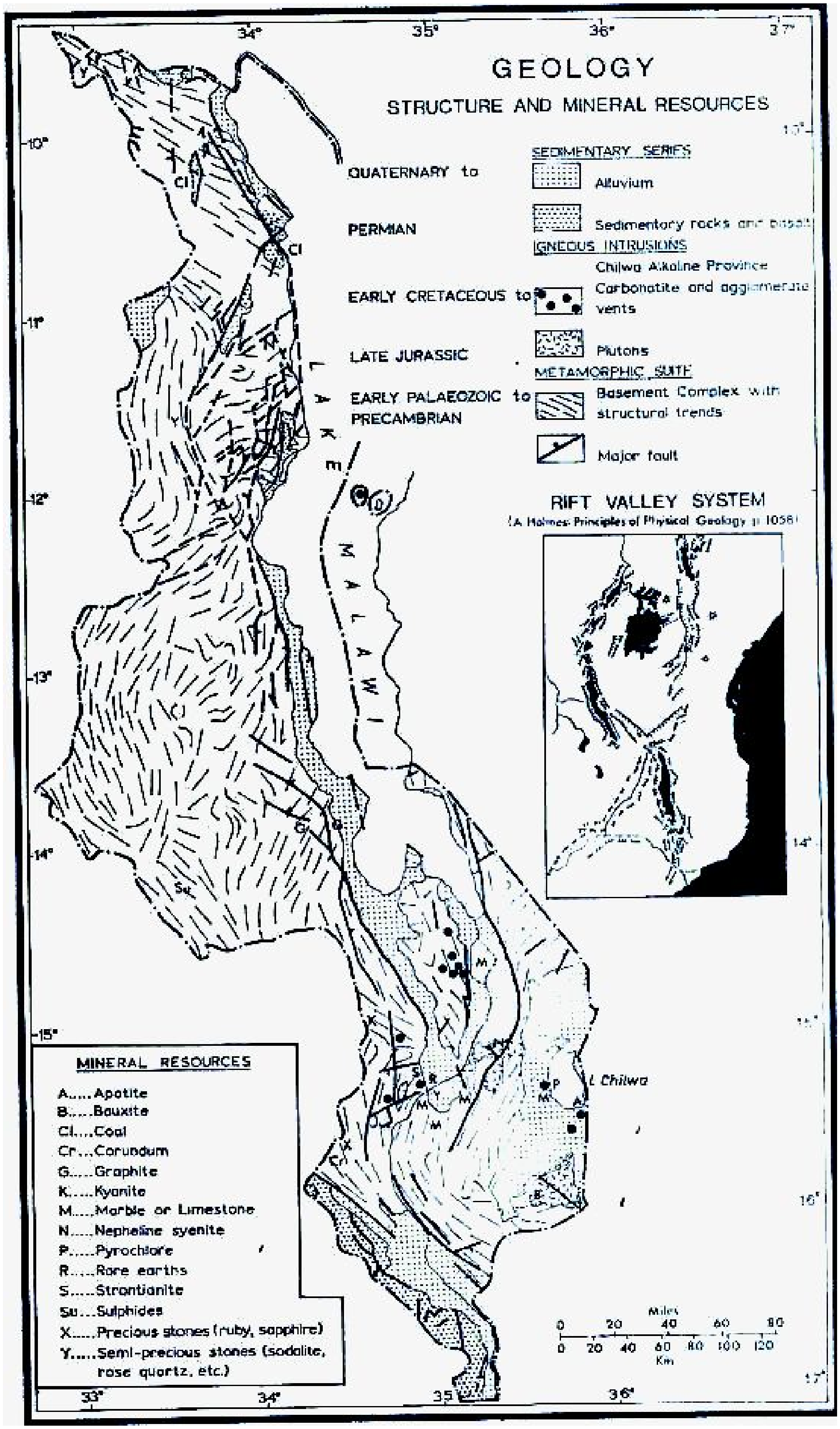


Figure 2.3: **The Geology of Malawi.**
**Source: Agnew and Stubbs (1972).**

### 2.1.5 Soils

There are four main soil groups, all differing markedly from each other in the environmental conditions under which they have been developed: in the process of formation; in a profile characteristics, and analytical properties (Agnew and Stubbs, 1972). The latosols are red to yellow, leached, acidic soils in which water movement within the profile is predominantly downwards. They occupy freely drained sites, mainly on the gently sloping plains, but also in some more steeply dissected areas. The calcimorphic soils are grey to greyish-brown, with a weakly-acid to weakly-alkaline reaction in which water movement is upward during at least part of the year. They occur on nearly level depositional plains with imperfect site drainage. The hydromorphic soils are black, grey or molted and water logged for all or part of the year. The fourth group comprises lithosols, which are shallow or stony, and regosols, which are immature, developed from sands (Agnew and Stubbs, 1972).

### 2.1.6 Hydrology

Twenty percent of the total area of Malawi is covered by water, comprising of Lake Malawi, Chilwa, Malombe, and Chiuta and major rivers such as Shire, Songwe, North and South Rukuru, Bua, Mwanza, Linthipe, and Ruo (**Figure 2.1a**). Lake Malawi is a dominant feature with a surface area of about 28,760km$^2$ with a catchment area of 96,918km$^2$. Annual rainfall over the Lake is estimated at 1549mm, with total inflow of 920m$^3$/s and out flow of 395m$^3$/s. The outlet of Lake Malawi is Shire River which has three sections, namely, upper (132km with a gradient of 5.29m), middle (384m with a total fall of 384m), and the lower section which stretches from the cataracts to the Zambezi River over a distance 281km (Linceham, 1972; and Agnew and Stubbs, 1972).

### 2.1.7 Vegetation

A greater proportion of Malawi's natural forest is dominated by Brachystegia woodlands (Abbot, 2005). The plateau areas are vegetated by Brachystegia-Julbernadia woodlands while the plain areas have broad-leaved deciduous Combretum, Acacia and Piliostigma (**Figure 2.4**). These tree species are being replaced by agricultural crops. Highlands like the Nyika are dominated by high altitude grassland while Mount Mulanje has Montane vegetation. Areas receiving low (< 750mm per annum) rainfall such as the Phalombe-Chilwa Plain are dominated by scrub vegetation.

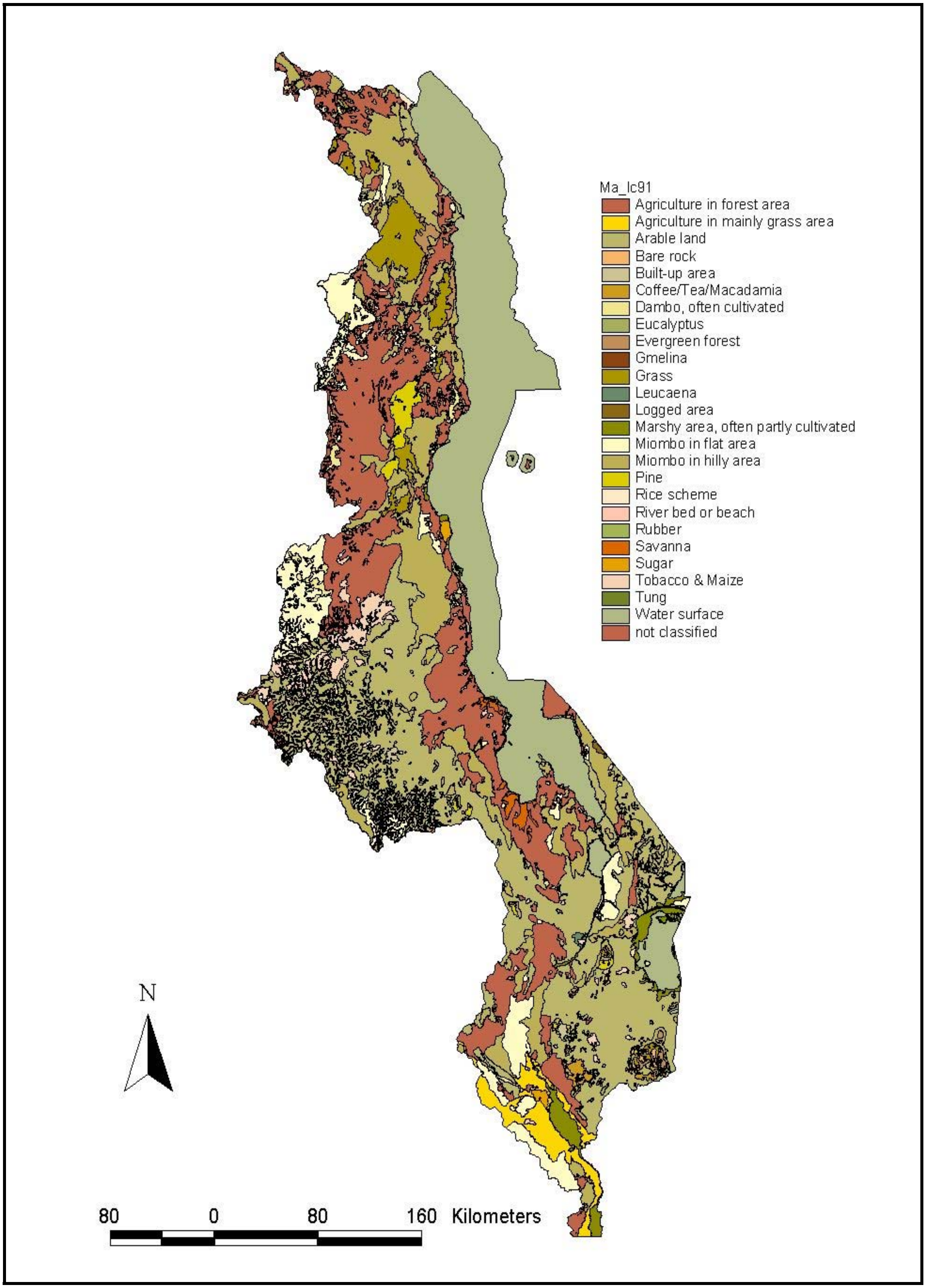


Figure 2.4: **Land use and land cover of Malawi.**
**Source: GoM (1995).**

Twenty percent of the country is covered by wetland vegetation, and 1.8% of the total forest is man-made. Deforestation is a serious concern (NEAP, 1998). In 1975, 47% of Malawi's land was classified as forest. In 2000, only 28% was classified as forest reserves. Deforestation rate is at about 2.8% per year, but the highest is Northern Malawi, where the rate is at around 3.4% (Kasulo, 2005). In 2001, 64 bush fires destroyed 1,520.04 hectares of forest cover (Kasulo, 2005).

### 2.1.8 Climate

Malawi experiences a tropical continental climate, with a cool dry season from May to August, a hot dry season from September to November, and a fairly hot wet season from December to April. Temperatures are influenced by variations in relief. Pike and Rimmington (1965) and Linceham (1972) note three temperature zones: the Shire Valley, and the Lake Malawi littoral experience mean annual temperature of 23$^0$C to 25$^0$C; the plateau areas are characterised by mean annual temperatures in the range of 19$^0$C to 23$^0$ C while the higher plateaus and mountain areas experience mean annual temperatures of 14$^0$C to 18$^0$C.

Most rainfall occurs between November and April, but certain areas receive rain throughout the year (Agnew and Stubbs, 1972). Only one-third of Malawi has a mean annual rainfall in excess 1000mm, and only five percent of the country receives less than 750mm; nearly two thirds of the country experiences rainfall between those values. Variations in relief and topography exert a considerable local influence (Linceham, 1972). The high plateau areas receive up to 2000mm per year; 900 to 1300mm are recorded annually in the medium plateau areas while the Karonga and southern lakeshore areas, the Shire Valley, and the Kasungu and Mzimba plains are drier and receive less than 900mm.

### 2.1.9 Climate Change

In recent years (1990's), Malawi has been experiencing significant variations in weather patterns ranging from severe drought (1991/2) to conditions of extreme flood events (1996/7). During years of extreme floods, for example, 1996/7, some parts of the extreme north of Malawi experienced drought (NEAP, 1998). Changes in the amount of rainfall and spatial variations have been recorded. There is scientific evidence that there are seasonal maximum and minimum temperature deviations over the mean influenced by climatic variation (NEAP, 1998). It is suggested that the disturbance of the Inter-Tropical Convergence Zone (ITCZ), shifts in global circulation patterns, deforestation, and changes in rates of evapo-transpiration, green house gas emissions and the disruption of the hydrological system are responsible for climate change (NEAP, 1998). However, no research at national level is going on in this area. No information is available to suggest that climate change is influencing landslide occurrences and their spatial distribution. This could possibly be an area for further research.

### 2.1.10 Population and Communication

In 1998, the population of Malawi was estimated at 12 million people with an annual growth rate of 3.2% (NSO, 1998). The population is expected to double in about 21 years. The population density in Malawi is considerably high, with a national average density of 87 people per $km^2$, and 171 people per $km^2$ of arable land. The population is unevenly distributed and the density decreases northwards. The Southern Region has the highest population density, ranging from 230 to 460 people per $km^2$. About 80% of the population live in rural areas, and agriculture is the mainstay of the country's economy. It is also estimated that 50% of the population is illiterate while 60% lives below the poverty line (NEP, 1996; and Slater and Tsoka, 2006). It is suggested that land degradation in Malawi is partly attributed to high population growth, poverty, and high illiteracy (Slater and Tsoka, 2006)

Malawi is divided into three administrative regions. Lilongwe is the present seat of government and is situated in the Central Region. Blantyre, located in the South of the country, is the largest urban area and is the main commercial and industrial centre. The administrative centre for the North is Mzuzu, situated in the Mzimba District (**Figure 2.1b**).

There is an adequate network of main and secondary roads throughout the country although communications are difficult in the mountainous and strongly dissected areas. The main routes are shown in **Figure 2.1a**. Two railway lines link Malawi with the coast. One extends southwards from Salima through Blantyre to the Mozambique border near Nsanje and on to Beira. The second skirts the northern end of Lake Chilwa and links Liwonde with the Port of Nacala.

## 2.2 Characterisation of the Study Areas

The research was carried out in three study areas, namely; the Ntchenachena Area and the Chiweta Area of the Rumphi District (Northern Malawi), and Mvai/Livilivi Catchments in the Ntcheu District (Central Malawi) (**Figure 2.1b**). The Ntchenachena and the Mvai/Livilivi areas were the primary sites, with Chiweta as a secondary site. Landslides in the Ntchenachena, the Mvai and the Livilivi areas occurred on natural slopes as opposed to those at the Chiweta Area which occurred on modified slopes.

### 2.2.1 Ntchenachena Area

#### 2.2.1.1 Location

The Ntchenachena Area, a country of rugged topography with interlocking spurs, is located in Rumphi District in the Northern administrative region of Malawi (**Figures 2.5 and 2.1b**). The area lies on the foot of the Nyika plateau, west of the Uzumara hills. It is bounded on the western side by longitude $34^0$05'E and on the south by latitude $10^0$35'S (Kemp, 1975; and GoM, 1977). It covers an area of approximately 264 hectares. The Ntchenachena hills are a continuation of the Uzumara hills to the north of the South Rukuru River and they abut the loftier East Nyika escarpments. The Livingstonia coal field is separated from the Ntchenachena Area by the Rumphi-Chitimba Road (GoM, 1987).

#### 2.2.1.2 Geology

Geologically, the region consists of a basement complex of Pre-Cambrian to Lower-Paleozoic rocks which is overlain by young sedimentary formations. In Northern Malawi, the Pre-Cambrian rocks were affected by both the Ubendian and Irumide Orogenies (Kemp, 1975). The resulting basement complex is largely composed of gneisses and muscovite schist of south easterly trend and structurally is the continuation of the Ubendian Belt of south-western Tanzania. The gneisses experienced a long period of erosion that was followed by deposition, mainly in the Permian and Triassic times of the Karoo Supergroup (Cooper and Habgood 1959). The Karoo Supergroup comprises sandstones, siltstones and shale with some coal seams near the base (Bloemfield, 1968; and Kemp, 1975). Within the study area, the geology of the Ntchenachena Area consists of highly jointed muscovite schist and biotite gneisses, with a gneiss foliation trend varying between $278^0$ and $114^0$. The average dipping angle is $45^0$. In some places, the lithology shows the presence of mica schists (GoM, 1977; and Kemp, 1975).

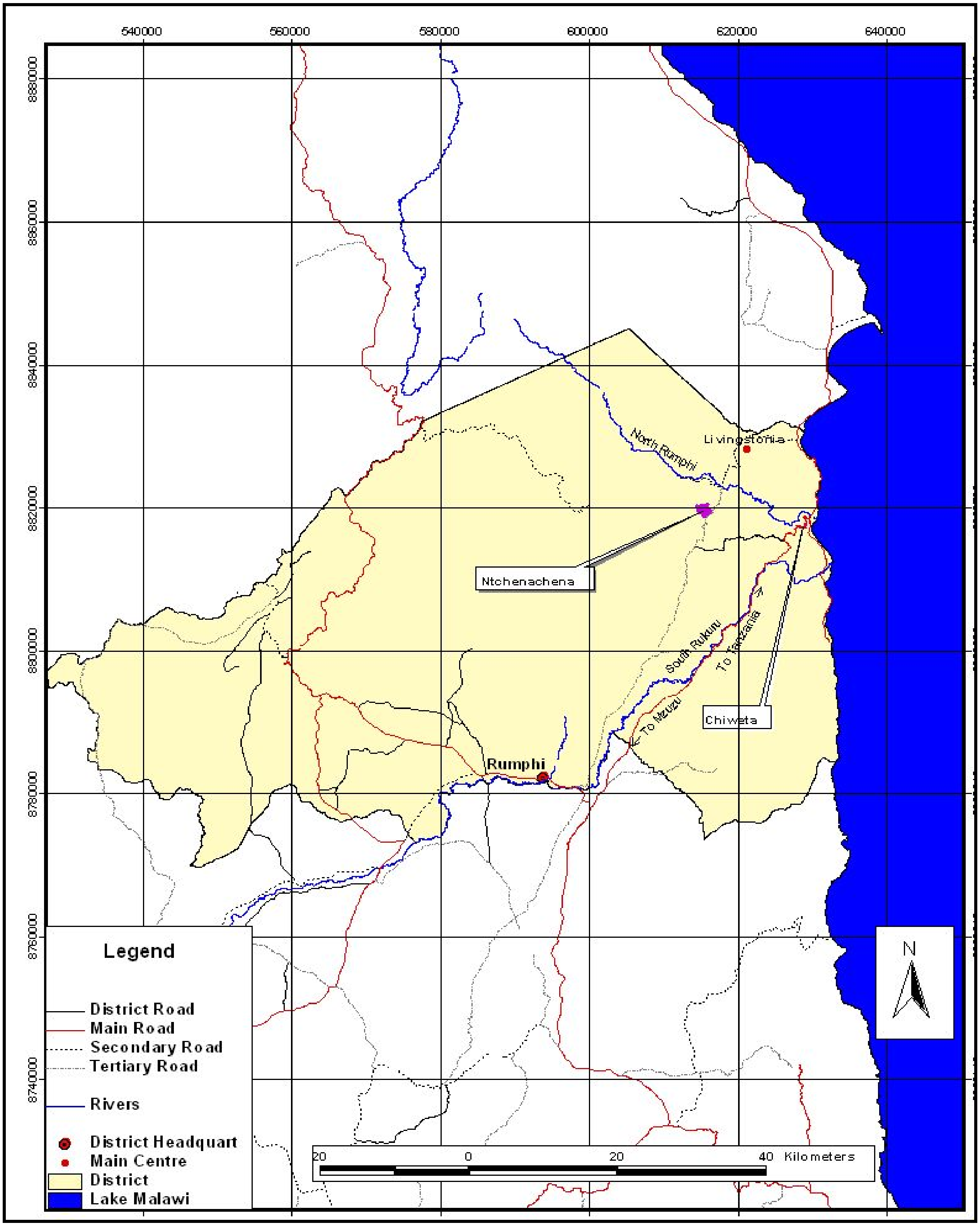


Figure 2.5: **Location of the Ntchenachena and the Chiweta Study Areas of Rumphi District in Northern Malawi.**

Due to deep chemical weathering, rock outcrops are rare in this area. In some localities quartz floats are present in the soil.

The geology is made up of quartzo-fiedspathic gneisses, which are also jointed in some areas. In most cases, these joints show a high intensity of weathering and the quartz and feldspar show myrmekitic structure. Within this area, quartz veins ranging from 0.10 to 0.35m in thickness, and pegmatites cut the gneisses at an oblique angle. The quartz-feldspar crystals increase in size towards the centre of the pegmatite. The contact between the pagmatites and the country rock is abrupt (Kemp, 1975).

#### 2.2.1.3 Topography

The Ntchenachena Area is a continuation of the East Nyika escarpments and is part of the Great African Rift Valley system (Kemp, 1975). The area is a belt of rugged country, consisting mainly of deeply dissected spurs which are almost funnel shaped (**Figure 2.6**) and much of it is almost inaccessible. Altitude varies significantly from 1295m to 1828m above sea level (GoM, 1987). Flat areas are concentrated along the valleys.

Figure 2.6: **Part of the Ntchenachena Area with interlocking spurs and funnel-like valleys: Note the landslide scars (26.08.06).**

#### 2.2.1.4 Soils

The soils of this area are derived from the deep chemical weathering of the muscovite schist, the gneiss and the Karroo sediments. The major soil group is ferrellic, of the soil family Luwatizi (Young, 1972). The Soils are very deep (>10m), with quartz floats in some areas (**Figures 2.7 and 2.8**). The surface stoniness is less than one percent. Generally, the soils are well-drained with a pH of 5.0 – 5.5. Organic matter content is in the range of 20% to 40% (Young, 1972). In the elongated valleys of the Ntchenachena Area, ferrisols are paramount. Red clays with a strongly developed blocky structure occur in association with leached ferralitic soils, but are less highly leached and more fertile. In the dambos, the gley or hydromorphic soils are dark coloured or mottled. They are locally known as dambo clays (Kemp, 1975).

Figure 2.7: **Deep ferrisols of the Ntchenachena Area in Rumphi District which are prone to liquefaction (26.08.06).**

Figure 2.8: **Ferrisols of the Ntchenachena Area with quartz floats which affect the shear strength of the soils. Note the formation of rills (26.08.06).**

### 2.2.1.5 Climate

The temperatures on the nearby Lakeshore are normally very high (over $30^0$ C), but owing to the high elevation of the study area, which is at 1828m above sea level, its temperatures are relatively low. The mean maximum monthly temperature ranges from $18.5^0$C to $20^0$C and mean minimum monthly temperature ranges from $7^0$C to $10.5^0$C (GOM, 2001).

The study area is one of the wettest areas in Malawi, having on average only one to two months as the dry period. Most of the rain falls between November and April. The mean annual rainfall range is over 1400mm, with the exceptional years when annual rainfall of over 2600mm is experienced (Linceham, 1972; and **Figure 7.2 p.126).** The main type of rain falling in the area is orographic although in summer (November to April) convectional rain falls. The types are influenced by maritime effects and the relief barrier. Warm moist air from Lake Malawi is forced to rise over the Livingstonia escarpments, resulting in rain formation (Agnew and Stubbs, 1972; and Linceham, 1972).

### 2.2.1.6 Vegetation

The vegetation of this area is classified as Afro-montane, with scattered grass and shrubs (**Figure 2.9**). Common shrubs in this area include *Protea*, *Faura saligna*, and *Syzigium* (**Section 7.3**). Most of the slopes are under cultivation (**Figure 7.5 p.131**), and this has resulted in large scale cutting down of trees, although isolated patches of pine trees are still growing along the ridges. The rate of deforestation has accelerated in recent years mainly due to seasonal burning of the trees, bushes and shrubs for shifting (slash and burn) cultivation and hunting. These shrubs and bushes represent a degenerated type of vegetation. Along the streams, dry season cultivation is being practiced, and that has resulted in the destruction of shrubs and dambo grass.

Figure 2.9: **Afro-Montane vegetation of Ntchenachena. Grasses and shrubs are dominant which do not provide maximum mechanical binding to the deep ferrisols (25.08.06).**

#### 2.2.1.7 Hydrology

Numerous streams originate from the Ntchenachena Area. Most of these are perennial due to the high rainfall that the area receives and the ability of the soil and weathered basement complex to absorb and store much of the precipitation (Linceham, 1972). However, the perennial rivers show marked seasonal variation with rainfall. Following the commencement of the rains in November/December, discharge from the perennial rivers increase progressively to a maximum in February or March (Young, 1972). The most notable rivers flowing out of the area are the Lutowo and Chikwezga. These join the Mzinga River which flows northwards to join the North Rumphi River at Phoka Court. Since the water table is high in most parts of the area, springs are numerous.

#### 2.2.1.8 Human Activity

Agriculture is the most important activity being carried out in the area. The majority of the people living in this area are subsistence farmers. The main crops grown in the area include maize, pineapples, cassava, millet, sorghum, bananas, and vegetables. Coffee and tobacco (**Figure 2.10**) are grown as cash crops, but on a small scale. The Phoka people herd animals, mainly goats (**Figure 7.12 p.142**), and they are also hunters.

Figure 2.10: **Tobacco curing shed in the Ntchenachena Area, contributing to deforestation. Note that the location of the Shed is on a remodeled slope affecting the balance of forces operating in slope (25.08.06).**

Lumbering (mainly pit sawing) is an important activity in this area (**Figure 2.11**). This has been boosted by the construction and carpentry industries which provide income generating opportunities for the local population. Valuable timber tree species include *Gmelina Blue gum, and Pinus pitula.*

Villages within the Ntchenachena Area tend to be scattered and isolated. In most of the villages, houses are built along ridges although some are built along slopes. Due to the nature of the terrain, with its dissected deep valleys and interlocking spurs (**Figure 2.6**), houses tend to be isolated and built in a linear pattern.

Figure 2.11: **Pit sawing in the Ntchenachena Area, contributing to deforestation and slope instability (30.08.06).**

### 2.2.2 Chiweta Area

#### 2.2.2.1 Location

The Chiweta Area is also located in Rumphi District (**Figures 2.1b and 2.5**). It is to the east of longitude $34^0$10'E and north of latitude $10^0$45'S. It covers an area of 84.6 hectares. The area borders Lake Malawi at Chiweta and is also part of the South Uzumara (GoM, 1977). Geologically, it is within the Livingstonia coalfield (Kemp, 1975; GoM, 1975).

#### 2.2.2.2 Geology

The geology of the area consists of a basement complex of Pre-Cambrian to Lower-Paleaozoic rocks mainly biotite gneiss (GoM, 1977). These rocks are overlain by young sedimentary formations (Kemp, 1975). In some areas, the basement is exposed due to intensive folding and erosion. In such areas, biotite gneiss with siliminate, muscovite and interbanded hornblende-gneiss can be seen. The Chiweta beds are the dominant feature made up of uplifted strata (**Figure 7.16 p.147**). They (K7 and K6) were originally described by Dixey (1926), occur in a small down–faulted block lying just to the north of the mouth of the North Rumphi River. The beds consist mainly of purplish mudstones (the Chiweta Bone Beds) dipping northwards at about $10^0$. An upper division (the Chiweta Grits) separated from the mudstones by an unconformity, consists of thick-bedded purplish grits with rare partings of mauve sandstone. The lower part of the mudstone sequence includes beds of modular limestone and marly conglomerates containing rolled limestone pebbles. Similar conglomerates in the central part of the sequence have pebbles composed of limestone, mudstones and rolled bone fragments. These have been recognised by Dixey (1926) as reptilian remains, one large skull having been tentatively identified as that of a Dicynodont. These rocks fall in the Karoo Supergroup (Kemp, 1975; and Cooper and Habgood, 1959). The area bordering the lake is dominated by unconsolidated lakeshore deposits and alluvium which are superficial deposits of Tertiary to Recent origin (**Figure 2.12**). There are numerous observed and inferred faults in the area (GoM, 1977).

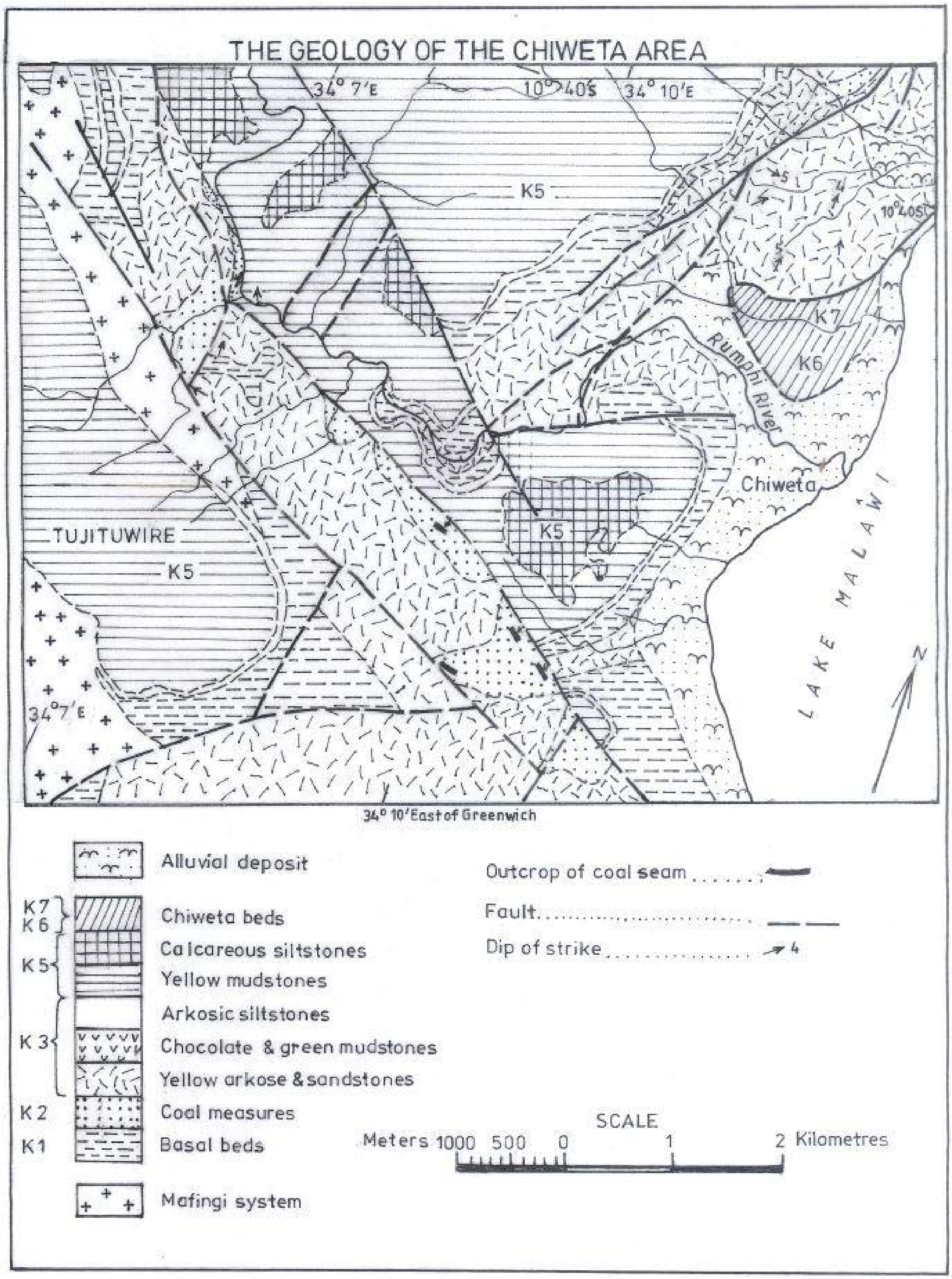


Figure 2.12: **The geology of the Chiweta Area, showing the stratigraphy of the beds Source: GoM (1975).**

#### 2.2.2.3 Topography

The Chiweta Area is made up of steep slopes due to the uplifting of sedimentary beds by rift faulting. Like the Ntchenachena Area, the terrain is rugged. The beds, mostly consisting of mudstones, are highly folded and fractured. Numerous proven and inferred faults have been mapped (GoM, 1977). In most parts of the area, the sedimentary rocks are highly weathered (**Figure 7.16 p.147**). Altitude ranges from 721m to 822m above sea level. Both the Ntchenachena and the Chiweta Areas fall in the Great African Rift Valley system (GoM, 1987).

#### 2.2.2.4 Soils

The soils of this area are derived from the rapid chemical weathering of limestone and mudstones. In the exposed surfaces, the soils are thin due to rapid soil erosion which exceeds the rate at which soil is replenished (Cooper and Habgood, 1959). In forested parts of the Chiweta beds, soils are deep. The major soil grouping is ferrisols. In areas along the Lakeshore, alluvial soils and sand deposits are dominant (**Figure 2.12**).

#### 2.2.2.5 Climate

Temperatures are generally high due to the proximity to the lakeshore and low altitude. During summer, daily temperatures are always greater than 30$^0$C. However, the upper parts of the Chiweta beds register relatively low temperatures (Linceham, 1972). Like the Ntchenachena Area, the area receives plentiful orographic rain between November and April. Annual average rainfall is greater than 1400mm. The high rainfall (**Figure 7.2 p.126**) is due to warm moist air ascending the beds from the adjacent Lake.

#### 2.2.2.6 Vegetation

The area is dominated by light forest trees, with bare areas along the slope cutting. This vegetation is broadly categorised as Miombo (**Figure, 2.13**), and the dominant tree species include *Brachystegia*, *Combretum*, *Diplorhynchus condylocarpon*, *Acacia*, *and Pseudolachnostlis* (**Section 7.3 p130**). Much of the forest is still undisturbed although the lower part is experiencing encroachment. Tree cutting is mainly due to a boom in tobacco production and increasing demand for fuel wood in Mzuzu City which is to the south of the study area. Because of the light forest canopy cover, savanna grasses flourish and are well-established. Areas along the lake are not forested due to the presence of sandy soils.

Figure 2.13: **Miombo woodlands typical of the Chiweta, Mvai and Livilivi Areas, which were observed to contribute to slope stability through mechanical binding of particles (28.08.06).**

#### 2.2.2.7 Hydrology

There are few streams flowing out of the area: one stream joins Lake Malawi at Chimphamba Kalua, and another one flows eastwards to join the North Rumphi River. Springs are numerous (GoM, 1987). It should also be noted that because the area is made up of highly weathered sedimentary rocks, this contributes to high percolation. This deep seepage may explain the absence of streams in this area.

#### 2.2.2.8 Human Activity

Within the Chiweta beds, settlements are absent, except for areas along the Lakeshore. This is due to the topography of the area. Houses are scattered along the plain areas adjacent to the lake. Villages in this area include: Kamphone, Bombo, Dimba Mhango, and Mtombolwa. The main activity taking place along the lake is fishing although general cultivation is practised (GoM, 1987). Crops grown include maize, rice, and cassava. Villagers keep livestock, mainly goats and pigs. Fuel wood selling is common in the lower section of the Chiweta beds and is contributing to deforestation.

### 2.2.3 Mvai/Livilivi Catchment Areas

#### 2.2.3.1 Location

These areas are located in Central Malawi in Ntcheu District (**Figure 2.1b**), covering an area of 2,714 km$^2$. The Mvai Catchment covers an area of 316.4 hectares while the Livilivi Catchment covers 146 hectares. The areas are bounded to the north by line of latitude 14$^0$30’ S, to the south by latitude 15$^0$00’ S, and to the east by longitude 35$^0$00’ SSE (**Figure 2.14**). Altitude varies from 1200m above sea level in the Livilivi Area to 1670m above sea level in the Mvai Area (GoM, 1987).

#### 2.2.3.2 Hydrology

The catchments have a number of streams although most of them are seasonal. The most important rivers originating from these catchments are the Mvai, which supplies water to the Mpira dam, and the Livilivi, which drains into Lake Malawi. These were the two rivers which were affected by the 2003 landslides. Numerous boulders can be seen lying along the channel.

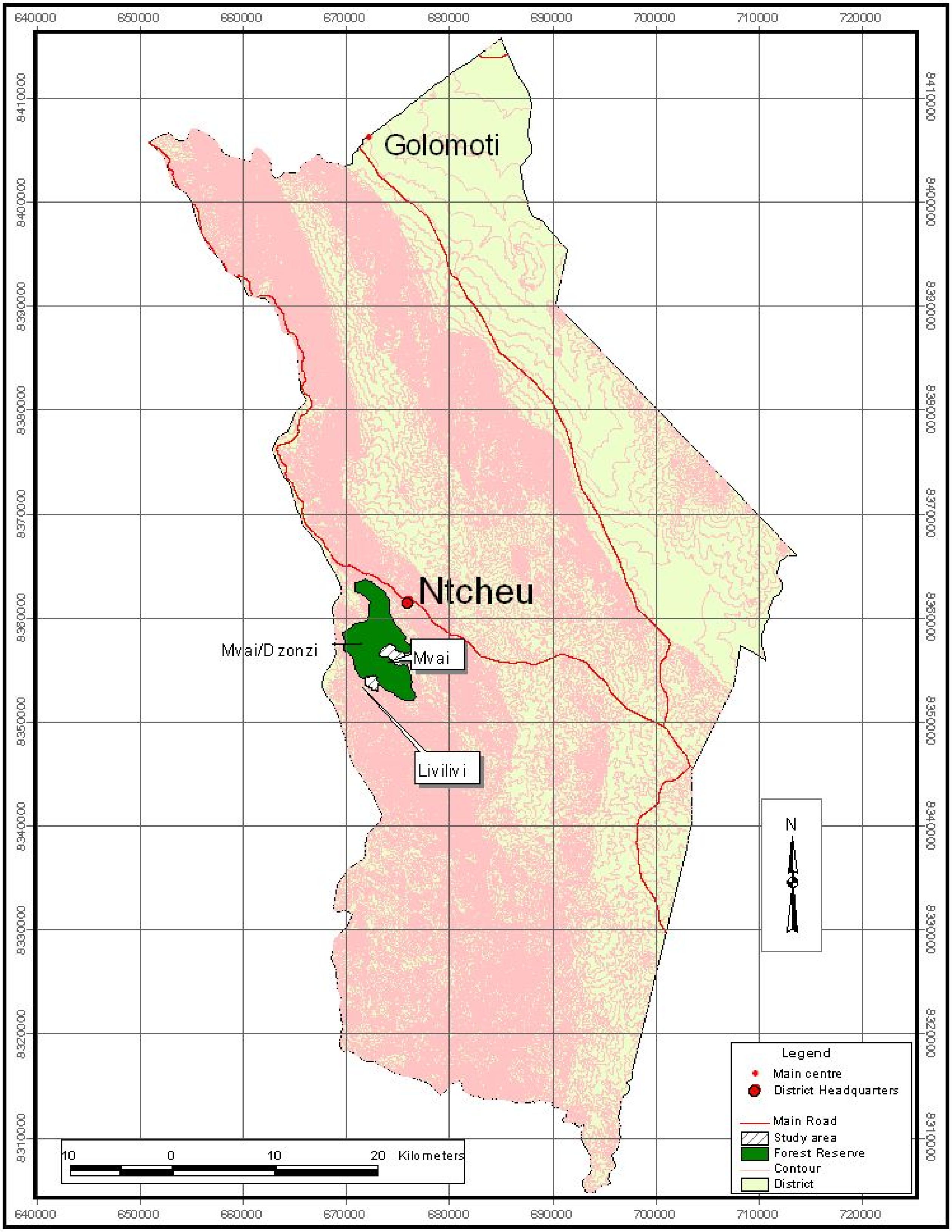


Figure 2.14: **The Ntcheu District of Central Malawi, showing the Mvai and Livilivi Study Areas.**

#### 2.2.3.3 Geology

The rocks of the catchments comprise mostly gneisses which include banded biotite gneiss and hornblende-garnet- gneiss. Bands of quartzo-feldspathic granulite and gneiss and perthite gneiss grading into perthosite represent major relief pattern in the area (Mwenelupembe, 2003). The rocks have a generally north-west trend which is also displayed by relief features in the area. In this area, rocks are heavily jointed and fractured and splitted (**Figures 7.9, 7.14 and 7.15 p.137, 145 and 146**), and this has led to the formation of boulders scattered through the hills making the catchments (**Figure 2.15**). In most areas, the boulders are resting in an unstable manner (**Figure 7.14 p.145**).

Figure 2.15: **Rock outcrop (gneisses) within the Mvai/Livilivi Catchments. Rockfalls have been reported in this Area. Note the Miombo woodlands in fore ground which arrest some falling boulders (2.09.06).**

#### 2.2.3.4 Vegetation

The two study sites fall within the Mvai and Dzonzi Forest Reserves (**Figure 2.14**). Most parts of the forests are dominated by stands of *Brychystegia*, *Combretum*, *Faurea Saligna*, *Dalbergia nitidula*, *Lannea discolor*, *Ozoroa insigns*, *Uapaca zanzibariaca*, *Ficus*, *Mbilima*, *Mpoloni*, *and Parinari kirkiana.* In some areas, grasses are dominant due to wanton cutting down of trees for fuel wood and charcoal burning (**Figure 7.6 and 7.7 p.132**). It should be noted that the forest reserves are suffering from severe deforestation (Abbot, 2005).

#### 2.2.3.5 Human Activity

In the Mvai/Livilivi Catchments, settlements are absent as these two areas fall in forest reserves. However, on the edges of the forest reserves settlements are present. The main economic activity is subsistence farming. Crops grown include maize, beans, irish potatoes, sweet potatoes, and cassava. Cultivation is mainly confined to the banks of the Mvai and Livilivi Rivers which make crops and farmland vulnerable to debris flows. Some people keep livestock, mainly goats and chickens for consumption. Some villagers are involved in fuel wood and charcoal selling to the nearby Ntcheu District Headquarters. These products are obtained illegally from the forest reserves. Basket and mat weaving are done on a small scale. Others are informally employed at Ntcheu District headquarters

## 2.3 Conclusion

The Chapter has described the geography of Malawi, and the characterisation of the study areas. Socio-economic aspects have been presented with a view to bring a better understanding of the physical and socio-economic environments in which landslides occur. In the next Chapter relevant literature pertaining to landslides generation mechanisms, causes, impacts, role of traditional knowledge and mitigation measures employed by some previous studies will be discussed.

# CHAPTER THREE

# LANDSLIDES: CLASSIFICATION, MECHANISMS, CONSEQUENCES, PREDICTION AND MITIGATION

The previous Chapter focused on the geography of Malawi and the characterisation of the study areas. This Chapter examines the concept of landslides. It discusses the classification of landslides and mechanisms of generation. The idea is to introduce the principles which help explain landslide mechanisms. This Chapter also reviews literature on the principles of causes, landslide mapping, damage caused by landslides, their prediction, and mitigation.

## 3.1 Concept of Landslides

"Landslide" is the most overused and loosely defined term employed in slope studies (Butler, 1976; Crozier, 1984; Bryant, 1991; Alexander, 1993; Coch, 1995; and Msilimba, 2002). It is a convenient umbrella term employed to cover a wide range of gravity-dominated processes that transport earth materials down slope. The displacement is achieved by one or more of three mechanisms: falling, flowing, and sliding (McCall, 1992). These three mechanisms produce a huge spectrum of slope failures in terms of form and behaviour. Channel sizes vary enormously, with some events moving very rapidly and others exceedingly slowly. In some cases, the displacement is achieved in a single, short-lived event typical of most landslides in Malawi; (Gondwe and Govati, 1991; Poschinger et al., 1998; and Msilimba, 2002) while in other circumstances the movement is gradual, cyclic or pulsed. The displaced materials can create irregular terrain of scars, ridges, humps, and hollows (Alexander, 1993; and Smith, 1996).

Geologists and Geomorphologists prefer the term "mass movement" as opposed to "landslides" because the displacements do not always occur on land, but on the seafloor as well, and may move by creeping or falling (Coch, 1995). Among the local people in Malawi, landslides are explained in the form of myths (Chikusa, 1985). In Southern Malawi, the local people call landslides, mudflows, water floods, and debris flows "Napolo" while in Northern Malawi they are called "Vwira". According to the local people, the word "Napolo" or "Vwira" describes a giant hydra-like snake that lives in a lake underneath the ground within the mountains. The snake is said to sleep on its back and when turning to make itself comfortable, the mountain bursts open. Some believe that it erupts in the form of a large flow of water when it feels lonely and wishes to go to a lake on the surface (Cheyo, 1999). In this study, the term landslide is used loosely to encompass slides, topples, flows, falls and creeps. In some cases the term is used interchangeably with the term mass movements.

## 3.2 Areas Prone to Landslides

A full understanding of danger-prone areas is central to effective landslide assessment, prevention, and mitigation. Smith (1996) identified areas where landslide occurrence probability is high. Such areas include the following: (1) Areas with major faults experiencing seismic shaking; (2) Mountain environments with high relative-relief; (3) Areas of moderate relief suffering severe land degradation; (4) Areas covered with a thick sheet of loess and (5) Areas subject to high rainfall, most commonly in tropical areas where material has been weathered to a reasonable depth. Most mountainous areas of Malawi fall in categories 1, 2, 3, and 5 (GoM, 1985; and NEP, 1996).

## 3.3 Classification of Landslides

Landslides classification is considered as an important first step to scientific investigation of landslides (Crozier, 1984; and Msilimba, 2002). A classification is designed to reduce the multitude of different, but related phenomena to a few easily recognised and meaningful groups on the basis of common attributes (Crozier, 1984). A good classification specifies its classificatory parameters in unambiguous, universal terms to allow for standardised application and reproducibility of results. A summary of the criteria for landslide classification is given by Varnes, (1978). Landslide classifications are also given by Campbell (1951), Zaruba and Mencl (1969), Crozier (1973), Hutchinson (1978), Coch (1995), and Smith, (1996). Below is a general landslide classification:

### 3.3.1 Topples

Topples involve the outward rotation (or inward buckling and basal collapse) of angular blocks or rock columns that become detached from cliffs (Crozier, 1984; Alexander, 1993). These blocks or columns are usually defined by the intersection of joints or other fractures, and their basal stability is often disturbed by erosion (Ludman and Koch, 1982). Topples have been observed to have occurred on the slopes of Nyambilo Hills in Southern Malawi (Chipili and Mshali, 1989).

### 3.3.2 Falls

Falls normally involve the free movement of rock material down steep slopes, with no permanent contact of the moving material to the slope surface (Crozier, 1984; Bryant, 1991; and Alexander, 1993). The movement is turbulent and the reach of the rock fall is in close relation to the angle of internal friction of the moving material, and is defined by the energy line (Bryant, 1991). Falls are common in Zomba Mountain Area of Southern Malawi(Poschinger et al., 1998).

### 3.3.3 Slides

Slides are the down slope movements of rock and soil along a slip surface and are characterised by almost permanent contact between the moving mass and the slide surface (Crozier, 1984; Bryant, 1991; Alexander, 1993; and Smith, 1996). The most common sub-groups are “translational” and “rotational” slides. Translational slides are relatively flat, planar movements along surfaces and they generally have pre-existing slide planes that are activated during the slide event. In contrast, rotational slides have a curved surface rupture and produce slumps by backward slippage (Alexander, 1993; and Smith, 1996). Some rotational slides are multiple regressive phenomena and are termed roto-translation (Alexander, 1993). When the slope is almost horizontal the debris spreads over a wider area; hence, the term lateral spread. Rotational slides were observed in the Vunguvungu/Banga catchments in Northern Malawi due to deep weathering of the basement (Msilimba, 2002; and Msilimba and Holmes, 2005). They are also common on the slopes of Mount Elgon in Uganda (Knapen et al., 2006).

### 3.3.4 Flows

Flows are down slope movements of fluidised soil and other materials acting as viscous masses. In a flow, the structure of the material changes into quasi – fluid (Johnson and Rodine, 1986; and Bryant, 1991). The most common type of flow is the debris flow (Corominas et al., 1996). It is the most dangerous type (Takahashi, 1991) due to the fact that debris flows often extend far from their sources, and their depositional areas often include inhabited sites. The 1991 Phalombe Landslide (Gondwe and Govati, 1991; and

Cheyo, 1999), and the 1946 Zomba Mountain Landslide (Poschinger et al., 1998) both in Southern Malawi, are typical examples of debris flows and they were associated with extensive damage to property and life. Other categories include: solifluction, mudflows, and debris avalanches (Coch, 1995).

### 3.3.5 Creeping

One of the least destructive mass movement phenomena is soil creeping which tends to be slow, superficial and predominantly seasonal (Hutchinson, 1978; Crozier, 1984; and Alexander, 1993). However, many of the other forms of landslides can undergo creeping and gradually do serious damage. Soil creeping was observed in Vunguvungu/Banga catchments in Northern Malawi (Msilimba, 2002). A summary of landslide classification and material involved in the movement is given in **Table 3.1.**

**Table 3.1: Classification of Landslides**

| Mass wasting Type | Character of Movement | Subdivision | Speed and Type of Movement |
|---|---|---|---|
| Falls | Particles fall from cliff and accumulate at base | Rockfall and Topples | Extremely rapid; develops in rocks |
| | | Soilfall | Extremely rapid; develops in sediments |
| Slides | Masses of rock or sediment slide down slope along planar surface | Rockslides (Translational) | Rapid to very rapid sliding of rock mass along a rectilinear/ inclined surface |
| | | Slump (Rotational) | Extremely slow to moderate sliding of sediment or rock mass along a curved surface |
| Flows | Displaced mass flows as plastic or viscous liquid | Solifluction | Very slow to slow movement of saturated regolith as lobate grows |
| | | Mudflow | Very slow to rapid movement of fine grained particles with 30% water |
| | | Debris flow | Very rapid flow of debris; commonly starts as a slump in the upslope area |
| | | Debris avalanche | Extremely rapid flow;fall and sliding of rock debris |
| Creeping | Regolith soil and rock | | Extremely slow superficial deposits and the influence of gravity. Predominantly seasonal. |
| Complex | Combination of two or more principle types of movements | | |

Adapted from: Smith (1992) and Coch (1995) (Modified)

### 3.4 Classification of Slopes

In slope stability analysis, the emphasis is on the determination of the state of the slope. The determination assists in the assigning degrees of relative risk and the development of prevention and mitigation measures (Zaruba and Mencl, 1969; Crozier, 1973; and Coch, 1995). Slopes can be divided into three classes (Crozier, 1986; and Knapen et al., 2006). Stable slopes are those whose margin of stability is sufficiently high to withstand all destabilising forces. Slopes of the Chinyebe Hill in Northern Malawi are a typical example of stable slopes (Msilimba, 2002); marginally stable slopes are those that will fail at some time in response to the destabilising forces attaining a critical level of activity. Slopes of the Nyankhowa Area in Rumphi District fall into this category (Msilimba, 2002; and Msilimba and Holmes, 2005). Active unstable slopes are those in which destabilising forces produce continuous or intermittent movement. Slopes of the Banga Hills are a good example (Msilimba, 2002). These stages must be seen as a continuum with the probability of failure increasing from the stable end of the spectrum, through the marginally stable range to reach certainty in the active unstable stage (Knapen et al., 2006). Another classification by Crozier (1984) puts slopes into five classes: Class V representing highest risk and Class I the lowest risk. Most of the slopes on the highlands of Malawi are marginally stable - a condition attributed to cultivation on fragile environments and deforestation (NEP, 1996; NEAP, 1998; and Kasulo, 2005).

In slope stability analysis, slope angle is regarded as the major topographic factor in determining stability (Hoek and Boyd, 1973; Crozier, 1984; and Msilimba and Holmes, 2005). Slope angle was a critical determinant to the occurrence of the 1991 Phalombe and the Zomba Mountain landslides (Poschinger et al., 1998; and Cheyo, 1999). Although slope angle is a major topographic attribute affecting hydrological conditions and stability analysis, its importance seems to have been over-estimated (Fernandes et al., 2006). Fernandes et al., (2006) found out that the frequency distribution of landslides (landslide potential index - LPI) depends on other factors. The study revealed that slope angles between $18.6^0$ and $37^0$ were the most frequent to fail, followed by $37.1^0$ to $55.5^0$ ranges. Beyond $55.5^0$, LPI decreased. The steepest sites were associated with shallow soils which have already failed. It was also established that hill slope orientation (aspect) affects indirectly other factors such as precipitation, soil moisture, vegetation cover and soil thickness. However, no studies have been carried out to correlate landslides and slopes aspect/angle in Malawi.

### 3.5 Dating and Geological Developments of Landslides

The dating of landslides poses a serious problem to many scientists (Kaufulu, 1991). This is partly because some events pass unnoticed in remote areas. Sliding phenomena are due to the activity of many factors, among which the time factor also plays an important role. As individual agents change in the course of time the slide passes through several phases of development (Zaruba and Mencl, 1969). According to their development, slides can be divided into initial, advanced or exhausted. Based on the degree of stabilisation, slides can be classified as active, dormant or stabilized. Based on their age, they can be categorised as contemporary, fossil (which cannot be revived under the present day climatic and morphological conditions) or dormant (Zoruba and Mencl, 1969). The 1946 Zomba Mountain Landslide in Southern Malawi falls in the dormant stabilised or exhausted because, since its occurrence 60 years ago, the event has never recurred (Poschinger et al., 1998). However, most of the landslides in the Vunguvungu/Banga catchments in Northern Malawi are active and recent (Msilimba, 2002).

### 3.6 Landslide Mechanics

Slope instability is the condition which gives rise to slope movements (Alexander, 1993). In every slope there are forces (stresses) which tend to promote movement (shear stress), and opposing forces which tend to resist movement (shear strength), (Bromhead 1984; Crozier, 1989; and Alexander, 1993). Sliding occurs when the forces tending to cause movements are greater than those resisting it. In normal circumstances, the shear stress is balanced by shear strength and a state of equilibrium is maintained (Alexander, 1993). However, this equilibrium can be disturbed by stress increments or the weakening of frictional force. Below is a discussion of different mechanics of landslide generation. Equations and formulas are given in **Appendix 1**.

#### 3.6.1 Stress and Strain

Any mass on an inclined plane is affected by gravity and the size of the gravitational force acting along the slope is directly related to the angle of the slope. Any additional mass on the slope causes the force of gravity to increase and this adds more stress to the soil/rock mass (Butler, 1976; and Crozier, 1989). The calculation of shear stress is given in **Appendix 1**. It should be noted that steeper slopes have greater values of slope angle and hence greater values of gravitational force and thus have an increased likelihood of failure of the material.

The effect of this shear stress upon the soil or regolith is called strain (Bryant, 1991; and Alexander, 1993). Strain is not directly equated with stress, but gives a measure of how much the soil or regolith is distorted by the stress. It is defined by displacement of upper surface relative to the bottom surface, divided by depth of material (**Appendix 1**). Strain may not occur uniformly in the soil body, but may be restricted to joints where fracturing will eventually occur (Butler, 1976; and Crozier, 1989). Resistance and shear stress analysis can be expressed by the ratio of resistance to shear stress. This ratio provides a factor of safety which is assumed to yield a value of 1.0 (resistance equals shear stress). Higher values represent progressive more stable situations. This method of assessing stability is referred to as limiting equilibrium analysis (Crozier, 1989) and is given in **Appendix 1**. In most of the landslides which occurred in Malawi, shear strength of the regolith was reduced by high prolonged precipitation, resulting in corresponding increase in stress (Gondwe and Govati, 1991; Dolozi and Kaufulu, 1992; Poschinger et al., 1998; and Msilimba, 2002).

### 3.6.2 Friction and Cohesion

The failure of the slope material depends partly on the strength of the frictional force between the sliding mass and the bedrock. This force is dependent on both the degree of roughness of the surfaces and the component of the weight of the sliding material perpendicular to the surface. But, it is independent of the area of contact between the body of regolith and the underlying substrata (Crozier, 1984; Alexander, 1993; and Matsushi et al., 2006). Thus, small areas of soil material can fail at the same angles as large areas. The size of the frictional force is expressed in terms of a coefficient of friction and the component of the weight normal to the slope (**Appendix 1**).

The critical angle at which sliding just begins is termed the "angle of plane sliding friction" (Finlayson, 1980). The balance of forces on the regolith can then be expressed in terms of the critical frictional resistance and the critical applied force. Failure commences when the critical applied force exceeds the critical frictional resistance (**Appendix 1**). However, for non-rigid objects, there is also an additional force resisting down slope movement which is termed cohesion (Bryant, 1991; Alexander, 1993; and Crozier, 1984).

### 3.6.3 Shear Strength of Soil

The way the soil particles, behave as a group or mass depends not only upon the inner cohesion of the particles but also upon the friction generated between individual soil grains (Bryant, 1991). The latter characteristic is termed internal friction or shearing resistance. How much shear stress a soil or regolith can withstand is given by the Mohr-Coulomb equation (Alexander, 1993; and **Appendix 1**). In the equation, the critical force for movement is determined by the stress normal to the slope due to the weight piled on the slope. In addition, the angle of the slope is not considered and that shear strength depends instead on the angle of shearing resistance, which represents the angle of contact between particles making up the unconsolidated material (Finlayson, 1980; and Bryant, 1991). Within the Banga Area in Northern Malawi and Mulanje massif in Southern Malawi, where the basement was found to be significantly weathered, shear strength was found to be low and that contributed to instability (Gondwe and Govati, 1991; and Msilimba, 2002).

### 3.6.4 Pore Water Pressure

A change in pore water pressure is regarded as the main triggering factor to land sliding (Ngecu and Mathu, 1999; Msilimba, 2002; Inganga, et al., 2005; and Knapen et al., 2006). If an external load is applied to a soil mass on a slope in the form of additional water, or overburden, the pore water pressure will build up in that mass and water will be expelled at weak points (Alexander, 1993; and Knapen et al., 2006). The increase in pore pressure in the Mohr-Coulomb equation reduces the effective resistance of the soil body or regolith (**Appendix 1**). In this case, the pore pressure reduces the effective normal stress, and the shear strength of the soil (Bryant, 1991). An increase in pore water pressure was found to be the major cause of landslides in Malawi and the East African region (Gondwe et al., 1991; Poschinger et al., 1998; Ngecu and Mathu, 1999; Ingaga et al., 2005; and Knapen, et al., 2006).

### 3.6.5 Implications of Joints and Rock Structures on Slope Stability

Like many parts of east and central Africa, the geology of Malawi is highly folded, faulted and fractured due to tectonic activity (Bloemfield, 1968; Carter and Bennet, 1973; and Kemp, 1975). Joints and rock structures have implications for slope stability (Butler, 1976; Hencher, 1987; Byrant, 1991; and Nicholas, 1995) as outlined below: pore spaces between particles allow fluids to pass through dissolving the cementing material and weathering the rocks; intersecting sets of parallel joints allow rocks to break into smaller masses that move more easily down slope; contact surfaces between beds of rocks that have different characteristics are points of weaknesses along which rocks can break; and tectonic pressures can re-orient rocks after their formation. Such dipping layers facilitate mass movement where they are inclined in the same direction as the slope of the land. Sometimes, rock layers are inclined away from the slope, but fractures within the rock are inclined down slope, and this makes the slope unstable (Poschinger et al., 1998).

### 3.6.6 Angle of Repose and Particle Packing

The maximum angles at which granular materials can be piled determines the stability of the slope material (Nicholas, 1995). Large particles maintain a steeper slope than smaller ones. Angular particles can also interlock and maintain steeper slopes than rounded particles of the same size. Poorly sorted sediments have a steeper angle of repose because smaller particles fit between the larger ones. Partially saturated sands have a steeper angle of repose because of water surface tension (Bryant, 1991).

The way particles are arranged in a deposit can affect slope stability (Bryant, 1976; Crozier, 1984; Alexander, 1993; and Nicholas, 1995). Particles can be arranged in two ways: cubic (loose) and rhombohedral (tight) packing. Particle parking is significant in slope failure because slope stability can be affected by a change in packing. A change from loose to tight packing decreases the volume and lowers the surface, resulting in reduced pore spaces. This reduction expels pore fluids and causes liquefaction (Coch, 1995). The 1989 Manyani Hill Landslide in Central Malawi occurred after the distortion of particle parking by the 10th March, 1989 earthquake (Dolozi and Kaufulu, 1992).

## 3.7 Causes of Landslides

The search for the preparatory factors and cause(s) of an individual landslide or an attempt to designate the state of instability is prompted to find an efficient way of responding to the problem by legal necessity, or simply by a desire for knowledge (Crozier, 1984). However, the difficulty arises when identifying the causes, determining their relative magnitude, sequence of operation and the evaluation of the relative significance of function compared to magnitude. The causes and circumstances for landslide occurrences are many and a summary is presented in **Table 3.2.**

**Table 3.2: Causes of Landslides**

| External Causes | Internal Causes |
|---|---|
| **1. Geometrical change**<br>• Height<br>• Gradient<br>• Slope length | **1. Progressive Failure (internal response to unloading)**<br>• Expansion and swelling<br>• Fissuring<br>• Straining, softening<br>• Stress concentration |
| **2. Loading**<br>• Natural<br>• Man-induced | **2. Weathering**<br>• Physical property changes<br>• Chemical changes |
| **3. Unloading**<br>• Natural<br>• Man-induced | **3. Seepage erosion**<br>• Removal of cements<br>• Removal of fine particles |
| **4. Shocks and Vibrations**<br>• Single<br>• Multiple/continuous | **4. Water regime change**<br>• Saturation<br>• Rise in water table<br>• Excess pressures<br>• Draw down |

**Source;** McCall (1992) and Msilimba (2002).

Internal changes (**Table: 3.2**) lead to a decrease in shear resistance while external changes act to increase shear stress (**Sections 3.6.1 to 3.6.4**). These factors combine to destabilise the slope (preparatory factors), and secondly, initiate movement (triggering factors). Controlling or perpetuating factors control the form, rate and duration of movement (Crozier, 1984). Preparatory factors and causes of landslides are discussed in further detail in the subsequent sections.

### 3.7.1 Seismicity and Other Vibrations

Although situated in the Great African Rift Zone, Malawi rarely experiences earthquakes (Bloemfield, 1968; Carter and Bennet, 1973; and Kemp, 1975). The 1989 Manyani Hill Landslide was however, induced by an earthquake (Dolozi and Kaufulu, 1992). However, within East African Region, earthquake induced landslides have been reported in south western Uganda and Kenya (Inganga et al., 2001). The phenomenon is therefore, briefly discussed below.

Earthquakes reduce stability by imparting both a shearing stress and a reduction in resistance to slope material. Earthquake wave propagation has three principal effects (Crozier, 1989; McCall, 1992; and Alexander, 1993) as outlined below: the direct mechanical effect of horizontal acceleration which provides a temporary increment to shearing stress; the cyclic loading which weakens inter particle bonding causing liquefaction (**Section 3.7.5**); and the reduction in inter-granular bonding by sudden shock irrespective of the degree of saturation. It should be noted that vibrations from traffic, heavy machinery, and explosives have the same effect as earthquakes. However, the impact is only in areas of extreme instability close to the site of energy release (Crozier, 1989).

### 3.7.2 Changes in Water Content

Regionally, landslides triggered by precipitation have been reported in Kenya (Ngecu and Mathu, 1999), and Uganda (Inganga et al, 2001; and Knapen et al., (2006). Most of the landslides in Malawi have been attributed to precipitation (Chikusa, 1985; Cheyo, 1999; and Dolozi, 1999; and Msilimba and Holmes, 2005). Changes in water content have been responsible for triggering, re-initiating and accelerating more landslides than any other factors (Butler, 1976; and Crozier, 1989). An increase in water content decreases stability in one or more of the following ways (Crozier, 1989): increasing interstitial pore water pressure (**Section 3.6.4**); developing of cleft-water pressure within joints voids and fissures, which will have a similar effect on resistance to that produced by interstitial pore pressure (**Section 3.6.4**); development of seepage pressures contributes to shear stress which also leads to gradual sub-terrain erosion and removal of underlying support; lubrication effect by converting joint fillings and thin clay-rich inter-bedded layers into slurries (Terzaghi, 1950); loading effect which affects shear stress (**Section, 3.6.1;** Butler, 1976); and water can decrease cohesion (apparent cohesion) as explained in **Sections 3.6.2 and 3.6.3**.

Apart from variations in precipitation, irrigation, faulty leaking pipes, and reservoirs are also known to have triggered landslides (Crozier, 1989; Msilimba 2002; and Msilimba and Holmes, 2005). Typical examples are the Nyankhowa landslides in Northern Malawi (Msilimba, 2002; and Msilimba and Holmes, 2005).

### 3.7.3 Expansion and Contraction of Water and Soil Particles

Expansion and contraction of soil grains or water within pore-spaces and cracks in the bedrock may cause slope failure. This mainly occurs through direct heating by the sun and cooling at night, causing soil particles or fragments of rocks to expand and contract preferentially down slope. The expansion and contraction of water in cracks also cause a net shift in the position of the material (Briggs, 1977; and Finlayson, 1980). This net-shift in the position of the material may trigger landslides. It has been suggested that the 1989 Nyambilo landslide in Southern Malawi occurred in this way (Chipili and Mshali, 1989).

### 3.7.4 Weathering of the Slope Forming Material

Most of the landslides in the Vunguvung/Banga catchments occurred in areas where the basement has been significantly weathered (Msilimba, 2002; and Msilimba and Holmes, 2005). Weathering is a long-term background process which causes material to lose its strength through time (Finlayson, 1980; and Alexander, 1993). However, it is never the immediate cause of land sliding. Weathering depends on the original mineralogy, the nature of climate and biological environment (Crozier, 1989). Weathering also causes slope failure indirectly by contributing to high permeability and positive pore water pressure (**Sections 3.6.4 and 3.7.2;** Carson and Petley, 1970; and Briggs, 1977).

### 3.7.5 Liquefaction of the Soil

Liquefaction involves the temporary loss of internal cohesion of the material such that it behaves as a viscous fluid (**Section 3.3.4**) rather than as a soil (Alexander, 1993). Soils containing a high percentage of sand and silt will deform more quickly than those containing a high percentage of clay. Because of their cohesive strength, clays adjust more slowly to increase pore-water pressure than unconsolidated soils. However, quick clays will liquefy if salt is leached by fresh water (Baver, 1959; Briggs, 1977; and Crozier, 1989).

When plastic and liquid limits are reached and exceeded, the soil will flow under its own weight (Alexander, 1993). Liquefaction can also be caused by seismic waves passing through a saturated material (**Section 3.7.1**; Alexander, 1993; and Crozier, 1989). The 1989 Manyani Hill and the 1997 Banga landslides were caused by the liquefaction of the soil (Dolozi and Kaufulu, 1992; Msilimba, 2002; and Msilimba and Holmes, 2005).

### 3.7.6 Human Activities

International literature on the causes of landslides in this region indicates that slope disturbance and deforestation are the major preparatory factors (Ngecu and Mathu, 1999; Gondwe and Govati, 1991; Ingaga et al., 2001; and Knapen et al., 2006). This is also true with other regions (Butler, 1976; and McCall, 1992). Below are examples of human activities causing landslides.

#### 3.7.6.1 Vegetation Cover Destruction

Deforestation is considered one of the main preparatory causal factors of landsliding in most of the East African highlands (Inganga et al., 2001; and Nyssen et al., 2002). Deforestation has been noted as a serious concern in Malawi (NEP, 1996; NEAP, 1998; and Kasulo, 2005). In Malawi, the 1997 Banga Landslide occurred in a deforested cultivated area (Msilimba, 2002; and Msilimba and Holmes, 2005).

Although deforestation accelerates mass movement (Crozier, 1989), landslides are also controlled by other factors (Bryant, 1991; Alexander, 1993; and Coch, 1995). For instance, large landslides occur mostly in areas overlain by healthy, mature vegetation. Although an area may have suffered deforestation, this is often off set to some extent by re-colonisation (Butler, 1976). The manner of deforestation and subsequent ground treatment affects the degree and rate of strength reduction (Butler, 1976; and Alexander, 1993). The vegetation cover may become a destabilising factor on steep-jointed rock. Minor landslides in Zomba were attributed to trees planted on unstable slopes (Cheyo, 1999).

The stabilising influences of forest cover (Crozier, 1989; and Alexander, 1993) that may be lost or reduced as a consequence of deforestation include: surcharge, although O'Loughlin, (1974) and Wu et al., (1979) argue that surcharge provides a normal stress of only 1 to 5 kPa which is too small to prevent failure; hydrological effect mainly through evaporative losses reducing pore water pressure (**Section 3.6.4**); organic influence promoting or maintaining freely draining soils. However, under very high rainfall intensities, high infiltration increases slope susceptibility to mass movement; micro-climatic effect, the forest micro-climate prevents extreme variation of daily conditions consequently reducing the development of cracks; mechanical reinforcement by tree roots attaching potentially unstable regolith to stable substrata (Alexander, 1993). This depends on the type of vegetation (Crozier, 1984; and Alexander, 1993). After deforestation, roots lose tensile strength by decay at rates averaging 300 and 500 kPa per month (Crozier, 1989) which means stabilisation effect remains for sometime after the destruction of the forest.

#### 3.7.6.2 Infrastructure Development

Earthwork developments, involving large land surfaces in mountainous areas, can have a big impact on the stability of slopes. A remarkable interference is the removal of lateral supports by excavation for road construction, dam building, housing and farming (Knapen et al., 2006). Other human activities, which vibrate the ground, can also trigger landslides (**Section 3.7.1**). Human-induced slides are numerous and include; the 1963 Vaiont Dam Landslide (McCall, 1992), the 1997 Mount Elgon Landslide in Uganda (Knapen et al., 2006), and the 1997 Masoui Makwueni Highway landslides in Kenya (Ngecu and Mathu, 1999). Locally, it has been suggested that the 1999 Chiweta Road Landslide and the 2000 Nyankhowa landslides were caused by the slope cutting that exposed covered dipping and jointed beds (Manda, 1999; Msilimba, 2002; and Msilimba and Holmes, 2005).

## 3.8 Damage Caused by Landslides

Landslides continue to be under-recognized in terms of the damage caused in comparison to the attention given to other hazards (McCall, 1992). In Malawi, the situation is no different. Little or no research is being carried out (Msilimba, 2002) and land sliding does not appear on the ten environmental concerns affecting the nation (NEP, 1996). McCall (1992) identified some reasons for this apparent neglect. Firstly, the largest landslides occur most frequently in mountainous terrains and traditionally had relatively limited impact on human society. Secondly, individual landslides rarely cause sufficiently large deaths-claiming enough media attention, or requiring political/managerial responses. Thirdly, appreciation of the significance of land sliding is diminished because widespread landslide impacts are often produced as a secondary consequence of violent geographical events such as earthquakes, volcanic eruptions, hurricanes or intense rainstorms. The 1991 Phalombe Landslide has been adequately researched on due to its devastating impacts, which included the loss of over 500 lives (Gondwe and Govati, 1991; Poschinger et al., 1998; Cheyo, 1999; and Mwafulirwa, 1999).

### 3.8.1 Factors Increasing the Vulnerability of Societies to Landslide Damage

Landslides only become hazards when people, property and livelihoods become threatened. This could explain why research in the past concentrated on landslides in Southern Malawi (Msilimba, 2002). However, a sound understanding of factors contributing to vulnerability is a key to effective prevention and mitigation. The vulnerability is increased by the following factors (Crozier, 1989). Firstly, there is increasing pressure on resources, forcing people to exploit hazardous areas. Secondly, urbanization concentrates people and fixed assets in a limited area. Political directives and policies force people into environments, land-use practices and socio-economic systems with which they are unfamiliar, and there is insufficient knowledge of endemic hazards, inappropriate adjustment mechanisms or too few resources to mitigate the hazards. Poverty and high illiteracy have been cited to increase communities' vulnerability to natural disasters and reduce resilience to shocks (NEP, 1996; NEAP, 1998; and Slater and Tsoka, 2006).

### 3.8.2 Landslide Related Costs

The costs of landslide activity can be classified as personal, economic loss and environmental damage. They can be immediate or long term. The assessment of the costs is difficult because landslides are associated with simultaneous occurring hazards (**Section 3.8**). This problem is compounded by problems of acquiring data of sufficient accuracy or representative-ness to illustrate the real costs and trend of landslide hazards (Crozier, 1986). Specific landslide costs are given in **Section 3.8.3.** Most of the landslide studies have been successful in assessing quantifiable costs as opposed to costs related to psychological and physical health (Cheyo, 1999; Mwenelupembe, 1999; Inganga et al., 2001; Msilimba and Holmes, 2005; and Knapen, et al, 2006). Below is a discussion of landslide related costs.

#### 3.8.2.1 Personal Costs

Personal costs include death, injury, and prolonged psychological and physical health problems. These effects may require a costly process of adjustment. Injury has long-term costs as it may not only reduce the social and productive role of an individual, but also may impose added costs for medical treatment and support (Crozier, 1989). Literature on personal costs related to landslides in Malawi, as well as in the East African region, is not available.

#### 3.8.2.2 Economic Costs

The direct economic consequences of landslides depend on the nature of the society, and the type of landscape affected. Small–scale events involve lesser, but more frequent direct costs (Crozier, 1989). The indirect costs related to landslides can be categorised into event-related indirect costs such as mobilization and support of relief, and temporary or replacement of housing and supplying food; and preventative costs which are more difficult to assess, including the cost of research and costs of implementing preventative or control measures. In Malawi, most of the studies fall short of addressing indirect economic costs of landslides (Poschinger, et al., 1998; Cheyo, 1999; Msilimba, 2002; and Msilimba and Holmes, 2005,). Other examples of economic costs are given by Crozier (1986).

#### 3.8.2.3 Environmental Costs

In very unstable environments which provide frequent or large volume slope movements, both the slope and downstream consequences may be severe and long lasting (Crozier, 1989). Environmental impacts of landslides have been given by several authors (Ngecu and Mathu, 1999; Msilimba and Holmes, 2005; and Knapen et al., 2006). Such environmental costs include: habitat degradation, the deranging of drainage system, alteration of drainage path ways, destruction of riparian vegetation, bank erosion within the stream channel, accelerated meander development and prevention of fish migration, and the loss of scenic beauty of mountainous environments (Crozier, 1986). Most of the landslides which occurred in Malawi left land degraded (Chipili and

Mshali, 1989; Gondwe and Govati, 1991; and Msilimba, 2002). A typical example is the 1991 Phalombe landslide where deep channels exist, and which are yet to be recolonised by vegetation (Gondwe and Govati, 1991).

### 3.8.3 Examples of Landslide Damages

#### 3.8.3.1 Infrastructure Damage

Landslides can cause enormous damage to infrastructure development. Such developments may include dams, roads, houses, etc. For instance, in the Italian town of Calabria, landslides destroyed roads, railways, aqueducts, and houses valued at US$200 million between 1972 and 1973 (McCall, 1992). In China, in 1998, 500,000 houses were destroyed by landslides, avalanches, and debris flows (Huabin et al., 2005). Locally, the 1991 Phalombe Landslide destroyed buildings, bridges, water pipes, and other infrastructures. Worse still, the Phalombe Trading Centre was covered with debris of thick mud, logs, trees and boulders (Gondwe and Govati., 1991; and Mwenelupembe, 1999).

#### 3.8.3.2 Damage to Crops and Agricultural Land

Landslides can also cause enormous damage to fields by eroding and transporting fertile soils from agricultural land. In Kenya, the 1997 landslides rendered many hectares of arable land unproductive, and destroyed 25 hectares of tea bushes (Ngecu and Mathu, 1999). The 1946 Zomba Mountain landslide resulted in the destruction of crops in the Chilwa–Phalombe Plain (Manda, 1999). The 1997 Banga landslides destroyed crops that were growing along the Banga dambo (Msilimba, 2002; and Msilimba and Holmes 2005). In Uganda, landslides devastated crops and farmland (Ingaga et al., 2001; and Knapen et al., 2006).

#### 3.8.3.3 Loss of Life and Displacement of People

Landslides can cause displacement, injury or death of people when their occurrence is close to populated areas, depriving societies and nations of the much required human resources. A typical example is the 1966 Aberfan landslide in Wales which destroyed a school, killing 5 teachers and 116 students (Alexander, 1993). In 1998, 1573 people were killed and 10,000 were injured by landslides in China (Huabin et al., 2005). The 1997 Mount Elgon Landslide in Uganda killed 48 people, and destroyed 885 dwellings (Knapen et al., 2006). Locally, and as already stated, the 1991 Phalombe Landslide killed over 500 people (Gondwe and Govati, 1991; and Poschinger et al., 1998). **Table**

**3.3** below gives details of the casualties and the damage caused by some international landslide events.

**Table 3.3: Damage Caused by Some Previous International Landslides**

| Place | Date | Type of Flow | Estimated volume in Million $m^3$ | Impact |
|---|---|---|---|---|
| Java | 1919 | Debris flow | - | 5100 killed 140 villages destroyed |
| Kure, Japan | 1945 | - | - | 1154 killed |
| S.W. of Tokyo Japan | 1958 | - | - | 1100 killed |
| Vaiont, Italy | 1963 | Rockside into reservoir | 250 | About 26,000 killed |
| Rio de Janeiro Brazil | 1966 | - | - | 1000 killed |
| Rio de Janeiro Brazil | 1967 | - | - | 1700 killed |
| Virginia, USA | 1969 | Debris flow | - | 150 killed |
| Japan | 1969-1972 | Various | - | 519 killed, 7328 houses destroyed |
| Chungar | 1971 | - | - | 259 killed |
| Kamijima | 1972 | - | - | 112 killed |
| Mount Semeru | 1981 | - | - | 500 killed |
| Pacita, Peru | 1983 | - | - | 233 killed |
| Western Nepal | 1983 | - | - | 186 killed |
| Dongxiang (Salashan, China) | 1983 | - | 3 | 4 villages destroyed 272 killed |
| Kansu, China | 16/12/1920 | Debris flow | - | 200,000 killed |
| California, USA | 31/12/1934 | Debris flow | - | 40 killed, 400 houses destroyed |
| Ranrachirea | 10/6/1962 | Lee and rock | 13 | 3500 killed |

| | | | | |
|---|---|---|---|---|
| | | avalanche | | |
| Abefan, Wales | 21/9/1966 | Flow slide | 0.1 | 144 killed |
| Southern Italy | 1972-3 | Various | - | About 100 villages abandoned |
| Mayumarca, Peru | 25/4/1974 | Debris flow | 1000 | Town destroyed, 451 killed |
| Armero, Colombia | 11/1985 | Lahar | - | About 22,000 killed |
| Catak, Turkey | 6/1988 | - | - | 66 killed |
| Kathmandu, Nepal | 07/1988 | Debris flow | - | 4 killed and 12 houses destroyed |
| Montana, USA | 03/1998 | Slide | 0.25 | Blocked Black Foot river |
| Antipolo City, Philippines | 08/1999 | Slide | 0.9 | 58 killed and houses destroyed |
| Taiwan, China | 10/1999 | Debris flow | - | 2,375 killed and 10,000 injured |

(**Source:** McCall (1992) and Higaki (2000)

## 3.9 Local/Indigenous Knowledge and the Environment

This section examines the role of indigenous knowledge in environment management. The point of departure is that, historically the environment has been sustainably managed under pre-scientific traditional systems and in some cases the resources have persisted for long periods of time without degradation, although not all traditional societies have lived harmoniously with their environment (Berkes and Folke, 1998). The study focuses on indigenous knowledge, with the understanding that knowledge changes and expands in relation to local reactions to an ever-changing set of circumstances perceived as a 'problem' (Holling, 1986). Although literature on traditional/indigenous knowledge on the occurrence and management of landslide hazard is not available, the importance of indigenous knowledge in conserving natural resources is documented in numerous case studies (Berkes, 1987; 1992 and 1995; Oldfield and Alcorn, 1991; Rajasekaran et al., 1991; Warren, 1992a; 1993; Berkes and Folke, 1998; Gadgil et al., 1993; Millar, 1994; Hyndman, 1994; Warren and Rajasekaran, 1994; Phillips and Titilola, 1995; and Verger, 1995). Therefore, it is imperative to explore the traditional mechanisms and coping strategies in relation to landslide occurrences. It is also important to investigate how those mechanisms evolve with time.

Although modernization theory has dominated the development discourse since 1945, there have been moves to reframe the debate (Briggs et al., 1994). In particular, an interest has developed in indigenous knowledge and the importance and value of recognising indigenous knowledge has been demonstrated. Seely (1998) noted that although the importance of indigenous knowledge has been recognized, it is usually seen as a source of knowledge to be taken and used by scientists rather than as an input into scientific or decision-making processes. Indigenous knowledge systems (IKS) have been given more attention, and their importance is addressed in development projects (Materer et al., 2001). Kloppenburg (cited in Materer et al., 2001), distinguishes between scientific and local knowledge. He indicates that scientific knowledge is that in which the ideas, theories and concepts are 'immutable mobiles' i.e. the knowledge is transferable, mobile and not tied to a singular locale, as opposed to local knowledge, which is less mobile, but more dynamic and thus mutable. However, Materer et al., (2001) disagreed with this distinction set between the two knowledge bases. They argues that with the advent of globalisation, many subsistence societies are fusing modern technologies with their traditional practices. Hence, knowledge systems in a local area are influenced by 'immutable mobiles' and adapted. Materer et al. (2001) prefer to identify IKS as LKS (Local Knowledge System) since it is unique because of the subject matter it contains, the context, and the way in which it is applied and interpreted. It is necessary that it is defined separately or else researchers, scientists and policy makers who work on developments will not take extra care in incorporating it into current projects. But Niemeijer and Mazzucato (2003) argue that in order for the local knowledge to be more useful for sustainable development interventions, it is necessary to explore indigenous management practices which have evolved within traditional societies over time.

### 3.9.1 Perceptions and Attitudes to Landslides

Acknowledging human perceptions of environmental problems is an important requirement for better understanding of environmentally damaging forms of production, and consumption (WBGU, 1995). Perceptions influence the way we behave or act and, therefore, an understanding of this concept is crucial in the resolution of environmental problems (Taun, 1974). Decisions by the local people and their local authorities as to whether or not to address the problem of environmental degradation are clearly influenced by perceptions and attitudes.

Perceptions as to the status of resources differ from one community to another. What one observer perceives to be an environmental hazard in one society, may be a normal run of events to another. Investigation of perceptions and attitudes among local groups can facilitate public involvement and provide critical information which resource managers can consider together with more scientific and technical data (Brinkcate and Hanvey, 1996; Hagos et al., 1999). Fairhead and Scoones (2005) contend that local experience and knowledge reveal an appreciation of the complex and interacting factors that influence environmental degradation. This study included the investigations of perceptions of the local community as an approach to enhancing their involvement and contribution to an understanding of environmental degradation, and the occurrence of landslides. The purpose was also to assess whether local initiatives exist in the management of environmental problems. Regrettably, literature on local/traditional knowledge on the occurrence of landslides and their coping strategies is not available.

### 3.10 Gender, Environment, and Their Specific Relationships

It has been observed by social scientists that the acceleration of the degradation of the environment in many ways is the most dangerous of the threats women face (Dankelman and Davidson, 1988). This research attempts to show that gender and environment have specific relationships; hence, the need for a gender-specific approach to the management of environmental problems such as the occurrence of landslides.

Historically, the environment has become an area of major socio-political focus during the past forty years (KIT, 2002). The interest grew not because people started to care much about the environment and its valued functions, but because of the increasing seriousness of environmental problems (Carson, 1962). Until the 1960s, the environment was the exclusive research area of the natural sciences. That the relationship between the people and the environment, and that the environment is not gender-neutral, became clear in the 1980s. Before that, the position and concerns of women were invisible in the environmental debate (KIT, 2002).

However, studies have shown that probably no other group is more affected by environmental destruction than the poor village women (CSE, 1985). This could be attributed to the fact that women are caught up in between poverty and environmental destruction, and that reduces their resilience to natural disasters.

This research recognises three important conclusions on gender and environment. Firstly, women bear the highest costs of the environmental crisis because of their roles in providing water, food, and energy at family and community levels (CSE, 1985). Secondly, women could potentially make a large contribution to the solution of the crisis precisely due to their role in the management of primary resources (Dankelman and Davidson, 1988). Finally, the empowerment of women and sustainability of development are ecologically tied (KIT, 2002). Therefore, as landslides occur, the quality of natural resources and biodiversity, as well as environmental quality, decreases strongly, affecting women's lives, adding to their workload, and worsening their health and social position.

Several studies have focused on women as a major social group and their environment (Dankelman and Davidson, 1988; Menon, 1991; and KIT, 2002). Such studies ignore the fact that women are not a single homogeneous group and, therefore, it is important to address the actual material relationships of different groups of women with nature and the occurrence of landslides. Such arguments have been advanced by researchers such as Braidotti et al., (1994) and Agarwal (1998). However, while recognising differences between women groups, this study focused on gender-sensitive approach to the understanding and management of slope stability problems. The study is also an attempt to give more visibility to the practical relationships between women and their physical environment, which does not feature in the current landslides literature.

### 3.11 Landslides Prediction

Land sliding is potentially one of the most predictable geological hazards, particularly with respect to small and medium scale events (Bryant, 1976; Crozier, 1984; and Alexander, 1993). However, most landslide studies in the East African Region, including

Malawi, emphasise only the causes. In cases where predictions have been made, procedures followed are not explained, or given, or are unclear (Gondwe and Govati, 1999; Inganga et al., 2001; and Knapen et al., 2006). The predictability depends upon three basic assumptions (Leighton, 1976): conditions that led to slope instability in the past and present will apply equally well in future (uniformitarian principle); the main conditions that cause land sliding can be identified (also explained in Huabin et al., 2005); and it is possible to estimate the relative significance of the individual factors.

Although prediction is possible, there are a number of limitations (McCall, 1992) such as: the significance of chemical changes has not yet been fully evaluated by scientists; uniformitarian principles can only be applied in general terms as there is variation in climate change and human interventions; and that it is not always possible to assign relative levels of significance to landslide causes in areas where complex sequences of rocks are involved in failure. Because of these limitations, landslide hazard assessment is concerned with establishing the general likelihood of slope instability (landslide prediction) rather than with specifying events (landslide forecasting). However, landslide prediction provides the framework for management planning, engineering and investment decision-making.

### 3.12 Landslide Potential Maps

Examination of past landslides and geological studies of potentially unstable slopes can be used to construct landslide potential/hazard maps (Crozier, 1978 and Alexander, 1993). These maps help in setting standards and requirements for the use of land, assessing the impacts of that use, and development of mitigation options (Crozier, 1986). In Malawi, no literature exists on the mapping exercise which was initiated by the German Technical Cooperation (GTZ) six years ago.

To make such maps, areas underlain by slide-prone soils or rocks are identified. These are then super-imposed on topographic maps. Where steep slopes and landslide prone-soils or rocks coincide, these are mapped as hazardous areas (Nicholas, 1995). However, in areas where landslides are triggered by rainfall, the prediction of the precise locations of instability is difficult due to uncertainty concerning the temporal distribution of rain storms (Ayalew, 2005). The nature, extent, and distribution of landslides during a rain storm are also greatly influenced by spatial variations in the susceptibility of the slope failure which depends on other factors (Ayalew, 2005). These factors change from time to time, and affect the accuracy of the maps. The analysis of causes and effects-causes relationship is not always simple (Ayalew, 2005 and Glen et al., 2006). Because of this complexity, hazard or susceptibility maps attract heavy criticisms on many occasions (Huabin et al., 2005).

### 3.12.1 Methods of Landslide Mapping and Assessment

Methods and techniques for evaluating landslide hazard and mapping have been proposed or practised but no agreement has been reached either on the procedures or scope of producing landslide hazard maps (Brabb, 1984; and Huabin et al., 2005). All the proposed methods are based on a few widely accepted principles or assumptions (Varnes, 1984), particularly the well known and widely applied principle ‘the past and present are keys to the future’ (**Section 3.9**). However, there is hardly any systematic comparison of different techniques in terms of respective strength and limitations (Huabin et al., 2005) or a critical discussion of the basic principles and underlying assumptions of landslide hazard evaluation (Varnes, 1984). No attempts have been made to define and distinguish conceptually or operationally landslide hazard and risk (Huabin et al., 2005).

Despite the above mentioned weaknesses, there is a general agreement on the most commonly used methods which include geomorphological hazard mapping, analysis of landslide inventories, heuristic or index based method, functional, statistical-based models, and geotechnical or physical-based models (Cotecchia, 1978; Carrara, 1983; Brabb, 1984; Varnes, 1984; Crozier, 1986; Einstein, 1988; Hartlen et al.,1988; Mulder, 1991; van Westen, 1993; IUGS, 1997; Cross, 1998; Miles et al., 1999; Baeza et al., 2000; Wu et al., 2000; and Clerici et al., 2005). Suffice to say that this study is a combination of geomorphologic and landslides inventory analysis methods (**Chapters 5 and 6**).

## 3.13 Determining Landslide Hazard, and Risk

The technical information base for the design of mitigation measures should ultimately give rise to a statement on landslide hazard, and risk (Crozier, 1989). After the 1991 Phalombe landslide, the massifs facing Phalombe District Headquarters were declared unstable as they posed a danger to settlements down slope. However, the study fell short of the identification and construction of maps showing different degrees of hazard or risk (Gondwe and Govati, 1991). However, a study by Msilimba and Holmes (2005) attempted to assign relative degree of hazard or risk by using a vulnerability score analysis. Crozier (1989) identified five steps involved in this task namely: identification of the nature, degree of activity and critical levels of external destabilising factors; determination of terrain sensitivity; identification of both frequency of occurrence of critical levels of the external factors and terrain sensitivity to produce a measure of probability of landslide occurrence; combination of the probability of landslide occurrence with mass movement characteristics; and combination of potential landslide hazard with the potential human, economic and environmental damage to produce a statement on landslide risk. However, this exercise is affected by insufficient data, time and financial constraints (Crozier, 1989). Other factors indicating potential stability are given in Cooke and Doornkamp (1974), and Crozier (1984).

## 3.14 Landslide Prevention, and Mitigation

Mitigation measures for natural geological hazards aim at protecting people, property and infrastructure (Crozier, 1984). The implementation of mitigation measures should be based on a detailed knowledge of the nature, scale, distribution, and causes of landslides. Most of the regional studies fail to address issues of prevention and mitigation after analyzing the causes (Ngecu and Mathu, 1999; Cheyo, 1999; Mwenelupembe, 1999; and Knapen et al., 2006). In cases where mitigations have been suggested (Msilimba, 2002; and Msilimba and Holmes, 2005), implementation has been a problem. However, it should be noted that most of the landslides which occurred in the East and Central African Regions lack mitigation measures; hence, most of the measures cited in this section are from developed countries and might not be applicable to less developed countries. Below are some mitigation options, some of which might apply to the current study.

### 3.14.1 Slope Drainage

Water build-up within slopes can be reduced by several engineering techniques (Zaruba and Mencl, 1969; and Nicholas 1995). Such techniques may include interceptor drains to capture runoff and transport it away; and peripheral ditches to divert the surface water flowing down from the adjacent slopes (a technique used effectively during the construction of the Lyon Marseille Motorway) (Pilot et al., 1988); drainage borings to collect water and drain it by gravity; and vertical exploration borings to drained water into drainage galleries. With reference to the last technique, it has to be remembered that galleries are expensive and laborious to construct and may be threatened by caving (Zaruba and Mencl, 1969).

### 3.14.2 Slope Reduction

An increase in slope height may result in increased weight over a potential shear plane (**Section 3.6.1;** and Crozier, 1984). Slope reduction can be achieved in a number of ways as outlined below (Crozier, 1984): slope angle can be graded into gentle ones; and if there is not enough room for such extensive grading, terraces or benches may be excavated into the slope.

### 3.14.3 Engineering Methods to Resist Mass Movement

Some of the engineering methods which can be used to resist mass movement include sealing of crevices by layers of concrete and crushed rock to prevent infiltration into the rock which cause frost wedging; construction of retaining walls especially in slopes underlain by sediment or loosely consolidated rock (Nicholas, 1995). However, it should be noted that such structures require a great deal of manual and skilled work, which is also expensive (Zaruba and Mencl, 1969); plugging of metal tubes into inclined rock layers (Zaruba and Mencl, 1969; and Coch, 1995). This technique was successfully implemented at the Briollay road cutting in France (Scholosser, 1979); and the use of buttresses to shove up the overhanging rocks and prevent movement.

### 3.14.4 Engineering Structures to Mitigate Damage

Where movement is inevitable, engineering structures can reduce the damage. These include the use of cable nets and wire fences that catch rock blocks before they cause damage (Coch, 1995); reinforcing structures such as rock sheds and tunnels which allow the mass to pass over without collapsing; and embankments whose size is determined by the selection of gradient that produces a stable slope given the local hydraulic conditions (Crozier, 1986). This last method was used during the construction of the A7 Motorway at Rognac in France (Pilot et al., 1988). In the Nyankhowa Area of Northern Malawi, stone embankments were constructed to stabilise slopes of the Vunguvungu/Banga Catchment Areas (VBCA) (Msilimba, 2002). Most of the landslides in this region, which were caused by slope remodeling (Ngecu and Mathu, 1999;

Ingaga et al., 2001; Msilimba, 2002; Msilimba and Holmes, 2005; and Knapen at al., 2006), require major engineering works to stabilise the steep faces.

### 3.14.5 Stabilisation by Vegetation

Afforestation is a promising method, but only for shallow sheet slides (Zoruba and Mencl, 1969). Afforestation proved successful in North Island, New Zealand (Pearce, 1988). However, landslides with deep lying planes cannot be detained by vegetation although vegetation can partly lower infiltration of the surface water into the slope, thereby contributing indirectly to stabilisation of the slide (**Section 3.7.6.1**). Recommended are those trees that have large consumption of water and highest evaporation (Skatula, 1953; and Sykola, 1961). Several studies in Malawi recommended re-afforestation (Chipili and Mshali, 1989; Gondwe and Govati, 1991 and Msilimba, 2002), but no afforestation has been carried out to date.

### 3.14.6 Hardening of Soils

Most of the methods used in the hardening of soils to stabilise slopes are adopted from engineering practices (Zaruba and Mencl, 1969). Such methods include drainage by electro-osmosis. This method has same effect as sub drainage, but differs in that water does not move towards the drainage by gravity, but the activity of the electric field (Casagrande, 1961; and Zaruba and Mencl, 1969); and thermic treatment. The exhaust gas with temperature of 1000$^0$C is driven into the borehole and penetrates into the pores of the soil which is baked into hard material (Zoruba and Mencl, 1969). Grouting which involves the displacement of water from the fissures by filling up with cement mortar can also be carried (Zaruba and Mencl, 1969).

### 3.14.7 Slip Surface Blasting

Slip surface blasting involves the blasting of the surface. This method is more applicable in landslides along straight planes with hard rock underneath (Zaruba and Mencl, 1969). The explosion will loosen the rock and reduce the up lifting of the ground water. The rock fragments will become mixed with the overlying clay material and increase its frictional resistance. However, this method is unreliable when employed to control deep landslides in fine–grained soils. Explosion may also produce harmful results in the surrounding areas. The measures concerning the quantity and the placing of explosives needs experienced experts (Zoruba and Mencl, 1969).

### 3.14.8 Legal Procedures of Government

The government can designate an area which contains signs of slope instabiliy, and also neighboring areas, suspected of contributing to, or stimulating landslides as "a landslide protection area" (Fukuoka, 1988). In Japan, for instance, several pieces of legislations have been passed to mitigate landslide events. Laws for the prevention of disasters, caused by the collapse of steep slopes, were passed in 1969 (Fukuoka, 1988). The purpose of these laws was to control the production of earth from slopes and riverbeds which was detrimental to slope and river stability. This could be more applicable to most mountaineous forests of Malawi where deforestation has been observed to be a major problem (NEP, 1996; NEAP, 1998; Kasulo, 2005; and Abbot, 2005).

## 3.15 Conclusion

This Chapter has provided a broader overview of landslide mechanisms of generation. It has discussed the causes, contributing factors, impacts and mitigation measures. Literature on indigenous knowledge, gender, and the environment has been reviewed. The next chapter will pay particular attention to landslides which have been studied in Malawi. The purpose is to examine the achievements and shortfalls in previous studies (also discussed in **Chapter 9**). This will expose research gaps and provide a broader understanding of landslide studies in Malawi.

# CHAPTER FOUR

# LANDSLIDES INVENTORY IN MALAWI

This chapter provides a general overview of landslides which are known to have occurred and which have been identified in Malawi. The aim is to provide a broader understanding of landslide studies in Malawi. The chapter also seeks to highlight achievements and deficiencies in landslide research in Malawi. The identified shortfalls will form the basis for future research although some deficiencies have been dealt with in this study.

## 4.1 Landslide Studies in Malawi

In Malawi, landslides are not new phenomena (Msilimba, 2002; and Msilimba and Holmes, 2005). Both fatal and non-fatal landslides have been recorded. Examples include the 1946 Zomba Mountain Landslide, which claimed 21 lives and caused substantial damage to property, and the 1991 Phalombe Landslide that killed over 500 people and destroyed crops, buildings and bridges (Cheyo, 1999; Msilimba, 2002; and Msilimba and Holmes, 2005). A summary of landslides that have occurred in Malawi are presented in **Table 4.1**.

Although a number of landslides have occurred throughout the country, studies concentrated on events in Southern Malawi until 2002. The exception to this was the study carried out by Dolozi and Kaufulu, (1992) in the Manyani Area (Kasungu District) of Central Malawi. The first detailed work was carried out in Northern Malawi in Rumphi District in 2002 (Msilimba, 2002; and Msilimba and Holmes, 2005). One reason for the apparent neglect could be that before 2000, major landslides occurred in Southern Malawi, and the events caused substantial damage (Gondwe and Govati, 1991; and Poschinger et al., 1998). However, most of the studies emphasised on site mapping after landslides had occurred and fall short of detailed analysis of soil, rainfall, geology, and other contributing factors to sliding. Most of the studies can be categorised as technical reports commissioned by the government (Msilimba, 2002). It should also be noted that most studies were carried out several years after the landslides (Msilimba, 2002; and Msilimba and Holmes, 2005). This affects the quality of data and the final results of the study. **Table 4.1** shows recorded landslides.

## Table 4.1 Mass Movements Inventory in Malawi and Their Impacts

| Event | Date | Impact | Status |
|---|---|---|---|
| Zomba (S) (Debris flow) | 1946 | 21 people killed, 24 bridges, buildings and roads destroyed, electricity and water supply disrupted, crops washed away, 2 villages swept away | Studied by Poschinger et al., (1998) and Cheyo, (1999) |
| Lumbadzi (C) (Debris flow) | 1975 | Casualties recorded, bridges destroyed, and a tanker swept. | Not studied |
| Banga (N)* (Landslide/flow) | 1984 | Crops destroyed | Studied by Msilimba (2002) |
| Ntonya/Ulumba (S) (Slide) | 1985 | | Studied by Chikusa (1985) |
| Dedza (C) (Slide/Falls) | 1989 | | Not studied |
| Manyani (C) (Slide) | 1989 | | Studied by Dolozi and Kaufulu (1992) |
| Nyambilo (S) (Rockfalls) | 1989 | | Studied by Chipili (1989) |
| Phalombe (S) (Debris/Mudflows) | 1991 | 500 people killed, crops washed away, buildings, roads and bridges destroyed | Studied by Gondwe et al (1991), Poschinger et al, (1998), Cheyo, (1998), Mwafulirwa, (1999), Mshali, (1992) |
| Malosa (S) (Slide/Flow/Falls | 1991 | | Not studied |
| Banga (N)* (Slide/Flows) | 1997 | Crops washed away | Studied by Msilimba (2002) and Msilimba and Holmes, (2005) |
| Zomba Mountain (S) (Slide/Falls) | 1997 | Road blockade | Not studied |
| Chiweta (N) (Falls) | 1999 | Road blockade | Not studied |
| Chilomoni (S) (Slide) | 1999 | | Not Studied |
| Zomba Mountain (S) (Falls) | 1999 | Road blockade | Not Studied |
| Nyankhowa A (N)* (Slides) | 2000 | Water supply pipes and roads destroyed | Studied by Msilimba (2002) |
| Nyankhowa (N)* (Slide) | undated | | Studied by Msilimba (2002) |
| Banga B (N)* (Slide) | undated | | Studied by Msilimba (2002) |
| Nyankhowa C (N)* (Slide) | undated | | Studied by Msilimba (2002) |
| Nyankhowa D (N)* (Slide) | undated | | Studied by Msilimba (2002) |
| Nyankhowa E (N)* (Slide) | undated | | Studied by Msilimba (2002) |
| Nyankhowa F (N)* (Slide) | undated | | Studied by Msilimba (2002) |

Adapted from Msilimba, 2002; and Msilimba and Holmes, 2005.
S = Southern Malawi; C = Central Malawi; N = Northern Malawi.
* Events which occurred in the Vunguvungu/Banga Catchments and were studied as a unit in 2002 (Msilimba and Holmes, 2005)

## 4.2 Analysis of the Previous Studies

The 1991 Pholombe and 1946 Zomba landslides have been the most studied events (Gondwe and Govati, 1991; Mshali, 1992; Poschinger et al., 1998; Cheyo, 1998; and Mwafulirwa, 1999). The studies were detailed and involved a careful investigation of fracture patterns to determine rock mass stability and strength. Hydro-geological analyses were also partly carried out, as well as the collection of drainage and rainfall data. Furthermore, soil mechanics analysis, surveying, and vegetation inventory were carried out. Studies on the Michesi and Zomba Mountain areas (Poschinger et al., 1998), and Banga/Vunguvungu catchments (Msilimba, 2002; and Msilimba and Holmes, 2005) also employed soil analysis techniques. The results in both cases showed that the mechanical properties of the soil were critical to the occurrences of debris flow and that mechanical properties of the underlying rock were of little significance. However, all studies ignored entirely the role of traditional knowledge in explaining the causes of landslides despite the existence of myths which are critical in the formulation of mitigation measures.

Studies on the 1989 Nyambilo landslide (Chipili and Mshali, 1989); the 1985 Ntonya-Ulumba landslide (Chikusa, 1985); and the 1989 Manyani landslide (Dolozi and Kaufulu, 1992) ignored the role of soil characteristics in landslide occurrences although the bulk of the moving mass was comprised of soil and weathered material. Socio-economic and political aspects to landslides were also overlooked. However, the Manyani Hill Landslide attempted to explain the role of earthquakes in causing soil liquefaction (Dolozi and Kaufulu, 1992).

## 4.3 Causes of Some Landslides in Malawi

Most of the landslides in Malawi have been triggered by rainfall, except for the Manyani Hill landslide (Dolozi and Kaufulu, 1992; Msilimba, 2002; and Msilimba and Holmes, 2005). Mwafulirwa (1991), Gondwe and Govati, (1991), Mshali (1992), Cheyo, (1999) studied the causes of the 1991 Phalombe Landslide, and concluded that rain water acted as the sole lubricant between the sliding masses and underlying rock. All the studies agree on the fact that the regolith became heavily water laden during three days of heavy precipitation, resulting in hill slope failures in several places in the Michesi Mountains. Gondwe and Govati, (1991) concluded that with a rainfall of 50 to 80mm per day, the Michesi massifs remain stable and that the joints did not cause the landslides, but rather determined where and how the rocks and regolith fail. Like the 1991 Phalombe Landslide, the 1946 Zomba Mountain Landslide occurred after 711mm of rainfall within two days (Cheyo, 1999; and Dolozi, 1999).

In their studies, Msilimba and Holmes (2005) concluded that the 1997 Banga Landslide was caused by prolonged low intensity rainfall which fell in the dry season. The rainwater penetrated the underlying banded planes of mica schist which are highly weathered and less resistant to deformation. The planes acted as zones of weakness and the pressure exerted between the planes caused the movement of the banded mica schist. The cause of the Nyambilo Landslide was also attributed to high precipitation (Chipili and Mshali, 1989). However, what triggered the landslide in the dry season was not determined.

Human activities have also been recorded as preparatory factors to landslides although the immediate cause has been high or prolonged precipitation (Dolozi and Kaufulu, 1992; Manda, 1999; and Msilimba, 2002). The 1989 Manyani Hill Landslide which was studied by Dolozi and Kaufulu (1992) concluded that the cutting down of trees increased the rate of water percolation into the soil. Increased pore-pressure induced down slumping and the earthquake of 10th March, 1989 probably provided the final trigger. The earthquake speeded the rate of liquefaction of the already saturated weathered material. According to Msilimba and Holmes' (2005) study on the Banga and Nyankhowa landslides, deep chemical rock weathering of the basement, cultivation, deforestation, infiltration from water supply pipes, and slope remodelling acted as preparatory factors while rainfall was the triggering factor.

Although causes of several landslides have been inferred (the 1989 Dedza, the 1997 and 1999 Zomba Mountain, the 1999 Chiweta, and the 1991 Malosa landslides), to-date no efforts have been made to reconstruct what might have happened. There remains an enormous task to landslide researchers to do more work on these landslides (Msilimba, 2002).

### 4.4 Proposed Mitigation Measures from Previous Landslide Studies

Although several studies have been carried out, only few studies proposed mitigation measures as one way of reducing the impacts of the landslides (Msilimba, 2002). Studies by Msilimba (2002) on the Banga/Nyankhowa landslides and Chikusa (1985) on the Ntonya/Ulumba landslides, recommended extensive re-afforestation of deforested slopes. The studies recommended tree species that provide dense canopy, promote high evaporative losses and high interception. Plant species should be deep rooted to provide for the maximum volume of soil influenced by root uptake of soil water. Studies by Gondwe and Govati (1991), and Msilimba and Holmes (2005) delineated danger prone areas and recommended that infrastructure or settlements situated on the debris flow path should be relocated to higher ground. The study by Msilimba (2002) further recommended the introduction of improved farming techniques, rehabilitation of remodeled slopes and reduction of water leakages from water supply lines. On the other hand, the study on the 1991 Phalombe Landslide recommended the relocation of Phalombe Sub District Headquarters (Gondwe and Govati, 1991) while Chipili and Mshali (1989) recommended that the slump areas of Nyambilo be left free from human activities that could accelerate rock mass movement. However, the study fell short of outlining such activities that could destabilise Nyambilo slopes. All the recommendations by the previous studies are yet to be implemented. Problems with implementation have been due to a lack of resources, lack of political will at both district and central government levels, and lack of local people's participation during the formulation process. In most cases, the social environment in which the measures were to be implemented has been ignored.

The study by Msilimba and Holmes (2005) in the Vunguvungu/Banga catchments of Northern Malawi was the first attempt to assign vulnerability scores to individual slopes, making up the spurs (interfluves) of the catchment. The development of vulnerability assessment procedures used a simple methodology applicable to developing countries. However, no attempts have been made to improve or build on this methodology. No attempts have been made to extrapolate the methodology to other areas.

## 4.5 Conclusion

It is evident that few detailed studies have been carried out; hence, an urgent need to commit adequate resources to landslide studies in Malawi. It is also clear that major landslide studies have been concentrated in Southern Malawi, except for a study by Msilimba (2002) in the Vunguvungu/Banga Catchment Areas in Rumphi District of Northern Malawi (Msilimba and Holmes, 2005). The section has also shown that since 2002, no major research work has been carried out in Northern Malawi, except for the current study. All landslide studies ignored socio-economic and political aspects of landslides. The role of traditional knowledge and peoples perceptions do not feature prominently in these studies.

Previous studies ignored the fact that the environment is engendered, and that women and men perceive environmental problems differently (KIT, 2002). The mitigation measures developed from the previous studies did not take gender dimensions of the problem. More importantly, previous studies fell short of detailed analysis of the interrelationships between the physical and anthropogenic factors.

Therefore, this study departs from previous studies by focusing on a detailed analysis of physical factors without losing focus on the role of anthropogenic factors. It is also the first attempt to incorporate indigenous knowledge and gender perceptions in studying landslides. This research work is also the first attempt to compare events in different physiographic and climatic regions of Malawi. The next Chapter provides a description of the materials and methods used to achieve the objectives of the study.

# CHAPTER FIVE
# METHODOLOGY

The current Chapter describes in detail procedures which were followed in the delineation and mapping of the study areas. It also describes the tools which were involved in the characterisation exercise of the study areas. The Chapter explains the procedures followed in landslide inventory. All the methods used in data collection, tools and sources of data are explained. Methods and procedures used in the social survey form part of this Chapter. The Chapter concludes by discussing various ways in which data were analysed.

## 5.1 Mapping of the Study Areas

The study areas were identified and mapped based on several parameters as detailed below.

### 5.1.1 Ntchenachena

The boundary on the map was delineated following the watersheds of the Mankhorongo, Chikwezga and Lutowo Rivers and their tributaries. Evidence of past landslides, mainly the presence of scars and gullies, was also considered in the demarcation of the study area. The location of settlements, land degradation, and steepness of the slope also formed part of the criteria. Aerial photography and topographic map interpretations were carried out in the delineation of the Ntchenachena area. The 1995 aerial photographs at the scale of 1:25,000, and the topographic map of Livingstonia area at the scale of 1:50,000 (GoM, 1987) were used.

Since it was not possible to obtain recently published maps and aerial photographs (after 1995), ground reference data and Landsat 7 ETM images were used. Reference data was used to correct errors caused by scale distortions on aerial photographs and topographic maps. Interpretation of aerial photographs was done following the standard procedures as described by Shaxson et al (1996).

The topographic map interpretation involved enlargement of the map, using an optical pantograph to the scale of 1:20,000. The topographic map was converted into digital format, using a digitizing tablet. Area was calculated, using surface operator in the ArcGIS version 9.0.

### 5.1.2 Chiweta

This study area was delineated based on the extent of uplifting of the Chiweta beds, slope remodelling, steepness of the slopes, and evidence of deep chemical weathering and past landslides. Evidence of rock falls and soil creeping formed part of the criteria. The location of settlements was not a criterion because within this area, where landslides are common, there are no settlement activities. The procedures which were followed in **Section 5.1.1** were also used in this area. Geological map of the South Uzumara (GoM, 1977) of the scale 1: 100,000 and topographic map of Livingstonia of the scale 1:50,000 were used in the mapping of the beds.

### 5.1.3 Mvai/Livilivi Catchments

The delineation of this area was based on the evidence of past landslides (mainly scars), location of settlements and human activities (mainly charcoal burning), evidence of rock falls, weathering and jointing of rock units. Aerial photographs, satellite images (Landsat 7 ETM images), and topographic and geological maps of Ntcheu District were used (GoM, 1978; and GoM, 1987). The procedures described in **Section 5.1.1** were followed.

## 5.2 Landslides Inventory

In all the areas, landslides were identified on aerial photographs taken in 1995 photos, at a scale of 1:25,000. Satellite images (Landsat 7 ETM) taken in 2003 were used to supplement the data obtained from the 1995 aerial photographs. This involved the identification of scars and channels and depositional areas. Interpretation of the photographs was carried out using a pair of stereoscopes and a hand lens both of magnification 3X. Stereoscopic viewing was used to provide a three dimensional view of the area, thereby making the observation of scars and channels easier. Mapping of the coordinates for the identified landslides was done using the Geographical Positioning System (Trimble Geo Explorer II GPS).

Ground reference data was acquired during fieldwork. This data was also used to verify occurrences and identify any scars not observed on the aerial photographs and satellite images. Fieldwork involved transversing the areas, inspecting all the spurs and slopes for scars, gullies, evidence of soil creeping and rock falls. Photographs were also taken during the field visits, using a Sony SF-516 digital camera. Local people, especially eye witnesses to the landslides, provided information on the location of the landslides, landslide histories, and the general weather conditions prior to the landslides.

Measurements of average widths, depths and lengths of channels and diameter of the scars were carried out, using a 200-meter surveying tape. The angle at which the scar is located was determined by an Abney level while the actual location was determined by GPS. The information was converted into digital format and processed, using ArcGIS version 9.0 package. The classification of landslides was based on Campbell (1951), Zaruba and Mencl (1969), Campbell (1975), Varnes (1978), Crozier (1973), Hutchinson (1978), Smith (1992), and Coch (1995). The results are presented in **Chapter 6** and **Appendix 15**. Landslides histories were obtained through interviews of the local people in the affected areas. A questionnaire was administered (**Appendix 3**).

### 5.3 Collection of Geological Data

Fieldwork was carried out to determine the dipping angle and foliation trends, using a Silva compass. Slope angles were measured, using an Abney level. Geological map interpretation was carried out to obtain additional information on the geology of the areas. This involved interpreting the geological maps of South Uzumara (GoM, 1977) and Ntcheu District (GoM, 1978) both at scales 1:100,000. Additional information was also obtained from the Livingstonia Coalfield, the Geology of the Uzumara Area, and the Geology of Ntcheu Area bulletins (Cooper and Habgood, 1959; and Kemp, 1975). These sources provided information on dipping angle, strike, foliation trends, faulting, and the type of geology. Digital elevation Model (DEM) of Malawi was used to calculate slope parameters such as slope, orientation, dipping, and foliation trends. Boulder measurements were carried out, using a 50-meter surveying tape. For block boulders, length, height, and width were measured, and for spherical or round boulders, diameter was measured. Fieldwork formed the bulk of geological data collection because at the scale of 1: 100,000, geological maps could not provide adequate details of geology of the study areas. This involved traversing the study areas. Additional geological data for the Ntchenachena Area was obtained from Msilimba and Holmes (2005). The results are presented, and discussed in **Chapter 7**.

### 5.4 Mapping of Settlements and Infrastructure

The identification of settlement and infrastructure is a critical step in achieving reduction in the risk posed by landslides. Settlements were identified and mapped, using aerial photographs (taken in 1995) at a scale 1:25,000. Infrastructures such as roads were also mapped from aerial photographs. More recent data was provided by Landsat 7 ETM images taken in 2003. Topographic maps of Livingstonia and Ntcheu areas at a scale 1:50,000 provided additional data.

Fieldwork provided ground reference data. This involved cross-checking information from topographic maps, satellite images and aerial photographs. GPS was used in the mapping of existing and abandoned settlements. Photographs of settlements and infrastructure were taken, using a Sony F-516 digital camera. Data was plotted on digital maps of the study areas. Information on the abandoned settlements was provided by the local people in the study areas.

### 5.5 Digital Topography

Digital elevation data was generated from the existing 1:50,000 topographic maps of the areas (GoM, 1987; and GoM, 1987) by digitising the contours. The vectorised contours, with a 50 feet interval (approximately 15m), were interpolated at a resolution of 5m X 5m, using triangulated irregular network technique as described by Knapen et al., (2006). Elevation and coordinates for various locations were recorded, using GPS and then transferred into ArcGis version 9.0 package.

### 5.6 Drainage Data Collection

Identification of rivers, drainage patterns, and the watershed were carried out, using the topographic sheets of Livingstonia and Ntcheu at a scale 1:50,000 (GoM, 1987 and GoM, 1987). This involved a detailed study of the contour and drainage patterns. Aerial photographs and Landsat 7 ETM provided additional information on patterns and drainage density. Data on drainage was plotted on a 1:20,000 drainage and contour map of the area. Field investigation was carried out to verify channel morphometry, density of drainage network, and the names of the rivers. Drainage maps were generated by digitising the drainage lines from the topographic maps.

### 5.7 Rainfall and Temperature Data Collection

As discussed in **Sections 3.6.4** and **3.7.2,** Climate plays a very important role in the triggering of landslides. Rainfall determines changes in ground water while temperature determines the rate of weathering. Both rainfall and temperature data were obtained from the meteorological stations at Livingstonia and Ntchenachena in Rumphi District and Nkhande in Ntcheu District. Only records for a period of 30 years (from 1976 to 2006) were obtained. However, additional data was obtained from the Central Meteorological Services at Chileka. A period of 30 years was chosen to provide a good analysis of rainfall patterns. The results are presented in **Chapter 7, Appendices 11** and **12.** It should be noted that the weather stations are located within 15km radius from the study sites and were the nearest weather stations.

### 5.8 Land-Use and Land-Cover

Land-use and land-cover data provides an indication of the stability or the disturbance of the slope. All this is important in hazard assessment and landslide mitigation (Alexander, 1993; and Crozier, 1984). Aerial photograph interpretation, using 1995 photographs, was carried out to identify various land-uses. No aerial photographs for the periods after 1995 were available. Recent data on land-use and land-cover were obtained from Landsat 7 ETM images of 2003. Interpretation of aerial photographs was done following procedures explained in **Section 5.2**. Boundaries were marked on 1:20,000 maps of the study areas which were then digitised. Additional information on land-use was obtained from topographic maps of the areas, as well as the Department of Forestry, and vegetation surveys (**Section 5.10**). Photographs were taken during field visits to provide additional records.

### 5.9 Soil Sampling

Soil and sediment textural and physical properties have an influence on the susceptibility of such material to failures (Bryant, 1976; and Msilimba, 2002). Sampling of soils was undertaken in order to determine physical characteristics (particle sizes, hydraulic conductivity, particle density, bulk density, total porosity, aggregate stability, liquit limit, plastic limit and plasticity index) that have a bearing on soil structural strength. Sampling procedures and rationale are described below. Additional soil data was obtained from the Land Husbandry Department, the Ministry of Agriculture and Fod Security, aerial photographs, and satellite images. Soil samples were collected at all the study areas, and the sampling coordinates are given in **Appendix 10**.

### 5.9.1 Ntchenachena

Due to the nature of the terrain which is rugged with interlocking spurs (**Section 2.2.1.3**), each spur formed a sampling unit. Both core and clod sampling were carried out, using standard procedures described in GoM (1988), and Fredlund and Riharjo (1993). For each sampling pit, two undisturbed and two disturbed samples were collected, using a core sampler and a soil auger. The sampling interval was 15m by 50m (based on the contour interval of 50m apart). Sets of two samples (one disturbed and one undisturbed) were collected at depths of 0 to 100cm, and >100cm, respectively. This was mainly done to find out if physical properties and hydraulic characteristics differ down the profile.

The sampling pits (sites) were mapped, using a GPS (**Appendix 10**). However, in areas where landslides had occurred, the samples were collected from the sides of the scar. In thickly forested areas, gullied areas and very rugged terrain sampling was difficult because of inaccessibility. The results from the rest of the spur were then generalised to include unsampled sites. In special cases, the selection of the sample locations was based on indications of slope instability, mainly soil creeping and cracking. The effective soil depth was determined using a screw soil auger, a surveying tape, depths of recent landslides, and slope remodelling. Photographs were taken during field visits to provide additional records. In the Ntchenachena Area, the following smaller areas were identified and formed the sampling units: Kasokoloka, Lutowo 1 to 8, Kasese Proper, Kasese Forest, Mankhorongo and Chikwezga.

### 5.9.2 Chiweta

Similar procedures, as described in **Section 5.9.1** above, were followed. However, the determination of sampling points was based on evidence of landslides and areas where the beds have been significantly weathered. Much of the sampling was restricted to the slope undercutting areas where soils are of reasonable depth. In most parts of this area, the beds are exposed and sometimes not weathered or partly weathered. Samples were collected from two units: Upper Chiweta and Lower Chiweta separated by the M1 road to Karonga.

### 5.9.3 Mvai and Livilivi Catchments

The same procedures, as outlined in **Section 5.9.1,** were also followed. However, in most parts of the area, soils are thin and contain unweathered crystalline metamorphic rocks (**Section 2.2.3.2**). Sampling was confined to areas where the basement is highly weathered, and areas with evidence of landslides. Samples were collected from the following units: Mvai 1, Mvai 2, Livilivi 1, 2, and 3.

## 5.10 Vegetation Survey

The roles of vegetation in stabilising and destabilising the soils have been explained by Crozier (1984) and Alexander (1993) and discussed in **Sections 3.7.5.1** and **3.12.5**. A Vegetation survey was carried out to establish tree heights, canopy cover, and diameter at breast height (i.e. 1.3m above the ground) as a measure of plant density. Quadrants of 20m by 20m were constructed at a spacing of 50m. However, the vegetation survey was concentrated in the forested areas of the study areas. Vegetation cover has been disturbed by cultivation and settlement activities (Ntchenachena), infrastructure development (Chiweta), human activities (mainly charcoal making and fuel wood selling) (Mvai/Livilivi).

The following materials were used in carrying out the vegetation survey: a diameter tape for measuring stem diameters; a 50 meter linear tape for measuring linear distances as well as canopy cover; a suunto hyposometer for booking height readings; standard board for determining height measurement distances; GPS for recording spatial information (coordinates and altitude); and pencils and data sheets. The results of the vegetation survey are presented in **Sections 7.3, 7.8** and **Appendix 15**.

### 5.10.1 Vegetation Survey Methodology

The vegetation survey methodology described below is also discussed in Chutter et al (1983), Von Gadow and Bredenkamp (1993), Avery and Burkhart (2002), and Bredenkamp (2002).

#### 5.10.1.1 Tree Height

The Suunto Hyposometer was used with a standard board placed at breast height (1.3m from the ground). Distances of 15m to 20m were used. The following trigonometric principle was used to determine height: $H = (\tan\theta_e + \tan\theta_d)xD$,

Where : *H* is tree height in meters

*D* is distance in meters from the tree being measured and the observer.

$\theta_e$ is angle of elevation

$\theta_d$ is angle of depression

When using the Suunto Hyposometer, scales of $\frac{1}{15}$ for 15m distances and $\frac{1}{20}$ for 20m distances were used to correspond with the scale on the board.

#### 5.10.1.2 Diameter

Diameter is also an important indicator of plant response to the site. It was possible to establish stem biomass volume out of diameter at breast height (dbh) and height (h). The dbh yields basal area of the stem. Using the diameter tape, stem girth over bark was determined at stump height (0.15m above ground), and breast height (1.3m above ground). The diameter at stump height (dsh) was determined to illustrate stems sizes, particularly those of less than 1.3m high. Measuring diameter at breast height (dbh) is the standard practice in forestry.

#### 5.10.1.3 Crown width

Crown cover is the surrogate of the photosynthetically active foliage which has a direct impact on the forest floor and precipitation interception (Ward, 1967). Two crown or canopy diameters were measured at right angles to the stem. The average of the maximum and minimum diameter was calculated as the canopy cover.

#### 5.10.1.4 Vegetation Density

This is the number of stems per unit area, normally expressed as stems per hectare. For this study, vegetation density was expressed in relative terms, i.e. percentage-wise. This was calculated to give an indirect measure of vegetation stabilisation of the soils.

## 5.11 Soil Analyses

Soil samples were analysed for the following: particle size, hydraulic conductivity, particle density, bulk density, total porosity, aggregate stability, liquid limit, plastic limit, and plasticity index. These parameters determine the structural properties of the soil (Finlayson, 1980; GoM, 1988; and Msilimba, 2002). The samples were analysed at the Bvumbwe Agricultural Research Station, under the Ministry of Agriculture. The analyses were based on standard procedures (Punmia, 1976; GoM, 1988; Non-Affiliated Soil Analysis Working Committee, 1990; and Okalebo et al., 1996, 2002). The results are presented in **Appendices 2, 13,** and **14,** and discussed in **Chapter 7.**

### 5.11.1 Particle Size Analysis

#### 5.11.1.1 Clay and Silt Percentages

In determining clay and silt percentages, the standard hydrometer method was used (Brasher, 1966; Punmia, 1976; and Non Affiliated Soil Analysis Working Committee, 1990). Fifty grams of the soil was put in a dispersion unit and 150ml of dispersion solution (sodium hexameraphosphate and sodium hydroxide) were added and dispersed for 5 minutes. The material was allowed to cool overnight, and then made up to 1 litre with tap water. Two drops of amlyl alcohol were added to remove excessive froth. The mouth of the cylinder was covered and shaken vigorously by inverting the cylinder several times during the course of one to two minutes, and the time was noted. After four minutes a clean hydrometer was inserted carefully, and readings were taken to the nearest 0.5 unit, exactly 5 minutes after setting the cylinder down. This first reading was recorded as $X_1$. The hydrometer was removed carefully without disturbing the suspension. Temperature was then recorded to the nearest 0.2°C ($T_1$).

After exactly five hours, the hydrometer and temperature readings were again taken ($X_2$ and $T_2$). 150ml dispersal solution was diluted to 980ml in a blank cylinder. The solution was shaken and hydrometer readings were taken after five minutes and five hours ($B_1$ and $B_2$). The fractions were calculated as follows:

$X_1$ and $X_2$ were corrected by subtracting the respective blank readings. The readings were corrected further for temperature by adding 0.3 units for every 1°C that temperature of the suspension was above 19.4°C or by subtracting 0.3 units for every 1°C that temperature was below 19.4°C and rounded off to the nearest 0.5 units i.e.

corrected reading $R_1=X_1+0.3\ (T_1-19.4)$. If $T_1$ and $T_2$ differ widely, $X_2$ was corrected by using the mean temperature i.e. $R_2=X_2-B_2 + \{0.3\ (T_1+T2/2) - 19.4^{o}C\}$. $R_1$ was doubled to give % clay plus % silt. $R_2$ was doubled to give % clay and the difference gave the % silt.

#### 5.11.1.2 Sand Fraction Analysis

Sand fraction analysis was carried out, using the standard sieving method (GoM, 1988; and Non-Affiliated Soil Analysis Working Committee, 1990). Sieves of mesh diameters 2.0 – 0.5mm and 0.5-0.05mm were used to determine the weight of coarse sand, medium to fine sand respectively. The total sand was allowed to pass through a series of sieves of decreasing aperture (increasing mesh number). The amount retained by each sieve was weighed, using a Sartorius digital balance and the weights were converted to percentages. For classification of the sand fractions, see **Appendix 13.**

#### 5.11.1.3 Determination of Hydraulic Conductivity

Hydraulic conductivity was determined using the technique described by Punmia (1976). The hydraulic conductivity scale is given in **Appendix 2**. Undisturbed samples were used in the test. The metal lids were carefully removed, and a piece of muslin cloth was stretched tightly across the ends. A metal cylinder was fastened on top of the core. The core was cloth-covered and placed downwards in a shallow tray containing tap water to a height a little less than the height of the soil column. The core was left overnight to allow water to saturate the soil column. A piece of filter paper was inserted to the core, and then slowly tap water was added to about 2 to 3 cm depth above the upper soil surface. A constant head was applied by means of an up turned plastic bottle. The volume of water passing through the soil column in a given time was measured. The depth of water above the soil surface to nearest mm (H cm) was measured. Determination of the area of cross-section (A sq. cm) and the length (L m) of the soil column) was carried out. Hydraulic conductivity was calculated as follows: if *V* is the volume of water (ml) passing through the sample in *t* minutes, then the hydraulic conductivity can be defined as;

$K = [V / A] \times [60 / t] \times [L + \{L + H\}]$ cm/hr (**Appendix 2**)

#### 5.11.1.4 Determination of Bulk Density

This was determined using the standard method (Brasher, 1966; and Punmia, 1976). Since the hydraulic conductivity test had previously been carried out on the core samples, the samples used in the test were used for the calculation of bulk density. The soil samples were placed in moisture tins and dried overnight in an oven at 105°C. The tins were removed from the oven and allowed to cool, then the moisture tin plus the metal sleeve, plus soil were weighted ($W_1$gm). The soil was discarded and the moisture tin and metal sleeves were washed and dried in an oven, allowed to cool, then reweighed together ($W_2$gm). Determination of internal area of cross-section (Asq.cm) and the length (Lcm) of the metal sleeve was carried out (**Section 5.11.1.3**).

Internal volume of the sleeve was calculated by:

$V = A \times L$ cm$^3$

Over-dry weight of soil contained by the sleeve was calculated by $W = W_1 - W_2$ gm

The bulk density is given by:

$D_b = W/V$ gm.cm$^{-3.}$ The final value was quoted to 2 decimal places.

#### 5.11.1.5 Determination of Particle Density

This was determined by the standard method described in the Soil Laboratory Manual (GoM, 1988). 50gm of sieved oven-dry soil was weighed and transferred into the volumetric flask and the flask together with the soil was re-weighed (Ws gm). Water was added to about 60ml, washing down any soil particles adhering to the inside of the flask. The flask was boiled gently for about 2 minutes to remove any entrapped air, and the material was swirled frequently to prevent excessive frothing. The flask was allowed to cool overnight. One hundred ml flask mark was made at room temperature by adding water, and then reweighed the flask and contents ($W_{sw}$ gm), and temperature was recorded. The flask was emptied and washed. Its outside part was dried carefully, then filled with water at room temperature and made up to the 100 ml mark and reweighed ($W_w$ gm). Particle density is given by:

$$dp = d_w \times \frac{Ws - Wa}{Ww + Wsw - Wa} \, gm.cm^{-3}$$

$d_w$ is the density of water at the given temperature (GoM, 1988) and results expressed to two decimal places.

$W_a$ is the weight of a clean dry 100 ml volumetric flask (no stopper) to three decimal places on the P120 balance.

### 5.11.1.6 Calculation of Total Porosity (st)

Total porosity was calculated from the bulk and particle density (Brasher, 1966), using the equation:

$$St = 100\text{x } \frac{dp - db}{dp}$$

Where St is total porosity

$d_p$ is the particle density

$d_b$ is the bulk density

### 5.11.1.7 Aggregate Stability Analysis

Procedures for aggregate stability tests are given in GoM (1988). A total of 500gm of soil obtained from the clod sample were air-dried. Large lumps were broken, using gentle finger pressure. The material was passed through an 8mm sieve and collected on a 2mm sieve for quartering for further sub sampling. Soil passing through the 2mm sieve was discarded. 25gm representative aliquots of air-dried (> 2mm diameter) material were weighed in duplicate for aggregate analysis. 0.5 and 2mm sieves were arranged in sequence, with the largest on top and clamped. The aggregated soil was carefully placed on the 2mm sieve and wetted to saturation by spraying with a very fine mist from an atomizer.

The cans were filled with water and adjusted for sieving so that the sample on the top screen remained submerged at the highest point of oscillation of the lift mechine, but the sieve would not be flooded at the lowest point. All samples were immersed and shaken for one minute, and then oscillated for 30 minutes. The rest of the sieves were raised and allowed to drain. The aggregates from each sieve were transferred into the large evaporation dish. Excess water was poured off, and aggregates were transferred by washing into the small evaporation dishes.

The samples were oven-dried overnight and weighted and 0 - 0.5mm sizes by difference were obtained. Weights of 0.05, 0.5 – 2.0, and 2.0 – 8.00mm sizes were recorded.

#### 5.11.1.8 Determination of Liquid Limit (LL)

Liquid limit was determined using the Casagrande method (Punmia, 1976). The Casagrande tool was adjusted by means of a gauge. When the adjustment was completed, the adjustment plate was secured by tightening its screws. 125gm of soil was passed through a 425 micron sieve, and mixed with distilled water in the evaporation dish so that a paste was formed. The soil was left so that water permeated. The mature time was 24 hours. A portion of the paste was taken and placed in the centre of the cup so that it was almost half filled. The top was levelled so that it was paralleled to the rubber base and the maximum depth of the soil depth (1cm). With the help of a grooving tool "a" the paste was divided along the cup diameter. Thus, a V-shaped gap, 2mm wide at the bottom and 11mm at the top and 8mm deep, was formed. However, in the case of sandy soils, tool 'a' did not form a neat groove; hence, tool "b" was used. The handle of the apparatus was turned at the rate of 2 revolutions per second, until the two parts of the soil came in contact with the bottom of the groove along a distance of 10mm. The number of revolutions required to cause the groove to close for the approximate length of 10mm were recorded. The remaining soil was removed from the cup and mixed with the soil left earlier on the marble plate. The consistency of the mix was changed by adding more water or leaving the soil to dry, depending on the soil moisture condition. The number of revolutions to close the groove was recorded.

#### 5.11.1.9 Determination of Plastic Limit (PL)

The plastic limit was calculated, using the Casagrande method, plus 3mm diameter rod (Punmia, 1976). Ten grams air-dried soil passing through a 420 micron sieve was used. The sample was mixed with distilled water to make it plastic enough to be shaped into a ball. The plastic material was left for at least 24 hours to mature to allow water to permeate. About 8gm of the plastic soil were taken and molded into a ball, then rolled on marble or glass. With the hand and just sufficient pressure, the ball was rolled into a thread of uniform diameter throughout its length. When the diameter of the thread decreased to 3mm, the specimen was kneaded together and rolled out again. The process was continued until the thread just crumbled at 3mm diameter. The readings were obtained for determination of the plasticity of the soil.

#### 5.11.1.10 Determination of Plasticity Index (PI)

Plasticity index was calculated from plastic limit and liquid limit as follows:

PI = LL - PL

## 5.12 Social Survey

### 5.12.1 Introduction

The social survey was carried out to ascertain peoples' perceptions on the occurrences of landslides, their knowledge on the causes and economic and environmental impacts of the landslides. The survey aimed to determine opinion as to whose responsibility the management of slope instability problems were, and what mitigations were being put in place to resolve these problems. Issues of coping strategies were also addressed. Gender differences and perceptions towards landslides were determined. The purpose was to assess landslide knowledge and awareness between sexes. It was envisaged that such an analysis would help to formulate a gender specific approach in managing slope stability problems, considering that the environment is not gender-neutral (Dankelman and Davidson, 1988).

The main techniques adopted to assess the knowledge and perceptions of the local people and managers as regards landslides occurrences in their localities were a questionnaire and interviews. The survey design was largely based on the standard social survey techniques presented by several authors (Sudman and Bradburn, 1983; Bailey, 1994; Oppenheim, 2000; and Dewar pers. com, 2001).

### 5.12.2 Survey Design

The study adopted a cross-sectional analysis of the perceptions of local people in the affected areas, eyewitnesses to the landslides, and government officials from the affected districts.

### 5.12.3 Questionnare/Interview Design

The questionnaire design drew largely from procedures recommended in the literature (Sudman and Bradburn, 1983; Wiggins, 1988; Bailey, 1994; Fowler, 1995; and Oppenheim, 2000). The best practice is characterised and the emphasis is on simplicity, appropriateness, clarity, and consistency. The questionnaires were pre-tested for accuracy. Samples of completed questionnaire in English are attached (**Appendix 3**).

The questionnaire was coded for easy administration and statistical analysis. There were three main sets of questionnaires targeting villagers in the affected areas, district commissioners in affected districts, and the Department of Geological Survey.

Part of the cover page was devoted to outlining the intentions and expectations of the study in reference to earlier communications. This part also points to the importance of the confidentiality of the respondents' answers, and indicates the procedure of the questionnaire administration.

### 5.12.4 Household Survey

Villages formed the basis of study units (clusters). The subjects were selected using stratified random sampling technique from the population data obtained from the National Statistical Office (NSO, 1998). This was to minimise biases arising from the use of simple random sampling technique (Sudman and Bradburn, 1983). The sample comprised 264 subjects of which 106 were from the Ntchenachena Area and 158 from the Mvai/Livilivi Areas. Questionnaires were not administered at Chiweta because there were no human settlements in proximity to landslide susceptible areas. Furthermore, there was no evidence to point to the fact settlement activities were contributing to landslides. Only subjects with ages above 20 years were involved in the study to provide landslide histories. It was assumed that respondents younger that twenty would not provide an accurate account of landslide histories.

Smaller samples of 15 households each from the Ntchenachena and Ntcheu Areas were identified randomly for an in-depth study of landslides occurrences, economic and environmental impacts, and peoples' responses to such landslide events. These households formed case studies of localised adjustments to the challenges posed by landslides in their local areas and their coping strategies.

Questionnaires and in-depth interviews were supplemented with focus group discussions (FGD). Naturally existing groups such as village chiefs and their advisors, farmers groups, women groups, and elderly people were mobilised to discuss their perceptions, landslides histories, economic, and environment impacts, and their coping strategies to landslides. Eyewitnesses to the landslides were targetted to give first hand information.

### 5.12.5 Household Survey Procedure

Personal interviews were conducted to ensure adequate control over actual respondent identity, high response rate and "public relations" answer (Sudman and Bradburn, 1983). In Northern Malawi, the questionnaires were administered in the dominant local language of Chitumbuka while in Central Malawi, Chichewa, which is widely spoken, was used. However, for Government officials, interviews were conducted in English which is the language for business in the country. Six research assistants were trained in basic survey techniques and procedures. All the questions were read loudly and clearly to the respondents and the research assistant recorded the response. Through the contacts with the communities, the research assistants were able to create a good relationship, and obtain successful responses. Preliminary visits were made to the study areas to explain about the forthcoming survey and its objectives. The message was delivered to the local chiefs and church leaders for easy disseminaton.

### 5.12.6 Survey of Government Officials

Two district comminissioners and two environmental officers were targetted. District commissioners were target because they were responsible for the implementation of government policies, and are also in direct contact with the affected people. environmental officers were targeted because they are responsible for the environmental issues in the districts. The Geological Survey Department was selected because of its role in the mapping of unstable hill slopes and inventorying landside events. It was also felt that the Department would give scientific causes of landslides while the local people would provide answers based on traditional knowledge. Personal structured interviews, as well as self administered questionnnares were used because of their significance in stimulating face-face interactions. Samples of questionnaires to government officials are given in **Appendices 4** and **5**.

### 5.12.7 Pilot Study and Implementation of the Survey

The initial drafts of the questionnaires were developed as a result of wide consultation of relevant literature and discussions with the supervisor and collegues familiar with social survey designs. Pre-testing was conducted on a relatively small sample at the Ntchenachena and the Mvai/Livilivi areas to ensure that unforeseen problems would not occur in the questionnaires. Letters of intention to undertake research on causes and impacts of landslides and seeking the participation of the affected communities were submitted to local chiefs who informed their subjects in turn.

### 5.13 Data Analysis

Time series analysis was carried out on aerial photographs to determine land use change and the results were converted into percentages. Hydraulic conductivity test results were analysed using a hydraulic conductivity table (**Appendix 2**: Non-Affiliated Soil Analysis Working Committee, 1990). Slope angles were analysed, using critical angle for sliding (Hoek and Boyd, 1973), and Fernandes critical slope angle ranges (Fernandes et al., 2006), and slope angle operator in the ArcGIS software package. Aggregate stability results were analysed, using aggregate stability scale (GoM, 1988). Rainfall data were analysed for mean monthly and mean annual rainfall, and the results were presented graphically. Temperature data was analysed for mean minimum and maximum temperatures. Data from porosity, particle size, liquid limit and plastic limit tests was analysed, using standard acceptable soil analysis techniques as described in Non-Affiliated Soil Analysis Working Committee (1990). The percentages and standard deviations were also calculated, and results were tabulated. Post Hoc comparison tests (LSD and Benforroni Statistics) and ANOVA equality of means tests were employed to determine significant differences for various soil parameters between study areas, within groups and between soil horizons. These three tests were used to improve reliability of the results. The results of these analyses are presented in **Chapter 7** while tables displaying basic data of the responses from administered questionnaires are given in **Appendices 6, 7, 8 and 9**.

#### 5.13.1 Analysis of Questionnaires

Data analysis involved comparing responses between groups and within groups. Responses were sorted and coded according to themes using the SSPS software programme. Since most responses were categorical and non parametric (either nominal or ordinal), Chi square methods of statistics were applied. Chi-square tests were carried out to establish the independence of responses from the two districts. Since the responses from the districts were interval in nature, Pearson's Product Moment Correlation was employed to check linear relationships (linear by linear association) between the districts. Cross-tabulation procedures were carried out in an attempt to establish associations among variables. Descriptive anlysis was carried out on aspects related to the socio-economic profile of the respondents as described by Johnston (1991).

### 5.14 Conclusion

Several methodologies employed in data collection have been presented, and explained. Procedures on soil samples have been discussed in detail. The findings of the procedures and analyses outlined above constitute the rest of the chapters that follow. The next Chapter presents and discusses landslides inventory, classification, and impacts.

# CHAPTER SIX

# LANDSLIDE DISTRIBUTION, LOCATION AND IMPACTS

This Chapter presents the results of landslides inventory from the analyses of aerial photographs, satellite images, and field observations as described in **Section 5.2**. It provides the dimensions of landslides, dating, as well as the location, and distribution of the landslides. A classification of landslides is also provided. The Chapter also provides details of channel morphometry, materials involved in the movement, altitude, slope type and aspect. It demonstrates the importance of lithology in determining channel dimensions and types of movements. Furthermore, it discusses factors controlling the spatial distribution of landslides. The impact of the observed landslides is also presented and discussed.

## 6.1 Results of the Landslides Inventory

A landslide inventory was carried out to give a measure of instability and the results are presented in **Table 6.1** and in **Figures 6.1, 6.2 6.3, 6.4,** and **6.5**. In total, 131 landslides were identified and mapped (coordinates are given in **Appendix 15**). The nomenclature of the landslides was based on the unit of the study area where the landslides occurred. Of all the landslides, 98 representing 74% occurred in Rumphi District, and 33 landslides, representing 26%, occurred in Ntcheu District. The Ntchenachena Area recorded the highest number of landslides (88 representing 67%), followed by Mvai with 25, representing 19% of all occurrences. The Chiweta Area recorded 10 landslides while Livilivi recorded 8. Of all the landslides, 78% occurred in 2003 while the rest were undated. Dimensions of landslides vary enormously with length ranging from 7m in the Ntchenachena/Livilivi Areas to 750m in the Mvai Area, with the Ntchenachena Area recording the highest average of 133m. Width ranged from 3m in the Mvai Area to 240m in the Ntchenachena. Ntchenachena recorded the highest average width of 54.14m. Depth ranged from 0.3m at the Chiweta Area to 24m at the Ntchenachena Area with an average of 7.09m. There were no significant variations in altitude between the Ntchenachena and the Livilivi/Mvai areas (1273m to1745m above the sea level). However, Chiweta registered lower values, ranging from 721m to 822m because of its proximity to Lake Malawi which is at 421m above sea level. Slope angles for the mapped landslides were high, ranging from $32^0$ to $69^0$ for the Ntchenachena

Area; $60^0$ to $85^0$ for the Chiweta; and $45^0$ to $71^0$ for the Livilivi/Mvai Catchments (**Section 7.3.1 and Table 7.2**). The roles of slope angle and altitude in determining the location and distribution of landslides will be discussed in **Chapter 7**.

**Table 6.1: Landslides Inventory**

| District | Study Area | Event | Year | Dimensions (M) | | | Slope Angle $(^0)$ | Slope Type | Altitude (M) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Length | Width | Depth | | | |
| **Rumphi** | **NTchenachena** | Kasokoloka | 2003 | 230 | 50 | 21 | 41 | concave | 1347 |
| | | Lutowo 1a | 2003 | 175 | 30 | 10 | 40 | concave | 1442 |
| | | Lutowo1b | 2003 | 75 | 11 | 4 | 40 | concave | 1442 |
| | | Lutowo 1c | 2003 | 121 | 15 | 4 | 40 | concave | 1442 |
| | | Lutowa 2 | 2003 | 201 | 20 | 11 | 39 | concave | 1376 |
| | | Lutowo 3 | 2003 | 101 | 49 | 25 | 40 | concave | 1385 |
| | | Lutowo 4a | 2003 | 63 | 31 | 4.1 | 49 | concave | 1747 |
| | | Lutowo4b | 2003 | 7 | 9 | 1.2 | 48 | concave | 1529 |
| | | Lutowo 4c | 2003 | 10 | 9.8 | 1.3 | 48 | Rectilinear | 1715 |
| | | Lutowo 4d | 2003 | 75 | 9 | 3.5 | 48 | Rectilinear | 1521 |
| | | Lutowo 4e | 2003 | 85 | 11 | 1 | 48 | Rectilinear | 1511 |
| | | Lutowo 4f | 2003 | 75 | 9 | 3.5 | 48 | Rectilinear | 1500 |
| | | Lutowo 4g | 2003 | 85 | 65 | 4 | 48 | Rectilinear | 1478 |
| | | Lutowo 4h | 2003 | 86 | 75 | 6 | 43 | Rectilinear | 1452 |
| | | Lutowo 4i | 2003 | 75 | 15 | 4 | 56 | Rectilinear | 1396 |
| | | Lutowo 5a | 2003 | 80 | 50 | 1.8 | 50 | Concave | 1464 |
| | | Lutowo 5b | 2003 | 98 | 12 | 3 | 50 | Concave | 1473 |
| | | Lutowo 5c | 2003 | 79 | 35 | 8 | 50 | Concave | 1491 |
| | | Lutowo 5d | 2003 | 21 | 11.4 | 1.5 | 50 | Concave | 1496 |
| | | Lutowo 5e | 2003 | 89 | 7 | 2 | 50 | Concave | 1513 |
| | | Lutowo 5g | 2003 | 65 | 50 | 4 | 50 | Concave | 1507 |
| | | Lutowo 6a | 2003 | 105 | 30 | 15.5 | 45 | Concave | 1555 |
| | | Lutowo 6b | Ancient | 106 | 40 | 16 | 45 | Concave | 1574 |
| | | Lutowo 6c | 2003 | 210 | 50 | 17 | 49 | Convex | 1594 |
| | | Lutowo 6d | 2003 | 115 | 52 | 1.5 | 49 | Convex | 1627 |
| | | Lutowo 7a | 2003 | 26 | 50 | 2 | 68 | Convex | 1634 |
| | | Lutowo 7b | 2003 | 46 | 15 | 0.4 | 68 | Convex | 1632 |
| | | Lutowo 7c | 2003 | 17 | 9 | 2 | 68 | Convex | 1635 |
| | | Lutowo 7d | 2003 | 100 | 64 | 4 | 51 | Linear | 1632 |
| | | Lutowo 7e | 2003 | 61 | 7 | 1.5 | 51 | Concave | 1619 |
| | | Lutowo 7f | Ancient | 25 | 16 | 1.7 | 55 | Concave | 1616 |
| | | Lutowo 7g | Ancient | 28 | 17 | 1.4 | 55 | Convex | 1600 |
| | | Lutowo 7h | 2003 | 19 | 6 | 3.4 | 45 | Convex | 1593 |
| | | Lutowo 7i | 2003 | 22 | 11 | 0.7 | 45 | Convex | 1587 |
| | | Lutowo 7j | 2003 | 31 | 13 | 0.9 | 45 | Convex | 1590 |
| | | Lutowo 7k | 2003 | 15 | 8 | 0.9 | 68 | Convex | 1568 |
| | | Lutowo 7l | 2003 | 19 | 13 | 2.5 | 68 | Convex | 1540 |
| | | Lutowo 7m | Ancient | 216 | 77 | 1 | 68 | Convex | 1537 |
| | | Lutowo 7n | 2003 | 79 | 31 | 8 | 44 | Concave | 1519 |
| | | Lutowo 7o | 2003 | 85 | 16.2 | 2.1 | 44 | Concave | 1500 |
| | | Lutowo 7p | 2003 | 27 | 12 | 3 | 59 | Convex | 1494 |
| | | Lutowo 7q | Ancient | 36 | 6 | 2.5 | 59 | Concave | 1468 |
| | | Lutowo 7r | 2003 | 42 | 10.7 | 6 | 59 | Concave | 1463 |
| | | Lutowo 7s | 2003 | 97 | 18.6 | 1.1 | 57 | Concave | 1421 |
| | | Lutowo 7t | 2003 | 52 | 24 | 1.3 | 57 | Concave | 1362 |
| | | Lutowo 7u | 2003 | 72 | 37 | 11.2 | 53 | Concave | 1343 |
| | | Lutowo 8a | 2003 | 37 | 19 | 2.7 | 54 | Concave | 1286 |
| | | Lutowo 8b | 2003 | 42 | 21 | 1.6 | 54 | Concave | 1336 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lutowo 8c | 2003 | 53 | 13 | 1.1 | 54 | Concave | 1328 |
| | | Lutowo 8d | Ancient | 66 | 14 | 1.5 | 54 | Concave | 1358 |
| | | Lutowo 8e | 2003 | 115 | 61 | 3.4 | 62 | Concave | 1379 |
| | | Lutowo 8f | 2003 | 127 | 32 | 1.2 | 62 | Concave | 1404 |
| | | Lutowo 8g | 2003 | 23 | 9.2 | 3.7 | 62 | Concave | 1450 |
| | | Lutowo 8h | 2003 | 212 | 87 | 5.1 | 62 | Concave | 1455 |
| | | Lutowo 8ia | 2003 | 121 | 240 | 3.0 | 62 | Concave | 1478 |
| | | Lutowo 8ib | 2003 | 121 | 240 | 3.0 | 62 | Concave | 1399 |
| | | Kasese 1a | 2003 | 75 | 55 | 12 | 60 | Concave | 1493 |
| | | Kasese 1b | 2003 | 31 | 10 | 4 | 50 | Concave | 1439 |
| | | Kasese 1c | 2003 | 30 | 95 | 12 | 51 | Concave | 1487 |
| | | Kasese 1d | 2003 | 99 | 32 | 13 | 51 | Concave | 1507 |
| | | Kasese 1e | 2003 | 60 | 11 | 0.5 | 69 | Concave | 1507 |
| | | Kasese 1f | 2003 | 40 | 6.7 | 0.5 | 69 | Concave | 1503 |
| | | Mankhorongo 1 | 2003 | 72 | 24 | 1.5 | 61 | Concave | 1360 |
| | | Mankhorongo 2 | 2003 | 106 | 33 | 3.8 | 61 | Convex | 1377 |
| | | Mankhorongo 3 | 2003 | 52 | 16 | 8.4 | 61 | Concave | 1378 |
| | | Mankhorongo 4 | 2003 | 108 | 39 | 3.4 | 65 | Concave | 1402 |
| | | Mankhorongo 5 | 2003 | 451 | 118 | 7 | 32 | Concave | 1457 |
| | | Mankhorongo 6 | 2003 | 324 | 73 | 5.6 | 53 | Concave | 1460 |
| | | Mankhorongo 7 | Ancient | 176 | 125 | 8.5 | 50 | Concave | 1485 |
| | | Mankhorongo 8 | 2003 | 24 | 17 | 7 | 55 | Concave | 1419 |
| | | Mankhorongo 9 | 2003 | 137 | 47 | 1.6 | 55 | Concave | 1415 |
| | | Mankhorongo 10 | 2003 | 140 | 14 | 1.1 | 55 | Concave | 1403 |
| | | Mankhorongo 11 | 2003 | 88 | 35 | 1.4 | 50 | Concave | 1388 |
| | | Mankhorongo 12 | Ancient | 117 | 22 | 4.3 | 52 | Concave | 1279 |
| | | Chikwezga 1 | 2003 | 52 | 19 | 2 | 51 | Linear | 1492 |
| | | Chikwezga 2 | 2003 | 27 | 9 | 2.4 | 51 | Concave | 1477 |
| | | Chikwezga 3 | 2003 | 47 | 27 | 3.2 | 51 | Concave | 1474 |
| | | Chikwezga 4 | 2003 | 83 | 43 | 4.2 | 51 | Rectilinear | 1482 |
| | | Chikwezga 5 | 2003 | 60 | 43 | 1.3 | 51 | Rectlinear | 1496 |
| | | Chikwezga 6 | 2003 | 91 | 30 | 0.8 | 51 | Rectlinear | 1501 |
| | | Chikwezga 7 | 2003 | 83 | 57 | 1.6 | 51 | Rectlinear | 1488 |
| | | Chikwezga 8 | 2003 | 27 | 13 | 1.5 | 51 | Convex | 1474 |
| | | Chikwezga 9 | 2003 | 406 | 15 | 2.6 | 51 | Concave | 1466 |
| | | Chikwezga 10 | 2003 | 31 | 9 | 0.4 | 67 | Concave | 1476 |
| | | Chikwezga 11 | 2003 | 37 | 11 | 1.4 | 67 | Concave | 1429 |
| | | Chikwezga12 | Ancient | 49 | 24 | 1.3 | 54 | Convex | 1438 |
| | | Chikwezga 13 | 2003 | 21 | 19.2 | 0.9 | 58 | Convex | 1392 |
| | | Chikwezga 14 | Ancient | 67 | 15 | 1.6 | 58 | Convex | 1408 |
| | **Chiweta** | Chiweta 1** | Ancient | | | | 83 | Cliff | 806 |
| | | Chiweta 2 | 2003 | 22 | 4.4 | 1.3 | 83 | Cliff | 822 |
| | | Chiweta 3** | Ancient | | | | 85 | Cliff | 791 |
| | | Chiweta 4** | Ancient | | | | 85 | Cliff | 756 |
| | | Chiweta 5 | 2003 | 27 | 3.9 | 0.4 | 85 | Linear | 730 |
| | | Chiweta 6 | 2003 | 22 | 11 | 3.1 | 75 | Linear | 768 |
| | | Chiweta 7 | 2003 | 19 | 14 | 0.3 | 67 | Linear | 757 |
| | | Chiweta 8** | 2003 | | | | 60 | Linear | 730 |
| | | Chiweta 9** | Ancient | | | | 61 | Cliff | 751 |
| | | Chiweta 10 | 1999 | 63 | 23 | 4 | 79 | Linear | 721 |
| **Ntcheu** | **Livilivi** | Livilivi 1 | 2003 | 21 | 7.2 | 6 | 48 | Rectilinear | 1363 |
| | | Livilivi 2 | 2003 | 7 | 11 | 1.1 | 65 | Convex | 1322 |
| | | Livilivi 3 | 2003 | 21 | 8 | 0.8 | 65 | Concave | 1302 |
| | | Livilivi 4 | Ancient | 25 | 17 | 1.4 | 45 | Concave | 1273 |
| | | Livilivi 5 | Ancient | 20 | 9.7 | 1.2 | 45 | Concave | 1287 |

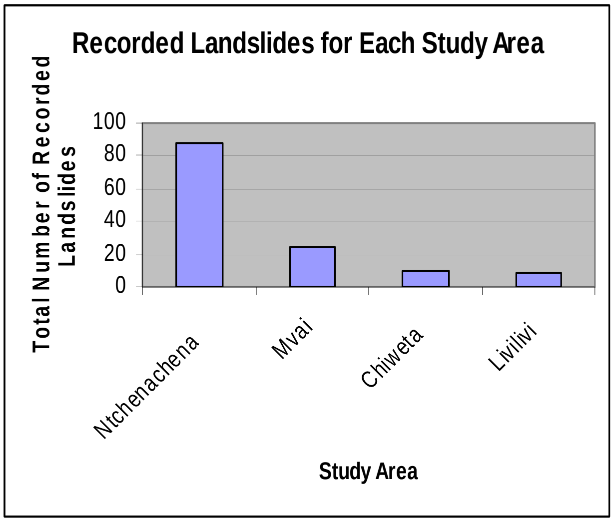
|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  | Livilivi 6 | 2003 | 17 | 7 | 0.6 | 45 | Concave | 1293 |
|  |  | Livilivi 7 | Ancient | 15 | 6 | 1.2 | 45 | Concave | 1297 |
|  |  | Livilivi 8 | Ancient | 130 | 16 | 1 | 45 | Concave | 1306 |
|  | **Mvai** | Mvai A1 | 2003 | 17 | 9 | 1.3 | 54 | Convex | 1427 |
|  |  | Mvai A2 | 2003 | 15 | 8 | 2.1 | 54 | Convex | 1469 |
|  |  | Mvai A3 | Ancient | 50 | 7 | 1.5 | 62 | Convex | 1489 |
|  |  | Mvai A4** | Ancient |  |  |  | 62 | Convex | 1493 |
|  |  | Mvai A5 | Ancient | 30 | 11 | 1.7 | 62 | Convex | 1523 |
|  |  | Mvai A6 | 2003 | 11 | 13 | 1.8 | 66 | Convex | 1668 |
|  |  | Mvai A7 | Ancient | 14 | 7.6 | 3.3 | 66 | Convex | 1673 |
|  |  | Mvai A8 | 2003 | 750 | 36 | 6.1 | 69 | Convex | 1710 |
|  |  | Mvai A9 | 2003 | 452 | 9 | 1.9 | 58 | Convex | 1612 |
|  |  | Mvai A10 | 2003 | 603 | 41 | 2.2 | 52 | Convex | 1546 |
|  |  | Mvai A11** | Ancient |  |  |  | 52 | Concave | 1503 |
|  |  | Mvai A12 | Ancient | 47.5 | 13 | 3.4 | 53 | Concave | 1471 |
|  |  | Mvai B1 | 2003 | 31 | 10 | 2 | 54 | Linear | 1481 |
|  |  | Mvai B2 | 2003 | 39 | 9 | 1.9 | 57 | Concave | 1477 |
|  |  | Mvai B3 | 2003 | 69 | 11 | 2.1 | 58 | Concave | 1424 |
|  |  | Mvai B4 | 2003 | 23 | 5 | 1.1 | 58 | Concave | 1414 |
|  |  | Mvai B5 | 2003 | 74 | 8 | 1.1 | 58 | Concave | 1432 |
|  |  | Mvai B6 | 2003 | 33 | 9 | 2.7 | 58 | Concave | 1451 |
|  |  | Mvai B7 | Ancient | 35 | 14 | 0.6 | 58 | Concave | 1430 |
|  |  | Mvai B8 | 2003 | 17 | 3 | 1.5 | 59 | Concave | 1427 |
|  |  | Mvai B9 | Ancient | 15 | 9 | 1 | 59 | Concave | 1405 |
|  |  | Mvai B10 | 2003 | 15 | 11 | 2.5 | 59 | Concave | 1405 |
|  |  | Mvai B11 | Ancient | 13 | 7 | 5 | 71 | Concave | 1405 |
|  |  | Mvai B12 | 2003 | 57 | 11 | 4.4 | 71 | Concave | 1398 |
|  |  | Mvai B13 | 2003 | 18 | 16 | 1.4 | 62 | Concave | 1368 |

** Observed Rock Falls

## 6.2 Slope Type and Aspect and the Distribution of Landslide Events

Out of all landslide occurrences, 59% were on concave slopes, 4% occurred on cliffs, 22% on convex slopes, and 6% on linear and 9% were on rectilinear slopes. In the Ntchenachena Area of Rumphi District, 64% of the landslides occurred on concave slopes, 20.45% on convex slopes (confined to small sections of the Lutowo and the Chikwezga units), and the rest occurred on either linear or rectilinear slopes. Although the Chiweta Area of Rumphi District is dominated by concave slopes, all the lands;lides occurred on cliffs and linear slopes of the remodeled slopes. In Ntcheu District, 83% of all the landslides at Mvai A occurred on convex slopes while at Mvai B and Livilivi, most of them occurred on concave slopes (92.31% and 75%, respectively).

In terms of slope aspect, the distribution of landslides as a percentage of the total landslides was as follows: NE, 22.9%; S, 22.9%; E, 16.03%; SE and SW, 14.5% each; W, 3.82%; N, 3.053%; and NW,2.29%. However, in terms of study areas, within the Ntchenachena Area of Rumphi District, most of the landslides occurred on S, NE, E and SW aspects (29.55%, 17.04%, 21.59% and 15.91%, respectively). In the Chiweta Area, the distribution was evenly among SE (30%), NE (20%), S (20%) and SW (30%). In Ntcheu District, landslides in the Livilivi Area were on SE and SW (25% each), W (37.5%) and NW (12.5%) facing slopes. In the Mvai Catchment Area, 52% occurred on NE facing slopes, 16% on N, 12% on SE and 8% each for E and S aspects.



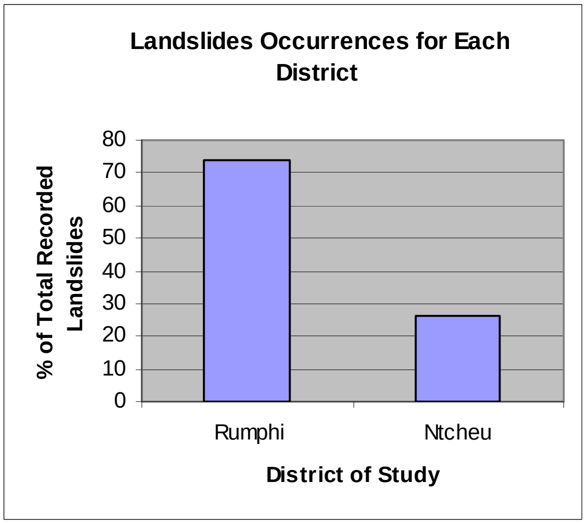


Figure6.1: **Recorded landslides for each study area.**

Figure 6.2: **Landslide occurrences for each District.**

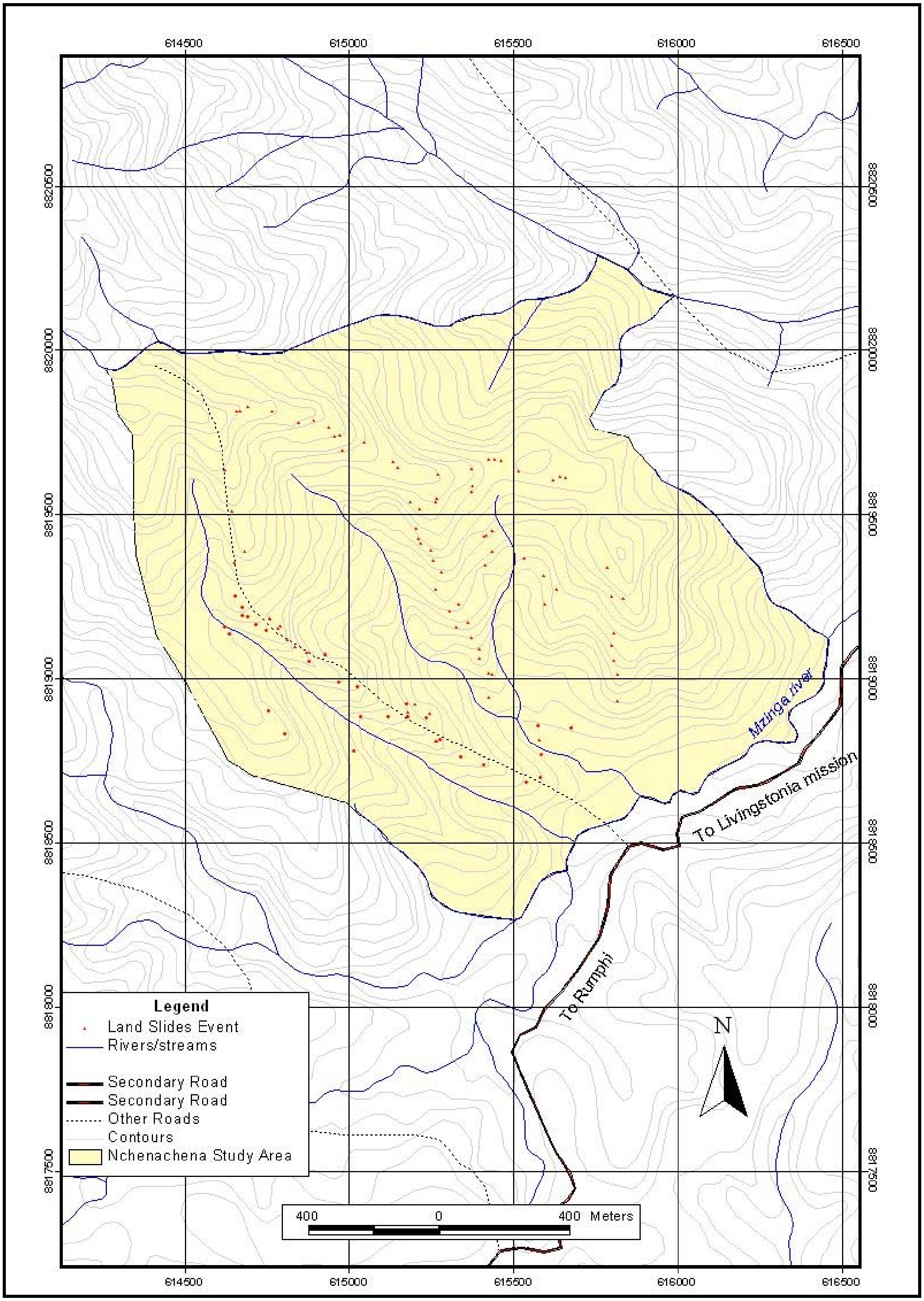


Figure 6.3: **Mapped landslides in the Ntchenachena Study Area.**

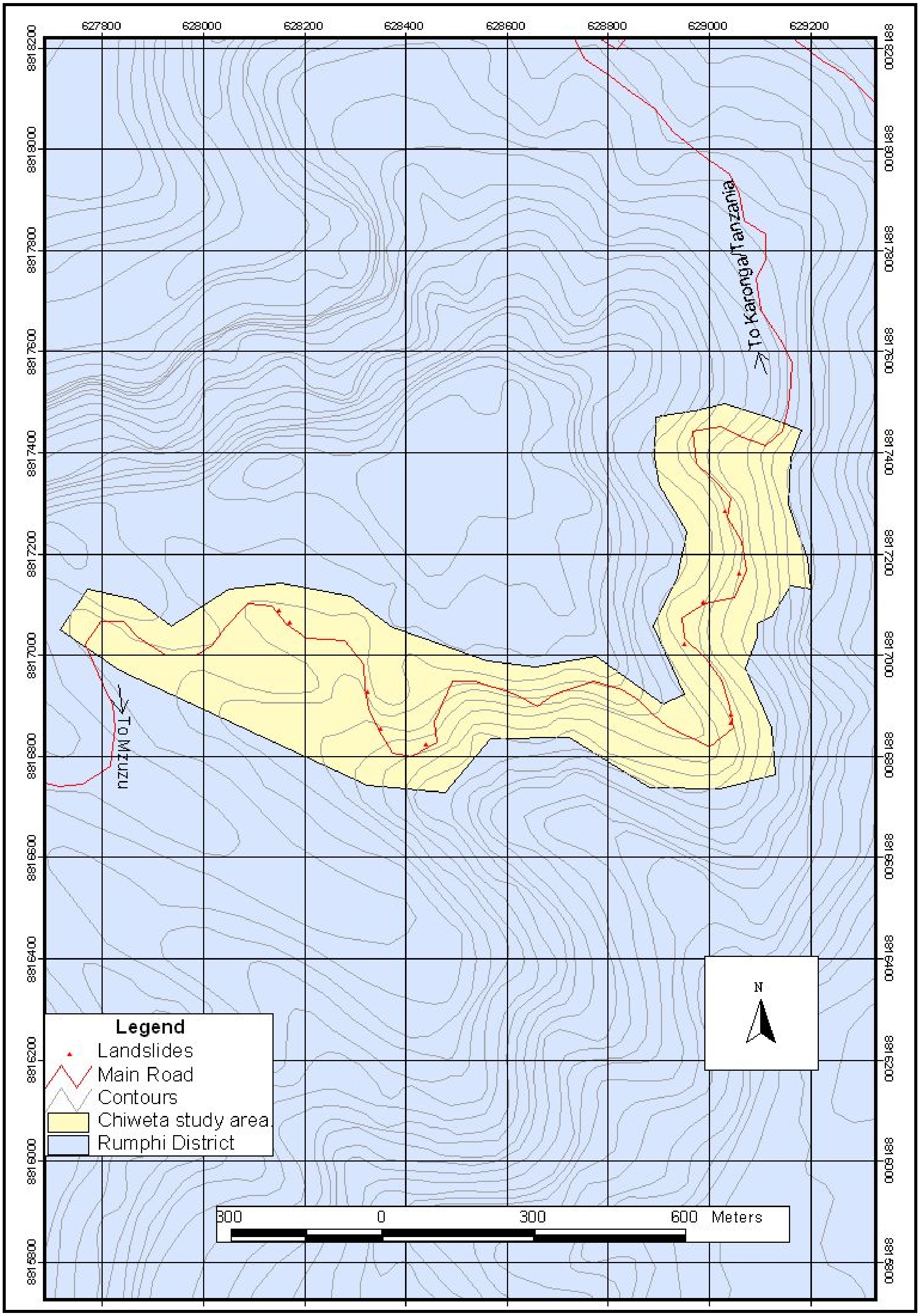


Figure 6.4: **Mapped landslides in the Chiweta Study Area.**

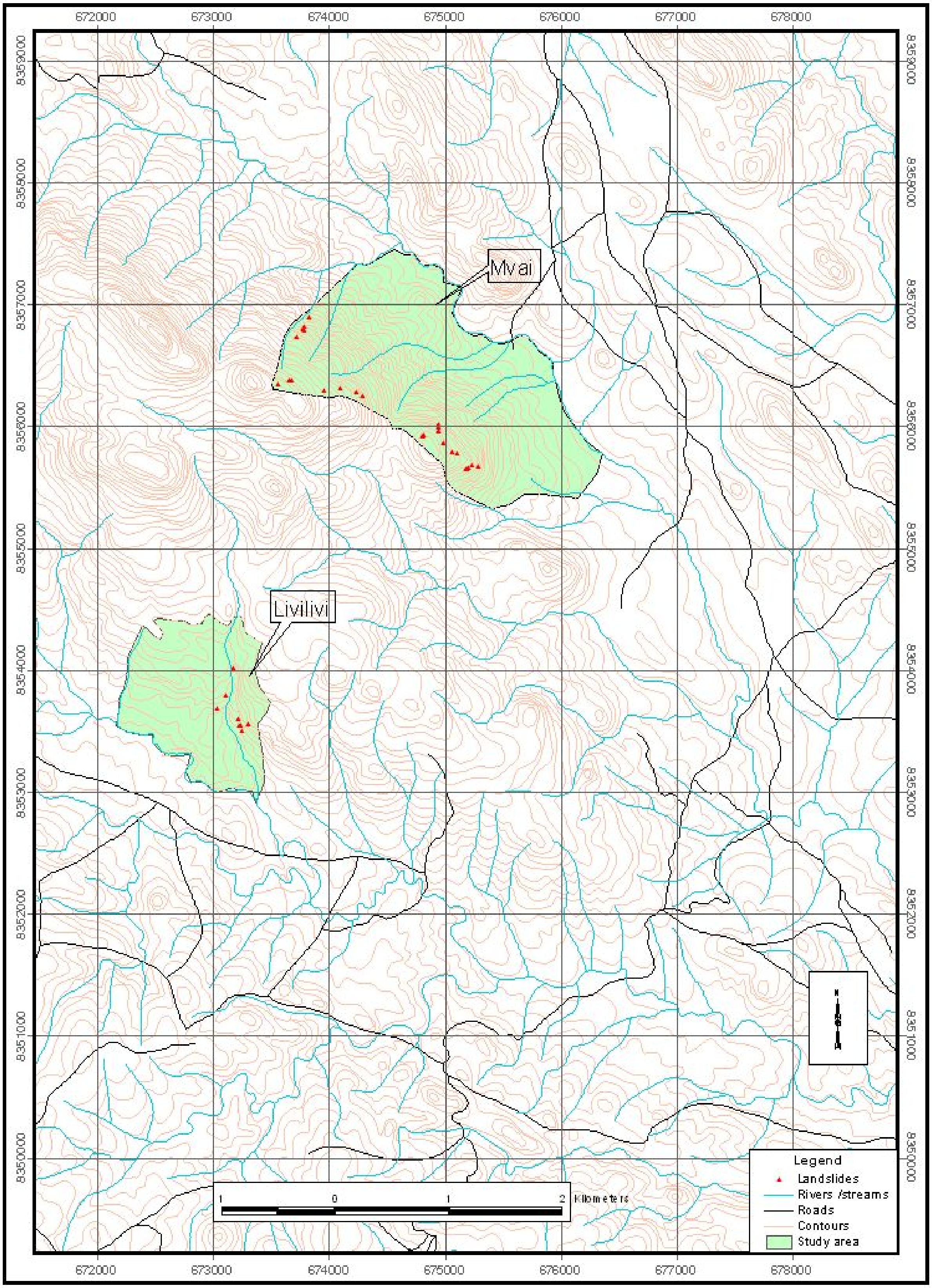


Figure 6.5: **Mapped landslides in the Mvai and Livilivi Catchments.**

## 6.3 Classification of the Mapped Landslides

The results of landslide classification are presented in **Tables 6.2, 6.3,** and **Figure 6.7**. The classifications are based on the type of movement, age and degree of stabilization, channel morphometry, and the type of material involved in the movement (**Sections 2.4 and 2.5**). The classifications are described by Campbell (1951), Zoruba (1969), Crozier (1973), Hutchinson (1978), Varnes (1978), Smith (1992), and Coch (1995).

### 6.3.1: Landslide Classification Based on the Type Movement

The results of this classification are given in **Figure 6.7**. One hundred and one landslides, representing 78.63% of the total occurrences, were classified as slides of which 74 (56.49%) were rotational, and 29 (22.14%) were translational. Nineteen landslides, representing 14.5% of all occurrences, were categorised as complex and the rest as falls (4.58%) or debris flows (2.29%). The majority of the landslides were rotational, with the exception of the occurrences in the Chiweta Area. This is typical of the East Africa region (Davies, 1996; Ngecu and Mathu, 1999; Ayalew, 1999; and Nyssen et al., 2003).

Figure 6.6: **Curved surface rupturing, common in the Livilivi and Ntchenachena Areas. Photo taken at Livilivi, Ntcheu District (2.09.06).**

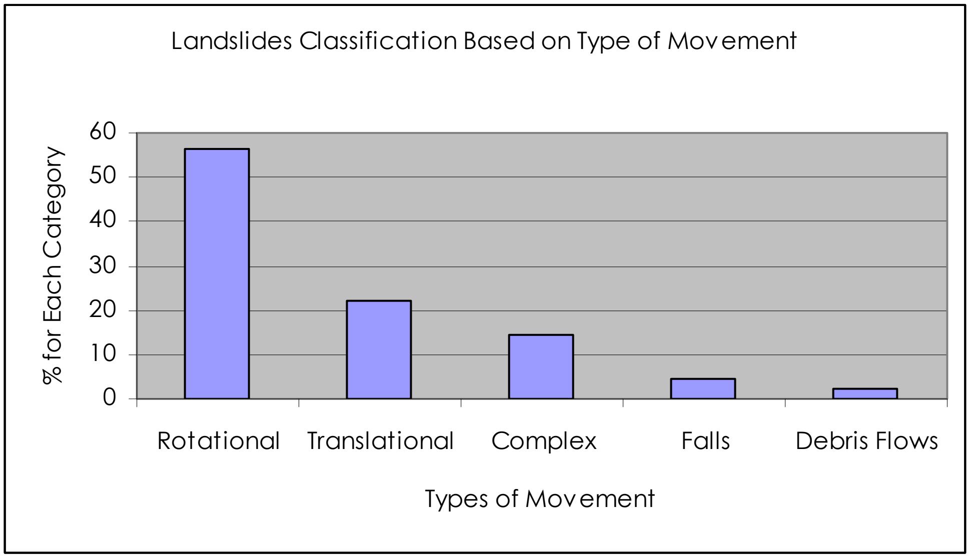


Figure 6.7: **Landslide Classification based on type of mass movement**

### 6.3.2 Landslide Classification Based on Age and Degree of Stabilization

The results of landslide classification based on age and degree of stabilisation are given in **Table 6.2.** Of all the landslides, 65.64% were classified as contemporary (occurred after 1990) and of which the majority occurred in 2003. The rest were ancient, although afew were re-activated in 2003. All the study sites had evidence of past landslide activity. In terms of degree of stabilisation, 48.85% of the landslides were still active, 32.06% were partially stabilised and 19.08% were either stabilised or dormant. Most of the landslides in the Ntchenachena Area were active or partially stabilised while in the Mvai/Livilivi Catchments, over half of the landslides were stabilised or dormant.

**Table 6.2: Landslides Classification Based on Age and Degree of Stabilization**

| District | Area | Unit | Age of Event | | Degree of StabiliSation | | |
|---|---|---|---|---|---|---|---|
| | | | Ancient | Contemporary | Active | Partially stabilized | Dormant Stabilized |
| Rumphi | Ntchenachena | Kasokoloka | | 1 | | 1 | |
| | | Lutowo | 15 | 40 | 27 | 24 | 4 |
| | | Kasese | | 6 | 5 | 1 | |
| | | Mankhorongo | 7 | 5 | 4 | 7 | 1 |
| | | Chikwezga | 2 | 12 | 6 | 6 | 2 |
| | Chiweta | Chiweta | 5 | 5 | 10 | | |
| Ntcheu | Livilivi | Livilivi | 5 | 3 | 2 | 1 | 5 |
| | Mvai | Mvai A | 6 | 6 | 5 | | 7 |
| | | Mvai B | 5 | 8 | 5 | 2 | 6 |
| **As a % of the total occurrences** | | | **34.35** | **65.64** | **48.85** | **32.06** | **19.08** |

### 6.3.3 Landslide Classification Based on Channel Morphometry and Material Involved

**Table 6.3** below gives the results of landslide classification based on morphometry of channels created and material involved in the mass movement. It was found that 49.18% of the landslides had parallel (U) shape morphometry while 33.61% had funnel (V) shaped, and 17.21% had irregular sides. Material involved in the movement ranged from soil mass, soil mass/weathered rocks/quartz floats in the Ntchenachena Area to boulders, rock fragments, soil, regolith, and vegetation in the rest of the study areas.

It was observed in some areas that landslide material moved a limited distance before stopping. The motion was inhibited by the dilation of the soil and commitant decrease in pore pressure. The soils, according to eyewitnesses, were looser and in a dilative state, absorbed water from the continued rainfall or from water ponding behind the slump, as was the case at the Lutowo Unit. As the slump mass resaturated, pore pressure increased again, initiating second failure. This contributed to the flooding of the banks of the Mzinga River. This mechanism is also described by Harp et al (1990), Fleming et al (1989), Dai et al (1999a) and (1999b), and Harp et al (2004).

**Table 6.3: Landslides Classification Based on Channel Morphometry and Materials Involved**

| District | Area | unit | Channel Morphometry | | | Materials |
|---|---|---|---|---|---|---|
| | | | **Parallel or U Shaped** | **Funnel or V Shaped** | **Irregular** | |
| Rumphi | Ntchenachena | Kasokoloka | 1 | | | Soil mass and vegetation |
| | | Lutowo | 26 | 25 | 4 | Mainly soil mass with weathered rocks, quartz floats and vegetation |
| | | Kasese | 3 | 1 | 2 | Mainly soil mass with weathered rocks, quartz floats and vegetation |
| | | Mankhorongo | 2 | 7 | 3 | Soil mass and vegetation |
| | | Chikwezga | 11 | | 3 | Mainly soil mass with weathered rocks, quartz floats and vegetation |
| | Chiweta | Chiweta | 6 | | | Boulders, Rock fragments, soil and regolith |
| Ntcheu | Livilivi | Livilivi | 3 | 4 | 1 | Boulders, Rock fragments, soil and regolith |
| | Mvai | Mvai A | 3 | 2 | 2 | Boulders, Rock fragments, soil and regolith |
| | | Mvai B | 5 | 2 | 6 | |
| **As a % of the Total Occurrences** | | | **49.18** | **33.61** | **17.21** | |

## 6.4 Determination of the Initial Point of Failure

The results of the determination of the point of initial failure on the slope for individual slides are given in **Table 6.4,** and discussed in **Section 6.6.3**. The majority of the landslides in all the study areas occurred on middle slopes, represented by 66.94% of all recorded landslides. Upper slopes recorded 22.31% of landslide occurrences while 10.74% were on the lower slopes. Results for the Chiweta Study Area have not been included because all the landslides occurred on remodeled or modified slopes.

**Table 6.4: The Determination of the Initial Point of Failure**

| District | Study Area | Study Unit | Location on the slope (Frequencies) | | |
|---|---|---|---|---|---|
| | | | Lower | Middle | Upper |
| Rumphi | Ntchenachena | Kasokoloka | | 1 | |
| | | Lutowo | 3 | 37 | 15 |
| | | Kasese | | 5 | 1 |
| | | Mankhorongo | 1 | 6 | 5 |
| | | Chikwezga | 4 | 8 | 2 |
| Ntcheu | Livilivi | Livilivi | 3 | 4 | 1 |
| | Mvai | Mvai | 2 | 20 | 3 |
| **As a % of 121 Landslide Events** | | | **10.74** | **66.94** | **22.31** |

## 6.5 Impact of Recorded Landslide Events

The impacts of recorded landslides are summarised in **Table 6.5,** and in **Chapter 8**. The damage varied from one area to the other. The Ntchenachena landslides occurred in inhabited areas, and the impacts included the death of 4 people, destruction of sources of livelihoods and damage to settlements and infrastructure. The impact was felt outside the study area due to the flooding of the Mzinga River and the washing away of the Phoka Bridge at the confluence of the Mzinga and North Rumphi Rivers (**Figure 6.8**).

Figure 6.8: **The remains of the Phoka Bridge at the confluence of the Mzinga and the North Rumphi Rivers after the 2003 landslides in the Ntchenachena Area (30.08.06).**

In the Chiweta Area, landslides and rock falls have blocked the M1 road to Karonga, and also disrupted the drainage system on several occassions. Vegetation was destroyed by moving debris. However, landslides did not affect settlements along the Chiweta Lakeshore Area. In Ntcheu District, landslides occurred in forest reserves and much damage was caused to vegetation growing on the path of debris. However, outside the reserves, landslides caused extensive damage to crops growing along the Livilivi and Mpira Rivers. Parts of the Bwanje Irrigation Scheme were destroyed. The water supply to Balaka and Ntcheu Districts was disrupted when parts of the Mpira Dam and the water intake were damaged.

**Table 6.5: Impact of Recorded Landslides**

| District | Place | Event | Date | Impact |
|---|---|---|---|---|
| Rumphi | Ntchenachena | Ntchenachena landslides | 28th March, 2003 | • Loss of crops |
| | | | | • 4 people killed |
| | | | | • Crops destroyed |
| | | | | • Farmland destroyed |
| | | | | • Accelerated soil erosion |
| | | | | • Destruction of vegetation |
| | | | | • Bank collapse |
| | | | | • Houses destroyed |
| | | | | • Loss of livestock |
| | | | | • Roads/bridges swept |
| | | | | • Water supply disrupted |
| | Chiweta | Chiweta landslides | 1999 and 2003 | • Accelerated soil erosion |
| | | | | • Blocked M1 road |
| | | | | • Destroyed drainage system |
| | | | | • Destruction of vegetation |
| | | | | • Frequent accidents due to rock falls |
| Ntcheu | Livilivi/Mvai catchments | Livilivi/Mvai landslides | 3rd January, 2003 | • Destruction of Vegetation |
| | | | | • Bank collapse |
| | | | | • Destruction of crops |
| | | | | • Destruction of farm land |
| | | | | • Destruction of roads/bridges |
| | | | | • Damaged Mpira dam |
| | | | | • Destruction of water supply system |

## 6.6 Discussion of the Landslides Mapping

### 6.6.1 Landslides Inventory

As shown in **Section 6.1**, the Ntchenachena Area recorded the highest number of landslide occurrences. The frequency of occurrences varied between and within the study areas. The total number of landslides depends on the combination of factors contributing to the occurrences, and the degree of instability of a given environment (Crozier, 1986). The reasons for the high density at Ntchenachena and variations in densities will be discussed in **Chapter 7**. The depths of channels depended on the thickness of the soil/weathered materials. In areas where the basement has been significantly weathered, for example, the Ntchenachena Area, (**Figures 2.7 and 2.8**), deeper channels were common. Width in most cases depended on the narrowness of the valleys and the nature of the lithology. In areas where the lithology is highly weathered, such as the Ntchenachena, the average width (7.09 m) was significantly high. This is significantly high compared to those areas where the basement is not highly weathered, for instance, the Mvai/Livilivi catchments with an average depth of 2.0m. However, the length of the channels depended on the initial point of failure, and the length of individual slopes. This is true for the Mvai landslides, which started on the top of the mountain and had lengths up to 750m. However, on average, landslides with greater lengths, widths and depths occurred in the Ntchenachena Area.

The role of slope types in the location and distribution of landslides has been discussed by Knapen et al., (2006). In their study, Knapen et al (2006) concluded that concave slopes were more prone to failure than other types of slopes. However, in this study, slope type did not determine the location and distribution of slope failure, but rather the type of failure. The majority of the landslides on concave slopes were rotational which is in agreement with the findings of Knapen et al (2006) in Uganda. For instance, in the study areas where the dominant slope was concave (Ntchenachena, Livilivi and Mvai), almost all the landslides occurred on concave slopes. Similarly, in Mvai A, where the dominant slope was found to be convex, the majority of the landslides occurred on such slopes. Although all the slopes of Chiweta fall in the category of concave slopes, no mass movements occurred on such slopes. All mass movements in this area occurred on either cliffs or linear slopes which were created by the slope remodelling for the M1 road to Karonga. Since all the landslides in the Chiweta Area occurred on remodeled slopes, it proved difficult to correlate slope type and landslide distribution.

Although few events occurred on linear and rectilinear slopes (**Table 6.1; and Section 6.2**), studies have shown that such slopes (with shallow soils and a sharp contrast between solum and saprolite) are inherently more unstable and the slides are translational (Westerberg and Christiansson, 1998). In this study, few landslides occurred on linear or rectilinear because such slopes were also few in all study sites. However, this does not diminish their high degree of instability to deformation.

In terms of slope aspect, studies have been carried out to correlate slope aspect and vegetation type and distribution, and also aspect and rainfall type and distribution. It has been shown that aspect controls the micro-climates of an area and affects vegetation distribution (Crozier, 1986). Studies have also been carried out to show the role of vegetation in stabilising slopes (**Chapters 3 and 7**). Although rainfall is particularly from the SE, E, NE and S in Malawi, there are no rainfall data to suggest that the distribution of landslides in an area is affected by aspect. The fact that most of the landslides occurred on NE, SE, E and S aspects - which coincide with rainfall distribution patterns of the country - could be an issue of further investigation. The vegetation survey did not show variations in vegetation type and density with aspect. It should also be noted that the location and distribution of landslides could be attributed to other factors apart from aspect as discussed in the next Chapter.

### 6.6.2 Classification of Landslides

Landslide which were classified as translational, were flat planar movements along surfaces and had pre-existing slide planes which were activated during the rainfall events. In the Mvai A and B areas, failure occurred at a point of contact between regolith/soil mass and the bed rock; hence, they were classified as translational. Similar patterns of failure were observed in the Chiweta Area. Failure occurred in bedded strata overlain by either weathered or unweathered materials. By way of contrast, most of the landslides in the Ntchenachena Area were rotational which involved curved surface rupturing and produced slumps by backward slippage (Smith, 1996; Westerberg and Christiansson, 1998; and Msilimba, 2002). Such failures are associated with deep soils as is the case with the Ntchenachena Area (Msilimba, 2002; Msilimba and Holmes, 2005 and Knapen et al, 2006). Scars revealing curved rupture and flat planes were observed. Falls are typical of the Chiweta Area and parts of the Mvai

Catchment where the rocks hang loosely (Mwenelupembe, 2003). Complex events combined two or more principle types of movements. In the Ntchenachena and the Mvai Areas, complex events started as slides and with increasing water content changed into mudflows (Ntchenachena) and debris flows (Mvai).

Figure 6.9: **Rock falls along the M1 Road to Karonga, typical of the Chiweta beds. These have been a major cause of accidents (29.08.06).**

Most of the landslide channels undergoing dissection due to erosion were not recolonised by vegetation. Evidence of instability was observed which included cracking of soils (**Figure 7.1**), gullying (**Figure 6.11**), fissuring (**Figure 7.11**), and the removal of basal support. Some channels had achieved 50% re-colonization by vegetation although erosion was still active in some parts of the channel. Those landslides which had achieved 90% or more of re-colonisation fall in this category. It should be noted that most of the landslidess fall in the active and partially active categories because the channels are fairly new and need time to rehabilitate.

The Ntchenachena, the Mvai and the Livilivi areas are dominated by funnel (V) shape valleys; hence, the shape of the channels was funnel-like. Those with parallel (U) shape occurred on relatively flat slopes where valleys were absent. Those with irregular channel morphometry, occurred on any part of the slope, but the shape was determined by variations in rock resistance and the presence of vegetation.

### 6.6.3 Determination of the Point of Failure

The results of the determination of the initial point of failure, where the shear band developed, agree with the findings of Fernandes et al (2006). Most of the landslides occurred on the middle part of the slope where the landslide potential index (LPI) is the highest (**Section 3.4)**. According to Fernandes et al (2006), the index decreases with height due to excessive removal of slope material as gravity tends to increase with height and slope angle (Smith, 1996). In the Ntchenachena Area, middle slopes had thick soil or weathered materials and 64% of the landslides occurred on middle slope. The upper slopes of the Mvai and Livilivi Catchments had thin soils (< 1m deep) with only 9% of all the occurrences.

## 6.7 Discussion of the Impacts of Landslides

Landslides, like many other high-energy natural processes, only become hazards when people, property and livelihoods become threatened. In most cases, the vulnerability of the society can be increased as a result of economic and political pressures which force people into environments, land use practices, and socio-economic systems which they are unfamiliar with or have insufficient knowledge of the endemic hazards, inappropriate adjustment mechanisms or too few resources for mitigating the hazards (Crozier, 1986; and Susman et al., 1983). Poor countries like Malawi have suffered greatly because of poverty and a heavy dependence on foreign aid when disasters strike. For instance, poverty in Malawi is widely spread and pervasive. Over half (52%) of the population, are deemed poor and 22% are ultra poor. The annual poverty line of MK16 165 is MK44.3 or US$0.50 per person per day; is significantly below the 'standard' US$1 per person per day (Slater and Tsoka, 2006). With this poverty situation, individuals fail to cope with life when a disaster strikes. The government finds it difficult to provide the basic needs after landslide occurrences. The impacts of the observed landslides are discussed under three sections: personal costs, economic costs, and environmental damages. A further discussion of the impact is given in **Chapter 8**.

### 6.7.1 Personal Costs

In the Ntchenachena Area, four people of the same family were swept away and only three bodies were recovered during the March 28th 2003 landslides. Although the death toll from these 131 landslides was not high as compared to the 1946 Zomba Mountain and the 1991 Phalombe landslides (Gondwe and Govati, 1991; and Poshinger et al, 1998), in terms of personal loss to the family, the damage was significant though difficult to quantify. Death by landslide is a tragically obvious personal cost. Death to the family or immediate members of the family could obviously involve the trauma of economic, social and emotional readjustment. This argument is further advanced by Taylor (1983). The combination of the effects of landslides (Loss of livelihood) and trauma requires a costly process of adjustment. The family bears the cost, and to date the government or local authority have not come to the rescue of this poor family.

### 6.7.2 Economic Costs

All the recorded landslides result in economic costs of some kind. This is true of past landslides in the East and Central African regions (Gondwe and Govati, 1991; Msilimba, 2002; and Knapen et al., 2006). However, the direct economic consequences of a given magnitude of landslide event depend on the nature of society and the type of landscape affected (Crozier, 1986). For instance, at household level, landslides in both districts caused substantial damage to crops and farmland although figures have not been released by the government. In the Ntchenachena Area, crops and farmland on the slopes, as well along the Lutowo, Chikwezga and Mzinga Rivers were destroyed while in Ntcheu landslides caused the flooding of gardens along the Mpira and the Livilivi Rivers. Furthermore, in Rumphi District, maize granaries, goats, chickens and three fish ponds were completely washed away (**Figure 6.10**). The economic costs can be appreciated if only studied in the current poverty situation (Slater and Tsoka, 2006; **Table 8.2B; and Section 8.1**). In Malawi, poverty is predominantly rural (56%), and that 61.6% of people in Rumphi and 51.6% in Ntcheu are poor (Slater and Tsoka, 2006). With the current poverty situation in the study districts, when landslides occur, individuals can easily drift into the ultra poverty category. It should also be pointed out that most of the households in these study areas have limited livelihood sources and earn their living only from their household farm and fishing activity (Slater and Tsoka, 2006). The societies, especially in the Ntchenachena Area remain, isolated from the rest of the country both physically and economically due to the rugged terrain which is inaccessible (**Figure 2.6**). A combination of such factors and landslides increases their vulnerability to poverty. Additionally, in the Ntchenachena Area, houses were destroyed and that increased the economic costs to the individuals. The Mwachumba Msiska Village was partly destroyed and later on abandoned. The cost of movement and resettlement was met by the individuals themselves.

Figure 6.10: **One of the three fish ponds that were destroyed during the 2003 Landslides in the Ntchenachena Area (25.08.06).**

The impacts of landslides in terms of damage to infrastucure were felt at local, regional and national levels. The Ntchenachena landslides in Rumphi District caused substantial damage to the road and bridges between Rumphi District Headquarters and the Livingstonia Mission Station where a referral hospital is located (**Figure 6.8**). The gravity-fed water supply system was also disrupted. The damage to infrastructure meant that people of the Ntchenachena Area could hardly access health services, transport farm produce, and lacked access to safe and potable drinking water. Four years after the occurrence of the landslides, the government is yet to rehabilitate the road infrastructure and the water supply system.

Chiweta lies along the northern corridor to Karonga and then to Tanzania where most of Malawi's oil imports come from. Frequent rock falls have been reported on local media as a source of road accidents in this area (Mwenelupembe, 1999). The Chiweta mass movements affected the country's economy through delays in the importation and exportation of goods. Most of the rockfalls and landslides blocked drainage channels as well as the road (**Figure 6.9**).

In Ntcheu District, the Livilivi/Mvai landslides damaged the Livilivi Bridge, cutting off communication between Ntcheu District Headquarters and the Mvai Forestry Offices. This affected the management of Dzonzi Forest Reserve where deforestation due to charcoal burning is a major problem. Parts of the Mpira Dam and its water intake were damaged. This drastically affected the water supply to Balaka and Ntcheu Districts. Extensive damage was caused to parts of the Bwanje Valley Irrigation Scheme, several kilometers down the Livilivi River. This affected the livelihoods of smallholder farmers on the scheme, and also indirectly affected the economy of the country. As in the previous studies in Malawi cited by Msilimba (2002), the extensive damage to road infrastructure was due to poor designing of drainage systems of roads and small water passages for bridges.

### 6.7.3 Environmental Costs

Landslides, particularly in the Livilivi/Mvai and the Ntchenachena Areas caused environmental damage. In most of the areas, landslides caused habitat degradation. The removal of soils and biomass by erosion and the formation of gullies interrupt natural processes which, in the long run are trying to achieve a climax community (Crozier, 1986). However, Moss and Rosenfeld (1978), suggest that instead of landslide activity being viewed as an agent of degradation, in some areas, it may present an important element in the maintenance of species diversity and re-vitalisation of the habitat. Much as this could be true, the catchments under study continue to experience further degradation, ranging from wanton cutting down of trees, to harmful bush fires and slope cultivation, resulting in accelerated soil erosion (**Figure 6.11**)

Figure 6.11: **Active erosion in most of the landslide channels, degrading the environment further. This is typical of the Ntchenachena Area (28.08.06).**

The Ntchenachena landslides disrupted the land surface by deranging the drainage system. The damming of the Lutowo Stream (**Figure 6.12**) altered the stream morphology and created poorly drained depressions. The artificial dam collapsed and flooded the Mzinga low lying areas. Similar effects were observed by Msilimba and Holmes (2005) in the Vunguvungu/Banga Catchment Areas of Northern Malawi. The huge volume of water released from the dam exhumed an old channel which had an average depth of 1.45m and width of 3.8m. The current average depth and width are 2.5m and 34.6m, respectively.

Figure 6.12: **Position where landslide debris dammed the Lutowo River which resulted in the flooding of Mzinga River. Debris remains can be seen at the site (26.08.06).**

The riparian vegetation suffered greatly in Rumphi and Ntcheu Districts. According to eyewitnesses, some mass movements developed into fast moving debris torrents which completely stripped off riparian vegetation from many kilometers of the channel. However, the effect of landslide debris, which reached the stream channel, depended on its rate of input, calibre of sediment, and its stability with respect to fluvial activity as observed elsewhere by Benda and Dune (1997).

It has been shown by Benda et al (2003) that the sediments and transported debris affect acquatic habitats. All the landslides occurred within the catchment area of Lake Malawi which gives a high probability of sediments being deposited into the lake. However, the impact of the sediments on acquatic habitat needs further investigation.

Landslides resulted in the depreciation of land value through accelerated soil erosion, formation of gullies, and destruction of vegetation. For instance, the scenic beauty of the Ntchenachena Area which is part of the East Nyika escarpment was lost. The landscape is now known for accelerated soil erosion, scars, deep gullies, river bank collapse (**Figure 6.13**) and absence or presence of degenerated vegetation. In the Mvai/Livilivi Catchments, vegetation was lost along the debris path. Boulders are scattered along the channels. However, further research work is required to assess environmental damages in monetary terms.

Figure 6.13: **Bank collapse caused by landslides, common at all Study Areas and contributing to siltation of rivers. This is an example from the Livilivi Catchment (28.08.06).**

## 6.8 Conclusion

This Chapter has presented the results of a landslide inventory. An attempt has been made to classify the landslides, based on morphological characteristics, age and degree of stabilization. The last section discussed the landslide inventory and the impacts of the mapped events. In summary, the Ntchenachena Area recorded the highest number of landslides which is an indication of high slope instability. Slope type did not determine the location and distribution of slope failures, but rather the type of failure. No correlation was established between aspect and the location and distribution of landslides. The majority of the landslides in the Mvai A, B and the Chiweta Areas were translational while in the Ntchenachena and the Livilivi Areas, rotational landslides dominated. Variations were due to the nature of lithologies. Rockfalls were pronounced at the Chiweta study site because of slope remodelling which exposed jointed beds. Landslide caused personal, economic as wells as environmental damages. The next Chapter will address factors that caused the mass movements. Contributing factors will also be discussed.

# CHAPTER SEVEN

# ANALYSIS OF THE LANDSLIDE CAUSES AND CONTRIBUTING FACTORS

The current Chapter focuses on those factors which cause landslides as well as contribute to their occurrence.

As outlined in **Chapter 5**, soil sampling was carried out using both core and clod sampling methods to determine the physical parameters that affect the shear strength of soil. The importance of soil parameters in slope failure are discussed by Finlayson (1980), Alexander (1993) and Knapen et al (2006) and **Sections 3.6.2, 3.6.3** and **3.6.6**. The soils were analysed for particle size, hydraulic conductivity, particle density, total porosity, aggregate stability, liquid limit, plastic limit, plasticity index, and bulk density (**Section 5.10**). Gelogical data was collected to determine structural rock weaknesses affecting slope stability (**Sections 3.6.5 and 3.7.4**). This involved field investigations and the interpretation of geological maps (**Section 5.3**). Vegetation data was collected to determine its role in stabilising slope (**Section 3.7.6.1**), using quadrant method as explained in **Section 5.10.** Land-use change (**Section 3.7.6**) and drainage data were collected to determine their roles in slope instability. This involved topographic and land-use map interpretation and fieldwork (**Sections 5.4, 5.6 and 5.8**). Rainfall data was collected to determine slope loading, pore pressure, and liquefaction (**Sections 3.6.4 and 3.7.5**).

## 7.1 Physical Properties of Soil

The importance of the physical properties of the soil in causing failure is discussed by Finlyson (1980), and Knapen et al (2006). Soil can give an indication of slope stability (**Figure 7.1**). The results of soil analyses are presented below.

Figure 7.1: **Soil cracking and deformation; an indication of instability, common in the Ntchenachena and the Livilivi Areas (Photo taken at Ntchenachena 26.08.06).**

### 7.1.1 Liquid Limit, Plastic Limit, and Plasticity Index Analyses Results

The Atterberg limits determine the bahaviour of soils before deformation occurs (Terzaghai, 1950; Bryant, 1991; and Alexander, 1993). The Atterberg limits were determined to establish structural strength of the soils in all the study areas. Liquid limit tests were carried out to determine the water content of the soils required to lose its cohesion and flow as a liquid. On the other hand, plastic limit tests were carried out to determine the water content required before the soils split or crumble. The plasticity index was calculated from liquid and plastic limits (**Section 5.11.1.10**) to give the range over which the soils in the study areas remain plastic before deformation. The results are presented by means of the tables. Multiple comparison tests for liquid limit, plastic limit, and plasticity index are given in **Appendix 6**.

The mean values for liquid limit ranged from 35.78% to 52.41%, with lower mean values for the Chiweta and the Livilivi Areas (**Table 7.1**). Multiple comparison tests (LSD) showed significant differences between the Livilivi/Chiweta Areas and the rest of the study areas ($p<0.050$). This was also confirmed by ANOVA test results ($p=0.007$). Both Benforroni and LSD tests results show no significant differences between the Mvai and the Ntchenachena Areas ($p>0.554$). However, the ranges were found to be high in all the study areas (**Table 7.1**). For instance, in the units where human settlements have been constructed, in the Ntchenachena Area, liquid limits were found to be low. This was true for the Mvai and Livilivi Areas where deforestation and charcoal making (**Figure 7.9**) have contributed to soil compaction. The lower values from the Chiweta site were possibly due to compaction caused during the road construction.

**Table 7.1 Liquid Limit for the Ntchenachena, Chiweta, Mvai and Livilivi Areas**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 50.92 | 10.47 | 28.64 | 81.42 |
| **Chiweta** | | 22 | 35.78 | 6.15 | 29.27 | 52.36 |
| **Mvai** | | 20 | 52.41 | 12.66 | 33.97 | 77.45 |
| **Livilivi** | | 14 | 44.60 | 7.40 | 33.37 | 61.17 |
| **Ntchenachena** | >100 | 77 | 48.63 | 11.44 | 15.99 | 87.34 |
| **Chiweta** | | 22 | 36.70 | 7.48 | 28.70 | 56.10 |
| **Mvai** | | 20 | 45.46 | 8.79 | 30.55 | 65.78 |
| **Livilivi** | | 14 | 39.86 | 8.87 | 29.31 | 64.85 |

Plastic limit results for the four sites show low mean values ranging from 25.14% in the Chiweta Area to 34.81% in the Mvai Area (**Table 7.2**). Significant differences were observed in mean values for upper layers at Mvai ($p<0.005$). Upper layers for the all the other sites did not show significant differences. However, in the lower sections of the profile, no significant differences were observed as shown by both LSD, Benforroni tests ($p>0.117$) and ANOVA tests ($p=0.106$). Generally, plastic limit mean values were low which implies that the range over which the soils in these study areas can behave like a plastic is low. Low plastic mean values have been recorded at VBCA, adjacent to the Ntchenachena Area (Msilimba, 2002; and Msilimba and Holmes, 2005). It was suggested that low plastic values contributed to slope instability at VBCA in Rumphi District of Northen Malawi.

**Table 7.2 Plastic Limit for the Ntchenachena, Chiweta, Mvai and Livilivi Areas**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 - 100 | 77 | 29.01 | 8.23 | 10.39 | 48.16 |
| **Chiweta** | | 22 | 25.24 | 4.42 | 16.98 | 34.76 |
| **Mvai** | | 20 | 34.81 | 8.79 | 23.36 | 52.45 |
| **Livilivi** | | 14 | 25.86 | 4.34 | 19.19 | 33.29 |
| **Ntchenachena** | >100 | 77 | 27.20 | 8.65 | 1.19 | 47.34 |
| **Chiweta** | | 22 | 25.12 | 4.58 | 19.33 | 40.34 |
| **Mvai** | | 20 | 26.88 | 8.08 | 4.34 | 42.96 |
| **Livilivi** | | 14 | 21.89 | 5.02 | 10.38 | 29.05 |

**Table 7.3: Plasticity Index for the Ntchenachena, Chiweta, Mvai and Livilivi Areas**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| Ntchenachena | 0 - 100 | 77 | 22.07 | 7.86 | 8.75 | 43.00 |
| Chiweta | | 22 | 10.55 | 3.34 | 4.52 | 17.60 |
| Mvai | | 20 | 16.69 | 7.66 | 2.03 | 39.62 |
| Livilivi | | 14 | 18.75 | 5.05 | 11.82 | 30.67 |
| Ntchenachena | >100 | 77 | 22.44 | 9.04 | 7.34 | 43.14 |
| Chiweta | | 22 | 11.60 | 4.54 | 6.64 | 26.12 |
| Mvai | | 20 | 17.21 | 8.12 | 6.61 | 44.90 |
| Livilivi | | 14 | 18 | 7.05 | 10.98 | 38.80 |

Plasticity Index mean values were generally low corresponding to low values of plastic limit (**Table 7.2**), and liquid limit (**Table 7.1**). Most of the sites show values around 20% and below, except for the Chikwezga unit within the Ntchenachena Area with a mean value of 28.43% (**Table 7.4**). Values less than 20% are considered low (Poschinger et al., 1998). However, within the study areas, for instance in the Ntchenachena Area, maximum value was 43.14%. The Ntchenachena Area recorded the highest clay content of all the study areas (**Table 7.15 and Section 7.1.6**). The lowest values were recorded in the Chiweta Area ranging from 10.46% to 11.75%. The results of Post Hoc and Equity of Means tests show significant differences between the Chiweta and the rest of the areas (p<0.033 and p=0.00, respectively). The very low values at the Chiweta site could be due to the presence of colluvium and partially weathered material (**Figure 7.16**). In all the areas, the range over which soils could exhibit plastic properties was found to be low. Low plasticity values were noted to have contributed to instability in the VBCA of Rumphi District (Msilimba, 2002; and Msilimba and Holmes, 2005).

**Table 7.4: Results of the Analyses of Liquid Limit, Plastic Limit and Plasticity Index**

| Area | Unit | Liquid Limit | | | Plastic Limit | | | Plasticity index | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | IQ | Skewness | Mean | IQ | Skewness | Mean | IQ | Skewness |
| Nchenachena | 1 | 37.24±1.8122 | 3.4825 | -.089 | 19.51±2.85 | 4.70 | -1.89 | 17.785 ± 3.0247 | 5.607 | -.408 |
| | | 44.21±2.195 | 4.115 | -.413 | 27.86±3.12 | 6.0 | -.098 | 16.345 ±1.8826 | 3.545 | .932 |
| | 2 | 47.93±6.538 | 6.42 | .742 | 28.74±7.34 | 3.22 | 1.594 | 20.05±5.214 | 5.82 | 1.28 |
| | | 41.42±2.704 | 3.25 | -.825 | 23.29±7.666 | 7.69 | -1.04 | 18.165 ± 8.211 | 5.42 | 2.232 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 53.29±10.72 | 15.32 | -.130 | 30.11±7.79 | 10.19 | .087 | 23.28±9.200 | 17.53 | .119 |
| | | 50.74±12.755 | 15.082 | -.425 | 28.24±7.770 | 7.835 | -.484 | 23.91±9.131 | 13.16 | .096 |
| | 4 | 47.72±7.723 | 13.45 | .038 | 27.07±7.313 | 13.125 | -.047 | 20.63±4.537 | 5.36 | -.127 |
| | | 47.74±7.59 | 14.31 | -.500 | 28.40±4.70 | 7.32 | .026 | 19.21±5.50 | 11.64 | .020 |
| | 5 | 54.70±13.03 | 16.91 | 1.33 | 31.51±11.47 | 17.98 | -.533 | 23.12±8.91 | 16.57 | .767 |
| | | 51.35±15.46 | 18.100 | 1.78 | 25.24±16.50 | 31.33 | -.172 | 28.43±11.27 | 20.35 | -.308 |
| **Chiweta** | 1 | 36.21±7.679 | 12.14 | 1.107 | 25.74±4.846 | 8.49 | .480 | 10.46±3.987 | 6.63 | .640 |
| | | 36.27±7.345 | 4.98 | 2.24 | 24.82±5.688 | 3.59 | 2.33 | 11.44±2.71 | 3.700 | .130 |
| | 2 | 35.35±4.47 | 6.61 | 1.33 | 24.73±4.108 | 6.08 | 0.32 | 10.62±2.738 | 5.29 | .448 |
| | | 37.12±7.946 | 13.60 | .840 | 25.40±3.388 | 4.77 | .693 | 11.75±5.98 | 7.19 | 1.65 |
| **Livilivi** | 1 | 44.98±4.511 | 7.93 | -.753 | 27.36±3.630 | 6.57 | .518 | 17.62±4.512 | 8.02 | .776 |
| | | 36.80±2.533 | 4.88 | -.199 | 21.77±2.668 | 4.87 | .899 | 15.03±1.6421 | 2.175 | 2.141 |
| | 2 | 39.91±5.44 | 10.42 | .013 | 23.81±1.855 | 3.455 | -.524 | 16.10±3.8866 | 7.08 | .664 |
| | | 35.92±6.83 | 12.91 | .276 | 19.78±1.714 | 3.125 | .233 | 16.14±5.893 | 10.24 | .654 |
| | 3 | 47.96±9.955 | 18.8 | .456 | 25.95±6.210 | 12.22 | -.029 | 22.01±5.435 | 9.215 | 1.159 |
| | | 46.08±11.77 | 20.41 | 1.199 | 23.68±8.014 | 12.78 | -1.594 | 22.99±9.557 | 15.91 | 1.520 |
| **Mvai** | 1 | 59.19±12.22 | 15.422 | -.387 | 39.38±8.143 | 12.195 | -.115 | 17.96±9.60 | 7.63 | .908 |
| | | 46.85±5.78 | 8.89 | .012 | 27.12±8.609 | 5.657 | -2.34 | 19.73±9.72 | 8.55 | 2.20 |
| | 2 | 45.63±9.304 | 19.695 | .154 | 30.229±7.088 | 10.01 | 1.265 | 15.414±5.280 | 6.020 | 1.182 |
| | | 44.04±11.200 | 14.95 | .898 | 26.63±7.970 | 10.85 | 1.364 | 14.691 | 5.515 | 7.047 |

### 7.1.2 Hydraulic Conductivity Test Results

Hydraulic conductivity tests were carried out to determine the rate at which water infiltrated through the soil horizons. Hydraulic conductivity has a direct effect on slope loading and high pore pressure (Bryant, 1976; Crozier, 1984; and Alexander, 1993). The degree of conductivity was determined, using hydraulic conductivity scale (**Appendix 2**; and GoM, 1988), and the results are presented in **Table 7.5**. The results show moderately rapid hydraulic conductivity for all the sites. The mean values range from 6.32cm/hr at Chiweta to 8.10 cm/hr in the Ntchenachena Area. This could be attributed to the high sand content and the high organic matter in some areas, and the loosening of soil by cultivation. Lower values were observed in areas disturbed by human activities such as settlement construction, road construction, and deforestation. In general, the four sites did not show significant differences in hydraulic conductivity as shown by LSD and ANOVA tests with a p-value of >0.050 (**Appendices 7 and 9**).

**Table 7.5: Hydraulic Conductivity Analysis Results**

| Area | Depth (cm) | Number | Mean (cm/hr) | Standard Deviation | Minimum (cm/hr) | Maximum (cm/hr) |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 - 100 | 77 | 7.84 | 2.4 | 1.72 | 15.74 |
| **Chiweta** | | 22 | 6.76 | 2.21 | 2.45 | 11.12 |
| **Mvai** | | 20 | 8.10 | 2.83 | 2.98 | 12.80 |
| **Livilivi** | | 14 | 7.53 | 2.11 | 3.45 | 10.02 |
| **Ntchenachena** | >100 | 77 | 7.16 | 2.31 | 1.45 | 14.88 |
| **Chiweta** | | 22 | 6.32 | 2.08 | 2.94 | 11.05 |
| **Mvai** | | 20 | 6.91 | 1.98 | 3.21 | 11.24 |
| **Livilivi** | | 14 | 7.56 | 1.73 | 3.79 | 9.27 |

**Table 7.6: Aggregate Stability Analysis**

| Area | Depth (cm) | Number | Mean (MWD) | Standard Deviation | Minimum (MWD) | Maximum (MWD) |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 2.86 | 0.62 | 0.28 | 3.47 |
| **Chiweta** | | 22 | 2.96 | 0.41 | 1.88 | 3.41 |
| **Mvai** | | 20 | 2.78 | 0.49 | 1.26 | 3.60 |
| **Livilivi** | | 14 | 2.20 | 0.73 | 1.19 | 3.38 |
| **Ntchenachena** | >100 | 77 | 2.70 | 0.72 | 0.23 | 3.65 |
| **Chiweta** | | 22 | 2.76 | 0.46 | 1.84 | 3.50 |
| **Mvai** | | 20 | 2.57 | 0.68 | 0.80 | 3.36 |
| **Livilivi** | | 14 | 1.87 | 0.84 | 0.44 | 3.29 |

### 7.1.3 Aggregate Stability Analysis Results

Soil aggregate stability analysis (**Table 7.6 and Appendix 7**) was carried out to provide a direct measure of the susceptibility of the soil to structural deterioration under the influence of rainfall (GoM, 1988). As with previous studies (Msilimba, 2000; and Msilimba and Holmes, 2005), mean values for aggregate stability were found to be high for the sites within the Banga Catchment. Mean values range from 1.45mm in the Livilivi Area to 3.17mm in the Ntchenachena Area (**Table 7.9**). Values less than 0.5mm indicate a strong structural instability (GoM, 1988; and Msilimba, 2002). Post Hoc tests (LSD) show significant differences between the Livilivi Area to the rest of the areas (p<0.036). This was confirmed by ANOVA test (p=0.001). The difference could be as a result of small range in total sand compared to the rest of the study areas (**Table 7.10**).

### 7.1.4 Bulk Density Tests Results

Bulk density tests were carried out to determine the degree of soil compaction. Bulk density determines soil porosity, hydraulic conductivity and the packing of soil particles (Bryant, 1976; and Alexander, 1993; and **Section 3.6.6**). Bulk density results were used in the calculation of the total porosity (**Section 5.11.1.6**). Pychonometer test results for bulk density are presented in **Table 7.7**. The results were compared with the average of 1.33g/cm$^3$ for soil which is not compacted (Finlyson, 1980; and GoM, 1988). Generally the results were below 1.33g/cm$^3$ which indicate that the soils were not compacted. These results agree with moderately high porosity values observed in all the study areas (**Table 7.9**). In some isolated areas, where human activities were observed, relatively higher values were obtained (**Table7.10**). Post Hoc LSD test shows significant differences between the Chiweta and the rest of the study areas (p<0.020) (**Appendix 7**). The ANOVA tests for the equality of means (**Appendix 9**) show significant differences in the upper layer (p=0.004) while the lower layers show no significant differences (p=0.153). The differences in the upper layers could be attributed to compaction of the surface by human settlements, deforestation, and road construction. Particle density values fall within the normal ranges of 2.45g/cm$^3$ – 260 g/cm$^3$ for fine particles and 2.70 g/cm$^3$ for coarse particles. Particle densities are important in fluid mechanisms (Bryant, 1976; Finlayson, 1980; and Alexander, 1993) which was not within the scope of this study. However, in this study, particle density was used in the calculation of total porosity (**Section 5.11.1.6**)

**Table 7.7: Bulk Density Results**

| Area | Depth (cm) | Number | Mean (g/cm$^3$) | Standard Deviation | Minimum (g/cm$^3$) | Maximum (g/cm$^3$) |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 1.10 | 0.15 | 0.78 | 1.51 |
| **Chiweta** | | 22 | 1.23 | 0.16 | 0.89 | 1.51 |
| **Mvai** | | 20 | 1.05 | 0.28 | 0.54 | 1.50 |
| **Livilivi** | | 14 | 1.17 | 0.17 | 0.92 | 1.46 |
| **Ntchenachena** | >100 | 77 | 1.13 | 0.19 | 0.75 | 1.68 |
| **Chiweta** | | 22 | 1.23 | 0.19 | 0.66 | 1.61 |
| **Mvai** | | 20 | 1.17 | 0.17 | 0.86 | 1.47 |
| **Livilivi** | | 14 | 1.14 | 0.14 | 0.90 | 1.41 |

### 7.1.5 Total Porosity Results

Total porosity tests were carried out to determine the percentage of void spaces which can be filled by water and cause high pore pressure, slope loading, and a corresponding increase in the gravitational force. The results are presented in **Table 7.8** below. It should be noted that although porosity determines hydraulic conductivity and slope loading, the initial porosity may not necessarily always be a reliable indicator of soil instability (Yamamuro and Lade, 1998). Therefore, the results were treated as an indirect measure of soil stability.

**Table 7.8: Total Porosity Results**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 58.30 | 5.57 | 43.02 | 70.17 |
| **Chiweta** | | 22 | 53.36 | 6.31 | 42.28 | 66.42 |
| **Mvai** | | 20 | 60.58 | 10.53 | 43.40 | 79.22 |
| **Livilivi** | | 14 | 54.58 | 9.33 | 28.30 | 65.28 |
| **Ntchenachena** | >100 | 77 | 57.12 | 7.09 | 36.60 | 71.70 |
| **Chiweta** | | 22 | 53.73 | 7.10 | 39.25 | 75.09 |
| **Mvai** | | 20 | 55.79 | 6.49 | 44.53 | 67.55 |
| **Livilivi** | | 14 | 56.67 | 5.23 | 46.79 | 66.04 |

All sites show moderately high values of porosity, with mean values ranging from 53% to 60%. Total porosity in all the sites was noted to decrease with depth (**Tables 7.8 and 7.9**). This possibly could have been due to the weight of the overlying material. High maximum values (**Tables 7.8 and 7.9**) were observed in units where organic matter was high and cultivation was taking place (Ntchenachena). Both LSD and Beforroni Post Hoc tests and ANOVA show significant differences between the Chiweta Area and the rest of the study areas ($p<0.017$). This could possibly be due to the impact of slope remodelling. The lower layers showed no significant differences (ANOVA test $p=0.229$). The similarities at lower layers at all sites could be attributed to minimum or no disturbances at that depth.

## Table 7.9: Results of the Analysis of Hydraulic Conductivity, Total Porosity, Aggregate Stability, and Bulk Density

| Area | Unit | Hydraulic Conductity | | | Total Porosity | | | Aggregate Stability | | | Bulk Density | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | IQ | Skew ness | Mean | IQ | Skew ness | Mean | IQ | Skew ness | Mean | IQ | Skew ness |
| Ntchenachena | 1 | 5.877 ±2.68 | 4.777 | -1.568 | 55.66±7.63 | 14.71 | -.324 | 2.876 ±.377 | .718 | -.516 | 1.18±.2024 | .390 | .324 |
| | | 4.925 ±3.16 | 5.69 | .053 | 47.85±8.973 | 17.12 | -.561 | 2.916 ±660 | 1.22 | -.583 | 1.33±.2372 | .452 | .556 |
| | 2 | 7.68± 1.552 | 3.05 | -.558 | 57.77± 5.102 | 6.79 | .513 | 3.179 ±.270 | .339 | -1.33 | 1.119 ±.135 | .180 | -.511 |
| | | 7.43± 1.764 | 2.59 | .733 | 60.58± 6.542 | 13.21 | .096 | 2.836 ±.422 | .647 | -.364 | 1.04±.1734 | .350 | -.097 |
| | 3 | 7.703 ±1.75 | 1.70 | -1.428 | 58.31± 6.067 | 8.02 | -.233 | 2.75± .674 | .742 | -1.34 | 1.102 ±.161 | .212 | .237 |
| | | 6.922 ±2.02 | 2.15 | -.809 | 57.05± 6.910 | 9.71 | -.457 | 2.63± .691 | .786 | -1.45 | 1.143 ±.178 | .250 | .498 |
| | 4 | 8.734 ±2.71 | 2.6 | 1.2 | 59.12± 4.978 | 8.49 | .058 | 2.67±.808 | .52 | -2.50 | 1.08± .131 | .225 | -.057 |
| | | 7.38± 3.234 | 3.57 | .509 | 56.57± 6.625 | 12.08 | .555 | 2.59± 1.04 | 1.54 | -1.21 | 1.15±.175 | .320 | -.555 |
| | 5 | 8.22± 2.07 | 2.03 | .204 | 58.91± 4.327 | 6.79 | -.979 | 3.18± .185 | .282 | -.516 | 1.088 ±.114 | .180 | .979 |
| | | 8.52± 1.500 | 2.18 | -.105 | 58.11± 5.797 | 8.49 | -.468 | 2.91± .618 | .694 | -1.75 | 1.11± .1536 | .225 | .467 |
| Chiweta | 1 | 6.44± 2.55 | 4.43 | -.026 | 53.20± 6.911 | 13.58 | -.595 | 2.76± .495 | .714 | -.766 | 1.23± .171 | .360 | .513 |
| | | 6.96± 2.164 | 2.94 | .466 | 55.9± 7.128 | 5.84 | 2.20 | 2.77± .386 | .510 | -.343 | 1.191 ±.198 | .180 | -2.20 |
| | 2 | 7.08± 1.889 | 1.60 | 1.083 | 53.51± 5.986 | 9.43 | 1.197 | 3.154 ±.187 | .3132 | -.267 | 1.23±.158 | .250 | -1.19 |
| | | 5.67± 1.865 | 2.77 | .169 | 51.52± 6.672 | 6.42 | -.250 | 2.74± .539 | 1.044 | -.388 | 1.28± .176 | .1700 | .251 |
| Livlivi | 1 | 7.99± .820 | 1.24 | -1.80 | 55.32± 4.617 | 8.49 | .905 | 2.52± .709 | 1.29 | -.297 | 1.18± .122 | .225 | -.906 |
| | | 7.32± 2.240 | 3.93 | -1.22 | 52.97± 3.594 | 5.28 | -1.87 | 2.19± .738 | 1.388 | .448 | 1.24± .095 | .1400 | 1.870 |
| | 2 | 8.912 ±1,06 | 1.9775 | -.894 | 60.56± 3.99 | 7.73 | -.003 | 2.34± .8971 | 1.65 | -.395 | 1.045 ±.105 | .2050 | .000 |
| | | 7.397 ±1.55 | 2.917 | .460 | 58.30± 5.342 | 9.437 | 1.599 | 2.00± 1.036 | 1.989 | .461 | 1.105 ±.141 | .250 | -.1.60 |
| | 3 | 5.95± 2.777 | 5.42 | .451 | 49.05± 13.23 | 23.02 | -1.06 | 1.76± .527 | 1.00 | .350 | 1.26±.20 | .390 | -.445 |
| | | 7.94± 1.621 | 2.56 | -.1.62 | 59.02± 5.288 | 7.55 | -1.944 | 1.45± .760 | 1.38 | -.396 | 1.08± .140 | .2000 | 1.944 |
| Mvai | 1 | 9.058 ±2.19 | 4.06 | -.577 | 65.27± 9.86 | 17.64 | -.527 | 2.82± .394 | .676 | -.493 | .919± .263 | .4675 | .497 |
| | | 7.296 ±2.25 | 3.03 | .022 | 58.64± 6.194 | 7.83 | -.389 | 2.62± .596 | .852 | -.892 | 1.096 ±.164 | .2075 | .389 |
| | 2 | 7.136 ±3.17 | 5.577 | .186 | 55.77±9.327 | 15.56 | .25 | 2.724 ±.589 | .325 | -1.65 | 1.172 ±.247 | .4125 | -.249 |
| | | 6.53± 1.678 | 2.29 | .357 | 52.94±5.695 | 6.692 | .750 | 2.510 ±.788 | 1.09 | -1.316 | 1.247 ±.151 | .1775 | -.750 |

### 7.1.6 Particle Size Analysis Results

Particle size analyses were carried out to determine the percentages of total sand and medium to fine sand which are prone to liquefaction under prolonged precipitation. Particle size also determines the other physical soil properties which give an indication of stability (Alexander, 1993; and Finlayson, 1980). In this study, aggregate stability, total porosity, Atterberg limits, and hydraulic conductivity depended on the particles of the soil. The results of the hydrometer tests and sieve analyses are presented in **Tables 7.10, 7.11, 7.12, 7.13, and 7.14.**

In general, in all the study areas, the soils showed a high percentage of sand. The upper layers had total sand, ranging from 37% (Ntchenachena) to 84% (Mvai). For the lower layer, total sand ranged from 33% (Ntchenachena) to 86% (Livilivi). The mean values ranged from 65.05% in the Ntchenachena Area to 71.61% in the Livilivi Area. Medium to fine sand made up the highest percentage of the sand fraction. Mean values ranged from 38.66% in the Ntchenachena to 54.53% in the Mvai Area.

The soils of the Ntchenachena Area showed lower values of total sand and medium to fine sand as compared to the rest of the study areas (**Tables 7.10, 7.11, and 7.13**). Post Hoc test of LSD and ANOVA show significant differences between the Ntchenachena Area and the rest of the study areas ($p<0.008$ and $p<0.001$ respectively). This could be attributed to relatively high clay content at the Ntchenachena site as shown in **Table 7.13**.

**Table 7.10: Total Sand Test Results**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 65.05 | 8.21 | 37.00 | 79.00 |
| **Chiweta** | | 22 | 69.73 | 9.26 | 46.00 | 82.00 |
| **Mvai** | | 20 | 71.32 | 8.35 | 46.00 | 85.70 |
| **Livilivi** | | 14 | 71.61 | 8.76 | 55.00 | 84.00 |
| **Ntchenachena** | >100 | 77 | 63.49 | 7.92 | 33.00 | 83.00 |
| **Chiweta** | | 22 | 67.81 | 9.35 | 46.00 | 86.00 |
| **Mvai** | | 20 | 69.40 | 9.60 | 50.00 | 86.00 |
| **Livilivi** | | 14 | 68.71 | 11.14 | 49.00 | 81.00 |

**Table 7.11: Medium/Fine Sand Test Results**

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 38.98 | 8.96 | 19.56 | 60.12 |
| **Chiweta** | | 22 | 45.80 | 13.72 | 18.39 | 65.64 |
| **Mvai** | | 20 | 54.53 | 11.99 | 26.88 | 71.20 |
| **Livilivi** | | 14 | 48.03 | 9.99 | 35.84 | 65.24 |
| **Ntchenachena** | >100 | 77 | 38.66 | 8.30 | 16.72 | 54.79 |
| **Chiweta** | | 22 | 45.17 | 11.27 | 26.68 | 65.92 |
| **Mvai** | | 20 | 51.63 | 12.33 | 24.52 | 69.64 |
| **Livilivi** | | 14 | 48.78 | 12.34 | 17.08 | 69.00 |

In all the study areas, the proportion of silt was found to be low (**Table 7.12**). The mean values for individual units (**Table 7.14**) ranged from 15.2% in the Livilivili Area to 21.8% in the Chiweta Area. Post Hoc tests of LSD and Benforroni did not show significant differences between the study sites (p>0.084 in all the tests). This was confirmed by ANOVA test for the equality of the means (p>.235). The importance of silt will be discussed later in relation to sand content.

**Table 7.12: Silt Test Results**

| Area | Depth | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 16.62 | 3.54 | 10.00 | 28.00 |
| **Chiweta** | | 22 | 18.72 | 6.58 | 12.00 | 38.00 |
| **Mvai** | | 20 | 18.40 | 7.72 | 8.00 | 42.00 |
| **Livilivi** | | 14 | 17.86 | 4.26 | 10.00 | 24.00 |
| **Ntchenachena** | >100 | 77 | 17.19 | 4.06 | 10.00 | 36.00 |
| **Chiweta** | | 22 | 19.18 | 6.07 | 10.00 | 36.00 |
| **Mvai** | | 20 | 17.20 | 8.42 | 2.00 | 36.00 |
| **Livilivi** | | 14 | 17.85 | 3.80 | 12.00 | 22.00 |

Mean clay values ranged from 7% in the Livilivi Area to 29.4% in the Ntchenachena Area (**Table 7.14**). The Ntchenachena Area showed higher values of clay content than the other study areas (**Tables 7.13 and 7.14**). The high component of clay was confirmed by both LSD and Benforroni Post Hoc tests (P<0.002 and p<0.008, respectively). ANOVA equality for means tests showed significant differences beween the Ntchenachena Area and the other study areas (p=0.000).

## Table 7.13: Clay Test Results

| Area | Depth (cm) | Number | Mean % | Standard Deviation | Minimum % | Maximum % |
|---|---|---|---|---|---|---|
| **Ntchenachena** | 0 – 100 | 77 | 18.35 | 6.66 | 8.00 | 43.00 |
| **Chiweta** | | 22 | 11.59 | 3.72 | 4.00 | 20.00 |
| **Mvai** | | 20 | 10.30 | 3.26 | 6.00 | 20.00 |
| **Livilivi** | | 14 | 10.50 | 6.02 | 5.00 | 23.00 |
| **Ntchenachena** | >100 | 77 | 19.31 | 7.30 | 6.00 | 47.00 |
| **Chiweta** | | 22 | 13.86 | 5.49 | 4.00 | 28.00 |
| **Mvai** | | 20 | 13.40 | 5.07 | 8.00 | 28.00 |
| **Livilivi** | | 14 | 13.29 | 8.11 | 5.00 | 29.00 |

## Table 7.14: Results of the Analysis of Soil Particles

| Area | Unit | Total Sand | | | Medium+Fine Sand | | | Silt | | | Clay | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **IQ** | **Skew ness** | **Mean** | **IQ** | **Skew ness** | **Mean** | **IQ** | **Skew ness** | **Mean** | **IQ** | **Skew ness** |
| **Ntchenachena** | 1 | 54.25±5.909 | 11.25 | .680 | 40.83±7.91 | 15.11 | .708 | 16.75±2.21 | 4.25 | -.48 | 29±4.242 | 8.0 | -.36 |
| | | 54.75±4.112 | 7.750 | .356 | 40.02±3.222 | 6.182 | .337 | 16.0±1.414 | 2.50 | 1.414 | 29.25±3.09 | 5.75 | -.13 |
| | 2 | 66.63±7.032 | 10.00 | -.946 | 34.65±7.678 | 11.24 | .516 | 15.63±4.88 | 6.00 | 1.667 | 17.72±4.83 | 8.00 | -.31 |
| | | 63.72±5.386 | 8.00 | -.060 | 34.13±8.828 | 15.04 | .064 | 16.54±4.39 | 8.00 | .478 | 19.72±6.08 | 12.0 | .020 |
| | 3 | 66.62±6.866 | 10.75 | -.159 | 38.86±9.571 | 11.43 | .088 | 16.37±2.87 | 4.00 | -.29 | 17.05±5.30 | 8.0 | .224 |
| | | 65.17±5.717 | 7.00 | -.673 | 39.67±9.102 | 13.77 | -.27 | 17.3±4.127 | 4.00 | 2.474 | 17.27 5.458 | 6.00 | .322 |
| | 4 | 59.92±10.758 | 13.00 | -1.25 | 41.32±8.983 | 12.12 | .549 | 17.53±4.55 | 6.00 | .935 | 22.53±8.45 | 11.00 | 1.22 |
| | | 60.23±14.38 | 19.00 | -.351 | 40.74±7.874 | 13.7 | -.01 | 15.84±3.78 | 5.00 | .741 | 24.69±10.4 | 16.00 | .778 |
| | 5 | 68.36±5.750 | 4.16 | -.244 | 40.56±7.622 | 15.44 | -.10 | 17.55±3.43 | 6.00 | -.51 | 14.11±5.10 | 7.00 | 1.21 |
| | | 64.33±3.61 | 5.00 | -1.01 | 36.04±2.690 | 3.48 | -.67 | 20.±3.74 | 5.00 | 1.178 | 15.66±4 | 14 | 4 |
| **Chiweta** | 1 | 65.08±10.25 | 14.00 | -1.02 | 38.20±15.11 | 19.16 | .678 | 21.81±7.61 | 8.00 | .914 | 13.90±3.01 | 4.0 | .588 |
| | | 65.64±10.64 | 15.00 | -.721 | 43.52±11.30 | 20.48 | .752 | 20.18±7.50 | 10.0 | .662 | 15.90±5.50 | 5.00 | 1.492 |
| | 2 | 74.39±5.20 | 9.00 | -.683 | 53.40±6.304 | 10.56 | .314 | 15.63±3.44 | 6.00 | .628 | 9.27±2.86 | 5.00 | -.11 |
| | | 69.97±7.730 | 9.00 | .686 | 46.83±11.537 | 17.68 | -.11 | 18.18±4.33 | 6.00 | -.71 | 11.81±4.89 | 9.00 | -.23 |
| **Livilivi** | 1 | 77.18±7.92 | 14.87 | -.579 | 55.69±11.15 | 21.17 | -.61 | 15.2±5.76 | 10.00 | 1.08 | 7.60±3.64 | 5.00 | 2.02 |
| | | 74.6±4.92 | 9.5 | .275 | 53.96±8.87 | 14.1 | 1.71 | 16.4±4.33 | 8.00 | .069 | 9.00±2.54 | 4.5 | 1.207 |
| | 2 | 73.41±1.82 | 3.41 | -.894 | 43.6±6.51 | 12.22 | .182 | 18.5±2.51 | 4.50 | 1.129 | 8.00±1.154 | 2.00 | .00 |
| | | 77.50±3.41 | 6.50 | -.753 | 56.17±5.19 | 9.81 | -.56 | 15.5±1.91 | 3.5 | .855 | 7.00±1.63 | 3.00 | .00 |
| | 3 | 64.6±8.98 | 17.0 | .383 | 43.92±7.32 | 12.32 | 1.29 | 20.0±2.44 | 4.00 | -1.3 | 15.4±7.53 | 15.00 | .022 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 55.8±6.41 | 12.00 | .608 | 37.69±12.42 | 20.56 | -.1.5 | 21.2±1.78 | 2.00 | -2.2 | 22.6±5.899 | 9.00 | -1.23 |
| **Mvai** | 1 | 69.2±9.34 | 10.5 | -1.956 | 48.72±10.57 | 13.35 | -.97 | 21.6±8.154 | 8.5 | 2.012 | 9.2±1.932 | 2.5 | .111 |
| | | 67.8±9.402 | 10.5 | .255 | 47.08±14.28 | 24.26 | .140 | 18.6±8.79 | 12.5 | -.92 | 13.6±6.58 | 8.0 | 1.504 |
| | 2 | 73.44±7.068 | 10.46 | 0.76 | 60.35±10.78 | 11.71 | -1.7 | 15.2±6.05 | 10.00 | 1.20 | 11.4±4.00 | 6.00 | .929 |
| | | 71.00±10.03 | 15.5 | -1.06 | 56.19±8.43 | 7.08 | -.2.2 | 15.8±8.24 | 10.5 | 1.93 | 13.2±3.29 | 5.00 | 0.60 |

## 7.2 Rainfall Data Analysis

The role of rainfall in triggering or contributing to slope failure is investigated in **Section 3.6**. Crozier (1984), Aryamanya-Mugisha, (2001), Msilimba (2002), Msilimba and Holmes (2005), Knapen et al (2006), and Ingaga et al (2006), give an analysis of the contribution of rainfall to slope instability.

### 7.2.1 Annual Rainfall Totals for Rumphi and Ntcheu

High annual total rainfalls have been reported to have conditioned the slopes for failure in Uganda (Aryamanya-Mugisha, 2001; and Knapen et al., 2006), in Kenya (Ngecu and Mathu, 1999), and in Malawi (Gondwe and Govati, 1991; Poschinger et al., 1998; Msilimba, 2002; and Msilimba and Holmes, 2005). **Figure 7.2** presents annual rainfall for Rumphi (Chiweta/Ntchenachena) and Ntcheu (Mvai/Livilivi) Districts (**Section 5.7**). The results show that the Ntchenachena and the Chiweta Areas receive more precipitation than the Mvai and the Livilivi areas. Annual rainfall ranges from 949mm (1988/9) to 2631mm (1987/8) for the Ntchenachena/Chiweta Areas of Rumphi District, with an average of 1472mm. The Mvai and Livilivi Areas of Ntcheu District, receive rain in the range of 647mm (1977/8) to 1613.1 mm (2002/3) with an average of 1034mm. During the 2002/3 season, Ntcheu was exceptionally wet with high precipitation of 1613mm, the highest since 1977. This is the same year when the landslides occurred. Annual totals for the same period for Rumphi are not available. As explained above, high annual totals were reported to have conditioned the occurrence of landslides in the East Africa region. Therefore, it is suggested that the high annual totals in 2003 probably increased the likelihood of slope failure by increasing the antecedent soil moisture.

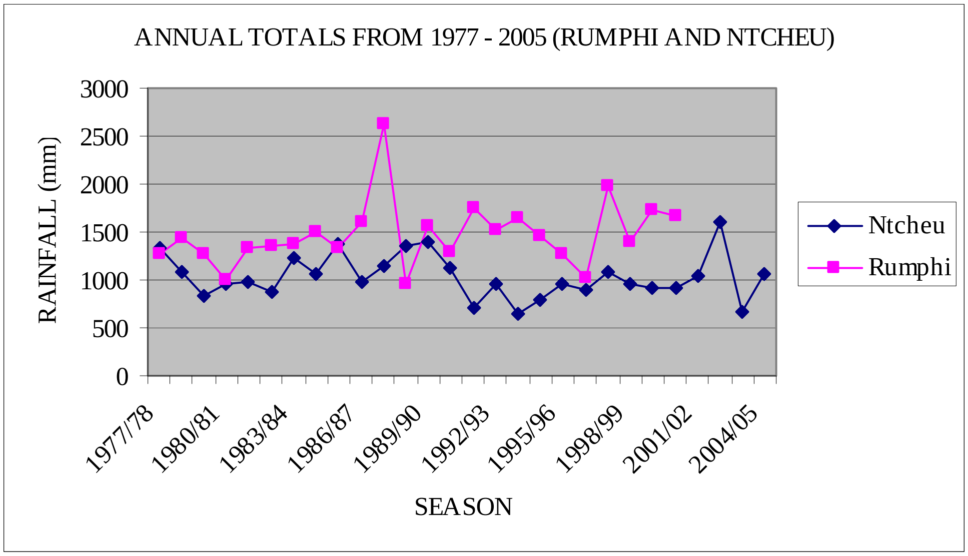


Figure 7.2: **Annual Rainfall Totals for Rumphi and Ntcheu Districts.**

### 7.2.2 Analysis of Daily Totals Which Triggered the Landslides

**Figures 7.3A** and **7.3B** show the daily rainfall for January, and March, 2003 which are suggested to have triggered the landslides in Ntcheu and Rumphi Districts. The results, as shown in **Figure 7.3A,** show that the landslides in the Chiweta and the Ntchenachena areas occurred after prolonged rainfall of 21mm on 26/27 March and 185mm on 27/28 March, 2003. Studies have shown that abrupt increase in pore pressure due to prolonged precipitation causes immediate liquefaction of the soil (Iverson, 2001; Westerberg and Chriastiansson, 1998). Total rainfall for the two days was 206mm which was more than half the total for the month of March which was 402mm. Before these rainfall events the areas had received 192mm of rainfall during the month of March. This was also towards the end of the rainy season. Therefore, it is suggested that the antecedent soil moisture was high and which put the slopes in a marginally stable condition. The 206mm probably caused the soil to exceed its liquid and plastic limits; hence, the failures. As it has been presented in **Section 7.1.1,** liquid and plastic limits were found to be low.

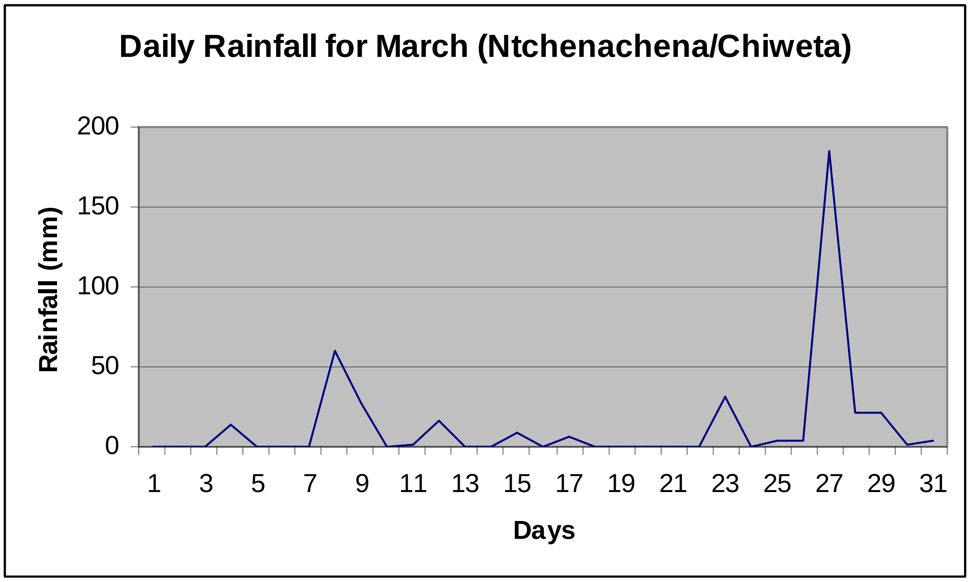


Figure 7.3A: **Daily Rainfall for March for the Ntchenachena and Chiweta Study Areas. Note the critical rainfall that triggered the events.**

The events occurred after prolonged rainfall of 325.6mm at the Mvai/Livilivi sites on 3rd January, 2003 (**Figue, 7.2B**). The Mvai and Livilivi areas received 29.1mm of rainfall on 1/2 January and 296.5mm on 2/3 January, 2003. This amount of rainfall was more than half the total for the month of January. Although the rains fell at the beginning of the rainy season, the antecedent soil moisture was relatively high considering that over 120mm of rainfall fell in December, 2002. The critical rainfall events which probably triggered the landslides in all the areas fell in different months of the same year (January for Mvai/Livilivi and March for Chiweta/Ntchenachena). This could be due to the shift in rain bearing systems which always moves northwards. However, this was not investigated by this study. From the analysis of the daily rainfall, it is suggested that the landslides were triggered by rainfall events of high magnitude (**Figure 7.3A and 7.3B**). This is also supported by available data which indicates that from 1977 to 2005, no single rainfall event in either area exceeded 70mm/day.

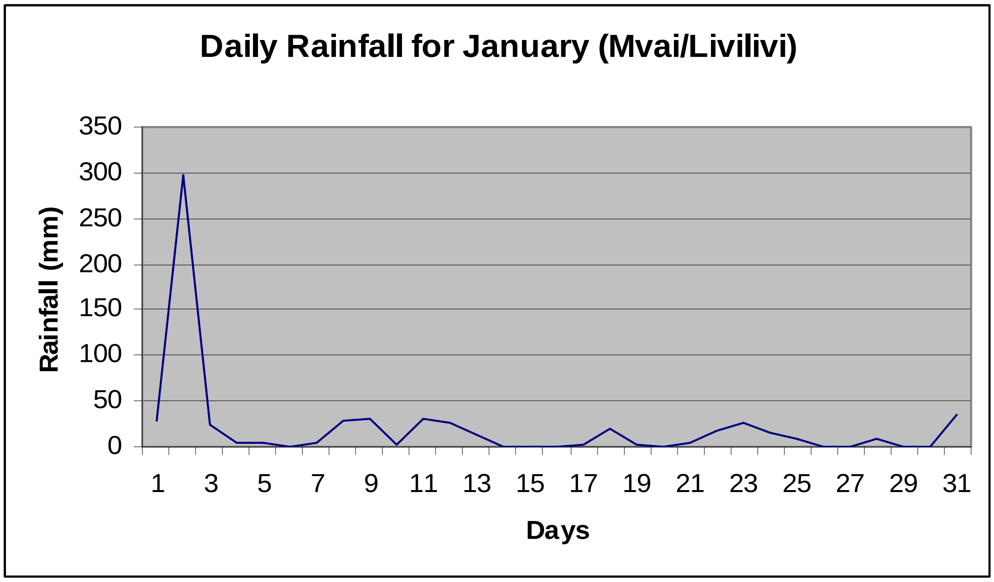


Figure 7.3B: **Daily Rainfall for January for the Mvai and Livilivi Study Areas. Note the critical rainfall which caused the landslides.**

### 7.2.3 Analysis of Monthly Totals from 1977 to 2005 for Rumphi and Ntcheu

**Figures 7.4A** and **7.4B** show monthly totals for the Rumphi and Ntcheu Districts from 1977 to 2005. From the analysis, it is evident that Ntcheu received very high precipitation during the month of January, 2003. This is also the month when the landslides occurred. The total monthly rainfall of 636mm was not only significantly high above the normal average for January of 266.76mm, but also the highest for one month since 1977.

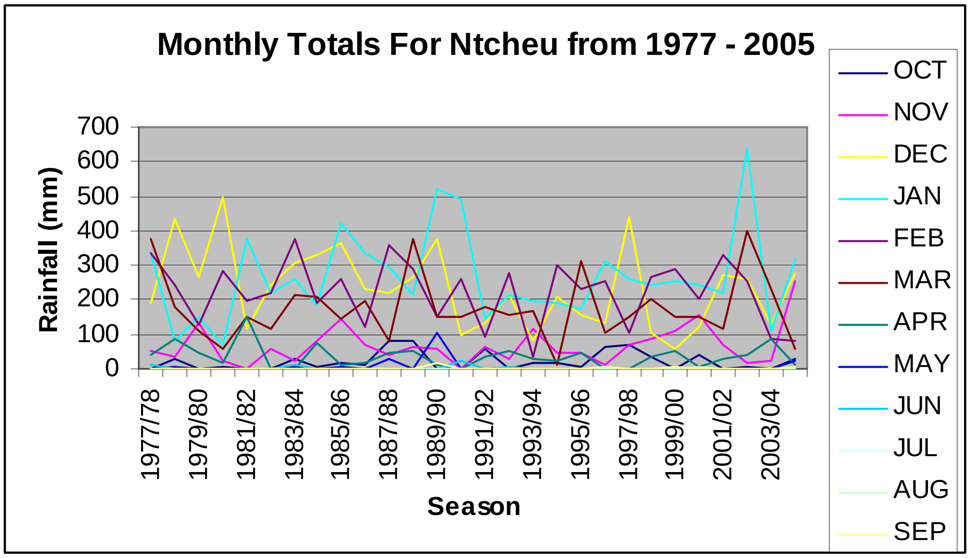


Figure 7.4A: **Monthly Rainfall Totals for Ntcheu District (1977 – 2005).**

The landslides of the Ntchenachena and Chiweta Areas occurred in March and recorded 406mm of rainfall above the normal monthly average of 301.9mm. Unlike the Ntcheu sites, March rainfall was not the highest (**Figure 7.4B**). However, in all the study areas, high monthly totals did not necessarily correlate with landslide occurrences. The January totals for Ntcheu District for the periods 1981/2, 1985/6, 1989/90 and 1991/2 registered high values above average and yet no landslides occurred. Similarly, the March totals for Rumphi for the periods 1981/2, 1987/8, 1991/2, and 1994/5 were significantly higher than the average of 301.9mm, and yet, no landslides were recorded. Other months both for the Ntcheu and Rumphi study areas showed higher values than the months when the landslides occurred.

It is suggested from these findings that high monthly totals are not the main causes of landslides; rather they only prepare the slope for eventual failure by raising antecedent soil moisture. If evenly distributed within the months, the high monthly rainfall totals will infiltrate down the profile, thereby reducing pore water pressure and slope loading. Similar observations are articulated in studies by Bryant (1991), Alexander (1993) and Westerberg and Christiansson (1998). This is also supported by the findings of particle size analyses (**Section 7.1.6**). The soils of the catchments have high sand content and hydraulic conductivity was found to be moderately rapid. Brachystegia trees are known for extracting substantial amount of water from the ground (Scheichtt, 1980). It appears, therefore, that landslides in all the study areas were in part triggered by prolonged precipitation, rather than high monthly totals.

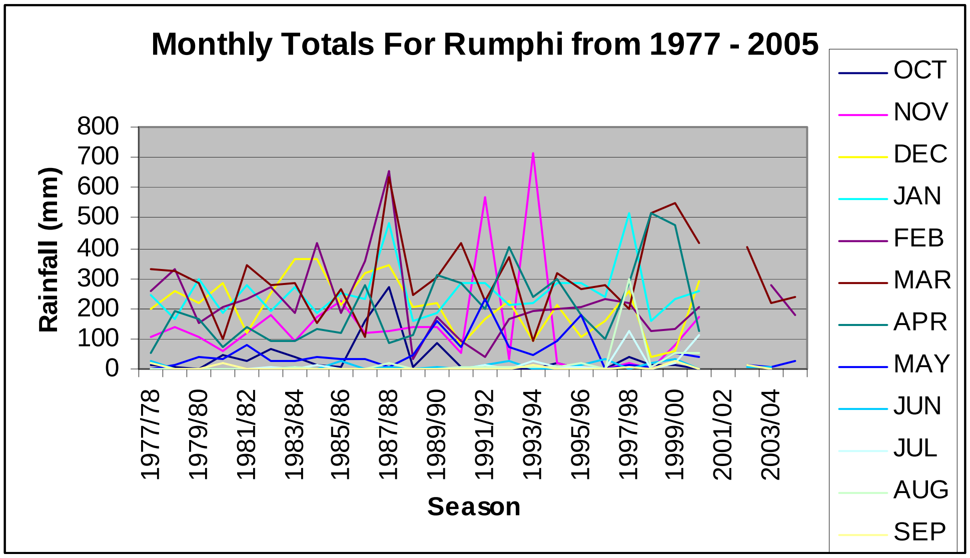


Figure 7.4B: **Monthly Rainfall Totals for Rumphi District (1977 – 2005).**

## 7.3 Results of Vegetation Survey

Vegetation determines slope stability through mechanical binding of soil particles and evaporative losses (Msilimba and Holmes, 2005; and Knapen et al., 2006). The results of the vegetation survey are presented in **Table 7.15** and **Appendix 15**. They show low values of Dsh, Dbh, H, and CC for all the sites in the Ntchenachena Area, and corresponding high values for the rest of the areas. The vegetation of the Ntchenachena Area can broadly be classified as afromontane with shrubs (*Protea*, *Faurea saligna*, *Syzigium*), ferns and grass dominating. In contrast, the vegetation of the Chiweta Area (Rumphi District) and the Livilivi/Mvai Catchments (Ntcheu District) fall in the broad group of Miombo woodlands. In the Chiweta Area, the dominant species include *Brachystegia*, *Combretum*, *Diplorhynchus condylocarpon*, *Acacia*, and *Pseudolachnostlis maprouneifolia* while in the Mvai/Livilivi Areas the dominant species include *Brachystegia*, *Combretum*, *U. kirkiana*, *Parinari kirkiana*, *and Faurea.*

**Table 7.15: Vegetation Parameters for the Study Areas**

| District | Area | Unit | Vegetation Parameters | | | |
|---|---|---|---|---|---|---|
| | | | Dsh (mm) | Dbh (mm) | H (cm) | CC (m) |
| Rumphi | Ntchenachena | Kasokoloka | 109 | 87 | 3.4 | 3 |
| | | Lutowo1- 3 | 67 | 50 | 3 | 1 |
| | | Lutowo4 | 69 | 46 | 2.5 | 1.1 |
| | | Lutowo5 | 97 | 71 | 4.9 | 1.3 |
| | | Lutowo6 | 127 | 100 | 4.3 | 2.8 |
| | | Lutowo7 | 110 | 86 | 4.2 | 3.0 |
| | | Lutowo8 | 89 | 65 | 3.8 | 2.0 |
| | | Chikwezga | 92 | 75 | 3.5 | 2.0 |
| | | Mankhorongo | 138 | 105 | 4.6 | 3.0 |
| | | Kasese | 125 | 93 | 5.5 | 3.6 |
| | Chiweta | Lower | 190 | 169 | 8.0 | 4.7 |
| | | Upper | 237 | 151 | 7.7 | 4.4 |
| Ntcheu | Mvai | Mvai A | 155 | 114 | 5.2 | 2.7 |
| | | Mvai B | 178 | 134 | 5.3 | 4.3 |
| | Livilivi | Livilivi 1 - 3 | 158 | 105 | 5.0 | 2.3 |
| | | Livilivi 4 - 8 | 111 | 88 | 4.3 | 3.4 |

## 7.4 Land Use Analysis

The contribution of land-use to slope instability is well-articulated in studies by Msilimba and Holmes (2005) in Northern Malawi, and Knapen et al (2006) on the slopes of Mount Elgon in Uganda. In Malawi, land-use (mainly cultivation) contributed to the degradation of marginal slopes (NEP, 1996; and NEAP, 1998). The results of land-use analysis are presented in **Appendix 15**. It is apparent from the field observations and analyses of maps and vegetation data that much of the Ntchenachena Area is under customary land tenure. Most of the units are under cultivation of cassava (**Figure 7.7**), tobacco (**Figure 2.10**), coffee, beans and maize.

Figure 7.5**: Cassava cultivation in the Ntchenachena Area leaves the ground bare, thereby making it prone to landslide (29.08.06).**

Patches of Afro-Montane vegetation are found although they have been disturbed by slush and burn cultivation. This practice is common in this area as was reported by Msilimba (2002). The Ntchenachena Area is dominated mostly by grasses and scattered shrubs along river valleys while the slopes are under cultivation, and settlement activity. The Chiweta Area is a proposed forest reserve dominated by Miombo trees. These trees are deep rooted with spreading canopies and of various ages and sizes (**Appendix 15**). The ground was completely covered with grass. The savanna grasses in this area are shallow rooted. The lower side of the remodelled slope shows minor disturbances by the road slope fills. The Mvai and Livilivi Areas are within forest reserves and dominated by Miombo woodlands. Tall grasses provide adequate ground cover although they are shallow rooted. Deforestation and seasonal burning were observed in the Chiweta and the Mvai/Livilivi Areas (**Figures 7.6 and 7.7**).

Figue 7.6: **Destruction of the Mvai/Dzonzi Forest Reserves contributing to the loss of shear strength of the soil. In the foreground, landslide scar is clearly visible (2.09.06).**

Figure 7.7: **Charcoal making in the Livilivi/Mvai Catchments contributing to instability. In some areas, the Miombo woodlands have completely disappeared (2.09.06).**

## 7.5 Results of Slope Angle Analysis

The importance of slope angle in initiating failure has been discussed by several authors (Hoek and Boyd, 1973; Selby, 1984; Bryant, 1991; Alexander, 1993; and Fernandes et al., 2006). The results from the determination of the slope angles and the occurrence of landslides are presented in **Tables 7.16** and **7.17**. The results have been compared with

Hoek's critical angle for sliding of $35^0$ (Hoek and Boyd, 1973), and critical slope angle ranges for sliding (Fernandes et al., 2006).

### 7.5.1 Results of the Determination of Slope Angle, Using Hoek's Critical Angle

Using critical slope angle of $35^0$ (Hoek and Boyd, 1973), the results presented in the **Table 7.16** show that 98.86% and 100% of the landslides in the Ntchenachena and the Ntcheu Districts, respectively occurred on slopes with slope angles greater than $35^0$. Of all the landslides, 99.24% of the total occurrences were on slopes greater than $35^0$ while only 0.763% of the landslides were on slopes less than $34^0$. The averages at all the sites were significantly higher than the critical angle for sliding. However, at the Mankhorongo unit within the Ntchenachena Area, some landslides occurred on slopes with angles less than $32^0$.

**Table 7.16: Slope Angle Determination Using Hoek's Critical Angle**

| District | Area | Unit | Slope Range | Average Slope | $0^0$ – $34^0$ | $35^0$ + |
|---|---|---|---|---|---|---|
| Rumphi | Ntchenachena | Kasokoloka | - | 41 | - | 1 |
| | | Lutowo | 39 – 69 | 52.69 | - | 55 |
| | | Mankhorongo | 32 - 65 | 54.16 | 1 | 11 |
| | | Chikwezga | 51 - 67 | 54.5 | - | 14 |
| | | Kasese | 51 - 69 | 58.33 | | 6 |
| | | **Overall** | **32 - 69** | **52.96** | **1.136%** | **98.86%** |
| | Chiweta** | Chiweta | 60 - 85 | 75.9 | - | 10 |
| Ntcheu | Livilivi | Livilivi | 45 - 65 | 41.875 | - | 8 |
| | Mvai | Mvai A | 52 - 69 | 59.16 | - | 12 |
| | | Mvai B | 54.71 | 60.15 | - | 13 |
| | | **Overall** | **45 -71** | **55.36** | **-** | **100%** |
| **As a Percentage of total Occurrences** | | | | | **0.763%** | **99.236%** |

**Chiweta is treated as a special case because events did not occur on natural slopes.

### 7.5.2 Results of the Determination of Slope Angles Using Fernandes's Critical Ranges

Slope angle critical values were determined, using Fernandes critical ranges (Fernandes et al., 2006). According to Fernandes et al (2006), slope angles between $18.6^0$ and $37^0$ are the most frequent to fall, followed by $37.1^0$ to $55.5^0$ category. The least to fail are slopes with angles greater than $55.5^0$. The results (**Table 7.17**) show that there were differences between the study areas. In the Nchenachena Area, 65.9% of the landslides occurred on slopes with angles ranging from $37.1^0$ to $55.5^0$, followed by $55^0$+ slopes with 32.95% of the landslides. In Ntcheu District, 63.63% of the landslides occurred within the $55^0$+ range while 36.36% of the landslides occurred within $37.1^0$ to $55.5^0$ slope range. However, 75% of the Livilivi landslides occurred within the $37.1^0$ to $55.5^0$ slope category.

The averages for the Ntchenachena and the Ntcheu Areas ($52.96^0$ and $55.36^0$, respectively) were within the $37.1^0$ to $55.5^0$ slope category although individual slopes at Mvai A and B and the Kasese units registered higher values. The results from the Chiweta Area landslides are treated as a special case considering the fact that all the Chiweta landslides/rockfalls occurred on remodelled slopes. Their significance will be discussed in **Section 7.7**.

**Table 7.17: Slope Angle Determination Using Fernandes's Critical Slope Ranges**

| **District** | **Area** | **Unit** | **Slope Range** | **Average Slope** | **$18.6^0$-$37^0$** | **$37.1^0$ - $55.5^0$** | **$55.5^0$ +** |
|---|---|---|---|---|---|---|---|
| Rumphi | Ntchenachena | Kasokoloka | - | 41 | | 1 | - |
| | | Lutowo | 29 - 69 | 52.69 | - | 37 | 18 |
| | | Mankhorongo | 32 - 65 | 54.16 | 1 | 7 | 4 |
| | | Chikwezga | 51 - 67 | 54.5 | - | 10 | 4 |
| | | Kasese | 51 - 69 | 58.33 | - | 3 | 3 |
| | | **Overall** | **32 - 69** | **52.96** | **1.136%** | **65.9%** | **32.95%** |
| | | Chiweta** | 60 - 85 | 75.9 | - | - | 10 (100%) |
| Ntcheu | Livilivi | Livilivi | 45 - 65 | 41.875 | - | 6 | 2 |
| | Mvai | Mvai A | 52 - 69 | 59.16 | - | 5 | 7 |
| | | Mvai B | 54 - 71 | 60.15 | - | 1 | 12 |
| | | **Overall** | **45 - 71** | **55.36** | **-** | **36.36%** | **63.63%** |

**Chiweta is treated as a special case because events occurred on modified slopes

## 7.6 Mechanisms of Landslides Generation

### 7.6.1 Liquefaction of the Soil

It was determined from the analysis of the data obtained that the landslides were likely triggered by liquefaction of the sand and silt fractions of the soil. In all the study areas, the soils contained a high percentage of sand, with mean values ranging from 65.05% at Ntchenachena to 71.61% at Livilivi (**Tables 7.10 and 7.14**). Medium to fine sand was abundant in all the areas where the mean percentage exceeded 38.66% of the total sample. Silt percentages, though not particularly high, ranged from 15.2% (Livilivi) to 21.8% (Chiweta). Medium to fine sands satisfy both criteria for liquefaction to occur. The particles are fine enough to inhibit rapid internal water movement and coarse enough to inhibit rapid capillary action. The particles are also coarse enough which means that cohesion is no longer relevant (Bryant, 1991; Msilimba, 2002; and Msilimba and Holmes, 2005). Since all the areas showed a high percentage of sand and that such sands are unconsolidated (Finlayson, 1980; and Iverson et al., 2000), the angle of shearing resistance for these soils was probably low, implying that failure might have occurred at an internal angle less than the slope angle upon which these materials were resisting.

Although some units in the Ntchenachena Area showed a high average percentage of clay (up to 47%), which would have reduced the rate of liquefaction (clays have a high angle shearing resistance) (Torrance, 1987; and Alexander, 1993), the strength of clay was probably reduced by high moisture content after 206mm of rainfall in two days. This means that under normal rainfall, which is evenly distributed, soils can resist deformation. However, generally the soils of all the study sites showed low values of liquid limit (**Table 7.1**), plastic limit (**Table 7.2**), plasticity index (**Table 7.3**), moderately rapid hydraulic conductivity (**Section 7.1.2**), and moderate total porosity (**Section 7.1.5**). This implies that with increased water content, as was the case in 2003 (**Section 7.2**), the soils easily crossed the threshold and liquefied. However, liquefaction was more pronounced in the Ntchenachena Area than in any other area. This could be attributed to high precipitation which falls in the area, deep weathering which has produced deep soils, the disturbance of the soil aggregation by cultivation, and the destruction of vegetation. A study at Vunguvungu, adjacent to the Ntchenchachena Area yielded similar results (Msilimba, 2002; and Msilimba and Holmes, 2005). In the Mvai Area, rock falls in some places were caused by the liquefaction of the basal support. Similar results were obtained by Chipili (1997) in Kanjati Village of the same District.

Figure 7.8: **Soils which liquefied and dried are common in the all study areas. The photo represents liquefaction at the Lutowo unit of the Ntchenachena Area (27.08.06).**

### 7.6.2 High Pore Pressure

Studies have shown that an increase in pore pressure reduces the effective resistance of the soil body or regolith (Finalyson, 1980; Bryant, 1991; Iverson, 2000; and Matsushi et al., 2006). The effect of high pore pressure on slope stability was also demonstrated in a study on the occurrence of the 1997 Banga Landslide in Rumphi District (Msilimba, 2000; and Msilimba and Holmes, 2005). The rainfall data, as shown in **Figures 7.2A** and **7.2B,** shows that all the areas received high annual precipitation (>900mm per year). Total annual precipitation for the Mvai/Livilivi Area was in excess of 1600mm/year. The antecedent moisture content was probably high as shown in **Section 7.2.1**. The 325mm and 206mm of rain which fell in the Mvai/Livilivi and the Ntchenachana/Chiweta Areas were unusual and above the average (**Section 7.2.2**). This, coupled with high sand content, moderately high porosity, and moderately rapid hydraulic conductivity (**Tables 7.6, 7.9 and 7.10**), increased pore pressure between the soil particles. With liquid limits and plasticity index being low (**Section 7.1**), high precipitation meant that the Atterberg limits were easily exceeded. This was found to be common in all the study areas. In the Chiweta Study Area, unconsolidated materials from weathered sandstones were observed. Such unconsolidated materials could deform easily due to a small increase in water content (Finlayson, 1980).

However, rotational slides are associated with high water pressure as compared to translational (Thomas, 1994; Ayalew, 1999; and Waterberg, 1999). This is due to the fact that rotational slides occur on concave slopes with deep soils while translational slides occur on shallow soils with pre-existing slide planes. This implies that translational landslides in the Mvai and Livilivi Areas were supposed to occur at a lower rainfall threshold than rotational slides common in the Ntchenachena Area. However, this is an area which requires further investigation.

### 7.6.3 Cleft Water Pressure

In the Mvai and the Chiweta Areas, joints and other forms of discontinuities were observed to have contributed to failure (**Figure 7.9**). It is suggested that the rain water penetrating joints and contacts between soil and rock masses contributed to failure by creating cleft water pressure. Results have shown that cleft pressure along discontinuities can have corresponding effects as pore water pressure (Crozier, 1984; and Alexander, 1993). Cleft water pressure reduces frictional force (**Section 2.6**) by acting as a lubricant (Crozier, 1984). The development of cleft pressure was confirmed by the nature of the events indicated by a toe failure or blow-out at the foot of the slope.

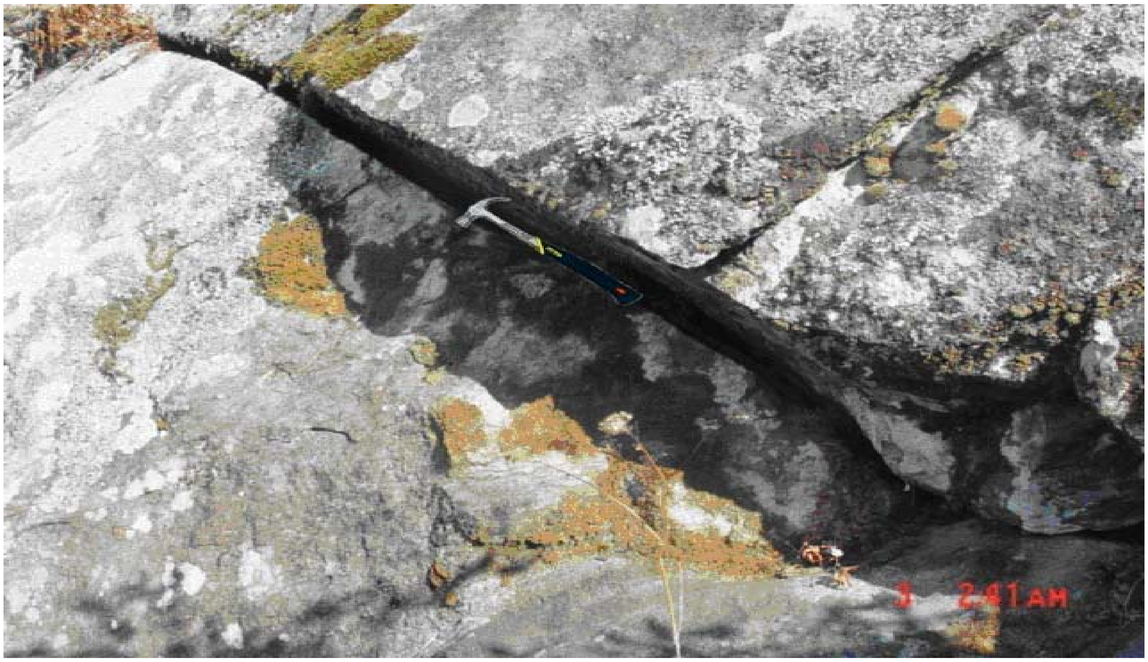


Figure 7.9: **Structural rock weaknesses through which water penetrated, causing high cleft pressure and land sliding at the Mvai Study Area (3.09.06).**

### 7.7 The Role of Slope Angle in the Occurrence of Landslides

In slope stability analysis, slope angle is regarded as the major topographic factor determining stability (Hoek et al., 1974; Crozier, 1984; Selby, 1987; and Msilimba and Holmes, 2005). The importance of slope angle is presented in **Section 3.6**. The results of slope angle analysis conform to that of Hoek's critical angle for sliding (Hoek and Boyd, 1973). The analysis shows that all the four study areas are high energy terrain, shown by high values of slope angles and altitude (**Table 6.1**). Similar results were obtained by Mwenelupembe (2003) in the Ntcheu Mountain Area, where failure occurred on slopes in the range of $40^0$ to $60^0$. Any mass on an inclined plane is affected by gravity which is directly related to the size of the slope angle (Butler, 1976). Although slope angle was not found to be the major cause of failure, high values resulted in greater values of gravitational force, thereby increasing the likelihood of slope failure. Similar results were found in a study in an area adjacent to the Ntchenachena Area (Msilimba, 2002; and Msilimba and Holmes, 2005). The study revealed that all eight landslides which occurred in the VBCA were on slopes with angles greater than $45^0$. Similar results were found in studies in Southern Malawi by Chipili (1997), Gondwe and Govati (1991), and Poschinger et al (1998).

When the slope angles were compared to Fernandes critical ranges (Fernandes et al, 2006), similarities were observed in the $37.1^0$ to $55.5^0$ slope ranges. In the Ntchenachena Area, where most landslides occurred in this category, the basement had been weathered significantly with deep soils of >10m. The thickening of soil mass, and lack of vegetation which is deep rooted with high root density (**Section 7.3**) prolonged precipitation (**Section 7.2**) might have increased gravitational force of such slopes. This is contrary to the widely accepted view that steeper slopes have thin soils (Fernandes et al., 2006). An except to this is the Ntchenachena Area. The occurrences of landslides on slopes greater than $55.5^0$ in the Mvai Area, could be attributed to less or no vegetation and the presence of structural rock weaknesses (**Section 7.9**). Middle slopes which had fallen are in areas where Miombo trees had been cut for charcoal burning. During fieldwork, it was observed that deforestation was taking place inside the reserves where it was difficult for the foresters to police. The Livilivi Area has thick soils and it is experiencing deforestation. This could partially explain the occurrence of landslides in the slope category of $37.1^0$ to $55.5^0$.

In all the comparisons (Hoek and Boyd, 1973; and Fernandes et al., 2006), similarities were observed although Hoek and Boyd's critical angle for sliding was found to be more applicable than that of Fernandes. Both models attest the importance of slope angle in increasing the likelihood of slope failure. However, contribution of slope angle can best be understood in relation to other passive factors that prepared slopes for eventual failure (Knapen et al., 2006; and Fernandes et al., 2006).

### 7.8 Vegetation and Slope Stability

Deforestation is often considered as one of the main preparatory causal factors for land sliding in the East African region (Rapp et al., 1972; Davies, 1996; Ingaga et al., 2001; and Nyssen et al., 2002). Studies have shown that deforestation reduces the safety factor (**Section 3.6.2**), through root decay by 30% to 60% (Knapen et al., 2006). Based on field observations, all landslides occurred in areas where vegetation has been destroyed. This suggests that destruction of vegetation contributed to slope failures. The Ntchenachena Area, dominated by afromontane grassland, and with poor ground cover of grasses and shrubs, recorded the highest number of landslides (**Table 6.1 and Section 6.1**). Although there is direct evidence to suggest that roots provide reinforcement through tensile resistance and frictional or adhesion properties (Anderson and Richards, 1985), root reinforcement depends primarily on the depth of the potential slip surfaces within the slope. At the Ntchenachena site, where the soils are very deep (> 10m), most of the landslides occurred beyond the root zone. This suggests that shallow rooted vegetation did not provide maximum tensile resistance to the soil mass. In areas where vegetation was cleared for cassava cultivation, the instability has been increased because cassava has low root density, and roots are shallow (Msilimba, 2002; and Msilimba and Holmes, 2005). Studies have shown that converting a forest to grassland or crops cultivation increases moisture in the soil, enough to cause landslide problems (De Graft, 1979). Similarly, cassava tubers crack the soil during formation, thereby increasing infiltration and slope loading. This was also noted to be a problem in landslide prone area of Banga in the same District (Msilimba and Holmes, 2005). The importance of forest cover in prohibiting mass movement was observed at the Kasese Unit within the Ntchenachena Area where no landslides were recorded (**Figure 7.10**).

Figure 7.10: **Part of the Kasese Forest where vegetation was observed to contribute to stability. All the observed landslides occurred outside the Forest (27.08.06).**

At the Ntchenachena site, grasses contributed to rapid infiltration, thereby increasing pore water pressure and slope loading. Grasses have been observed to contribute to high infiltration rates (Nassif and Wilson, 1975). Although studies have shown high infiltration rates on slopes with grass, a study by Scheichtt (1967) showed that grasses have lower transpiration rates than deciduous forests. It could, therefore, be concluded that the rate at which the water infiltrated (**Table 7.6**) was greater than the rate at which the vegetation could transpire, thereby increasing both the load and the pore pressure. In parts of the Chikwezga and the Mankhorongo units, where patches of pine trees were planted, landslides also occurred. It was observed that although pine trees have high interception losses, as compared to deciduous trees (Ward, 1967; and Thomas, 1996), the shallow rooting system could not provide maximum tensile resistance. The trees could not tap water from the lower soil stratum. Pine trees might have contributed an extra load to the slope material, thereby increasing the gravitational force through surcharges both normal and down slope. Manda (1999) studied the effect of pines trees on slope stability within the Zomba Mountain Area, and concluded that the replacement of indigenous forest by exotic forest caused some slopes to become more unstable.

In the Mvai/Livilivi Catchments and the Chiweta Area, vegetation stabilised areas, which would otherwise experience failure. Deciduous trees, mostly *Brachystegia*, *Faurea siligna*, *Erythrina abyynica*, *Diplorhynchus condylocarpon*, and *Combretum* provided maximum mechanical binding to soil particles. These trees are deep-rooted with high root density. Therefore, mechanical binding was probably high. By binding the slope particles at the ground surface, it was observed that roots reduced the rate of soil erosion which could otherwise lead to slope undercutting and instability. Water absorption from the lower horizons not reached by grass roots was possible. Vegetal debris lying on the ground surface may have high absorptive capacities, thereby contributing further to the water-loss. Spreading canopies of deciduous trees, and ground coverage by grasses contributed to high interception lowering ground water. Studies have shown higher transpiration rates for deciduous trees than grasses (Ward, 1967; and Scheichtt, 1980). In the Mvai and Livilivi Areas, it was also observed that in some areas, trees served as barriers to arrest the fall of boulders.

However, it should be pointed out that both in the Mvai/Livilivi Catchments and the Chiweta Area, on rocky slopes, tree roots penetrated rock discontinuities, wedged blocks apart, possibly causing the detachment and fall of boulders (**Figures 7.11 and 7.14**). Most of the landslides occurred in deforested areas of the catchments and areas with major structural rock weaknesses at the contact between rock masses, or between soil and rock masses. The importance of vegetation in stabilising the slopes was evident at the Chiweta site where no single landslide occurred in the Miombo woodlands, except for along the slope cutting. Similar results were obtained in a study by Msilimba and Holmes (2005) within the VBCA, 15 and 18 kilometers from the Chiweta and the Ntchenachena Areas, respectively.

Figure 7.11: **Vegetation wedging boulders apart at Mvai, contributing to mechanical weathering. Rockfalls were observed to have been caused by root wedging (3.09.06).**

Therefore, it can be concluded that destruction of vegetation and change of land-use contributed to the high number of landslide occurrences at the Ntchenachena Area. The variations in the dimension of landslides (where the landslides with larger depths and length were located in the Ntchenachena Area) could partly be attributed to vegetation destruction. The rapid destruction of vegetation had the same effect at the Mvai/Livilivi catchments. The Chiweta Area appears to be stable, except for the areas along the slope cutting. Evidence of deforestation and burning was also observed. If the destruction of vegetation is not checked, slope instability could follow. The Chiweta, the Mvai and the Livilivi areas have dominant tree species which are commonly used for fuel wood and charcoal in Malawi (Abbot, 2005). Unless alternative sources of energy are identified and poverty situation is improved, deforestation will continue.

Figure 7.12: **Goats destroying remaining shrubs and grass in the Ntchenachena Area, contributing to the loss of tensile strength of soils (30.08.06).**

Figure 7.13: **Landslide occurrences in the Mvai Area where deforestation has taken place (3.09.06).**

## 7.9 Degree of Aggregation and Slope Stability

In all the study areas, average aggregate stability values were high (>1.87mm), which implies that the soils were structurally stable. Few units within the Ntchenachena Area showed values lower than 0.5mm of MWD. This probably could be attributed to disturbance caused by deforestation, cultivation, and settlement activities. Variations could also be due to differences in water absorption, the properties of the soils such as clay type, the organic matter content, and the amount of cement in the material (Alexander, 1993). This was not investigated by this study due to limited resources, and lack of equipment. However, high aggregate stability values in all study areas could be an indication of soil relative resistance to slaking or dispersion. The high degree of aggregation was also found to correspond with moderately high values of porosity and moderately rapid hydraulic conductivity (**Tables 7.6 and 7.9**).

However, it has been observed that aggregation tends to be less when wet than dry (Briggs, 1977). This arises from two main reasons: water entering the aggregates interfering with the electrochemical forces which cause the particles to cohere to one another, and the water dissolving some of the cements which bind and stabilise the aggregates (Bulter, 1976; Bryant, 1991; Alexander, 1993; and Msilimba, 2002). From the rainfall data (**Figures, 7.2, 7.3A, 7.3B, 7.4A and 7.4B**), the study areas received high precipitation which could have an effect on aggregation. This, however, requires further investigation.

In conclusion, the high values of the calculated aggregate stability analysis would indicate that the soils are structurally stable. This was supported by rainfall data which showed high monthly totals without slope failures. Any slope instability cannot be attributed directly to the structural instability of the soil. However, since high aggregate stability values contribute to high porosity and permeability (Msilimba, 2002; and GoM, 1988), the rate of hydraulic conductivity during the rain storms in January and March of 2003, probably raised the water table, with the resultant high pore pressure, lowering aggregation and causing eventual liquefaction of the soils. Similar suggestions were raised in a study by Msilimba and Holmes (2005), in an adjacent area to the Ntchenchena Area.

## 7.10 Geology, Slope Remodeling and Slope Instability

### 7.10.1 Ntchenachena Area

The description of geology for the study areas is given in **Sections 2.2.1.2, 2.2.2.2** and **2.2.3.3**. It appears that the geology of the Ntchenachena Area did not contribute much to the slope failure. In all the occurrences mapped in this area, the basement was not involved in the movement. There were no pre-existing slide planes to suggest that geology contributed to the failures. Most of the landslides were rotational which attests that the soil mass was of significant depth as shown in **Chapter 6** and **Figure 2.7**. The basement which comprises of muscovite schist and biotite gneiss has been reduced by rapid chemical weathering (Msilimba, 2002). The weathering of the basement reduces particle attraction and loosens the material, thereby making it more porous (Thomas, 1996; and Taylor and Cripps, 1987). In the Ntchenchena Area, the weathering of the basement probably contributed to moderately rapid hydraulic conductivity, thereby raising water pore pressure and reducing the strength of the material. The 206mm of rain which fell in March of 2003 for 2 days might have contributed to slope loading, thereby altering the balance of forces operating on the slopes (**Section 3.6.1**). Similar results were observed in a study by Msilimba (2002) within VBCA adjacent to the Ntchenachena Area. It should be noted that studies by Chipili and Mshali (1989), Gondwe and Govati (1991), Kaufulu (1992), Cheyo (1999) and Mwenelupembe (2003) on hills in Malawi have shown that fissures and joints can contribute to landslides. The significance of soil properties in generation of landslides has been elaborated in **Section 7.6.1**.

It was observed that slope remodelling, though on a small scale, had negative effects on the slope stability at the Ntchenachena site. Slopes were remodelled for various reasons. Firstly, all house building on steep slopes forced people to excavate large parts of the slope to create flat areas. The construction of foot paths involved slope excavation. In addition, farmers often dig away parts of the slope in order to level their plots. Leveling was also done to construct irrigation channels. The creation of slope terraces by agricultural practices and intensified natural processes removed the lateral support, caused water stagnation in some areas and increased slope loading, leading to increased pore pressure and landslide risk. In the Manjiya Area of Uganda, it was observed that numerous landslides occurred on remodelled slope for agriculture and settlement activities (Knapen et al., 2006).

### 7.10.2 Mvai/Livilivi Catchments

By the way of contrast, in the Mvai/Livilivi Catchments and the Chiweta Area, rock properties played a significant role in determining areas of failure and types of failure. In the Mvai/Livilivi Areas, the rocks are heavily jointed and fractured (**Section 2.2.3 and**

**Figures 7.14 and 7.15**). This has partly contributed to the formation of boulders scattered throughout the catchments (**Figure 2.15**). According to eyewitnesses, boulder movements are common in this area. It was observed that in some areas boulders were resting on a soil mass which, if saturated, could lose its strength, causing the boulders to roll down the slope. Similar results were observed by Chipili (1997), at the Kanjati Village in the same District. Root wedging was also noted as a contributing factor to instability (**Figure 7.11**). The growth of roots caused the widening of cracks and resulted in eventual failure of rocks. It was observed in several places that there was a net shift in the position of rocks due to root expansion. Fractures and joints act as passages for the infiltrating water, increasing the weight, and the gravitational force (**Section 3.6.1**). Infiltration probably reduced the frictional force between the sliding surfaces. In some areas, failures occurred at points of contact between soil/rock masses or rock/rock masses. Rocky slopes with predominantly parallel joints, which are concordant with the general foliation of the gneisses in the area, have been observed by Mwenelupembe (2003).

It is therefore, suggested that the impervious sub-strata contributed to the build up of water in the soil or weathered material above. This probably contributed to the loss of suction; hence, the liquefaction of the material above. The frictional resistance between sliding planes was lost; hence, the translational failures.

Figure 7.14: **Hanging boulders within the Mvai/Livilivi Catchments. With increasing instability, they can roll down the slope (3.09.06).**

Figure7.15: **Point of failure between rock masses, as observed in the Mvai Area. Note the presence of shallow soils on the edge of the scar: an example of a translational slide, common in the Mvai and Chiweta Study Areas (2.09.06).**

### 7.10.3 Chiweta Area

In the Chiweta Area, which is composed of uplifted sedimentary beds of mudstones, geology contributed to the failures. Mass movements concentrated in areas where the slope cutting took place, exposing the rather jointed and fractured beds. Studies have shown that building a road which cuts the toe of step slope increases landslide susceptibility (Kocklman, 1985; and Knapen et al., 2006). All the mass movements were in areas where mudstone beds have been highly weathered, highly jointed, and dipping towards the road (**Figure 7.16**).

Figure 7.16: **Highly weathered Chiweta beds dipping along the main road to Karonga. Note the creeping of weathered colluvium at the base of the cliff (30.08.06).**

Slope remodelling affected the stability of the Chiweta beds in several ways. Firstly, slope cutting increased slope angles from $24^0$ – $69^0$ range to $61^0$ - $87^0$ range. This affected the balance of forces operating on the slope (**Section 3.6**). Secondly, the exposure of otherwise covered strata accelerated the rate of weathering, promoting infiltration, and slope loading. Thirdly, the blasting during the construction of the road might have contributed to further fracturing and fissuring. Finally, in some areas along the slope cutting, erosion is contributing to frequent rock falls by removing basal support.

The vegetation was also noted to cause instability on the remodelled slopes, especially when roots penetrate already disjointed strata. In the Zomba Mountains of Southern Malawi, minor landslides were caused by slope cutting (Mwenelupembe, 1999). It has been suggested that rock falls at the Chiweta site have been caused by slope remodeling (Manda, 1999). Within the East African region, the landslides of 1997 in Kenya, occurred along the remodelled slopes of Masui-Makweuni Road (Ngecu and Mathu, 1999). However, the flat areas created did not contribute to increased infiltration because of the concrete surfaces. Along the slope cutting, in areas where the beds are not weathered and are horizontal or dipping into the slope, no landslides were recorded.

Although the Chiweta and the Nthenachena Areas fall within the African Rift Valley System, with numerous observed and inferred faults (Bloemfield, 1968; Carter and Bennet, 1973; Carter and Haslam, 1973; and GoM, 1977), there is no conclusive evidence to suggest that landslides were caused by earthquakes and tremors. However, the location of these areas and the high percentage of sand (**Tables 7.10 and 7.14; Section 7.1.6**) give a high probability of seismic-generated landslides. But, it should be noted that landslides caused by earthquakes have been reported in Malawi (Dolozi and Kaufulu, 1992), and in the East African region (Ingaga et al., 2001). Heavy trucks passing through the area could have contributed to vibration, creeping and rock falls. This requires further investigation.

### 7.11 Conclusion

This Chapter has discussed the causes, and contributing factors to landslides. From the analyses of data, it is suggested that landslides were triggered by high precipitation which caused soil liquefaction. The high percentage of medium to fine sand and abrupt rise in pore pressure accelerated the process of liquefaction. Cleft water pressure at the point between regolith and soil mass caused a number of slides in the Mvai and the Chiweta Areas. High slope angles, deep weathering of the basement and high annual total rainfall contributed to the slope instability. Human activities through cultivation, slope remodeling, and deforestation significantly alter the conditions of the slopes, thereby increasing the degree of landslide hazard present in these areas. The next Chapter will discuss the results of the analysis of social data, with emphasis on the *perceived* causes, and contributing factors. Traditional knowledge and perceptions surrounding landslides will also be discussed. In the final analysis, coping strategies and suggested mitigation measures by the local people will also be discussed.

# CHAPTER EIGHT

# TRADITIONAL KNOWLEDGE, AND THE OCCURRENCE OF LANDSLIDES; PEOPLE'S PERCEPTIONS AND COPING STRATEGIES

This Chapter focuses on the results of socio-economic surveys carried out in the Rumphi and the Ntcheu Districts. Most of the landslide studies have placed emphasis on the mechanics that generate landslides, neglecting the social aspect which also contributes to and is affected by landslides. Traditions and beliefs governing landslides in rural areas have not been investigated and documented previously in Malawi. The Chapter is arranged in the following sections; the analysis of socio-demographic aspects of the respondents which include age, duration of residence, gender, education attainment, and income; peoples knowledge on landslide occurrences; perceived weather conditions prior to the landslides; traditional beliefs and the occurrence of landslides; perceived causes of landslides; impacts of landslides; coping strategies; slope stability management; and gender perceptions towards the occurrence of landslides. Associations between variables (education and perceived contributing factors; knowledge of landslides and education; age and traditional beliefs; and level of education and traditional beliefs) were tested, using cross-tabulation procedures. Significant tests, using Chi square and Pearson's product moment correlation, were also employed (**Section 5.13.1**).

## 8.1 Analysis of Socio-Demographic Aspects of Respondents

### 8.1.1 Sample Size and Duration of Residence

The sample comprised of 264 respondents, of which 158 (59.84%) were from the Ntcheu District, and 106 (40.15%) were from the Rumphi District. The sample comprised of 52.3% females and 47.7% males. This coincides with the demographic structure of Malawi, where 52% of the population are females and 48% are males (NSO, 1998). Of all the respondents, 9.3% had lived in the areas for less than ten years, while 90.7% had lived in the study areas for more than 10 years, with the majority having lived for more than twenty years (**Table 8.1A**). Variations were observed between the districts, with Ntcheu having more people who had lived in the area for more than 30 years. Most of the respondents from the Rumphi District were evicted from the Nyika National Park in 1974 while those from Ntcheu had lived there from time immemorial. However, in both districts, the duration of residence was long enough to ensure a good probability of mastering the physical environment. This also gives a possibility of respondents witnessing landslides, which might have occurred more than ten years ago.

**Table 8.1A: Duration of Residence**

| Duration of Residence | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | <10 | 24 | 9.1 | 9.3 | 9.3 |
| | 10-19 | 22 | 8.3 | 8.5 | 17.8 |
| | 20-29 | 72 | 27.3 | 27.8 | 45.6 |
| | 30-39 | 43 | 16.3 | 16.6 | 62.2 |
| | 40-49 | 35 | 13.3 | 13.5 | 75.7 |
| | 50-59 | 31 | 11.7 | 12.0 | 87.6 |
| | 60+ | 32 | 12.1 | 12.4 | 100.0 |
| | Total | 259 | 98.1 | 100.0 | |
| Missing | System | 5 | 1.9 | | |
| Total | | 264 | 100.0 | | |

### 8.1.2 Age Structure of Respondents

The ages of the respondents are given in **Table 8.1B**. The majority of the respondents (61.6%) were older than 30 years, of which 38.4% were from Ntcheu. Thirty-eight percent were in the age group 20 to 30 years, of which 22% were from Ntcheu. There were no significant differences in the ages between the districts (p=0.324 for Chi-square). There was also a strong linear by linear association between the districts (p=0.674). The majority of the respondents were older than 30 years, which gives a high probability of respondents witnessing landslides, which might have occurred in the past 20 years. The period of residence is also essential in the development of landslide knowledge and environmental awareness, which is central in explaining landslide histories.

**Table 8.1B: Age of Respondents**

| District | Measurement | Age of Respondents | | | | Total |
|---|---|---|---|---|---|---|
| | | 20-30 | 31-40 | 41-50 | >50 | |
| Rumphi | As % of District Sample | 40.8 | 16.5 | 10.7 | 32 | 100 |
| | As % of Total Sample | 16.2 | 6.5 | 4.2 | 12.7 | 39.6 |
| Ntcheu | As % District Sample | 36.9 | 14.6 | 19.1 | 29.3 | 100 |
| | As % of Total Sample | 22.3 | 8.8 | 11.5 | 17.7 | 60.4 |
| **Overall %** | | **38.5** | **15.4** | **15.8** | **30.4** | **100** |

### 8.1.3 Education Attainment of Respondents

The level of educational attainment was assessed because of its importance in the understanding of scientific causes and contributing factors to landsliding. Within the study districts, educational attainment varied as shown in **Table 8.2A** (p=0.000). The majority of the respondents had attained primary education, represented by 68.2%, of which 37.5% were from Rumphi and 30.7% were from Ntcheu. Only 7.6% of the respondents had attained secondary education. All those who had attained tertiary education were from Rumphi. Illiteracy was noted to be high (23.5%), with Ntcheu having the highest percentage (20.8%). It appears that the majority of the people from these areas were either illiterate or semi-literate. There was no linear by linear relationship between the two districts (p=0.000). In Rumphi, literacy was higher possibly because of the influence of the Livingstonia Mission Station which opened primary schools around 1900, and a secondary school later.

**Table 8.2A: Education of Respondents**

| **District** | **Measurement** | **Level of Education** | | | | **Total** |
|---|---|---|---|---|---|---|
| | | **Primary** | **Secondary** | **Tertiary** | **None** | |
| Rumphi | % of District Sample | 77.1 | 14.3 | 1.9 | 6.7 | 100 |
| | % of Total Sample | 30.7 | 5.7 | 0.8 | 2.7 | 39.8 |
| Ntcheu | % of District Sample | 62.3 | 3.1 | 00 | 34.6 | 100 |
| | % of Total Sample | 37.5 | 1.9 | 00 | 20.8 | 60.2 |
| **Overall %** | | **68.2** | **7.6** | **0.8** | **23.5** | **100** |

### 8.1.4 Economic Status of Respondents

Incomes in both districts were low (**Table 8.2B**), with the majority of the respondents having no monthly income (86.15%: 37.3% for Rumphi, and 48.85% for Ntcheu). No significant differences were observed between the districts (p=0.738). The negative linear by linear association was observed between the districts (p=0.058). Only 13.8% of the respondents had monthly income, with 1.54% earning more than K5000 per month (the equivalent of US$35.71/month). Within the districts, 94.1% of the respondents from Rumphi and 80.9% from Ntcheu had no monthly source of income. The results suggest that the people were generally poor with unreliable or limited sources of income. The findings are in agreement with the poverty situation in Malawi (NEP, 1996; NEAP, 1998; and Slater and Tsoka, 2006). The occurrence of landslides increased their vulnerability to poverty and reduced their resilience to natural disasters.

**Table 8.2B: Income of Respondents**

| District | Measurement | Income of Respondents (MK) | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | None | <1000 | 1001-2000 | 2001-5000 | >5001 | |
| Rumphi | % of Distict Sample | 94.1 | 1.94 | 0.38 | 0.38 | 1.94 | 100 |
| | % of Total Sample | 37.3 | 0.77 | 0.38 | 0.38 | 0.77 | 39.6 |
| Ntcheu | % of Distict Sample | 80.9 | 1.91 | 9.55 | 6.37 | 1.27 | 100 |
| | % of Total Sample | 48.85 | 1.15 | 5.77 | 3.85 | 0.77 | 60.38 |
| **Overall %** | | **86.15** | **1.92** | **6.15** | **4.23** | **1.54** | **100** |

### 8.1.5 Type of Housing

The type of housing was determined with the aim of assessing the houses' vulnerability to landsliding and also as a measure of poverty. The results are presented in **Table 8.3**. In both districts, 94.75% of the respondents were living in temporary houses. There were no significant differences in the type of housing between the districts (p=0.12). There was no linear by linear association established (p=0.012). Over 90.4% of the respondents in Rumphi, and 97.5% in Ntcheu, resided in houses built of mud or unburnt bricks, with grass thatched roofs (**Figure 8.1**). This type of housing is in line with the poverty situation in Malawi in general (Slater and Tsoka, 2006), and in the study areas in particular (**Table 8.2B**). The houses were noted to be very vulnerable not only from landslides, but also from excessive precipitation.

Figure 8.1: **Traditional houses common in rural areas of Malawi. This house is built on an excavated slope in the Ntchenachena area (25.08.06).**

**Table 8.3: Types of Housing**

| District | Measurement | Type of Housing | | Total |
|---|---|---|---|---|
| | | Temporary | Permanent | |
| Rumphi | % of District Sample | 90.4 | 9.6 | 100 |
| | % of Total Sample | 35.7 | 3.8 | 39.5 |
| Ntcheu | % of District Sample | 97.5 | 2.5 | 100 |
| | % of Total Sample | 58.9 | 1.5 | 60.5 |
| **Overall %** | | **94.7** | **5.3** | **100** |

### 8.1.6 Determination of the Location of Houses

The results determining the location of houses are given in **Table 8.4**. The location of houses varied between the districts (p=0.000), with positive linear by linear association (p=0.072). It was observed that the location of houses was given in relation to where one stays or cultivates. Most of the settlements were located on steep slopes (42%), of which the majority are in the Ntcheu District (**Table 8.4**). In the Rumphi District, most of the houses were located along ridges (35.2%), the tops of the hills (32%), and along slopes (22.9%). In general, houses were scattered. However, the difference between the districts was due to the fact that in Rumphi, slopes are mostly under cultivation and settlements were/are located on the ridges and in the valleys. This is a common practice in this area as was also observed by Msilimba (2002), and Msilimba and Holmes (2005). In contrast, cultivation in the Ntcheu District was/is mainly practised along the river banks, and the settlements were situated on relatively high ground. However, in both the areas, the settlements were located on danger-prone areas. These areas were either where landslides started or along the debris paths.

**Table 8.4: Location of Settlements**

| District | Measurement | Location of the Houses | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Ridge | Valley | Top of Hill | Slopes | Others | |
| Rumphi | % of District Sample | 35.2 | 7.6 | 32.4 | 22.9 | 1.9 | 100 |
| | % of Total Sample | 14 | 3 | 12.9 | 9.1 | 0.8 | 39.8 |
| Ntcheu | % of District Sample | 16.4 | 13.8 | 8.8 | 54.7 | 6.3 | 100 |
| | % of Total Sample | 9.8 | 8.3 | 5.3 | 33 | 3.8 | 60.2 |
| **Overall %** | | **23.9** | **11.4** | **18.2** | **42** | **4.5** | **100** |

### 8.1.7 Reasons for the Location of Houses

The reasons for the location of the houses were determined, and the results are presented in **Table 8.5**. Most of the houses were located on ancestral land, as represented by 80.1% of the sample. There were significant differences between the two districts (p=0.000), with no linear by linear association (p=0.000). In Ntcheu, 92.5% of the sampled population indicated that they were residing on ancestral land, against 60.8% from Rumphi. Fourteen percent of the sample acquired land through marriage or buying, of which the majority were from Rumphi (11.1%). In these areas, customary land tenure was dominant, but it was more pronounced in Ntcheu. It should be noted that some people of the Ntchenachena Area were evicted from the Nyika National Park. This might have a bearing on the land tenure system. This could also explain why more people from this area bought their land. However, customary land tenure has been noted for abuse, and lacks security (Mwafongo, 1996); hence, people are reluctant to invest in conservation and rehabilitation of degraded slopes. Also, the relocation of people from their ancestral land has proved to be difficult (NEAP, 1998). Even if the land is threatened by natural disasters, local people will maintain the right to stay and die on their ancestral land.

**Table 8.5: Reasons for the Location of the House**

| **District** | **Measurement** | **Reason for the Location** | | | | **Total** |
|---|---|---|---|---|---|---|
| | | **Ancestral land** | **Given by Chiefs** | **Shortage of Land** | **Others** | |
| Rumphi | % of District Sample | 60.8 | 3.9 | 6.9 | 28.4 | 100 |
| | % of Total Sample | 23.8 | 1.5 | 2.7 | 11.1 | 39.1 |
| Ntcheu | % of District Sample | 92.5 | 1.9 | 0.6 | 5.0 | 100 |
| | % of Total Sample | 56.3 | 1.1 | 0.4 | 3.1 | 60.9 |
| **Overall %** | | **80.1** | **2.7** | **3.1** | **14.2** | **100** |

### 8.2 People's Knowledge on Landslide Occurrences

Knowledge of past landslides is vital in explaining landslides histories. Questions were asked to ascertain people's awareness of the occurrence of landslides, and the results are presented in **Table 8.6**. The majority of the respondents (97.7%) were aware of landslides occurrences. There were differences between the districts (p=0.010), with all the 158 respondents from Ntcheu indicating that they had knowledge of landslide occurrences. Those respondents (1.9%) with no knowledge of landslides were from the Ntchenachena Area (Rumphi) and came to settle in the area during the 1974 and 1992/3 migrations. These migrants might not have witnessed past landslides.

**Table 8.6: Knowledge of Past Landslides**

| **District** | **Measurement** | **Knowledge of Past Landslides** | | | **Total** |
|---|---|---|---|---|---|
| | | **Yes** | **No** | **Others** | |
| Rumphi | % of District Sample | 94.3 | 4.8 | 1.0 | 100 |
| | % of Total Sample | 37.6 | 1.9 | 0.4 | 39.9 |
| Ntcheu | % of District Sample | 100 | 00 | 00 | 100 |
| | % of Total Sample | 60.1 | 00 | 00 | 60.1 |
| **Overall %** | | **97.7** | **1.9** | **0.4** | **100** |

Landslides in the Ntcheu District were perceived not to be new phenomena as was the case in Rumphi. In Ntcheu, landslides were traced back to the 1950s, while in the Rumphi District landslides were traced back to the 1990s (**Table 8.7**). However, in both districts landslides occurences have increased after 2000. Of all the respondents, 82.4% indicated that landslides frequencies increased after 2000. This was due to the encroachment of the Mvai/Livilivili Catchments (Ntcheu District) after the introduction of multi-party democracy in 1992; and the increase in population in the Ntchenachena Area (Rumphi District) as a result of 1974 and 1992/3 migrations.

It should also be noted that people mostly remember the most devastating and most recent events (Leighton, 1976; Chikusa, 1985; and Crozier, 1984; McCall, 1992; Alexander, 1993; and Huabin et al, 2005). Therefore, it might be suggested that the respondents could not remember ancient landslides because they might have passed unnoticed because the events were too small or did not cause significant damage.

**Table 8.7: Years of Landslides Occurrences**

| **District** | **Measurement** | **Years of Landslide Occurrence** | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | | **1950s** | **1960s** | **1970s** | **1980s** | **1990s** | **>2000** | |
| Rumphi | % of District Sample | O0 | 00 | 00 | 00 | 4.9 | 95.1 | 100 |
| | % of Total Sample | 00 | 00 | 00 | 00 | 1.9 | 37.5 | 39.5 |
| Ntcheu | % of District Sample | 4.4 | 2.5 | 3.8 | 6.3 | 8.9 | 74.1 | 100 |
| | % of Total Sample | 2.7 | 1.5 | 2.3 | 3.8 | 5.4 | 44.8 | 60.5 |
| **Overall %** | | **2.7** | **1.5** | **2.3** | **3.8** | **7.3** | **82.4** | **100** |

According to the local people, landslides in these areas took them by surprise as is often the case with natural disasters (Mwafongo, 1996; and Crozier, 1984). The majority of the respondents did not anticipate the occurrence of landslides (**Table 8.8**). There were no significant differences between the districts (p=0.219), with a strong linear by linear association (p=0.224). Only 8% (3.8% from Ntcheu, and 4.2% from Rumphi) expected landslides to occur. They cited environmental degradation as an indicator. They could also explain the occurrences based on past landslide events. However, the majority of the respondents (92%) could not predict the occurrence of landslides. This is in agreement with the assertions by Bryant (1976), Crozier (1984), Alexander (1993), Briggs (1995), and Msilimba (2002), that landslide prediction is always difficult in terms of timing and magnitude. This poses a serious challenge in mitigating the impacts.

**Table 8.8: Did Events Occur as a Surprise?**

| **District** | **Measurement** | **Did the Events Occur as A Surprise** | | **Total** |
|---|---|---|---|---|
| | | **Yes** | **No** | |
| Rumphi | % of District Sample | 89.5 | 10.5 | 100 |
| | % of Total Sample | 35.6 | 4.2 | 39.8 |
| Ntcheu | % of District Sample | 93 | 6.3% | 100 |
| | % of Total Sample | 56.4 | 3.8 | 60.2 |
| **Overall %** | | **92** | **8.0** | **100** |

### 8.3 Perceived Weather Conditions Prior to the Landslide Events

Weather conditions have been observed to influence the timing of landslides (Ngecu and Mathu, 1999; Msilimba, 2002; Ingaga et al., 2001; and Knapen et al., 2006). Questions were asked to determine whether the respondents could remember the weather conditions prior to the events. The results are presented in **Table 8.9**. The majority of the respondents indicated prolonged precipitation (37%), and high intensity precipitation (55.5%) prior to landsliding. There were variations in responses between the study districts, with no linear by linear association (p=0.000). In Rumphi, 64.9% of the respondents indicated prolonged showery precipitation while in Ntcheu the majority of the respondents (75.8%) indicated high intensity precipitation. Their responses were in agreement with the rainfall data from the Central Meteorological Station and the Ntchenachena and the Nkhande Weather Stations (**Section 7.2**). This suggests that the local people are observant of changes taking place in their physical environment and keep records of extreme events. Such information forms the bulk of indigenous knowledge which is essential in environmental management.

**Table 8.9: Weather Conditions Before the Landslides**

| **District** | **Measurement** | **Weather Conditions before Landslides** | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | | **Dry** | **Wet** | **Prolonged Precipitation** | **High Intensity Precipitation** | **Can not Remember** | **Others** | |
| Rumphi | % of District Sample | 1 | 4.1 | 64.9 | 22.7 | 5.2 | 2.1 | 100 |
| | % of Total Sample | 0.4 | 1.6 | 24.8 | 8.7 | 2.0 | 0.8 | 38.2 |
| Ntcheu | % of District Sample | 0 | 1.9 | 20.4 | 75.8 | 1.3 | 0.6 | 100 |
| | % of Total Sample | 0 | 1.2 | 12.6 | 46.9 | 0.8 | 0.4 | 61.8 |
| **Overall %** | | **0.4** | **2.8** | **37.4** | **55.5** | **2.8** | **1.2** | **100** |

## 8.4 Repetition of Landslide Occurrences

Field observations indicated that some of the landslides were a reactivation of landslides which had occurred in the past. Some landslides were still active although in some areas stabilisation was taking place (**Section 6.3**). Questions were asked to verify whether the majority of the landslides were of recent occurrence or reactivations of the past landslides. The results are presented in **Table 8.10**. They show similarities between field observations (**Sections 6.1, 6.3.2 and Table 6.3**), and the perceptions from the people. Most of the respondents (77.8%) indicated that landslides occurred in new areas while 22.8% indicated that landslides occurred in areas, which had already experienced failure. There were no significant differences between the study districts, with strong linear by linear association (p=0.416). This also suggests that local people observe changes taking place in their localities, and keep record of such changes as already explained in **Section 8.3**. Therefore, it can be suggested that despite being illiterate and semi-literate (**Section 8.1.3**), people had knowledge of their physical environment.

The fact that most of the respondents (77.8%) indicated that landslides occurred in new areas, suggests that slope instability is extending to other areas as land degradation accelerates. This phenomenon was also noted in Southern Malawi by Kasulo (2005). This environmental awareness and knowledge by the local people could also form the basis for landslide prediction and hazard mapping.

**Table 8.10: Repetition of Landslide Occurrences in the Same Area**

| Rumphi | Measurement | Repeated ness of landslides in the Same Area | | Total |
|---|---|---|---|---|
| | | Yes | No | |
| Rumphi | % of District Sample | 20.2 | 79.8 | 100 |
| | % of Total Sample | 8.1 | 32 | 40.2 |
| Ntcheu | % of District Sample | 24.5 | 75 | 100 |
| | % of Total Sample | 14.7 | 45.2 | 59.8 |
| **Overall %** | | **22.8** | **77.2** | **100** |

## 8.5 Cross Tabulation of Perceived Contributing Factors and Level of Education

The perceived contributing factors to landsliding were cross-tabulated with the level of education. This was to assess whether the knowledge of contributing factors correlated with education attainment. The results are presented in **Table 8.11**. The level of education did affect the level of understanding of the causes of landslides (p=0.691), with a strong linear by linear association (p=0.580). Of all the respondents, 46.3% believed that traditional beliefs contributed to landsliding. The majority of these were from the primary school category (32.5%), and those without formal education (10.4%). They cited Napolo, Wvira, and the will of God as the determinants (**Table 8.3**). This supports the assertion that tradional beliefs are deeply rooted in the less educated members of the society (Homewood, 2005; and Abbot, 2005).

Land degradation featured highly among the primary school category (25%), secondary school (11.1%), and those without formal education (21%). Poor farming methods were cited highly by those who attained secondary school education (22.2%), while changes in weather pattern was cited highly by those who had attained tertiary education. Of particular importance, was the fact that 21.2% of those without formal education also indicated climate change as a perceived contributing factor. Citing climate change, which is a recent phenomenon (**Section 2.1.9**), underscores the point that the local people are observant of changes taking place in their physical environment although such changes are explained using traditional beliefs. However, this comes with experience and experimentation with the environment (Homewood, 2005).

**Table 8.11: Level of Education and Factors Contributing to Landslides**

| Level of Education | Measurement | Contributing Factors to Landslides | | | | Total |
|---|---|---|---|---|---|---|
| | | Land degradation and Deforestation | Poor Farming Methods | Changes in Weather | Others | |
| Primary | % Within Education | 25 | 9.5 | 19 | 46 | 100 |
| | % of Total Sample | 17.5 | 6.7 | 13.3 | 32.5 | 70 |
| Secondary | % Within Education | 11.1 | 22.2 | 27 | 38.9 | 100 |
| | % of total Sample | 0.8 | 1.7 | 2.1 | 2.9 | 7.5 |
| Tertiary | %Within Education | 00 | 00 | 50 | 50 | 100 |
| | % of total Sample | 00 | 00 | 0.4 | 0.4 | 0.8 |
| None | %Within Education | 21.2 | 9.6 | 21.2 | 48.1 | 100 |
| | % of total Sample | 4.6 | 2.1 | 4.6 | 10.4 | 21.7 |
| **Overall %** | | **22.9** | **10.4** | **20.4** | **46.3** | **100** |

## 8.6 Cross-Tabulation of Knowledge of Landslides and Education

Results of cross tabulation between knowledge of past landslides and level of education are presented in **Table 8.12**. Education did not determine the knowledge of past landslides (p=0.952). The illiterate, semi-literate, and literate were all knowledgeable of past landslides. For instance, 97.8% of the respondents with primary education, 100% with tertiary education, 95% with secondary education, and 98.4% without any formal education had knowledge of past landslides. The results suggest that experience with the environment is important in the development of traditional knowledge. However, a better understanding of the causes and contributing factors would require scientific knowledge which the majority of the people were lacking due to their low level of education (**Table, 8.2A**).

**Table 8.12: Level of Education and Knowledge of Past Landslides**

| Education | Measurement | Knowledge of Past landslides | | | Total |
|---|---|---|---|---|---|
| | | Yes | No | Other | |
| Primary | % within Education | 97.8 | 1.7 | 0.6 | 100 |
| | % of total Sample | 66.9 | 1.1 | 0.4 | 68.4 |
| Secondary | % within Education | 95 | 5 | 0 | 100 |
| | % of total Sample | 7.2 | 0.4 | 0 | 7.6 |
| Tertiary | % within Education | 100 | 0 | 0 | 100 |
| | % of total Sample | 0.8 | 0 | 0 | 0.8 |
| None | % within Education | 98.4 | 1.6 | 0 | 100 |
| | % of total Sample | 22.8 | 0.4 | 0 | 23.2 |
| **Overall %** | | **97.7** | **1.9** | **0.4** | **100** |

## 8.7 Traditional Beliefs and the Occurrence of Landslides

Traditional beliefs have been noted to be central in explaining the occurrence of landslides, especially in Southern Malawi. The phenomenon of a snake locally known as

Napolo has been reported in works by Chikusa (1985), Cheyo (1999), and Msilimba (2002). The results presented in **Table 8.13A**, show variations in traditional beliefs (p=0.00), with no linear by linear association between the districts (p=0.00). In the Ntcheu District, the dominant traditional belief was that of Napolo (84%). This could be due to its proximity to Southern Malawi where the myth is dominant. This also shows the importance of cultural diffusion as explained by Lindsey (1996). According to Lindsey (1996), the spreading of innovations and information, among other things, is affected by the physical distance.

In the Rumphi District, the responses varied greatly, ranging from God's determination (31.6%), through the existence of spirits in the form of snakes or animals with multiple heads (39.8%) to Vwira (20.4%). According to the Phoka people of the Rumphi District, Vwira is a snake (Puff adder). It is alleged that a person from the Ntchenachena Area killed Vwira in the Nyika National Park. The spirits became angry; hence, the landslide occurrences. The belief that landslides were a punishment from God for man's sinful nature is dominant in Rumphi District, and could be as a result of the influence of Christianity which was introduced by the Scottish missionaries in the area in 1894 (Pike, 1968).

**Table 8.13A: Traditional Beliefs and the Occurrence of Landslides**

| District | Measurement | Traditional Beliefs | | | | Total |
|---|---|---|---|---|---|---|
| | | **Napolo** | **God** | **Vwira** | **Others** | |
| Rumphi | % of District Sample | 8.2 | 31.6 | 20.4 | 39.8 | 100 |
| | % of Total Sample | 3.1 | 12.1 | 7.8 | 15.2 | 38.3 |
| Ntcheu | % of District Sample | 84.2 | 8.9 | 00 | 7.0 | 100 |
| | % of Total Sample | 52 | 5.5 | 00 | 4.3 | 61.7 |
| **Overall %** | | **55.1** | **17.6** | **7.8** | **19.5** | **100** |

## 8.8 Age of Respondents and Traditional Beliefs

The relationship between age of the respondents and traditional beliefs was tested. The results are presented in **Table 8.13B**. The age of respondents in this study did not affect their traditional beliefs (p=0.000), and there was no linear by linear association between the two variables (p=0.00). The results show that traditional beliefs were deeply rooted in all age categories. This could be due to the fact that all the respondents targeted were older than twenty years, and they had already acquired the traditions through the process of socialisation (Lindsey, 1996).

**Table 8.13B: Age of Respondents and Traditional Beliefs**

| Age of Respondents | Traditional Beliefs | | | | Total % |
|---|---|---|---|---|---|
| | Napolo % | God % | Vwira % | Others % | |
| 20 – 30 | 51 | 22 | 9.0 | 18 | **38** |
| 31 – 40 | 55 | 16 | 11 | 18 | **15** |
| 41 – 50 | 68 | 12 | 7.0 | 12 | **16** |
| +51 | 54 | 17 | 5.0 | 24 | **31** |
| **Total %** | **55** | **18** | **8.0** | **19** | **100** |

### 8.9 Level of Education, and Traditional Beliefs

In terms of level of education and traditional beliefs, education did not affect people's traditional beliefs (p=0.00). Traditional beliefs were deeply rooted in all categories of education. However, it should be noted that the education which the majority acquired (**Table 8.2A**) was basic which in turn might not change their traditional thinking significantly. Secondly, the percentage of those with secondary and tertiary education was low therefore the correlation between education and traditional beliefs was difficult to establish.

**Table 8.13C: Level of Education and Traditional Beliefs**

| Level of Education | Traditional Beliefs | | | | Total % |
|---|---|---|---|---|---|
| | Napolo % | God % | Vwira % | Others % | |
| Primary | 52 | 15 | 10 | 23 | **68** |
| Secondary | 16 | 53 | 16 | 16 | **7.0** |
| Tertiary | 50 | 00 | 00 | 50 | **1.0** |
| None | 76 | 15 | 00 | 10 | **24** |
| **Total %** | **55** | **18** | **8** | **20** | **100** |

### 8.10 Perceived Causes and Contributing Factors to Landslides

The analysis of the perceived causes and contributing factors to landslides is central in addressing misconceptions in the traditional knowledge. Questions were asked to determine whether there were differences in the perceived causes and contributing factors between the districts of study. The results have been presented in **Tables 8.14A** and **8.14B**. These show significant differences between the districts (p=0.01), with a strong linear by linear association of p=0.284. Most of the respondents (46.3%) believe that Napolo, Vwira, God, and harmful bush fires (22.1% for Ntcheu, and 24.2% for Rumphi) have contributed to landslides. This is contrary to the scientific explanation of the causes and contributing factors to these landslides as discussed in **Chapter 7**. This suggests that a knowledge gap exists between the scientific and indigenous bodies of knowledge. Therefore, an understanding of traditional beliefs may assist scientists clarify the misconceptions that exist in the indigenous body of knowledge.

**Table 8.14A: Factors Contributing to Landslides**

| District | Measurement | Factors Contributing to Landslides | | | | Total |
|---|---|---|---|---|---|---|
| | | Land degradation | Poor Farming Methods | Changes in Weather | Others | |
| Rumphi | % of District Sample | 5.0 | 14.9 | 22.8 | 57.4 | 100 |
| | % of Total Sample | 2.1 | 6.3 | 9.6 | 24.2 | 42.1 |
| Ntcheu | % of District Sample | 36 | 7.2 | 18.7 | 38.1 | 100 |
| | % of Total Sample | 20.8 | 4.2 | 10.8 | 22.1 | 57.9 |
| **Overall %** | | **22.9** | **10.4** | **20.4** | **46.3** | **100** |

From the analysis of data, it was evident that the respondents had difficulties in distinguishing between the causes and contributing factors to landslides. For instance, in Rumphi, deforestation and weathering of the basement were perceived as important causes (23.7% for deforestation and 12% for weathering). Yet these were the preparatory factors to the occurrence of landslides (**Chapter 7**). Therefore, it can be concluded that due to low educational attainment, the local people finds it difficult to distinguish between what **contributes to** and what **causes** landslides; hence, the need to promote formal education at all levels.

**Table8.14B: Causes of Landslides**

| District | Measurement | Causes of Landslides | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PP | HIP | WR | DN | FCJ | EQ | ID | PFM | WC | Others | |
| Rumphi | % of District Sample | 23.7 | 25.8 | 12.4 | 23.7 | 5.2 | 00 | 00 | 1.0 | 4.1 | 4.1 | **100** |
| | % of Total Sample | 9.1 | 9.9 | 4.8 | 9.1 | 2.0 | 00 | 00 | 0.4 | 1.6 | 1.6 | **38.5** |
| Ntcheu | % of District Sample | 36.8 | 36.1 | 2.6 | 9.7 | 2.6 | 0.6 | 0.6 | 0.6 | 1.9 | 8.4 | **100** |
| | % of Total Sample | 22.6 | 22.2 | 1.6 | 6.0 | 1.6 | 0.4 | 0.4 | 0.4 | 1.2 | 5.2 | **61.5** |
| **Overall %** | | **31.7** | **32.1** | **6.3** | **15.1** | **3.6** | **0.4** | **0.4** | **0.8** | **2.8** | **6.7** | **100** |

*KEY: PP, Prolonged Precipitation; HIP, High intensity Precipitation; WR, Weathering of Rocks; FCJ, Fracturing, Cracking and Jointing; EQ, Earthquakes; ID, Infrastructure Development; PFM, Poor Farming Methods; WC, Weather Changes.*

### 8.10.1 Level of Education, and Causes of Landslides

The relationship between the level of education attainment and causes was assessed. This was to determine whether formal education increases the understanding of the causes of landslides. The results are presented in **Table 8.14C**. There was a strong correlation between education and level of understanding of landslide (p=0.583), with a strong linear by linear association between the variables. Although there were no significant differences between primary and secondary education (**Table 8.14C**), those with tertiary education were observed to have a better understanding of the causes. They were able to articulate the causes of landslides better than those with primary and secondary education. Therefore, it is suggested that primary and secondary education is inadequate in bringing a better understanding of the scientific explanation of mechanisms generating landslides.

**Table 8.14C: Causes of Landslides, and Level of Education**

| **Education** | **Measurement** | **Causes of landslides** | | | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **pp** | **hp** | **W** | **dn** | **ffj** | **Eq** | **id** | **pf** | **wc** | **Others** | |
| Primary | Within Level of Education | 28.7 | 35.7 | 5.8 | 15.8 | 4.1 | 00 | 00 | 0.6 | 1.8 | 7.6 | 100 |
| | % of Total Sample | 19.4 | 24.2 | 4 | 10.7 | 2.8 | 00 | 00 | 0.4 | 1.2 | 5.2 | 67.9 |
| Secondary | Within Level of Education | 27.8 | 22.2 | 11.1 | 27.8 | 00 | 00 | 00 | 00 | 5.6 | 5.6 | 100 |
| | % of Total Sample | 2.0 | 1.6 | .8 | 2.0 | 00 | 00 | 00 | 00 | 0.4 | 0.4 | 7.1 |
| Tertiary | Within Level of Education | 00 | 50 | 0 | 00 | 00 | 00 | 00 | 00 | 50 | 00 | 100 |
| | % of Total Sample | 00 | 0.4 | 0 | 00 | 00 | 00 | 00 | 00 | 0.4 | 00 | .8 |
| None | Within Level of Education | 42.6 | 24.6 | 6.6 | 9.8 | 3.3 | 1.6 | 1.6 | 1.6 | 3.3 | 4.9 | 100 |
| | % of Total Sample | 10.3 | 6 | 1.6 | 2.4 | 0.8 | 0.4 | 0.4 | 0.4 | 0.8 | 1.2 | 24.2 |
| **Overal %** | | **31.7** | **32.1** | **6.3** | **15.1** | **3.6** | **0.4** | **0.4** | **0.8** | **2.8** | **6.7** | **100** |

***Key**: pp, Prolonged Precipitation; hp, High Intensity Precipitation; w, Weathering of Rocks; dn, Deforestation; ffj, Fracturing, Fissuring and Jointing; eq, Earthquakes; id, Infrastructure Development; pf, Poor Farming Methods; and wc, Changes in Weather Pattern.*

### 8.10.2 Perceived Danger-Prone Areas

In terms of perceived danger-prone areas, 45.5% of the respondents (18% from Rumphi, and 26.7% from Ntcheu) indicated steep slopes as unsuitable for human habitation (**Table 8.15**). Marginal (fragile) lands with slopes greater that $15^0$ ranked second, with 26.7% of which the majority of respondents (24.7%) were from Ntcheu. In Rumphi, danger-prone areas ranged from deforested areas (15.6%), degraded areas (11.5%), and areas with fissured/jointed rocks (13.5%).

The results show increasing awareness of the parts of the slopes which are susceptible to landsliding. The results also demonstrate an understanding of danger-prone areas unsuitable for human habitation. However, despite the existence of this knowledge, the location of settlements and economic activities were in areas which respondents perceived to be susceptible to landslides. For instance, in the Ntchenachena Area, settlements and gardens were located on marginal and fragile land while in the Mvai/Livilivi Areas, gardens were located along the debris path (**Section 8.11, Table 8.4,**

**and Figures 8.2, 8.3, and 8.4**). It should be noted that the location of infrastructure and economic activities (in fragile/marginal areas despite being aware of the danger prone areas) is due to limited land available which is also rugged (**Sections 2.2.1.3, and 2.2.3.5**).

**Table 8.15: Perceived Danger-Prone Areas**

| District | Measurement | Danger-Prone Areas | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Deforested | Degraded | Slopes | Fissured/ jointed Area | Cultivated Marginal | Others | |
| Rumphi | % of District Sample | 15.6 | 11.5 | 50 | 13.5 | 5.2 | 4.2 | 100 |
| | % of Total Sample | 5.9 | 4.3 | 18.8 | 5.1 | 2.0 | 1.6 | 37.6 |
| Ntcheu | % of District Sample | 9.4 | 0.6 | 42.8 | 2.5 | 39.6 | 5.0 | 100 |
| | % of Total Sample | 5.9 | 0.4 | 26.7 | 1.6 | 24.7 | 3.1 | 62.4 |
| **Overall %** | | **11.8** | **4.7** | **45.5** | **6.7** | **26.7** | **4.7** | **100** |

## 8.11 Impacts of Landslides

Landslides become a hazard where or when they cause damage to property and death to human beings and livestock (Crozier, 1984; Alexander, 1993; and Knapen et al., 2006). The damage caused also determines how human beings adjust to the changing environment. Questions were asked to assess the impacts of landslides, and the results are presented in **Table 8.16**. Significant differences were observed between the districts (p=0.00), with strong linear by association association of p=0.087. Generally, the most devastating impacts were loss of crops (37.3%), and destruction of farmland (25.8%).

In the Rumphi District, human fatalities (17.6%) were also among the important impacts. It was reported that four people died in the Ntchenachena Area. In Ntcheu District, landslides destroyed graveyards and exhumed dead bodies. These are social and psychological problems to the affected individuals and go with trauma, and require a lot of time and counseling to heal.

In the Ntcheu District, the destruction of houses was also observed as a problem (11.4%). The destruction of houses, though not ranked highly (**Table 8.16**), was a problem to individuals affected. Those who had their houses destroyed had to think of resources and time to construct new houses. Time was spent in searching for food through low paying piece work. This worsened food shortage as households had limited or no time to cultivate in their own gardens. It should also be noted that houses are mostly constructed of mud and unburnt bricks which makes it difficult to undertake construction during the rainy season; hence, the affected households lacked decent accommodation (**Figure, 8.2**).

Figure 8.2: **Remains of the abandoned settlement at Mwachumba Village at Ntchenachena after the 2003 landslides. Note the material of material used which increased the risk of failure (29.08.06).**

In the Ntchenachena Area, loss of livestock (11.8%), and destruction of property (17.6%), were high due to the location of settlements which are on steep slopes or along debris path. This impacted negatively on the livelihoods of the people, and probably worsened the poverty situation as explained in **Section 8.1.4.**

**Table 8.16: Impact of Landslides**

| District | Measurement | Impacts | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DH | IP | LL | LC | DFL | DI | F | DP | Others | |
| Rumphi | % of District Sample | 4.9 | 12.7 | 11.8 | 25.5 | 14.7 | 9.8 | 2 | 17.6 | 1.0 | **100** |
| | % of Total Sample | 1.9 | 5.0 | 4.6 | 10 | 5.8 | 3.8 | 0.8 | 6.9 | 0.4 | **39.2** |
| Ntcheu | % of District Sample | 11.4 | 00 | 1.3 | 44.9 | 32.9 | 3.2 | 5.1 | 00 | 1.3 | **100** |
| | % of Total Sample | 6.9 | 00 | 0.8 | 27.3 | 20 | 1.9 | 3.1 | 00 | 0.8 | **60.8** |
| **Overall %** | | **8.8** | **5** | **5.4** | **37.3** | **25.8** | **5.8** | **3.8** | **6.9** | **1.2** | **100** |

***KEY:*** *DH= Destruction of Houses; IP= Injuries to People; LL= Loss of Livestock; LC= Loss of Crops; DFL= Destruction of Farmland; DI= Destruction of Infrastructure; F= Flooding; DP= Death of People*

There were also significant differences in the crops affected between the districts (p=0.00), with linear by linear association (p=0.028) between the districts. The differences between the districts arise from the differences in the staple foods. More damage was caused to the maize crop than to cassava in the Ntcheu District, as compared to the Rumphi District (**Table, 8.17**). However, in both districts the staple food was affected, which impacted negatively on the people's livelihoods. Since the majority of the people had no source of income (**Table 8.2B**), the destruction of staple foods meant a further worsening of the poverty situation.

**Table 8.17: Damage Caused to Crops by the Landslides**

| District | Measurement | Crops Affected | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | maize | cassava | Sweet potatoes | Iris Potatoes | Beans | Coffee | Others | |
| Rumphi | % of District Sample | 40.6 | 28.7 | 10.9 | 2.0 | 10.9 | 2.0 | 5.0 | 100 |
| | % of Total Sample | 16.2 | 11.5 | 4.3 | 0.8 | 4.3 | 0.8 | 2.0 | 39.9 |
| Ntcheu | % of District Sample | 60.5 | 4.6 | 3.3 | 3.3 | 11.2 | 0.7 | 16.4 | 100 |
| | % of Total Sample | 36.4 | 2.8 | 2.0 | 2.0 | 6.7 | 0.4 | 9.9 | 60.1 |
| **Overall %** | | **52.6** | **14.2** | **6.3** | **2.8** | **11.1** | **1.2** | **11.9** | **100** |

No significant differences were observed between the two districts in terms of destruction to farmland (p=0.162), with a linear by linear association of p=0.028. A total of 42% of the respondents lost more than one hectare of farmland (19.7% from Rumphi, and 22.3% from Ntcheu). Only 10.9% of the respondents lost less than a quarter of a hectare, 25.8%, half of a hectare, and 21.4% one hectare (**Table 8.18**). The damage was assumed to be high, considering that the average farm size is 0.5ha at national level (NSO, 1998; and Slater and Tsoka, 2006). The damage to crops and farmland was high because landslides occurred in rural agricultural areas, and that crops were being grown in marginal or fragile areas, as discussed in **Section 8.10.2**. Degraded marginal land along the Mpira River in the Ntcheu District is clearly observable in **Figure 8.3**. In the Ntchenachena Area, the degradation of farmland is still continuing as shown in **Figure 8.4**.

**Table 8.18: Damage Caused to Cropland**

| District | Measurement | Size of crop Area Affected (Hectares) | | | | Total |
|---|---|---|---|---|---|---|
| | | < ¼ Ha | ½ Ha | 1Ha | >1Ha | |
| Rumphi | % of District Sample | 6.5 | 22.6 | 22.6 | 48.4 | 100 |
| | % of Total Sample | 2.6 | 9.2 | 9.2 | 19.7 | 40.6 |
| Ntcheu | % of District Sample | 14 | 27.9 | 20.6 | 37.5 | 100 |
| | % of Total Sample | 8.3 | 16.6 | 12.2 | 22.3 | 59.4 |
| **Overall %** | | **10.9** | **25.7** | **21.4** | **42** | **100** |

Figure 8.3: **Degraded agricultural land along the Mpira River, Mvai Catchment, caused by the boulders deposited by the 2003 Landslides (2.08.06).**

Figure 8.4: **Destruction of agricultural land in the Ntchenachena Area. On both sides of the cassava field, scars can be seen. The edges are still collapsing, thereby reducing the area of land available for cultivation (26.08.06).**

### 8.12 Action Taken During and After the Landslides, and External Support to the Victims

Differences were also observed in the action taken by the respondents (**Table 8.19**). Action taken during and after the landslide events varied (p=0.00), with no linear by linear association between the district (p=0.002). Those with houses on the debris path had to move to safer ground although most of the households returned after the landslides. A total of 49% of the respondents (24.3% from Rumphi, and 24.8% from Ntcheu) indicated that they moved to safer ground, of which 47% of the respondents indicated returned to their homes. Only 2% relocated themselves permanently to new areas.

Several studies have shown that during natural disasters such as floods and landslides, people would move voluntarily to safer ground only to return after the waters have subsided. Such cases are common along the lakeshore areas, the Songwe Flood Plain and the Lower Shire Plain (Slater and Tsoka, 2006; and Msilimba and Jimu, 2006). People believe that such events are one of those misfortunes which rarely happen. However, their continued stay in such fragile areas, degrades the land further, thereby increasing their vulnerability to natural disasters.

Up to 43.6% of the respondents (33.2% within Ntcheu, and 10.4% within Rumphi), replanted crops when water had subsided, built new houses, opened new gardens, and sold honey to buy food.

**Table 8.19: Action Taken During and After the Landslides**

| District | Measurement | Action Taken | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Moved to safer ground | Injured taken to hospital | Relocated | NGOs provide Assistance | Others | |
| Rumphi | % of District Sample | 57.6 | 3.5 | 4.7 | 9.4 | 24.7 | 100 |
| | % of Total Sample | 24.3 | 1.5 | 2.0 | 4.0 | 10.4 | 42.1 |
| Ntcheu | % of District Sample | 42.7 | 00 | 00 | 00 | 57.3 | 100 |
| | % of Total Sample | 24.8 | 00 | 00 | 00 | 33.2 | 57.9 |
| **Overall %** | | **49** | **1.5** | **2.0** | **4.0** | **43.6** | **100** |

Although some households (only 76.1% from the Rumphi District) received aid from the NGOs, the waiting period was excessive. Only 4.8% of the beneficiaries received aid after one day; 14% after one week; 14.6% after two weeks; 6.8% after three weeks; and 59.3% after one month or more. Those who got assistance (**Table 8.20**) indicated that food was the most important form of assistance (58.5%). Twenty-three percent indicated blankets, buckets, cups, water containers, clothes, and tents. The Government did not provide any form of assistance in any of the areas despite carrying out an assessment of the damage. Lack of Government support probably worsened the poverty situation, considering that these are rural poor people with no steady source of income (**Table 8.2B**).

**Table 8.20: Assistance Provided by NGOs**

| District | Measurement | Assistance | | | | Total |
|---|---|---|---|---|---|---|
| | | Food | Relocation | Nothing | Others | |
| Rumphi | % of District Sample | 58.5 | 8.5 | 9.8 | 23.2 | 100 |
| | % of Total Sample | 58.5 | 8.5 | 9.8 | 23.2 | 100 |
| Ntcheu | % of District Sample | 00 | 00 | 00 | 00 | 00 |
| | % of Total Sample | 00 | 00 | 00 | 00 | 00 |
| **Overall %** | | **58.5** | **8.5** | **9.8** | **23.2** | **100** |

### 8.13 Landslides Occurrences and Coping Strategies

When natural disasters such as landslides occur and affect sources of livelihood, human beings devise new strategies to survive in such environments (Crozier, 1984; and Homewood, 2005). Such strategies (environmental adaptations and processes), may include changes in land-use practices, technological innovations, and economic diversification that reduce the impacts (Batterbury and Forsyth, 1999). Various coping strategies adopted are presented in **Table 8.21**. Significant differences were observed between the districts (p=0.00), with no linear by linear association (p=0.00). The difference arose from the fact that aid was only provided to the people of Rumphi. Most of people in the Rumphi District (76.1%) relied on aid from the Anglican Church and the Livingstonia Synod.

From the analysis of the results, only 7 respondents representing 2.7% of the total sample (all from the Ntcheu District) indicated replanting crops. The results (**Table 8.21**) show that 97.3% of the respondents lost trust in replanting. They were not sure whether landslides would recur or not. Studies have shown that rural people will wait before venturing into any economic activity to minimise risks (Mwafongo, 1996; and Homewood, 2005). Few people resorted to selling household property (0.4% Rumphi and 1.8% Ntcheu). Therefore, the study asserts that these poor households have very limited durable assets and livestock which they can sell in times of disaster. This was also reflected in the small number of respondents managing to buy food (0.9% in Rumphi and 0.95 in Ntcheu District). This also underscores the argument that the majority of the households were poor with no steady source of income (**Section 8.1.4, and Table 8.2B**).

The above situation compelled most of the households to seek external assistance which the Government failed to provide. Up to 61% of all the households (88.8% within Ntcheu, and 20% within Rumphi) survived by doing piece work at the Ntcheu District Headquarters or the Livingstonia Mission Station. In the Ntcheu District, people were obliged to brew and sell local beer, and to weave baskets and mats which they exchanged for food from as far away as Mozambique. In Malawi, poverty is predominantly rural and is manifested by low incomes, temporary housing, subsistence farming, and perpetual engagement in low paying piece work, locally known as Ganyu (Slater and Tsoka, 2006). Studies have shown that the poorest rural households only derive 9% of their total household consumption from Ganyu (Homewood, 2005; and Slater and Tsoka, 2006) which is not significant to off-set the impacts of landslides. Therefore, although people of Ntcheu were involved in low paying piece work, their poverty situation did not improve significantly.

**Table 8.21: Coping Strategies Adopted After the Landslides**

| **District** | **Measurement** | **Coping Strategies After the Events** | | | | | **Total** |
|---|---|---|---|---|---|---|---|
| | | **Replanted Crops** | **Sold Household Property** | **Bought Food** | **Food Aid from NGOs** | **Others** | |
| Rumphi | % of District Sample | 00 | 1.1 | 2.2 | 76.1 | 20.7 | 100 |
| | % of Total Sample | 00 | 0.4 | 0.9 | 31 | 8.4 | 40.7 |
| Ntcheu | % of District Sample | 4.5 | 3.0 | 1.5 | 2.2 | 88.8 | 100 |
| | % of Total Sample | 2.7 | 1.8 | 0.9 | 1.3 | 52.7 | 59.3 |
| **Overall %** | | **2.7** | **2.2** | **1.8** | **32.3** | **61.1** | **100** |

## 8.14 Measures Taken to Combat Landslides

Measures taken to combat landslides are central to the mitigation of their impacts. The perceived measures provided by the respondents are given in **Table 8.22**. The results show that measures which have been taken varied from one area to another (p=0.017), but with a linear by linear association of p=0.467. Up to 20.9% of the respondents (10.2% from Rumphi, and 10.7% from Ntcheu), indicated carrying out afforestation programmes although that was not observed in the Ntcheu District. Even in the Ntchenachena Area of the Rumphi District, only a small patch had evidence of afforestation. Thirteen percent of the respondents (12% Ntcheu, and 1% Rumphi), indicated abandoning cultivation on marginal land, while 59.6% (25.8% Rumphi, and 33.8% Ntcheu) indicated that no measures have been taken to address the problem. These findings are similar to studies carried out elsewhere in Malawi (Gondwe and Govati, 1991; Chipili and Mshali, 1989; Dolozi and Kaufulu., 1992; Poschinger et al., 1998; and Msilimba and Holmes, 2005). The results from these studies have shown that once the impacts of natural disasters have been reduced, little or nothing is done to rehabilitate the unstable slopes by the local people themselves.

The indifference to carryout mitigation measures was partly due to lack of resources, and partly due to the fact that some mitigation measures were in conflict with their production systems. For instance, in the Ntchenachena Area (Rumphi District), in areas where pine trees were planted by the Malawi Social Action Fund (MASAF), local people destroyed them deliberately (**Figure 8.5**). The people have come to realize that pine trees provide good habitat for monkeys which destroy their crops, especially maize and cassava. The efforts by MASAF were seen as affecting negatively their source of livelihood which is agriculture. Furthermore, cultivation on marginal lands is continuing because flat areas are limited and abandoning cultivation on such areas will create land shortage problem. Therefore, mitigation measures need to address the problem of land if the people are to abandon cultivation on steep slopes. In addition, a clear understanding of local people's production systems is crucial to the successful implementation of mitigation measures.

Figure 8.5: **Deliberate destruction of pine trees planted by MASAF in the Ntchenachena Area by arson, thereby increasing the probability of slope failure (29.08.06).**

**Table 8.22: Measures Taken to Combat Landslides**

| District | Measurement | Measures Taken | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Afforestation | Avoiding Cultivating on Marginal land | Relocation of Settlements | Proper sitting of Settlements | Others | |
| Rumphi | % of District Sample | 25.3 | 4.4 | 5.5 | 1.1 | 63.7 | 100 |
| | % of Total Sample | 10.2 | 1.8 | 2.2 | 0.4 | 25.8 | 40.4 |
| Ntcheu | % of District Sample | 17.9 | 20.1 | 3.7 | 1.5 | 56.7 | 100 |
| | % of Total Sample | 10.7 | 12 | 2.2 | 0.9 | 33.8 | 59.6 |
| **Overall %** | | **20.9** | **13.8** | **4.4** | **1.3** | **59** | **100** |

## 8.15 Slope Stability Management, and Government/NGOs Perceived Roles

The question of whose responsibility the maintenance of slope stability is, was asked to determine the cause of people's unwillingness to rehabilitate, protect and manage the degraded areas. The results are presented in **Table 8.23**. There were significant differences observed between the two districts (p=0.000), with no linear association (p=0.000). Forty-seven percent of the respondents strongly believe that the management of the slopes lies in the hands of the local people, of which 40.3% were from Ntcheu. Up to 37% of the respondents believe that the role of managing slopes is with the Government, of which 22.9% were from Rumphi. The results also show that 10.3% of the respondents, of which 8.7% were from Rumphi, believe that the local chiefs have the responsibility of mobilising their subjects to do community work.

Therefore, it can be concluded that in the Ntcheu District, people were/are willing to carry out the rehabilitation of the slopes themselves rather than waiting for external support. This is crucial in community based natural resources management where local people's participation is at the centre of successful implementation of projects. By way of contrast, people within the Ntchenachena Area of Rumphi District depend more on external support. This could possibly be due to the histories of the areas. Some of the people in the Ntchenachena Area, as it has already been noted, were evicted from Nyika National Park in 1974, and they are still waiting for the day they will return to their original home while people in the Ntcheu District live on their ancestral land which gives them security to invest on the land. The people also believe that the Government is reluctant to rehabilitate the Ntchenachena Area because it will be seen as endorsing the presence of the Phokas in this area. Therefore, the rehabilitation of the Ntchenachena Hills requires a political solution to the problem of eviction.

**Table 8.23: Responsibility for Slope Stability**

| District | Measurement | Whose Responsibility | | | | Total |
|---|---|---|---|---|---|---|
| | | Local People | Government | NGOs | Others | |
| Rumphi | % of District Sample | 17.5 | 59.8 | 00 | 22.7 | 100 |
| | % of Total Sample | 6.7 | 22.9 | 00 | 8.7 | 38.3 |
| Ntcheu | % of District District | 65.4 | 24.4 | 7.7 | 2.6 | 100 |
| | % of Total Sample | 40.3 | 15 | 4.7 | 1.6 | 61.7 |
| **Overall %** | | **47** | **37.9** | **4.7** | **10.3** | **100** |

In order to mitigate the impacts of landslides, the households were asked what they perceive as the roles to be played by the Central Government and Non-Governmental Organizations (NGOs). The results have been summarised in **Table 8.24**. Significant differences were observed between the districts (p=0.00), with no linear by linear association (p=0.000). Most of the respondents (51%) indicated that the Government and the NGOs should promote the rehabilitation of degraded and deforested slopes by providing tree seedlings (26.3% from Rumphi, and 25.5% from Ntcheu). In general, the measures suggested ranged from launching awareness campaigns on landslide hazard areas and the dangers of deforestation (11.6%; 6.2% Ntcheu, and 4.9% Rumphi); through to the introduction of village housing schemes to replacing of temporary traditional houses (14.8%: 11.9% Ntcheu, and 2.9% Rumphi). Out of all the respondents, 17.3% (15.6% Ntcheu, and 1.6% Rumphi) suggested that the Government and NGOs should provide farm inputs, provide food aid, rehabilitate damaged infrastructure such as bridges and water supply pipes, introduce agricultural extension services, introduce food for work programmes, arrest charcoal burners and sellers, and introduce income generating activities. Some people in the Ntchenachena Area still want the Central Government to allow them to return to the Nyika National Park from where they were evicted in 1974. The diversity in suggested actions simply shows the complexity in the management of the slope stability problems. However, it also shows the realisation within communities of the importance of fixing the problem, and that it requires participation by all stakeholders.

Therefore, considering the levels of poverty and education attainment, it is suggested that the local people require external support from the Government and NGOs. However, the participation of external partners needs to follow a bottom-up approach. This comes from the background that governments and NGOs have been criticized as authoritarian, paternalistic and non-democratic, and that they hinder active community participation in environmental conservation (Perlman, 1994).

It is also suggested that addressing poverty is central to the management and rehabilitation of the environment. Respondents believed that charcoal burning and engagement into low paying jobs are a function of poverty. If income generating activities could be introduced, the people would be economically empowered. This may be an incentive to those involved in charcoal and fuelwood selling to abandon the malpractice. Community management of the Mvai/Livilivi Forest Reserves, if advocated, could address the problem of deforestation. It should be noted that, although these Forest Reserves are located on people's ancestral land, they (i.e. the people) have no access to forest resources.

**Table 8.24: Expected of Government and Non-Governmental Organisations**

| District | Measurement | Expected Roles | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Provide Seedlings | Awareness Campaigns | Provide Building Standards | Introduce Housing Schemes | Relocating Settlements | Others | |
| Rumphi | % of District Sample | 68.1 | 12.8 | 3.2 | 7.4 | 4.3 | 4.3 | 100 |
| | % of Total Sample | 26.3 | 4.9 | 1.2 | 2.9 | 1.6 | 1.6 | 38.7 |
| Ntcheu | % of District Sample | 41.6 | 10.1 | 3.4 | 19.5 | 00 | 25.5 | 100 |
| | % of Total Sample | 25.5 | 6.2 | 2.1 | 11.9 | 00 | 15.6 | 61.3 |
| **Overall %** | | **51.9** | **11.1** | **3.3** | **14.8** | **1.6** | **17.3** | **100** |

## 8.16 Gender Perspective on the Occurrence of Landslides

Using the natural environment and protecting it, directly involves many social groups, of which women are part (Crowfoot and Wondolleck, 1990). Therefore, the achievement of environmental protection and management requires common values among all groups and participation by all the stakeholders. This underlines the importance of collaboration between men and women in the protection of the environment. However, in most cases women have been marginalised and treated as being without knowledge compared to their male counter-parts (Lindsey, 1996). It should be noted that despite their marginalization in various spheres of life, women constitute the largest proportion of the world's population (NEAP, 1998; KIT, 2002; and Homewood, 2005). Similarly, in this study, the proportion of women in the population was greater than that of men (**Section 8.1**).

This study, therefore, realises that the relationship between the people and the environment is not gender-neutral; and that the position and concerns of women have been invisible in the environmental debates and programmes; and that at the heart of the re-organisation of communities, is the acknowledgement that women manage the environment and sustain communities (Patel, 1994; Harford and Leonard, 2001; KIT, 2002; and Buhl, 2005).

### 8.16.1 Gender and Knowledge of Past Landslides

In terms of knowledge of past landslides, gender did not affect the knowledge of landslides (p=0.269). Both sexes were fully aware of the past landslides. A total of 97% of male respondents and 98% of females, had knowledge of when the landslides occurred, general weather conditions prior to the landslides, causes and contributing factors (**Table 8.25A**), and danger-prone areas. This is contrary to the widely accepted view that men are more aware of environmental issues than women (Patel, 1994; Malunda and Mpinganjira, 2004; and 2001; and Homewood, 2005). During field investigations, it was observed that women interacted with the environment through cultivation, fetching water and fuel wood, and collecting forest products. It is through such interactions that women develop environmental awareness and knowledge. It is this awareness that is critical in natural resources management.

A total of 24.16% of male respondents and 38.6% of females believe that prolonged precipitation caused landslides. Up to 34.16% of males and 30.30% females indicated high intensity precipitation as the cause. Both sexes believe that land degradation, poor farming methods, and changes in weather patterns contributed to slope failures.

**Table 8.25A: Gender and Causes of Landslides**

| **Causes of Landslides** | **Gender** | | **Total %** |
|---|---|---|---|
| | **Males %** | **Females %** | |
| Prolonged precipitation | 24.16 | 38.6 | 31.74 |
| High Intensity Precipitation | 34.16 | 30.3 | 32.14 |
| Weathering of Rocks | 7.5 | 5.30 | 6.34 |
| Deforestation | 17.5 | 12.8 | 15.07 |
| Fracturing, Jointing and Fissuring | 4.16 | 3.03 | 3.57 |
| Earthquakes | 00 | 0.75 | 0.39 |
| Poor Farming Methods | 0.83 | 0.75 | 0.79 |
| Infrastructure Development | 00 | 0.75 | 0.39 |
| Changes in Weather patterns | 3.33 | 2.27 | 2.77 |
| Others | 8.33 | 5.30 | 6.74 |
| **Total %** | **100** | **100** | **100** |

In terms of action taken during and after the landslides, there were significant differences between the groups (p=0.002). As shown in **Table 8.25B**, the majority of men, (60%) indicated moving to safer ground as the first priority, compared to 38% of females. The majority of women (54%), compared to 31.4% for men, indicated that they replanted crops, built new homes, opened new gardens, and participated in income generating activities. No assistance from the Government was acknowledged by both genders**.** Since studies have shown that women bear the highest costs of the environmental crises because of their roles in providing water, food and energy at family level (CSE, 1985; and KIT, 2002), lack of Government support and intervention probably worsened their poverty and increased their workload.

**Table 8.25B: Gender and Action Take During and After the Lanslides**

| **Gender** | **Action taken** | | | | | | **Total %** |
|---|---|---|---|---|---|---|---|
| | **Moved to safer ground** | **Injured taken to hospital** | **Government Assistance** | **Relocated** | **NGOs Assisted** | **Others** | |
| Males % | 60 | 1 | 0 | 3 | 4 | 31.6 | 49 |
| Females % | 38 | 2 | 0 | 1 | 4 | 54 | 51 |
| **Overall %** | **49** | **1** | **0** | **2** | **4** | **43.56** | **100** |

In terms of expected roles, both sexes realised the importance of rehabilitating degraded slopes through afforestation. Up to 60% of males and 40% of females were for afforestation. The figure for women is lower compared to that of men because in most cases, women are concerned with the immediate needs of the family such as food availability (Talle, 1988; Sikana et al., 1993; and Hodgson, 2000). Similar results were found among the Fulbe women of the Sahel Region (Buhl, 2005). However, by mentioning tree planting, it underscores the fact that both sexes are aware that deforestation contributes to slope instability; hence, the need to involve both sexes in the rehabilitation and protection of susceptible and degraded slopes.

The results of the comparisons of expected roles by the Government and NGOs and gender are presented in **Table 8.25C.** These show variations in the responses between sexes. Although both sexes agree on afforestation (65% males and 40% females), more women (25% as opposed to 4%) were for the introduction of village housing schemes. It was found that 22% of the women were for the introduction of income generating activities, involvement in the management of forests, provision of farm inputs and introduction of food for work programmes and food aid. However, 12% of the men wanted the NGOs/Government to rehabilitate damaged infrastructure, and to allow the people to return to the Nyika Plateau.

**Table 8.25C: Gender and Expected Roles by Government and Non Governmental Organisations**

| Gender | Expected Roles | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | Afforestation | Building Standards | Housing Schemes | Relocating Villages | Awareness Campaigns | Others | |
| Males % | 65 | 4.0 | 4.0 | 3.0 | 13 | 12 | 47 |
| Females % | 40 | 3.0 | 25 | 1.0 | 9.0 | 22 | 53 |
| **Overall %** | **52** | **3.0** | **15** | **2.0** | **11** | **17** | **100** |

Consequently, it can be concluded that environmental management of the unstable slopes can greatly be improved if the decisions are made from the analysis of gender perceptions. This is because women are involved in environmental management on a daily basis, (as already noted), and although they are excluded from community and high level formal decision-making processes (Perlman, 1994). Therefore, a system needs to be designed to build up women's capacities and create conditions which will promote women's involvement in environmental management.

## 8.17 General Synthesis

### 8.17.1 Vulnerability of Society to Landslides

The previous sections have demonstrated the role of traditional knowledge in explaining the occurrence of landslides. The sections also demonstrated local people's vulnerability to landslides which worsens the poverty situation. The objective of this Section is to discuss the factors that have contributed to the people's vulnerability to landslides. The factors will be discussed under the following sub-sections: low incomes, location of settlements, production systems and land-use, and government policy.

#### 8.17.1.1 Low Incomes

Factors increasing the vulnerability of societies to landslides are given in **Section 3.8.1,** and are also discussed by Crozier (1984), and Slater and Tsoka (2006). The analyses of socio-demographic data revealed that the majority of the people were poor, with only 13.8% receiving a monthly income. Similar results are given by Slater and Tsoka (2006) for the same districts.

Low incomes, coupled with low education attained, have resulted in unsustainable and inappropriate farming methods which continue to degrade fragile lands further. It was observed in the Ntchenachena Area that cultivation was done on steep slopes without appropriate land husbandry practices. In the Mvai, the Livilivi and the Chiweta Areas, deforestation was attributed to poverty. Such activities increase the likelihood of slope failure, and increase vulnerability to landslides. In most developing countries economic factors have been observed to increase the vulnerability of rural communities to landslides (Alcantara-Ayala, 2002; and Guinau, 2005). It is, therefore, suggested that poverty in all the areas, among other things, reduces society's resilience to natural disasters such as landslides.

#### 8.17.1.2 Location of Settlements

In both districts, the location of settlements increased the societies' vulnerability to landslides. Most of the settlements were located on areas susceptible to failure (**Figures 8.6 and 8.7**). The Ntchenachena Area is located in a very rugged topography, with interlocking spurs (**Section 2.2.1.3**). Flat areas are absent, except along the Mzinga River. Two recent waves of migration into the area (in 1974 and 1992/3) increased land pressure and demand for resources. The settlement activities have contributed to instability in four ways:

(a) Water supply channels common in this area were noted to contribute to high infiltration, slope loading and high pore pressure. In some areas where the channels pass through, liquefaction was common. Similar results were observed in the Vunguvungu/Banga Catchments in Northern Malawi which is adjacent to the Ntchenachena Area (Msilimba, 2002; and Msilimba and Holmes, 2005).

(b) Settlements on steep slopes increased the load on the highly weathered basement, thereby altering the balance of forces operating on the slope. Similar effects were observed by Knapen et al (2006) in Mount Elgon, Uganda.

(c) Slope remodelling for settlement activity and agriculture increased slope angles and possibly contributed to rapid infiltration in some areas where compaction had not taken place.

(d) Finally, settlement activity, hunting, and agriculture contributed to the destruction of vegetation which provides mechanical binding to soil particles and reduce pore pressure through evaporative losses.

By way of constrast, areas outside the Mvai/Livilivi Catchments are not nearly as rugged as is the case with the Ntchenachena Area. The soils are stony which makes cultivation difficult and also reduces the area for cultivation. The only areas where alluvial soils are located are along the river banks. However, when landslides occur and cause flooding, crops are washed away. Even settlements close to the river banks are threatened. It should be noted that settlement activities and poverty have contributed to deforestation taking place within the catchments, thereby increasing the likelihood of slope failures. Furthermore, cultivation along river banks has resulted in the destruction of riparian vegetation, thereby increasing the frequency and magnitude of floods.

Figure 8.6: **Houses located in a floodplain along the Mzinga River in the Ntchenachena Area. This is the Area which was flooded during the 2003 Landslide (25.08.06).**

Figure 8.7: **A settlement located at the foot of Mankhorongo Hill. Note the landslide scar above the settlement, an indication of slope instability (25.08.06).**

#### 8.17.1.3 Production Systems and Land-Use

In both areas, poor households own limited assets and rely on very limited land. In the Ntcheu District, the cultivation along the Livilivi and the Mpira Rivers has resulted in the destruction of the riparian vegetation which offers resistance to the river banks. This has contributed to banks collapsing, thereby destroying crops. When banks burst, houses on relatively higher ground get affected. The situation is compounded by deforestation in the forest reserves (Abbot, 2005) which has contributed to increased run-off. Deforestation is due to the high demand for fuel wood and charcoal and high levels of poverty. All the landslides in the Ntcheu District occurred in deforested areas as observed in **Chapters 6** and **7**. Numerous rock falls have also been associated with deforestation, and this puts settlements along boulder paths in extreme danger.

In the Rumphi District, the cultivation on steep slopes increases the likelihood of landslides. It was observed that cultivation on such areas was done without appropriate controlling measures. Worse still, cultivation increases infiltration as observed in **Chapter 7,** and which in turn increases weight of the slope (Butler, 1976; Crozier, 1984; Alexander, 1993; and Ingaga et al., 2001). This increases the force of gravity as shown in **Section 3.6**. This was also observed in Uganda by Knapen et al (2006). Unlike in the Ntcheu District, people of the Ntchenachena Area depend on cassava as their staple food (**Figure 7.5**). Cassava has low root density, shallow roots, and low evaporative losses, and contributes to rapid infiltration through cracking of the soil (Msilimba, 2002). This increases the likelihood of failure, thereby increasing the vulnerability of people to landslides.

Some people within the Ntchenachena Area continue to practise hunting of wild animals. The use of fire to drive out animals destroys the remaining shrubs which offer some stability to slopes. This was also observed to be a serious problem in the VBCA adjacent to the Ntchenachena Study Area (Msilimba, 2002). In addition, overgrazing by goats, poses a threat to the remaining shrubs in the river valleys (**Figure 7.12**). The destruction of shrubs and grasses along the Lutowo, the Chikwezga, and the Mzinga Rivers has resulted in bank collapse (**Figure 6.12**) as is the case with Mpira and Livilivi Rivers in Ntcheu. During the 2003 landslides, most of the crops which were damaged were grown along these rivers.

### 8.17.1.4 Government Policy

The majority of people in the Ntchenachena and the Mvai/Livilivi Areas believe that the Government is responsible for slope stability problems (**Table 8.23**). In Malawi, slope susceptibility mapping is yet to be carried out by the Geological Survey Department. Furthermore, the Government is yet to commission studies which will assess the stability status of the Ntchenachena and Mvai/Livilivi Areas after the 2003 devastating landslides. Until the conditions of the slopes are known, the risk still remains. After the occurrence of landslides in 2003, no alternative sources of livelihood were provided. Unless alternatives are identified, deforestation in the Mvai/Dzonzi and the Chiweta Forest Reserves and cultivation on marginal lands in the Ntchenachena Area will continue, thereby increasing people's vulnerability to landslides. Failure to enforce laws, for instance not to cultivate on slopes greater than $15^0$ (GoM, 1988), and allowing people to stay on fragile slopes, aggravates the situation.

The Government's failure to address land disputes with those people who were evicted from the Nyika National Park contributes to further degradation of the Ntchenachena Area. Relocation to safer grounds is the most appropriate solution to the problem, but it requires political will. As long as the Government remains silent, degradation will continue, and which will increase the likelihood of slope failure. In turn, this will increase the society's vulnerability to landslide disasters.

### 8.17.2 Knowledge of Landslides

Although the majority of people in the Ntcheu and Rumphi Districts are illiterate or semi-literate (**Section 8.1.3 and Table 8.2A**), they were aware of past landslide events. Through experience and interaction with the environment, they are likely to have developed philosophies, environmental knowledge, and a system of natural resources management. The generations of coping with the environmental conditions are likely to have given them scope for local innovations and adaptations. This argument is well articulated by Brinkcate and Hanvey (1996), Berkes and Folke (1998), Hagos et al (1999), and Fairhead and Scoones, (2005).

Despite high illiteracy levels (**Section 8.13 and Table 8.2A**), and the existence of myths and beliefs (**Section 8.7 and Table 8.13A**), the local people were able to suggest scientific causes and contributing factors to landslides. This underscores the fact that both traditional and scientific knowledge can be integrated to provide a better understanding of landslide occurrences, as explained by Hagos et al (1999). For instance, the weather accounts narrated by the local people are in agreement with the rainfall data obtained from the Central Meteorological Station (**Section 7.2**). This also shows environmental awareness, and how perceptive the local people are to any change taking place in their physical environment. However, the local people will interpret the changes, using their traditional beliefs as explained in **Sections 8.2 and 8.17.3.**

### 8.17.3 Role of Traditional Knowledge

The study has shown that traditional beliefs are deeply rooted in the culture of the people, and they help them explain occurrences. Unless these are understood and incorporated into the body of scientific knowledge, mitigation measures developed will not be accepted by the local people. More often than not, scientists have ignored traditional knowledge in favour of scientific knowledge (Lindsey, 1996; and Homewood, 2005). The local people have been regarded as empty vessels who do not understand their own environment (Malunda and Mpinganjira, 2004; and Homewood, 2005). Each locality is known by its own beliefs and customs, as shown by this study. For instance, as previously mentioned, in the Ntcheu District, people believe in the myth of “Napolo”, while in Rumphi District, people believe in the phenomenon of “Vwira”. It should be noted that the existence of several myths in one area, underscores the complexity and diversity in traditional knowledge. A diversity in the myths narrated by the local people is given below;

‘*That was the end of the world because of sinful nature of mankind similar to the destruction of the earth during Noah’s time”.*

“*People killed a puff adder in the Nyika National Park and that caused the failure of slope. The man was from this area that is why the spirits punished us.*”

“*Some people destroyed the habitat for a puff adder which became angry and resulted in high intensity rainfall”.*

*“During Napolo a big snake leads the way followed by small snakes. The snakes remove stones on their way. In 1949, “Napolo” came twice, but of reduced magnitude”.*

*“Spirits in the form of animals reside deep in the mountain. They reside at the source of the landslide, with heavy rains, they run out of the curves with a lot of water, smoke and*

*noise from drums. These spirits are in the form of cows, snakes. After some time, the return to the mountain cave".*
*"Landslides are caused by ghosts who reside in the mountains".*

The belief that landslides are associated with snakes emanates from the sound of water as it comes from the mountains with high speed, passing between plant logs and boulders. A whistling sound is produced in the process, and that is interpreted as coming from the snake. Channels are created by water which has high energy to erode the surface of the earth which people believe could be the path taken by the snake. The concept of landslides being spirits or ghosts residing in the mountains originates from the sound (similar to that from drums) which is produced by rolling boulders.

In Ntcheu, where the belief of spirits/ghost was dominant, the source was the presence of white clothes along the Mpira River. People believe that the clothes were left by the spirits and ghosts. However, field observations revealed that the clothes were from exhumed graves when water from the Mpira River flooded a grave yard. The steam which was observed might have come from friction between rocks moving at high speed, and the smell could possibly be from decomposing plant and animal matter. However, the elderly maintained the view that landslides were caused by the destruction of the environment and man's sinful nature. They indicated that deforestation and cultivation of mountains as examples of man's disobedience to God; hence, the punishment. In the Ntchenachena Area, the destruction of a habitat of a puff adder causing landslides, underscores the degradation of the environment.

While acknowledging the blending of traditional and scientific knowledge in explaining landslide mechanisms, by and large the scientific approach is the best. Therefore, it can be concluded that the misconceptions explained above can be clarified using scientific knowledge, and this can bring a better understanding of the causes and contributing factors to landsliding. This is also crucial to the formulation of mitigation measures which can reduce their vulnerability to landslides and be accepted by the affected communities.

### 8.17.3.1 Education and Traditional Beliefs

The study failed to establish the correlation between education and traditional beliefs in both areas. Although some people attained basic education, they retained their traditional beliefs on the occurrence of landslides. These people stay in rural environments and each society is known by its culture, traditions, beliefs and myths (Malunda and Mpinganjira, 2004). It should also be appreciated that the majority of them had only attained primary education or were illiterate. This implies that the impact of modernization, through education, was low. Studies have shown that traditions are mostly rooted in the illiterate members of the society (Malunda and Mpinganjira, 2004; Homewood, 2005). Therefore, the promotion of formal education could be an important tool in bridging the gap between traditional and scientific bodies of knowledge, thereby clarifying misconceptions created by traditional beliefs.

## 8.18 Conclusion

The Chapter has shown that traditional beliefs and myths were deeply rooted in the culture of the people and they help them explain landslide occurrences. However, myths were found to be location specific. Level of knowledge about past landslides did not depend on the level of education. Knowledge depended on the period of interaction with the physical environment. However, a better understanding of the causes and contributing factors require scientific knowledge, which the majority of the people were lacking due to the low level of education.

In all the areas, landslides caused extensive damage to crops and farmland and that worsened the povert situation. Production systems increased societies' vulnerability to landslides. A clear understanding of peoples' production system, livelihood sources and traditional beliefs are central to the successful formulation and implementation of mitigation measures.

Despite their marginalisation in various spheres of life, women were equally aware of the causes and contributing factors to landslides. Therefore, their integration in the decision-making process can help in the management of degraded environments. The next Chapter attempts to provide a synthesis of landslide occurrences throughout the country, and geohazard mitigation measures to slope stability problems in all the study areas.

# CHAPTER NINE

# ANALYSIS OF LANDSLIDE STUDIES IN MALAWI AND GEOHAZARD MITIGATION MEASURES

This Chapter attempts to draw the story of landslides in Malawi together in a national context. The purpose is to assess similarities and differences in landslide types and causes, with reference to geographical location. The Chapter also suggests possible mitigation measures (recommendations) for landslide geo-hazards for the Ntchenachena, the Chiweta, the Mvai, and the Livilivi Areas. The mitigation measures are from the analysis of landslide mapping (**Chapter, 6**), causes and contributing factors to landslides (**Chapter 7**), and the role of traditional knowledge in landslide occurrences presented in **Chapter 8**. Although landslides are a hazard in all the areas studied (**Chapter 6**), there is currently little or no national effort to reduce landslide hazard and damage. The only effort at national level was in 1998 through a GTZ/Government joint project in mapping landslide-prone areas in Southern Malawi (Poschinger et al., 1998) which is yet to be concluded. In Malawi, national attention and funding have been deficient to adequately address landslide hazard mapping (NEP, 1996; and NEAP, 1998). This is shown by the lack of funding directed towards landslides or slope stability assessment. However, an effective landslide mitigation programme is important because it addresses emergency management response and may assist in the long-term reduction of landslide impacts.

## 9.1 Analysis of Landslide Occurrences in Malawi

Most of the landslide occurrences in Malawi, including the current study, have been induced by heavy or prolonged precipitation (Gondwe and Govati, 1991; Cheyo, 1999; Msilimba, 2002; and Msilimba and Holmes, 2005). For instance, in Southern Malawi, the 1946 Zomba Mountain and the 1991 Phalombe landslides were induced by heavy precipitation of more than 500mm in two days (Poschinger et al., 1998; and Cheyo, 1999). This is also true for the 1989 Manyani Hill Landslide in Central Malawi, and the 1997 Banga landslides in Northern Malawi (Dolozi and Kaufulu, 1992; Msilimba, 2002; and Msilimba and Holmes, 2005). Regardless of regions, landslides occurrences in Malawi have been in areas with high rainfall - typical of tropical areas subjected to cyclonic rainfall and towards the end of the rainy season. This observation suggests that sufficient antecedent rainfall is necessary to bring the regolith up to field capacity such that rainfall may produce positive pore pressure, and trigger landslides. Although the significance of rainfall thresholds in triggering landslides has not been assessed in Malawi, several authors have demonstrated the importance of seasonal threshold in triggering landslides (Wieczorek, 1987; Larsen and Simon, 1993; and Mathias and Weatherly, 2003). What has not been recognised in landslide studies throughout the country are:

(a) The identification of rainfall amounts that lead to landslides which may help mitigate the loss of life and property in rural communities of Malawi where landslides are common.
(b) The development of quantitative models relating to landslide initiation which may provide insight into the process of landslide initiation in various regions of Malawi.
(c) The exploration of how rainstorms trigger landslides is of critical importance in understanding the linkages between anthropogenic and climatic factors. Several authors have demonstrated the significance of this relationship (Keefer et al., 1987; Caine, 1980; Caine and Mool, 1982; Cannon and Ellen, 1985; Larsen and Simon, 1993; and Crozier, 1999).

Although Malawi falls in the Great African Rift Valley System, with considerable tectonic activity (Pike and Rimmington, 1965; Carter and Bennet, 1973; and Dolozi and Kaufulu, 1992)), the country rarely experiences landsides. Therefore, landslide occurrences cannot be attributed to seismic activity. There is insufficient data to suggest that instability is due to earthquakes, except for the 1989 Manyani Hill Landslide in Central Malawi (Dolozi and Kaufulu, 1992). However, within the East African region, earthquake induced landslides have been reported in Uganda and Kenya (Inganga et al., 2001) which gives a high possibility of seismic generated landslides. It should also be noted that limited landslide research has been going on in the country (Msilimba, 2002; and Msilimba and Holmes, 2005) which gives a possibility of earthquake generated landslides passing unnoticed or unstudied. Therefore there is great need to devote efforts to the assessment of future hazards related to seismically induced landslides

Throughout the country, human activities have been observed to prepare slopes for eventual failure (Chilkusa, 1985; Poschinger et al., 1998; and Msilimba, 2002). This is also true for the entire East Africa region (Ngecu and Mathu, 1999; Inganga et al., 2001; and Knapen et al., 2006). For instance, the 1985 Ntonya-Ulumba and the 1991 Phalombe landslides in Southern Malawi were due to deforestation and cultivation on steep slopes (Chikusa, 1985; and Poschinger et al., 1998). Similar observations were made by Dolozi and Kaufulu (1992) on the occurrence of Manyani Hill Landslide in Central Malawi. In Northern Malawi, the 1997 Banga and the 2000 Nyankhowa landslides were attributed to deforestation and cultivation on fragile environments (Msilimba, 2002; and Msilimba and Holmes, 2005). This study has also concluded that the occurrence of landslides in Northern Malawi (Ntchenachena Area) and Central Malawi (Mvai/Livilivi Areas) is due to deforestation and cultivation. It is worthy mentioning that deforestation and cultivation have been noted as serious environmental concerns the country is experiencing (NEP, 1996; NEAP, 1998; and Kasulo, 2005). Therefore, the findings of this study on the occurrence of landslides in Central and Northern Malawi are in agreement with the current land degradation taking place throughout the country.

However the occurrence of landslides in terms of spatial distribution has been noted to decrease southwards. Major landslides have occurred in Southern Malawi between 1946 and 1991. After this period, no major landslides on natural environments have been recorded except for those minor landslides along the Kuchawe Road (Zomba District) in 1997 and 1999 (Msilimba, 2002). In Central Malawi, minor landslides were recorded in 1975, and 1989 (Dolozi and Kaufulu, 1992). In Northern Malawi, landslides occurrence is a new phenomenon with major events occurring in 1997 in the Banga Area of Rumphi District (Msilimba, 2002; and Msilimba and Holmes, 2005)). Landslide intensity has increased in recent years in this region with nine landslides mapped in 2002 (Msilimba 2002; and Msilimba and Holmes, 2005) and 98 landslides recorded in this study. An increase has been observed by this study in Ntcheu District of Central Malawi, with 33 landslides.

The reasons for the spatial distribution between regions are different. Southern Malawi experienced rapid population growth and deforestation during the period of colonisation and early years of independence (Pike, 1968) which accelerated the rate of degradation, and put most of the slopes into marginally stable or active unstable state. This resulted in numerous landslides in Southern Malawi. In contrast, during the same period, Northern Malawi registered low deforestation due to small population and few tobacco estates. Currently, Northern Malawi is experiencing more rapid deforestation than any other region (Kasulo, 2005) and this corresponds with the increasing number of landslides in the region. Although Central Malawi experienced rapid deforestation soon after independence in 1964 as a result of the establishment of estates (Mwafongo, 1996), few landslides of low magnitude have occurred. This area is dominated by plain areas which are low energy terrains as is the case with Southern and Northern Malawi (Lister, 1967; and Agnew, 1972). Major high plateau areas are also located in Southern and Northern Malawi, and they receive high precipitation of over 1300mm/year while much of Central Malawi is drier, with annual precipitation of less than 900mm (Pike and Rimmington, 1965; Linceham, 1972; and Agnew and Stubbs, 1972). Exceptional to this are the Mvai and Livilivi Mountains in Central Malawi which form part of the Dzonzi Forest Reserve.

The increase in landslide occurrence in these areas - which are moderately high energy terrain - is due to human encroachment and deforestation taking place as was observed by this study. Therefore, it is suggested that most of the slopes of Southern Malawi had already experienced failure while most of the slopes of Northern Malawi are currently experiencing degradation which has put them in an active unstable state. For Central Malawi, the topography is generally flat and not conducive for landslide occurrence, except for isolated inselbergs in the Lilongwe-Kasungu and Mchinji Plains (Dixey, 1926; and Lister, 1967). However, in all the regions, no studies have been carried out to determine the factor of safety for individual slopes. The factor of safety is critical in slope stability assessment as has been demonstrated by several authors (for example, Jibson et al., 1998; Iwahashi et al., 2001; and Iwahashi et al., 2003).

Marked differences have been observed between the regions in terms of material involved in the movement. In Southern and Central Malawi, the materials involved in the movement have been unweathered metamorphic and igneous rocks of various sizes, together with tree logs (Chikusa, 1985; Gondwe and Govati, 1991; Mshali, 1992; Cheyo, 1998; Poschinger et al., 1998; and Mwenelupembe, 2003). Most of the failures have been in the areas of contact between rock and soil masses. In sharp contrast, landslide occurrences in Northern Malawi have been on highly weathered basement of metamorphic rocks due to rapid chemical rock weathering (Msilimba 2002; and Msilimba and Holmes, 2005).

This explains why the majority of landslides in Southern and Central Malawi are classified as translational or topples/rockfalls while in Northern Malawi most of the landslides are classified as rotational as has been shown by this study. The process of soil liquefaction is much pronounced in Northern Malawi as was observed by Msilimba (2002), and Msilimba and Holmes (2005), and this current study. Rockfalls which have been reported in Northern Malawi, are due to slope cutting at Nyankhowa and Chiweta (Msilimba, 2002). This is in contrast with rockfalls in Southern and Central Malawi, which occur on natural slopes such as Kanjati, Ntonya-Ulumba, Ntcheu Mountain, Nyambilo and Zomba mountains (Chikusa, 1985; Chipili and Mshali, 1989; Chipili, 1997; Poschinger et al., 1998; and Mwenelupembe, 2003).

The differences in the material involved in the movement partly explain the degree of damage caused by landslides. The combination of boulders of varying sizes, together with soil mass and plant logs in Southern and Central Malawi are known to have caused substantial damage to property, and loss of life during the 1946 Zomba Mountain, the 1991 Phalombe and the 2003 Mvai landslides (Gondwe and Govati, 1991; and Poschinger et al., 1998). Although studied landslides in Northern Malawi caused damage, as was observed by Msilimba (2002), Msilimba and Holmes (2005), and this current study, their severity was of lesser magnitude as compared to the landslides in the other regions. For instance, fatal landslides have been reported in Southern Malawi, with a death toll of 21 in 1946 and over 500 in 1991 (Poschinger et al., 1998; and Msilimba, 2002) while in Northern Malawi, reported 4 deaths only in 2003 as has been shown by this study. The high population densities, especially in Southern Malawi (NSO, 1998), also partly account for high death tolls and substantial damage caused by landslides.

In all the regions, landslides are explained by myths which are deeply rooted in the cultures of the people. For instance, local people in Southern Malawi believe that landslides are caused by a snake called "Napolo", as explained in **Section 3.1**, also described by Chikusa, (1985), Gondwe and Govati (1991), and Poschinger et al (1998). This myth is also dominant in the Central Region of Malawi, in particular Ntcheu District which borders with Southern Malawi, as shown in **Chapter 8**. In Northern Malawi, the same concept of "Napolo" exists although with a different name "Vwira". Other traditional beliefs dominant in Central and Northern Malawi have been documented in **Section 8.19.**

Although traditional beliefs explaining landslides occurrence exist throughout the country, no attempts in all the previous studies (exceptional to this study) were made to understand and incorporate them in the existing scientific body of knowledge. Landslide studies in Malawi have, therefore been based on natural sciences ignoring the valuable contribution traditional knowledge can make to the management of the environment as has been shown in **Sections 3.9, 3.9.1, and 3.10.** Misconceptions and misunderstanding of landslide causes and contributing factors still exist in most affected rural communities (**Section 10.1),** a situation which needs to be addressed.

## 9.2 Recommendations - Hazard Mitigation Measures

In this study, hazard mitigation is referred to as the sustainable action that reduces or eliminates long term risk to people and property from natural hazards and their effects. The goal, therefore, is to reduce vulnerability and exposure to landslides. The suggested mitigations are both soft and hard. In this case, soft measures will mainly address issues of avoidance, zoning, and use of regulations. Hard measures will involve construction of structures to create more stable slopes. Although hard measures have been advocated and implemented in slope stabilisation, studies have shown that soft solutions can achieve effectively long term hazard reduction (Crozier, 1984; and Hencher, 1987). Soft solutions have also been found to be more cost effective measures over long term than hard measures (Schlosser, 1979; and Pilot et al., 1988).

### 9.2.1 Vulnerability Reduction

#### 9.2.1.1 Alteration of the Environment

In areas where landslides were caused by anthropogenic factors, mainly slope remodelling (**Section 7.4**), the alteration of the environment needs to be carried out. In the Ntchenachena Area, where slopes have been cut for settlement activity, there is need for rehabilitation by replanting vegetation which will reduce erosion. As shown in **Chapter 8**, most of the houses are temporary structures and built on danger-prone areas. Proper siting of houses, which meets building standard codes, can help minimise damage from landslides. In areas where houses were contributing to instability, restricting settlement activities partially or even completely would be more appropriate.

In the Chiweta Area, the major problem, as observed by the study, was slope cutting for road construction (**Section 7.4**). Vulnerability can be reduced by engineering works. However, mitigation measures must be based on a full understanding of the geometry and hydrological regimes of affected areas. Suggested measures are based on suggested causes of landslides in this area as presented in **Chapter 7**.

#### 9.2.1.2: Improving of Stability by Geometric Methods

In the Chiweta Area, it was observed that slope remodelling increased slope ranges of $24^0 - 69^0$ to $61^0 - 87^0$. The increase in slope angle can disturb the balance of forces (**Section 3.6**). Therefore, slope reduction is recommended to create a gentler slope and this might reduce the component of the gravitational force acting along the slope (Crozier, 1984; and Alexander, 1993). However, geometric methods are expensive and, with dwindling Central Government resources, the implementation would pose a serious financial challenge.

In areas where slopes are collapsing on their own, the construction of embankments, whose size can be determined by the selection of gradient that will provide a stable slope given the local hydraulic conditions, can provide stability. The embankments can be of stone and wire mesh as used in stabilising the Nyankhowa slopes in Northern Malawi (Msilimba, 2002; and Msilimba and Holmes, 2005; **Figures 9.1 and 9.2**) or can be of concrete as was used in A7 Motorway at Rognac, near the Etang de Berre in France (Pilot et al., 1988). Considering the economy of the country, stone embankmenks will be less costly to implement. However, civic education should be carried extensively around this area. What can be foreseen as a problem would be vandalism of wire meshes holding the stones. Stealing of wire mesh was observed in the Vunguvungu Area where similar measures had been used (Msilimba, 2002). In some cases, the vandalism is due to high poverty level (Slater and Tsoka, 2006) which needs to be addressed if mitigation measures are to be implemented successfully.

Figure 9.1: **Stone embankments, using wire mesh, constructed to stabilise Nyankhowa slopes in Northern Malawi. Similar structures ca be used to stabilise the Chiweta beds (11.08.01).**

Figure 9.2: **Concrete stone embankments constructed to stabilise landslide prone slopes at Overtoun in Northern Malawi. Note the plastic tubing to prevent the build up of water table 11.08.01).**

### 9.2.1.3 Stabilisation by Drainage

Stabilisation by drainage has been noted as a very effective means of protecting unstable hill slopes from sliding (Pilot et al., 1988). In the Chiweta Area, water was noted to have infiltrated into the weathered and jointed beds which in turn increase both pore and cleft water pressures (**Sections 7.6.2 and 7.6.3**). The construction of concrete embankments may result in a build up of water in the slope, creating further instability. The local ground level can be lowered through the installation of curtains every five meters. This method proved very effective along the Lyon-Marseille Motorway (Pilot et al., 1988). In this area, stone embankments, using wire meshes, will reduce significantly the build up of water in the slope (**Figure 9.1**). Such structures are less expensive and more applicable to developing countries.

In the Ntchenachena Area, where the basement has been significantly weathered (**Section 7.4.3**) and high precipitation is received (**Sections 7.2.1, 7.2.2, and 7.2.3**), ground water can be reduced by excavating trenches to the effective weathering depth. Borings which use gravity can be constructed because they are relatively cheap compared to drainage by galleries (Zaruba and Mencl, 1969; and Nicholas, 1995). The excavation of the trenches can be done through community participation. However, the members of the community will participate in such activities if they foresee the benefits. This can be implemented through public works programmes, where the local people will be given cash in return for labour. The Government should provide all the necessary materials such as picks, shovels, metal, and plastic tubes. However, the period of slope rehabilitation should not concide with the period of cultivation because this might result in competition for labour.

#### 9.2.1.4 Stabilisation by Plugging

In areas where the beds are fissured and jointed creating instability as shown in **Section 7.4.3**, such areas can be stabilised by strengthening the material by pinning. This will involve the injection of metal tubes. This method is used mostly when stabilisation by embankments or drainage has failed (Schlosser, 1979). Tubes can be inserted through the disjointed Chiweta beds, dipping along the road. In areas where fissuring is severe and openings are wide enough, grouting can be used. Such methods, though costly, have been tried along the Briollay Road cutting where the plugging of the bank was carried out by driving metal tubes 50mm in diameter into inclined boreholes, fitting 16mm rods into them and injecting a cement grouting (Pilot et al., 1988). The results proved effective. The major problem would be resources, as explained above. However, the road is an important route to the east where most of oil imports come from. Therefore, a deliberate funding policy is recommended. Cooperating partners may also be consulted for possible funding.

#### 9.2.1.5 Rehabilitation by Afforestation

It was observed that deforestation in all the areas contributed to landsliding, especially in the Ntchenachena Area (**Section 7.8**). In this area, extensive tree planting, combined with the construction of trenches, may stabilise the slopes through increased evaporative losses associated with tall, deep-rooted vegetation. The root density must be high to achieve maximum tensile strength (Pearce, 1988; Skatula, 1953; and Sykola, 1961). In North Island, New Zealand, afforestation programmes have significantly reduced the occurrence of landslides and mudflows (Pearce, 1988). However, a careful selection of tree species needs to be carried out. This exercise can be done in conjuction with the Forestry Department and the Forestry Research Institute of Malawi (FRIM). It was observed in the Zomba Mountains in Southern Malawi that pine trees planted to stabilising slopes were causing instability due to their own weight and shallow rooting system (Mwenelupembe, 1997). For afforestation to be successful, the root causes of deforestation need to be addressed.

Deforestation was noted to be a function of poverty (NEAP, 1998; Kasulo, 2005; and Slater and Tsoka, 2006). The increasing demand for fuel wood (NEAP, 1998; and Kasulo, 2005) requires urgent attention. Alternative sources, which are within the means of the local people, need to be introduced. These could be the use of coal, gel fuel, and crop residues. However, the issue of preference in terms of carolific value needs to be addressed. According to Abbot (2005), the local trees are preferred because of the high carolific values. However, afforestation programmes should not affect time allocated to farming activities. Cash for work programmes can be introduced to facilitate afforestation. Apart from motivating the people, the programmes can partly alleviate the poverty situation in the areas.

The Miombo woodlands around the Chiweta Area need to be conserved. The area has been a proposed forest reserve for over 10 years. At present, the forest remains a common property. It has been noted that common property resources are prone to over- exploitation (Mwafongo, 1996). If this area can be declared a forest reserve by an act of Parliament, and local people form part of the management, the stability of slopes within the forest can be guaranteed. The local people should not be excluded from the benefits of conservation efforts. The importance of conserving needs to be thoroughly explained to these people. In this area, the people should realise that continued destruction of the vegetation will result in frequent rock falls which will affect their settlements along the lake.

#### 9.2.1.6 Stabilisation and Rehabilitation of River Banks

As was observed in Rumphi and Ntcheu Districts (**Chapter 6 and 8**), extensive damage was done to crops and farmland along the Mzinga River in Rumphi, and the Mpira and Livilivi Rivers in Ntcheu. This was due to the destruction of riparian vegetation. If the banks can be rehabilitated, through afforestation, the effects of floods would be reduced. The problem of bank collapsing, and contributing to siltation and floods, could be checked.

### 9.2.2 Mitigation by Vulnerability Avoidance

This can be achieved in a number of ways by both the affected people and the stakeholders.

#### 9.2.2.1 Economic Incentives

In both districts, it was observed that people are poor with very limited assets. The majority had no steady source of monthly income. They depended mostly on seasonal low paying piece work. The destruction of the Mvai and the Chiweta forests were attributed to poverty. If the people can be given economic incentives in terms of new sources of livelihood, they may abandon the destruction of trees. The incentives might include soft laons which can be used as start up capital, and cash for work programmes. In some areas, cash for work programmes have been hailed for improving rural incomes. However, the new alternatives must be good enough in terms of advantages compared to the current practices. In the Ntchenachena Area, for the people either to stop cultivating on steep slopes or relocating to safer areas, a political solution must be found, accompanied by a package of incentives.

#### 9.2.2.2 Limiting Activities in Hazard Areas

The Government, through local assemblies, needs to limit human activities that contribute to slope instability. For instance, the cultivation along river banks can be controlled. In the 1940's up to 1960s, there were restrictions not to cultivate very close to the river banks, and that worked out very well (Pike, 1968). Cultivation on slopes greater than $15^0$ can be banned or permitted, depending upon the crop to be grown as well as land husbandry practices to be followed. In Malawi land husbandry practices exist, but the problem is monitoring and enforcement. Extension workers need to intensify awareness campaigns on appropriate land husbandry practices.

#### 9.2.2.3 Community Participation in Developing Mitigation Measures

In the process of creating mitigation strategies, community involvement is critical if they are to be accepted by the affected people. Community collaboration is important because the measures will be implemented in the affected communities, and the affected people will be the implementers in most cases (Perlman, 2004; and Patel, 2004). For instance, in the Ntcheu Area, the rate of deforestation is high because, among other things, the people are not part of the management of the reserves. They lack access to forest resources though these are located in their localities. If these people can be involved through collaboration, their participation will be greater which in turn will increase their resilience to landslide hazards. Women interact and use environmental resources and need to be part of the management. They should not be excluded from the decision-making process.

#### 9.2.2.4 Public Awareness and Outreach

Vulnerability avoidance can be achieved if outreach and public awareness of the causes, contributing factors, and mitigation techniques can be increased. **Chapter 8** presented a variety of traditional beliefs which local people employ in explaining occurrences. Unless these are incorporated into the existing body of scientific knowledge, the risk remains high. A clear understanding of their production systems must be achieved before any attempt is made to introduce mitigation measures. As shown in **Section 8.14,** people actually destroyed pine trees planted by the Malawi Social Action Fund (MASAF) because they thought their production system will be affected negatively by the monkeys. In this case, civic education, as well as the identification of measures, are important to mitigate externalities. Techniques developed through collaboration should be propagated to all the members of the affected communities. Public awareness can be done through extension workers, local leaders, church leaders and district environmental officers. This can be accomplished through landslide hazard safety programs, community risk reduction workshops, and increased media coverage of existing landslide hazard areas.

Furthermore, future research should explore the need for and benefits of establishing landslide insurance programmes, and raising the awareness of people living in areas at risk of landslides.

#### 9.2.2.5 Government Participation

The study has shown that the Government did not assist the landslide victims in both areas, and that worsened their poverty situation, especially in Ntcheu District (**Section 8.17.4**). The Government should develop a disaster preparedness plan on how to respond to such disasters promptly. For instance, the Government can create and update state and local geo-hazards mitigation plans. This can be achieved by funding research in slope stability problems by research institutions and individuals. The Government should create policies for landslides mitigation implementation and land-use planning. This should be tied to the development of emergency operation plan which is not in place as of now.

The Government should develop, adopt, and enforce building codes and standards so that houses built can withstand landslide hazards. As shown in **Table 8.3**, people of the affected areas, live in temporary houses which are prone to failure. It is up to the government to come in with village housing schemes. This could also act as a motivation for relocation to safer ground. Considering that the Ntchenachena Area is very vulnerable, and had the highest density of landslide occurrences (**Section 6.1**), the Government should promote relocation of settlements from high risk areas. This can be achieved through a process of consultation, provision of incentives, and trust building. The incentives must be high enough to achieve willingness to move. Above all, the dangers of staying in that environment needs to be explained properly.

#### 9.2.2.6 Establishment of Early Warning System

As shown in **Section 7.2.2,** all the landslides were caused by either prolonged or high intensity precipitation well above the normal averages. If an early warning system can be developed, then people could be warned well in advance, and this could not only reduce damage to property, but even more importantly minimize loss of lives. The early warning system will provide timely information to all stakeholders involved in disaster management.

#### 9.2.2.7 Engineering Structures to Reduce Damage

As shown in **Section 7.4.3**, rock falls are common in the Chiweta and the Mvai Areas. Rock falls have been noted to be a source of accidents in the Chiweta Area (**Chapter 6**). To reduce the damage, cable nets and wire fences can be used to trap falling rocks in areas along the slope cutting where movement of boulders is inevitable. This is the most effective way of reducing damage rather than stabilising the slopes as explained by Coch (1995). In both areas, sign posts of rock falls need to be put in place to warn people passing along the Chiweta Road, and those climbing the Mvai Mountain. This can be adapted as an interim measure as the Government looks for resources for major engineering works.

#### 9.2.2.8 Proper Designing of Roads and Drainage

As shown in **Chapter 6 and 8**, roads and bridges were damaged by the landslides. The damages were severe partly because of poor designing of roads and bridge clearance. The Livilivi and the Phoka bridges need to be elevated to accommodate probable maximum floods. Although this might appear expensive, in the long run, the savings from mitigating the damage will be higher. Improving the road network between these places and urban centres can promote trade. This may improve people's income, thereby reducing their vulnerability to natural disasters.

#### 9.2.2.9 Integration of Indigenous Knowledge in the Education Curriculum

Since indigenous knowledge, gender and the environment are not currently included in the educational curricula in Malawi, the study recommends the introduction of these into the curricula so that students can appreciate the vitality and resilience of their own dynamic systems as they reflect changing situations and circumstances. This may instill a spirit of managing and conserving their environment.

#### 9.2.2.10 Monitoring of Landslide Occurrences

Finally, the study recommends monitoring of landslide occurrences. Monitoring of landslide activity over extensive areas could be of paramount importance for landslide hazard, and risk assessment. This can be achieved by field-based geodetic, geotechnical, and geophysical techniques, complemented with aerial photo interpretation. This approach has been tried by several researchers and the results have been encouraging (Mikkelson, 1996; Keaton and DeGraff, 1996; and Hervas, 2003).

# CHAPTER TEN

# CONCLUSIONS AND SUGGESTED AREAS FOR FURTHER STUDY

This concluding Chapter is based on a synthesis of the results presented in **Chapters 6, 7, and 8,** and mitigation measures presented in **Chapter 9**. The Chapter also provides areas for further study.

## 10.1 Conclusions

The study was carried out in the Rumphi District of Northern Malawi and the Ntcheu District of Central Malawi to assess landslides occurrences and develop mitigations. The study addressed the following objectives: mapping observable individual landslide events in the study areas; determining of the extent and channel morphology of these landslide events; classifying of observed landslides; determining the factors that contributed and caused the landslides; assessing the slope stability status for the study areas; assessing the socio-economic and environmental impacts of the landslide events; investigating the role of traditional knowledge in explaining landslide occurrences; investigating gender perceptions towards landslides; and proposing mitigation measures for landslide geo-hazards.

The study which compares the causes and contributing factors associated with landslides in Northern and Central Malawi, is the first of its kind to be carried in the country. It is also the first study in Malawi to attempt to classify landslide events. Furthermore, as far as can be ascertained, it is the first attempt to understand the role of traditional knowledge in explaining landslides. Importantly, this is the first study to address gender perceptions towards landslides.

The study involved a landslide inventory of all observed landslides. The physical characteristics of the terrain (i.e. slope length, angles, aspect and altitude, and channel lengths, widths, and depths) were measured. Landslides were classified based on type of movement, degree of stabilisation, and type of material. Soil samples were tested for plastic limit, liquid limit and plasticity index, bulk density, hydraulic conductivity, aggregate stability, and particle sizes. Rainfall data was analysed for means. A social survey was carried out to ascertain the role of traditional knowledge in explaining landslides. Gender perceptions towards landslides occurrences were also investigated. The responses were analysed using the SPSS software package, and results were subsequently presented.

In total, 131 landslides were mapped, of which 98 occurred in Rumphi District and 33 in Ntcheu District. The highest density was recorded at the Ntchenachena Area of Rumphi District, with 67.18% of all the landslide occurrences. The density varied, depending upon the combination of contributing factors. The measurements of the channels depended upon the thickness of the weathered material, and the depth of contact point between rock and soil mass. In the Ntchenachena Area, where the deepest channels were located, the basement was highly weathered. However, the lengths were observed to depend upon the initial point of failure and lengths of individual slopes.

It was established in all the study areas that slope type and aspect were of less significance than slope angle in the occurrence and distribution of landslides. The study did not find any correlation between slope type and aspect with occurrence of landslides. Therefore, the location and distribution of landslides are attributed to other factors such as structural rock weaknesses, slope angle, degree of slope disturbance, and shear strength of soils.

Most of the landslides at the Mvai A and B units were classified as translational because movements occurred along pre-existing slide planes which were activated during the 2003 rainfall events. In the Ntchenachena Area, the majority of the landslides were rotational in nature as observed by curved surface rupturing that produced backward slippage. Those landslides with parallel sided morphometry occurred on relatively low angle slopes where valleys were absent. Landslides with funnel shape morphometry occurred along river valleys.

Of all the landslides, 65.64% were classified as contemporary because erosion was still active and experiencing dissection. The majority of these occurred in 2003. All the areas showed evidence of past landslides. Most of the landslides in the Ntchenachena Area were active or partially stabilised while in Ntcheu, over half of the landslides were stabilised or dormant. This was attributed to the stabilising effects of vegetation. The material involved in the movement ranged from soil mass and weathered rocks/quartz floats in the Ntchenachena Area to boulders, rock fragments, soil, regolith and vegetation in the rest of the study areas.

Landslides caused injury to the people. For instance, in the Ntchenachena Area, four people died when their house was swept away in 2003. Compared to previous landslides (Gondwe and Govati, 1991; and Poschinger et al., 1998), the death toll was very low. However, landslides caused economic losses at all the sites through destruction of crops and farmland both in Rumphi and Ntcheu, destroying of bridges along the Livilivi and Mzinga Rivers, blocking of the M1 Road at Chiweta, and the disrupting of the water supply system and irrigation schemes in the Ntcheu District.

In all the areas, landslides caused substantial damage to vegetation, especially along the debris path. The riparian vegetation along the Mzinga River (Rumphi), and the Livilivi and Mpira Rivers (Ntcheu) was destroyed. The scenic beauty of these areas was compromised due to the formation of gullies, scars, and dissections.

From the analysis of data, it is suggested that landslides were caused by liquefaction of sand and silt fractions of the soil. In all the areas the soils contained a high percentage of sand, with medium to fine sand constituting the highest proportion (**Tables 7.10 and 7.11**). The significance of clay in reducing liquefaction in the Ntchenachena Area was reduced by high moisture content after prolonged precipitation

At all the study sites, high monthly or annual totals appear not to have been the direct cause of landslides. There was no correlation between high monthly/annual totals and occurrence of landslides. Rather, high monthly precipitation totals prepared the slope for eventual failure by raising antecedent soil moisture. Therefore, landslides in all the areas were triggered by prolonged precipitation of high intensities. The high prolonged precipitation contributed to high pore and cleft water pressures. High cleft water pressure was noted as a factor in the Chiweta and the Mvai Areas where structural rock weaknesses were observed. On the other hand, in the Ntchenachena Area, high pore water pressure was the critical cause of soil liquefaction.

The destruction of vegetation in all the areas, the cultivation on steep slopes in the Ntchenachena Area, the high slope angles in all areas, the weathering of the basement, and slope remodelling in the Ntchenachena and the Chiweta Areas, contributed to instability. Rock falls in the Mvai and the Chiweta Areas were also caused by root wedging and high cleft water pressure.

Vulnerability of societies to landslides was attributed to low incomes which was a function of lack of employment, no steady monthly income, lack of capital assets, and perpetual reliance on low paying seasonal work. Houses were located on danger-prone areas, and that increased their vulnerability to failure.

Production systems were found to contribute to landslides through cultivation on fragile environments as was the case in the Ntchenachena Area. The destruction of the vegetation through charcoal making in Ntcheu, and grazing by animals (mainly goats) in the Ntchenachena Area was noted as a problem. Failure by Government to rehabilitate the slopes, evacuate victims, and provide emergency assistance increased the hardships.

The study has shown that although the people of these areas are illiterate or semi-literate, they have an awareness of the environmental problems. It has been shown that through interaction with the environment, they have developed philosophies, traditional knowledge, and a system of natural resource management.

In both districts, traditional beliefs were deeply rooted in the culture of the people which helped them explain landslide occurrences. This body of knowledge needs to be incorporated in the existing scientific knowledge. The misconceptions in the traditional knowledge can be clarified using scientific explanations. This will bring a better understanding of the mechanisms of landslide generation to the local people. The integration of knowledge can be a prerequisite to local people's participation in environmental management and protection.

The research has demonstrated that low incomes, poor siting of settlements, inappropriate production systems, and a lack of slope susceptibility mapping by government have contributed to societies' vulnerability to landslides. The occurrence of landslides also reduced societies' resilience to natural disasters. Furthermore, the research has demonstrated how societies cope with landslides. Coping strategies included selling beer, mat-making, basket-weaving, and involvement in low paying jobs. However, the number of people involved in low paying piece work was higher in Ntcheu than in Rumphi because no aid was provided to the people of the Ntcheu District.

In terms of gender, the sex of an individual did not affect the awareness of landslides vis-a'-vis causes and contributing factors. Women had the same level of awareness as their male counter-parts. The similarities in the level of awareness can be attributed to experience of and interaction with the environment.

Landslide events caused substantial damage to crops and farmland. These were the most devastating impacts because affected communities are rural subsistence farming communities. Destruction of crops and farmland worsened the poverty situation of the communities, thereby increasing their vulnerability.

Little rehabilitation was found to be taking place in the various areas, and this increases the risk. Although little rehabilitation is taking place, the local people had an awareness of what needs to be done. There was also evidence of heavy reliance on external assistance. The people believe NGOs and the Government should promote afforestation, awareness campaigns, introduce housing schemes, and even more importantly, introduce income generating activities.

In terms of mitigation measures, the study recommends that a combination of soft and hard solutions need to be implemented (**Section 9.2**). However, in the Chiweta Area major engineering works are required to stabilise the remodelled slopes. The major structural engineering works should be done with a full understanding of geometry and hydrological regimes of the Chiweta beds. The only problem which is foreseen could be lack of resources.

In the Ntchenachena Area, relocation of settlements is a probable solution to the problem but requires a political solution rather than an academic one. However, stabilisation can also be achieved through afforestation, boring, and construction of trenches to lower ground water levels.

The Mvai, the Livilivi and the Chiweta Areas require community collaboration in the management of the Miombo woodlands. Co-management will bring a sense of ownership and contribute towards effective management. However, the resources from the forest must be of benefit to all the stakeholders.

### 10.2 Suggested Areas for Further Study

Based on the limitations of the study highlighted in the thesis and the recognition that advanced geophysical and geotechnical field and laboratory analyses and advanced remote sensing techniques can be applied, the study recommends the following:

**10.2.1** Since the problem of relocation in the Ntchenachena Area is political in nature, where the people believe that the problem was caused by their eviction from the Nyika National Park, a detailed survey needs to be carried out to assess their willingness to move to safer ground. The survey should also address a package of incentives, which will motivate the Phokas to move to safer ground.

**10.2.2** The study recommends a detailed geological survey to determine the degree of weathering, jointing, foliation trends and fissuring. The study should also focus on the strength of the Chiweta beds and their orientation.

**10.2.3** Hydrological regimes of these areas require investigation to assess the changes in ground water regimes that affects the development of pore, and cleft water pressures. A thorough investigation of such changes will result in a better understanding of how shear bands develop on both consolidated and unconsolidated materials.

**10.2.4** The development of predictive models will be quite useful in explaining landslide occurrences and probable areas of failure. However, the models need to take into account the hydrological, topographical, geological, and anthropogenic factors. The study recommends the following models to be tested;

- Models for plane slip surfaces (Haefeli, 1984). This infinite slope model mainly used for slides on long, uniform slopes will be more applicable in the Livilivi/Mvai Catchments where slopes are long and uniform.
- The method of slices developed mainly for simple rotational slides (Petterson, 1955) developed using the concept of effective stress. This model can be

applied to the study of rotational slides in the Ntchenachena and the Livilivi Areas, where rotational slides are dominant.

- Advanced computer-based models (Little and Price, 1958) which allow for increasingly refined analyses of internal stress state of the slope. As discussed in **Section 7.6.1**, liquefaction caused most of the failures in the Livilivi and the Ntchenachena Areas. Therefore, the application of advanced computer-based models can help explain the development of positive pore pressure in both consolidated and unconsolidated material.
- Residual strength models (Bishop, 1971), which have become increasingly refined analyses and vitally important where strain dependence of strength and reactivation of old slides is an issue. As shown in **Section 6.3.2**, some landslides were a reactivation of ancient landslides; therefore, such models could assess the mechanisms behind their reactivation.
- Finally, since rock falls were/are common in the Chiweta and the Mvai Areas (**Section, 6.3.1**), Models of non-slide failures (Dunbaven, 1983) are recommended.

**10.2.5** As shown in this study, the landslides occurred in different months which could be an indication of different rainfall patterns for Rumphi and Ntcheu Districts. Episodes of high-prolonged precipitation were also observed, an indication of climate change. It is therefore important to assess the impact of climate change on the occurrence of landslides based on general circulation models (Dehn and Buma, 1999). As observed by the Department of Environmental Affairs, Malawi started experiencing climate change in the 1990s (**Section 2.1.9**; NEAP, 1998), its effect on landslides occurrence and distribution has not been assessed.

**10.2.6** Since the study concentrated on landslides in Northern and Central Malawi, the study recommends further work to be carried out in Southern Malawi to provide a comparative basis for future studies. The information generated will form the basis for landslide mapping/assessment.

### 10.3 Limitations of the Study

Despite an attempt at a comprehensive and holistic piece of research, the work was affected by limited funding. It was difficult to extend areas of study, carry out field experiments, simulations and modeling. Malawi is a developing country, lacking technical and financial resources. However, the study is a contribution to the restricted knowledge on landslides in Malawi and the entire East African region. It is also the first attempt in Malawi to address traditional knowledge, gender and local people's perceptions surrounding landslide occurrences.

# REFERENCES

Abbot, J.: 2005, *Out of Woodland into the Fire, Fuel Wood and Livelihoods Within and Beyond Lake Malawi National Park.* **Rural Resource Use and Local Livelihoods in Sub Saharan Africa,** Oxford**,** Pagrave and Macmillan, 15 – 35.

Afshar, H.: 1991, *Women and Development: Myths and Realities – Some Introductory Notes* in Halel Afshar (Ed). **Women, Development and Survival in the Third World**, Essex, Longman Group.

Agarwal, B.: 1998, *The Gender and Environment Debate*. In K, Roger (ed), **Political Ecology: Global and Local**, London, Routledge.

Agnew, S. and Stubbs, M.: 1972, **Malawi in Maps**, London, University of London Press.

Alcantara-Ayala.: 2002, *Geomorphology, Natural Hazards, Vulnerability and Prevention of Natural Disasters in Developing Countries*. **Geomorphology** 47, 107 - 124.

Alexander, D.: 1993, **Natural Disaster**, London, University College Library Press.

Anderson, M.G and Richards, K.S.: 1987, **Slope Stability; Geotechnical Engineering and Geomorphology**, Chichester, John Wiley and Sons.

Aryamanya-Mugisha H.: 2001, **State of the Environmental Report for Uganda 2000/1 Technical report**, Kampala, National Environmental Management Authority.

Avery, T. and Burkhart, H.: 2002, **Forest Measurements, 5th Edition,** New York, McGraw-Hill Companies.

Ayalew, L.: 1999, *The Effects of Season Rainfall in the Highlands of Ethiopia.* **Bulletin of Engineering Geology and Environment** 58, 9 - 19.

Ayalew, L. Yamagishi, H. Marui, H. and Kanno, T.: 2005, *Landslides in Sado Island of Japan: Part II. GIS Based Susceptibility Mapping with Comparison from two Methods and Verifications.* **Engineering Geology** 81, 432 - 445.

Badshah, A.: 1994, *The Mega-Cities; Transferring Workable Approaches*, **Enabling Sustainable Community Development**, Washington D.C, World Bank, 32-34.

Baeza, C. and Corominas, J.: 2001, *An Assessment of Shallo Landslide Susceptibility by Means of Multi Variate Statistical Technique*, **Earth Surface Processes and Landforms**. 26, 1251 - 61.

Bailey, D.K.: 1994, **Methods of Social Research. 4th Edition**. New York, Free Press.

Bartley, T. and Bergesen, A.: 1987, *World System Studies of the Environment*. **Journal of World System Research** 3, 369 - 380.

Batterbury, S. and Forsyth, T.: 1999, *Fighting Back: Human Adaptation in Marginal Environment*, http://www.findarticles.comp/p/articles/mi_m10761/is_6_41 (20.02.07)

Benda, L. and Dune, T.: (1997), *Stochastic Forcing of Sediment Routing and Storage in Channel Network.* **Water Resources Research** 33, 2849 - 2863.

Benda, L. Miller, D. Bigelow, P. and Andras, K.: 2003, *The Effects of Post Wild Fire Erosion on Channel Environments, Boise River, Idah*. **Forest Ecology and Management**, 178, 105.

Berkes, F. and Folke, C.: 1998, *Linking Social and Ecological Systems for Resilience and Sustainability*, in Berkes, F., Folke, C. and Colding, J. (eds), **Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Buliding Resilience**, Cambridge, Cambridge Univeristy Press.

Berkes, F.: 1987, *Common Property Resource Management and Cree Indian Fisheries in Subartic, Canada*. In B McCay and J Acheson (eds), **Question of the Commons: the Culture and Ecology of Communal Resources**, Arizona, Tucson, University of Arizona.

Berkes, F.: 1992, **Common Property Resources: Ecology and Community-Based Sustainable Development**, London, Belhave Press.

Berkes, F.: 1995, *Indigenous Knowledge and Resources Management Systems: a Native Canadian Case Study from James Bay*, in S. Hanna and M. Munasinghe (eds), **Property Rights in a Social and Ecological Context; Case Studies and Design Applications**, Washington DC; The Beijer International Institute of Ecological Economics and the World Bank.

Bishop, A.W.: 1971, *The Influence of Progressive Failure to the Mechanisms Causing it*, **Tech Note. Geology** 21, 168 - 172.

Blaikie, P.: 1985, **The Political Economy of Soil Erosion in Developing Countries**. London, Longman, 12 – 116.

Blaikie, P.: 1987, *Approaches to the Study of Land Degration and Society*, in P. Blaikie and H. Brookefield (eds). **Land Degradation and Society**, London, Methuen.

Boserup, E.: 1970, **Women's Role in Economic Development**, London, Allen and Unwin.

Bloomfield, K.: 1968, **The Pre-Karroo Geology of Malawi**, Zomba, Geological Survey Department.

Brabb, E.E.: 1984, *Innovation Approaches to Landslide Hazard Mapping*, in **Proceedings of 5th International Symposium on Landslides**, Rotterdam, Balkema.

Braidotti, R. Charkiewicz, E. Hausler, S. and Wieringa, S.: 1994, **Women, the Environment and Sustainable Development; Towards a Theoretical Synthesis**, London, Zed Books.

Brasher, B.R.: 1966, *Use of Saran Resin to Coat Natural Solid Clods for Bulk-Density and Water Retention Measurement*. **Soil Science** 101, 108.

Braver, L. D.: 1956, **Soil Physics,** 3rd edition, New York, John Wiley and Sons.

BredenKamp, B.: 2002, **Forest Measurements**, StellenBosch, StellenBosch University.

Briggs, D.: 1977, **Soils**, London, ButterWorths.

Briggs, D.: 1995, **Fundamentals of Physical Geography**, London, Routledge.

Briggs, J. Badri, M. and Mekki, M.: 1994, *Indigenous Knowledge and Vegetation Use Among Bedouin in Eastern Desert of Egypt.* **Applied Geography** 19 (2), 87 - 103.

Brinkcate T. and Hanvey, P.: 1996, *Perceptions and Attitudes Towards Soil Erosion in Madebere Community, North West Province*. **South African Geographical Journal** 78 (1), 75 - 82.

Brockington, D.: 2005, *The Contigency of Community Conservation*, in **Rural Resource Use and Local Livelihoods in Sub Saharan Africa**, Oxford**,** Pagrave and Macmillan.

Bromhead, E.N.: 1987, *Slopes and Embankment* in P. Attewell and R. Taylor (eds), **Ground Movements and their Effects on Sructures**, Glassglow, Survey University Press, Blackie Group.

Brunsden, D.J.: 1970, **Processes in Geomorphology**, London, Edward Arnol.

Bryant, E.A.: 1991, **Natural Hazards**, Cambridge, Cambridge University Press.

Buhl, S.: 2005, *Gender Equity? NO! What do Fulbe Women Really Want?* In **Rural Resource Use and Local Livelihoods in Sub Saharan Africa,** Oxford**,** Pagrave and Macmillan.

Butler, J.: 1976, **Natural Disasters**, Victoria, Heinemann.

Caine, N.: 1980, *The Rainfall Intensity-Duration Control of Shallow Landslides and Debris Flow.* **Geografiska Annaler** 62A, 23 - 27.

Caine, N. and Mool, P.: 1982, *Landslides in the Kolpu Khola Drainage, Middle Mountains, Nepal.* **Mountain Research and Development** 2, 157 - 173.

Campbell, D.A.: 1951, *Types of Erosion Prevalent in New Zealand*, **Association International d'Hydrologie Scientifique, Assemblee Generale de Bruxelles**. Tome II.

Campbell, R.H.: 1975, *Soil Slips, Debris Flows, and Rainstorm in Santa Monica Mouintains and Vicinity, Southern Californa*, **Professional Paper** 851. USGS, Washington, D.C. 50.

Cannon, S. and Ellen, S.: 1985, *Rainfall Conditions for Abundant Debris Avalanches, California*. **Geology** 38, 267 - 272.

Carson, M.A. and Petley D.J.: 1987, *The Existence of Threshold Hillslopes in the Denudation of the Landscape*, in **Trans. Inst. Britain. Geogrs** 49, 71 - 96.

Carson, R.: 1962, **Silent Spring**, London, Greenwich and Fawcett.

Carter, G.S. and Bennet, J.D.: 1973, **The Geology and Mineral Resources of Malawi 2nd** Edition**,** Zomba, Geological Survey Department.

Carter, G.S. Haslam, H. and Smith, H.: 1973, **Regional Geochemical Reconnaissance of Malawi**, Zomba, Geological Survey Department.

Cheyo, D.R.: 1999, **Geohazard Around the Michesi and Zomba Areas,** in the Proceedings of the Symposium on Natural Geological Hazards in Southern Malawi, Zomba, 27th – 28th July.

Chikusa, C.M.: 1985, **The Phenomenon of "Napolo" in Zomba with Reference to the 1985 Ntonya – Ulumba Events**, Zomba, geological Survey Department.

Chipili, E. and Mshali, R.: 1989, **A Report on Nyambilo Landslide – Nsanje District,** Zomba, Geological Survey Department.

Chipili, E.: 1997, **Rock Avalanche at Kanjate, Ntcheu District. Technical Report**, Zomba, Geological Survey Department.

Chutter, J.: 1983, **Timber Management, A Quantitative Approach**, NewYork, John Wiley and Sons.

Clerici, A. Perego, S. Tellini, C. and Vescovi, P.: 2002, *A Procedure for Landslide Susceptibility Zonation by the Conditional Analysis Method.* **Geomorphology** 48. 349 - 364.

Coch K.C.: 1995, **Geohazards: Natural and Human**, New Jersery, Prentice Hall Inc.

Cooke, R.U and Doornkamp, J.C.: 1990, **Geomorphology in Environmental Management**, Oxford, Clarendon.

Cooper, W.G.G. and Habgood, F.: 1959, **The Geology of the Livingstonia Coalfield,** Zomba**,** Geological Survey Department.

Corominas, J. Remondo, J. Farias, P. Esterao, M. Zezere, T. Dias de Teran, J. Dikan, R. Schott, L. Moya, J. and Gonzalez, A.: 1996, **Debris flow – International Association of Geomorphologists** 5, 61 - 180.

Cotecchia, V.: 1978, *Systematic Reconnaissance Mapping and Registration of Slope Movements*. **Bulletin International Association Engineering Geology**, Vol. 17, 5-37.

Cross, M.: 1998, *Landslides Susceptibility Mapping Using the Matrix Assessment Approach: a Derbyshire Case Study* in J. Maund and M. Eddleston (eds), **Geo-Hazards in Engineering Geology** 15, 247 - 261.

Crowfoot, J.E. and Wondolleck, J.M.: 1990, **Environmental Disputes; Community Involvement in Conflict Resolution,** Washington, D.C, Island Press.

Crozier M.J.: 1973, *Techniques for the Morphometric Analysis of Landslips*, **Zeitschrift fur Geomrphologi**e 17 (1), 78 - 101.

Crozier M.J.: 1984, *Field Assessment of Slope Instability* in D Brunsden and D Prior (eds), **Slope Instability,** , New York, John Wiley and Sons.

Crozier M.J.: 1986, **Landslides: Causes, Consequences and Environment**, London, Croom Helm.

Crozier, M.: 1999, *Prediction of Rainfall-Triggered Landslides: A test of the Antecedent Water Status Model*, **Earth Surface Processes and landforms** 24, 825 - 833.

CSE.: 1985, The State of Indias Environment 1984 - 1985: The Second Citizen Report, New Dehli, CSE.

Dai C.F. Lee, C.F. and Wang, S.J.: 1999, *Stress-Strain Behaviour of Loosely Compacted Volcanic Soils and Significance to Rainfall Induced Fill Slope Failure*, **Engineering Geology** 53, 359 - 370.

Dai C.F Lee, C.F. Wang J.S. and Feng Y.Y.: 1999, *Analysis of Rainstorm Induced Slide Behaviour Flows on Natural Terrain of Lantau Island*, *HongKong*, **Engineering Geology** 51, 279 - 290.

Dankelman, I. and Daividson, J.: 1988, **Women and Environment in the Third World; Alliance for Future**, London, Earthscan.

Davies T.C.: 1996, *Landslides Research in Kenya.* **Journal of African Earth Science** 4, 541 - 549.

De Graff, J.V.: 1979, *Initiation of Shallow Mass Movement by Vegetation Type Conversion*, **Geology ,** 426 - 429.

Dixey, F.: 1926, *The Tertiary and Post Tertiary Lacstrine Sediments of Nyasan Rift Valley*, **Quartenary Journal of Geology** 83, 432 - 442.

Dixey, F.: 1956, **The East African Rift System. Bulletin Supplementary**, Colonial Geological Miner, Resource 1.

Dixon-Mueller, R.: 1985, **Women's Work in Third World Agriculture,** Geneva, International Labour Organisation.

Dolozi, M.B.: 1999, **Climatic and Geological Factors of Landslide Hazards in the Zomba Mountain Area, Southern Malawi**, Zomba, Chancellor College.

Dolozi, M.B. and Kaufulu, Z.: 1992, *The Manyani Hill Landslide in North Eastern Kasungu*, *Malawi* in **National Papers of the Malawi Department of Antiquities 1**.

Dunbaven, M.: 1983, *Discussion on RS Evance (1981)*, **Engineering Geology**16, 243 -245.

Einstein, H.H.: 1988. *Special Lecture: Landslides Risk Assessment Procedure*, in **Proceedings of 5th International Symposium on Landslides** 2, 1075 - 90.

Fairhead, J. and Scoones, I.: 2005, *Local Knowledge and Social Shaping of Soil Iinvestiments Critical Perspectives on the Assessment of Soil Degradation in Africa.* **Land Use Policy** 22 (1), 33 - 41.

Fleming, R.W. Ellen, S.D. and Algus M.A.: 1989, *Transformation of Dilative and Contractive Landslide Debris Flow – An Example from Marin County, California*. **Engineering Geology** 27, 201 - 223.

Fernandes, F. Guimaraes, R. Vieira, B. Montgomery, D. and Greenberg, H.: 2006, *Topographic Controls of Landslides in Rio de Janeiro: Field Evidence and Modeling*. **Catena** 55, 163 - 181.

Finlayson, B. and Statham, I.: 1980: **Hillslope Analysis**, London, Butterworths.

Fowler, F.J.: 1999, *Improving Survey Questionnaires: Design and Evaluation.* **Applied Social Research Methods Series** 38, London, Thousand Oaks A Cage.

Fredlund, D.G. and Riharjo, H.: 1993, **Soil Mechanics for Saturated Soils,** New York, John Wiley and Sons Inc.

Fukuoka, M.: 1988, ***Protective Measures Against Landslides in Japan*** in **Landslides and Mudflows Part 2**, Muscow, UNEP.

Gabet, E.J and Dune T.: 2003, *Astochastic Sediment Supply Model for a Steep Mediterrain Landscape.* **Water Resources Research** 39, 237.

Gadgil, M. Berkes, F. and Folke, C.: 1993, *Indigenous Knowledge for Biodiversity Conservation.* **Ambio** 22, 155 - 156.

GoM.: 1975, **The Livingstonia Coalfield**, Zomba, Geological Survey.

GoM.: 1977, **Map of South Uzumara**, Zomba, Geological Survey Department.

GoM.: 1985, **Map of Malaw**i, Zomba, Department of Surveys.

GoM.: 1987, **Map of Livingstonia Area**, Zomba, Surveys Department.

GoM.: 1987, **Map of Ntcheu**, Zomba, Geological Survey Department, GoM.: 1988, **Soil Laboratory Analysis Manual**, Bvumbwe, Bvumbwe research Station.

GoM.: 1994, **National Environmental Policy,** Lilongwe, Department of Environmental Affairs.

GoM.:1995, **Land-Use and Land-Cover Malawi**, Lilongwe, Ministry of Agriculture and Food Security.

GoM.: 1996, **National Forestry Policy,** Lilongwe**,** Department of Forestry.

GoM.: 1998, **National Environmental Action Plan,** Lilongwe**,** Department of Environmental Affairs.

GoM.: 2001, **Weather Bulletin**, Blantyre, Department of Meteorological Services.

Gondwe, P. C. and Govati C.C.: 1991, **The Stability status of Mishesi Mountain** unpublished report, Zomba, Geological Survey Department.

Gresswell, R.K.: 1970, **Physical geography**, London, Longman Group of Companies.

Guinau, M.: 2005, *A Feasible Methodology for Landslide Susceptibility Assessment in Developing Countries: A Case-Study of NW Nicaragua After Hurricane Mitch.* **Engineering Geology** 80, 316 - 327.

Guzzetti, F. Cardilla, M. Reichenbach, P. Cipolla, F. Sebastian, C. Galli, M. and Salvati, P.: 2004, *Landslides Triggered by the 23rd November, 2000 Rainfall event in Imperial Province Western Liguria, Italy.* **Engineering Geology** 73, 229 - 245.

Haefeli, S.R.: 1948, *The Stability of Slopes Acted upon by Parallel Seepage*. **Proc. 2nd Int. Conf. on soil mechanics**, Rotterdam 1, 57 - 62.

Hagos, H. Pender, J. and Gebreselassie, J.: 1999, *Land Degradation in the Highlands of Tigray and Strategies for Sustainable Land Management*, **Socio-Economic and Policy Working Paper** No.25.

Harlford, S. and Leonard, P.: 2001, **Gender, Power and Organisations**, Houndmills, Palgrave.

Harp, E.L. Wade, G. Wells, J. and Sarmiento.: 1989, *Pore Pressure Response During Failure in Soils.* **Geological Society of America Bulletin** 102, 428 - 438.

Harp, E.L. Reid M.E. and Michael, J.: 2004, *Hazard Analysis of Landslides Triggered by Typhoon Chata'an on July 2, 2002 in Chuuk State*, **Federal State of Micronesia, UGSS open file report 2004** .1348 US Department of the Interior, Washington.

Hartlen, J. and Viberg, L.: 1988, *Evaluation of Landslide Hazard*, in **Proceedings of 5th International Symposium on Landslides,** Rotterdam, Balkema, 37 - 58.

Hencher, S.R.: 1987, *The Implications of Joints and Structure for Slope Stablity*, **Slope Stability,** London**,** Wiley and Sons Ltd.

Herva, J. Rosin, L. Pasuto, A. Mantovani, F. and Silvano, S.: 2003, *Monitoring Landslides from Optical Remotely Sensed Imagery: The Case History of Tessina Landslide, Italy.* **Geomorphology** 54, 63 - 75.

Higaki, D.: 2000, *Landslides Near Kathmandu Nepal in 1998 – a Preliminary Report* in **Landslide News** 13, 1 - 12.

Hillel, D.: 1980, **Foundantals of Soil Physics**, New York, Academic Press.

Heok, E.: and Boyd, J.M.: 1973, *Stability of Slopes in Jointed Rocks*. **Journal of the Institution of Highway Engineers** 4.

Hodgson, D. (ed): 2000, **Rethinking Pastoralism in Africa; Gender, Culture and the Myth of Patriarchal Pastoralist,** Oxford, James Currey.

Holling, C.: 1986, *The Resilience of Terrestrial Ecosystems; Local Surprise and Global Change.* **Sustainable Development of the Biosphere**, W. Clarke and Munn, R. (eds), Cambridge, Cambridge University Press.

Homewood, K.: 2005, **Rural Resource Use and Local Livelihoods in Sub Saharan Africa**, Oxford, Pagrave and MacMillan Publishers.

Howard, A and Remson, I.: 1978, **Geology in Environmental Planning**, New york, McGraw Hill Book Company.

Huabin, W. Gangjun, L. Weiya, X and Gonghui, W.: 2005, *GIS-based Landslide Hazard Assessment: an Overview.* **Progress in Physical geography** 29, (4) 548 - 567.

Hutchinson, J.N.: 1978, **A Geotechnical Classification of Landslides**, London, Imperial College, London.

Hyndman, D.: 1994, *Conservation Through Self-Determination; Promoting the Interdependence of Culture and Biodiversity*, **Human Organisation** 53, 296 - 302.

Inganga, S. and Ucakuwun, E.: 2001, *Rate of Swelling of Expansive Soils: A critical Factor in Triggering of Landslides and Damage to Structure*, **Documenta Naturae** 136, 93 – 98.

International Union of Geological Science (IUGS).: 1997, *Quantitative Risk Assessment for Slopes and Landslides – the State of the Art*, In Cruden D and Fell R. (eds), **Landslide Risk Assessment,** Rotterdam**:** Balkema.

Iverson R.M. Reid, M.E. Iverson, N. Lahusen, R. Logan, M. and Mann, J.E.: 2000, *Acute Sensitvity of Landslide Rate to Initial Soil Porosity*. **Science** 290, 513 - 516.

Iwahashi, J. Watanabe, S. and Furuya, T.: 2001, *Landform Analysis of Slope Movements using DEM in Higashikubiki area, Japan.* **Computers and Geosciences** 27, 851-865.

Iwahashi, J. Watanabe, S. and Furuya, T.: 2003, *Mean Slope-Angle Frequency Distribution and Size Frequency Distribution of Landslide Masses in Higashikubiki Area, Japan.* **Geomorphology** 50, 349 - 364.

Jibson, R.W. and Keefer, D.K.: 1968, **Landslides Triggered by Earthquakes in Central Mississippi Valley;** Tennessee and Kentucky, US Geological Survey Professional Paper.

Jibson, R. Harp, L. and Michael, J.: 1998, *A Method for Producing Digital Probabilistic Seismic Landslide Hazard Maps: An Example from the Los Angeles, California area*. **USGS open File Report**, 98 -113.

Johnson, A.M. and Rodine, J.R.: 1986, **Slope Instability,** New york**,** John Wiley and Sons Ltd.

Johnston, R.J.: 1991, **Multivariate Statistical Analysis in Geography**, Essex, Longman.

Kamwendo, S.: 1999, *Impact of Natural Geological Hazards in Phalombe* in **Proceedings of the Symposium on Natural Geological Hazards in Southern Malawi**, Zomba 27th – 28th July 1999.

Kandiyoti, D.: 1985, **Women in Rural Production System; Problems and Policies,** Paris. UNESCO.

Kasulo, V.: 2005, *Forest Resources Acounting for Improved National Income Accounts of Malawi*, A Presentation at the First Technical Training and Research Workshop on **Environmental Accounting Under Phase III of the Natural Resource Account in Eastern Africa Project**, Maputo, Mozambique, 12 – 16 June, 2005.

Kaufulu, Z.: 1991, **Ancient Landslides and their Recurrence at Phalombe Malawi**; A preliminary Report, Zomba, Malawi.

Keaton, J. and DeGraff, J.: 1996, *Surface Observation and Geologic Mapping*, in Turner A. and Schuster, R (eds); **Landslides Investigation and Mitigation, Transport**, Research Board and Special Report 247. National Research Council, Washington, D.C.

Keefer, D. Wilson, R. Mark, E. and Brown, W.M.: 1987, *Real-Time Landslide Warning During Heavy Rainfall.* **Science** 238, 4829.

Kemp, J.: 1975, **The Geology of the Uzumara Area**, Zomba, Geological Survey Department.

KIT.: 2002, *Gender, Society and Development; Natural Resources Management and Gender*, **A Global Source Book**, Amsterdam, KIT .

Knapen, J. Kitutu, M. Poesen, J. Brengelmans, W. Deckers, J. and Muwanga, A.: 2006, *Landslides in Densely Populated County at the Foot Slopes of Mount Elgon (Uganda): Characteristics and Causal Factors*, **Geomorphology** 73, 149–165.

Kockelman, W.J: 1985, *Some Techniques for Reducing Landslide Hazards*, **Bulletin of the Association of Enginneering Geologists** 22.

Larsen, M. and Simon, A.: 1993, *Rainfall-Threshold Conditions for Landslides in a Humid-Tropical System, Puerto Rico*, **Geografiska Annaler** 75, 13 - 23.

Leighton, F.B.: 1976, *Urban Landslides: Target for Landuse Planning in California*, **Geographical Magazine** 16 (8), 38 - 43.

Lillesand, M.T. Kiefer, R. and Chipman, J.: 2004, **Remote Sensing and Image Interpretation** 5th Edition, New York, John Wiley and Sons.

Linceham, I.: 1972, *Climate 4; Rainfall* in S. Agnew and G. Stubbs (eds), **Malawi in Maps,** 32, London, University of London Press.

Lindsey, L.: 1996, *Women and Agriculture in the Developing World*, in Paul J. Dubeck and Kathryn Borman (eds) **Women and Work; A Handbook**, NewYork, Garland.

Lindsey, L.: 1997, **Gender Roles; A Sociological Persepective 3rd Edition**, New Jersey, Prentice-Hall Inc.

Lister, L.A.: 1967, **Erosion Surfaces in Malawi**, Zomba, Records of the Geological Survey.

Little, A.L. and Price, V.C.: 1958, *The Use of an Electronic Computer for Slope Stability Computation*, **Geotechnique** 8, 113 -120.

Longley, P.A.: 2001, **Geographic Information System and Science**, Chichester, John wiley and Sons.

Ludman, A. and Koch, N.I.: 1982, **Physical Geology**, London, McGraw-Hill Book Company.

Malunda, E. and Mpinganjira, M.: 2004, **Social and Development Studies**, Book 3, Blantyre, Jhango.

Manda, B.W.C.: 1999, *Geological Hazards in Malawi (A historical overview)*, in the Proceedings on Natural Geological Hazards in Southern Malawi.

Marshall, T.J.: 1988, **Soil Physics**, Cambridge, Cambridge University Press.

Matsushi, Y. Hattanji, T. and Matsukura, Y.: 2006, *Mechanics of Shallow Landslides on Soil Mantled Slopes with Permeable and Impermeable Bedrock in Boso Peninsula, Japan*, **Geomorphology** 76, 92 -108.

Materer, S.C., Valdivia, C. and Gilles J.: 2001, *Indigenous Knowledge System; Characteristics and Importance to Climate Uncertainty*, **AEWP-2001-03, Working paper.**

Mathias, J. and Weatherly, H.: 2003, *A Hydroclimatic Threshold for Landslide Initiation on the North Shore Mountains of Vancouver, British Columbia*, **Geomorphology** 54, 137-156.

McCall, G.J.H.: 1992, **Geohazards "Natural and Man-Made"** London, Chapman and Hall.

Mikkelsen, P.E.: (n.d), *Field Instrumentation*, in Turner A. and Schuster, R (eds).: **Landslides Investigation and Mitigation,** Transport, Research Board and Special Report 247. National Research Council, Washington, D.C 278 - 316.

Miles, S.B and Ho, C.: 1999, *Rigorous Landslide Hazard Zonation Newmarks Method and Stochastic Ground Motion Simulation*, **Soil Dynamics and Earth Engineering** 18 308 - 23.

Momsem, J.H.: 1991, **Women and Development in the Third World,** London**,** Routledge.

Msilimba, G.G.: 2002, **Landslides Geohazard Assessment of the Vunguvungu/Banga Catchment Area in Rumphi District,** MSc. Environmental Science Thesis, Unpublished, Zomba, University of Malawi.

Msilimba, G.G. and Holmes, P.J.: 2005, *A Landslide Hazard Assessment and Vulnerability Appraisal Procedure; Vunguvungu/Banga Catchment, Northern Malawi.* **Natural Hazards** 34, 199 - 216.

Msilimba, G.G. and Jimu, I.M.: 2006, *Transboundary Water Resources Governance in the Songwe River Basin, Malawi: Conventional Management Techniques, Local Perceptions and Development Needs.* Mzuzu, Mzuzu University (Unpublished).

Moeyerson, J.: 1988, *The Complex Nature of Creep Movements on Steep Sloping Ground in Southern Rwanda.* **Earth Surface Processes and Forms** 13, 511 - 524.

Moeyerson, J.: 1989a, *La nature de l'erosion des versants au Rwanda*, in **Annuals of the Royal Museum for Central Africa** 19, 396.

Moeyerson, J.: 1989b, *A Possible Causal Relationship Between Creep and Sliding.* **Earth Surface processes and Landforms** 14, 597 - 614.

Moeyerson, J.: 2003, *The topographic Thresholds of Hill Slope Incisions in SouthWestern Rwanda*, **Catena** 50, 381 - 400.

Mshali. R.S.: 1992, **High Rainfall Intensity as Cause of Land Degradation,** Zomba**,** Geological Survey Department.

Mulder, H.F.: 1991, **Assessment of Landslide Hazard**, Utrecht, university of Utrecht.

Muziyama, T. and Ishikawa, Y.: 1990, **Prediction of Debris Flow Prone Areas and Damage; Hydraulics/Hydrology of Arid Lands,** New York, American A society of Civil Engineers, 712 - 717.

Muwanga, A. Schuman, A. and Biryabarema, M.: 2001, *Landslides in Uganda: Documentation of Natural Hazards*, Documenta **Natuae** 136, 111 - 115.

Mwafongo, K.W.M.: 1996, **Rural Development**, Zomba, University of Malawi.

Mwafulirwa, A.S.O.: 1991, **Preliminary Investigation of the Phalombe Rock Avalanche/Flush flood Disaster,** Zomba, Geological Survey Department.

Mwenelupembe, J.: 1999, *Debris Flow in Zomba and Michesi Mountain Slopes; Their Causes, Mitigation and Return Period*, in the **Proceedings of the Symposium on Natural Geological Hazards in Southern Malawi**.

Mwenelupembe, J.: 2003, **The Ntcheu Debris Flow of 3rd January, 2003**, Zomba, Geological Survey Department.

**National Environmental Policy (NEP).:** 1996**,** Lilongwe, Department of Environmental Affairs.

**National Environmental Action Plan (NEAP).:** 1998**,** Lilongwe**,** Department of Environmental affairs.

NSO.: 1998, **Population and Housing Census.** Zomba, Government Printing Press.

Ngecu, M. and Mathu, E.M.: 1999, *The El-Nino Triggered Landslides and Their Socio-Economic Impact on Kenya.* **Environmental Geology** 38, 277 - 284.

Niemeijer, D. and Mazzucato V.: 2003, *Moving Beyond Indigenous Soil Taxonomies: Local Theories of Soil for Sustainable Development*. **Geoderma** 3, 403 - 424.

Non Affliated Soil Analysis Working Committee: 1990, **Handbook of Standard Soil Testing for Advisory Purposes,** Pretoria, Soil Science Society.

Nyssen, J. Moeyersons, J. Poesen, J. Deckers, J. and Mitiku, H.: 2003, *The Environmental Significance of the Remobilization of Ancient Mass Movement in Atbara-Tekeze Headwaters Near Hagere Selam, Tigray, Northern Ethiopia.* **Geomorphology** 49, 203.

Okalebo, J.R. Gathua, K.W. and Woomer, P.L.: 1993, **Laboratory Methods of Soil and Plant Analysis.** 1st edition, Nairobi, Soil Chemical laboratory, KARI and TSBF.

Okalebo, J.R. Gathua K.W. and Woomer, P.L.: 2002, **Laboratory Methods of Soil and Plant Analysis**. 2nd edition, Nairobi, Soil Chemical Laboratory, KARI and TSBF.

Oldfield, M. and Alcorn, J.: 1991, **Biodiversity: Culture, Conservation and Ecodevelopment**, Westview, Boulder.Col and Westview Press.

Oppenheim, A.N.: 2000, **Guide to the Design on Questionnaire. A General Introduction to the Design on Questionnaire for Survey Research,** Leeds**,** University of Leeds.

Patel, S.: 1994, *Gender and Community Change*, in **Enabling Sustainable Community Development**, Washing D.C, World Bank.

Pearce, J.A.: 1988, **Protection of Extensive Areas of Land from Landslides and Erosion – An Example from New Zealand" in Landslide and Mudflows part 2**, Muscow, UNEP.

Peets, R. and Watts, M.: (eds) 1996, **Liberation Ecologies: Environment, Development, Social Movements,** London, Routledge.

Perlman, J.: 1994, *Promising Solutions at the InterSection of Poverty and the Environment, in* **Enabling Sustainable Community Development,** Washington D.C**,** World Bank.

Petterson, K.E.: 1955, *The Early History of Circular Sliding Surfaces*, **Geotechnique** 5, 275 - 296.

Phillips, A. and Titilola, (eds).: 1995, **Indigenous Knowledge Systems and Practices; Case Studies from Nigeria, Ibadan**, Lagos, Nigeria Institute of Social and Economic Research.

Pike, J.G.: 1968, **Malawi; A Political and Economic History**, London, Pall Mall Press.

Pike, J.G. and Rimmington, G.T.: 1965, **Malawi; A Geographical Study**, Oxford University Press.

Pilot, G. and Cartier, G.: 1988, **Protection of Highways and Linear Installations from Landslides in France in Landslides and Mudflows Part 2,** Muscow, UNEP.

Pitty, A.F.: 1984, **Geography and Soil Properties**, London, Methuen and Company Limited.

Poschinger, A. Cheyo, D. and Mwenelupembe, J.: 1998, *Geohazards in the Michesi and Zomba Mountain Areas in Malawi*; **Technical Cooperation Report No. 96. 20915.5**, Zomba, Geological Survey.

Punmia, B.C.: 1976, **Introductory Soil Mechanics**, Delhi, Standard house.

Rajasekaran, B. Warren, D.M. and Babu, S.C.: 1991, *Indigenous Natural-Resource Management Systems for Sustainable Agricultural Development – A Global Perspective*, in **Journal of International Development** 3, 387 - 401.

Rapp, A. Berry, L. and Temple, P.: 1972, **Landslides in the Mgeta Area, Western Uluguru Mountains, Tanzania,** Studies of Erosion and Sedimentation in Tanzania, Bureau of resources Assessment and Landuse Planning, University of Dares-Salaam and Department of Physical Geography, University of Uppsala.

Schiecht, H.M.: 1980, **Bio-Engineering for Land Reclamation and Conservation**, Edmonton, University of Albert Press.

Schlosser, F. and Juran, I.: 1979, *Improvement and Strengthening of Soils*, **Records of the 7th European Conference on Soil Mechanism and Foundation Engineering,** Brighton 5, 197 - 226.

Seely, M.K.: 1998, *Can Science and Community Action Connect to Combat Desertification?* **Journal of Arid Environment** 39 (2), 267 - 277.

Selby, M.J. (1987); *Rock Slopes*, in **Slope Stability**, Anderson M. and Richards S (eds), Chichester, John Wiley and Sons.

Shaxson, T.F. Hunter, N.D. Jackson, T.R. and Alder, J.R.: 1996, **A Land Husbandry Manual**, Lilongwe, Ministry of Agriculture and Food Security.

Sidle, R.C, Pearce, A.J and O'loughlin, C.L .: 1985, *Hill Slope Stability and Land Use*, **Water Resources Monograph Series, No. 11**, Washington D.C, American Geophysical Union.

Sikana, P. Kerven, C. and Behnke, R.H.: 1993, *From Subsistence to Specialized Commodity Production: Commercial and Pastoral Diarying in Africa*, in **Pastoral Development Network Paper 34(d)**, London, Overseas Development Institute.

Slater, R. and Tsoka, M.: 2006, **Social Protection in Malawi: A Status Report**, Zomba, Center for Social Research, University of Malawi.

Smith, K.: 1996, **Environmental Hazards; Assessing Risk and Reducing Disaster,** London, Routledge.

Sudman, S. and Bradburn, N.M.: 1983, **Asking Questions**, San Francisco, Jossey-Brass.

Susman, P.: 1983, *Global Disasters, a Radical Interpretation*, in K Hewitt (eds), **Interpretations of Calamity,** London, Allen and Unwin.

Takahashi, T.: 1991, **Debris Flow,** Rotterdam, A.A. Balkema.

Talle, A.: 1988, *Women at a Loss, in* **Changes in Massai Pastoralism and their Effects on Gender Relations. Studies in Social Anthropology,** No.19, Stockholm.

Taylor, R.K. and Cripps, J.C.: 1987, *Weathering Effects: Slopes in Mudrocks and Over Consolidated Clays*, **Slope Stability**, Anderson M. and Richards S (eds), Chechister, John Wiley and Sons.

Terzaghai, K.: 1950, *Mechanics of Landslides*, **Engineering Geology,** Berkey,Geology Society of America, 83 - 123.

Thomas, M.F.: 1996, **Geomorphology in the Tropics**, Chichester, John Wiley and Sons.

Torronce, J.K.: 1987, *Quick Clays*. **Slope Stability**, Anderson, M. and Richards, S. (eds), John Wiley and Sons, Chichester.

Tsukamoto, Y. and Kusakabe, O.: 1984. *Vegetation Influences on Debris Slide Occurrences on Steep Slopes in Japan, in* **Proc. Symp. On Effects of Forest Land Use on Erosion and Stability, Environmental and Policy Institute,** Honolulu, Hawaii.

Tuan, Y.F.: 1974, **Topopholia; A study of Environmental Perceptions, Attitude and Values**, New Jersey, Prentice-Hall.

Varnes, D.J.: 1978, *Slope Movement and Types and Process*; In Schuster, R.L. and Krizek, R.J. (eds), **Landslides: Analysis and Control**, Transportation Research Board Special Report 176, National Academy of Sciences, Washington, D.C.

Varnes, D.J.: 1984, **Landslides Zonation: a Review of Principles and Practices**. Paris, UNESCO.

Varnes, D.J.: 1985, *Landslide Hazard Zonation; A Review of Principles and Practices*, **UNESCO Natural Hazards Series**, No.3, Paris, UNESCO.

Van Western, C.J.: 1993, **Application of Geographical Information System to Landslide Hazard Zonation**, Enschede**,** ITC.

Verger, P.: 1995, **Ewe; the Use of Plants in Yoruba Society**, Sao Paulo, Odebrecht-Companhia das Letras.

Von Godow, K. and Bredenkamp, B.: 1992, **Forest Management**, Pretoria, Academic Hatfield.

Ward, R.: 1967, **Principles of Hydrology**, London, McGraw – Hill.

Waring, M.: 1988, **If Women were Counted; A New Feminist Economics**, San Francisco, Harper.

Warren, D.: 1992, *Indigenous Knowledge, Biodiversity, Conservation and Development*", *A Key Note Address***, International Conference on Conservation of Biodiversity in Africa; Local Initiatives and Institutional Roles**; August 30 – September 3, 1992, National Mesium of Kenya, Nairobi.

Warren, D.: 1993, *Indigenous Knowledge and Sustainable Agriculture and Rural Development in Africa; Policy Issues and Strategies for the Twenty-First Century*, Paper Presented at the Annual Meeting of the **African Studies Association**, Boston, December 4-7, 1993.

Warren, D. and Rajasekaran, B.: 1994, *Using Indigenous Knowledge for Sustainable Dry-Land management: A Global Perspective*, in **Listening to the People; Social Aspects of Dry-Land Management**, D. Stiles (ed), Nairobi, Desertification Control Program Activity Centre, United Nations Environment Programme, 89 – 100.

WBGU.: 1995, *World in Transition; Ways Towards Global Environmental Solutions*, **Annual Report**, Bonn, German Advisory Council on Global Change.

Westerberg, L.O.: 1999, **Mass Movement in East African Highlands: Processes, Effects and Scarp Recovery,** Dissertation, Department of Physical Geography, Stockholm, Stockholm university.

Westerberg, L.O. and Christiansson, C.: 1998, *Landslides in East African Highlands, Slope Instability and its Interrelations with Landscape Characteristics and Landuse*, **Advances in Geo-Ecology** 31, 317 - 325.

Wiggins, B.B.: 1998, **Designing Survey Questions. Institute for Research in Social Sciences**. Http://www.irss.unc.edu/irss/bwiggins/shortcourse/designing questions.pdf. 10.12.06

Wieczorek, G.: 1987, *The effects of Rainfall Intensity and Duration on Debris Flows in Central Santa Cruz Mountains, California*, in Costa, J and Wieczorek, G. (ed). Reviews in **Engineering Geology** 7, 93 -104.

Worgu, S.O.: 2000, **Hydro Exploitation, Environmental Degradation and Poverty in the Niger Delta Region of Negeria**, Lund, Lund University.

Wu T.H. and Abdel-Latif, M.A.: 2000, *Prediction and Mapping Landslide Hazard, in* **Canadian Geotechnical Journal** 14, 781 - 795.

Yamamuro, J.A and Lade, P.V.: 1998, *Steady state concepts and static liquefaction of silty sands*, **Journal of Geotechnical and Environmental Enginnering** 124, 868 - 877.

Young, A.: 1972, *Soils*, **Malawi in Maps**, London, Longman.

Young, A.: 1978, **Slopes**, London, Longman.

Zoruba, Q. and Mencl, V.: 1969, *Landslides and their Control*, **Developments in Geotechnical Engineering,** Czechoslovakia Academy of Sciences, Prague 2.

# APPENDICES

## APPENDIX 1: EQUATIONS FOR LANDSLIDE MECHANISMS

### Stress and Strain/Gravitational Force

$W_{// = W} \sin a$ (1)

Where W = weight =mg

m = mass

g = acceleration due to gravity

and a = the slope angle

***Shear stress on the slope***

Stress = $W_{//}$ / A

where A = the area of contact between the soil/regolith and bedrock

Strain = x/h

where x = displacement of upper surface relative to the bottom surface and

and h = depth of material

### Limiting Equilibrium Analysis (LEA*)*

$$\text{Factor of Safety} = \frac{S}{T}$$

$$\text{Factor of Safety} = \frac{c + (\sigma - \cup)\tan\phi}{T} = \frac{c + \left(\frac{W}{A}\cos B - \cup\right)\tan\phi}{\frac{W}{A}\sin B} \quad (2)$$

Where S = shear strength

T = shear stress

C = cohesion with respect to normal stress

σ = total normal stress

$\phi$ = angle of internal friction with respect to effective normal stress

$\cup$ = pore water pressure

W = weight of material that is $\gamma$ v

$\gamma$ = bulk density of slope material

A = area of shear plane

v = volume of slope material involved

B = angle of the surface on which movement occurs

## Friction and Cohesion

The size of the frictional force, $f_f$, is expressed in terms of a coefficient of friction, μ, and the component of the weight normal to the slope $W_\perp$.

Where $f_f = \mu W_\perp = \mu W \cos a$ (3)

## The critical angle for sliding

The balance of forces on the regolith can then be expressed in terms of the critical frictional resistance ($R_{ferit}$) and the critical applied force ($F_{crit}$). Failure commences when the critical applied force exceeds the critical frictional resistance as follows

$F_{crit} > R_{ferit}$

i.e $F_{crit} > \mu W \cos a$ (4)

## Cohesion

$F_{crit} > \mu W \cos a + C$ (5)

where C = cohesion.

## Shear Strength of Soil

## Mohr-Coulomb Equation

$$\tau_s = C + \sigma \tan \varnothing \tag{6}$$

Where $\tau_s$ = the shear strength of the soil.

C = Soil cohesion.

$\sigma$ = the normal stress (at right angles to the slope)

And $\varnothing$ = the angle of internal friction or shearing resistance

## Pore Water Pressure

## Mohr-Coulomb Equation and Pore Water Pressure

$\tau_s = C + (\sigma - \xi)$ (7)

Where $\xi$ is pore pressure

## APPENDIX 2: HYDRAULIC CONDUCTIVITY TABLE

| **Class** | **K/Cm/Hr** |
|---|---|
| Very slow | < 0.125 |
| Slow | 0.125 to 0.5 |
| Moderately Slow | 0.5 to 2.0 |
| Moderate | 2.0 to 6.25 |
| Moderately Rapid | 6.25 to 12.5 |
| Rapid | 12.5 to 25.0 |
| Very Rapid | > 25.0 |

## APPENDIX 3: HOUSEHOLD QUESTIONNAIRE

## A COMPARATIVE STUDY OF LANDSLIDES AND GEOHAZARD MITIGATION IN NORTHERN AND CENTRAL MALAWI

## HOUSEHOLD QUESTIONNAIRE

### INTRODUCTION

The study is aimed at ascertaining peoples' perceptions on the occurrence of landslides in their respective areas by focusing on the causes and contributing factors of landslides. It will also look at landslide histories, socio-economic and environmental impacts of landslides. Issues of coping strategies will also be addressed.

Information which will be obtained will be used for academic purposes only and will be treated with absolute confidentiality.

Interviewer

| |
|---|
| |

Questionnaire Number

| |
|---|
| |

District

| | |
|---|---|
| Name | |
| Code | |

Study Area

| | |
|---|---|
| Name | |
| Code | |

Traditional Authority

| | |
|---|---|
| Name | |
| Code | |

Village

| | |
|---|---|
| Name | |
| Code | |

Name of Interviewee

| |
|---|
| |

Duration of residence in the affected area (years)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Code | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Years | <10 | 10-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60+ |
| Tick | | | | | | | |

## A. DEMOGRAPHIC DATA

1. Age of Respondent

| Age range | Code | Tick |
|---|---|---|
| 20 – 30 yrs | 1 | |
| 31 – 40 yrs | 2 | |
| 41 – 50 yrs | 3 | |
| > 51 yrs | 4 | |

2. Gender

| Gender | Code | Tick |
|---|---|---|
| Male | 1 | |
| Female | 2 | |

3. Head of Household

| | | |
|---|---|---|
| Yes | 1 | |
| No | 2 | |

## B. SOCIO-ECONOMIC DATA

4. What is your level of education?

| | | |
|---|---|---|
| Primary (Std 1 – 8) | 1 | |
| Secondary (Form 1 – 4) | 2 | |
| Tertiary (certificate, diploma, degree) | 3 | |
| No formal education | 4 | |

5. Are you employed?

| | | |
|---|---|---|
| Yes (proceed to Q 6) | 1 | |
| No (go to Q 8) | 2 | |

6. Tick your category of employment

| | | |
|---|---|---|
| Self-employed | 1 | |
| Formally employed | 2 | |
| Informally employed | 3 | |

7. What is your monthly income?

| | | |
|---|---|---|
| < K1000 | 1 | |
| K1001 – K2000 | 2 | |
| K2001 – K5000 | 3 | |
| >K5001 | 4 | |

8. Tick your type of housing

| | | |
|---|---|---|
| Temporary structures | 1 | |
| Permanent structures | 2 | |

9. Where is your house located?

| | | |
|---|---|---|
| Along the ridge | 1 | |
| Along the valley | 2 | |
| At the foot of the mountain or hill | 3 | |
| Along the slope | 4 | |

10. Why is your house located where it is?

| | | |
|---|---|---|
| It is on ancestral land | 1 | |
| Land given by the chief | 2 | |
| Shortage of land | 3 | |
| Other reasons (Please specify) | 4 | |

## C. LANDSLIDES HISTORIES, CAUSES AND IMPACTS

11. Do you have any knowledge of past landslides?

| | | |
|---|---|---|
| Yes | 1 | |
| No | 2 | |
| Give reason(s) | 3 | |

12. Do you remember when the events happened?

| | | |
|---|---|---|
| 1940s | 1 | |
| 1950s | 2 | |
| 1960s | 3 | |
| 1970s | 4 | |
| 1980s | 5 | |
| 1990s | 6 | |
| 2000 > | 7 | |

13. Did the events come as a surprise?

| | | |
|---|---|---|
| Yes | 1 | |
| No | 2 | |

14. Before the landslide events, what were the general weather conditions?

| | | |
|---|---|---|
| It was dry | 1 | |
| It was wet | 2 | |
| It was after prolonged rain showers | 3 | |
| It was after high intensity rain fall | 4 | |
| Cannot remember | 5 | |
| Others (Specify) | 6 | |

15. What do you think were the causes of landslides? (Answer all)

| **Causes** | **1. strongly agree** | **2. agree** | **3. neutral** | **4. disagree** | **5. strongly disagree** |
|---|---|---|---|---|---|
| A. Prolonged precipitation | | | | | |
| B. High intensity precipitation | | | | | |
| C. Weathering of rocks | | | | | |
| D. Deforestation | | | | | |
| E. Fracturing, fissuring and jointing | | | | | |
| F. Earth tremors or earthquakes | | | | | |
| G. Poor farming practices | | | | | |
| H. Infrastructure development | | | | | |
| I. Changes in weather patterns | | | | | |
| J. Others (Specify) | | | | | |

15. What are the traditional beliefs on the occurrence of landslides?

| | | |
|---|---|---|
| Napolo | 1 | |
| Pre-determined by God | 2 | |
| Vwira | 3 | |
| Others (Specify) | 4 | |

16. When did the area start experiencing landslides?

| | | |
|---|---|---|
| Before 1940s | 1 | |
| 1941 - 1950 | 2 | |
| 1951 – 1960 | 3 | |
| 1961 – 1970 | 4 | |
| 1971 – 1980 | 5 | |
| 1981 – 1990 | 6 | |
| 1991 – 2000 | 7 | |
| After 2000 | 8 | |

18. Do the landslides occur repeatedly in the same area?

| | | |
|---|---|---|
| Yes | 1 | |
| No | 2 | |

19. What do you think has contributed to the frequent occurrence of landslides?

| | | |
|---|---|---|
| Land degradation (Deforestation) | 1 | |
| Poor farming methods | 2 | |
| Changes in weather patterns | 3 | |
| Others (Please Specify) | 4 | |

20. How often do landslides occur in your area?

| | | |
|---|---|---|
| Every year | 1 | |
| Every two years | 2 | |
| Every three years | 3 | |
| Every four years | 4 | |
| Every five years | 5 | |
| Every ten years | 6 | |
| Cannot remember | 7 | |

21. Which parts of the slopes are susceptible to landslides? (Choose from the list)

| | | |
|---|---|---|
| Upper slopes | 1 | |
| Middle slopes | 2 | |
| Lower slopes | 3 | |
| The whole slope | 4 | |
| I don’t know | 5 | |
| Other places (Specify) | 6 | |

22. Which are the danger-prone areas?

| | | |
|---|---|---|
| Deforested areas | 1 | |
| Degraded land | 2 | |
| Steep slopes | 3 | |
| Areas with fissures, joints and cracks | 4 | |
| Cultivated marginal lands | 5 | |

23. What were the impacts of landslides in your area?

| | | |
|---|---|---|
| Destruction of Houses | 1 | |
| Injuries of people | 2 | |
| Loss of livestock | 3 | |
| Loss of crops | 4 | |
| Destruction of farmland | 5 | |
| Destruction of infrastructure | 6 | |
| Flooding | 7 | |
| Death of people | 8 | |
| Others (Specify) | 9 | |

24. What was the most devastating impact of landslides in your area? (Tick only one)

| | | |
|---|---|---|
| Destruction of houses | 1 | |
| Injuries of people | 2 | |
| Loss of livestock | 3 | |
| Loss of crops | 4 | |
| Destruction of farmland | 5 | |
| Destruction of infrastructure | 6 | |
| Flooding | 7 | |
| Death of people | 8 | |
| Others (Specify) | 9 | |

25. How did you bridge the food gap created by landslide events?

| | | |
|---|---|---|
| Food aid from Government | 1 | |
| Replanted crops | 2 | |
| Sale of livestock | 3 | |
| Sale of household property | 4 | |
| Bought food using monthly income | 5 | |
| Food aid from NGOs | 6 | |
| Others (Specify) | | |

26. Which crops were affected by the landslides?

| | | |
|---|---|---|
| Maize | 1 | |
| Cassava | 2 | |
| Sweet potatoes | 3 | |
| Irish potatoes | 4 | |
| Beans | 5 | |
| Coffee | 6 | |
| Others (Specify) | 7 | |

27. What was the size of the crop area that was affected by different landslide events?

| | | |
|---|---|---|
| < ¼ of a hectare | 1 | |
| ½ of a hectare | 2 | |
| 1 hectare | 3 | |
| > 1 hectare | 4 | |

28. How much do the affected crops contribute to household nutrition?

| **Crop** | **Much** | **Less** | **Insignificant** | **Code** |
|---|---|---|---|---|
| Maize | | | | 1 |
| Cassava | | | | 2 |
| Beans | | | | 3 |
| Sweet potatoes | | | | 4 |
| Irish potatoes | | | | 5 |
| Coffee | | | | 6 |
| Others (Specify) | | | | 7 |

29. What was done during the events?

| | | |
|---|---|---|
| Moved to safer ground | 1 | |
| The injured were taken to the hospital | 2 | |
| Government came to our rescue | 3 | |
| We were relocated | 4 | |
| NGOs came to our rescue | 5 | |
| Others (Specify) | 6 | |

30. What was done after the events?

| | | |
|---|---|---|
| Moved to safer ground | 1 | |
| The injured were taken to the hospital | 2 | |
| Government came to our rescue | 3 | |
| We were relocated | 4 | |
| NGOs came to our rescue | 5 | |
| Others (Specify) | 6 | |

31. How long did it take before the Government to provide assistance?

| | | |
|---|---|---|
| A few hours | 1 | |
| One day | 2 | |
| One week | 3 | |
| Two weeks | 4 | |
| Three weeks | 5 | |
| One month | 6 | |
| Others (Specify) | 7 | |

32. How long did it take before the Non Governmental Organizations (NGOs) to provide assistance?

| | | |
|---|---|---|
| A few hours | 1 | |
| One day | 2 | |
| One week | 3 | |
| Two weeks | 4 | |
| Three weeks | 5 | |
| One month | 6 | |
| Others (Specify) | 7 | |

33. What assistance was provided by Government?

| | | |
|---|---|---|
| Food distribution | 1 | |
| Medical care | 2 | |
| Tents | 3 | |
| Relocation of settlements | 4 | |
| Nothing | 5 | |
| Others (Specify) | 6 | |

34. What assistance was provided by NGOs?

| | | |
|---|---|---|
| Food distribution | 1 | |
| Medical care | 2 | |
| Tents | 3 | |
| Relocation of settlements | 4 | |
| Nothing | 5 | |
| Others (Specify) | 6 | |

35. What was the most important form of assistance provided by the Government? (Tick only one)

| | | |
|---|---|---|
| Food distribution | 1 | |
| Medical care | 2 | |
| Tents | 3 | |
| Relocation of settlements | 4 | |
| Others (Specify) | 5 | |

36. What was the most important form of assistance provided by NGOs? (Tick only one)

| | | |
|---|---|---|
| Food distribution | 1 | |
| Medical care | 2 | |
| Tents | 3 | |
| Relocation of settlements | 4 | |
| Others (Specify) | 5 | |

37. What measures have you taken to combat landslides?

| | | |
|---|---|---|
| Afforestation programs | 1 | |
| Avoiding cultivation on marginal land/steep slopes | 2 | |
| Relocation of settlements | 3 | |
| Proper sitting of buildings | 4 | |
| Proper building codes | 5 | |
| Others (Specify) | 6 | |

38. Whose responsibility is the management of slope instability problems in your area?

| | | |
|---|---|---|
| Local people themselves | 1 | |
| Government departments | 2 | |
| Non Government Organizations | 3 | |
| Others (Specify) | 4 | |

39. What do you think the Government or NGOs should do to address the problem?

| | | |
|---|---|---|
| Provide seedlings for the afforestation program | 1 | |
| Awareness campaigns on the dangers and causes of landslides | 2 | |
| Provide building standards | 3 | |
| Introduce village housing schemes | 4 | |
| Relocate settlements to safer ground | 5 | |
| Others (Specify) | 6 | |

40. What do you think the NGOs should do to address the problem?

| | | |
|---|---|---|
| Provide seedlings for the afforestation program | 1 | |
| Awareness campaigns on the dangers and causes of landslides | 2 | |
| Provide building standards | 3 | |
| Introduce village housing schemes | 4 | |
| Relocate settlements to safer ground | 5 | |
| Others (Specify) | 6 | |

**Thank you for your participation**

## APPENDIX 4: DISTRICT COMMISSIONERS, ENVIRONMENTAL OFFICERS QUESTIONNARE

### A COMPARATIVE STUDY OF LANDSLIDES AND GEOHAZARD MITIGATION IN NORTHERN AND CENTRAL MALAWI

### DISTRICT COMMISSIONERS, ENVIRONMENTAL OFFICERS QUESTIONNAIRE

### INTRODUCTION

The study seeks to assess landslide geo-hazards in your district. The study will assess the causes and contributing factors to land sliding. The study will establish how human interventions have modified landslide magnitude, frequency, and geographical distribution. It will map danger-prone areas. It will also look at government and non governmental response to landslides

Information which will be obtained will be used for academic purposes only and will be treated with absolute confidentiality.
Interviewer
District Name
Date

1. Do you have any knowledge of landslides in your district?

______________________________________________________________
______________________________________________________________
______________________________________________________________

2. Do you have records of past landslide events?

______________________________________________________________
______________________________________________________________
______________________________________________________________

3. How often do landslides occur in your district?

______________________________________________________________
______________________________________________________________
______________________________________________________________

4. Which are the major affected areas in your district?

______________________________________________________________
______________________________________________________________
______________________________________________________________

5. When was the last event reported to your office?

6. Who did the reporting?

7. What was done immediately after the event?

8. What were the impacts of the landslides?

9. In your opinion, what do you think are the causes or contributing factors to land sliding?

10. Are the local people aware of the causes of landslides?

11. How do you determine danger-prone areas in your district?

12. To what extent do the following influence the occurrence of landslides?

A. Population growth

B. distribution patterns

C. and human activities

13 How long does it take for information on landslide events to reach your office and for your office to respond with assistance?

14 Are there studies which are being carried out in your district on landslides?

15 Do you have a landslide Disaster Management Plan for the district?

16 If, yes, what are the major issues in the landslide Disaster Management Plan?

17 In the absence of a disaster management plan, what mitigation measures have been put in place to prevent or reduce landslides?

18 Are the local people involved in the management of their environment?

19 Are they aware of the Landslide Management Plan?

**Thank you for your participation**

## APPENDIX 5: GEOLOGICAL SURVEY DEPARTMENT QUESTIONNARE

## A COMPERATIVE STUDY OF LANDSLIDES AND GEOHAZARD MITIGATION IN NORTHERN AND CENTRAL MALAWI

## GEOLOGICAL SURVEY DEPARTMENT QUESTIONNAIRE

### INTRODUCTION

The study seeks to assess landslide geo-hazards in the Ntchenachena and Chiweta areas (Rumphi District) and Mvai/Livilivi Catchments (Ntcheu District). The study will assess the causes and contributing factors to landsliding. The study will establish how human interventions have modified landslide magnitude, frequency, and geographical distribution. It will map danger prone areas.

Information which will be obtained will be used for academic purposes only and will be treated with absolute confidentiality.

1. What is the spatial distribution of landslides in Malawi?

______________________________________________

______________________________________________

______________________________________________

2. In terms of landslides, which areas are considered danger-prone areas in Malawi?

______________________________________________

______________________________________________

______________________________________________

3. Do you keep records of landslide occurrences in Malawi (inventory maps)?

______________________________________________

______________________________________________

______________________________________________

4. When your office receives reports about landslides, how do you respond?

______________________________________________

______________________________________________

______________________________________________

5. Are there any projects dealing with landslide mapping?

6. How far have you gone with landslide susceptibility mapping exercises?

7. How do you predict landslide occurrences?

8. What in your opinion, is the stability status of the:
    a. Ntchenachena hills?

    b. Chiweta beds?

    c. Ntcheu Mountain Area?

9. To what extent do you disseminate the findings to the local people in the affected areas?

10. In your opinion, what are the causes of landslides in Malawi?

11. What are the contributing factors to landslide occurrences in Malawi?

12. How does the scientific explanation differ from traditional view of landslides?

13. What measures can be instituted to rehabilitate and manage fragile slopes by the:

A. Local people,

B. Government

C. Non-Governmental Organizations

14. Why in your opinion, it is that landslide studies have been concentrated in Southern Malawi?

15. Why in you opinion it is that so little research work on landslides is being carried out at the moment?

16. To what extent is the Department of Geological Survey working with research institutions and universities in researching landslides?

**Thank you for participating**

## APPENDIX 6: MULTIPLE COMPARISON TESTS ON LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX

### Post Hoc Multiple Comparison Tests On Liquid Limit, Plastic Limit and Plasticity Index

| Dependent Variable | Site Code I | Site Code J | LSD Test | | Benforroni Test | |
|---|---|---|---|---|---|---|
| | | | Mean Difference | Sig. | Mean Difference | Sig. |
| Liquid limit 0 – 100cm | Ntchenachena | Chiweta | 15.1394* | .000 | 15.1394* | .000 |
| | | Mvai | -1.4899 | .554 | -1.4899 | 1.00 |
| | | Livilivi | 6.3214* | .031 | 6.3214 | .188 |
| | Chiweta | Ntchenachena | -15.1394* | .000 | -15.1394* | .000 |
| | | Mvai | -16.6293* | .000 | -16.6293* | .000 |
| | | Livilivi | -8.8180* | .011 | -8.8180 | .066 |
| | Mvai | Ntchenachena | 1.4899 | .554 | 1.4899 | 1.00 |
| | | Chiweta | 16.6293* | .000 | 16.6293* | .000 |
| | | Livilivi | 7.8113* | .027 | 7.8113 | .160 |
| | Livilivi | Ntchenachena | -6.3214* | .031 | -6.3214 | .188 |
| | | Chiweta | 8.8180* | .011 | 8.8180 | .066 |
| | | Mvai | -7.8113* | .027 | -7.8113 | .166 |
| Liquid limit >100cm | Ntchenachena | Chiweta | 11.9361* | .000 | 11.9361* | .000 |
| | | Mvai | 3.1787 | .220 | 3.1787 | 1.00 |
| | | Livilivi | 8.7740* | .004 | 8.7740* | .023 |
| | Chiweta | Ntchenachena | -11.9361* | .000 | -11.9361* | .000 |
| | | Mvai | -8.7574* | .007 | -8.7574* | .040 |
| | | Livilivi | -3.1621 | .370 | -3.1621 | 1.00 |
| | Mvai | Ntchenachena | -3.1787 | .220 | -3.1787 | 1.00 |
| | | Chiweta | 8.7574* | .007 | 8.7574* | 0.40 |
| | | Livilivi | 5.5953 | .120 | 5.5953 | .723 |
| | Livilivi | Ntchenachena | -8.7740* | .004 | -8.7740* | .023 |
| | | Chiweta | 3.1621 | .370 | 3.1621 | 1.00 |
| | | Mvai | -5.5953 | .120 | -5.5953 | .723 |
| Plastic Limit 0 – 100cm | Ntchenachena | Chiweta | 3.7825* | .039 | 3.7825 | .234 |
| | | Mvai | -5.7891* | .003 | -5.7891* | .015 |
| | | Livilivi | 3.1729 | .148 | 3.1729 | .889 |
| | Chiweta | Ntchenachena | -3.7825* | .039 | -3.7825* | .234 |
| | | Mvai | -9.5717* | .000 | -9.5717* | .000 |
| | | Livilivi | -.6069 | .813 | -.6069 | 1.000 |
| | Mvai | Ntchenachena | 5.7891* | .003 | 5.7891* | .015 |
| | | Chiweta | 9.5717* | .000 | 9.5717* | .000 |
| | | Livilivi | 8.926* | .001 | 8.926* | .005 |
| | Livilivi | Ntchenachena | -3.1729 | .148 | -3.1729 | .889 |
| | | Chiweta | .6096 | .813 | .6096 | 1.000 |
| | | Mvai | -8.9621* | .001 | -8.9621* | .005 |
| Plastic Limit >100cm | Ntchenachena | Chiweta | 2.0792 | .267 | 2.0792 | 1.00 |
| | | Mvai | .3161 | .871 | .3161 | 1.00 |
| | | Livilivi | 5.3101* | .019 | 5.3101* | .117 |
| | Chiweta | Ntchenachena | -2.0792 | .267 | -2.0792 | 1.00 |
| | | Mvai | -1.7631 | .461 | -1.7631 | 1.00 |
| | | Livilivi | 3.2309 | .223 | 3.2309 | 1.00 |
| | Mvai | Ntchenachena | -.3161 | .871 | -.3161 | 1.00 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  | Chiweta | 1.7631 | .461 | 1.7631 | 1.00 |
|  |  | Livilivi | 4.9940 | .066 | 4.9940 | .395 |
|  | Livilivi | Ntchenachena | -5.3101* | .019 | -5.3101* | .117 |
|  |  | Chiweta | -3.2309 | .223 | -3.2309 | 1.00 |
|  |  | Mvai | -4.9940 | .066 | -4.9940 | .395 |
| Plasticity Index 0 – 100cm | Ntchenachena | Chiweta | 11.5224* | .000 | 11.5224* | .000 |
|  |  | Mvai | 5.3783* | .003 | 5.3783* | .017 |
|  |  | Livilivi | 3.3140 | .107 | 3.3140 | .643 |
|  | Chiweta | Ntchenachena | -11.5224* | .000 | -11.5224* | .000 |
|  |  | Mvai | -6.1441* | .005 | -6.1441* | .033 |
|  |  | Livilivi | -8.2084* | .001 | -8.2084* | .005 |
|  | Mvai | Ntchenachena | -5.3783* | .003 | -5.3783* | .017 |
|  |  | Chiweta | 6.1441* | .005 | 6.1441* | .033 |
|  |  | Livilivi | -2.06443 | .401 | -2.06443 | 1.00 |
|  | Livilivi | Ntchenachena | -3.3140 | .107 | -3.3140 | .643 |
|  |  | Chiweta | 8.2084* | .001 | 8.2084* | .005 |
|  |  | Mvai | 2.0643 | .401 | 2.0643 | 1.00 |
| Plasticity Index >100cm | Ntchenachena | Chiweta | 10.8360* | .000 | 10.8360* | .000 |
|  |  | Mvai | 5.2235* | .012 | 5.2235 | .070 |
|  |  | Livilivi | 4.2415 | .075 | 4.2415 | .451 |
|  | Chiweta | Ntchenachena | -10.8360* | .000 | -10.8360* | .000 |
|  |  | Mvai | -5.6125* | .027 | -5.6125 | .164 |
|  |  | Livilivi | -6.5945* | .019 | -6.5945 | .116 |
|  | Mvai | Ntchenachena | -5.2235* | .012 | -5.2235 | .070 |
|  |  | Chiweta | 5.6125* | .027 | 5.6125 | .164 |
|  |  | Livilivi | -.9820 | .730 | -.9820 | 1.00 |
|  | Livilivi | Ntchenachena | -4.2415 | .075 | -4.2415 | .451 |
|  |  | Chiweta | 6.5945* | .019 | 6.5945 | .116 |
|  |  | Mvai | .9820 | .730 | .9820 | 1.00 |

# APPENDIX 7: MULTIPLE COMPARISON TESTS ON AGGREGATE STABILITY, HYDRAULIC CONDUCTIVITY, BULK DENSITY AND TOTAL POROSITY

## Post Hoc Multiple Comparison Tests on Aggregate Stability, Hydraulic Conductivity, Bulk Density and Total Porosity

| Dependent Variable | Site Code I | Site Code J | LSD Test | | Benforroni Test | |
|---|---|---|---|---|---|---|
| | | | Mean Difference | Sig. | Mean Difference | Sig. |
| Aggregate Stability 0 – 100cm | Ntchenachena | Chiweta | -.996 | .488 | -.996 | 1.00 |
| | | Mvai | .0832 | .577 | .0832 | 1.00 |
| | | Livilivi | .6599* | .000 | .6599* | .001 |
| | Chiweta | Ntchenachena | .0996 | .488 | .0996 | 1.00 |
| | | Mvai | .1828 | .320 | .1828 | 1.00 |
| | | Livilivi | .7595* | .000 | .7595* | .002 |
| | Mvai | Ntchenachena | -.0832 | .577 | -.0832 | 1.00 |
| | | Chiweta | -.1828 | .320 | -.1828 | 1.00 |
| | | Livilivi | .5768* | .006 | .5768* | .036 |
| | Livilivi | Ntchenachena | -.6599* | .000 | -.6599* | .001 |
| | | Chiweta | -.7595* | .000 | -.7595* | .002 |
| | | Mvai | -.5768* | .006 | -.5768* | .036 |
| Aggregate Stability >100cm | Ntchenachena | Chiweta | -.0597 | .721 | -.0597 | 1.00 |
| | | Mvai | .1344 | .440 | .1344 | 1.00 |
| | | Livilivi | .8274* | .000 | .8274* | .000 |
| | Chiweta | Ntchenachena | .0597 | .721 | .0597 | 1.000 |
| | | Mvai | .1941 | .365 | .1941 | 1.000 |
| | | Livilivi | .8871* | .000 | .8871* | .002 |
| | Mvai | Ntchenachena | -.1344 | .440 | -.1344 | 1.000 |
| | | Chiweta | -.1941 | .365 | -.1941 | 1.000 |
| | | Livilivi | .6930* | .005 | .6930* | .028 |
| | Livilivi | Ntchenachena | -.8274* | .000 | -.8274* | .000 |
| | | Chiweta | -8871* | .000 | -8871* | .002 |
| | | Mvai | -.6930* | .005 | -.6930* | .028 |
| Hydraulic Conductivity 0 – 100cm | Ntchenachena | Chiweta | 1.0762* | 0.46 | 1.0762 | .279 |
| | | Mvai | -.2571 | .644 | -.2571 | 1.00 |
| | | Livilivi | .3099 | .630 | .3099 | 1.00 |
| | Chiweta | Ntchenachena | -1.0762 | .046 | -1.0762 | .276 |
| | | Mvai | -1.3334 | .053 | -1.3334 | .318 |
| | | Livilivi | -.7664 | .312 | -.7664 | 1.00 |
| | Mvai | Ntchenachena | .2571 | .644 | .2571 | 1.00 |
| | | Chiweta | 1.3334 | .053 | 1.3334 | .318 |
| | | Livilivi | .5670 | .463 | .5670 | 1.00 |
| | Livilivi | Ntchenachena | -.3099 | .630 | -.3099 | 1.00 |
| | | Chiweta | .7664 | .312 | .7664 | 1.00 |
| | | Mvai | -.5670 | .463 | -.5670 | 1.00 |
| Hydraulic Conductivity 100cm | Ntchenachena | Chiweta | .8370 | 113 | .8370 | 680 |
| | | Mvai | .2443 | .655 | .2443 | 1.00 |
| | | Livilivi | -.4083 | .519 | -.4083 | 1.00 |
| | Chiweta | Ntchenachena | -.8370 | .113 | -.8370 | .680 |
| | | Mvai | -.5927 | .379 | -.5927 | 1.00 |
| | | Livilivi | -1.2453 | .096 | -1.2453 | .575 |
| | Mvai | Ntchenachena | -.2443 | .655 | -.2443 | 1.00 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  | Chiweta | .5927 | .379 | .5927 | 1.00 |
|  |  | Livilivi | -.6526 | .390 | -.6526 | 1.00 |
|  | Livilivi | Ntchenachena | .4083 | .519 | .4083 | 1.00 |
|  |  | Chiweta | 1.2453 | .096 | 1.2453 | .575 |
|  |  | Mvai | .6526 | .390 | .6526 | 1.00 |
| Bulk Density 0 – 100cm | Ntchenachena | Chiweta | -.1284* | .003 | -.1284* | .020 |
|  |  | Mvai | .0584 | .193 | .0584 | 1.00 |
|  |  | Livilivi | -.0682 | .188 | -.0682 | 1.00 |
|  | Chiweta | Ntchenachena | .1284* | .003 | .1284* | .020 |
|  |  | Mvai | .1868* | .001 | .1868* | .005 |
|  |  | Livilivi | .0601 | .324 | .0601 | 1.00 |
|  | Mvai | Ntchenachena | -.0584 | .193 | -.0584 | 1.00 |
|  |  | Chiweta | -.1868* | .001 | -.1868* | .005 |
|  |  | Livilivi | -.1266* | .043 | -.1266 | .257 |
|  | Livilivi | Ntchenachena | .0682 | .188 | .0682 | 1.00 |
|  |  | Chiweta | -.0601 | .324 | -.0601 | 1.00 |
|  |  | Mvai | .1266* | .043 | .1266 | .257 |
| Bulk Density >100cm | Ntchenachena | Chiweta | -.0994* | .024 | -.0994 | .144 |
|  |  | Mvai | -.0327 | .471 | -.0327 | 1.00 |
|  |  | Livilivi | -.0097 | .852 | -.0097 | 1.00 |
|  | Chiweta | Ntchenachena | .0994* | .024 | .0994 | .144 |
|  |  | Mvai | .0667 | .233 | .0667 | 1.00 |
|  |  | Livilivi | .0896 | .148 | .0896 | .886 |
|  | Mvai | Ntchenachena | .0327 | .471 | .0327 | 1.00 |
|  |  | Chiweta | -.0667 | .233 | -.0667 | 1.00 |
|  |  | Livilivi | .0229 | .715 | .0229 | 1.00 |
|  | Livilivi | Ntchenachena | .0097 | .852 | .0097 | 1.00 |
|  |  | Chiweta | -.0896 | .148 | -.0896 | .886 |
|  |  | Mvai | -.0229 | .515 | -.0229 | 1.00 |
| Porosity 0 – 100cm | Ntchenachena | Chiweta | 4.9423* | .004 | 4.9423* | .027 |
|  |  | Mvai | -2.2224 | .212 | -2.2224 | 1.00 |
|  |  | Livilivi | 3.7215 | .072 | 3.7215 | .433 |
|  | Chiweta | Ntchenachena | -4.9423* | .004 | -4.9423* | .027 |
|  |  | Mvai | -7.1646* | .001 | -7.1646* | .008 |
|  |  | Livilivi | -1.2208 | .614 | -1.2208 | 1.00 |
|  | Mvai | Ntchenachena | 2.2224 | .212 | 2.2224 | 1.00 |
|  |  | Chiweta | 7.1646* | .001 | 7.1646* | .008 |
|  |  | Livilivi | 5.9439* | .017 | 5.9439 | .103 |
|  | Livilivi | Ntchenachena | -3.7215 | .072 | -3.7215 | .433 |
|  |  | Chiweta | 1.2208 | .614 | 1.2208 | 1.00 |
|  |  | Mvai | -5.9439* | .017 | -5.9439 | .103 |
| Porosity >100cm | Ntchenachena | Chiweta | 3.3949* | .042 | 3.3949 | .252 |
|  |  | Mvai | 1.3329 | .439 | 1.3329 | 1.00 |
|  |  | Livilivi | .4678 | .814 | .4678 | 1.00 |
|  | Chiweta | Ntchenachena | -3.3949* | .42 | -3.3949 | .252 |
|  |  | Mvai | -2.0620 | .331 | -2.0620 | 1.00 |
|  |  | Livilivi | -2.9271 | .213 | -2.9271 | 1.00 |
|  | Mvai | Ntchenachena | -1.3329 | .439 | -1.3329 | 1.00 |
|  |  | Chiweta | 2.0602 | .331 | 2.0602 | 1.00 |
|  |  | Livilivi | --.8651 | .717 | --.8651 | 1.00 |
|  | Livilivi | Ntchenachena | -.4678 | .814 | -.4678 | 1.00 |
|  |  | Chiweta | 2.9271 | .213 | 2.9271 | 1.00 |
|  |  | Mvai* | .8651 | .717 | .8651 | 1.00 |

## APPENDIX 8: MULTIPLE COMPARISON TESTS ON SOIL PARTICLES

### Post Hoc Multiple Comparison Tests on Soil Particles

| Dependent Variable | Site Code I | Site Code J | LSD Test | | Benforroni Test | |
|---|---|---|---|---|---|---|
| | | | Mean Difference | Sig. | Mean Difference | Sig. |
| Total Sand 0 – 100cm | Ntchenachena | Chiweta | -4.6840* | .024 | -4.6840 | .142 |
| | | Mvai | -6.2668* | .004 | -6.2668* | .023 |
| | | Livilivi | -6.5587* | .009 | -6.5587 | .052 |
| | Chiweta | Ntchenachena | 4.6840* | .024 | 4.6840 | .142 |
| | | Mvai | -1.5828 | .546 | -1.5828 | 1.00 |
| | | Livilivi | -1.8747 | .518 | -1.8747 | 1.00 |
| | Mvai | Ntchenachena | 6.2668* | .004 | 6.2668* | .023 |
| | | Chiweta | 1.5828 | .546 | 1.5828 | 1.00 |
| | | Livilivi | -.2919 | .921 | -.2919 | 1.00 |
| | Livilivi | Ntchenachena | 6.5587* | .009 | 6.5587 | .052 |
| | | Chiweta | 1.8747 | .518 | 1.8747 | 1.00 |
| | | Mvai | .2919 | .921 | .2919 | 1.00 |
| Total Sand >100 | Ntchenachena | Chiweta | -4.3170* | .004 | -4.3170 | .266 |
| | | Mvai | -5.9061* | .008 | -5.9061 | .050 |
| | | Livilivi | -5.2204* | .043 | -5.2204 | .258 |
| | Chiweta | Ntchenachena | 4.3170* | .044 | 4.3170 | .266 |
| | | Mvai | -1.5891 | .560 | -1.5891 | 1.00 |
| | | Livilivi | -.9034 | .764 | -.9034 | 1.00 |
| | Mvai | Ntchenachena | 5.9061* | .008 | 5.9061 | .050 |
| | | Chiweta | 1.5891 | .560 | 1.5891 | 1.00 |
| | | Livilivi | .6857 | .823 | .6857 | 1.00 |
| | Livilivi | Ntchenachena | 5.2204* | .043 | 5.2204* | .258 |
| | | Chiweta | .9034 | .764 | .9034 | 1.00 |
| | | Mvai | -.6857 | .823 | -.6857 | 1.00 |
| Medium + Fine Sand 0 - 100 | Ntchenachena | Chiweta | -6.8210* | .008 | -6.8210* | .047 |
| | | Mvai | -15.5568* | .000 | -15.5568* | .000 |
| | | Livilivi | -9.0535* | .003 | -9.0535* | .021 |
| | Chiweta | Ntchenachena | 6.8210* | .008 | 6.8210* | .047 |
| | | Mvai | -8.7358* | .008 | -8.7358* | .046 |
| | | Livilivi | -2.2325 | .533 | -2.2325 | 1.00 |
| | Mvai | Ntchenachena | 15.5568* | .000 | 15.5568* | .000 |
| | | Chiweta | 8.7358* | .008 | 8.7358* | .046 |
| | | Livilivi | 6.5033 | .076 | 6.5033 | .485 |
| | Livilivi | Ntchenachena | 9.0535* | .003 | 9.0535* | .021 |
| | | Chiweta | 2.2325 | .533 | 2.2325 | 1.00 |
| | | Mvai | -6.5033 | .076 | -6.5033 | .458 |
| Medium + Fine Sand >100 | Ntchenachena | Chiweta | .-6.5231* | .008 | .-6.5231* | .046 |
| | | Mvai | -12.9824* | .000 | -12.9824* | .000 |
| | | Livilivi | -10.1273* | .001 | -10.1273* | .004 |
| | Chiweta | Ntchenachena | 6.5231* | .008 | 6.5231* | .046 |
| | | Mvai | -6.4594* | .038 | -6.4594 | .226 |
| | | Livilivi | -3.6042 | .291 | -3.6042 | 1.00 |
| | Mvai | Ntchenachena | 12.9824* | .000 | 12.9824* | .000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Chiweta | 6.4594* | .038 | 6.4594 | .226 |
| | | Livilivi | 2.8551 | .412 | 2.8551 | 1.00 |
| | Livilivi | Ntchenachena | 10.1273* | .001 | 10.1273* | .004 |
| | | Chiweta | 3.6042 | .291 | 3.6042 | 1.00 |
| | | Mvai | -2.8551 | .412 | -2.8551 | 1.00 |
| Silt 0 – 100cm | Ntchenachena | Chiweta | -2.1039 | .084 | .084 | .506 |
| | | Mvai | -1.7766 | .159 | .159 | .957 |
| | | Livilivi | -1.2338 | .398 | .398 | 1.00 |
| | Chiweta | Ntchenachena | 2.1039 | .084 | .084 | .506 |
| | | Mvai | .3273 | .833 | .833 | 1.00 |
| | | Livilivi | .8701 | .612 | .612 | 1.00 |
| | Mvai | Ntchenachena | 1.7766 | .159 | .159 | .957 |
| | | Chiweta | -.3273 | .833 | .833 | 1.00 |
| | | Livilivi | .5429 | .756 | .756 | 1.00 |
| | Livilivi | Ntchenachena | 1.2338 | .398 | .398 | 1.00 |
| | | Chiweta | -.8701 | .612 | .612 | 1.00 |
| | | Mvai | -5429 | .756 | .756 | 1.00 |
| Silt >100 | Ntchenachena | Chiweta | -1.9870 | .120 | -1.9870 | .721 |
| | | Mvai | -.0052 | .997 | -.0052 | 1.00 |
| | | Livilivi | -.6623 | .665 | -.6623 | 1.00 |
| | Chiweta | Ntchenachena | 1.9870 | .120 | 1.9870 | .721 |
| | | Mvai | 1.9818 | .224 | 1.9818 | 1.00 |
| | | Livilivi | 1.3247 | .462 | 1.3247 | 1.00 |
| | Mvai | Ntchenachena | .0052 | .997 | .0052 | 1.00 |
| | | Chiweta | -1.9818 | .224 | -1.9818 | 1.00 |
| | | Livilivi | -.6571 | .720 | -.6571 | 1.00 |
| | Livilivi | Ntchenachena | .6623 | .665 | .6623 | 1.00 |
| | | Chiweta | -1.3247 | .462 | -1.3247 | 1.00 |
| | | Mvai | .6571 | .720 | .6571 | 1.00 |
| Clay 0 – 100cm | Ntchenachena | Chiweta | 6.7597* | .000 | 6.7597* | .000 |
| | | Mvai | 8.0506* | .000 | 8.0506* | .000 |
| | | Livilivi | 7.8506* | .000 | 7.8506* | .000 |
| | Chiweta | Ntchenachena | -6.7597* | .000 | -6.7597* | .000 |
| | | Mvai | 1.2909 | .472 | 1.2909 | 1.00 |
| | | Livilivi | 1.0909 | .583 | 1.0909 | 1.00 |
| | Mvai | Ntchenachena | -8.0506* | .000 | -8.0506* | .000 |
| | | Chiweta | -1.2909 | .472 | -1.2909 | 1.00 |
| | | Livilivi | -.2000 | .921 | -.2000 | 1.00 |
| | Livilivi | Ntchenachena | -7.8506* | .000 | -7.8506* | .000 |
| | | Chiweta | -1.0909 | .583 | -1.0909 | 1.00 |
| | | Mvai | .2000 | .921 | .2000 | 1.00 |
| Clay >100cm | Ntchenachena | Chiweta | 5.4481* | .001 | 5.4481* | .008 |
| | | Mvai | 5.9117* | .001 | 5.9117* | .005 |
| | | Livilivi | 6.0260* | .003 | 6.0260* | .018 |
| | Chiweta | Ntchenachena | -5.4481* | .001 | -5.4481* | .008 |
| | | Mvai | .4636 | .827 | .4636 | 1.00 |
| | | Livilivi | .5779 | .805 | .5779 | 1.00 |
| | Mvai | Ntchenachena | -5.9117* | .001 | -5.9117* | .005 |
| | | Chiweta | -.4636 | .827 | -.4636 | 1.00 |
| | | Livilivi | .1143 | .962 | .1143 | 1.00 |
| | Livilivi | Ntchenachena | -6.0260* | .003 | -6.0260* | .018 |
| | | Chiweta | -.5779 | .805 | -.5779 | 1.00 |
| | | Mvai | -.1143 | 962 | -.1143 | 1.00 |

## APPENDIX 9: TESTS FOR THE EQUALITY OF MEANS FOR THE FOUR SITES

### Tests for the Equality of Means for the Four Sites Using ANOVA

| Variable | Group | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Liquid Limit (0-100 cm) | Between Groups | 4492.239 | 3 | 1497.413 | 14.994 | .000 |
| | Within Groups | 12882.559 | 129 | 99.865 | | |
| | Total | 17374.798 | 132 | | | |
| Liquid Limit (>100cm) | Between Groups | 2898.376 | 3 | 966.125 | 9.156 | .000 |
| | Within Groups | 13611.959 | 129 | 105.519 | | |
| | Total | 16510.335 | 132 | | | |
| Plastic Limit (0-100cm) | Between Groups | 1124.939 | 3 | 374.980 | 6.657 | .000 |
| | Within Groups | 7266.782 | 129 | 56.332 | | |
| | Total | 8391.720 | 132 | | | |
| Plastic Limit (100cm) | Between Groups | 371.722 | 3 | 123.907 | 2.078 | .106 |
| | Within Groups | 7693.285 | 129 | 59.638 | | |
| | Total | 8065.007 | 132 | | | |
| Plastic Index (0-100 cm) | Between Groups | 2404.860 | 3 | 801.620 | 16.214 | .000 |
| | Within Groups | 6377.710 | 129 | 49.440 | | |
| | Total | 8782.570 | 132 | | | |
| Plastic Index (>100 cm) | Between Groups | 2164.255 | 3 | 721.418 | 10.894 | .000 |
| | Within Groups | 8542.330 | 129 | 66.220 | | |
| | Total | 10706.585 | 132 | | | |
| Coarse Sand % (0-100 cm) | Between Groups | 1374.684 | 3 | 458.228 | 4.551 | .005 |
| | Within Groups | 12988.830 | 129 | 100.689 | | |
| | Total | 14363.514 | 132 | | | |
| Course Sand % (>100cm) | Between Groups | 942.218 | 3 | 314.073 | 3.765 | .012 |
| | Within Groups | 10761.702 | 129 | 83.424 | | |
| | Total | 11703.920 | 132 | | | |
| Medium Sand %(0-100 cm) | Between Groups | 4133.125 | 3 | 1377.708 | 14.535 | .000 |
| | Within Groups | 12227.642 | 129 | 94.788 | | |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Total | 16360.767 | 132 |  |  |  |
| Medium Sand % (>100 cm) | Between Groups | 1683.958 | 3 | 561.319 | 6.068 | .001 |
|  | Within Groups | 11932.272 | 129 | 92.498 |  |  |
|  | Total | 13616.230 | 132 |  |  |  |
| Fine Sand %(0-100 cm) | Between Groups | 2535.261 | 3 | 845.087 | 12.235 | .000 |
|  | Within Groups | 8910.142 | 129 | 69.071 |  |  |
|  | Total | 11445.403 | 132 |  |  |  |
| Fine Sand %(>100cm) | Between Groups | 2440.852 | 3 | 813.617 | 11.382 | .000 |
|  | Within Groups | 9221.626 | 129 | 71.485 |  |  |
|  | Total | 11662.478 | 132 |  |  |  |
| SILT% (0-100 cm) | Between Groups | 107.992 | 3 | 35.997 | 1.438 | .235 |
|  | Within Groups | 3228.956 | 129 | 25.031 |  |  |
|  | Total | 3336.947 | 132 |  |  |  |
| Silt% (>100cm) | Between Groups | 71.810 | 3 | 23.937 | .867 | .460 |
|  | Within Groups | 3560.265 | 129 | 27.599 |  |  |
|  | Total | 3632.075 | 132 |  |  |  |
| CLAY %(0-100 cm) | Between Groups | 1840.367 | 3 | 613.456 | 18.265 | .000 |
|  | Within Groups | 4332.551 | 129 | 33.586 |  |  |
|  | Total | 6172.917 | 132 |  |  |  |
| Clay %(>100cm) | Between Groups | 1078.541 | 3 | 359.514 | 7.680 | .000 |
|  | Within Groups | 6038.768 | 129 | 46.812 |  |  |
|  | Total | 7117.308 | 132 |  |  |  |
| Degree of Aggregation (MWD) for 0-100cm | Between Groups | 5.883 | 3 | 1.961 | 5.580 | .001 |
|  | Within Groups | 45.335 | 129 | .351 |  |  |
|  | Total | 51.219 | 132 |  |  |  |
| Degree of aggregation (MWD) for >100cm | Between Groups | 8.761 | 3 | 2.920 | 6.124 | .001 |
|  | Within Groups | 61.510 | 129 | .477 |  |  |
|  | Total | 70.270 | 132 |  |  |  |
| Hydraulic conductivity cm/hr (0-100 cm) | Between Groups | 24.215 | 3 | 8.072 | 1.653 | .180 |
|  | Within | 629.801 | 129 | 4.882 |  |  |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Groups |  |  |  |  |  |
|  | Total | 654.016 | 132 |  |  |  |
| Hydraulic conductivity cm/hr (>100 cm) | Between Groups | 16.616 | 3 | 5.539 | 1.174 | .322 |
|  | Within Groups | 608.406 | 129 | 4.716 |  |  |
|  | Total | 625.022 | 132 |  |  |  |
| Bulk Density g/cm (0-100 cm) | Between Groups | .445 | 3 | .148 | 4.697 | .004 |
|  | Within Groups | 4.071 | 129 | .032 |  |  |
|  | Total | 4.516 | 132 |  |  |  |
| Bulk Density g/cm (>100cm) | Between Groups | .173 | 3 | .058 | 1.784 | .153 |
|  | Within Groups | 4.176 | 129 | .032 |  |  |
|  | Total | 4.349 | 132 |  |  |  |
| Total Porosity% (0-100cm) | Between Groups | 728.201 | 3 | 242.734 | 4.861 | .003 |
|  | Within Groups | 6441.433 | 129 | 49.934 |  |  |
|  | Total | 7169.634 | 132 |  |  |  |
| Total Porosity % (>100cm) | Between Groups | 204.630 | 3 | 68.210 | 1.459 | .229 |
|  | Within Groups | 6031.885 | 129 | 46.759 |  |  |
|  | Total | 6236.514 | 132 |  |  |  |
| Total sand % (0-100cm) | Between Groups | 1099.458 | 3 | 366.486 | 5.112 | .002 |
|  | Within Groups | 9248.385 | 129 | 71.693 |  |  |
|  | Total | 10347.843 | 132 |  |  |  |
| Total Sand % (>100cm) | Between Groups | 873.391 | 3 | 291.130 | 3.767 | .012 |
|  | Within Groups | 9969.140 | 129 | 77.280 |  |  |
|  | Total | 10842.531 | 132 |  |  |  |
| Medium and Fine sand % (0-100cm) | Between Groups | 4412.260 | 3 | 1470.753 | 13.475 | .000 |
|  | Within Groups | 14079.571 | 129 | 109.144 |  |  |
|  | Total | 18491.831 | 132 |  |  |  |
| Mediun and Fine sand % (>100cm) | Between Groups | 3510.073 | 3 | 1170.024 | 11.812 | .000 |
|  | Within Groups | 12777.613 | 129 | 99.051 |  |  |
|  | Total | 16287.686 | 132 |  |  |  |

# APPENDIX 10: SOIL SAMPLING GPS COORDINATES

## NTCHENACHENA AREA

| FEATURE | EASTINGS | NORTHINGS | ELEVATION |
|---|---|---|---|
| Spur 1 Pit 1 | 0615335 | 8818464 | 1335 |
| Spur 1 Pit 2 | 0615298 | 8818484 | 1345 |
| Spur 1 Pit 3 | 0615274 | 8818566 | 1347 |
| Spur 1 Pit 4 | 0615322 | 8818566 | 1318 |
| Landslide | 0615271 | 8818548 | 1345 |
| Litowo Spur 1 Pit 1 | 0615050 | 8818632 | 1428 |
| Litowo Spur 1 Pit 2 | 0615022 | 8818652 | 1438 |
| Litowo 2 Pit 1 | 0615180 | 8818596 | 1426 |
| Litowo 2 Pit 2 | 0615210 | 8818572 | 1394 |
| Litowo 2 Pit 3 | 0615181 | 8818612 | 1367 |
| Litowo 2 Pit 4 | 0615230 | 8818595 | 1373 |
| Litowo 3 Pit 1 | 0615147 | 8818576 | 1396 |
| Litowo 3 Pit 2 | 0615209 | 8818528 | 1375 |
| Litowo 3 Pit 3 | 0615105 | 8818590 | 1409 |
| Litowo 3 Pit 4 | 0615114 | 8818578 | 1401 |
| Litowo 3 Pit 4 | 0615066 | 8818570 | 1393 |
| Litowo 4 Pit 1 | 0614709 | 8818858 | 1514 |
| Litowo 4 Pit 2 | 0614734 | 8818874 | 1523 |
| Litowo 4 Pit 3 | 0614791 | 8818826 | 1503 |
| Litowo 4 Pit 4 | 0614891 | 8818740 | 1478 |
| Litowo 5 Pit 1 | 0614792 | 8818834 | 1513 |
| Litowo 5 Pit 2 | 0614808 | 8818826 | 1500 |
| Litowo 5 Pit 3 | 0614837 | 8818802 | 1499 |
| Litowo 5 Pit 4 | 0614860 | 8818768 | 1492 |
| Litowo 6 Pit 1 | 0614590 | 8819004 | 1574 |
| Litowo 6 Pit 2 | 0614679 | 8819154 | 1592 |
| Litowo 6 Pit 3 | 0614655 | 8819310 | 1626 |
| Litowo 7 Pit 1 | 0614684 | 8819488 | 1632 |
| Litowo 7 Pit 2 | 0614729 | 8819504 | 1633 |
| Litowo 7 Pit 3 | 0614812 | 8819506 | 1634 |
| Litowo 7 Pit 4 | 0614877 | 8819464 | 1624 |
| Litowo 7 Pit 5 | 0614972 | 8819454 | 1601 |
| Litowo 7 Pit 6 | 0615076 | 8819396 | 1568 |
| Litowo 7 Pit 8 | 0615230 | 8819226 | 1520 |
| Litowo 7 Pit 9 | 0615282 | 8818952 | 1422 |
| Litowo 8 Pit 1 | 0615468 | 8818680 | 1313 |
| Litowo 8 Pit 2 | 0615459 | 8818714 | 1313 |
| Litowo 8 Pit 3 | 0615439 | 8818739 | 1334 |
| Litowo 8 Pit 4 | 0615412 | 8818768 | 1360 |
| Litowo 8 Pit 5 | 0615387 | 8818842 | 1359 |
| Litowo 8 Pit 6 | 0615358 | 8818882 | 1365 |
| Litowo 8 Pit 7 | 0615350 | 8818920 | 1394 |
| Litowo 8 Pit 8 | 0615331 | 8818940 | 1416 |

| | | | |
|---|---|---|---|
| Litowo 8 Pit 9 | 0615288 | 8819034 | 1445 |
| Litowo 8 Pit 10 | 0615274 | 8819106 | 1470 |
| Litowo 8 Pit 11 | 0615273 | 8819166 | 1495 |
| Kasese Pit 1 | 0615129 | 8818470 | 1337 |
| Kasese Pit 2 | 0615092 | 8818490 | 1352 |
| Kasese Pit 3 | 0614980 | 8818435 | 1420 |
| Kasese Pit 4 | 0614867 | 8818496 | 1464 |
| Kasese Pit 5 | 0614833 | 8818508 | 1484 |
| Kasese Pit 6 | 0614800 | 8818540 | 1500 |
| Kasese Pit 7 | 0614778 | 8818568 | 1507 |
| Kasese Pit 8 | 0161775 | 8818612 | 1494 |
| Kasese Pit 1F | 0614740 | 8818652 | 1505 |
| Kasese Pit 2F | 0614727 | 8818728 | 1504 |
| Kasese Pit 11 | 0614667 | 8818816 | 1513 |
| Kasese Pit 12 | 0614647 | 8818842 | 1510 |
| Kasese Pit 13 | 0614600 | 8818852 | 1504 |
| Chikkwezga A | 0615440 | 8818866 | 1331 |
| Chikkwezga B | 0615444 | 8818912 | 1337 |
| Chikkwezga C | 0615481 | 8818938 | 1335 |
| Chikkwezga D | 0615507 | 8819036 | 1365 |
| Chikkwezga 1 | 0615895 | 8819294 | 1478 |
| Chikkwezga 2 | 0615576 | 8819320 | 1489 |
| Chikkwezga 3 | 0615408 | 8819336 | 1497 |
| Chikkwezga 4 | 0615400 | 8819262 | 1450 |
| Chikkwezga 5 | 0615408 | 8819166 | 1439 |
| Mankhorongo A | 0615560 | 8819024 | 1363 |
| Mankhorongo B | 0615813 | 8818502 | 1287 |
| Mankhorongo C | 0615851 | 8818572 | 1286 |
| Mankhorongo D | 0615851 | 8818642 | 1349 |
| Mankhorongo E | 0615820 | 8818636 | 1337 |
| Mankhorongo F | 0615794 | 8818660 | 1365 |
| Mankhorongo 1 | 0615841 | 8818692 | 1362 |
| Mankhorongo 2 | 0615840 | 8818836 | 1417 |
| Mankhorongo 3 | 0615825 | 8818974 | 1459 |
| Mankhorongo 4 | 0615782 | 8819066 | 1477 |
| Mankhorongo 5 | 0615784 | 8819108 | 1481 |

### CHIWETA AREA

| Feature | Eastings | Northings | Elevation |
|---|---|---|---|
| Chiweta 11U | 0628986 | 8816846 | 786 |
| Chiweta 10U | 0628806 | 8816806 | 842 |
| Chiweta 9U | 0628742 | 8816700 | 878 |
| Chiweta 8U | 0628638 | 8816608 | 858 |
| Chiweta 7U | 0628540 | 8816660 | 856 |
| Chiweta 6U | 0628491 | 8816654 | 853 |
| Chiweta 5U | 0628430 | 8816646 | 865 |
| Chiweta 4U | 0628405 | 8816514 | 853 |
| Chiweta 3U | 0628387 | 8816574 | 860 |

|  |  |  |  |
|---|---|---|---|
| Chiweta2U | 0628267 | 8816768 | 848 |
| Chiweta 1U | 0628174 | 8816770 | 855 |
| Chiweta 1L | 0628179 | 8816726 | 855 |
| Chiweta 2L | 0628269 | 8816712 | 845 |
| Chiweta 3L | 0628319 | 8816620 | 843 |
| Chiweta 4L | 0628345 | 8816508 | 810 |
| Chiweta 5L | 0628484 | 8816472 | 804 |
| Chiweta 6L | 0628556 | 8816574 | 780 |
| Chiweta 7L | 0628652 | 8816554 | 777 |
| Chiweta 8L | 0628860 | 8816480 | 764 |
| Chiweta 9L | 0629011 | 8816430 | 766 |
| Chiweta 10L | 0629062 | 8816566 | 752 |
| Chiweta 11L | 0629013 | 8816750 | 724 |

### MVAI AND LIVILIVI CATCHMENT AREA

| feature | Easting | Northing | Elevation |
|---|---|---|---|
| Livilivi 1 Pit 1 | 0673139 | 8353707 | 1333 |
| Livilivi 1 Pit 2 | 0673171 | 8353757 | 1359 |
| Livilivi 1 Pit 3 | 0677312 | 8353744 | 1354 |
| Livilivi 1 Pit 4 | 0670191 | 8353695 | 1352 |
| Livilivi 1 Pit 5 | 0673143 | 8353708 | 1364 |
| Livilivi 2 Pit 1 | 0673055 | 8353490 | 1323 |
| Livilivi 2 Pit 2 | 0673058 | 8353527 | 1328 |
| Livilivi 2 Pit 3 | 0672994 | 8353540 | 1337 |
| Livilivi 2 Pit 4 | 0672986 | 8353489 | 1358 |
| Livilivi 4 Pit 1 | 0673248 | 8353263 | 1350 |
| Livilivi 4Pit 2 | 0673200 | 8353290 | 1279 |
| Livilivi 4 Pit 3 | 0670174 | 8353249 | 1266 |
| Livilivi 4 Pit 4 | 0673201 | 8353184 | 1277 |
| Livilivi 4 Pit 5 | 0673234 | 8353222 | 1285 |
| Mvai 1 Pit 1 | 0673313 | 8356645 | 1420 |
| Mvai 1 Pit 2 | 0673799 | 8356622 | 1447 |
| Mvai 1 Pit 3 | 0673772 | 8356514 | 1461 |
| Mvai 1 Pit 4 | 0673713 | 8356385 | 1545 |
| Mvai 1 Pit 5 | 0673815 | 8356281 | 1573 |
| Mvai 1 Pit 6 | 0673961 | 8356211 | 1569 |
| Mvai 1 Pit 7 | 0674025 | 8356158 | 1517 |
| Mvai 1 Pit 8 | 0674106 | 8356090 | 1557 |
| Mvai 1 Pit 9 | 0674289 | 8356025 | 1496 |
| Mvai 1 Pit 10 | 0674381 | 8355930 | 1476 |
| Mvai 2 Pit 1 | 0674736 | 8355651 | 1461 |
| Mvai 2 Pit 2 | 0674881 | 8355633 | 1478 |
| Mvai 2 Pit 3 | 0674820 | 8355659 | 1477 |
| Mvai 2 Pit 4 | 0675018 | 8355589 | 1468 |
| Mvai 2 Pit 5 | 0675113 | 8355499 | 1392 |
| Mvai 2 Pit 6 | 0675201 | 8355458 | 1424 |
| Mvai 2 Pit 7 | 0675254 | 8355414 | 1411 |

| | | | |
|---|---|---|---|
| Mvai 2 Pit 8 | 0675274 | 8355428 | 1379 |
| Mvai 2 Pit 9 | 0675332 | 8355400 | 1364 |
| Mvai 2 Pit 10 | 0675494 | 8355338 | 1333 |

## APPENDIX 11: RAINFALL DATA FOR THE CHIWETA AND NTCHENACHENA AREAS

| RAINFALL DATA FOR CHIWETA/NTCHENACHENA FROM 1977 TO 2005 IN MM | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | ANNUAL |
| 1977/78 | 14.2 | 107.2 | 196.9 | 247.7 | 257.3 | 333.8 | 54.1 | 2.3 | 26.2 | 0.3 | 0.3 | 23 | 1263.2 |
| 1978/79 | 7.4 | 139.2 | 261.1 | 167.7 | 331.7 | 322.1 | 188.5 | 15.7 | 0 | 0.3 | 0 | 0 | 1434 |
| 1979/80 | 1.8 | 103.2 | 220.7 | 298.9 | 154 | 286.5 | 165.1 | 37.4 | 0 | 2 | 0 | 1 | 1270.6 |
| 1980/81 | 45 | 60 | 281.5 | 183 | 207 | 102 | 69.5 | 34.4 | 1.1 | 0 | 1.5 | 20 | 1005 |
| 1981/82 | 25 | 122 | 120.5 | 278 | 230 | 340.5 | 139 | 78.5 | 1.5 | 0 | 0 | 0 | 1335 |
| 1982/83 | 63 | 181.1 | 250.3 | 190 | 268.5 | 275.5 | 91 | 28 | 1 | 5.5 | 0.5 | 0 | 1354.4 |
| 1983/84 | 41.5 | 92.5 | 364 | 272.5 | 182 | 281.5 | 95 | 28 | 7 | 2.5 | 4 | 0 | 1370.5 |
| 1984/85 | 16.5 | 172.5 | 366.5 | 188 | 414.6 | 155 | 131.4 | 39 | 2.1 | 14 | 0 | 0 | 1499.6 |
| 1985/86 | 5.6 | 226.4 | 209.9 | 254.2 | 185 | 265.2 | 117.8 | 32.7 | 28.5 | 0 | 0 | 1 | 1325.8 |
| 1986/87 | 157.8 | 117.2 | 314.8 | 229.3 | 354.9 | 104.2 | 280.6 | 36 | 0 | 0.1 | 0 | 0 | 1594.9 |
| 1987/88 | 271.2 | 124.1 | 341.9 | 481 | 653.6 | 632.5 | 88.6 | 8.5 | 9.6 | 0 | 18.8 | 2 | 2631.9 |
| 1988/89 | 4.7 | 141.7 | 202.8 | 156.8 | 31.9 | 246.9 | 115.4 | 48.8 | 0 | 0 | 0.5 | 0 | 949.5 |
| 1989/90 | 88.3 | 139.4 | 215.5 | 184 | 172 | 301 | 312 | 156 | 3.8 | 0 | 0.5 | 0 | 1572 |
| 1990/91 | 4 | 53 | 78 | 284 | 94 | 414.8 | 286 | 70.7 | 0 | 2.4 | 9.5 | 0 | 1296.4 |
| 1991/92 | 9.1 | 568 | 164.5 | 285 | 42.3 | 222 | 197 | 233 | 14 | 10.9 | 7 | 1 | 1753.3 |
| 1992/93 | 0 | 34 | 221.8 | 212 | 163.8 | 373 | 403 | 72 | 25.8 | 0 | 8 | 0 | 1513.4 |
| 1993/94 | 1.5 | 714 | 95.5 | 216 | 192.4 | 94.6 | 237.5 | 43 | 0 | 24 | 8.3 | 12 | 1638.3 |
| 1994/95 | 19 | 21 | 210 | 287.2 | 199.9 | 319.5 | 295.3 | 89.6 | 0 | 9.4 | 8.8 | 0 | 1459.8 |
| 1995/96 | 0 | 0 | 107 | 286.5 | 205.9 | 265.5 | 180 | 181 | 12 | 4.7 | 20.5 | 0 | 1263.4 |
| 1996/97 | 1.5 | 0 | 156 | 238.8 | 230.4 | 275 | 97 | 0 | 30 | 2 | 0 | 0 | 1030.7 |
| 1997/98 | 40 | 21 | 260 | 514 | 218 | 197.4 | 286.5 | 15 | 0 | 126 | 295 | 10 | 1982.4 |
| 1998/99 | 12 | 0 | 38 | 156 | 128 | 517.5 | 516 | 4.9 | 17 | 0 | 6 | 2 | 1397.4 |
| 1999/00 | 13 | 81 | 59 | 230 | 131 | 552 | 474.5 | 55 | 36 | 17 | 52 | 24 | 1724.5 |
| 2000/01 | 0 | 174 | 294 | 259.5 | 207 | 414 | 127 | 38 | 0 | 111 | 52 | 0 | 1676.5 |
| 2001/02 | | | | | | | | | | | | | |
| 2002/03 | | | | | | 405.5 | 104 | 10 | 4.8 | 10 | | 13 | |
| 2003/04 | | 68.3 | | | 275.8 | 216.5 | | 9.3 | 8.3 | | | 2 | |
| 2004/05 | 3.9 | | 446 | 198 | 180.1 | 238.6 | 114.3 | 25 | | | | | |

## APPENDIX 12: RAINFALL DATA FOR THE MVAI AND LIVILIVI CATCHMENTS

| **RAINFALL DATA FOR MVAI/LIVILIVI FROM 1977 TO 2005 IN MM** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEASON | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | ANNUAL |
| 1977/78 | 0 | 50.4 | 189.1 | 335.9 | 333.6 | 378.6 | 39.9 | 0 | 12.7 | 0 | 0 | 0 | 1340.2 |
| 1978/79 | 26.4 | 33.4 | 433.1 | 83.3 | 241 | 179.8 | 87.1 | 3 | 0 | 0 | 0 | 0 | 1087.1 |
| 1979/80 | 0 | 131.6 | 266.9 | 152.4 | 129.1 | 111.8 | 44.7 | 0 | 0 | 0 | 0 | 0 | 836.5 |
| 1980/81 | 3.2 | 20.8 | 497 | 69.6 | 284 | 60.5 | 15.7 | 0 | 0 | 0 | 0 | 0 | 950.8 |
| 1981/82 | 0 | 0 | 115.1 | 374.5 | 196 | 149.5 | 147.8 | 0 | 0 | 0 | 0 | 0 | 982.9 |
| 1982/83 | 0 | 60.1 | 245.1 | 222.1 | 218.9 | 118.5 | 0.7 | 0 | 0.5 | 2.2 | 0 | 0 | 868.1 |
| 1983/84 | 31 | 24.6 | 306.6 | 257.6 | 374.4 | 212.9 | 0 | 6.2 | 10.7 | 0 | 0 | 0 | 1224 |
| 1984/85 | 3.8 | 82 | 332.4 | 182.4 | 188.6 | 210.5 | 72.4 | 0 | 0 | 0 | 0 | 0 | 1072.1 |
| 1985/86 | 17.1 | 147.2 | 365.5 | 419.5 | 259.1 | 143.6 | 14.3 | 3.5 | 0 | 0 | 0 | 0 | 1369.8 |
| 1986/87 | 11.7 | 70.3 | 230.6 | 333.3 | 123.2 | 195.9 | 20 | 0 | 0 | 0 | 0 | 0 | 985 |
| 1987/88 | 80.2 | 42.5 | 222.3 | 294.7 | 361.2 | 79.4 | 46.8 | 26.2 | 0 | 0 | 0 | 0 | 1153.3 |
| 1988/89 | 81.1 | 64.6 | 264.1 | 214.5 | 291.4 | 376.7 | 54.8 | 1.5 | 0 | 0 | 1.7 | 0 | 1350.4 |
| 1989/90 | 0 | 59.3 | 376.5 | 521.9 | 148 | 147.7 | 10.7 | 105 | 0 | 0 | 1.4 | 16 | 1386.2 |
| 1990/91 | 0 | 0.8 | 100.4 | 492.4 | 258.6 | 149.7 | 0 | 0 | 22.5 | 0 | 0 | 0 | 1024.4 |
| 1991/92 | 56 | 65.4 | 132.6 | 146.7 | 95.2 | 178.3 | 36.4 | 0 | 0 | 0 | 0 | 0 | 710.6 |
| 1992/93 | 0 | 29.8 | 213.4 | 213.9 | 280.4 | 159 | 52.9 | 2.3 | 5.4 | 0 | 0 | 0 | 957.1 |
| 1993/94 | 17.5 | 118.5 | 80.2 | 198.7 | 35.7 | 168.5 | 28.6 | 0 | 0 | 0 | 0 | 0 | 647.7 |
| 1994/95 | 17.2 | 45.5 | 206.7 | 188.5 | 302.6 | 10.2 | 25 | 0 | 0 | 0 | 0 | 0 | 795.7 |
| 1995/96 | 3.4 | 43.4 | 157.8 | 171.3 | 232 | 314.2 | 43.9 | 0 | 0 | 0 | 0 | 0 | 966 |
| 1996/97 | 65.4 | 10.3 | 132.4 | 313.7 | 257.3 | 104 | 0 | 0 | 0 | 0 | 0 | 5 | 887.6 |
| 1997/98 | 70 | 68 | 439 | 262.5 | 101.9 | 149.4 | 0 | 0 | 0 | 0 | 0 | 0 | 1090.8 |
| 1998/99 | 35.7 | 84 | 103.8 | 241.9 | 264.1 | 204.1 | 33 | 0 | 0 | 0 | 0 | 0 | 966.6 |
| 1999/00 | 0 | 112 | 56.1 | 254 | 286.5 | 150.2 | 49.4 | 0 | 1.8 | 0 | 0 | 6 | 915.7 |
| 2000/01 | 37.8 | 155 | 119.7 | 242.2 | 200.1 | 150.4 | 6 | 2.1 | 0 | 0 | 8 | 0 | 921.7 |
| 2001/02 | 0 | 70 | 274 | 221 | 330 | 117.8 | 29.9 | 0 | 1.5 | 0 | 0 | 0 | 1044.2 |
| 2002/03 | 4.2 | 18.3 | 261.8 | 636 | 252 | 401.2 | 39.3 | 0 | 0 | 0.3 | 0 | 0 | 1613.1 |
| 2003/04 | 0 | 23.9 | 125 | 108 | 85 | 229.4 | 85.3 | 1 | 0.6 | 0 | 0 | 0 | 658.2 |
| 2004/05 | 28.2 | 256 | 277.2 | 317 | 83.4 | 58.3 | 9.4 | 25.4 | 1.4 | 0.4 | 0 | 9 | 1065.2 |

# APPENDIX 13: RESULTS OF PARTICLE SIZE ANALYSES

| PIT or PLOT | Depth (cm) | LL | P L | P I | Coarse Sand % | Medium Sand % | Fine Sand % | SILT % | CLAY % | Degree of Aggregation M.W.D | Hydraulic Conductivity cm/hr | Bulk Density g/cm | Total Porosity % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KASOKOLOKA** | | | | | | | | | | | | | |
| PIT1 KAS | 0-100 | 36.34 | 15.27 | 21.27 | 10.84 | 21.96 | 29.20 | 14 | 24 | 3.2393 | 2.00 | 1.42 | 46.42 |
| PIT1 KAS | >100 | 45.83 | 31.24 | 14.59 | 11.84 | 14.44 | 23.72 | 18 | 32 | 2.9484 | 2.12 | 1.68 | 36.60 |
| PIT 2 KAS | 0-100 | 35.20 | 21.31 | 13.89 | 15.22 | 5.57 | 27.21 | 19 | 33 | 3.1215 | 6.24 | 1.25 | 52.83 |
| PIT 2 KAS | >100 | 43.20 | 24.32 | 18.86 | 16.11 | 20.69 | 23.20 | 15 | 25 | 3.0145 | 2.28 | 1.46 | 44.91 |
| PIT 3 KAS | 0-100 | 39.21 | 21.07 | 18.14 | 12.65 | 16.37 | 25.98 | 18 | 27 | 2.7356 | 7.23 | 1.07 | 59.62 |
| PIT 3 KAS | >100 | 41.60 | 26.32 | 15.28 | 13.65 | 13.04 | 28.31 | 16 | 29 | 2.0478 | 7.25 | 1.15 | 56.66 |
| PIT 4 KAS | 0-100 | 38.24 | 20.39 | 17.85 | 14.95 | 7.51 | 29.54 | 16 | 32 | 2.4106 | 8.04 | 0.96 | 63.77 |
| PIT 4 KAS | >100 | 46.21 | 29.56 | 16.65 | 17.29 | 7.3 | 29.41 | 15 | 31 | 3.6541 | 8.05 | 1.24 | 53.21 |
| | | | | | | | | | | | | | |
| **LUTOWO** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 LUT 1 | 0-100 | 71.20 | 36.21 | 34.99 | 19.99 | 21.8 | 30.21 | 18 | 10 | 2.4562 | 8.28 | 1.26 | 52.45 |
| PIT 1 LUT 1 | >100 | 68.98 | 37.21 | 31.77 | 23.25 | 19.34 | 32.41 | 15 | 10 | 2.6147 | 9.24 | 0.95 | 64.15 |
| PIT 2 LUT 1 | 0-100 | 67.25 | 35.10 | 32.15 | 21.62 | 30.8 | 23.58 | 16 | 8 | 1.2583 | 8.07 | 1.22 | 53.96 |
| PIT 2 LUT 1 | >100 | 72.65 | 37.8 | 34.86 | 27.10 | 10.60 | 24.30 | 19 | 19 | 1.2365 | 6.89 | 1.00 | 62.26 |
| PIT 1 LUT 2 | 0-100 | 63.24 | 31.89 | 31.35 | 22.58 | 19.19 | 24.23 | 17 | 17 | 1.2456 | 7.98 | 1.19 | 55.09 |
| PIT 1 LUT 2 | >100 | 67.25 | 30.97 | 36.28 | 17.61 | 21.88 | 29.51 | 16 | 15 | 2.8459 | 6.89 | 1.00 | 62.26 |
| PIT 2 LUT 2 | 0-100 | 70.24 | 31.06 | 39.18 | 16.94 | 20.86 | 31.20 | 18 | 13 | 2.5470 | 7.63 | 1.21 | 54.34 |
| PIT 2 LUT 2 | >100 | 68.45 | 33.81 | 34.64 | 25.18 | 16.51 | 25.31 | 19 | 14 | 2.5480 | 8.67 | 1.28 | 51.70 |
| PIT 3 LUT 2 | 0-100 | 59.60 | 29.41 | 30.19 | 21.35 | 16.49 | 24.16 | 17 | 21 | 1.8910 | 1.72 | 1.51 | 43.02 |
| PIT 3 LUT 2 | >100 | 72.61 | 31.51 | 41.10 | 16.21 | 24.58 | 30.21 | 12 | 17 | 2.5130 | 1.83 | 1.52 | 42.64 |
| PIT 4 LUT 2 | 0-100 | 68.53 | 35.14 | 33.39 | 18.22 | 20.57 | 27.21 | 15 | 19 | 2.7845 | 7.75 | 1.30 | 50.94 |
| PIT 4 LUT 2 | >100 | 63.58 | 30.27 | 33.31 | 19.24 | 22.11 | 28.65 | 18 | 12 | 2.3587 | 3.45 | 1.12 | 57.74 |
| PIT 1 LUT 3 | 0-100 | 68.45 | 36.21 | 32.24 | 25.10 | 24.39 | 23.51 | 17 | 10 | 1.4783 | 8.24 | 1.21 | 54.34 |
| PIT 1 LUT 3 | >100 | 59.69 | 32.15 | 26.54 | 17.61 | 24.82 | 26.57 | 14 | 17 | 2.4712 | 7.24 | 1.28 | 51.70 |
| PIT 2 LUT 3 | 0-100 | 63.52 | 31.28 | 32.24 | 19.24 | 16.15 | 24.61 | 18 | 22 | 1.2580 | 6.27 | 1.07 | 59.62 |
| PIT 2 LUT 3 | >100 | 65.57 | 31.51 | 35.06 | 19.67 | 23.79 | 27.54 | 15 | 14 | 1.2583 | 7.25 | 1.07 | 59.62 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 3 LUT 3 | 0-100 | 69..80 | 34.31 | 35.49 | 17.88 | 30.52 | 29.60 | 12 | 10 | 2.6509 | 7.25 | 1.04 | 60.75 |
| PIT 3 LUT 3 | >100 | 55.30 | 33.70 | 21.60 | 29.12 | 18.52 | 20.36 | 16 | 16 | 3.0820 | 8.27 | 1.25 | 52.83 |
| PIT 4 LUT 3 | 0-100 | 59.66 | 33.53 | 26.13 | 16.20 | 17.68 | 20.12 | 18 | 28 | 2.8679 | 8.68 | 0.99 | 62.64 |
| PIT 4 LUT 3 | >100 | 58.97 | 30.69 | 28.28 | 12.84 | 21.92 | 21.24 | 16 | 28 | 2.9495 | 7.26 | 1.08 | 59.25 |
| PIT 1 LUT 4 | 0-100 | 48.51 | 39.69 | 8.82 | 35.76 | 14.92 | 19.32 | 16 | 14 | 3.4230 | 9.39 | 0.85 | 67.92 |
| PIT 1 LUT 4 | >100 | 52.24 | 27.74 | 24.50 | 57.28 | 4.68 | 12.04 | 16 | 10 | 3.4234 | 6.40 | 1.09 | 58.87 |
| PIT 2 LUT 4 | 0-100 | 39.33 | 27.59 | 11.59 | 30.44 | 15.32 | 20.24 | 16 | 18 | 3.1201 | 7.89 | 1.16 | 56.23 |
| PIT 2 LUT 4 | >100 | 47.93 | 24.90 | 23.03 | 41.40 | 11.92 | 16.68 | 16 | 14 | 2.1939 | 6.45 | 1.25 | 52.83 |
| PIT 3 LUT 4 | 0-100 | 52.73 | 28.67 | 24.06 | 31.68 | 12.8 | 21.52 | 18 | 16 | 2.7190 | 8.24 | 0.92 | 65.28 |
| PIT 3 LUT 4 | >100 | 47.68 | 26.68 | 21.60 | 24.64 | 16.72 | 28.64 | 14 | 16 | 3.3613 | 6.27 | 1.17 | 55.85 |
| PIT 4 LUT 4 | 0-100 | 37.97 | 17.00 | 20.92 | 34.56 | 16.36 | 15.08 | 14 | 20 | 3.1769 | 6.28 | 1.17 | 55.85 |
| PIT 4 LUT 4 | >100 | 51.51 | 25.11 | 26.40 | 44.08 | 3.68 | 20.24 | 12 | 20 | 3.3503 | 6.84 | 1.21 | 54.34 |
| PIT 1 LUT 5 | 0-100 | 57.71 | 32.33 | 25.38 | 24.36 | 31.08 | 22.56 | 10 | 12 | 2.9581 | 9.24 | 0.94 | 64.53 |
| PIT 1 LUT 5 | >100 | 48.82 | 27.87 | 20.95 | 24.24 | 10.1 | 33.66 | 14 | 18 | 2.7025 | 7.24 | 1.16 | 56.23 |
| PIT 2 LUT 5 | 0-100 | 61.99 | 33.59 | 28.15 | 29.44 | 0 | 37.68 | 20 | 14 | 3.1825 | 6.97 | 1.18 | 55.47 |
| PIT 2 LUT 5 | >100 | 56.33 | 27.84 | 28.49 | 22.08 | 11.32 | 30.60 | 20 | 16 | 3.1826 | 6.87 | 1.07 | 67.23 |
| PIT 3 LUT 5 | 0-100 | 51.88 | 32.00 | 19.88 | 35.84 | 0 | 38.88 | 18 | 8 | 3.2581 | 7.58 | 1.04 | 60.75 |
| PIT 3 LUT 5 | >100 | 51.88 | 30.95 | 20.93 | 20.84 | 13.77 | 39.32 | 18 | 8 | 2.9365 | 6.97 | 1.17 | 55.85 |
| PIT 4 LUT 5 | 0-100 | 48.04 | 22.14 | 25.90 | 23.40 | 15.20 | 23.40 | 20 | 18 | 3.1728 | 8.39 | 1.13 | 57.36 |
| PIT 4 LUT 5 | >100 | 24.02 | 15.30 | 8.72 | 24.20 | 19.80 | 18.00 | 20 | 18 | 3.1202 | 6.52 | 1.16 | 56.23 |
| PIT 1 LUT 6 | 0-100 | 34.05 | 20.16 | 13.89 | 40.88 | 7.44 | 25.68 | 12 | 14 | 3.3513 | 4.67 | 1.37 | 48.30 |
| PIT 1 LUT 6 | >100 | 38.71 | 23.74 | 14.97 | 31.48 | 7.36 | 23.16 | 16 | 22 | 0.2316 | 3.91 | 1.37 | 48.30 |
| PIT 2 LUT 6 | 0-100 | 38.13 | 24.11 | 14.02 | 31.80 | 10.60 | 19.60 | 16 | 22 | 3.4094 | 5.48 | 1.31 | 50.57 |
| PIT 2 LUT 6 | >100 | 28.73 | 7.50 | 21.23 | 23.76 | 0.48 | 27.76 | 18 | 30 | 2.2091 | 6.54 | 1.16 | 56.23 |
| PIT 3 LUT 6 | 0-100 | 47.98 | 35.97 | 12.01 | 33.72 | 7.08 | 13.20 | 18 | 28 | 3.2337 | 6.21 | 1.03 | 61.13 |
| PIT 3 LUT 6 | >100 | 42.52 | 31.95 | 10.57 | 20.12 | 16.28 | 15.60 | 18 | 30 | 2.6442 | 7.26 | 1.22 | 53.96 |
| PIT 1 LUT 7 | 0-100 | 66.47 | 48.16 | 18.31 | 56.44 | 4.08 | 15.48 | 12 | 12 | 2.8574 | 8.67 | 0.93 | 64.15 |
| PIT 1 LUT 7 | >100 | 34.22 | 46.65 | 43.14 | 22.08 | 8.72 | 37.20 | 20 | 12 | 2.3682 | 7.31 | 0.75 | 71.70 |
| PIT 2 LUT 7 | 0-10 | 50.32 | 14.21 | 36.11 | 22.10 | 28.50 | 26.40 | 12 | 11 | 1.0783 | 9.60 | 0.89 | 66.42 |
| PIT 2 LUT 7 | >100 | 15.99 | 8.65 | 7.34 | 40.48 | 6.68 | 20.84 | 22 | 10 | 1.6508 | 6.56 | 1.27 | 52.08 |
| PIT 3 LUT 7 | 0-100 | 43.46 | 17.61 | 25.85 | 27.28 | 14.8 | 25.92 | 18 | 14 | 2.8305 | 7.75 | 1.03 | 61.13 |
| PIT 3 LUT 7 | >100 | 51.47 | 17.74 | 33.75 | 27.00 | 11.92 | 21.08 | 22 | 18 | 2.0843 | 9.64 | 0.95 | 64.15 |
| PIT 4 LUT 7 | 0-100 | 44.46 | 35.72 | 8.75 | 36.28 | 0.72 | 19.00 | 22 | 22 | 3.1508 | 7.21 | 1.11 | 58.11 |
| PIT 4 LUT 7 | >100 | 45.51 | 36.89 | 8.62 | 35.92 | 10.67 | 23.41 | 14 | 16 | 2.9557 | 3.64 | 1.41 | 46.79 |
| PIT 5 LUT 7 | 0-100 | 42.84 | 29.84 | 13.00 | 46.12 | 5.44 | 20.44 | 12 | 16 | 3.1308 | 8.97 | 1.03 | 61.13 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 5 LUT 7 | >100 | 47.14 | 30.01 | 17.13 | 28.40 | 19.08 | 14.52 | 18 | 20 | 3.1030 | 9.78 | 0.94 | 64.54 |
| PIT 7 LUT 7 | 0-100 | 50.49 | 26.13 | 24.36 | 20.04 | 6.4 | 39.56 | 16 | 18 | 2.9407 | 10.21 | 0.78 | 70.17 |
| PIT 7 LUT 7 | >100 | 56.14 | 29.86 | 26.52 | 19.44 | 24.2 | 22.36 | 14 | 20 | 2.7463 | 8.24 | 0.97 | 63.40 |
| PIT 8 LUT 7 | 0-100 | 56.05 | 33.25 | 22.80 | 30.56 | 26.44 | 11.00 | 12 | 20 | 3.3678 | 8.67 | 1.10 | 56.60 |
| PIT 8 LUT 7 | >100 | 56.65 | 35.96 | 20.69 | 19.92 | 22.28 | 23.80 | 14 | 20 | 3.0558 | 3.07 | 1.44 | 45.66 |
| PIT 9 LUT 7 | 0-100 | 61.57 | 45.96 | 15.61 | 25.24 | 17.2 | 17.56 | 18 | 22 | 3.1506 | 8.45 | 1.07 | 59.62 |
| PIT 9 LUT 7 | >100 | 68.38 | 42.46 | 26.22 | 14.12 | 35.04 | 8.96 | 36 | 6 | 3.5341 | 9.04 | 1.11 | 58.11 |
| PIT 1 LUT 8 | 0-100 | 52.25 | 25.42 | 26.84 | 33.04 | 11.96 | 17.00 | 14 | 24 | 3.0252 | 6.24 | 1.20 | 54.71 |
| PIT 1 LUT 8 | >100 | 44.75 | 25.25 | 19.50 | 27.32 | 10.2 | 21.48 | 16 | 25 | 1.7656 | 9.21 | 1.06 | 60.00 |
| PIT 2 LUT 8 | 0-100 | 42.49 | 24.78 | 17.71 | 34.28 | 13.44 | 25.28 | 14 | 13 | 2.9956 | 7.91 | 1.25 | 52.83 |
| PIT 2 LUT 8 | >100 | 40.66 | 24.25 | 16.41 | 32.52 | 12.24 | 20.24 | 16 | 19 | 2.3202 | 9.23 | 0.95 | 64.15 |
| PIT 3 LUT 8 | 0-100 | 28.64 | 18.41 | 10.23 | 39.22 | 15.46 | 18.32 | 15 | 12 | 2.2216 | 8.21 | 1.16 | 56.23 |
| PIT 3 LUT 8 | >100 | 37.57 | 22.93 | 14.64 | 30.92 | 3.52 | 32.56 | 16 | 17 | 1.9357 | 2.36 | 1.60 | 39.62 |
| PIT 4 LUT 8 | 0-100 | 50.26 | 28.46 | 21.80 | 20.44 | 24.64 | 11.92 | 22 | 21 | 2.3849 | 8.61 | 0.94 | 64.53 |
| PIT 4 LUT 8 | >100 | 48.39 | 23.21 | 25.18 | 19.36 | 12.92 | 20.72 | 24 | 23 | 2.9709 | 9.62 | 1.07 | 59.62 |
| PIT 5 LUT 8 | 0-100 | 46.54 | 26.98 | 19.56 | 27.04 | 6.36 | 31.60 | 18 | 17 | 2.1990 | 9.78 | 1.18 | 55.47 |
| PIT 5 LUT 8 | >100 | 46.57 | 24.46 | 22.11 | 29.92 | 17.48 | 21.60 | 12 | 9 | 3.2509 | 7.24 | 1.11 | 58.11 |
| PIT 6 LUT 8 | 0-100 | 46.61 | 25.95 | 20.66 | 34.32 | 6 | 28.68 | 14 | 17 | 3.2433 | 8.54 | 0.95 | 64.15 |
| PIT 6 LUT 8 | >100 | 44.32 | 26.49 | 17.83 | 12.80 | 37.36 | 12.84 | 16 | 21 | 2.6730 | 6.45 | 0.92 | 65.28 |
| PIT 7 LUT 8 | 0-100 | 55.46 | 35.58 | 19.88 | 24.88 | 4.24 | 31.88 | 18 | 21 | 3.3274 | 6.97 | 1.08 | 59.25 |
| PIT 7 LUT 8 | >100 | 50.31 | 32.10 | 18.21 | 24.48 | 29.6 | 12.92 | 16 | 17 | 3.2918 | 5.90 | 1.11 | 58.11 |
| PIT 8 LUT 8 | 0-10 | 53.43 | 44.28 | 9.15 | 18.40 | 4.25 | 34.36 | 18 | 25 | 3.1008 | 10.24 | 0.82 | 69.06 |
| PIT 8 LUT 8 | >100 | 42.82 | 33.60 | 9.22 | 29.64 | 6.6 | 26.76 | 20 | 17 | 2.9580 | 9.67 | 0.99 | 62.64 |
| PIT 9 LUT 8 | 0-100 | 47.83 | 34.75 | 13.08 | 12.88 | 28.88 | 13.24 | 20 | 25 | 3.4531 | 9.83 | 1.01 | 61.89 |
| PIT 9 LUT 8 | >100 | 45.98 | 26.66 | 19.33 | 18.36 | 24.68 | 19.96 | 20 | 17 | 2.9466 | 8.67 | 0.94 | 64.53 |
| PIT 10 LUT 8 | 0-100 | 60.28 | 21.64 | 43.00 | 31.72 | 6.84 | 26.44 | 18 | 17 | 2.9577 | 6.86 | 1.07 | 59.62 |
| PIT 10 LUT 8 | >100 | 60.17 | 23.12 | 37.05 | 17.12 | 24.88 | 23.00 | 16 | 19 | 3.2491 | 7.38 | 1.16 | 56.23 |
| PIT 11 LUT 8 | 0-100 | 52.73 | 20.16 | 32.57 | 18.84 | 7.08 | 43.08 | 18 | 13 | 3.2890 | 3.21 | 1.41 | 46.79 |
| PIT 11 LUT 8 | >100 | 49.43 | 20.38 | 29.05 | 28.44 | 9.84 | 22.72 | 18 | 21 | 3.2389 | 5.64 | 1.39 | 47.55 |
| | | | | | | | | | | | | | |
| **KASESE** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 KAS SP | 0-100 | 50.81 | 29.50 | 21.31 | 3.52 | 18.2 | 15.28 | 20 | 43 | 2.9226 | 10.09 | 1.07 | 59.62 |
| PIT 1 KAS SP | >100 | 56.66 | 34.00 | 22.66 | 4.64 | 8.92 | 19.44 | 20 | 47 | 0.8403 | 14.88 | 1.30 | 50.94 |
| PIT 1 | 0-100 | 48.68 | 24.46 | 24.22 | 25.56 | 18.76 | 22.68 | 12 | 21 | 3.0276 | 15.74 | 0.86 | 67.55 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KASFOR | | | | | | | | | | | | | |
| PIT 1 KASFOR | >100 | 43.06 | 30.98 | 12.08 | 15.76 | 17.88 | 25.36 | 14 | 27 | 3.0839 | 6.28 | 1.13 | 57.36 |
| PIT 2 KAS | 0-100 | 50.88 | 28.44 | 21.49 | 4.32 | 15.12 | 21.56 | 26 | 33 | 2.0145 | 5.17 | 1.20 | 54.72 |
| PIT 2 KAS | >100 | 53.78 | 28.44 | 25.34 | 4.64 | 19.12 | 17.24 | 20 | 39 | 1.1532 | 7.24 | 1.26 | 52.45 |
| PIT 2 KASFOR | 0-100 | 59.45 | 34.35 | 25.10 | 13.28 | 30.36 | 25.36 | 16 | 15 | 3.1008 | 10.23 | 0.98 | 63.02 |
| PIT 2 KASFOR | >100 | 54.69 | 28.95 | 25.74 | 35.72 | 36.32 | 10.96 | 12 | 15 | 3.3349 | 9.31 | 0.98 | 63.02 |
| PIT 3 KAS | 0-100 | 58.15 | 28.54 | 29.61 | 12.48 | 27.92 | 30.60 | 14 | 15 | 2.9278 | 9.56 | 1.11 | 58.11 |
| PIT 3 KAS | >100 | 51.49 | 31.04 | 20.45 | 20.56 | 24.72 | 25.72 | 14 | 15 | 3.4862 | 6.45 | 1.21 | 54.34 |
| PIT 4 KAS | 0-100 | 44.86 | 33.80 | 11.06 | 16.64 | 22.4 | 19.96 | 16 | 25 | 0.2807 | 6.89 | 1.27 | 52.08 |
| PIT 4 KAS | >100 | 51.46 | 25.43 | 26.01 | 17.00 | 23.28 | 24.72 | 14 | 21 | 3.2344 | 3.78 | 1.40 | 47.17 |
| PIT 5 KAS | 0-100 | 41.13 | 23.29 | 17.84 | 28.16 | 18.6 | 16.24 | 16 | 21 | 3.2040 | 8.21 | 1.19 | 55.09 |
| PIT 5 KAS | >100 | 37.21 | 20.31 | 16.90 | 29.26 | 13.9 | 23.84 | 14 | 19 | 3.4451 | 5.32 | 1.26 | 52.45 |
| PIT 6 KAS | 0-100 | 41.08 | 18.61 | 22.47 | 18.56 | 12.96 | 27.48 | 14 | 27 | 2.9484 | 8.23 | 1.25 | 52.83 |
| PIT 6 KAS | >100 | 40.22 | 26.48 | 13.74 | 18.92 | 17.04 | 21.04 | 16 | 27 | 3.0060 | 8.55 | 1.26 | 52.45 |
| PIT 7 KAS | 0-100 | 35.61 | 16.22 | 19.39 | 32.52 | 12.64 | 15.84 | 14 | 25 | 2.2307 | 4.98 | 1.21 | 54.34 |
| PIT 7 KAS | >100 | 35.15 | 22.77 | 12.38 | 29.84 | 14.32 | 16.84 | 16 | 23 | 2.3581 | 5.94 | 1.29 | 51.32 |
| PIT 8 KAS | 0-100 | 38.93 | 16.86 | 22.07 | 38.66 | 16.38 | 13.96 | 14 | 17 | 3.3750 | 9.68 | 0.98 | 63.02 |
| PIT 8 KAS | >100 | 39.62 | 25.67 | 13.95 | 22.20 | 17.52 | 15.28 | 14 | 31 | 2.6973 | 9.34 | 1.18 | 55.47 |
| PIT 11 KAS EFG | 0-100 | 54.00 | 35.67 | 19.00 | 8.60 | 27.56 | 14.84 | 26 | 23 | 2.8482 | 7.55 | 1.04 | 60.75 |
| PIT 11 KAS EFG | >100 | 50.60 | 24.96 | 25.64 | 9.00 | 22.48 | 13.52 | 24 | 31 | 0.5456 | 9.10 | 0.90 | 66.04 |
| PIT 12 KAS | 0-100 | 41.77 | 23.62 | 18.13 | 19.88 | 36.2 | 8.92 | 20 | 15 | 2.9906 | 7.75 | 0.98 | 63.02 |
| PIT 12 KAS | >100 | 50.59 | 35.70 | 14.69 | 18.80 | 31.84 | 16.36 | 18 | 15 | 3.2217 | 8.31 | 0.93 | 64.91 |
| PIT 13 KAS | 0-100 | 55.11 | 38.61 | 16.50 | 19.56 | 43.22 | 4.22 | 20 | 13 | 2.9455 | 9.47 | 0.94 | 64.53 |
| PIT 13 KAS | >100 | 56.11 | 34.58 | 20.21 | 27.00 | 27.16 | 24.84 | 10 | 11 | 3.2699 | 1.45 | 0.86 | 67.55 |
| | | | | | | | | | | | | | |
| **MANKHLONGO** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 MANKH 1 | 0-100 | 50.11 | 27.55 | 22.56 | 19.72 | 25.28 | 20.00 | 12 | 23 | 3.3317 | 7.37 | 1.18 | 55.47 |
| PIT 1 MANKH 1 | >100 | 43.79 | 35.80 | 7.98 | 19.88 | 17.4 | 23.72 | 14 | 25 | 3.1569 | 10.21 | 0.86 | 67.55 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 2 MANKH 1 | 0-100 | 44.16 | 25.13 | 17.73 | 39.00 | 17.68 | 16.32 | 10 | 17 | 3.4111 | 6.08 | 1.35 | 49.06 |
| PIT 2 MANKH 1 | >100 | 40.66 | 27.71 | 12.95 | 40.12 | 16.84 | 10.04 | 12 | 21 | 3.1561 | 7.23 | 1.05 | 60.38 |
| PIT 3 MANKH 1 | 0-100 | 46.64 | 28.35 | 18.29 | 33.60 | 16.52 | 22.88 | 12 | 15 | 3.3661 | 7.24 | 1.17 | 55.85 |
| PIT 3 MANKH 1 | >100 | 41.10 | 21.95 | 19.15 | 41.60 | 9.96 | 15.44 | 20 | 13 | 2.1239 | 8.12 | 0.96 | 63.77 |
| PIT 4 MANKH 1 | 0-100 | 50.58 | 26.32 | 24.26 | 33.34 | 10.82 | 16.84 | 18 | 21 | 3.2341 | 6.03 | 1.17 | 55.85 |
| PIT 4 MANKH 1 | >100 | 42.15 | 22.71 | 19.44 | 34.84 | 5.48 | 14.68 | 20 | 25 | 3.2497 | 6.02 | 1.28 | 51.70 |
| PIT 5 MANKH 5 | 0-100 | 60.42 | 44.34 | 16.88 | 36.84 | 6.8 | 21.36 | 16 | 19 | 3.2881 | 9.35 | 1.14 | 56.98 |
| PIT 5 MANKH 5 | >100 | 40.04 | 23.21 | 17.19 | 34.20 | 18.32 | 16.48 | 14 | 17 | 2.6629 | 10.56 | 0.83 | 68.68 |
| PIT 6 MANKH | 0-100 | 44.92 | 26.28 | 18.64 | 26.16 | 19.92 | 28.92 | 16 | 9 | 3.0310 | 9.13 | 1.18 | 55.47 |
| PIT 6 MANKH | >100 | 40.04 | 20.11 | 19.93 | 15.60 | 27.92 | 21.48 | 22 | 13 | 2.2710 | 5.43 | 1.21 | 54.34 |
| PIT 7 MANKH | 0-100 | 42.30 | 25.76 | 16.54 | 37.24 | 24 | 11.76 | 14 | 13 | 2.5631 | 9.56 | 1.11 | 58.11 |
| PIT 7 MANKH | >100 | 40.72 | 23.89 | 16.83 | 32.80 | 20.04 | 20.16 | 14 | 13 | 2.5093 | 8.61 | 0.79 | 70.18 |
| PIT 8 MANKH | 0-100 | 38.19 | 20.43 | 17.76 | 37.87 | 10.33 | 20.8 | 18 | 13 | 3.0997 | 8.34 | 0.95 | 64.15 |
| PIT 8 MANKH | >100 | 35.28 | 19.16 | 16.12 | 36.92 | 9.88 | 16.20 | 24 | 13 | 2.6824 | 7.60 | 1.16 | 56.23 |
| PIT 9 MANKH | 0-100 | 44.51 | 41.65 | 12.86 | 27.96 | 10.52 | 12.52 | 28 | 21 | 2.8720 | 7.81 | 1.00 | 62.26 |
| PIT 9 MANKH | >100 | 43.29 | 27.8 | 15.49 | 24.00 | 13.48 | 19.52 | 18 | 25 | 2.8720 | 6.20 | 0.99 | 62.64 |
| PIT 10 MANKH | 0-100 | 57.75 | 25.41 | 32.34 | 28.60 | 22.44 | 13.96 | 16 | 19 | 3.4741 | 8.79 | 0.86 | 67.55 |
| PIT 10 MANKH | >100 | 42.83 | 28.81 | 14.02 | 22.76 | 29.88 | 12.36 | 12 | 23 | 3.4316 | 5.76 | 1.26 | 52.45 |
| PIT 11 MANKH | 0-100 | 47.66 | 24.96 | 22.70 | 31.48 | 11.32 | 20.20 | 12 | 25 | 3.3060 | 4.78 | 1.20 | 54.72 |
| PIT 11 MANKH | >100 | 45.76 | 5.09 | 40.67 | 22.80 | 21.44 | 14.76 | 12 | 29 | 3.0846 | 6.25 | 1.10 | 58.49 |
| | | | | | | | | | | | | | |
| **CHIKWEZGA** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 CHIKWE | 0-100 | 53.20 | 39.02 | 14.18 | 35.92 | 21.08 | 12.32 | 14 | 17 | 3.2474 | 9.20 | 0.96 | 63.77 |
| PIT 1 CHIKWE | >100 | 53.29 | 34.32 | 18.97 | 28.52 | 17.72 | 20.76 | 18 | 15 | 3.1152 | 8.64 | 1.11 | 58.11 |
| PIT 2 CHIKWE | 0-100 | 45.51 | 31.42 | 14.09 | 29.29 | 31.63 | 10.08 | 14 | 15 | 3.3548 | 8.24 | 1.06 | 60.00 |
| PIT 2 CHIKWE | >100 | 38.22 | 1.19 | 37.03 | 36.24 | 22.44 | 8.32 | 16 | 17 | 3.3102 | 7.13 | 1.38 | 47.92 |
| PIT 3 CHIKWE | 0-100 | 48.41 | 31.88 | 16.53 | 18.24 | 30.6 | 16.16 | 18 | 17 | 2.9036 | 8.24 | 1.09 | 58.87 |
| PIT 3 CHIKWE | >100 | 47.53 | 36.06 | 11.47 | 25.85 | 14.47 | 22.68 | 20 | 17 | 2.9819 | 10.09 | 1.16 | 56.23 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 4 CHIKWE | 0-100 | 81.42 | 43.45 | 37.97 | 8.00 | 30.04 | 18.96 | 18 | 25 | 3.2591 | 12.18 | 1.00 | 62.26 |
| PIT 4 CHIKWE | >100 | 61.20 | 43.53 | 17.60 | 21.72 | 10.86 | 24.40 | 18 | 25 | 2.4013 | 10.94 | 1.05 | 60.38 |
| PIT 5 CHIKWE | 0-100 | 40.90 | 20.16 | 20.16 | 47.52 | 13.16 | 18.32 | 12 | 9 | 3.4546 | 8.67 | 0.98 | 63.02 |
| PIT 5 CHIKWE | >100 | 39.78 | 6.60 | 33.18 | 29.12 | 18.66 | 21.22 | 16 | 15 | 3.4811 | 8.96 | 0.99 | 62.64 |
| PIT 6 CHIKWE | 0-100 | 52.05 | 33.72 | 18.33 | 22.96 | 28.72 | 17.32 | 20 | 11 | 2.8973 | 4.91 | 1.32 | 50.19 |
| PIT 6 CHIKWE | >100 | 87.34 | 47.34 | 40.90 | 31.04 | 19.68 | 14.28 | 20 | 15 | 1.5008 | 8.67 | 0.88 | 66.79 |
| PIT 7 CHIKWE | 0-100 | 45.75 | 10.39 | 35.36 | 33.16 | 12.2 | 23.64 | 20 | 11 | 3.1995 | 8.12 | 1.17 | 55.85 |
| PIT 7 CHIKWE | >100 | 38.51 | 22.18 | 36.33 | 28.80 | 21.28 | 14.92 | 22 | 13 | 3.1652 | 7.56 | 1.12 | 57.74 |
| PIT 8 CHIKWE | 0-100 | 70.23 | 47.23 | 23.00 | 35.72 | 17.04 | 14.24 | 20 | 13 | 3.1460 | 5.72 | 1.17 | 55.85 |
| PIT 8 CHIKWE | >100 | 45.79 | 25.61 | 20.18 | 29.88 | 20.24 | 14.88 | 22 | 13 | 3.3710 | 5.96 | 1.29 | 51.32 |
| PIT 9 CHIKWE | 0-100 | 54.85 | 26.35 | 28.50 | 19.40 | 27.08 | 22.52 | 22 | 9 | 3.1976 | 8.71 | 1.05 | 60.38 |
| PIT 9 CHIKWE | >100 | 50.57 | 10.33 | 40.24 | 23.44 | 6.8 | 30.76 | 28 | 11 | 2.8907 | 8.73 | 1.01 | 61.89 |
| | | | | | | | | | | | | | |
| **CHIWETA** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 (U) CHIW | 0-100 | 41.89 | 31.24 | 10.65 | 30.88 | 12.28 | 32.84 | 20 | 13 | 3.1895 | 6.45 | 1.07 | 59.62 |
| PIT 1 (U) CHIW | >100 | 56.10 | 40.34 | 15.76 | 21.76 | 10.08 | 29.16 | 22 | 17 | 2.6391 | 8.39 | 1.12 | 57.74 |
| PIT 1 (L) CHIW | 0-100 | 38.82 | 28.07 | 10.75 | 30.44 | 29.52 | 15.04 | 18 | 7 | 2.9763 | 10.45 | 0.89 | 66.42 |
| PIT 1 (L) CHIW | >100 | 28.93 | 21.98 | 6.95 | 26.20 | 9.50 | 31.3 | 20 | 13 | 1.8406 | 4.21 | 1.31 | 50.57 |
| PIT 2 (U) CHIW | 0-100 | 29.71 | 20.60 | 9.11 | 20.80 | 26.25 | 13.95 | 22 | 17 | 3.0559 | 2.45 | 1.43 | 46.04 |
| PIT 2 (U) CHIW | >100 | 31.88 | 23.98 | 7.90 | 21.20 | 9.56 | 41.36 | 24 | 23 | 2.5843 | 3.64 | 1.34 | 49.43 |
| PIT 2 (L) CHIW | 0-100 | 30.24 | 21.99 | 8.25 | 26.08 | 41.2 | 7.72 | 14 | 11 | 3.4007 | 7.58 | 1.10 | 58.49 |
| PIT 2 (L) CHIW | >100 | 40.20 | 29.42 | 11.18 | 17.56 | 17.12 | 38.32 | 20 | 7 | 3.2948 | 6.28 | 1.14 | 56.98 |
| PIT 3 (U) CHIW | 0-100 | 35.52 | 26.97 | 8.55 | 45.32 | 19.36 | 9.32 | 14 | 12 | 3.1276 | 3.59 | 1.51 | 43.02 |
| PIT 3 (U) CHIW | >100 | 41.20 | 28.62 | 12.58 | 15.03 | 23.17 | 31.8 | 14 | 16 | 3.0751 | 8.60 | 1.06 | 60.00 |
| PIT 3 (L) CHIW | 0-100 | 45.84 | 32.31 | 13.53 | 28.88 | 26.6 | 23.52 | 12 | 9 | 3.1389 | 6.86 | 1.31 | 50.57 |
| PIT 3 (L) CHIW | >100 | 52.56 | 26.44 | 26.12 | 28.72 | 18.56 | 19.72 | 18 | 15 | 3.2081 | 3.46 | 1.52 | 42.64 |
| PIT 4 (U) CHIW | 0-100 | 29.75 | 21.68 | 8.07 | 5.40 | 32.72 | 28.88 | 18 | 15 | 2.4130 | 6.79 | 1.11 | 58.11 |
| PIT 4 (U) CHIW | >100 | 29.51 | 21.92 | 7.59 | 7.44 | 27.6 | 25.96 | 22 | 17 | 1.9954 | 6.48 | 1.25 | 52.83 |
| PIT 4 (L) CHIW | 0-100 | 32.29 | 24.55 | 7.74 | 32.28 | 24.44 | 22.28 | 14 | 7 | 2.9974 | 10.58 | 1.04 | 60.75 |
| PIT 4 (L) CHIW | >100 | 30.91 | 22.13 | 8.78 | 19.04 | 31.68 | 24.28 | 16 | 9 | 2.9080 | 6.98 | 1.17 | 55.85 |
| PIT 5 (U) CHIW | 0-100 | 31.17 | 26.65 | 4.52 | 8.36 | 43.24 | 22.40 | 12 | 14 | 3.3177 | 7.01 | 1.34 | 49.43 |
| PIT 5 (U) CHIW | >100 | 36.86 | 25.51 | 11.35 | 10.08 | 48.52 | 17.40 | 12 | 12 | 2.6724 | 6.32 | 1.38 | 57.92 |
| PIT 5 (L) CHIW | 0-100 | 32.15 | 23.45 | 8.70 | 27.64 | 29.88 | 18.48 | 12 | 12 | 3.2474 | 6.27 | 1.30 | 50.93 |
| PIT 5 (L) CHIW | >100 | 47.09 | 32.33 | 14.74 | 41.32 | 5 | 21.68 | 16 | 16 | 3.4996 | 2.94 | 1.61 | 39.25 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 6 (U) CHIW | 0-100 | 29.27 | 19.55 | 9.72 | 31.92 | 22.48 | 15.60 | 20 | 10 | 3.0209 | 3.24 | 1.45 | 42.28 |
| PIT 6 (U) CHIW | >100 | 32.57 | 22.37 | 10.20 | 33.48 | 23.2 | 19.32 | 16 | 8 | 3.4296 | 11.05 | 0.66 | 75.09 |
| PIT 6 (L) CHIW | 0-100 | 36.65 | 28.73 | 7.92 | 17.08 | 38.36 | 20.56 | 12 | 12 | 3.4081 | 7.43 | 1.38 | 47.92 |
| PIT 6 (L) CHIW | >100 | 33.54 | 26.90 | 6.64 | 38.32 | 17.76 | 21.92 | 12 | 10 | 2.5889 | 6.54 | 1.22 | 53.96 |
| PIT 7 (U) CHIW | 0-100 | 38.65 | 23.95 | 14.70 | 34.04 | 14.64 | 11.32 | 26 | 14 | 2.8039 | 5.98 | 1.24 | 53.21 |
| PIT 7 (U) CHIW | >100 | 36.5 | 23.20 | 13.20 | 31.56 | 11.4 | 19.04 | 24 | 14 | 3.1133 | 6.21 | 1.26 | 52.45 |
| PIT 7 (L) CHIW | 0-100 | 34.33 | 21.46 | 12.87 | 10.80 | 39.48 | 18.04 | 16 | 8 | 3.2371 | 5.98 | 1.38 | 47.92 |
| PIT 7 (L) CHIW | >100 | 31.33 | 23.78 | 7.55 | 10.04 | 39.48 | 20.48 | 24 | 6 | 2.6807 | 5.31 | 1.34 | 49.43 |
| PIT 8 (U) CHIW | 0-100 | 52.36 | 34.76 | 17.60 | 28.08 | 27.24 | 14.68 | 20 | 10 | 1.8839 | 8.02 | 1.07 | 59.62 |
| PIT 8 (U) CHIW | >100 | 36.44 | 21.41 | 15.03 | 31.12 | 24 | 14.88 | 16 | 14 | 2.9467 | 6.12 | 1.30 | 50.93 |
| PIT 8 (L) CHIW | 0-100 | 31.49 | 16.98 | 14.51 | 19.88 | 25.04 | 29.08 | 18 | 8 | 2.8158 | 4.98 | 1.34 | 49.43 |
| PIT 8 (L) CHIW | >100 | 28.70 | 20.77 | 7.93 | 28.00 | 27.04 | 10.96 | 20 | 14 | 2.0655 | 5.64 | 1.32 | 50.19 |
| PIT 9 (U) CHIW | 0-100 | 45.88 | 29.91 | 15.97 | 13.68 | 17.8 | 14.52 | 38 | 16 | 2.4152 | 11.12 | 1.04 | 60.75 |
| PIT 9 (U) CHIW | >100 | 34.24 | 24.41 | 9.83 | 16.92 | 17.12 | 15.96 | 36 | 14 | 3.0133 | 9.41 | 1.25 | 52.83 |
| PIT 9 (L) CHIW | 0-100 | 34.72 | 26.48 | 8.24 | 5.84 | 46.56 | 17.60 | 20 | 10 | 3.3106 | 6.54 | 1.22 | 53.96 |
| PIT 9 (L) CHIW | >100 | 35.70 | 24.60 | 11.10 | 17.32 | 12.4 | 30.00 | 22 | 18 | 2.1636 | 8.79 | 0.97 | 63.40 |
| PIT 10 (U) CHIW | 0-100 | 30.51 | 21.42 | 9.09 | 47.60 | 7.20 | 15.12 | 18 | 12 | 3.1171 | 7.87 | 1.18 | 55.47 |
| PIT 10 (U) CHIW | >100 | 32.30 | 19.33 | 12.97 | 41.12 | 13 | 23.88 | 10 | 12 | 2.5649 | 5.66 | 1.22 | 53.96 |
| PIT 10 (L) CHIW | 0-100 | 33.59 | 23.76 | 9.83 | 10.76 | 37.08 | 16.16 | 22 | 14 | 3.1435 | 4.97 | 1.35 | 49.06 |
| PIT 10 (L) CHIW | >100 | 34.94 | 25.28 | 9.66 | 5.52 | 39.8 | 14.68 | 22 | 18 | 2.8175 | 8.03 | 1.20 | 54.72 |
| PIT 11 (U) CHIW | 0-100 | 33.63 | 26.45 | 7.18 | 29.61 | 5.23 | 13.16 | 32 | 20 | 2.0307 | 8.36 | 1.12 | 57.74 |
| PIT 11 (U) CHIW | >100 | 31.47 | 21.97 | 9.50 | 13.68 | 14.52 | 17.80 | 26 | 28 | 2.5390 | 4.78 | 1.27 | 52.08 |
| PIT 11 (L) CHIW | 0-100 | 38.76 | 24.25 | 14.51 | 21.20 | 44.48 | 16.32 | 14 | 4 | 3.0280 | 6.28 | 1.24 | 53.21 |
| PIT 11 (L) CHIW | >100 | 44.51 | 25.86 | 18.65 | 22.48 | 43.12 | 20.40 | 10 | 4 | 3.1277 | 4.24 | 1.33 | 49.81 |
| | | | | | | | | | | | | | |
| **MVAI** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| PIT 1 MVAI 1 | 0-100 | 77.45 | 37.83 | 39.62 | 18.00 | 38.00 | 16.00 | 18 | 10 | 3.2800 | 9.40 | 0.84 | 68.30 |
| PIT 1 MVAI 1 | >100 | 56.73 | 36.04 | 20.69 | 15.28 | 37.04 | 23.68 | 14 | 10 | 3.3388 | 6.76 | 1.03 | 61.13 |
| PIT 2 MVAI 1 | 0-100 | 34.99 | 24.58 | 10.41 | 10.92 | 41 | 20.08 | 16 | 12 | 3.0840 | 8.59 | 1.14 | 56.98 |
| PIT 2 MVAI 1 | >100 | 41.83 | 27.03 | 14.80 | 9.64 | 36.64 | 15.72 | 22 | 16 | 3.1610 | 8.24 | 1.06 | 60.00 |
| PIT 3 MVAI 1 | 0-100 | 60.64 | 43.02 | 17.62 | 14.36 | 38.36 | 21.28 | 18 | 8 | 2.9800 | 11.44 | 0.91 | 65.66 |
| PIT 3 MVAI 1 | >100 | 49.09 | 29.36 | 19.73 | 16.36 | 54.08 | 15.56 | 6 | 8 | 2.7700 | 5.97 | 1.18 | 55.47 |
| PIT 4 MVAI 1 | 0-100 | 66.16 | 45.86 | 2.03 | 21.44 | 34 | 18.56 | 18 | 8 | 2.4454 | 11.12 | 0.72 | 72.83 |
| PIT 4 MVAI 1 | >100 | 49.47 | 33.16 | 16.31 | 23.92 | 27.52 | 18.56 | 20 | 10 | 2.8151 | 9.64 | 1.06 | 60.00 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 5 MVAI 1 | 0-100 | 51.99 | 36.07 | 15.92 | 26.20 | 28.52 | 9.28 | 26 | 10 | 2.1840 | 10.24 | 0.83 | 68.68 |
| PIT 5 MVAI 1 | >100 | 49.24 | 4.34 | 44.90 | 33.48 | 12.32 | 12.20 | 30 | 12 | 2.1886 | 8.67 | 1.10 | 58.49 |
| PIT 6 MVAI 1 | 0-100 | 52.98 | 34.57 | 18.41 | 10.00 | 33.64 | 20.36 | 26 | 10 | 3.0780 | 5.61 | 1.30 | 50.93 |
| PIT 6 MVAI 1 | >100 | 39.33 | 26.07 | 13.26 | 19.32 | 20.4 | 12.28 | 26 | 22 | 2.3902 | 6.98 | 1.12 | 57.74 |
| PIT 7 MVAI 1 | 0-100 | 55.75 | 33.14 | 22.61 | 28.52 | 21.8 | 21.68 | 20 | 8 | 2.4222 | 9.35 | 0.88 | 66.79 |
| PIT 7 MVAI 1 | >100 | 38.68 | 26.77 | 11.91 | 31.44 | 7.84 | 30.72 | 20 | 10 | 2.4585 | 5.61 | 1.26 | 52.45 |
| PIT 8 MVAI 1 | 0-100 | 74.14 | 52.45 | 21.69 | 33.64 | 33.16 | 11.20 | 14 | 8 | 3.2114 | 7.63 | 0.54 | 79.22 |
| PIT 8 MVAI 1 | >100 | 43.89 | 31.95 | 11.94 | 26.92 | 26.12 | 14.96 | 24 | 8 | 3.2858 | 6.64 | 0.88 | 66.79 |
| PIT 9 MVAI 1 | 0-100 | 63.92 | 48.05 | 15.77 | 22.6 | 24.12 | 29.28 | 18 | 6 | 3.0746 | 11.53 | 0.69 | 73.96 |
| PIT 9 MVAI 1 | >100 | 51.98 | 28.10 | 23.88 | 24.04 | 23.6 | 18.36 | 22 | 12 | 2.4980 | 11.24 | 0.86 | 67.55 |
| PIT 10 MVAI 1 | 0-100 | 53.89 | 38.31 | 15.58 | 19.12 | 7.24 | 19.64 | 42 | 12 | 2.4990 | 5.67 | 1.34 | 49.43 |
| PIT 10 MVAI 1 | >100 | 48.32 | 28.39 | 19.93 | 6.76 | 36.2 | 27.04 | 2 | 28 | 1.3502 | 3.21 | 1.41 | 46.79 |
| PIT 1 MVAI 2 | 0-100 | 41.97 | 28.01 | 13.96 | 16.04 | 34.72 | 25.24 | 16 | 8 | 2.7020 | 2.98 | 1.50 | 43.40 |
| PIT 1 MVAI 2 | >100 | 34.21 | 20.87 | 13.34 | 10.12 | 9.8 | 54.08 | 12 | 14 | 3.1115 | 5.98 | 1.22 | 53.96 |
| PIT 2 MVAI 2 | 0-100 | 35.85 | 24.41 | 11.44 | 28.04 | 1.04 | 32.92 | 28 | 10 | 2.5153 | 3.56 | 1.44 | 45.66 |
| PIT 2 MVAI 2 | >100 | 36.05 | 22.14 | 13.91 | 23.96 | 40.56 | 15.48 | 10 | 10 | 0.8036 | 9.75 | 0.96 | 63.77 |
| PIT 3 MVAI 2 | 0-100 | 56.82 | 43.34 | 13.48 | 6.80 | 30.92 | 40.28 | 10 | 12 | 2.7650 | 5.69 | 1.34 | 49.43 |
| PIT 3 MVAI 2 | >100 | 58.76 | 42.96 | 11.80 | 13.52 | 12.64 | 43.84 | 12 | 18 | 2.8577 | 5.29 | 1.23 | 53.58 |
| PIT 4 MVAI 2 | 0-100 | 39.69 | 26.65 | 13.04 | 9.44 | 31.2 | 25.36 | 14 | 20 | 2.9825 | 7.21 | 1.18 | 55.47 |
| PIT 4 MVAI 2 | >100 | 46.86 | 29.55 | 17.31 | 6.56 | 26.96 | 26.48 | 22 | 18 | 2.6678 | 3.68 | 1.47 | 44.53 |
| PIT 5 MVAI 2 | 0-100 | 55.92 | 42.19 | 13.73 | 13.8 | 33.84 | 22.36 | 20 | 10 | 2.8183 | 12.80 | 0.74 | 72.08 |
| PIT 5 MVAI 2 | >100 | 65.78 | 20.80 | 22.60 | 15.84 | 9.76 | 24.40 | 36 | 14 | 2.5591 | 5.97 | 1.31 | 50.57 |
| PIT 6 MVAI 2 | 0-100 | 57.05 | 32.42 | 24.63 | 19.04 | 35.5 | 31.16 | 8 | 6 | 2.9804 | 3.54 | 1.41 | 46.79 |
| PIT 6 MVAI 2 | >100 | 47.81 | 22.86 | 24.95 | 16.52 | 27.8 | 31.68 | 12 | 12 | 3.1170 | 6.21 | 1.36 | 48.68 |
| PIT 7 MVAI 2 | >100 | 53.15 | 28.32 | 24.83 | 10.08 | 35.92 | 34.00 | 12 | 8 | 2.7076 | 9.62 | 1.05 | 60.38 |
| PIT 7 MVAI 2 | >100 | 37.93 | 23.36 | 13.57 | 22.84 | 32.04 | 27.12 | 10 | 8 | 3.3572 | 7.01 | 1.29 | 51.32 |
| PIT 8 MVAI 2 | 0-100 | 36.65 | 23.36 | 13.39 | 8.40 | 27.52 | 36.08 | 14 | 14 | 1.2605 | 8.94 | 1.03 | 61.13 |
| PIT 8 MVAI 2 | >100 | 44.78 | 38.17 | 6.61 | 18.12 | 15.92 | 45.96 | 10 | 10 | 1.5940 | 7.87 | 1.24 | 53.21 |
| PIT 9 MVAI 2 | 0-100 | 33.97 | 25.00 | 8.97 | 8.40 | 27.44 | 40.16 | 10 | 14 | 2.9212 | 8.05 | 1.10 | 58.49 |
| PIT 9 MVAI 2 | >100 | 30.55 | 19.49 | 11.06 | 9.92 | 25.04 | 37.04 | 14 | 14 | 2.1657 | 5.68 | 1.35 | 49.06 |
| PIT 10 MVAI 2 | 0-100 | 45.26 | 28.59 | 16.67 | 10.80 | 24.16 | 33.76 | 20 | 12 | 3.5960 | 8.97 | 0.93 | 64.91 |
| PIT 10 MVAI 2 | >100 | 37.93 | 26.17 | 11.76 | 10.68 | 22.96 | 32.36 | 20 | 14 | 2.8723 | 7.89 | 1.04 | 60.75 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

| **LIVILIVI** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT 1 LIV 1 | 0-100 | 50.13 | 32.57 | 17.56 | 17.52 | 27.68 | 36.80 | 12 | 6 | 3.3686 | 6.59 | 1.29 | 51.32 |
| PIT 1 LIV 1 | >100 | 39.76 | 25.64 | 14.12 | 9.00 | 23.68 | 45.32 | 12 | 10 | 2.9316 | 8.16 | 1.19 | 55.09 |
| PIT 2 LIV 1 | 0-100 | 38.17 | 25.44 | 12.73 | 18.76 | 13.72 | 51.52 | 10 | 6 | 2.4169 | 7.98 | 1.21 | 54.34 |
| PIT 2 LIV 1 | >100 | 34.51 | 19.90 | 14.61 | 22.96 | 20.16 | 30.88 | 18 | 8 | 3.0390 | 6.52 | 1.25 | 52.83 |
| PIT 3 LIV 1 | 0-100 | 43.59 | 29.07 | 14.52 | 22.24 | 4.1 | 41.76 | 18 | 14 | 3.0183 | 8.36 | 1.29 | 51.32 |
| PIT 3 LIV 1 | >100 | 33.86 | 19.44 | 14.42 | 21.64 | 7.28 | 40.08 | 18 | 13 | 1.4355 | 3.79 | 1.41 | 46.79 |
| PIT 4 LIV 1 | 0-100 | 47.49 | 23.06 | 24.43 | 21.48 | 1.08 | 60.28 | 12 | 5 | 2.2730 | 8.41 | 1.00 | 62.26 |
| PIT 4 LIV 1 | >100 | 38.38 | 20.43 | 17.95 | 26.52 | 32.76 | 21.72 | 12 | 7 | 1.8004 | 9.23 | 1.19 | 55.09 |
| PIT 5 LIV 1 | 0-100 | 45.52 | 26.66 | 18.86 | 27.48 | 7.4 | 34.12 | 24 | 7 | 1.5331 | 8.64 | 1.13 | 57.36 |
| PIT 5 LIV 1 | >100 | 37.53 | 23.44 | 14.09 | 23.08 | 10.24 | 37.68 | 22 | 7 | 1.7576 | 8.94 | 1.19 | 55.09 |
| PIT 1 LIV 2 | 0-100 | 33.37 | 21.55 | 11.82 | 27.04 | 15.88 | 28.08 | 22 | 7 | 2.3694 | 10.02 | 0.92 | 65.28 |
| PIT 1 LIV 2 | >100 | 29.31 | 18.33 | 10.98 | 17.32 | 17.08 | 42.60 | 16 | 7 | 2.3483 | 5.98 | 1.22 | 53.96 |
| PIT 2 LIV 2 | 0-100 | 38.73 | 23.05 | 15.68 | 22.88 | 0.6 | 51.16 | 18 | 7 | 1.1854 | 7.47 | 1.08 | 59.25 |
| PIT 2 LIV 2 | >100 | 31.17 | 18.33 | 12.84 | 18.72 | 0.76 | 53.52 | 18 | 9 | 0.9369 | 9.27 | 1.13 | 57.36 |
| PIT 3 LIV 2 | 0-100 | 41.08 | 25.43 | 15.65 | 32.16 | 13.2 | 29.64 | 16 | 9 | 3.3757 | 8.95 | 1.17 | 55.85 |
| PIT 3 LIV 2 | >100 | 43.78 | 20.78 | 23.00 | 29.28 | 27.6 | 22.12 | 14 | 7 | 3.2858 | 8.07 | 1.17 | 55.85 |
| PIT 4 LIV 2 | 0-100 | 46.49 | 25.23 | 21.26 | 37.16 | 12.83 | 23.01 | 18 | 9 | 2.4298 | 9.21 | 1.01 | 61.89 |
| PIT 4 LIV 2 | >100 | 39.42 | 21.68 | 17.74 | 20.00 | 0.60 | 60.40 | 14 | 5 | 1.4355 | 6.27 | 0.90 | 66.04 |
| PIT 1 LIV 4 | 0-100 | 61.17 | 30.50 | 30.67 | 37.68 | 20.44 | 18.88 | 16 | 7 | 2.2730 | 9.45 | 1.05 | 60.38 |
| PIT 1 LIV 4 | >100 | 44.01 | 28.17 | 15.84 | 12.40 | 20.12 | 26.48 | 18 | 23 | 1.8004 | 5.21 | 1.33 | 49.81 |
| PIT 2 LIV 4 | 0-100 | 55.21 | 33.29 | 21.92 | 29.68 | 22.04 | 17.28 | 22 | 9 | 1.5331 | 3.45 | 1.41 | 46.79 |
| PIT 2 LIV 4 | >100 | 64.85 | 29.05 | 38.80 | 17.32 | 11.56 | 36.12 | 22 | 13 | 1.7576 | 8.20 | 1.05 | 60.38 |
| PIT 3 LIV 4 | 0-100 | 44.69 | 26.65 | 18.04 | 16.48 | 17.8 | 20.72 | 22 | 23 | 2.3694 | 5.15 | 1.35 | 49.06 |
| PIT 3 LIV 4 | >100 | 48.76 | 28.95 | 19.81 | 14.92 | 8.72 | 27.36 | 22 | 25 | 2.3483 | 7.98 | 1.06 | 60.00 |
| PIT 4 LIV 4 | 0-100 | 41.80 | 19.19 | 22.61 | 10.00 | 14.56 | 32.44 | 20 | 23 | 1.1854 | 8.29 | 1.04 | 60.75 |
| PIT 4 LIV 4 | >100 | 35.08 | 10.38 | 24.70 | 7.96 | 4.84 | 36.20 | 22 | 29 | 0.9369 | 9.27 | 0.98 | 63.02 |
| PIT 5 LIV 4 | 0-100 | 36.97 | 20.16 | 16.81 | 9.52 | 21.88 | 33.60 | 20 | 15 | 1.4495 | 3.45 | 1.46 | 28.30 |
| PIT 5 LIV 4 | >100 | 37.70 | 21.87 | 15.83 | 37.92 | 1.36 | 15.72 | 22 | 23 | 0.4380 | 9.05 | 1.01 | 61.89 |

## APPENDIX 15: RESULTS OF VEGETATION SURVEY

### NTCHEU FIELD DATA

| DOMINANT VEGETATION AND GROWTH | | | | | VEGETATION ON EVENT | | | SLIDE | WGS 84 UTM 36 L | | | ASPT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MVAI 1-12** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | **Type** | **Characteristics** | **Recolonisation/ Density (%)** | **UNIT** | **LAT** | **LON** | **ALT** | |
| Brachystegia | 430 | 330 | 11.2 | 8 | Miombo woodlands | ▪ Generally trees deep rooted and spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Grasses give adequate ground coverage but;<br>▪ Shallow rooted<br>Seasonal burning evident | 60 | Mvai 1 | 0673813 | 8356647 | 1427 | N |
| Combretum | 161 | 120 | 9.3 | 1.5 | | | 50 | Mvai 2 | 0673774 | 8356569 | 1469 | NE |
| Faurea saligna | 64 | 44 | 2.5 | 0.8 | | | 90 | Mvai 3 | 0673769 | 8356542 | 1489 | NE |
| Dalbergia nitidula | 70 | 50 | 2.7 | 0.9 | | | 90 | Mvai 4 | 0673758 | 8356547 | 1493 | N |
| Lannea discolor | 107 | 81 | 2.8 | 3 | | | 90 | Mvai 5 | 0673710 | 8356483 | 1523 | NE |
| Ozoroa insigns | 265 | 197 | 10.7 | 4.2 | | | 70 | Mvai 6 | 0673657 | 8356118 | 1168 | NE |
| Uapaca zanzibariaca | 141 | 100 | 3.7 | 3.1 | | | 95 | Mvai 7 | 0673642 | 8356123 | 1673 | E |
| Ficus | 130 | 72 | 4.3 | 2 | | | 30 | Mvai 8 | 0673542 | 8356087 | 1710 | NE |
| Mbilima | 95 | 45 | 1.6 | | | | 60 | Mvai 9 | 0673949 | 8356037 | 1612 | NE |
| Mpoloni | 103 | 90 | 3.1 | 1.3 | | | 50 | Mvai 10 | 0674094 | 8356054 | 1546 | NE |
| Parinari kirkiana | 141 | 120 | 5.3 | 2.5 | | | 50 | Mvai 11 | 0674234 | 8356022 | 1503 | NE |
| Grasses | | | | | | | 90 | Mvai 12 | 0674283 | 8355996 | 1471 | NE |
| ***AVERAGE*** | **155** | **114** | **5.2** | **2.7** | **Forest Reserve** | | **67** | | | | | |
| **MVAI 2-1-13** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **ALT** | |
| Brachystegia | 165 | 155 | 5.1 | 7 | Miombo woodlands | ▪ Generally trees deep rooted and | 60 | Mvai 2-1 | 0674808 | 8355653 | 1481 | NW |
| Faurea saligna | 200 | 120 | 2.9 | 3.5 | | | 60 | Mvai 2-2 | 0674820 | 8355659 | 1477 | N |
| U. kirkiana | 165 | 120 | 5.5 | 6.5 | | | 60 | Mvai 2-3 | 0674956 | 8355728 | 1424 | NE |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jubernadia glob. | 220 | 165 | 7.3 | 4 | | spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Grasses give adequate ground coverage but;<br>▪ Shallow rooted<br>▪ Seasonal burning evident | 65 | Mvai 2-4 | 0674952 | 8355747 | 1414 | NE |
| Dalbergia nitidula | 142 | 109 | 3.1 | 1.9 | | | 65 | Mvai 2-5 | 0674956 | 8355699 | 1432 | NE |
| Cussonia arborea | 205 | 140 | 6.1 | 3.7 | | | 80 | Mvai 2-6 | 0674999 | 8355603 | 1451 | SE |
| Bwazi | 190 | 140 | 6.3 | 5.1 | | | 60 | Mvai 2-7 | 0675072 | 8355519 | 1430 | NE |
| Mpinjipinji | 62 | 33 | 2 | 2 | | | 70 | Mvai 2-8 | 0675116 | 8355515 | 1427 | E |
| Pericorpsis angolensis | 254 | 225 | 5.8 | 4.7 | | | 95 | Mvai 2-9 | 0675246 | 8355414 | 1405 | E |
| | | | | | | | 60 | Mvai 2-10 | 0675212 | 8355397 | 1405 | SE |
| | | | | | | | 50 | Mvai 2-11 | 0675202 | 8355383 | 1405 | S |
| | | | | | | | 50 | Mvai 2-12 | 0675196 | 8355378 | 1398 | S |
| | | | | | | | 60 | Mvai 2-13 | 0675302 | 8355400 | 1368 | SE |
| ***AVERAGE*** | **178** | **134** | **4.9** | **4.3** | **Forest Reserve** | | **64** | | | | | |
| **LIVILIDZI 1-3** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **ALT** | |
| Brachystegia | 149 | 109 | 8.2 | 2.5 | Miombo woodlands | ▪ Generally trees deep rooted and spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Tall grasses give adequate ground coverage but; | 60 | Livi 1 | 0673155 | 8353725 | 1363 | NW |
| Faurea saligna | 253 | 181 | 8.1 | | | | 60 | Livi 2 | 0673079 | 8353491 | 1322 | SE |
| Combretum | | | 5 | | | | 60 | Livi 3 | 0673010 | 8353386 | 1302 | SE |
| Strychnos spinosa | 130 | 74 | 3.6 | 1.5 | | | | | | | | |
| Cussonia arborea | 164 | 94 | 4.1 | 1.6 | | | | | | | | |
| Ozoroa insigns | 232 | 159 | 5.6 | | | | | | | | | |
| Mnthopa | 130 | 78 | 2.7 | 2.1 | | | | | | | | |
| Acacia (Mwape) | 77 | 73 | 4.2 | 2.6 | | | | | | | | |
| U. zanzibarica | 184 | 78 | 4.1 | 2.1 | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mchenje | 167 | 130 | 5.7 | 4.1 | | ▪ Shallow rooted<br>▪ Seasonal burning evident | | | | | | |
| U. kirkiana | 95 | 71 | 3.2 | 2.1 | | | | | | | | |
| ***AVERAGE*** | **158** | **105** | **5.0** | **2.3** | **Forest Reserve** | | **60** | | | | | |
| **LIVILIDZI 4-8** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **ALT** | |
| Brachystegia | 163 | 90 | 5.8 | 2.5 | Miombo woodlands | ▪ Generally trees deep rooted and spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Tall grasses give adequate ground coverage but;<br>▪ Shallow rooted<br>▪ Seasonal burning evident | 80 | Livi 4 | 0673202 | 8353241 | 1273 | SW |
| Erythrina absynica | 180 | 143 | 5.3 | 2.6 | | | 95 | Livi 5 | 0673217 | 8353244 | 1287 | SW |
| Protea | 49 | 30 | 1.7 | 1.5 | | | 95 | Livi 6 | 0673189 | 8353290 | 1293 | W |
| U. kirkiana | 63 | 55 | 2.1 | 1.1 | | | 95 | Livi 7 | 0673222 | 8353196 | 1297 | W |
| Mpoloni | 120 | 105 | 5.2 | 4.5 | | | 60 | Livi 8 | 0673276 | 8353251 | 1306 | W |
| Bwazi | 120 | 96 | 4.5 | 2.6 | | | | | | | | |
| Diplorhynchus condylocarpon | 131 | 128 | 6.1 | 8.0 | | | | | | | | |
| Acacia (Mwape) | 62 | 54 | 3.7 | 4.0 | | | | | | | | |
| ***AVERAGE*** | **111** | **88** | **4.3** | **3.4** | **Forest Reserve** | | **85** | | | | | |

**CHIWETA FIELD DATA**

| DOMINANT VEGETATION | GROWTH PARAMETERS | | | | VEGETATION ON EVENT | | | SLIDE | WGS 84 UTM 36 L | | | ASPT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CHIWETA L1-11** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | **Type** | **Characteristics** | **Recolonisation / Density (%)** | **UNIT** | **LAT** | **LON** | **ALT** | |
| Diplorhynchus condylocarpon | 230 | 125 | 8.4 | 2 | Miombo woodlands | ▪ Fill side of the road, minor disturbance by the road slope fill.<br>▪ Trees deep rooted and spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Grasses give adequate ground coverage but;<br>▪ Shallow rooted.<br>▪ Seasonal burning evident. | 60 | CL 1 | 0628196 | 8816740 | 859 | S |
| Combretum | 145 | 140 | 8.6 | 5 | | | 75 | CL 2 | 0628283 | 8816730 | 835 | S |
| Brachystegia | 379 | 311 | 13.3 | 7 | | | 45 | CL 3 | 0628340 | 8816604 | 859 | SW |
| Brachy. Shrubs | 63 | 50 | 1.8 | | | | 50 | CL 4 | 0628357 | 8816516 | 821 | SW |
| Dombeya rotundifolia | 62 | 54 | 5.4 | 0.4 | | | 50 | CL 5 | 0628473 | 8816484 | 797 | SE |
| Ozoroa insigns | 93 | 80 | 5.3 | 1 | | | 85 | CL 6 | 0628556 | 8816574 | 821 | SE |
| Mkandazovu | 30 | - | 1.2 | 0.5 | | | 80 | CL 7 | 0628651 | 8816532 | 791 | S |
| Aeschynomene indica | | | | | | | 85 | CL 8 | 0628857 | 8816494 | 779 | S |
| Short grasses | | | | | | | 85 | CL 9 | 0629005 | 8816434 | 752 | S |
| Flueggea virosa | 89 | 80 | 5.5 | 8 | | | 85 | CL 10 | 0629070 | 8816558 | 744 | NE |
| Acacia, Mthyethye | 650 | 630 | 24.6 | 15 | | | 85 | CL 11 | 0629017 | 8816772 | 727 | SE |
| Ficus | 302 | 245 | 8.9 | 6 | | | | | | | | |
| Strychnos spinosa | 145 | 120 | 3.5 | 5.4 | | | | | | | | |
| Dalbergia nitidula | 170 | 147 | 3.8 | 1.2 | | | | | | | | |
| Bridelia micrantha | 136 | 112 | 15.5 | 5.1 | | | | | | | | |
| Piliostigma thonningii | 160 | 105 | 5.6 | 4.2 | | | | | | | | |
| Bwitizi | | | | | | | | | | | | |
| ***AVERAGE*** | **190** | **169** | **8.0** | **4.7** | **Proposed Forest Reserve** | | **71** | | | | | |

| CHIWETA U1-11 | Dsh (mm) | Dbh (mm) | H (m) | CC (m) | | | | UNIT | LAT | LON | ALT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brachystegia | 367 | 322 | 15.3 | 10.1 | Miombo woodlands | ▪ Cut side of the road, almost undisturbed.<br>▪ Trees deep rooted and spreading crowns.<br>▪ Uneven aged and sizes.<br>▪ Grasses give adequate ground coverage but;<br>▪ Shallow rooted.<br>▪ Seasonal burning evident. | 75 | CU 1 | 0628174 | 8816770 | 855 | S |
| Diplorhynchus condylocarpon | 122 | 103 | 6.7 | 3 | | | 80 | CU 2 | 0628267 | 8816768 | 848 | S |
| Combretum | 103 | 87 | 5.1 | 3.1 | | | 80 | CU 3 | 0628387 | 8816574 | 860 | W |
| Pseudolachnostylis maprouneifolia | 241 | 215 | 9.4 | 8 | | | 80 | CU 4 | 0628405 | 8816514 | 853 | S |
| Mnthopa | | | | | | | 80 | CU 5 | 0628430 | 8816606 | 865 | SE |
| Maltidentia crassa | 65 | 56 | 2.3 | 1 | | | 80 | CU 6 | 0628491 | 8816654 | 853 | SE |
| Ozoroa insigns | 770 | 145 | 6.9 | 3 | | | 85 | CU 7 | 0628540 | 8816660 | 856 | SE |
| Pericorpsis angolensis | 220 | 170 | 7.2 | 3.2 | | | 85 | CU 8 | 0628638 | 8816608 | 858 | S |
| Faurea saligna | 143 | 103 | 6.1 | 5.2 | | | 85 | CU 9 | 0628742 | 8816700 | 878 | SE |
| Chigula | 188 | 170 | 6.4 | 5.2 | | | 85 | CU 10 | 0628806 | 8816806 | 842 | SE |
| Dalbergia nitidula | 151 | 135 | 11.1 | 2.6 | | | 85 | CU 11 | 0628986 | 8816846 | 786 | E |
| ***AVERAGE*** | **237** | **151** | **7.7** | **4.4** | **Proposed Forest Reserve** | | **82** | | | | | |

### RUMPHI - NTCHENACHENA

| DOMINANT VEGETATION | GROWTH PARAMETERS | | | | VEGETATION ON EVENT | | | SLIDE | WGS 84 UTM 36 L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **GABILANYIKA** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | **Type** | **Characteristics** | **Recolonisation / Density (%)** | **UNIT** | **LAT** | **LON** | **ALT** |
| Kandankhuku | 45 | 43 | 3 | | Afromontane grassland | ▪ Mostly grassland. | 30 | 1 | 0615263 | 8818558 | 1347 |
| Combretum | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridelia micrantha | 84 | 65 | 3.5 | 3.3 | | ▪ Poor ground cover.<br>▪ Scattered shrubs and grasses especially in valleys.<br>▪ Site under active settlement and cassava cultivation. | | | | | |
| Mavilo | | | | | | | | | | | |
| Faurea saligna | | | | | | | | | | | |
| Grasses | | | 2 | | | | | | | | |
| Ndola | | | | | | | | | | | |
| Mnthopa | | 60 | 3.7 | 2.3 | | | | | | | |
| Dombeya rotundifolia | | | | | | | | | | | |
| Mnyekamaso | | | | | | | | | | | |
| Mangifera indica | 244 | 214 | 5.1 | 4.1 | | | | | | | |
| Syzigium, Fuwu | 61 | 52 | 2.8 | 2.1 | | | | | | | |
| ***AVERAGE*** | **109** | **87** | **3.4** | **3.0** | **Customary Land** | | **30** | | | | |
| **KASESE 1a-g** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **ALT** |
| Mnthunu | 36 | 27 | 4.1 | 1.9 | Afromontane grassland | ▪ Mostly grassland.<br>▪ Good ground coverage but;<br>▪ Shallow rotted n abandoned gardens.<br>▪ Scattered shrubs deep rooted, especially in valleys.<br>▪ Severely disturbed. | 40 | Kas 1a | 0615042 | 8818456 | 1393 |
| Bridelia micrantha | 103 | 85 | 5.5 | 3.2 | | | 40 | Kas 1b | 0614940 | 8818470 | 1439 |
| Combretum | 81 | 65 | 6.3 | 4 | | | 50 | Kas 1c | 0614833 | 8818510 | 1487 |
| Bangula | 61 | 47 | 5.9 | 2.2 | | | 50 | Kas 1d | 0614784 | 8818578 | 1507 |
| Anona | 113 | 91 | 5.2 | 3.2 | | | 0 | Kas 1e | 0614664 | 8818812 | 1507 |
| Faurea saligna | 219 | 187 | 6.1 | 5.9 | | | 0 | Kas 1f | 0614652 | 8818832 | 1503 |
| Protea | 130 | 103 | 4.7 | 6.4 | | | 0 | Kas 1g | 0614648 | 8818856 | 1507 |
| Syzigium | 319 | 179 | 7.5 | 4.6 | | | | | | | |
| Cussonia arborea | 126 | 92 | 4.7 | 4 | | | | | | | |
| Parinari | 78 | 61 | 4.9 | 1.7 | | | | | | | |
| Erythrina absynicca | 105 | 91 | 5.6 | 3 | | | | | | | |

| ***AVERAGE*** | **125** | **93** | **5.5** | **3.6** | **Customary Land** | | **26** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **LITOWO 1a-3** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **ALT** |
| Faurea saligna | 31 | 30 | 1.1 | 0.4 | Afromontane grassland | ▪ Grasses and shrubs on abandoned settlements and gardens. | 50 | Lit 1a | 0615054 | 8818650 | 1424 |
| Parinari | 54 | 35 | 1.6 | 0.6 | | | 50 | Lit 1b | 0615054 | 8818650 | 1424 |
| Syzigium | 99 | 66 | 4.3 | 1.8 | | | 50 | Lit 1c | 0615054 | 8818650 | 1424 |
| Mnthopa | | | | | | | 65 | Lit 2 | 0615205 | 8818600 | 1376 |
| Cussonia arborea | 84 | 70 | 1.6 | 1 | | | 100 | Lit 3 | 0615148 | 8818562 | 1385 |
| Combretum | | | 5.2 | | | | | | | | |
| Bridelia micrantha | | | 5.4 | | | | | | | | |
| Grasses | | | 2 | | | | | | | | |
| Ferns | | | | | | | | | | | |
| ***AVERAGE*** | **67** | **50** | **3.0** | **1.0** | **Customary Land** | | **63** | | | | |
| **LITOWO 4a-i** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **(m)** |
| Syzigium | 91 | 61 | 3.6 | 1.6 | Afromontane grassland | ▪ Grasses and shrubs on abandoned gardens.<br>▪ Patches of trees apparent on undisturbed patches. | 50 | Lit 4a | 0615064 | 8818564 | 1396 |
| Protea | 66 | 36 | 2.4 | 1.5 | | | 50 | Lit 4b | 0614999 | 8818666 | 1452 |
| Parinari | 65 | 35 | 2.3 | 0.5 | | | 50 | Lit 4c | 0614908 | 8818730 | 1478 |
| Cussonia arborea | 78 | 60 | 1.8 | 1 | | | 50 | Lit 4d | 0614775 | 8818822 | 1500 |
| Faurea saligna | 43 | 40 | 2.5 | 1 | | | 75 | Lit 4e | 0614745 | 8818842 | 1511 |
| Bwitizi | | | | | | | 50 | Lit 4f | 0614722 | 8818864 | 1521 |
| Ferns | | | | | | | 50 | Lit 4g | 0614705 | 8818868 | 1715 |
| Bridelia micrantha | | | | | | | 50 | Lit 4h | 0614704 | 8818892 | 1529 |
| Mnthopa | | | | | | | 50 | Lit 4i | 0614681 | 8818930 | 1747 |
| Kandankhuku | | | | | | | | | | | |
| Erythrina | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Grasses | | | | | | | | | | | |
| ***AVERAGE*** | **69** | **46** | **2.5** | **1.1** | **Customary Land** | | **53** | | | | |
| **LITOWO 5a-g** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **(m)** |
| Faurea saligna | 73 | 68 | 2 | 1.5 | Afromontane grassland | ▪ Mostly grasses and scattered shrubs.<br>▪ Seasonal burning evident. | 20 | Lit 5a | 0614956 | 8818748 | 1464 |
| Parinari | 126 | 81 | 5 | 2 | | | 20 | Lit 5b | 0614901 | 8818752 | 1473 |
| Bwitizi | | | | | | | 40 | Lit 5c | 0614866 | 8818770 | 1491 |
| Cussonia arborea | 135 | 103 | 20 | 1.8 | | | 50 | Lit 5d | 0614838 | 8818770 | 1496 |
| Syzigium | 94 | 62 | 3 | 0.8 | | | 90 | Lit 5e | 0614818 | 8818834 | 1513 |
| Vitex doniana | 75 | 58 | 1.5 | 0.3 | | | 50 | Lit 5f | 0614786 | 8818860 | 1506 |
| Multidentia crassa | 82 | 54 | 2 | 0.8 | | | 50 | Lit 5g | 0614785 | 8818856 | 1507 |
| M'mama | 92 | 69 | 3 | 1.2 | | | | | | | |
| Combretum | 106 | 78 | 3.2 | 1.5 | | | | | | | |
| Pericorpsis angolensis | 90 | 66 | 4.6 | 2 | | | | | | | |
| ***AVERAGE*** | **97** | **71** | **4.9** | **1.3** | **Customary Land** | | **46** | | | | |
| **LITOWO 6a-d** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **(m)** |
| Bwitizi | | | | | Afromontane grassland | ▪ Mainly grass cover on abandoned settlements and gardens. | 50 | Lit 6a | 0614681 | 8819028 | 1555 |
| Vitex doniana | 96 | 74 | 3.5 | 1.2 | | | 60 | Lit 6b | 0614709 | 8819062 | 1574 |
| Syzigium | 102 | 60 | 2 | 1.5 | | | 60 | Lit 6c | 0614673 | 8819184 | 1594 |
| Faurea saligna | 70 | 50 | 2 | 1.3 | | | 60 | Lit 6d | 0614650 | 8819310 | 1627 |
| Mnthunu | 94 | 60 | 3 | 1.5 | | | | | | | |
| Erythrina absynica | 213 | 187 | 9.1 | 6 | | | | | | | |
| Combretum | 188 | 167 | 6 | 5 | | | | | | | |
| ***AVERAGE*** | **127** | **100** | **4.3** | **2.8** | **Customary Land** | | **58** | | | | |

| LITOWO 7a-u | Dsh (mm) | Dbh (mm) | H (m) | CC (m) | | | | UNIT | LAT | LON | (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mnthunu | 70 | 56 | 3.6 | 4 | Afromontane grassland | ▪ Mainly grass cover on abandoned settlements and gardens. | 70 | Lit 7a | 0614696 | 8819490 | 1634 |
| Mnthopa | 61 | 43 | 2.3 | 0.3 | | | 0 | Lit 7b | 0614684 | 8819488 | 1632 |
| Faurea saligna | 55 | 50 | 1.9 | 1.6 | | | 60 | Lit 7c | 0614723 | 8819506 | 1635 |
| Cussonia arborea | 100 | 76 | 2.1 | 1 | | | 60 | Lit 7d | 0614795 | 8819486 | 1632 |
| Erythrina absynica | | | | | | | 60 | Lit 7e | 0614874 | 8819454 | 1619 |
| NyaUhango | | | | | | | 50 | Lit 7f | 0614922 | 8819460 | 1616 |
| Aeschynomene indica | 10 | 8 | 3.7 | 2.3 | | | 50 | Lit 7g | 0614967 | 8819440 | 1600 |
| Chisuja | 62 | 43 | 1.8 | 1 | | | 0 | Lit 7h | 0614984 | 8819414 | 1593 |
| Syzigium | 93 | 87 | 6.2 | 2.3 | | | 50 | Lit 7i | 0615001 | 8819416 | 1587 |
| Chinuski | 6 | 5 | 1.8 | | | | 50 | Lit 7j | 0615010 | 8819368 | 1590 |
| Bridelia micrantha | 59 | 52 | 4.2 | 2.6 | | | 0 | Lit 7k | 0615076 | 8819396 | 1568 |
| Parinari | 581 | 443 | 14 | 12 | | | 40 | Lit 7l | 0615162 | 8819334 | 1540 |
| Grasses | | | | | | | 40 | Lit 7m | 0615175 | 8819316 | 1537 |
| | | | | | | | 60 | Lit 7n | 0615216 | 8819212 | 1519 |
| | | | | | | | 40 | Lit 7o | 0615241 | 8819192 | 1500 |
| | | | | | | | 40 | Lit 7p | 0615232 | 8819132 | 1494 |
| | | | | | | | 90 | Lit 7q | 0615240 | 8819102 | 1468 |
| | | | | | | | 50 | Lit 7r | 0615246 | 8819086 | 1463 |
| | | | | | | | 60 | Lit 7s | 0615291 | 8818948 | 1421 |
| | | | | | | | 60 | Lit 7t | 0615334 | 8818878 | 1362 |
| | | | | | | | 40 | Lit 7u | 0615353 | 8818830 | 1343 |
| ***AVERAGE*** | **110** | **86** | **4.2** | **3.0** | **Customary Land** | | **46** | | | | |
| **LITOWO 8a-j** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | **Type** | **Characteristics** | **Recolonisation / Density (%)** | **UNIT** | **LAT** | **LON** | **ALT** |
| Mnthunu | 73 | 60 | 4.8 | 2.2 | Afromonta | ▪ Mainly grass | 50 | Lit 8a | 0615464 | 8818686 | 1286 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Combretum | 93 | 68 | 3.6 | 1.5 | ne grassland | cover on abandoned settlements and gardens. | 60 | Lit 8b | 0615423 | 8818764 | 1336 |
| Parinari | 83 | 70 | 3.2 | 1.2 | | | 60 | Lit 8c | 0615400 | 8818798 | 1328 |
| Vitex doniana | 78 | 63 | 4.5 | 1.3 | | | 60 | Lit 8d | 0615389 | 8818846 | 1358 |
| Bridelia micrantha | 84 | 69 | 3.2 | 1.7 | | | 50 | Lit 8e | 0615361 | 8818900 | 1379 |
| Mnthopa | 113 | 86 | 4.9 | 2.6 | | | 55 | Lit 8f | 0615309 | 8818998 | 1404 |
| Pericorpsis angolensis | 88 | 63 | 3.4 | 1.6 | | | 50 | Lit 8g | 0615285 | 8819034 | 1450 |
| Bwitizi | 22 | 16 | 2.7 | 0.4 | | | 40 | Lit 8h | 0615279 | 8819064 | 1455 |
| Syzigium | 102 | 53 | 4.2 | 1.3 | | | 40 | Lit 8i | 0615290 | 8819214 | 1478 |
| Esorospermum febrifugum | 101 | 57 | 3.8 | 2.1 | | | 50 | Lit 8j | 0615298 | 8819296 | 1512 |
| Ficus | 88 | 60 | 2.2 | 4.7 | | | | | | | |
| Faurea saligna | 145 | 109 | 5.1 | 3.8 | | | | | | | |
| ***AVERAGE*** | **89** | **65** | **3.8** | **2.0** | **Customary Land** | | **52** | | | | |
| **CHIKWEZGA 1a-n** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** | | | | **UNIT** | **LAT** | **LON** | **(m)** |
| Bwitizi | 8 | 5 | 2 | 0.3 | Afromontane grassland | ▪ Mainly grass cover on abandoned settlements and gardens.<br>▪ Few pine trees available and stable. | 60 | Chi 1a | 0615686 | 8819288 | 1492 |
| Esorospermum febrifugum | 95 | 84 | 2.6 | 2.7 | | | 60 | Chi 1b | 0615669 | 8819290 | 1477 |
| Cussonia arborea | 178 | 150 | 6.2 | 4.6 | | | 50 | Chi 1c | 0615648 | 8819280 | 1474 |
| Protea | 78 | 56 | 1.9 | 1.3 | | | 50 | Chi 1d | 0615542 | 8819306 | 1482 |
| Vitex doniana | 134 | 90 | 6.1 | 2.5 | | | 50 | Chi 1e | 0615489 | 8819340 | 1496 |
| Msungabanthu | 112 | 105 | 5.4 | 1.3 | | | 50 | Chi 1f | 0615453 | 8819342 | 1501 |
| Syzigium | 220 | 170 | 4.7 | 5.9 | | | 65 | Chi 1g | 0615401 | 8819312 | 1488 |
| Ndola | 54 | 48 | 1.9 | 0.7 | | | 70 | Chi 1h | 0615404 | 8819262 | 1474 |
| Sungwi | | | | | | | 0 | Chi 1i | 0615401 | 8819242 | 1466 |
| Bridelia micrantha | 71 | 56 | 1.8 | 2.1 | | | 80 | Chi 1j | 0615465 | 8819126 | 1476 |
| Combetum | 8 | 5 | 1.9 | 0.6 | | | 50 | Chi 1k | 0615445 | 8819110 | 1429 |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mnthunu |  |  |  |  |  |  | 50 | Chi 1l | 0615438 | 8819106 | 1438 |
| Parinari | 71 | 64 | 2.4 | 1 |  |  | 80 | Chi 1m | 0615465 | 8819064 | 1392 |
| Bangula | 55 | 52 | 4.7 | 2.6 |  |  | 50 | Chi 1n | 0615444 | 8819018 | 1408 |
| Mtunthulu | 45 | 44 | 2.9 | 0.4 |  |  |  |  |  |  |  |
| Faurea saligna | 146 | 110 | 4.9 | 2.1 |  |  |  |  |  |  |  |
| Mnthopa | 125 | 97 | 3 | 3.1 |  |  |  |  |  |  |  |
| Ficus | 75 | 70 | 3.2 | 1 |  |  |  |  |  |  |  |
| ***AVERAGE*** | **92** | **75** | **3.5** | **2.0** | **Customary Land** |  | **55** |  |  |  |  |
| **MANKHO--LONGO 1a-l** | **Dsh (mm)** | **Dbh (mm)** | **H (m)** | **CC (m)** |  |  |  | **UNIT** | **LAT** | **LON** | **(m)** |
| Dombeya rotundifolia | 194 | 70 | 3.7 | 1.5 | Afromontane grassland | ▪ Mainly grass cover on the ridge.<br>▪ Few pine trees introduced by MASAF. | 40 | Mak 1a | 0615844 | 8818688 | 1360 |
| Faurea saligna | 165 | 111 | 5.6 | 2.9 |  |  | 50 | Mak 1b | 0615833 | 8818730 | 1377 |
| Eucalyptus | 60 | 47 | 7.4 | 1 |  |  | 50 | Mak 1c | 0615826 | 8818774 | 1378 |
| Bwitizi |  |  |  |  |  |  | 50 | Mak 1d | 0615833 | 8818310 | 1402 |
| Syzigium | 128 | 93 | 4.7 | 2.1 |  |  | 30 | Mak 1e | 0615864 | 8818918 | 1457 |
| Combretum | 253 | 228 | 7.2 | 5.1 |  |  | 100 | Mak 1f | 0615828 | 8818194 | 1460 |
| Protea | 100 | 80 | 3.8 | 4.2 |  |  | 30 | Mak 1g | 0615812 | 8819014 | 1485 |
| Mnthopa | 120 | 100 | 2.7 | 6.2 |  |  | 50 | Mak 1h | 0615560 | 8819040 | 1419 |
| Lannea | 200 | 163 | 4.8 | 3.1 |  |  | 50 | Mak 1i | 0615619 | 8818988 | 1415 |
| Aeschynomene indica |  |  |  |  |  |  | 50 | Mak 1j | 0615661 | 8818948 | 1403 |
| Pinus kesiya | 135 | 112 | 6.2 | 2.1 |  |  | 80 | Mak 1k | 0615623 | 8818900 | 1388 |
| Pericopsis angolensis | 124 | 104 | 3.7 | 1.5 |  |  | 70 | Mak 1l | 0615846 | 8818606 | 1279 |
| Vitex doniana | 48 | 43 | 1.6 | 0.3 |  |  |  |  |  |  |  |
| Strychnos spinosa | 130 | 107 | 4.3 | 6.2 |  |  |  |  |  |  |  |
| ***AVERAGE*** | **138** | **105** | **4.6** | **3.0** | **Customary Land** |  | **54** |  |  |  |  |