LANDSLIDE OCCURRENCES IN THE HILLY AREAS OF BUDUDA DISTRICT IN EASTERN UGANDA AND THEIR CAUSES

BY

KITUTU KIMONO MARY GORETTI

Bsc MUK, Msc. (ITC, Netherlands)

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DECLARATION

This thesis is my original work and has never been presented for the award of any degree in any University.

Signed……………………………………Date ……………………………..

Kitutu Kimono Mary Goretti

This thesis has been submitted for examination with my approval as the University Supervisor:

Prof. Dr. Jean Poesen,
Catholic University of Leuven.

Signed……………………………………Date 16/11/2010

Prof. Dr. Seppe Deckers,
Catholic University of Leuven.

Signed……………………………………Date 16/11/2010

Dr. Andrew Muwanga,
Department of Geology, Makerere University.

Signed……………………………………Date ……………………………..

DEDICATION

To God be the glory for the good life and blessing given to me during the time of writing this thesis. To my husband and family who have always inspired and prayed for me to succeed.

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ABSTRACT

Although on a global scale Uganda is not known for landslide disasters, in the recent past especially in the years with above normal rainfall the loss of life and property from these disasters is increasing. This study assesses the factors that influence landslide occurrences in Bududa District and their impacts on to the livelihood of the people. Between 1997 and 2004, heavy rains left 48 people dead and ten thousand displaced and landless. The volume of debris from ninty eight landslides was 11 million m^3 and this was deposited into rivers and streams. Twenty nine of these landslides dammed rivers resulting in destruction of bridges and roads when the dams broke. The main landslide types are debris slumps which occur on concave slopes where water concentrates. These landslides occur on steep slopes that are plano concave and between slope angles of 14^0 to 41^0. Slopes facing north-east are most prone to landslides which coincide with the dominant rainfall direction. The soil types in this area are those conditioned by topography and tropical climate namely *Nitisols*, *Cambisols*, *Lixisols*, *Ferralsols*, *Leptosols*, *Gleysols*, and *Acrisols.* The texture of the soil in the horizons was significant to the landslide occurrences especially in the western zone. In the eastern zone, soil profile horizon is significant in some of the landslides but in the shallow landslides the slope and the shallow depth which creates a discontinuity between the saprolite and the rock causing water stagnation is the main influence. The knowledge from farmers' is almost similar to scientific observations. Farmers mentioned steep slopes, areas with concavities and those with flow of water from underground as areas prone to landslides. Although their observations have a limitation in that they cannot determine the threshold. The soils contain medium to high plasticity clays and according to the Atterberg limits they approximately fall in the categories of kaolinite and illite. The top soils also have a high infiltration rate which allows fast flow of water into the deeper clay rich horizons promoting water stagnation causing slope failure. The main triggering factor is rainfall and rainfall events of low intensity but prolonged for days are thought to be more disastrous however, this is an area that needs further investigation. Terraces are not popular among farmers in some of the areas because they believe that terraces promote water infiltration which triggers landslides. Using the LAPSUS-LS landslide model the slopes in Bududa District are identified as inherently unstable and the volumes of soil redistribution can yield four times higher than what was observed in 1997 (44,000,000 m^3). These will end up in stream channels possibly damming rivers and causing damage to infrastructure or siltation and pollution of streams.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Landslide occurrence is on the increase worldwide the consequences of which can be loss of life, loss of livestock, damaging or destroying residential and industrial developments, villages or even entire towns, destroying agricultural and forest land and negatively influencing the quality of water in rivers and streams (UNESCO/UNEP, 1988). The worldwide increased population and economic pressures in mountainous areas have forced human activities to shift to practices such as deforestation, urban development and agriculture into potentially hazardous regions (Guthrie, 2002). In Uganda it is reported that all mountainous areas are either vulnerable to or currently facing serious soil erosion (NEMA, 1997). It is also reported that farmers do not have incentives to undertake conservation measures in mountainous areas of Uganda (NEMA, 1997). Due to these shortcomings mountain disasters such as landslides have had significant impacts but limited interventions exist to minimize them. Landslides are caused by a combination of both natural and human related causes (Tanya, 2001). For example, between 1830 and 1950 the steep slopes northeast of Puerto Rico were cleared for agriculture resulting in gullies and landslides (Clark and Wilcock, 2000). Further still, Inganga *et al*, in 2001 reported that many landslides that occurred in Nyeri district in central Kenya were caused by human activities which included cultivation, deforestation and terracing of steep slopes. They further report that the soils also have high clay content and probably the swelling clays are another important factor in triggering landslides. In addition Bagoora 1988, in the assessment of massmovements in Rukiga area South Western Uganda observed that landslides occur during peak rainy seasons of March and April. Geologic factors have also been found to cause mass movements on slopes and these include shallow soils over hard impermeable rocks or glacial till, soft, clay-rich rocks that produce thick plastic soil mantles, alignment of lineaments parallel to the ground slope and planar rock structures, unconsolidated or weakly consolidated deposits (Sidle *et al.*, 1985). A landslide occurs when the average shear stress of the hillslope material becomes greater than the average shear resistance (Larsen and Torres-Sanchez, 1998). Favorable conditions for sliding may exist or accumulate for a long period of time without any movement taking place (Scharpe 1938). Nevertheless, the right impulse can develop a number of slides that happen simultaneously or within a short period of time. These are normally referred to as triggering factors. These causes can be divided into internal and external factors. The internal factors include pore water pressure, decrease in the cohesion of the slope material, steeply dipping beds and steepness of the cliff faces. Meanwhile the external factors include rainfall, earthquakes, vibrations from heavy machinery, artificial increase of slope angle and removal of lateral support (Inganga *et al*., 2001). Rainfall is a common triggering factor. Tsereteli (in UNESCO/UNEP, 1988), stated that a close relationship exists between landslide activity and the amount of precipitation. The amount of rainfall has considerable influence on the moisture content and the pore water pressure in soils. Landslides are more likely to occur if high amounts of intense rainfall are preceded by a period of light but incessant precipitation. This is because saturation of soils needs a much longer period and, that is why there are higher numbers of landslides during September than July in the Ethiopian highlands. The high rainfall in July is absorbed by dry soils and towards September the soils become saturated resulting in higher possibility of slope failure (Ayalew, 1999). In the Aberdare ranges in Kenya, many landslides occur at the beginning of the rainy season (Inganga *et al*, 2001) and this is because of deep cracks in the soils which allow water infiltration into the soil to deep levels causing landslides.

Slope steepness is also a significant factor and the greater the height, steepness and concavity of slopes, the greater the volumes of the landslides (UNESCO/UNEP, 1988). In tropical areas, slope failures are most common on slopes between 30° and 60°. Landslides in the Aberdare ranges in Kenya are confined to slopes 20° and more (Ngecu and Mathu, 1999). Slope failure is more common in concave landscape parts due to the long-term accumulation of sediment transported from adjacent slopes resulting in thicker soils and the convergence of subsurface flow leading to higher pore pressures (Gabet and Duune, 2002).

Chenery in 1960, in the major soil surveys done in the country, mentioned the risk of soil slips in Bududa. He mentions the presence of cracks in the soils and recent scars of landslips in that year. As these disasters continue to take their toll, there is need for an in-depth study that will provide information to minimize on the risk.

1.2 THE PROBLEM STATEMENT

Although it is clear that landslides have caused damage in the mountainous areas of Bududa District, (NEMA, 1998) their causes and factors that influence them in the Bududa areas are still not well understood. The challenge of some of the hilly areas not affected as compared to others heavily devastated leaves more questions to be answered on what the actual causes are. Available information indicates that the heavy rains experienced between October 1997 to January 1998 caused landslides, which killed 48 people and displaced 10,000 from the slopes of Bududa. Further still, the heavy rains in August and September 2007 left five people dead, crops and a lot of property damaged. 80% of Bududa is a fragile ecosystem because of its extreme steepness and at the same time it has an average population density of 952 people per km^2 (UBOS 2002) making it one of highly populated areas in Uganda. The estimated land holding per person is at 32 m^2 (Knapen et al., 2006) which creates extreme pressure on land probably leading to the high landslides incidences. Government had proposed resettlement of some of the affected people to safer areas in Mbale District. This was hampered when Bududa was made a district. The situation is likely to become worse because the sediment from landslide will cause siltation of river channels and wetlands downstream resulting into floods and affecting more communities.

1.3 RESEARCH OBJECTIVES

The main objective of this study was to provide decision makers in Uganda with the landslide hazards and risk assessment methodology for proper management and planning of development in mountainous and hilly areas.

The specific objectives were to:

1. Assess and identify the geological and topographic factors that cause landslides. In addition assess the chemical and physical properties that influence landslides in Bududa.
2. Locate the landslide potential areas and generate landslide hazard maps.

3. Test the farmers understanding on landslides and promote community involvement in landslide management.
4. Assess the influence of rainfall.

1.4 RESEARCH HYPOTHESES

Objective 1:

Geomorphic factors such as geology, topography and relief have a high influence on landslide types and occurrences in this region.

Soil properties such as particle size and pore distribution of the soil matrix are a conditioning factor to landslide occurrences.

Objective 2:

Landslide hazards can be predicted and classified using the LAPSUS – LS model.

Objective 3:

Farmers' knowledge and perception on the controlling factors has no strong linkage to the scientific observations.

Objective 4:

Rainfall is the main triggering factor for landslide occurrences in Bududa.

1.5 JUSTIFICATION OF THE STUDY

This study will provide more information and data on what already exists globally in understanding landslide processes and their impacts in Bududa. Bududa was selected as a study area because of the high number of landslide incidences in the country. The findings can be applied to other areas of the country with similar problems. Landslides occurrences are associated with decrease in crop yields, damage to property and infrastructure. Factors that cause landslides in the world are generally known, however no specific research has been made done in Uganda which creates a gap on information on this processes. Other areas in Uganda suffer from landslides and most policies concentrate more on soil erosion. The findings from this research can be used to improve on the existing policies on the management of mountainous areas in Uganda, reduce on their occurrence in order to minimize losses from these disasters.

1.6 STUDY AREA

The study is carried out in Bududa District situated in Eastern Uganda (Figure 1a). Bududa was formerly Manjiya County under Mbale District (Figure 2) and it lies in the south west of the surroundings of the Mount Elgon Volcano. It is geographically bound by latitude 2^0 49' N and 2^0 55' N, longitude 34^0 15' E and 34^0 34' E (Figure 1a).

1.7 STRUCTURE OF THE THESIS

The structure adopted in this thesis is in the most recent Ph.D Guidelines for Makerere University, where it is recommended that some of the chapters can be presented as published papers. This thesis was also transferred from the Catholic University of Leuven to Makerere University hence the variation in methodology of carrying out research. For example the method of working with Master Degree students is widely used in the carrying out of research at the Catholic University of Leuven where the Ph.D candidate is a junior supervisor. In addition all publications should include all contributors and supervisors whereby in this case they were published with Msc students as the first authors. This thesis has nine chapters and their contents are outlined below.

Chapter one is an introductory chapter that gives an overview of the problem of landslides in Bududa. It also gives the objectives of this study and what hypotheses are to be tested to achieve these objectives.

Chapter two deals with the literature review about landslide occurrences and hazards elsewhere in the world. This chapter examines what other authors have done and the findings, observations and conclusions that have been made about the controlling factors in other areas. These are then related to what has been observed in Bududa.

Chapter three is a publication in the international Journal for Geomorphology which gives characteristics of landslides and some of the controlling factors.

Chapter four is another paper in the same journal which assesses the LAPSUS – LS model in identifying areas prone to landslide hazard. This model also assesses the sediment distribution after failure.

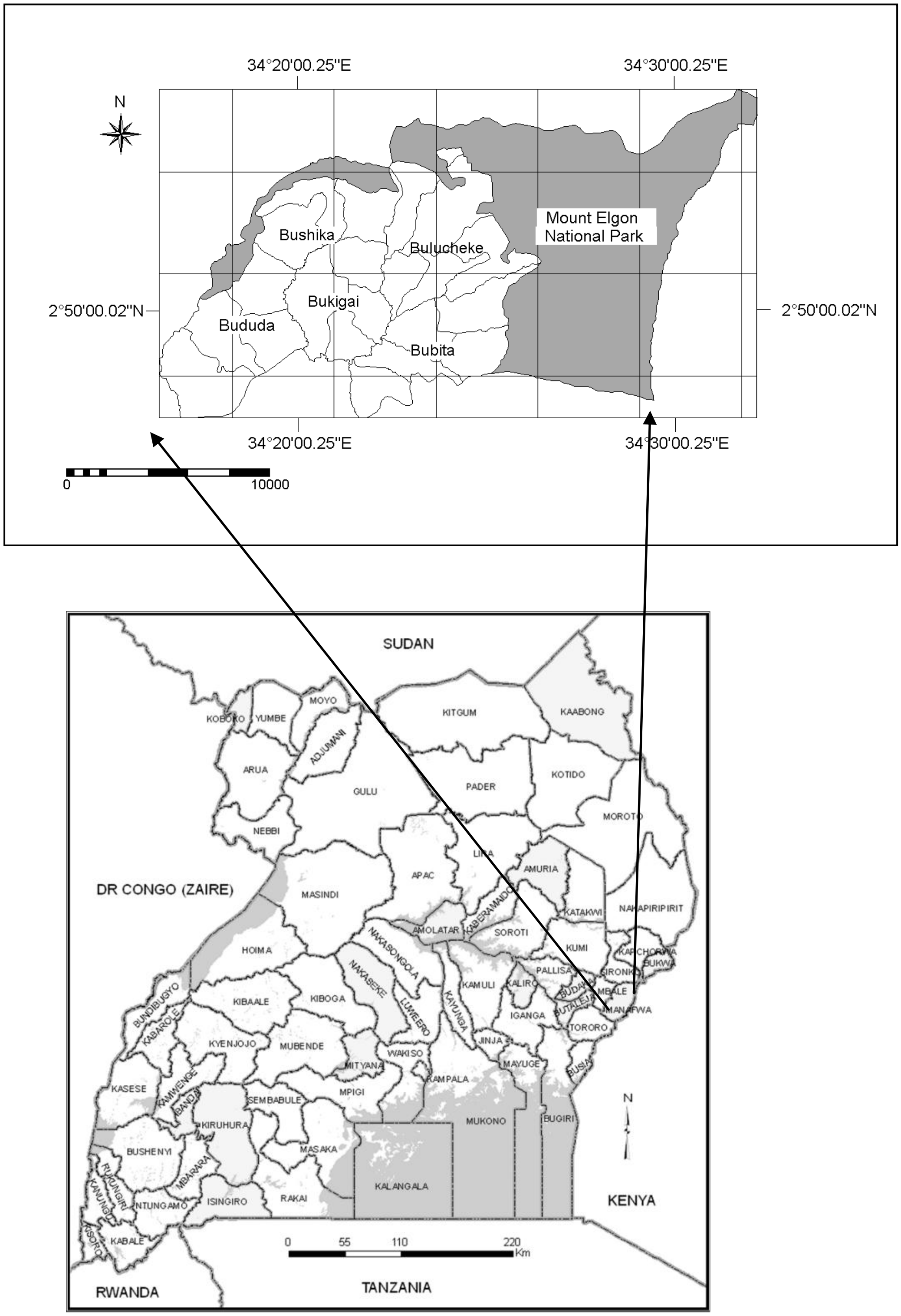


Figure 1a: Location of Bududa District in Uganda

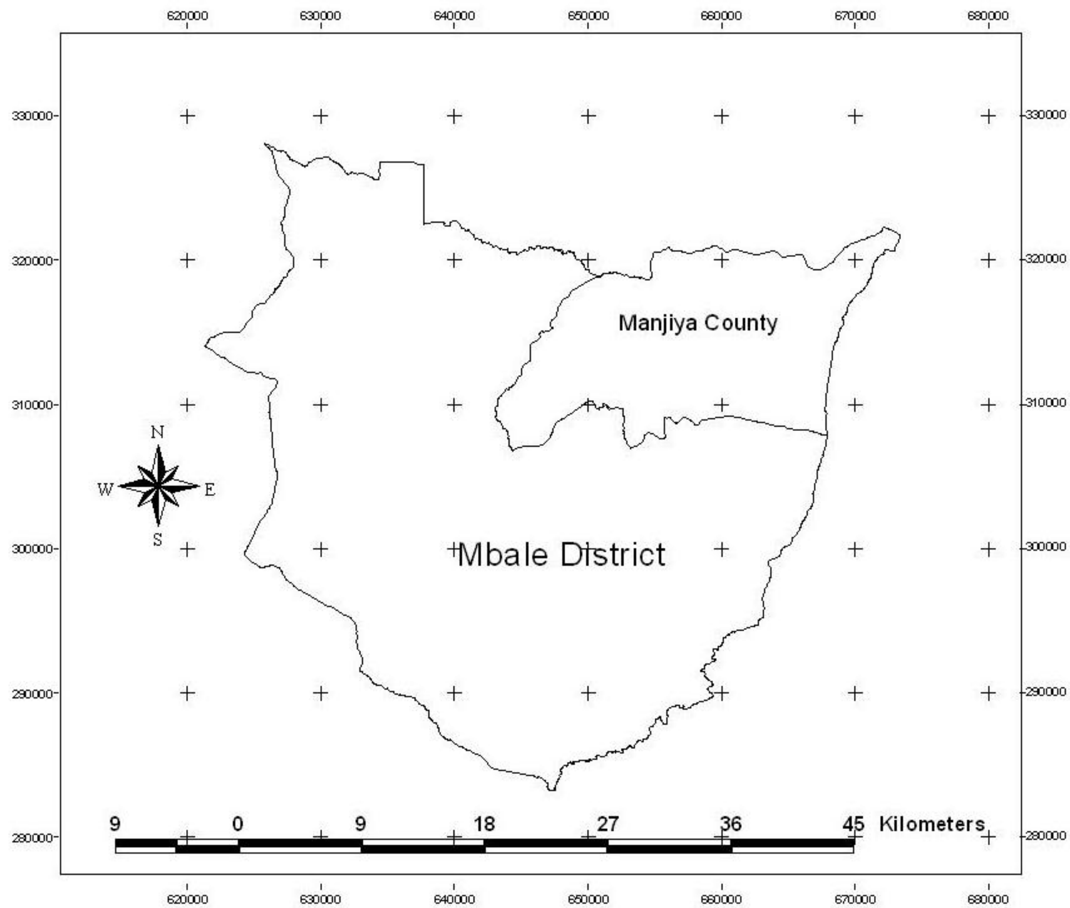


Figure 2: Manjiya County as originally under Mbale District. This is what became Bududa District

Chapters three and four were co-authored with Masters Students, other contributors and Supervisors.

Chapter five is a publication in the African Journal of Agricultural Research and it deals with the influence of soil properties.

Chapter six is another publication this African journal which assesses the farmer's perception on landslide occurrences.

Chapter seven is an earlier publication in a local journal that describes the impacts of landslides on the livelihood of the people.

Chapter eight highlights important unpublished work and Chapter nine draws general conclusions from this study and also gives recommendations.

References

Ayalew, L. 1999. The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Bull. Eng. Geol. Env. 58: p. 9-19.

Bagoora, F. D. K. 1988. Soil erosion and mass wasting risk in the highland areas of Uganda, Mountain research and Development, Volume 8, Nos. 2/3, pp 173-182.

Chenery, E. M. 1960. An introduction to the soils of the Uganda Protectorate, Memoirs of the Research Division, series 1, number 1, Department of Agriculture.

Clark, J. J and Wilcock, P. R. 2000. Effects of landuse change on channel morphology in northeastern Puerto Rico. Geological Society of America Bulletin 112, no 12 p. 1763-1777.

Gabet, E.J and Dunne, T.,2002. Landslides on coastal sage-scrub and grassland hillslopes in a severe El Niño winter: The effects of vegetation conversion on sediment delivery. Geological Society of America Bulletin 114, no.8, p.983-990.

Guthrie, R. H. 2002. The effects of logging on the frequency and distribution of landslides in three watersheds on Vancouver Island, British Columbia. Geomorphology 43, p. 273-292.

Inganga, S.F. Ucakuwun, E.K and Some, D.K. 2001. Rate of swelling of expansive soils: a critical factor in the triggering of landslides and damage to structures. Documenta Naturae, 136: 93-98.

Larsen, M.C and Torres-Sánchez, A.J. 1998. The frequency and distribution of recent landslides in three Montane tropical regions of Puerto Rico. Geomorphology 24, p.309-331.

Ngecu, W. M and Mathu, E.M. 1999. The El Nino-triggered landslides and their socioeconomic impact on Kenya. Environmental Geology, 38 (4): 277-284.

National Environment Management Authority. 1997. District State of Environment Report, Mbale, 1997, Uganda, 128 pp.

National Environment Management Authority**.** 1998**.** State of the Environment Report for Uganda**.**

Scharpe, S.C.F. 1938. Landslides and related phenomena. A study of mass-movements of soil and rock. Columbia University Press, New York. 137p.

Sidle, R. C. Pearce, A. J and O' Loughlin, C. L. 1985. Hillslope stability and landuse. American Geophysical Union, Washington DC, USA, 125 pp.

Uganda Bureau of Statistics, 2004. The 2002 Uganda Population and Housing Census. (http://www.ubos.org/2002census.html)

UNESCO / UNEP, 1988. Landslides and mudflows Volume 1. UNEP/UNESCO, Moscow. 236p

Tanya, P. 2001. http://www.mtnforum.org/oldocs/621.pdf).

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Because of the increasing risks and losses from landslides worldwide (Table 1), many significant researches have been carried out of which some are in the tropical countries of Africa (Table 2).

Table 1: Historic landslides, their causes and impacts

Date and year	**Place**	**Damage**
19 September 1889	Quebec City in Canada	Quebec rockslide occurred when an overhanging piece of slate rock broke off from Cap Diamant and fell 90 meters onto the houses below. The homes of 28 families on Champlain Street were crushed, burying roughly 100 people under 24 meters of broken slate rock. The final death toll exceeded 40 people.
29 April 1903	Turtle Mountain, Alberta, Canada	Frank, Alberta is a coal mining town in the Crowsnest Pass, Alberta. 90 million tones (30 million cubic meters) of limestone crashed from the east face of Turtle Mountain and covered approximately three square kilometers of the valley floor.. The slide dammed the Crowsnest River and formed a small lake, covered 2km of the Canadian Pacific Railway, destroyed most of the coal mine's surface infrastructure, and buried seven houses on the outskirts of the sleeping town of Frank, as well as several rural buildings. It is estimated that 90 of the roughly 100 individuals in the path of the slide were killed.
July 10, 1949	Khait landslide in the Soviet Union.	The landslide was triggered by the 1949 Khait earthquake and buried 33 villages and by some estimates killed 28,000 people.
October 9, 1963	Italy	260 million cubic meters of rock slid down the side of Mount Toc caused by a minor earth tremor and plunged into the reservoir created by the Vajont Dam at an estimated 100 mph, creating a seiche 250 meters high, that came over the dam wall and destroyed the town of

		Longarone and its suburbs, killing almost 2,000 people.
January 9, 1965	British Columbia	The volume of rock involved in the landslide has been estimated at 47 million cubic meters and four people were killed.
1966	Welsh village in Aberfan	The Aberfan disaster was a catastrophic collapse of a colliery spoil-tip that occurred in the Welsh village of Aberfan, killing 116 children and 28 adults.
November 30, 1977.	Tuve, Gothenburg in Sweden	Some 67 houses were destroyed, killing 9, injuring about 60 and making around 600 people homeless.
August 8, 1979.	Dunedin, New Zealand	It was the largest landslide in a built-up area in New Zealand's history, resulting in the destruction of 69 houses - around one sixth of the suburb - but no fatalities.
July 28, 1987	Italy	The flow entrained estimated 5-8 million cubic meters of debris. The created alluvial fan dammed the Adda River and created a lake. The mass run about 1.5 km downstream and generated an upstream mud wave 35m high which travelled about 2.7 km. The landslide resulted in a 35 m deepening of the Val Pola canyon. Villages were evacuated before.
30 July 1997	Australia.	Two ski lodges collapsed, and a total of 18 died.
December, 1999	Vargas state in Venezuela	Torrential rains, flash floods and debris flows killed tens of thousands of people and destroyed thousands of homes.
June 11, 2007	Chittagong, Bangladesh	Heavy monsoon rainfall caused landslides that engulfed slums around the hilly areas of the city. The death toll was reported to be at least 128, including at least 59 children, with more than 150 injured.
September 6, 2008	Cairo, Egypt	Informal settlement in the Manshiyet Nasser neighborhood of east Cairo, Egypt. 119 people died in the rockslide.
1st March 2010	Bududa District in Uganda	About 365 people killed, three villages completely destroyed and 8,000 people resettled.
August 8, 2010	Gansu, China	The mudslides killed more than 1,471 people, while 1,243 others have been rescued and 294 remain missing.

Source: http://en.wikipedia.org/wiki/Landslide

Table 2: Studies that have been done on landslides in the East African region

COUNTRY	REGION	AUTHOR
Uganda	Mount Elgon	Inganga *et .al*, 2001 Muwanga *et .al*, 2001 Kitutu , 2004 Erima, 2004 Wendy, 2003 Knapen *et .al*, 2006 Claessens *et.al*, 2007 Kitutu *et. al*, 2009 Kitutu *et. al*, 2010
	Mount Rwenzori	Rapp *et .al*, 1972 Ucakuwun, 1999 Muwanga *et .al*, 2001
	South West Uganda	Inganga *et. al* , 2001 Bagoora, 1988
Tanzania	Western Uluguru	Rapp *et.al*, 1972 Westerberg and Christiansson ,1998 Westerberg ,1999 Christiansson and Westerberg, 1999
	Rungwa	Rapp *et.al*, 1972
Rwanda	Butare, Gikongoro, Kibuye district	Moeyersons, 1988 Moeyersons, 1989a Moeyersons, 2003
	Rwaza hill	Moeyersons, 1989b
Ethiopia	Northern Ethiopian Highlands	Nyssen *et.al*., 2003
	Ethiopian Highlands	Ayalew 1999 Temegen *et.al* , 2001

Kenya	Aberdare Range	Davies, 1996 Ngecu and Ichangi, 1998 Westerberg and Christiansson, 1998 Ngecu and Mathu 1999 Westerberg, 1999 Ucakuwun, 1999 Inganga *et .al*, 2001
	Mau Hills	Ngecu and Mathu, 1999
	Mount Kenya	Ngecu and Mathu, 1999
	Chyulu range	Ngecu and Mathu, 1999

Source: Compiled from Literature.

2.2 POPULATION DYNAMICS ON MOUNT ELGON

The East African highlands are heavily populated because of their medium to high agricultural potential and their suitability for human habitation (Michael *et.al*, 2003). Mount Elgon, locally known as Masaba after the legendary father of the Bagisu, has a long history of human occupation. The first settlers on the southern and southwestern slopes were the Bagisu who came from the Kenyan side at around the 14th century and presently they live in Bududa, Mbale, Sironko and Manafwa Districts in eastern Uganda. A Nilo-Cushtic tribe, the Sebei, settled on the northern slopes of the Ugandan side of the mountain. Originally these pastoralists lived in the forest zone between 2500 and 3000m where they grazed their cattle, goats and sheep. In 1983 and 1990 two resettlement programmes allocated these people outside the park, where they now adopt commercial maize and wheat cultivation. All these people have strong bounds with the mountain and its resources such as medicinal plants, vegetables, honey, bamboo and water (http://www.visituganda.com).

In Uganda, according to NEMA (2006), demographic projections by District, suggest that as a country, Uganda will be depleted of land available for farmers by around 2022. It is further stated that by region, the eastern region where Bududa is situated will run out of available land for agriculture, earlier than all the other regions, by around 2010. The reason for this land scarcity is the high population growth rate of 3.8% (Table 3) as evidenced from the high number of houses (Figure 3) which forces people to inhabit areas prone to landslide hazards.

2.3 CLASSIFICATION OF LANDSLIDES

Many definitions have been applied to the term landslide and they all vary depending on the objective of the author. Cruden, (1991), defined a landslide as a movement of a rock, earth or debris down a slope. The most accepted classification is that proposed by Varnes, (1978). He distinguishes five types of movements namely falls, topples, slides, flows and spreads and also subdivides the type of material into bedrock, debris and earth. This is illustrated in Table 4 and Figure 4. These materials may move by falling, toppling, slumping, sliding, spreading or flowing. The various types of landslides can be differentiated by the kinds of material involved and the mode of movement.

2.3.1 SLUMPS

A slump is the form of slide most common in thick, homogenous, cohesive materials such as clay (Selby, 1993). The surface of failure beneath a slump block is spoon-shaped, concave upward or outward. Slumps may be caused by currents in water undercutting the foot of a slope. They are also common if faulty engineering design of cut embankments. Slumps have curved failure planes and involve rotational movement. In Bududa the dominant type movement is rotational which mostly occurs on concave slopes and at a large distance from the water divide where runoff and subsurface water concentrates (Knapen *et. al*, 2006).

2.3.2 SLIDES

Mass wasting where a mass of rock or weathered debris moves downhill along discrete shear surfaces is defined as a slide (Selby 1993). Subcategories of slide in various classifications include rock slide, block glide, mudslide, and debris slide. Rock slides or block glides are slides where material remains largely unreformed as it moves over a planar slide plane. These have no specified size, but thickness is normally only about 10% of their down slope length. Translational slides occur in Bududa at a shorter distance from the water divide because they require a less increase in pore water pressure to occur. Furthermore, they occur on rectilinear slopes with shallow soils (Knapen *et. al*, 2006).

Table 3: Census population (1991 and 2002) for eastern region and district projected (2010 and 2011) mid-year population

District	Census Population		Growth Rate 2002 %	Mid-Year Projected population	
	1991	2002		2010	2011
Amuria	69,353	180,022	8.2	344,200	374,000
Budaka	100,348	136,489	2.6	169,300	174,000
Bududa	79,218	123,103	3.8	167,000	173,700
Bugiri	239,307	412,395	4.7	599,000	628,500
Bukedea	75,272	122,433	4.2	171,100	178,600
Bukwa	30,692	48,952	4	67,500	70,400
Busia	163,597	225,008	2.7	281,200	289,300
Butaleja	106,678	157,489	3.3	206,300	213,600
Iganga	365,756	540,999	3.4	709,600	734,900
Jinja	289,476	387,573	2.5	475,700	488,400
Kaberamaido	81,535	131,650	4.1	183,100	191,000
Kaliro	105,122	154,667	3.3	202,200	209,300
Kamuli	380,092	552,665	3.2	716,700	741,100
Kapchorwa	86,010	141,439	4.3	199,200	208,100
Katakwi	75,244	118,928	3.9	163,100	169,800
Kumi	161,422	267,232	4.3	377,900	395,100
Manafwa	178,528	262,566	3.3	343.2	355.2
Mayuge	216,849	324,674	3.5	429,400	445,100
Mbale	240,929	332,571	2.8	416,600	428,800
Namutumba	123,871	167,691	2.6	207,300	213,100
Pallisa	257,308	384,089	3.4	506,900	525,300
Sironko	212,305	283,092	2.5	346,600	355,800
Soroti	204,258	369,789	5.1	555,100	584,900
Tororo	285,299	379,399	2.4	463,600	475,700
Sub Total	**4,128,469**	**6,204,915**	**3.5**	**8,301,800**	**8,623,700**

Source: Uganda Bureau of Statistics, 2010.

2.3.3 TOPPLES

A topple failure is a process that may be treated as a distinct entity in a classification. Its primary characteristic is that it has a distinct component of rotation and sliding before a fall takes place (Selby, 1993). Toppling is common in slates and schists but also occurs in thinly bedded sedimentary rocks and in columnar jointed igneous rocks such as basalt and dolerite. The distinction between toppling and sliding failures is based upon the ratio between the width of the joint block and its height.

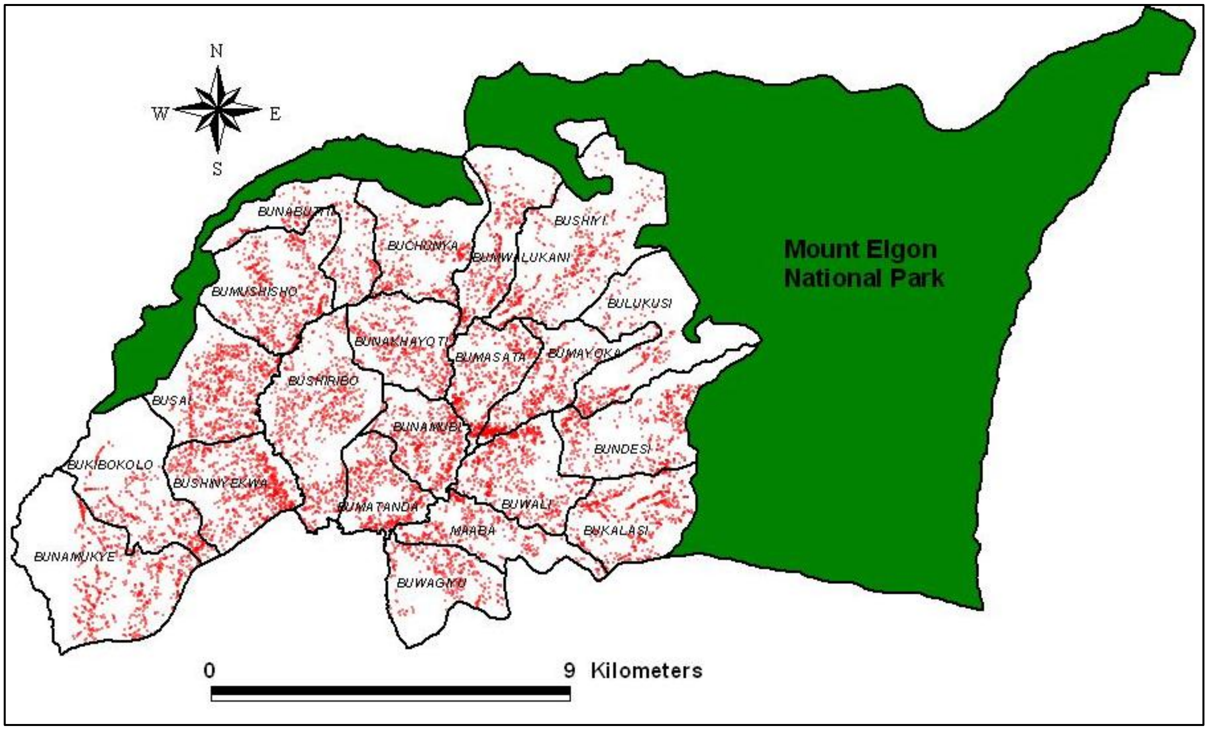


Figure 3: Location of houses in Bududa District. The red dots are houses which characterises this area as densely populated. Location of houses was ddigitized from the wide view high resolution satellite image for 13th March 2010. Courtesy: United States Geological Survey (USGS).

Wide low blocks slide but tall narrow blocks overturn (topple) (Selby, 1993). Toppling is also influenced by structure steeply jointed rocks topple. These are rare in the Bududa area.

2.3.4. FALLS

Falls in soils or soft rocks usually involve only small quantities of material because steep slopes in weak weathered materials are necessarily very short. These falls are usually due to undercutting of the toe or face of the slope by a river or by wave action (Selby 1993). Falls are not found in Bududa

Table 4: Landslide classification after Varnes, 1978

Type of movement			**Type of material**		
			Bedrock	Engineering soils	
				Predominantly coarse	Predominantly fine
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational	Few units	Rock slump	Debris slump	Earth slump

	Translational	Many units	Rock slide	Debris slide	Earth slide
Lateral spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow	Debris flow	Earth flow
Complex			Combination of two or more principle type of movements.		

2.4 CAUSES OF LANDSLIDES

2.4.1. CAUSAL FACTORS

Causes of landslides may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable (http://en.wikipedia.org/wik/Causes_of_landslides).

2.4.1.1 INFLUENCE OF SOIL PROPERTIES

Two soil series occur in Bududa District as described by Ollier and Harrop in 1959 and these are the Bududa Series which consists of red clay loams originating from the Elgon volcanics and Basement Complex colluvium with a high to medium productivity. The other is the Bubutu Series which consists of non-lateritised brown sandy clay loams originating from the Basement Complex granites with a medium productivity. A third series, the Bubulo Series is located in Manafwa District and consists of non-lateritised red loams and clay loams originating from the Basement Complex granites and amphibolites with a medium productivity (Ollier and Harrop, 1959). According to Reedman (1973), two basic types of residual soil occur at Butiriku carbonatite in Bududa. These are light grey sandy soils which are rarely more than 5m thick and the fenite complex gave rise to much finer grained, red-brown soils, with a very thin A-horizon, which grades imperceptibly into an extremely thick and uniform B-horizon.

The influence of soil in mass movements cannot be underestimated. Soils play a dual role because it is a by-product of the landslide process and at the same time it is an important causal factor. The most important properties in soil stability are those that influence the rate of water movement in the soils and the capacity of the soil to hold water (Sidle *et. al*., 1985). These include particle size and pore distribution of the soil matrix.

Finer soils tend to hold higher volumes of water under unsaturated conditions than do coarse textured soil. Clay particles are 0.002mm or less in diameter and clay soils normally have more than 20% of these particles.

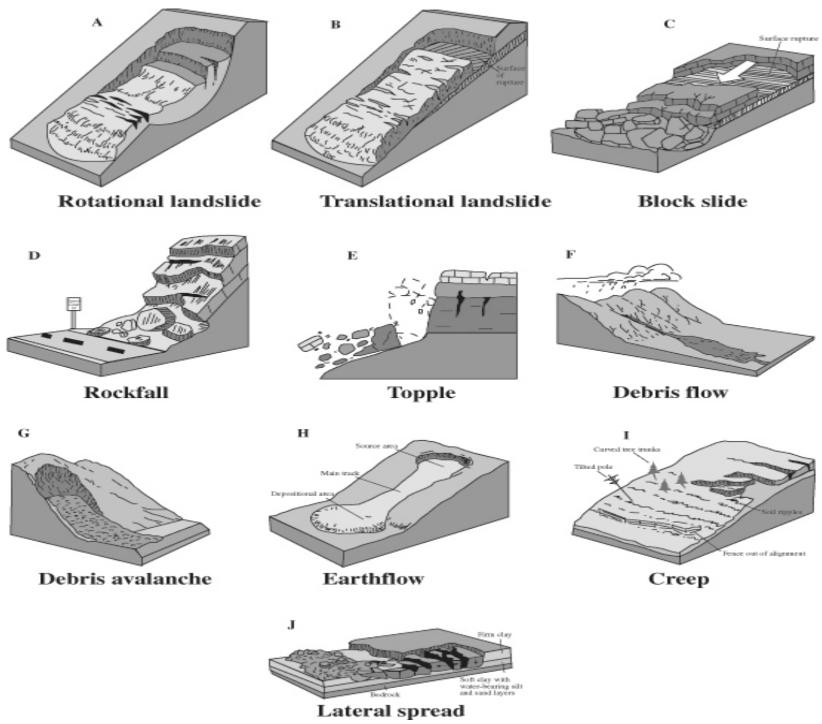


Figure 4: Schematic representation of landslide types

Source: http://pubs.usgs.gov/fs/2004/3072/images/Fig3grouping-2LG.jpg

Soils in Bududa have high clay content (Wendy, 2003, Kitutu *et. al,* 2009). High clay content in deeper soils may increase the water holding capacity and give rise to long term progressive movement in certain cases and to move rapid failure in extreme cases (Sidle *et al*., 1985). Ngecu and Ichangi, (1998), report a landslide in Maringa village in Kenya, caused by over saturation of clay soils known as Andosols. Soil layers rich in clay in deep horizons are significant in the cause of the slumps in the western side of Bududa (Kitutu *et. al,* 2009). Clay minerals result from the chemical weathering and breakdown of minerals in rocks and the production of secondary minerals. Chemical weathering disrupts the bonds between particles thus causing a reduction in cohesion.

Depending on the water content, soil may behave as a solid, semi-solid, plastic or liquid. The amount of water needed to change the behavior depend on the species of clay mineral present (Selby, 1993). Atterberg, 1846-1916 suggested the concept of boundaries to the four states in which a soil may exist namely Liquid Limit (LL) and the Plastic Limit (PL). The plastic limit (PL) is the water content where soil starts to exhibit plastic behavior. A thread of soil is at its plastic limit when it is rolled to a diameter of 3 mm and begins to crumble. The liquid limit (LL) is the water content where a soil changes from plastic to liquid behavior (http://en.wikipedia.org/wiki/Atterberg_limits). High values of LL and PL indicate the presence of smectite clays and low values the presence of the kaolinitic clays (Selby, 1993). Plastic Limit is influenced by the amount of clay size material in the sample and the Plasticity Index is controlled by the amount of each clay species. In Bududa the Atterberg limits reveal that the medium to high plasciticity clays occur and plot in the area of illite and kaolinite (Kitutu *et. al*, 2009).

In areas with expansive soils and where rotational landslides occur, the clay fraction often contains clay minerals of the montmorillonite group. These can take up water or organic liquids between their structural layers making them swell. Natural dry montmorillonitic clays will have water content of less than 15%, but they can absorb water up to 30% (Inganga *et al*., 2001). Three parameters play part in the triggering of landslides and these include, the clay content of the soil at a particular depth, the rate at which water infiltrates into the clay at that depth and the volume change of the soil over the period of water infiltration. The montrimollironite group of clays has not been encountered in Bududa.

2.4.1.2 INFLUENCE OF SLOPE STEEPNESS

Relief is a principal factor in the determination of the intensity and character of landslides. It has direct as well as indirect influences. Direct influences encompass slope, steepness, river valley morphology and thalweg gradients. The most important relief characteristic is the steepness, which affects the mechanism as well as the intensity of the landslides. The greater the height, steepness and convexity of slopes, the greater the volumes of the landslides. The stability of the slope against sliding is defined by the relationship between the shear forces and the resistance to shear. The main force responsible for mass wasting is gravity (UNESCO/UNEP, 1988). Gravity is the force that acts everywhere on the earth's surface, pulling everything in a direction toward the center of the earth. On a flat surface the force of gravity acts downward and so long as the material remains on the flat surface it will not move under the force of gravity. On a slope, the force of gravity can be resolved into two components, one acting perpendicular to the slope and another acting tangential to the slope.

The perpendicular component of gravity helps to hold the object in place on the slope. The tangential component of gravity causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope. On a steeper slope, the shear stress or tangential component of gravity increases and the perpendicular component of gravity decreases. The forces resisting movement down the slope are grouped under the term shear strength which includes frictional resistance and cohesion among the particles that make up the object. When the shear stress becomes greater than the shear strength then the slope fails.

An important factor in the distribution of landslides is the slope gradient and mass movements only occur when a critical angle is exceeded. The threshold slope angles for landslide occurrences in some parts of Eastern Africa are summarized in the Table 5. In Bududa landslides occur on slopes as low as 14° which is the lowest in all the studies.

Table 5: Slope gradient threshold for landslides in Eastern Africa

Location	**slope**	**Author**
Tropical areas	26° - 50°	Thomas, 1994
Humid tropics	> 40°	Birot, 1960
Abadare ranges (Kenya)	> 20°	Ngecu and Ichangi, 1998
	> 35°	Davies, 1996
Northern and Southern Ethiopian highlands.	20° - 45°	Ayalew, 1999
Northern Ethiopia	19° – 56°	Nyssen *et. al*., 2002
Wondogenet (Ethiopia)	10°-20°	Temesgen et. al.,2001
Western Uluguru (Tanzania)	28° - 44°	Rapp *et al.*, 1972
Southwest Rwanda	> 25°	Moeyersons, 2003
Western Uganda	> 26°	Doornkamp, 1971 (in Rapp *et. al*,. 1972)
Bududa	14°- 41°	Knapen *et. al*, 2006.

Source: Knapen *et. al,* 2006.

Slope failure is more common in concave landscape parts due to the long-term accumulation of sediment transported from adjacent slopes resulting in thicker soils and the convergence of subsurface flow leading to higher pore pressures (Gabet and Duune, 2002). This phenomenon was similarly observed in most of the slumps in Bududa (Knapen *et. al*, 2006).

In the tropics, the slope aspect does not cause large differences in soil temperature because of the low latitude. But it is most relevant in relation to prevailing winds and the resulting rainfall and soil moisture conditions (Larsen and Torres-Sanchez, 1998). In Bududa landslides were common on slopes oriented in the east and north direction which coincides with the dominant direction in which rain falls (Knapen *et. al,* 2006).

2.4.1.3 INFLUENCE OF UNDERCUTTING OF SLOPES

Rockslides resulting from human activities such as undercutting by roads or railroad excavations are more widespread than rockslides resulting from natural causes (Scharpe, 1938). Human activities such as construction of roads, building developments, mines and quarries, dams and reservoirs, canals, increase of groundwater levels, changes in vegetative cover, tunnels and communication systems have a great impact on the stability of the area and are seen as the major factors causing slope failures in the twentieth century (UNESCO/UNEP, 1988). These human modifications fundamentally alter hill slope stability (Larsen and Torres-Sanchez, 1998). Slope undercutting due to house construction and also foot paths cause concentrated flows which trigger landslides mostly in the western part of Bududa (Knapen *et. al,* 2006).

2.4.1.4 INFLUENCE OF THE GEOLOGICAL FACTORS

It is believed that Mount Elgon may have been higher than Mount Kilimanjaro but the summit of Elgon collapsed into the chamber from which volcanic material had been expelled resulting in a caldera of 8 Km in diameter. It differs from the other Rift Valley volcanoes by its age, which is estimated to be at least 24 million years (Davies 1956). In Bududa District three main lithologies can be distinguished and these are the Butiriku carbonatite covering the central part which corresponds with the sub county of Bukigai, a zone of fenitised basement rocks of Precambrian age surrounding this central carbonatite outcrop and the third zone with Mount Elgon agglomerates and tuffs situated in the north east of Bududa District and falling within the borders of Mount Elgon National Park. These highly weathered rocks are composed of extremely fine pyroclasts of potash feldspar and are referred to as potash ultra-fenites (Reedman, 1973).

There are many associations of mass movements with certain rock types (Sidle *et al*., 1985, UNESCO/UNEP, 1988). Hard intact rocks have strengths controlled by their internal cohesive and frictional properties. Existence of areas of weakness such as faults and joints may lead to rock failures and these are more common in granites and sandstone (Selby 1993). Fault zones often contain fractured and crushed rocks. The inherent weakness of these zones increases the deep percolation of water into bedrock and subsequent weathering of crushed rocks into clay rich soil susceptible to failures. This phenomenon was observed at the Bugobero rockslide where joints in a dyke act as water infiltration points causing water to accumulation at the discontinuity between the main rock and the dyke. The water acting as lubricant then triggered a huge rockslide (Kitutu, 2010, unpublished). This weakness can be enlarged by deep percolating water into the bedrock and subsequent chemical weathering of the rocks. The existence of a relatively impermeable layer in the bedrock promotes the formation of a perched water table during storms or heavy rainfall, increasing the risk for slope failures (Sidle *et al*., 1985). The susceptibility of the whole mass to sliding is determined by the weakest link, for example a layer of clayey in between massive rocks (UNESCO/UNEP, 1988). Down slope dipping planes separating rocks of different competence, as well as planar discontinuities orientated parallel to the slope, may impede vertical drainage and root penetration. In addition they can act as a potential failure plane. Beddings with a horizontal or cross-dipping orientation may act as natural buttresses increasing the stability of slopes (Sidle *et al*., 1985). In some areas of Bududa, especially the eastern zone the parent rock is nearer to the surface and the porous saprolite forms an abrupt discontinuity with the coherent basement complex granite. In here the conditioning factors are soil horizon differ-rentiation and the saprolite forming a discontinuity with the parent rockgranite. During rains, drainage of water through the soil profile is stopped at the point of discontinuity thereby causing water to accumulate. These phenomena results in a semi-solid sub soil material that will easily flow or slump under pressure from the top soil (Kitutu *et. al*, 2009).

Seismicity has caused slope failures in areas such as Alaska 1964 (McSaveney 1978). Although mass movements due to seismic activity have been very common, little attention has been paid to documenting the intensity and geomorphic, ecological and socio-economic significance of such events (Sidle *et al*., 1985). Even though situated in the East African Rift zone, the Elgon region rarely experiences earthquakes (Hollnack, 2001). Therefore, seismicity cannot be considered to be a main triggering factor in Bududa, contrasting with some regions in southwestern Uganda and Kenya (Inganga et al., 2001) where earthquakes were responsible for a few landslides (Knapen *et. a,l* 2006).

2.4.2 TRIGGERING FACTORS

A triggering factor is an external stimulus that triggers the movement and one of the renowned triggering factor is rainfall. Rainfall is an important factor in triggering landslides. Precipitation conditions determine infiltration and run-off. Prolonged rains with a lower intensity result in a higher and deeper infiltration and lower run-off in sloping areas. On the other hand, in these regions, torrential rains increase run-off and result in a lower amount of infiltration. Nevertheless they promote the wetting of soil along fissures which serve as natural rainwater collectors (UNESCO/UNEP, 1988; Smedema et al., 1983). The amount of rainfall has a considerable influence on the moisture content and the pore pressure in the soils (Ayalew, 1999). A higher moisture content can increase the specific mass of rocks by 20 to 30% and at the same time lower their shear resistance by 50% and even more, due to increased pore-water pressure (UNESCO/UNEP, 1988). This greatly reduces shear strength and hence slope failure.

2.4.2.1 INFLUENCE OF RAINFALL

The climate of Mount Elgon varies a lot from its surroundings in view of geomorphologic settings. The climate is determined by the alternating moist south-westerly and dry north-easterly airstreams. The mountain area experiences a bimodal rainfall pattern (Figure 5). The wettest period of the year is from March till October, while the dry season occurs from November till February with a short dry period around July. Rainfall is higher at the southern and western slopes (1500-2000 mm/yr) than at the eastern and northern slopes (1000-1500 mm/yr). Information from old rainfall data reveals that Bududa receives an average rainfall of 1588 mm while Bulucheke receives 1615 mm which indicates local variations. In the year 2001 six rain gauges were installed in various schools throughout the district with the aim of collecting rainfall at various locations in Bududa. However, four of them were vandalized and only two at Bududa S.S and Bulucheke (Figure 6) were successful which shows the limitation of data collection in this area. The rainfall peaks for rainfall data collected by farmers compare with that from the Department of meteorology (Figures 5 and 6). Information from farmers reveals that rainfall showers mostly occur in the afternoon hours while the mornings are clearer with no rains apart from some seasons of higher rainfall when it rains throughout the day. No temperature extremes exist in this region due to its location near the equator and altitudinal variations. Average maximum temperature ranges from 27 to 32°C, the minimum temperature from 15 to 17°C. High cloud cover, relatively low temperatures, high rainfall and high relative humidity (76% in the morning and 57% during afternoon) contribute to low evapotranspiration (NEMA, 1997).

The relationship between climatic factors such as rainfall and landslides have been observed by Ayalew, (1999). Climate can have a dramatic influence on mass wasting events. Heavy precipitation can initiate certain types of mass wasting by creating hydrostatic pressure and serve to lubricate slides once they are in motion.

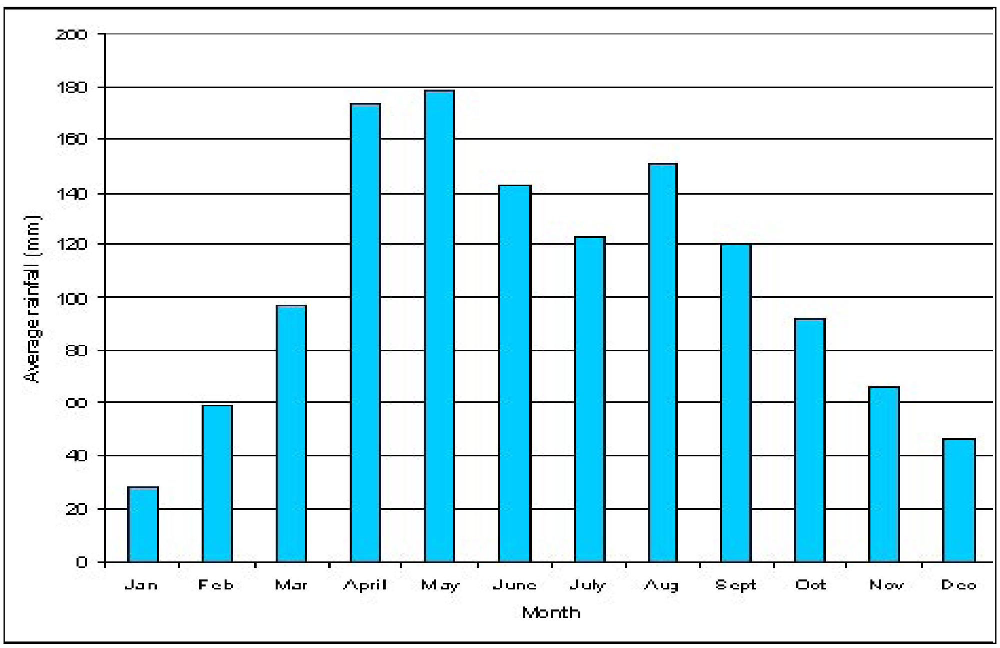


Figure 5: Rainfall distribution for the Mount Elgon Climatic Zone

Source: Meteorology Department.

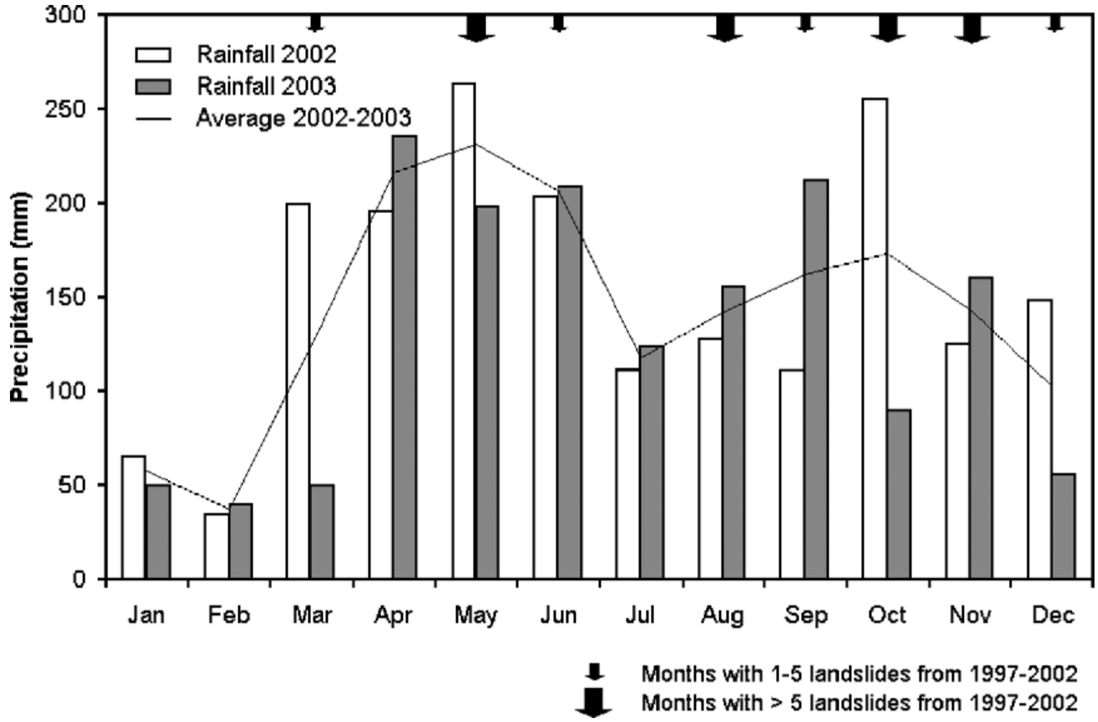


Figure 6: Monthly rainfall for 2002 - 2003 at Bulucheke (1350 a.s.l) measured using a local raingauge. Months with landslides information obtained from farmers. (Knapen *et.al,* 2006).

Ngecu and Mathu (1999) reported that the landslides that affected Kenya in the period of 1997 to 1998 were as a result of continuous heavy rainfall leading to over saturation of soils. Rainfall is one of those factors that have been found to trigger landslides because high rainfall events result in high water saturation in soils reducing the strength of the soil. Increase in water content increases pore water pressure.

The influence of precipitation is even more complicated because landslides are more common when rainfall is continuous and exceeds the field capacity of the soil (Ayalew, 1999). Landslides are more likely to happen if high amounts of intense rainfall are preceded by a period of light but incessant precipitation. Drizzle infiltrates easily downwards in the soil, increasing the soil moisture. In the Aberdare ranges in Kenya, many landslides happen at the beginning of the rainy season. After a period of dry and hot weather, the soil will be desiccated with lots of deep cracks. The first torrential rains cause very much run-off, but also a lot of water infiltrates in the soil to deep levels through the cracks. Water absorption will be very high and rapid where the montmorillonite content is high, leading to a rapid and huge volume change triggering landslides. As the rainy season progresses, the moisture absorption rate does not cause rapid changes in volume anymore, lowering the risk for landslides (Inganga et al., 2001). During intermittent rainfall, soils lose their moisture and regain their strength within a few days. Saturation of the soils needs a much longer period, explaining the higher number of landslides in the Ethiopian highlands during September than in July. The higher precipitation amount during July is absorbed by the dry soil. Towards September these soils become saturated resulting in a higher possibility of slope failures (Ayalew, 1999). A distinct rainfall threshold for the initiation of landslides is difficult to assess for Bududa District because of the range of landslide types and dimensions, the heterogeneity of the study area and the lack of known landslide dates and rainfall data (Knapen *et. al,* 2006). Landslide events most frequently take place in years with exceptionally high rainfall, such as 1998, especially at the end of the rainy season when the soil saturation is maximized. Based on the few landslides for which the date of occurrence could be traced (Figure 6), it is difficult to demonstrate this (Knapen *et. al,* 2006).

2.5 INDIGENOUS KNOWLEDGE AND FARMERS PERCEPTION ON LANDSLIDE OCCURRENCES

Use of indigenous Knowledge captured through farmer participatory methods could be of use if found to be in line with the scientific explanations. Farmer participatory methods have been used in natural resource management in Uganda (Nicoliene and Adrienne, 2003). According to Nathalie, 2003, through experiences often going back for generations, farmers have developed local systems for appraising land resources, which are surprisingly accurate. In many ways their knowledge is obtained by approaches that are similar to those of scientists' observation and experimentation. Several participatory approaches have been developed to involve farmers in an interdisciplinary approach to agricultural research (Nicoliene and Adrienne, 2003). These give greater attention to actual farming practices, farmers' needs and knowledge. However, despite recognition in principle that local knowledge is a valuable source, its contribution is often limited due to a general lack of understanding of what local knowledge actually is and how it can be explored.

There is a growing interest in involving the local population in technology development. Farmers' participation has been used to identify improved rice varieties in South- East Tanzania (Kafiriti *et.al* 2003). Using a participatory method on farmers, plots they were able to identify rice varieties and also show that soil bunds can appreciably increase the production of rain-fed lowland rice.

Similarly these approaches can be used to involve farmers in landslide hazard assessment and management. Farmers' observations on land characteristics, climate patterns and landslide occurrence can lead to cheaper evaluation techniques especially in situations of limited financial support. According to Kirsten *et al.*, 1990, there was close connection between farmers' assessment of landslide hazard and their landuse decisions in Kathmandu valley in Nepal. The farmers in Kathmandu chose not to make terraces on steep slopes because they promote landslides. Farmers are often good observers and integration of their knowledge in land management may be essential in sustainable development. However some authors have questioned the comparison of local knowledge with scientific knowledge. Considerable debate has been ongoing about the most appropriate terminology for local knowledge systems, whether they should be labeled as local, indigenous, folk or traditional. Societies and people are not isolated from each other; changes in knowledge are generated by interactions between and within societies and people's adaptations to changes in their environment (Nicoliene and Adrienne, 2003). In Bududa farmers were able to identify areas vulnerable to landslides and also the factors that influence the landslide occurrences. In addition the farmers in Bududa especially in the eastern zone do not encourage making of terraces on steep slopes because they act as water concentration points and trigger landslides (Kitutu *et. al*, 2010). However, there is a limitation in their observation especially determining the threshold on slope and rainfall that causes landslides (Kitutu *et. al*, 2010). This then calls for an integrated approach to combine both knowledge.

References

Ayalew, L., 1999. The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Bull. Eng. Geol. Env. 58: p. 9-19.

Atterberg, A.M., 1846-1916. Geotechnique, 3(1), pp. 17-19.

Bagoora, F.D.K., 1988. Soil erosion and mass wasting risk in the highland area of Uganda, Mountain Research and Development, Volume 8, N0s. 2/3, pp 173-182.

Birot, P., 1960. Le Cycle d'Erosion sous les Differents Climats.Batsford, London.

Christiansson, C and Westerberg, L.O., 1999. Highlands in East Africa. Unstable slopes, unstable environments. Ambio, 18: 419-429.

Claessens, L., Knapen, A., Kitutu, M.G., Poesen , J and Seppe, D., 2007. Modeling landslide hazard, soil redistribution and sediment yield of landslides on the Ugandan footslopes of Mount Elgon, Geomorphology 90 (2007) 23–35.

Cruden, D. 1991. A simple definition of a landslide. Bulletin IAEG. 43: 27-29.

Davies, K.A., 1956. The building of Mount Elgon (East Africa). The geological Survey of Uganda, 68 pp.

Davies, T.C., 1996. Landslide Research in Kenya. Journal of African Earth Sciences, 23 (4): 541-549.

Erima, G, 2004. An Engineering geological evaluation of landslides and their socio-economic impact in Bubita sub-county, mbale district, eastern Uganda, Master of Science Thesis (Unpublished), Makerere University, Department of Geology.

Gabet, E.J and Dunne, T., 2002. Landslides on coastal sage-scrub and grassland hillslopes in a severe El Niño winter: The effects of vegetation conversion on sediment delivery. Geological Society of America Bulletin 114, no.8, p.983-990.

Hollnack, D., 2001. Some aspects on the seismic risk in East Africa. Documenta Naturae 136, 85– 92.

Inganga, S.F., Ucakuwun, E.K and Some, D.K., 2001. Rate of swelling of expansive soils: a critical factor in the triggering of landslides and damage to structures. Documenta Naturae, 136: 93-98.

Kafiriti, E, 2003. Coming to grips with farmers variety selection the case of new improved rice varieties under irrigation in South East Tanzania, Tropicultura Journal, 21 (4), 211-217.

Kirsten, J, Elizabeth A. O and Sumitra, M., 1982. Environmental knowledge and response to natural hazards in mountainous Nepal, Mountain Research and development journal, 2 (2).

Kitutu, K.M.G, 2004, Local perception of landslide problems in Manjiya County, Mbale District, Eastern Uganda, mountain ecosystems, resources and development in Uganda, a publication of Mountain Resource Centre, Department of Geography , Makerere University, pages 94-98. isbn 9970-05-017-6.

Kitutu, M.G., Muwanga, A., Poesen, J and Deckers J. A., 2009. Influence of soil properties on landslide occurrences in Bududa district, Eastern Uganda, African Journal of Agricultural Research Vol. 4 (7), pp. 611-620, Available online at http://www.academicjournals.org/AJAR ISSN 1991-637X © 2009 Academic Journals

Kitutu, M.G., Muwanga, A., Poesen, J and Deckers J. A., 2010. Farmers' perception on landslide occurrences in Bududa District, eastern Uganda, African Journal of Agricultural Research (In press)

Knapen, A., Kitutu, M.G., Poesen, J., Breugelmans, W., Deckers, J and Muwanga, A., 2006. Landslides in a densely populated county at the footslopes of Mount Elgon (Uganda): characteristics and causal factors. Geomorphology 73, 149–165.

Larsen, M.C and Torres-Sánchez, A.J. 1998. the frequency and distribution of recent landslides in three Montane tropical regions of Puerto Rico. Geomorphology 24, p.309-331.

McSaveney, M. J. 1978. The magnitude of erosion across the Southern Alps. Proceedings of the Conference on Erosion Assessment and Control in New Zealand, Christchurch, NZ Association of Soil Conservators, p 7-24.

Michael, H., Elke D and Greg Agola., 2003. International Centre for Research in Agroforestry Kenya.

Muwanga, A., Schuman, A., Biryabarema, M., 2001. Landslides in Uganda - Documentation of a Natural Hazard. Documenta naturae, 136: 111-115.

Moeyersons, J., 1988. The complex nature of creep movements on steep sloping ground in Southern Rwanda. Earth Surface Processes and Landforms, 13: 511-524.

Moeyersons, J., 1989a. La nature de l'erosion des versants au Rwanda. Ann. Royal Museum Centr. Africa Tervuren, Series Economische wetenschappen, 19: 396 pp.

Moeyersons, J., 1989b. A possible causal relationship between creep and sliding on Rwaza hill, Southern Rwanda. Earth Surface Processes and Landforms, 14: 597-614.

Moeyersons, J., 2003. The topographic tresholds of hillslope incisions in southwestern Rwanda. Catena, 50: 381-400.

Nathalie C., 2003. Multiscale participatory Land resource Assessment in Northwest Syria. PhD Thesis 559, Catholic University, Leuven, Department of Land Management, Belgium.

National Environment Management Authority, 1997. District State of Environment Report, Mbale, 1997, Uganda, 128 pp.

National Environment Management Authority, 2006. State of Environment Report for Uganda.

Nicoliene O., and Adrienne M., 2003. Methods and issues in exploring local knowledge on soils, Geoderma 111 387-401.

Ngecu, W.M., and Ichangi, D.W., 1998. The environmental impact of landslides on the population living on the eastern footslopes of the Aberdare ranges in Kenya: a case study of Maringa village landslide. Environmental Geology, 38 (3): 259-264.

Ngecu, W.M., and Mathu, E.M., 1999. The El Nino-triggered landslides and their socioeconomic impact on Kenya. Environmental Geology, 38 (4): 277-284.

Nyssen, J., Moeyersons, J., Poesen, J., Deckers, J and Mitiku H., 2003, The environmental significance of the remobilization of ancient mass movements in the Atbara-Tekeze headwaters near Hagere Selam, Tigray, Northern Ethiopia, Geomorphology.

Ollier, C.D. and Harrop, J.F., 1959. Memoirs of the research division, series 1 – soils, number 2. The soil of the eastern province of Uganda. Kawanda Research Station, Kampala, 55 pp.

Rapp, A., Berry, L and Temple, P., 1972. Landslides in the Mgeta area, western Uluguru mountains, Tanzania. Studies of soil erosion and sedimentation in Tanzania, Bureau of resource assessment and landuse planning, University of Dar es Salaam, Department of Physical Geography, University of Uppsala, Sweden, 19 pp.

Reedman, J.H., (1973). Potash Ultra-fenites at the Butiriku carbonatite complex in south-east Uganda. Univ. Leeds Res. Inst. African Geol. 17th Ann. Rep., 78-81.

Scharpe, S.C.F., 1938. Landslides and related phenomena. A study of mass-movements of soil and rock. Columbia University Press, New York. 137p.

Selby, M.G.,1993. Hillslope materials and processes, Oxford University Press. New York.

Sidle, R.C., Pearce, A.J and O' Loughlin, C.L., 1985. Hillslope stability and landuse. American geophysical union, Washington DC, USA, 125 pp.

Smedema, 1983. Land drainage. Batsford academic and education Ltd, London. P. 174-194.

Temesgen, B., Mohammed, M.U and Korne, T., 2001. Natural hazard assessment using GIS and Remote Sensing methods, with particular reference tot the landslides in the Wondogenet area,Ethiopia. Physics and Chemistry of the Earth, Part C: Solar, Terrestrial and Planetary Science 26 (9), 665–675.

Ucakuwun, E.K., 1999. Rate of swelling of expansive soils-a critical factor in the triggering of landslides and the destruction of structural features. A paper presented at the workshop on Challenges and perspectives of Interdisciplinary GEO-Networks in East-Africa, DAAD,Uganda, 8 pp.

Statistical Abstract, 2010, Uganda Bureau of Statistics.

Thomas, F.T., 1994. Landsliding and other mass movement. In: Geomorphology in the tropics: A study of weathering and denudation in Low Latitudes, John Wiley & sons Ltd., Chichester, UK: 165-189.

UNESCO/UNEP, 1988. Landslides and mudflows UNEP/Unesco, Moscow. 236p.

Varnes, D. J., 1978. Slope movement types and processes: In: Landslide Analysis and Control: In Schuster, R. L., Krizak, eds. Transportation Research Board Special Report No. 176, National Academy of Sciences, Washington, D. C., P. 11-33.

Wendy,B., 2003. Influence of soil properties, landuse and deforestation on the occurrence of landslides in Manjiya county, Mount Elgon area, East Uganda, Master of Science thesis (Unpublished) Catholic University of Leuven.

Westerberg, L.O and Christiansson, C., 1998. Landslides in East African Highlands. Slope instability and its interrelations with landscape charactyeristics and land use. Advances in GeoEcology, 31: 317-325.

Westerberg, L.O., 1999. Mass Movement in East African Highlands: Processes, Effects and Scar Recovery. Dissertation 14, Dept of Physical Geography, Stockholm University, Sweden.147 pp.

http://www.visituganda.com

http://en.wikipedia.org/wiki/Landslide

http://en.wikipedia.org/wiki/Causes_of_landslides

http://en.wikipedia.org/wiki/Atterberg_limits

CHAPTER THREE

A paper published in the journal Geomorphology 73, (2006) 149–165.

LANDSLIDES IN A DENSELY POPULATED COUNTY AT THE FOOTSLOPES OF MOUNT ELGON (UGANDA): CHARACTERISTICS AND CAUSAL FACTORS.

CHAPTER FOUR

A paper published in the journal Geomorphology 90 (2007) 23–35

MODELLING LANDSLIDE HAZARD, SOIL REDISTRIBUTION AND SEDIMENT YIELD OF LANDSLIDES ON THE UGANDAN FOOTSLOPES OF MOUNT ELGON.

CHAPTER FIVE

A paper published in the African Journal of Agricultural Research Vol. 4 (7), pp. 611-620, July 2009.Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2009 Academic Journals

INFLUENCE OF SOIL PROPERTIES ON LANDSLIDE OCCURRENCES IN BUDUDA DISTRICT, EASTERN UGANDA

CHAPTER SIX

Under review (Africa Journal of Agricultural Research) Ms Number: AJAR-09-158

FARMER'S PERCEPTION ON LANDSLIDE OCCURRENCES IN BUDUDA DISTRICT, EASTERN UGANDA

CHAPTER SEVEN

Mountain Ecosystems, Resources and Development in Uganda Department of Geography, Makerere University, (2004), Pages 94-98. ISBN 9970-05-017-6

LOCAL PERCEPTION OF LANDSLIDE PROBLEMS IN MANJIYA COUNTY, MBALE DISTRICT, EASTERN UGANDA

CHAPTER EIGHT

INFLUENCE OF CLIMATIC FACTORS AND GEOLOGY ON LANDSLIDE OCCURRENCES IN BUDUDA DISTRICT

8.1 EFFECTS OF EL NIÑO

In the recent years, scientists have observed that sometimes there is increased rainfall in Eastern Africa due to the El Niño phenomena. El Niño is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. El Niño was originally recognized by fisherman off the coast of South America as the appearance of unusually warm water in the Pacific Ocean, occurring near the beginning of the year (http://www.enotes.com/earth-science/el-nino-la-nina-phenomena). El Niño means the little boy or Christ child in Spanish. This name was used for the tendency of the phenomenon to arrive around Christmas. The known El Niño years are 1957-1958, 1965-1966, 1977-1978, 1987-1988, 1992–1993, 1994–1995, 2002-2003 and 2006 for weak and moderate El Niño (http://apollo.lsc.vsc.edu/classes/met130/notes/chapter10/elnino.html).

The strong El Niño years are 1972-1973, 1982–1983, 1991–1992, and 1997–1998. Seventy two landslides whose years of occurrence are known were correlated with the known El Niño years (Table 6). Seventy nine percent of the landslide mapped occurred in El Niño years with the highest number in 1997 leading to a conclusion that El Niño has an influence on landslide occurrences. However, some landslides occurred during normal years reason being that this is a high rainfall area and landslides can still occur in a normal year if other conditioning factors are favorable.

8.2 EFFECT OF RAINFALL

Most farmers revealed that all landslides occur during rainfall seasons. To investigate this factor six local rain gauges that had been calibrated by technical officers from the Department of Meteorology were spread out in various secondary schools namely Bulucheke, Bududa SS, Bushika S.S, Bulucheke S.S, Bukalasi S.S and on at Busayi in Bududa District. Some teachers and students were trained to collect this data daily and unfortunately all the rain gauges were vandalized except for the two at Bududa S.S and Bulucheke.

Table 6: Landslide years correlated with the El Nino events

Year	Number of Landslides	El Niño year
2006	4	Weak El Niño
2003	7	Weak El Niño
2002	9	Weak El Niño
2001	4	Normal year
1999	3	Normal year
1998	6	Strong El Niño
1997	27	Strong El Niño
1996	6	Normal year
1988	2	Weak El Niño
1976	1	Normal year
1973	1	Strong El Niño
1966	1	Weak El Niño
940	1	Normal year

Rainfall data for the year 1997 for Bududa when many landslides occurred is not available. The daily rainfall data collected by farmers in 2002 and 2003 was correlated with that of Buginyanya and Mutufu rainfall stations for the same years. This was an attempt to determine whether there was relation in rainfall amounts between Bududa rainfall station and that of Buginyanya and Mutufu which would then allow estimation of rainfall amounts for Bududa for the period 1997 using stastical methods. The low values of R^2 in Figures 8 and 9 is an indication that there is no correlation in rainfall of Mutufu and Buginyanya with Bududa. However, there could be limitations in a way that rainfall for two years may not be sufficient to give a good statistical relationship. Otherwise the results suggest that rainfall in the Mount Elgon region is irregularly distributed. Currently the Meteorology Department gives data for the Mutufu station to represent the Mount Elgon area which may be misleading.

Rainfall data collected by farmers in the years 2002 and 2003 shows two rainfall seasons from March to June and August to November (Figure 10). The annual rainfall for the year 2002 and 2003 was 1842 mm and 1627 mm respectively, which characterizes the area as a high rainfall area. The months of May, June and October 2002 received rainfall of more than 200 mm.

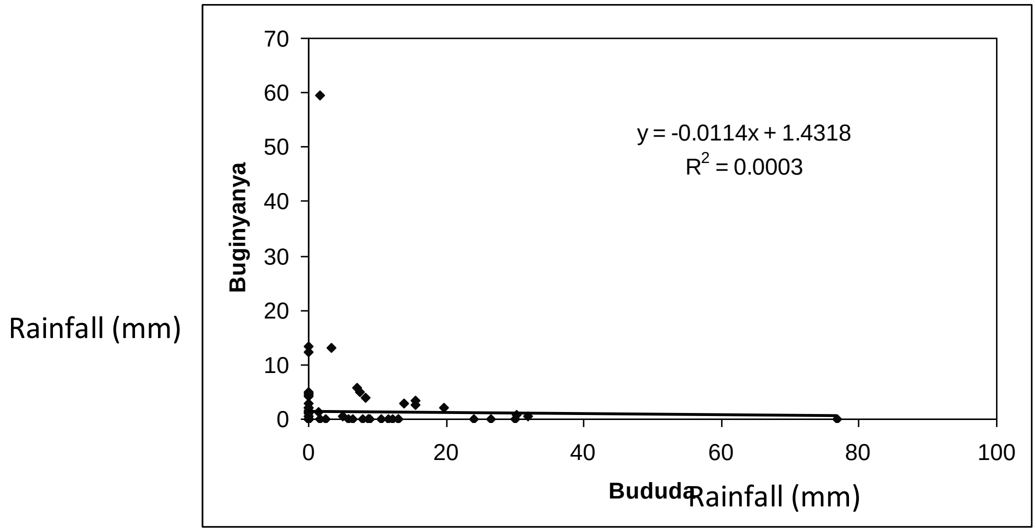


Figure 7: Correlation of rainfall data for Bududa with Buginyanya rainfall station

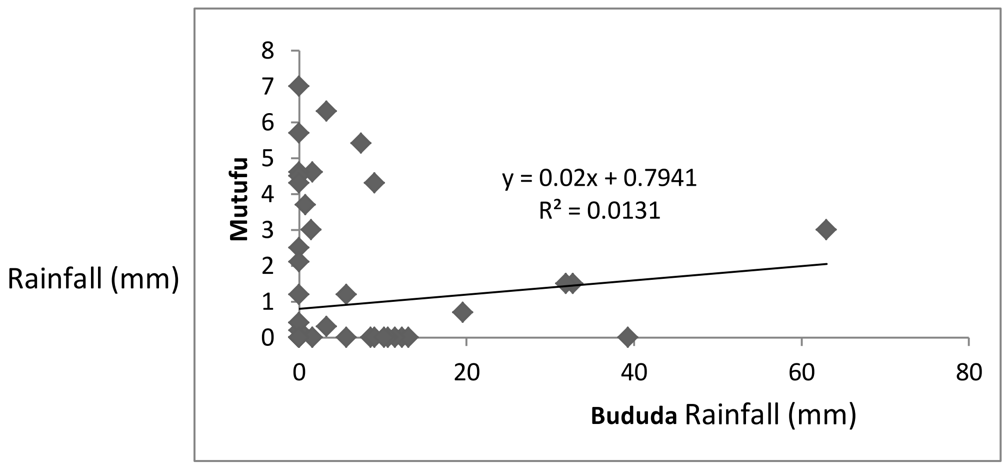


Figure 8: Correlation of rainfall data collected for Bududa with Mutufu rainfall station

The months of May, August, October and November had the highest numbers of landslides occurrences for the period from 1997 to 2002 (Figure 10). More correlation of landslides with rainfall was done in 2006 and 2007. Rainfall and landslide occurrences were collected by farmers in Bushika (Tables 7 and 8). High numbers of landslides were recorded in the months of June 2007 and November 2006 in the Nusu and Bududa landslide zones. November 2006 had a rainfall amount of 167.4 mm and June 2007 had rainfall of 99.7 mm (Table 7).

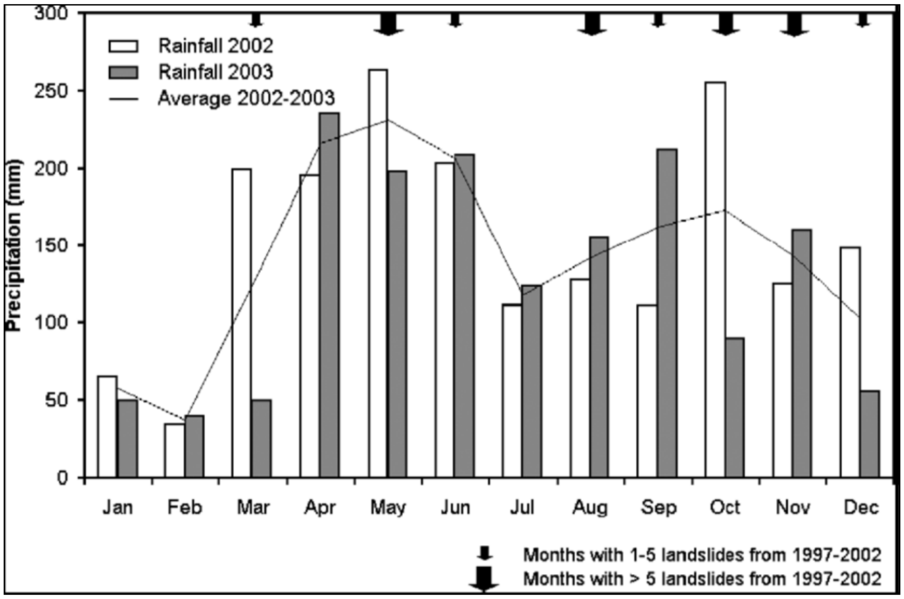


Figure 9: Rainfall data from a local rain gauge monitored by farmers in Bulucheke

The high number of landslides in June 2007 could have been due to continuous rainfall in the previous months from January to May 2007. Similarly the high number of landslides in November 2006 was due to the contonous rains from July 2006 to November making the soils saturated hence causing landslides. A similar phenomenon was observed by Ayalew (1999), in the Ethiopian highlands where he concluded that some regions with steep slopes maintain their stability irrespective of the amount of rainfall while others with gentler relief may fail following relatively small amounts of rain over consecutive days.

Table 7: Monthly rainfall for the years 2006 and 2007

	2006	2007
January		39.5
February		93.1
March		32.2
April		73.2
May		78.2
June	74	99.7
July	152.4	152.4
August	99.5	123.7
September	178.4	164.3
October	113.4	38
November	167.4	23.6
December	125.7	7.2

Table 8: Landslide occurrences in the years 2006 and 2007 for the three subcounties

Sub County	Year	Month	Number of landslides	Monthly rainfall recorded at the station in Bushika. (mm)
Bumayoka.	2007	June.	34	99.7
	2007	October.	6	38
	2006	November.	4	167.4
	2006	December.	5	125.7
Bukibokolo.	2006	November.	36	167.4
	2007	June.	2	99.7
Bushika.	2006	July.	4	152.4
	2007	October.	3	38

8.3 INFLUENCE OF LITHOLOGY AND SLOPE

Lithology is one of those parameters known to influence landslides in some regions because certain geological conditions accelerate weathering and prepare the rock for mass movements. There are numerous associations of mass movements with particular rocks which demonstrate the importance of lithology and mass movements (Sidle *et. al,* 1985). Association of landslides with weathering of pyroclastic rocks in the Abedare ranges in Kenya have been reported by Ngecu and Mathu (1999).

The lithology in Bududa consists of the basement granites,Elgon agglomerates and the carbonatite rocks. Ijolite-pegmatite dykes also occur in the basement. In order to understand which class in the lithology has more influence the landslide map was combined together with geology and slope, then a landslide susceptibility index calculated for each of the combined classes using the Failure Rate Method (FR). The Failure Rate method is a univariate statistical approach in which the importance of each factor or combined factors is individually analyzed from the spatial distribution of existing landslides (Amod *et al*., (1999). The assumption in this method is that the factors that influenced the occurrence of landslides in the past will be the same to influence future landslide occurrences.This method was used to assess the influencing factors for landslides in the Kulekhani watershed in Nepal (Amod et al., 1999) and geology was found to be the most influencing factor.

Using the map cross function in the ILWIS GIS the factor maps geology and slope were crossed to produce combined maps. The combined factor maps were then each combined with the landslide map. To assess the influence of each class a score known as the landslide Susceptibility index was calculated using the formula below.

Landslide Susceptibility Index (LSI) = R (L)/ R (A).

- Where R (L) is the ratio of area of a landslide scar in a combined class to the total landslide area.
- R (A) = ratio of area belonging to that particular combined factor class to the total study area.

For example if the landslide area in the combined class of phonolite dyke / slope angle 30^0 is 0.5 ha and the total landslide area is 70 ha. A combination of phonolite dyke / slope angle 30^0 covers an area of 80 ha and the total area is 3000 ha. The index score for the class phonolite dyke / 30^0 is (0.5/70)/ (80/3000) = 0.27. An index above 1 indicates that the class influences landsliding and below 1 means the class inhibits landsliding.

The areas with a combination of Phonolite–dyke and steep slopes had the highest landslide susceptibility index of 9.6, followed by the combined factor of fenitized basement-steepslopes with a landslide susceptibility index of 5.1 and finally the fenitized basement-medium slopes with a susceptibility index of 3.7 (Table 9). All the other class combinations are below 1 and they have no influence on landslides. This can lead to a conclusion that areas with a combination of steep slopes, fenitised basement and phonolite dykes are most prone to landslides.

Table 9: Landslide susceptibility index for the various classes

Combined factor maps	Combined classes	Combined class code	Susceptibility index
Slope gradient – Geology	Basement- Medium slopes	1	0.13
	Basement – Steepslopes	2	0.38
	Basement – Gentle slopes	3	0.0
	Fenitized basement-steepslopes	4	5.1
	Fenitized Basement- medium slopes	5	3.7
	Fenitized Basement – gentle slopes	6	0.9
	Phonolite dyke- steepslopes	7	9.6
	Phonolite dyke- medium slopes	8	0.0
	Alluvium Deposits	9	0.04

8.4 INFLUENCE OF FENITIZATION ON THE WEATHERING OF GRANITES

The rate of weathering was assessed on soil samples obtained near the soil profiles. Al_2O_3 was analyzed using XRF and the others were analyzed using the atomic absorption spectrophotometer in the Department of Geology Makerere University (Appendix I). Influence of weathering was assessed by calculating the Miura index which gives the rate of weathering (Selby, 1993). Samples were taken and assessed for the % of minerals MnO, FeO, CaO, MgO, Na_2O, K_2O, Fe_2O_3, Al_2O_3 and H_2O. Using the equation below the Miura index was calculated:

$$\text{Miura Index } (M_i) = \frac{MnO + FeO + CaO + MgO + Na_2O + K_2O}{Fe_2O_3 + Al_2O_3 + H_2O} \quad \text{(Selby, 1993)}$$

The Miura index gives the rate of weathering and the results do not have any correlation with landslides because at the sample areas with high number of landslides the Miura index value is comparable to other areas (Table 10). Neither do the values have any significance as you move away from the carbonatite, which indicates that the fenitized basement is highly weathered throughout and equally vulnerable to landsliding if other contributing factors are favorable. In addition, according to Selby (1993) rates of weathering are quite difficult to assess in high mountain environments because of the extreme variability induced by drainage conditions which could be the situation in the Bududa area.

Table 10: Miura index values and number of landslides in the sample areas

Sample number	Distance from the rim of the carbonatite (km)	Number of landslides	**Miura Index**	**Description of weathering according to Miura index**
Gr1	1	0	0.09	Solum
Gr2	2	0	0.04	Completely weathered
Gr3	3	0	0.02	Completely weathered
Gr7	3	0	0.07	Solum
Gr8	2	4	0.04	Completely weathered
Gr9	1	0	0.02	Completely weathered
Gr10	1	0	0.07	Solum
Gr11	2	0	0.04	Completely weathered
Gr12	3	2	0.05	Completely weathered
Gr13	4	7	0.12	Highly weathered
Gr14	5	0	0.08	Solum
Gr15	1	0	0.05	Completely weathered
Gr16	2	1	0.04	Completely weathered

Gr17	3	13	0.02	Completely weathered
Gr18	4	0	0.05	Completely weathered
Basement Granite	30	0	0.67	Slightly weathered
Carbonatite	0	0	0.36	Moderately weathered
Carbonatite	0	0	0.43	Moderately weathered

Note: The samples Gr1 to Gr18 were obtained from the fenitised basement rocks.

Fenitization, shattering and shearing of the basement is very conspicuous up to a range of 3 km from the outer edge of the carbonatite (Reedman, 1973). This fenitization is characterized by the partial replacement of the original quartz by sodic amphibole (Hornblende). The fenite is a sheared grey-blue rock containing porphyroblasts of potash feldspars.

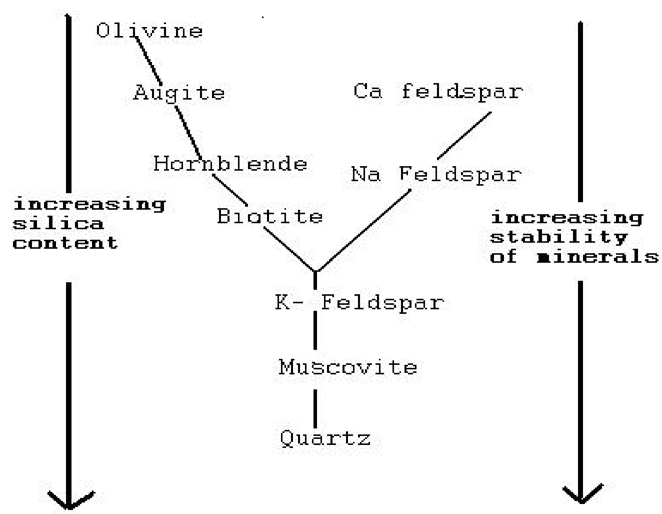


Figure 10: Stability of minerals to dissolution and chemical weathering (Selby 1993)

The stable minerals such as quartz were replaced by amphibole which is weaker on the stability series of minerals (Figure 11). This weakening could have resulted in accelerated weathering of the basement rocks forming thicker soils rich in clay hence vulnerable to landsliding. Rates of weathering are controlled by the permeability of the rock and not by chemical reactivity of the minerals (Selby 1993). Rocks which are massive and less fractured will weather slowly as compared by those that are fractured. This is in agreement with what is observed in the basement granite which is slightly weathered as compared to fenitised basement (Table 10).

8.5. INFLUENCE OF JOINTS AND LINEAMENTS

Joints, fractures and fault zones often show an inherent geological weakness because of the fractured, crushed or partly metamorphosed host rocks they contain. This weakness zone can be enlarged by deep percolating water into the bedrock and subsequent chemical weathering of the rocks (Sidle *et.al.,* 1985). Shattering and brecciation of the basement around Butiriku has created numerous joints but because of the high rate of weathering jointed outcrops are hard to come by and assessment was done on the only exposure at the scar of the Bugobero rockslide. Joints permit water to penetrate the rock and so promote weathering processes. The mode of failure is greatly influenced by the inclination and intensity of jointing. At Bugobero rockslide the 86 joints measured dip steeply into the slope of which 72 have dip angles above 65^0 (Appendix D). These act as water infiltration points and the water collects on the larger joints of lower dip angles causing sliding surfaces and failure. This phenomenon was also studied by Erima, (2003) who observed that the rock strength was lowered because of the presence of joints. He further, identified the numerous joints dipping in the NE-SW and NW-SE trend. These joint planes are filled with clay material, which acts as a lubricant to the sliding when filled with water. A lot of water comes out of this rock scar during the rain season and a well for the local people is just 2 m away from the scarp of the landslide. It was observed that water in this well increases during the wet seasons which runs down into the discontinuity between the dyke material and the basement and this is what could have triggered the 1997 rockslide which claimed the lives of five people. One of the elders mentioned that a landslide occurred on this same slope in 1933 and this was evidenced by a scar in the landscape (Figure 12).

The Bugobero rockslide (Figure 12) covered an area of 34,705 m^2 and the run out material affected an area of 71,758 m^2 on the other side of the slope which killed a family of five burying their bodies which have never been seen. In areas with v-shaped valleys the risk may be higher on the opposite side of the affected slope as was the case in the Bugobero rockslide. The debris from this slide dammed the water in the river Tsutsu for about one and half days. A lot of damage was done to the bridges and roads when this dam broke.

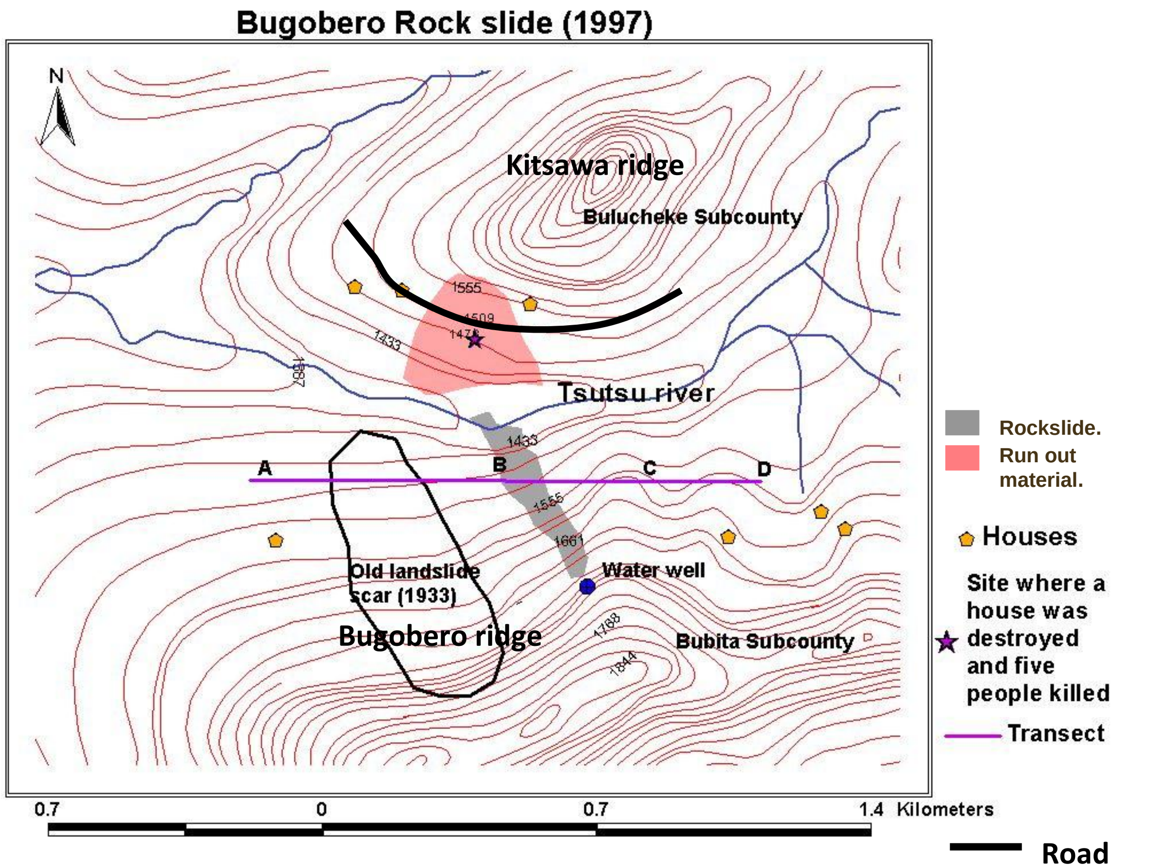


Figure 11: The map of Bugobero rockslide and surrounding areas

8.6 INFLUENCE OF DYKES

Dykes are tabular bodies of igneous rocks and they result from intrusion of magma while others are a result of metasomatic replacement. These plutonic bodies are common in this mountainous part of the area. Small ijolite-pegmatite dykes are found where the rock has been eroded away and they consist of circular crystals of pyroxene embedded in a matrix of coarse nepheline, forming a poikilitic structure (Davies, 1956) (Table 11).

Nepheline contains sodic feldspars that are less resistant to weathering creating clay minerals which influence landsliding in Bududa. Areas with dykes also have very steep slopes $35 - 60^0$ which also contribute to the frequency of the landsliding. Dykes have been identified at Nusu, Kitsawa and Bugobero ridges.

Table 11: Mineral Composition of Ijolite-pegmatite dykes at Nusu

Mineral	% composition
Nepheline	79.9
Pyroxene	15.8
Apatite	1.4
Sphene and Peroskite	1.2
Iron ore	1.7

Source: The Geology of Mount Elgon (Davies 1956).

8.6.1 NUSU RIDGE DYKE

The Nusu ridge (Figure 13) is very steep and has frequent landslide occurrences. The rock material is very soft and fractured as seen in Figure 14. The rocks are fractured and jointed. This makes the plants and shrub roots grow into the joints widening them allowing in more water infiltration and later the rock fails, given the steepness of the slope.

Figure 12: Nusu ridge dyke

8.6.2. KITSAWA RIDGE DYKE

The Kitsawa hill (Figure 15) is very steep and farmers indicate that they hear vibrations like the ground is hollow when they walk at the top of this hill. The soils are like dark ash and soft. No water or streams exist on this hill indicating that water does not infiltrate or if it does then there are no openings for it to come out. The Kitsawa ridge has stabilized landforms with evidence of past landslide activity. The types of landslides are the surfical which appear to be caused by water saturation between the soils and rock discontinuity with the undercutting of the slope by a road constructed across the hill in 1984 acting as the triggering factor.

Figure 13: Fractured rocks at the tip of Nusu dyke

Figure 14: Kitsawa ridge dyke

8.7 INFLUENCE OF SOIL PERMEABILITY

The ability of water to flow through a soil is referred to as the soil's permeability. There are several factors that influence the permeability of a soil (or rock material): the viscosity of its water, size and shape of the soil particles, degree of saturation, and void ratio. The more tightly materials particles are packed, the tendency for the material to allow water to flow through it is reduced. Permeability tests were carried out both in the field and at Makerere University soil mechanics laboratory using the Constant Head Method. In the field pits of 20 cm in depth were dug using an auger. The hole was saturated for one day before measurements of permeability were made the following day. The pit was filled with water and using a stop clock the time taken for the water to drain through a certain height was determined. Tests were carried out in the fenitised basement and in the areas covered by carbonatite rocks. For the laboratory tests soil cores were taken from the landslide site in Bududa zone and analyzed from the laboratory for permeability.

Table 12: Permeability of soils from the laboratory tests

Geological unit	Coefficient of permeability (K m/s)	Relative permeability
Fenitised basement 1	0.0000144	Low
Fenitised basement 2	0.0000105	Low
Fenitised basement 3	0.000001754	Low
Fenitised basement 4	0.000000462	Very low
Fenitised basement 5	0.0000022	Low
Carbonatite 1	0.00000254	Low
Carbonatite 2	0.000000246	Very low

Table 13: Permeability of soils from field measurements

Geological unit	Coefficient of permeability (K m/s)	Relative permeability
Fenitised basement	0.00267	medium
Fenitised basement	0.000304	medium
Fenitised basement	0.000363	medium
Carbonatite	0.000296	medium
Carbonatite	0.00027	medium
Carbonatite	0.00025	medium

The values of permeability coefficient from field measurements were higher than those from the laboratory (Tables 12 and 13). Laboratory measurements rarely agree with data collected in the field due to the difficulty of obtaining truly undisturbed soil samples. Further, laboratory test results are usually at least an order of magnitude lower than actual field results (US Patent 6098448). This agrees with what was observed because measurements in the laboratory show that the permeability for all the soils is low and only two samples showed very low permeability while field results show that the samples have medium permeability. In addition the laboratory tests do not take into account the heterogeneity of the site as only a small sample is tested.

8.8 CONCLUSIONS

El Niño phenomenon has an influence on landslide occurrences although landslides can still occur in normal years. Landslides mostly occur during the months of May, August, October and November. Months with a total rainfall of 200 mm are prone to landslide occurrences but some other months with lower monthly rainfall can be prone if there was continuous rainfall in the previous months. Areas of dykes are more prone to landslides followed by the fenitised basement. Fenitisation of the basement granite has weakened the granite causing accelerated weathering resulting in thick soil profiles especially in the Bududa zone. No correlation can be observed between landslide occurrences and permeability which may require further research.

References

Amod, S.D., Takaaki, A and Masamu Aniya, 1999. Landslide hazard mapping and the application os GIS in the Kulekhani watershed, Nepal, Mountain research and development, Vol. 19, No. 1, pp3-16

Ayalew, L., 1999. The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Bull. Eng.Geol. Env. 58: p. 9-19.

Davies, K.A., 1956. The building of Mount Elgon (East Africa). The geological Survey of Uganda, 68 pp.

Erima, G, 2004. An Engineering geological evaluation of landslides and their socio-economic impact in Bubita sub-county, mbale district, eastern Uganda, Master of Science Thesis (Unpublished), Makerere University, Department of Geology.

Ngecu, W.M and Mathu, E.M., 1999. The El Nino-triggered landslides and their socioeconomic impact on Kenya. Environmental Geology, 38 (4): 277-284.

Reedman, J.H., 1973, Potash Ultra-fenites at the Butiriku carbonatite complex in south-east Uganda. Univ. Leeds Res. Inst. African Geol. 17th Ann. Rep., 78-81.

Selby, M.G, 1993, Hillslope materials and processes, Oxford University Press. New York.

Sidle, R.C., Pearce, A.J and O' Loughlin, C.L., 1985. Hillslope stability and landuse. American geophysical union, Washington DC, USA, 125 pp.

US Patent 6098448 - In situ measurement apparatus and method of measuring soil permeability and fluid flow, 2000. http://www.patentstorm.us/patents/6098448/description.html

http://www.enotes.com/earth-science/el-nino-la-nina-phenomena

http://apollo.lsc.vsc.edu/classes/met130/notes/chapter10/elnino.html

CHAPTER NINE

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The conclusive examination of the hypotheses below shows that many factors control landslide processes in Bududa District. These landslides are likely to continue occurring given that the population and demand for land is growing which leads to settlements in areas prone to landslide hazard.

9.1 GEOMORPHIC FACTORS SUCH AS GEOLOGY, TOPOGRAPHY AND RELIEF HAVE A HIGH INFLUENCE ON LANDSLIDE TYPES AND OCCURRENCES IN THIS REGION.

Verification of this hypothesis involved the mapping and classification of landslides, assessment of slope, aspect and distance to the water divide. The areas most sensitive to landslides are between slope angles of 14^0 to 41^0, plan concave in form and oriented to the north and north-east directions. The depth of the landslide scar controls the volume of material displaced from the erosional area of the landslide. The width and length have no relationship with the volume of material displaced. Variation in type of movement as rotational or translational is topographically controlled. The brecciation and shattering of the basement granite caused accelerated weathering resulting into thick soil profiles rich in clay. The areas with dykes and fenitised basement are most vulnerable to landslides.

The hypothesis that "Geomorphic factors such as geology and relief factors have a major control on the landslide processes in this region" is accepted on the basis that slope, slope shape, aspect and lithology contribute to landslide processes in Bududa area.

9.2 SOIL PROPERTIES SUCH AS PARTICLE SIZE AND PORE DISTRIBUTION OF THE SOIL MATRIX ARE A CONDITIONING FACTOR TO LANDSLIDE OCCURRENCES

Verification of this hypothesis involved carrying out soil profile description. The soil types on the carbonatite dome are *Rhodic Nitisols* and those around the dome are mainly those conditioned by topography and wet tropical climate namely *Cambisols*, *Lixisols, Ferralsols, Leptosols, Gleysols, Nitisols* and *Acrisols.* The soils have high clay content and the clay minerals present are Kaolinite and illite as derived from Atterberg limits. Landslides in western zone are due to soil horizon stratification that favors water stagnation in the lower horizons and they are only confined to places where there is water stagnation in the lower soil horizons. The landslides in the eastern zone are dependent on several factors which include soil texture, depth to the bedrock, landuse and slope shape. The study highlights that soils stratification is linked to landslide occurrences in Bududa which supports the hypothesis that soil properties are a conditioning factor to landslide occurrences.

9.3 FARMERS' KNOWLEDGE AND PERCEPTION ON THE CONTROLLING FACTORS HAS NO STRONG LINKAGE TO THE SCIENTIFIC OBSERVATIONS

Open- ended questions were used in assessing farmers understanding of the main causes of landslides. Farmer's listed steep slopes, slope shape and continuous rainfall as factors that influence landslide occurrences. Knowledge from farmers' is similar to the scientific findings on the landslide causes in this area and so the hypothesis that farmers' knowledge and perception on the controlling factors has no strong linkage to the scientific observations is rejected. Only farmers were used for this survey because they are the affected group. Future research can focus on other stakeholders such as regulatory institutions and policy makers.

9.4 LANDSLIDE HAZARD CAN BE PREDICTED AND CLASSIFIED USING THE LAPSUS – LS MODEL

11,000,000m^3 of soil was lost from 98 landslides investigated. Only shallow landslides that occur mainly in the eastern part of the study area could be predicted and classified correctly by the LAPSUS –LS model. The deeper rotational landslides in the western part could not be 'captured' by the model as only shallow, topographically controlled landslides can be simulated using the equations. According to the LAPSUS-LS model, the volume of soil material displaced could be four times higher than that observed in the 2002 field survey (44,099,994 m^3). In addition, more than half of this volume is predicted to end up in the stream network and so contribute to the catchment sediment yield which will end up damming rivers causing damage to property and also causing siltation of stream channels and wetlands. These findings support the hypothesis that "zoning of landslide risk can assist planners in curbing landslide related disasters".

9.5 RAINFALL IS THE MAIN TRIGGERING FACTOR FOR LANDSLIDE OCCURRENCES IN BUDUDA.

Although farmers mention rainfall as one of the triggering factors for landslides in Bududa there are limitations in its measurement in the field because unknown people vandalize the local rain gauges. Despite this limitation it is very evident from the little information collected that extreme rainfall events have lead to landslides occurrences.

Therefore, the hypothesis rainfall is the main triggering factor is could be accepted but further research is recommended especially to understand the rainfall intensity and distribution in the area in relation to landslides.

9.6 SCOPE OF FUTURE RESEARCH

Mention of rainfall as a triggering factor by farmers has identified some gaps in this research and there is need to formulate more hypotheses to examine this factor critically. Association of rainfall with landslides has been investigated by several authors (Ayalew (1999), Ngecu and Mathu (1999), Inganga *et al.*, (2001). Further still the Elnino occurrences are becoming more frequent in the recent years and their influence on landslide occurrences needs to be well understood.

Farmers' mentioned losses from landslides which requires a detailed study on the socio-economic impacts and also the downstream impacts on the communities downstream and also the impacts on the siltation of wetlands which may lead to flooding.

Rainfall induced soil erosion and shallow landslides are the main sources of sediment supply in hilly catchments. These processes are generally modeled separately. Erosion models are used to predict soil loss and landslide models are used to assess slope failures and mass movements. However, an integrated model is desirable because it would permit the chronological simulation of pre-failure sediment yield, the prediction of landslide occurrences, and post-failure sediment yield. This is an area of potential research.

Population has been identified as one of the main drivers to land pressure which results in settlements in areas of high hazard. There is need to carry out in-depth studies to understand the main factors that contribute to this increased population growth.

According to Mattia *et.al*, (2005), vegetation and slope stability are interrelated by the ability of the plant life growing on slopes to both promote and hinder the stability of the slope. The relationship is a combination of the type of soil, the rainfall regime, the plant species present, the slope aspect, and the steepness of the slope. Knowledge of the underlying slope stability as a function of the soil type, its age, horizon development, compaction, and other impacts is a major underlying aspect of understanding how vegetation can alter the stability of the slope. Information on vegetation changes in Bududa is scanty but could be obtained from old remotely sensed data. This is another area of potential research.

9.7 RECOMMENDATIONS

1. High population in Bududa is the main driver to land pressure which consequently results in the environmental disasters and encroachment on the fragile ecosystems. Therefore, population control should be taken as a critical intervention if the proposed restoration activities are to succeed.

2. To strengthen programmes that target education of the youth and enhance their vocational skills so that they can get alternative activities to occupy them. This will reduce the pressure on land.

3. Although this research did not investigate the influence of vegetation and trees on landslide occurrences several researches have shown that landslides are likely to reduce when trees are planted. Roots from trees reinforce the soil through growing across failure planes, root columns acting as piles, and through limiting surface erosion (Cammeraat et al., 2005; Morgan 2007; Perry et al. 2003). When roots grow across the plane of potential failure there is an increase in shear strength by binding particles. The roots anchor the unstable surficial soil into the deeper stable layers or bedrock (Mattia et al., 2005). This most readily occurs when there is rapid deep growth (1.5 m deep) of roots which last for more than two years. However it is important to note that the strength exerted by roots generally only extends down to 1m while most failures occur between 1.2 – 1.5 m soil depth (Perry et al. 2003).

4. Farmers should avoid settling in areas of high hazard. The landslide hazard map developed in this study should guide the resettlement plan.

5. Local governments should promote integrated watershed management.

6. Development and enforcement of by- laws in the management of this mountainous area should be strengthened.

7. Although rainfall was not fully investigated it is believed that it is the main trigger therefore collection of rainfall data to enhance more research.

8. The findings of this research can be applied in other areas which suffer from landslides in Uganda. For example areas with soil horizon differentiation may be prone to landslides and so mitigation measures such as agro-forestry should be highly encouraged. In

addition slopes above 14^0 in areas with high rainfall should to be cultivated or inhabited with caution.

9. The use of terraces as conservation measures can only be done after a detailed study.

References

Ayalew, L., 1999. The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Bull. Eng. Geol. Env. 58: p. 9-19.

Cammeraat, C. Van Beek, R and Kooijman, A. 2005, ‘Vegetation succession and its consequences for slope stability in SE Spain’, Plant and Soil, vol. 278, no.1, pp.135-147.

Inganga, S.F., Ucakuwun, E.K and Some, D.K., 2001. Rate of swelling of expansive soils: a critical factor in the triggering of landslides and damage to structures. Documenta Naturae 136, 93– 98.

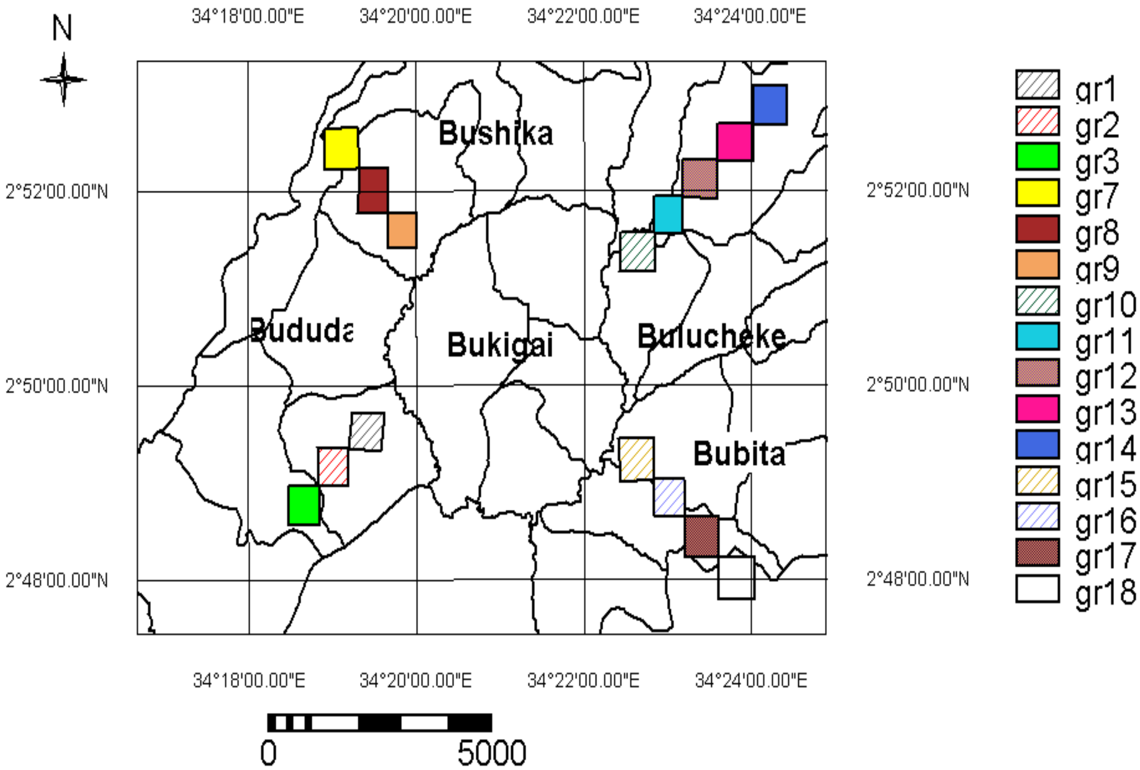
Mattia, C. Bishetti, G. and Gentile, F. 2005, ‘Biotechnical characteristics of root systems of typical Mediterranean species’, Plant and Soil, vol. 278, no.1, pp. 23-32.

Morgan, R. 2007, ‘Vegetative-based technologies for erosion control’, in Stokes, A. (eds), Eco- and Ground Bioengineering: The use of vegetation to Improve Slope Stability, Dordrecht, London, pp. 265 -272.

Ngecu, W.M and Mathu, E.M. 1999. The El Nino-triggered landslides and their socioeconomic impact on Kenya. Environmental Geology, 38 (4): 277-284.

Perry, J., Pedley, M and Reid, M. 2003, Infrastructure embankments condition appraisal and remedial treatment, MWL Digital, Pontypool, South Wales.

APPENDIX A



Transects and sample areas for soil profile description.

SOIL PROFILE DESCRIPTION

BUDUDA TRANSECT

a). Soil profile number:	**gr1 (*Fluvic Cambisol*)** Coordinates: 0647392 and 0113338.
Author:	Kitutu
Parish:	Bushinyekwa
Landuse:	bananas and coffee,
Slope:	4% in the eastern direction.

Ap 0-20cm - Very dark reddish brown (2.5YR 2/3) clay loam; moderate medium sub angular blocky; very firm; sticky and plastic; many fine pores; many fine and medium roots; occasional quartz grains; clear parallel boundary.

AB 20-32cm - dark reddish brown (2.5Y 3/4); very coarse sand; single grained; non sticky, non plastic; more than 80% stones (mainly sand stones) many fine roots; clear wavy boundary.

B 32-90cm -Very dark reddish brown (2.5YR 2/3); clay; strong coarse sub angular blocky; firm, sticky and plastic; occasional quartz stones; common cracks up to one cm wide; common fine and medium pores; many medium and coarse roots; clear parallel boundary.

BC 90-120cm - Dark reddish brown (5YR 3/3) clay; moderate medium sub angular blocky; firm, sticky and plastic; many fine and coarse pores; many coarse roots; more than 60% boulders and stones; diffuse parallel boundary.

C 120cm+ -dark yellow brown (10YR 4/4) clays; moderate fine sub angular blocky; very firm, sticky and plastic; few fine roots; many fine and coarse pores; horizon continues.

Profile analytical data gr1 *(Fluvic Cambisol)*

Depth	**cm**	**0-20**	**20-32**	**32-90**	**90-120**	**120+**
pH		6.5		6.2	6.1	6.1
Sand	%	45.1		41.1	41.1	33.1
Clay	%	43.6		45.6	47.6	57.6
Silt	%	11.3		13.3	11.3	13.3
Textural Class	-	Sandy Clay		Clay	Clay	Clay
Exchange Capacity (K)	ppm	40.95		14.4	16.53	18.56
Exchange Capacity (Na)	ppm	0.092		2.085	2.099	0.091
Available P	ppm	13.34		17.41	11.4	10.58
Organic Matter	%	3.8		3.4	1.8	1.7
CEC	c.moles kg^{-1}			26.1	24.7	21.2
Base totals				8.16	13.58	12.62
% Base saturation				31.2	55.0	59.0
Na^{+}	c.moles kg^{-1}			0.1	0.16	0.19
K^{+}	c.moles kg^{-1}			1.5	1.9	1.09
Ca^{2+}	c.moles kg^{-1}			4.6	8.4	8.2
Mg^{2+}	c.moles kg^{-1}			1.96	3.12	3.14

b). Soil profile number: **gr2 (*Rhodic Nitisol*) Coordinates**: 0647571 and 0112219

Author: Kitutu.

Parish: Bushinyekwa.

Landuse: bananas and coffee.

Slope: 5% in the south-western direction.

Ap 0-15cm - Dark reddish brown (2.5YR 3/3) dry, dark reddish brown (2.5YR 3/4) moist; clay loam; weak fine sub angular, blocky tending to crumb; friable sticky and plastic; many fine pores; many fine and medium roots; diffuse parallel boundary.

B 15-45cm - Dark red (2.5YR 3/6) dry; dark reddish brown (2.5YR 3/3) moist, clay loam; moderate medium sub angular blocky; soft friable sticky and plastic many fine and medium roots and few coarse roots; few fine pores; many large krotovinas; diffuse parallel boundary, shiny peds.

Bt 45-80cm - Red (2.5YR 4/8); clay; strong medium sun angular blocky; very firm, sticky and plastic; few fine roots; many fine and medium pores; thick manganese coatings on the peds; thin patchy cutans in the pores; diffuse parallel boundary, shiny ped faces.

BC 80-150cm - Dark reddish brown (5YR 3/3) clay; moderate medium sub angular blocky; very firm, sticky and plastic; many fine pores; few medium roots; thin cutans in the pores and root channels; horizon continues.

Profile analytical data gr2 (*Rhodic Nitisol)*

Depth	**cm**	**0-15**	**15-45**	**45-80**	**80-150**
pH		5.8	5.6	5.6	5.7
Sand	%	29.1	29.1	39.1	35.1
Clay	%	55.6	55.6	53.6	45.6
Silt	%	15.3	7.3	19.3	17.3
Textural Class	-	Clay	Clay	Clay	Clay
Exchange Capacity (K)	ppm	8.39	8.33	10.29	46.74
Exchange Capacity (Na)	ppm	0.092	0.091	0.090	0.091
Available P	ppm	5.47	3.04	2.27	11.54
Organic Matter	%	3.6	2.6	2.5	2.1
CEC	c.moles kg^{-1}	30.2	24.7	26.1	31.5
Base totals		7.21	4.06	9.25	15.28
% Base saturation		24.0	16.0	35.0	48.0
Na^+	c.moles kg^{-1}	0.1	0.1	0.09	0.17
K^+	c.moles kg^{-1}	0.7	0.6	0.6	2.1
Ca^{2+}	c.moles kg^{-1}	4.8	2.4	2.4	9.0
Mg^{2+}	c.moles kg^{-1}	1.61	0.96	0.96	4.01

c). Soil profile number: **gr3 (*Rhodic Acrisol*)** Coordinates: 0646274 and 0111302.

Author: Kitutu

Parish: Bukibokolo

Landuse: bananas and coffee,

Slope: 17%

Ap 0-15cm - Dark reddish brown (2.5YR 2/4) dry, very dark reddish brown (2.5YR 2/3) clay loam; strong medium sub angular blocky; hard, very firm, sticky and plastic many fine roots; many fine and medium pores; vertical cracks up to 1cm wide; diffuse parallel boundary.

Bt_1 15-50cm - Dark red (2.5YR 3/6) clay loam; strong coarse sub angular blocky; very form, sticky and plastic; common coarse and few fine pores; many fine roots mainly along cracks thin continuous cutans mainly along pores; occasional termite nests; diffuse wavy boundary.

Bt_2 50-160cm - Dark reddish (2.5YR 3/4) clay; strong coarse sub angular blocky; very firm, sticky and plastic; many fine and medium pores; few fine roots; thin patchy cutans on the peds; diffuse broken boundary.

BC 160-200cm - Red (2.5YR 4/6) clay; moderate medium sub angular blocky; firm, sticky and plastic; very few fine roots; few fine pores; horizon continues.

Profile analytical data gr3 (*Rhodic Acrisol*)

Depth	**cm**	**0-15**	**15-50**	**50-160**	**160-200**
pH		6.2	6.0	5.6	5.2
Sand	%	29.1	7.1	9.1	17.1
Clay	%	53.6	81.6	83.6	77.6
Silt	%	17.3	11.3	7.3	5.3
Textural Class	-	Clay	Clay	Clay	Clay
Exchange Capacity (K)	ppm	66.51	44.72	8.28	6.31
Exchange Capacity (Na)	ppm	0.09	0.091	0.09	0.091
Available P	ppm	3.44	1.12	2.18	3.01
Organic Matter	%	5.3	1.6	1.4	1.0
CEC	c.moles kg^{-1}	27.8	25.8	17.2	23.7
CEC (clay)	c.moles kg^{-1}	14.9	21	14.4	18.4
Base totals	cmoles kg^{-1}	10.03	6.31	6.47	8.79
% Base saturation	%	36.0	24.0	37.0	37.0
Na^+	c.moles kg^{-1}	0.07	0.19	0.13	0.07
K^+	c.moles kg^{-1}	0.8	0.8	0.56	0.8
Ca^{2+}	c.moles kg^{-1}	7.0	4.2	4.0	5.7
Mg^{2+}	c.moles kg^{-1}	2.16	1.12	1.78	2.22

BUSHIKA TRANSECT

d). Soil profile number: **gr7** ***(Endoskeletic Cambisol*)** Coordinates: 0647242E and 0116382N.

Author: Kitutu

Parish: Bumushisho

Landuse: annual crops,

Slope: 22%

A_p 0-30cm - Dark reddish brown (2.5YR 3/3) clay strong coarse sub angular blocky; very firm, sticky and plastic; many fine roots, few fine and medium pores; diffuse parallel boundary.

B 30-50cm -Dark reddish brown (5YR 3/4) clay; moderate coarse sub angular blocky; firm; sticky and plastic; few fine random roots; many fine tubular pores, thin cutans on peds; clear parallel boundary.

B 50cm+ - As above but more than 70% boulders and stones.

Profile analytical data (**gr7 *Endoskeletic Cambisol***)

Depth	**cm**	**0-30**	**30-50**
pH		5.6	6.0
Sand	%	41.1	39.1
Clay	%	49.6	55.6
Silt	%	9.3	5.3
Textural Class	-	Clay	Clay
Exchange Capacity (K)	ppm	22.33	10.42
Exchange Capacity (Na)	ppm	0.09	0.092
Available P	ppm	4.23	2.41
Organic Matter	%	2.9	1.8
CEC	c.moles kg^{-1}	22.0	22.4
Base totals		13.06	5.06
% Base saturation		59.0	22.0
Na^{+}	c.moles kg^{-1}	0.14	0.05
K^{+}	c.moles kg^{-1}	1.4	0.6
Ca^{2+}	c.moles kg^{-1}	8.4	3.3
Mg^{2+}	c.moles kg^{-1}	3.16	1.11

e) Soil profile number: gr8 (*Rhodic Nitisol*) Coordinates: 0648078E and 0116648N

Author: Kitutu

Parish: Bunamasongo

Landuse: cultivated land,

Slope: 27%

A_p 0-30cm - Dark red (2.5YR 3/6); clay loam; strong fine sub angular blocky; slightly hard, firm, sticky and plastic; vertical cracks; few fine and coarse roots; many fine pores; clear wavy boundary.

B 30-80cm - Yellowish red (5YR 4/8) clay loam; moderate medium columnar breaking to strong fine sub angular blocky; friable, sticky and plastic; many fine coarse roots; few fine pores; thin patchy cutans in pores; occasional cracks; diffuse parallel boundary.

B_t 80-120cm - Dark reddish brown (5YR 3/6) clay; strong medium sub angular blocky; very firm, sticky and plastic; many medium and coarse pores; many fine and medium roots; thin continuous cutans on the peds; clear broken boundary.

B 120cm+ - As above but more than 70% boulders and stones.

Profile analytical data gr8 **(***Rhodic Nitisol***)**

Depth	cm	0-30	30-80	80-120
pH		5.3	5.4	5.7
Sand	%	27.1	45.1	37.1
Clay	%	57.6	43.6	53.6
Silt	%	15.3	11.3	9.3
Textural Class	-	Clay	Sandy Clay	Clay
Exchange Capacity (K)	ppm	6.27	4.29	6.27
Exchange Capacity (Na)	ppm	0.09	trace	Trace
Available P	ppm	2.91	3.9	3.12
Organic Matter	%	3.1	2.8	2.7
CEC	c.moles kg^{-1}	26.1	23.1	23.7
Base totals		10.04	13.62	15.95
% Base saturation		38.0	58.9	67.0
Na^+	c.moles kg^{-1}	0.12	0.16	0.09
K^+	c.moles kg^{-1}	1.2	1.9	0.7
Ca^{2+}	c.moles kg^{-1}	6.6	8.4	11.0
Mg^{2+}	c.moles kg^{-1}	2.12	3.16	4.16

f). Soil profile number: gr9 (*Haplic Lixisol*) Coordinates: 0648577E and 0116244N

Author: Kitutu

Parish: Bunamasongo

Landuse: bananas and coffee,

Slope: 17%

A_p 0-30cm - Dark reddish brown (5YR 3/6) clay loam; moderate medium sub angular blocky; firm, sticky and plastic; an any fine pores; few fine and coarse roots abundant animal borings and occasional termite nests; clear wavy boundary.

B_t 30-90cm -Yellowish red (5YR 4/8) grit clay loam; strong medium sub angular blocky; very firm, sticky and plastic; common coarse roots; many fine medium and coarse pores; occasional animal borings; thin continuous cutans on the peds; diffuse parallel boundary.

BC 90-160cm **-**Yellowish red (5YR 4/8); clay; weak fine sub angular blocky tending to powdery; friable; sticky and plastic; many fine and medium pores; few fine roots; horizon continuous.

Profile analytical data gr9 *(Haplic Lixisol)*

Depth	**cm**	**0-30**	**30-90**	**90-160**
pH		5.2	5.3	4.9
Sand	%	31.1	19.1	25.1
Clay	%	57.6	69.6	67.6
Silt	%	11.3	11.3	7.3
Textural Class	-	Clay	Clay	Clay
Exchange Capacity (K)	ppm	14.4	8.33	6.31
Exchange Capacity (Na)	ppm	trace	trace	0.091
Available P	ppm	3.88	2.26	2.76
Organic Matter	%	2.9	2.1	1.1
CEC	c.moles kg^{-1}	9.68	21.1	26.4
Base totals		5.11	12.62	8.47
% Base saturation		53.0	59.8	32.0
Na^+	c.moles kg^{-1}	0.05	0.19	0.07
K^+	c.moles kg^{-1}	0.6	1.09	0.8
Ca^{2+}	c.moles kg^{-1}	3.5	8.2	5.7
Mg^{2+}	c.moles kg^{-1}	0.96	3.14	1.9

BULUCHEKE TRANSECT.

g). Soil profile number: **gr10 (*Haplic Ferralsol*)** Coordinates: 0625281E and 0116510N

Author: Kitutu

Parish: Bumwalukani

Landuse: sugarcane and eucalyptus,

Slope: 03% in the eastern direction.

A_p 0-20cm - Dark brown (7.5YR 4/6) clay; moderate medium sub angular blocky; friable, sticky and plastic; many fine and medium roots; many tabular micro pores; diffuse parallel boundary.

AB 20-40cm - Dark brown (7.5YR 3/4) clay; weak medium sub angular blocky tending to structure less; sticky and plastic; abundant fine and medium roots; many fine pores; occasional krotovinas; occasional quartz; diffuse parallel boundary.

B 40-80cm - Dark reddish brown (5YR 3/4) clay; weak medium sub angular blocky; rather firm, sticky and plastic; many fine roots; few fine pores; clear wavy boundary.

BC 80-120cm - Reddish brown (5YR 4/4) clay; weak medium sub angular blocky; firm, more than 50% quartzite, sandstones and altered metamorphic rocks; few fine roots' few fine pores; horizon continues.

Profile analytical data gr10 (*Haplic Ferralsol*)

Depth	**cm**	**0-20**	**20-40**	**40-80**	**80-110**
pH		5.7	5.2	5.7	5.7
Sand	%	47.1	37.1	41.1	57.1
Clay	%	39.6	45.6	41.6	35.6
Silt	%	13.3	17.3	17.3	7.3
Textural Class	-	Sandy Clay	Clay	Clay	Clay
Exchange Capacity (K)	ppm	40.4	22.33	12.38	8.39
Exchange Capacity (Na)	ppm	0.09	0.09	0.09	0.091
Available P	ppm	15.59	11.36	8.05	15.96
Organic Matter	%	3.5	3.1	1.9	1.2
CEC	c.moles kg^{-1}	24.7	32.5	25.1	24.1
Base totals		4.06	8.31	11.65	2.48
% Base saturation		16.0	25.0	46.0	10.0
Na^+	c.moles kg^{-1}	0.1	0.05	0.09	0.03
K^+	c.moles kg^{-1}	0.6	0.6	0.7	0.5
Ca^{2+}	c.moles kg^{-1}	2.4	5.7	7.9	1.5
Mg^{2+}	c.moles kg^{-1}	0.96	1.96	2.96	0.45

h). Soil profile number: **gr11 (*Hyperskeletic Leptosol*)** Coordinates: 0653545E and 0116440N

Author: Kitutu

Parish: Busiliwa

Landuse: cultivated garden

Slope: 15%

Note: Profile dug up to one meter depth, having below 50cm more than 70% boulders of amphibole gneisses; altered granites with almost no quartz.

A_p 0-25cm Dark reddish brown (2.5YR 4/3) clay, moderate fine and medium sub angular blocky; firm; sticky and plastic; common fine pores; many fine and medium roots; diffuse irregular boundary.

B 25-50cm Dark reddish brown (5YR 3/4) clay; strong medium sub angular blocky; firm, sticky and plastic; more than 70% boulders and stones; many fine roots; few fine pores; horizon continues.

No soil description done because soil samples could not be taken because it was not possible. The soils are too stony.

i). Soil profile number: gr12 (*Endoleptic Lixisol*)

Author: Kitutu

Parish: Busiliwa

Landuse: grazing land,

Slope: 12%

A_p 0-20cm - Dark brown (7.5YR 4/6) dry; dark brown (7.5YR 4/3) moist; clay loam; weak fine sub angular blocky; slightly hard, firm, sticky and plastic; many fine roots; very few fine pores; diffuse parallel boundary.

B_t 20-70cm - Dark brown (7.5YR 4/3) clay loam; moderate fine sub angular blocky; firm sticky and plastic; few fine roots; many fine and medium pores; moderately thick patchy cutans; many large and small krotovinas; diffuse parallel boundary.

BC 70-90cm - Weathering iron concentrations, amphibolite gneisses and granites; horizon continues.

Profile analytical data gr12 (*Endoleptic Lixisol*)

Depth	**cm**	**0-20**	**20-70**	**70-90**
pH		5.8	6.0	6.4
Sand	%	53.1	51.1	49.1
Clay	%	25.6	33.6	37.6
Silt	%	21.3	15.3	13.3
Textural Class	-	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay
Exchange Capacity (K)	ppm	22.48	36.88	47.05
Exchange Capacity (Na)	ppm	0.091	Trace	Trace
Available P	ppm	15.45	51.1	34.3
Organic Matter	%	2.4	1.5	0.8
CEC	c.moles kg^{-1}	25.4	16.3	24.6
Base totals		14.22	8.40	8.03
% Base saturation	%	56.0	51.0	54.1
Na^+	c.moles kg^{-1}	0.16	0.1	0.03
K^+	c.moles kg^{-1}	1.6	1.1	0.79
Ca^{2+}	c.moles kg^{-1}	9.5	5.1	5.89
Mg^{2+}	c.moles kg^{-1}	2.96	2.1	1.29

J). Soil profile number: **Gr13 (*Haplic Gleysol*)** Coordinates: 0655601E and 0117486N

Author: Kitutu.

Parish: Bushiyi

Landuse: banana and coffee,

Slope: 13% in the eastern direction.

Note: Water table at 100cm from the surface.

A_p 0-30cm - Light grey (5YR 7/1) dry; dusk red (2.5YR 3/2) moist; clay; moderately coarse sub angular blocky; soft; friable, sticky and plastic; many fine pores; many fine and medium roots; diffuse parallel boundary.

B_t 30-70cm - Weak red (2.5YR 4/2) clay loam; moderate medium sub angular blocky; firm, sticky and plastic; many fine roots; few fine and coarse pores; diffuse broken boundary.

B_g1 70-110cm - Grey (5YR 6/2) matrix; 20% yellowish red (5YR 5/8) 10 % dark reddish grey (5YR 4/2) clay ; strong medium sub angular blocky; more than 80% rotting rocks forms the upper boundary of the water table; diffuse parallel boundary.

B_g2 110-130cm - Greenish grey (10GY 5/1) matrix. 30% yellowish red (5YR 4/8) clay; moderately fine sub angular blocky; sticky and plastic; more than 90% rotting rocks; horizon totally under water.

Profile analytical data gr13 (*Haplic Gleysol*)

Depth	**cm**	**0-30**	**30-70**	**70-110**	**110-130**
pH		6.0	5.8	6.2	6.3
Sand	%	63.1	61.1	53.1	55.1
Clay	%	25.6	31.6	37.6	7.3
Silt	%	11.3	7.3	9.3	7.3
Textural Class	-	Sandy Clay loam	Sandy Clay loam	Sandy Clay	Sandy Clay
Exchange Capacity (K)	ppm	12.29	4.32	16.53	12.38
Exchange Capacity (Na)	ppm	0.09	trace	4.107	4.079
Available P	ppm	2.13	0.71	1.7	6.08
Organic Matter	%	2.4	1.5	0.8	0.7
CEC	c.moles kg^{-1}	22.2	27.8	23.4	30.5
Base totals		13.31	11.17	11.35	4.95
% Base saturation	%	32.6	40.0	48.0	16.0
Na^+	c.moles kg^{-1}	0.19	0.09	0.16	0.05
K^+	C.moles kg^{-1}	1.6	2.3	2.1	0.5
Ca^{2+}	C.moles kg^{-1}	8.42	6.6	6.8	3.3
Mg^{2+}	C.moles kg^{-1}	3.1	2.18	2.29	1.1

K). Soil profile number: **Gr14 (*Gleyic Lixisol*)** Coordinates: 0656528E and 0118297N

Author: Kitutu.

Parish: Bushiyi

Landuse: banana and coffee

Slope: 3% in the south direction.

A_p 0-30cm - Dark reddish brown (5YR 3/2) clay loam; weak fine sub angular blocky tending to crumb; friable, sticky and plastic; many fine, medium and coarse roots; many fine pores; many animal borings; diffuse parallel boundary.

B_t 30-70cm - Dark red (2.5YR 3/2) clay loam; moderate medium sub angular blocky; firm; sticky and plastic; few fine roots; many medium and coarse pores; occasional small and large krotovinas; diffuse parallel boundary.

B_g 70-110cm - Yellowish red (5YR 5/6) matrix; 20% strong brown (7.5 YR 5/6) indistinct mottles; clay ; weak medium sub angular blocky tending to granular; friable, sticky and plastic; few fine roots; many fine and medium pores; about 45% weathering rock fragments; horizon continues.

Profile analytical data gr14 (Gleyic *Lixisol*)

Depth	**cm**	**0-30**	**30-70**	**70-110**
pH		5.7	6.1	6.1
Sand	%	61.1	45.1	53.1
Clay	%	19.6	39.6	29.6
Silt	%	19.3	15.3	17.3
Textural Class	-	Sandy loam	Sandy loam	Sandy clay loam
Exchange Capacity (K)	ppm	12.38	20.6	87.75
Exchange Capacity (Na)	ppm	Trace	0.092	0.092
Available P	ppm	12.06	15.37	19.21
Organic Matter	%	4.6	2.2	1.3
CEC	c.moles kg^{-1}	24.0	27.2	26.6
Base totals		5.48	2.49	14.69
% Base saturation		22.8	9.5	55.2
Na^+	c.moles kg^{-1}	0.1	0.1	0.19
K^+	c.moles kg^{-1}	0.6	0.8	2.2
Ca^{2+}	c.moles kg^{-1}	3.5	1.1	9.0
Mg^{2+}	c.moles kg^{-1}	1.28	0.49	3.3

BUBITA TRANSECT.

I). Soil profile number: Gr15 (*Haplic Ferralsol*) Coordinates: 0652732E and 0111577N

Author: Kitutu

Parish: Maaba

Landuse: bananas and coffee,

Slope: 02% in the western direction.

A_p 0-28cm - Dull reddish brown (2.5YR 4/3) dry; dusky red (2.5YR 3/2) moist. Clay loam; strong medium sub angular blocky; hard, firm, sticky and plastic; many fine and medium coarse roots; many fine and medium pores; occasional krotovinas; diffuse parallel boundary.

B1 28-50cm - Dark reddish brown (5YR 3/4) clay moderate medium sub angular blocky; friable, sticky and plastic; few fine and coarse roots; many fine and medium pores; thin patchy cutans on the ped faces diffuse irregular boundary.

B2 50-100cm - Dark reddish brown (5YR 3/4) clay; moderate fine sub angular blocky; firm, sticky and plastic; many fine and medium roots; many medium and coarse pores; thick patchy cutans and the ped faces; diffuse broken boundary.

BC 100-140cm - Dark reddish brown (5YR 3/4) clay; weak fine platy tending to structureless; friable; sticky and plastic; many fine and medium roots; few fine pores; horizon continues.

Profile analytical data gr15 **(***Haplic Ferralsol*)

Depth	**cm**	**0-28**	**28-50**	**50-100**	**100-140**
pH		5.8	5.8	5.8	5.7
Sand	%	45.1	33.1	35.1	35.1
Clay	%	39.6	45.6	53.65	55.6
Silt	%	15.3	21.3	11.3	9.3
Textural Class	-	Sandy Clay	Clay	Clay	Clay
Exchange Capacity (K)	ppm	30.36	22.63	18.56	6.35
Exchange Capacity (Na)	ppm	Trace	Trace	2.099	2.099
Available P	ppm	23.26	15.36	11.60	24.27
Organic Matter	%	3.6	2.3	2.1	1.7
CEC	c.moles kg^{-1}	26.4	24.4	21.0	27.0
Base totals		14.78	11.71	9.24	10.36
% Base saturation		56.0	48.0	44.0	38.0
Na^+	c.moles kg^{-1}	0.19	0.05	0.18	0.1
K^+	c.moles kg^{-1}	2.2	0.5	1.12	0.6
Ca^{2+}	c.moles kg^{-1}	9.0	8.1	5.5	7.5
Mg^{2+}	c.moles kg^{-1}	3.39	3.06	2.44	2.16

m). Soil profile number: **Gr16 (*Hyperskeletic Leptosol*)** Coordinates: 0653464E and 0111255N

Author: Kitutu

Parish: Maaba

Landuse: bananas and coffee

Slope: 13%

Note: Many boulders and stones throughout the profile not possible to collect samples.

A_p 0-20cm - Dark reddish brown (5YR 3/4) clay; moderate medium sub angular blocky; firm; sticky and plastic; many fine pores; few fine and medium roots; many krotovinas; clear irregular boundary.

B 20cm+ - Colour and texture as above but more than 75% boulders and stones the bulk of which are unweathered; horizon continues.

No soil samples taken.

n). Soil profile number: **Gr17 (*Haplic Acrisol*)** Coordinates: 0654353E and 0110655N

Authors: Kitutu

Parish: Maaba

Landuse: cultivated garden.

Slope: 14% in the north-eastern direction.

A_p 0-20cm - Dusky red (2.5YR 3/2) dry; dark reddish brown (2.5YR 2/4) moist; clay loam; moderate coarse plate and fine sub angular blocky; slightly hard, very friable, sticky and plastic; many fine and very fine roots; many fine and few medium vesicular pores; diffuse wavy boundary.

Bt1 20-50cm - Yellowish red (5YR 4/6) clay loam; strong fine columnar very firm; very fien roots; common fine and medium tabular pores; common thin cutans in pores; occasional termite nests; diffuse parallel boundary.

Bt2 50-80cm - Yellowish red (5YR 4/8) clay; weak fine columnar breaking up to fine sub angular blocky; friable; sticky and plastic; many fine and medium pores; few fine roots; thin patchy cutans in pores; many krotovinas; diffuse broken boundary.

Bt3 80-130cm - Dark reddish brown (5YR 3/6) clay; weak coarse columns breaking to moderate and fine sub angular blocks; firm, sticky and plastic; many fine and medium roots, many fine pores; thin patchy cutans on the peds; horizon continues.

Profile analytical data gr17 (*Haplic Acrisol*)

Depth	**cm**	**0-20**	**20-50**	**50-80**	**80-100**
pH		5.3	5.4	5.4	5.3
Sand	%	49.1	25.1	27.1	41.1
Clay	%	39.6	59.6	59.6	55.6
Silt	%	11.3	15.3	13.3	3.3
Textural Class	-	Sandy clay	Clay	Clay	Clay
Exchange Capacity (K)	ppm	6.35	6.35	4.32	4.29
Exchange Capacity (Na)	ppm	Trace	Trace	Trace	Trace
Available P	ppm	0.84	1.42	3.28	3.44
Organic Matter	%	2.7	1.9	1.2	1.2
CEC	c.moles kg^{-1}	22.8	23.7	27.8	23.7
Base totals		13.0	8.79	6.06	5.48
% Base saturation		57.0	37.0	22.0	23.0

Na^+	c.moles kg^{-1}	0.12	0.07	0.1	0.1
K^+	c.moles kg^{-1}	0.8	0.8	1.0	0.6
Ca^{2+}	c.moles kg^{-1}	9.0	5.7	3.7	3.5
Mg^{2+}	c.moles kg^{-1}	3.12	2.22	1.26	1.28

0). Soil profile number: **Gr18 (*Rhodic Lixisol*)** Coordinates: 0655854E and 0111406N

Author: Kitutu.

Parish: Bukalasi.

Landuse: grazing field.

Slope: 25% in the eastern direction.

A 0-20cm - Dark reddish brown (2.5YR 3/3) clay; very weak fine sub angular blocky; tending to granular; friable, sticky and plastic; many fine roots; many fine interstitial pores; clear wavy boundary.

Bt1 20-50cm - Red (2.5YR 4/8) clay loam; weak medium and coarse prisms breaking to weak fine sub angular blocks; friable; sticky and plastic; many fine roots; few fine and medium pores; arbitrary boundary.

Bt2 50-150cm - Reddish brown (5YR 5/4) clay; weak fine sub angular blocky; friable, sticky and plastic; many fine roots; many fine and medium pores; abundant boulders of volcanic rocks; horizon continues.

Profile analytical data gr18 (*Rhodic Lixisol*)

Depth	**cm**	**0-20**	**20-50**	**50-150**
pH		5.0	5.1	4.9
Sand	%	29.1	21.1	27.1
Clay	%	55.6	67.6	67.6
Silt	%	15.3	11.3	5.3
Textural Class	-	Clay	Clay	Clay
Exchange Capacity (K)	ppm	8.28	6.35	6.31
Exchange Capacity (Na)	ppm	Trace	0.092	Trace
Available P	ppm	1.27	1.87	4.9
Organic Matter	%	3.3	2.1	1.3
CEC	c.moles kg^{-1}	28.1	26.4	27.1
Base totals		2.49	14.78	17.0
% Base saturation		9.0	56.0	62.0
Na^+	c.moles kg^{-1}	0.1	0.19	0.09
K^+	c.moles kg^{-1}	0.8	2.2	0.7
Ca^{2+}	c.moles kg^{-1}	1.1	9.0	12.0
Mg^{2+}	c.moles kg^{-1}	0.49	3.39	4.21

p). Soil profile number CB: **Carbonatite (*Rhodic Nitisol*)** Coordinates: 0648610E and 0112201N

Author: Kitutu.

Parish: Bukigai

Landuse: bananas and coffee,

Slope: 35%

A 0-40cm - Dusky red (10R 3/4) dry; very dark reddish brown (10r 2/3) wet clay; strong medium sub angular blocky; hard, very firm, sticky and plastic; many fine and medium roots; many medium and coarse pores; abundant cracks (vertical) up to 1cm wide; occasional termite nests; diffuse parallel boundary.

B 40-140cm - Dusky red (10R 3/4) dry; dark reddish brown (10R 3/3) moist clay; strong coarse sub angular blocky; slightly hard firm; sticky and plastic; many fine and medium pores; few fine roots; many cracks (vertical) up to 1 cm wide; horizon continues.

Profile analytical data Carbonatite hill (*Rhodic Nitisol*)

Depth	**cm**	**0-40**	**40-150**
pH		5.7	5.9
Sand	%	29.1	23.1
Clay	%	49.6	63.6
Silt	%	21.3	13.3
Textural Class	-	Clay	Clay
Exchange Capacity (K)	ppm	42.7	34.84
Exchange Capacity (Na)	ppm	trace	Trace
Available P	ppm	26.59	4.31
Organic Matter	%	3.0	1.8
CEC	c.moles kg^{-1}	28.2	24.4
Base totals		10.12	11.71
% Base saturation		36.0	48.0
Na^{+}	c.moles kg^{-1}	0.16	0.05
K^{+}	c.moles kg^{-1}	0.8	0.5
Ca^{2+}	c.moles kg^{-1}	7.0	8.1
Mg^{2+}	c.moles kg^{-1}	2.16	3.06

APPENDIX B

SOIL PROFILE EXAMINATION IN BUKIGAI AND BULUCHEKE SUBCOUNTIES

THE SITE FOR WATER INFILTRATION AT SAMPLE POINT GR12 NEAR THE NUSU RIDGE DYKE

APPENDIX C

STRUCTURED - INTERVIEW SHEET FOR BUDUDA DISTRICT. MAY 2004

1.0 Personal Information

1.1 Date of the interview

1.2 Name of Sub County

1.3 Name of Parish

1.4 Name of the village

1.5 Name of Person

1.6 Age of the person

1.7 Education level

1.8 What is your occupation?

2.0 Landlessness due to landslides.

2.1 How much land do you own?

2.2 Is the land sufficient for your needs?

2.3 Are there any people without land?

2.4 If yes, why don't they have land?

3.0 Changes in landuse.

3.1 Has there been any change in landuse?

3.2 If yes, describe the landuse change during each of the following period.

1. Before 1960
2. 1960 to 1970
3. 1970 to 1980
4. 1980 to 1990

5 1990 to 2000

3.2 Explain why the land was used that way in each period above.

1. Before 1960

2 1960 to 1970

3 1970 to 1980

4 1980 to 1990

5 1990 to 2000

4.0 Where do the landslides occur?

4.1 Have you ever experienced landslides on your land?

4.2 If yes, how severe was it?

4.3 Do you know of other people who have experienced landslides on their land?

4.4 If yes, where

4.5 Can you describe how an area where a landslide is likely to occur looks like in terms of slope steepness, slope form and vegetation cover?

4.6 What are the type of soils in areas where landslides occur.

4.7 Do you know areas where landslides do not occur?

4.8 Would you give reasons why the landslides do not occur in these soils?

4.9 What are the type of the soils in these areas?

4.10 Do you know any forested area where landslides have occurred?

4.11 If yes where?

5.0 When do landslides occur?

5.1 During which months did landslides occur?

5.2 What was the rainfall pattern in these months?

5.3 In which years did you experience many landslides?

5.4 Why were the landslides many?
5.5 Do you think landslides are caused by certain type of rainfall?

5.6 If yes, can you describe the kind of rainfall?

6) Influence of terraces and undercutting of slopes.

6.1 Is your land terraced?

6.2 If yes, do you experience landslides on terraced land?

6.3 If no, why is it not terraced?

6.4 Has terracing of land caused any landslides?

6.5 If yes, where?

6.6 Are houses constructed on slopes?

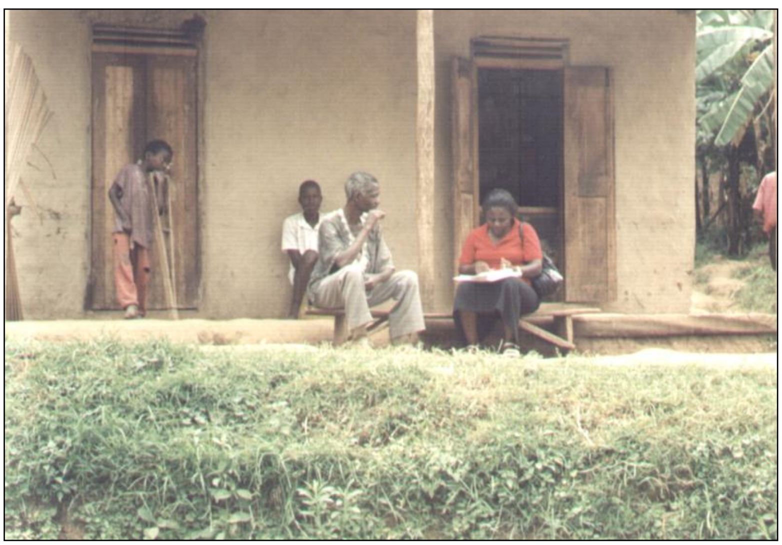
6.7 If yes, have landslides occurred on a slope after a house is constructed?

7) What are the negative effects of landslides?

7.1 List problems caused by landslides in your area.

7.2 Can you estimate the loss of income due to landslides on your land?

A farmer being interviewed in Bushiyi (Bulucheke subcounty)



APPENDIX D

ORIENTATION OF JOINTS FROM BUGOBERO ROCKSLIDE

302/ 065	279/075	044/085
308 / 070	348/085	044/080
308/ 070	295/070	060/075
308/065	309/087	044/085
311/065	286/025	072/067
299/085	295/068	058/080
300/080	343/090	025/055
326/083	297/072	034/055
284/055	281/072	036/055
348/077	277/032	035/045
310/088	320/070	041/055
276/080	286/025	040/065
314/085	296/080	048/075
277/086	295/068	020/080
294/090	018/080	073/075
294/080	005/087	066/085
308/088	052/085	075/085
280/075	044/085	010/080
336/080	049/073	006/065
285/089	052/080	008/055
281/090	077/078	012/080
342/082	083/090	002/047
340/085	083/083	013/045
277/072	006/045	015/070
325/070	025/070	010/080
319/068	006/080	015/072
315/075	006/045	
320/070	077/072	
318/078	054/090	
300/089	072/080	

APPENDIX E:

LANDSLIDE FIELD ASSESSMENT

Code	height (m)	parish	Date	Classification	Width (m)	length (m)	Depth (m)	Volume of material (m3)	slope (%)	slope form	aspect	distance to the water divide
Ls 10	1675	Bushiyi	1966	multiple debris slump	9	24	1.5	324	51	concave	w	213
LS20	1890	Bushiyi	Oct-97	debris slide	40	320	1.5	19200	52	concave	w	68
LS30	1965	Bushiyi	Oct-97	rock slide	90	145	1.7	22185	57	concave	w	230
LS40	1990	Bushiyi	1940	rock slide	65	60	2.3	8970	58	rectilinear	w	139
LS50	1660	Bushiyi	1997	rock slump	24	27	6	3888	67	concave	w	289
LS6a0	1830	Bushiyi	recent	single debris slump	27	99	5.5	14702	42	convex	w	423
LS6b0	1830	Bushiyi	recent	single debris slump	19	75	6	8550	44	concave	w	426
LS70	2015	Bushiyi	old	single debris slump	14	33	2.5	1155	62	?	w	118
LS80	1770	Bushiyi	young	single debris slump	23	30	1.2	828	43	?	w	457
LS90	1735	Bushiyi	young	single debris slump	18	20	1.4	504	39	?	w	172
LS100	1570	Bumwalukani	recent	single debris slump	13	21	4.5	1229	33	rectilinear	E	295
LS110	1600	Bumwalukani	recent	single debris slump	26	31	4.8	3869	42	rectilinear	E	304
LS120	1585	Bumwalukani	Oct-97	debris slide	16	20	1	320	38	rectilinear	E	300
LS130	1580	Bumwalukani	recent	single debris slump	16	22	1.2	422	24	rectilinear	E	514
LS140	1620	Bumwalukani	old	rock slide	27	35	2	1890	26	rectilinear	E	620
LS150	1770	Bumwalukani	young	debris flow	13	26	0.8	270	55	rectilinear	E	103
LS160	1830	Bumwalukani	young	debris slide	11	56	0.9	554	51	rectilinear	E	180
LS170	1740	Bumwalukani	?	?	10	12	1	120	33	rectilinear	E	305
LS180	1725	Bumwalukani	?	?	10	12	1	120	33	rectilinear	E	358
LS200	1540	Bumayoka	28-08-1988	single debris slump	14	60	2.5	2100	38	concave	N	1080
LS210	1570	Bumayoka	30-08-1988	multiple debris slump	25	60	3	4500	38	concave	N	941
LS220	1695	Bumayoka	1-11-97, 05-02	multiple debris slump	30	85	2.6	6630	42	concave	N	499
LS230	1720	Bumayoka	Nov-97	single debris slump	36	92	4.5	14904	45	concave	N	450
LS240	1780	Bumayoka	Aug-95	multiple debris slump	22	75	4	6600	49	concave	N	212
LS250	1740	Bumayoka	10-01, 06-02	single debris slump	60	190	4	45600	?	concave	W	480

LS260	1885	Bushiyi	young	debris slide	8	200	0.5	800	68	rectilinear	E	193
LS270	1755	Bushiyi	1997	single debris slump	10	150	0.75	1125	70	concave	S	366
LS280	1740	Bushiyi	2002	debris slide	10	30	2	600	55	concave	S	114
LS290	1690	Bushiyi	2002	single debris slump	15	35	3.5	1838	50	concave	S	56
LS300	1860	Bushiyi	old	rock slide	90	280	4	100800	87	?	S	345
LS310	1630	Bumayoka	Oct-73	single debris slump	25	120	3	9000		rectilinear	N	40
LS320	1616	Bumayoka	1976	single debris slump	18	100	2	3600		rectilinear	N	30
LS330	1815	Bumayoka	Sep-96	single debris slump	55	180	2	19800	49	concave	S	379
LS340	1690	Bumayoka	1996	single debris slump	15	15	2	450	40	concave	S	248
LS350	1830	Bumayoka	old	?	9	12	2	216	49	rectilinear	S	523
LS360	1875	Bulukusi	Sep-96	rock slump	290	350	3	304500	54	concave	E	591
LS370	1570	Buwali	Aug-98	single debris slump	45	40	2.5	4500	48	concave	W	677
LS380	1620	Buwali	Nov-97	single debris slump	30	60	5.5	9900	52	rectilinear	N	394
LS390	1570	Bundesi	young	single debris slump	15	25	1.2	450	?	concave	N	550
LS400	1770	Bundesi	young	single debris slump	16	20	1.5	480	?	concave	N	680
LS410	1710	Bundesi	old	single debris slump	700	950	12	7980000	48	convex	W	555
LS420	1630	Bundesi	young	single debris slump	12	15	1	180	50	concave	N	682
LS430	1815	Bulukusi	?	?	?	?	?	?	?	?	W	396
LS440	1615	Buwali	Jun-99	single debris slump	200	350	1	70000	52	concave	N	406
LS450	1660	Buwali	Jun-02	rock slump	45	29	1.3	1697	54	concave	W	636
LS460	1615	Buwali	old, react	single debris slump	65	130	1	8450	38	concave	S	653
LS470	1520	Buwali	1997, 1998	single debris slump	210	400	3.5	294000	50	convex	S	850
LS480	1540	Maaba	03-98, react	single debris slump	120	200	7.5	180000	?	concave	N	250
LS490	1510	Maaba	1998	debris slide	20	25	0.5	250	?	rectilinear	N	244
LS500	1675	Maaba	?	?	?	?	?	?	?	?	S	288
LS510	1415	Maaba	Mar-02, react	single debris slump	15	24	0.5	180	?	concave	N	590
LS520	1445	Maaba	Mar-02, react	single debris slump	34	60	3.2	6528	55	concave	N	491
LS530	1540	Maaba	Mar-98, react	single debris slump	56	75	5	21000	52	concave	N	237
LS540	1545	Maaba	Aug-01	single debris slump	7	15	1	105	49	concave	N	200
LS550	1480	Maaba	Aug-01	single debris slump	12	15	8	1440	58	concave	N	254
LS560	?	Maaba	23- 26/11/97	single debris slump	35	110	3	11550	?	concave	N	260
LS570	1460	Maaba	97-98-99- 01	rock slide	8	15	2	240	?	rectilinear	N	355

LS580	1450	Maaba	1999	single debris slump	10	20	2.5	500	?	concave	N	460
LS590	1485	Maaba	2001	single debris slump	10	20	2	400	?	concave	N	390
LS600	1495	Maaba	1999	single debris slump	15	15	2	450	?	concave	N	350
LS610	1480	Maaba	old	rock slide	8	20	0.75	120	?	concave	N	200
LS620	1560	Maaba	young	debris slide	25	82	1	2050	?	concave	W	370
LS630	1555	Maaba	old	single debris slump	18	25	2	900	?	convex	N	400
LS640	1560	Maaba	old	single debris slump	20	25	0.75	375	?	concave	N	400
LS650	1570	Maaba	young	single debris slump	40	86	3.5	12040	?	concave	W	200
LS660	1495	Maaba	recent	single debris slump	40	35	3	4200	?	concave	W	205
LS670	1690	Buchunya	young	?	?	?	?	?	?	concave	S	63
LS680	1845	Buchunya	young	?	?	?	?	?	?	rectilinear	S	54
LS690	1780	Buchunya	?	?	?	?	?	?	?	concave	S	122
LS1W	1495	Busai	Aug-97	single debris slump	180	290	6.5	339300	31	concave	E	691
LS2W	1565	Busai	97-98	multiple debris slump	78	45	3.75	13163	34	concave	E	433
LS3W	1660	Busai	Jan-97	multiple debris slump	28	125	2.2	7700	39	concave	N	365
LS4W	1675	Busai	15-05-97	single debris slump	245	450	4.8	529200	33	concave	N	348
LS5W	1755	Bumushisho	Dec-97	single debris slump	80	190	3.9	59280	36	concave	S	383
LS6W	1555	Bumushisho	Nov-97	earth slump	65	70	4.2	19110	41	concave	E	984
LS7W	1630	Bunabutiti	Nov-97	multiple debris slump	45	165	3.8	28215	59	concave	E	395
LS8W	1660	Bunabutiti	Nov-97	multiple debris slump	60	180	4.8	51840	61	concave	E	457
LS9W	1480	Bumushisho	1997	earth slump	60	68	2.9	11832	27	concave	W	653
LS10W	1585	Bumushisho	1997	single debris slump	32	28	2	1792	26	concave	E	176
LS11W	1830	Bumushisho	1996	single debris slump	17	50	3.1	2635	35	concave	E	307
LS12W	1765	Bumushisho	1996	multiple debris slump	75	175	3	42075	39	concave	E	301
LS13W	1725	Bumushisho	1997	multiple debris slump	30	8	1.75	1620	41	concave	E	476
LS14W	1570	Bumushisho	27-11-97	single debris slump	50	32	4	6400	36	convex	E	574
LS15W	1585	Bumushisho	1996	single debris slump	85	95	1.2	9690	42	rectilinear	S	813
LS16W	1660	Bunabutiti	recent	earth slide	?	?	?	?	?	rectilinear	S	?
LS1B	1585	Bukalasi	97-99-02	multiple debris slump	30	40	5	6000	35	concave	S	583
LS2B	1660	Bukalasi	1997	earth slide	25	30	3	2250	38	concave	S	385
LS3B	1640	Bukalasi	1997	earth slide	80	120	0.5	4800	50	concave	N	123
LS4aB	1780	Bukalasi	1997	earth slide	25	30	0.5	375	?	concave	S	261

LS4bB	1785	Bukalasi	May-02	earth slide	20	25	1	500	?	concave	S	275
LS5B	1700	Bukalasi	Nov-02	earth slide	22	18	0.4	158	?	concave	N	75
LS6B	1735	Bukalasi	1997	earth slide	15	20	0.5	150	?	concave	N	285
LS7B	1765	Bukalasi	97,react	earth slide	110	90	2	19800	53	concave	S	396
LS8B	1770	Bukalasi	old	earth slide	400	300	2.5	300000	51	concave	S	449
LS9B	1760	Bukalasi	old	earth slide	30	60	1.5	2700	42	concave	S	553
LS10B	1770	Bukalasi	old	single debris slump	25	75	1.5	2813	?	concave	N	466
LS11B	1880	Bukalasi	1997	earth slide	19	66	1.75	2195	?	concave	S	164
LS12B	1720	Bukalasi	1997	earth slide	20	25	1	500	?	concave	S	202
LS13B	1675	Bukalasi	old	single debris slump	35	55	2	3850	?	concave	N	186

APPENDIX F:

PERMEABILITY TESTS

Location: Fenitised basement 1

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Refernce point	Height above datum y (mm)	Height above outlet h (mm)	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:00:32	0.533	435/200 = 2.18
2		200	0:01:43	1.72	$\log_{10}$ (218)= 0.328
0					

Permeability K = 3.84 La/At $\log_{10}$ (hi/hf) x 10^{-5}

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10^{-5} m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 0.533 x 10^{-8} = 2.2 x 10^{-5} m/s

Test run (3-2) K= 1.168 / 1.72 x 10^{-8} = 6.80 x 10^{-6} m/s

Permeability (25^0C) = 1.44 x 10^{-5} m/s

Location: Fenitised basement 2

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Refernce point	Height above datum y (mm)	Height above outlet h (mm)	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:00:5	0.083	435/200 = 2.18
2		200	0:00:10	0.166	Log $_{10}$ (218)=0.328
0					

Permeability K = 3.84 La/At Log $_{10}$ (hi/hf) x 10 $^{-5}$

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10 $^{-5}$ m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 0.083 x 10^{-8} = 1.4 x 10 $^{-4}$ m/s

Test run (3-2) K= 1.168 / 0.166 x 10^{-8} = 7.0 x 10 $^{-8}$ m/s

Permeability (25^{0}C) = 1.05 x 10 $^{-4}$ m/s

Location: Fenitised basement 3

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^{0}C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Refernce point	Height above datum y mm	Height above outlet h mm	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:00:30	0.50	435/200 = 2.18
2		200	0:10:10	1.00	Log $_{10}$ (218)=0.328
0					

Permeability K = 3.84 La/At Log $_{10}$ (hi/hf) x 10 $^{-5}$

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10 $^{-5}$ m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 0.5 x 10^{-8} = 2.34 x 10^{-5} m/s

Test run (3-2) K= 1.168 / 1.0 x 10^{-8} = 1.168 x 10^{-5} m/s

Permeability (25^0C) = 1.754 x 10^{-5} m/s

Location: Fenitised basement 4

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Refernce point	Height above datum y mm	Height above outlet h mm	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:1:47	1.78	435/200 = 2.18
2		200	0:4:24	4.40	Log $_{10}$ (218)=0.328
0					

Permeability K = 3.84 La/At Log $_{10}$ (hi/hf) x 10^{-5}

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10^{-5} m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 1.78 x 10^{-8} = 6.56 x 10^{-6} m/s

Test run (3-2) K= 1.168 / 4.4 x 10^{-8} = 2.65 x 10^{-6} m/s

Permeability (25^0C) = 4.62 x 10^{-6} m/s

Location: Fenitised Basement 5

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Reference point	Height above datum y mm	Height above outlet h mm	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:00:24	0.40	435/200 = 2.18
2		200	0:00:47	0.79	Log_{10} (218)=0.328
0					

Permeability K = 3.84 La/At Log_{10} (hi/hf) x 10^{-5}

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10^{-5} m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 0.4 x 10^{-8} = 2.92 x 10^{-5} m/s

Test run (3-2) K= 1.168 / 0.79 x 10^{-8} = 1.48 x 10^{-5} m/s

Permeability (25^0C) = 2.2 x 10^{-5} m/s

Location: Carbonatite 1

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Reference point	Height above datum y mm	Height above outlet h mm	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:00:5	0.083	435/200 = 2.18
2		200	0:00:10	0.166	Log_{10} (218)=0.328
0					

Permeability K = 3.84 La/At Log_{10} (hi/hf) x 10^{-5}

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10^{-5} m/s=1.168/t x 10^{-8} m/s

Test run (1-3) K = 1.168 / 0.33 x 10^{-8} = 3.54 x 10 $^{-5}$ m/s

Test run (3-2) K= 1.168 / 0.77 x 10^{-8} = 1.52 x 10 $^{-5}$ m/s

Permeability (25^0C) = 2.54 x 10 $^{-5}$ m/s

Location: Carbonatite 2

Method of preparation: Un-disturbed sample

Sample diameter: 100 mm **Area**: 7857 mm^2

Length: 125 mm **Volume**: 1001 cm^3

Test temperature: 25^0C

Standpipe diameter: 3.0 mm **Area**: 7.0714 mm^2

Reference point	Height above datum y mm	Height above outlet h mm	Test Hrs min. sec.	t min	Height ratios
1		950			950/435 = 2.18
3		435	0:06:24	6.40	435/200 = 2.18
2		200	0:17:40	17.67	Log $_{10}$ (218)=0.328
0					

Permeability K = 3.84 La/At Log $_{10}$ (hi/hf) x 10 $^{-5}$

K = 3.84 x (7.0714 x 1.00)/7857t x 0.338 x 10 $^{-5}$ m/s=1.168/t x 10^{-8} m/s

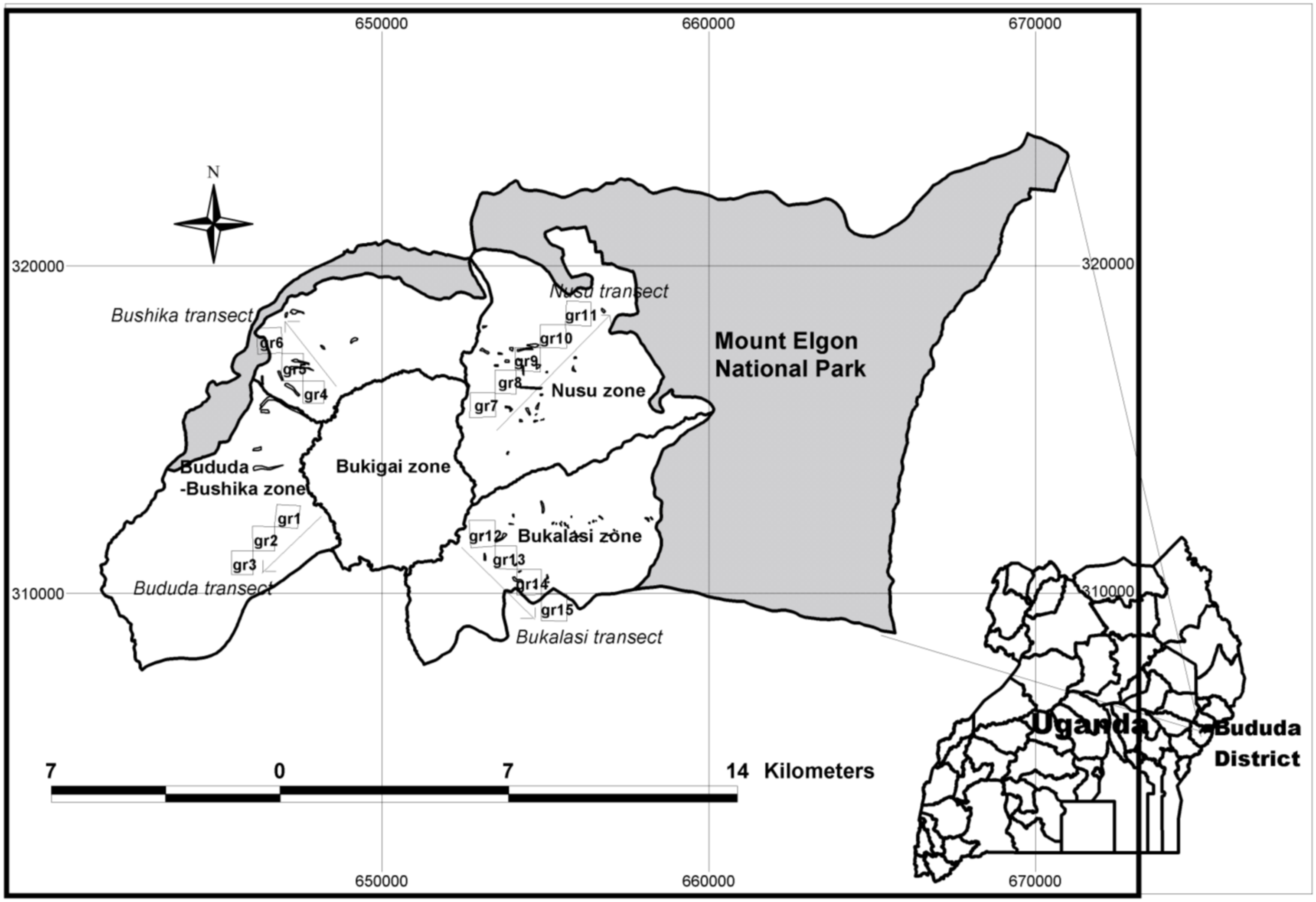
Test run (1-3) K = 1.168 / 6.4 x 10^{-8} = 1.8 x 10 $^{-6}$ m/s

Test run (3-2) K= 1.168 / 17.67 x 10^{-8} = 6.80 x 10 $^{-7}$ m/s

Permeability (25^0C) = 2.46 x 10 $^{-6}$ m/s

APPENDIX G

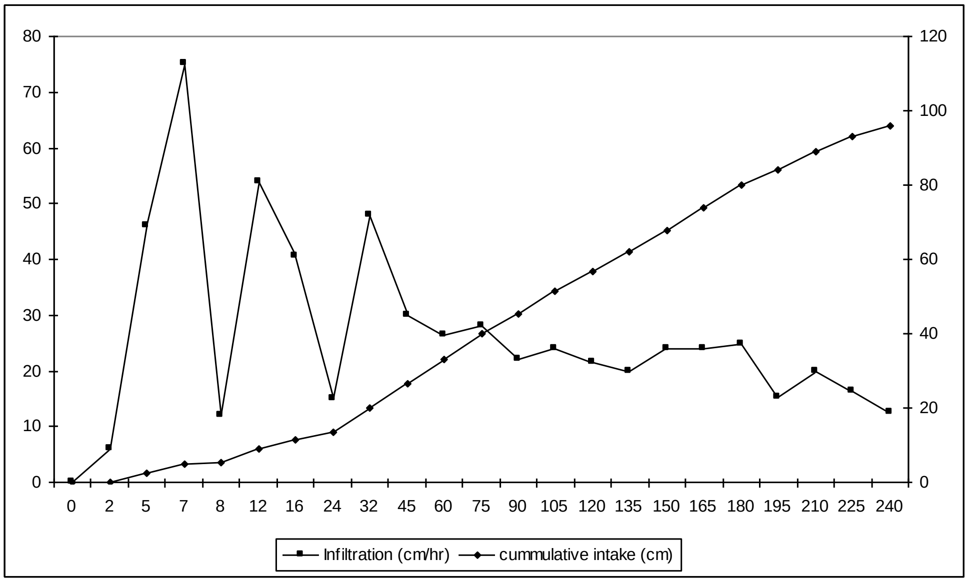
MAP FOR SAMPLE AREAS



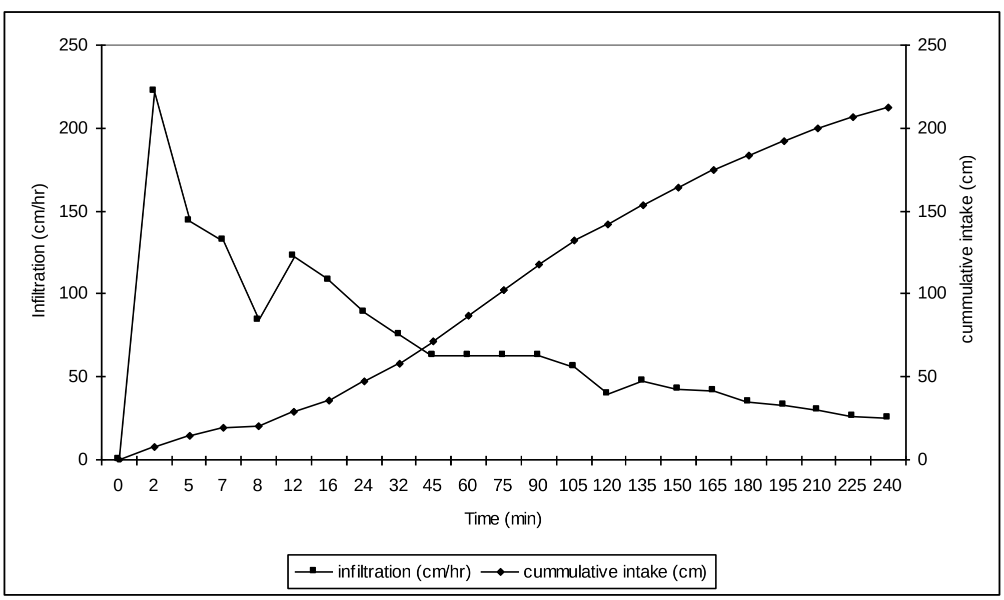
APPENDIX H:

INFLTRATION RATE MEASUREMENTS

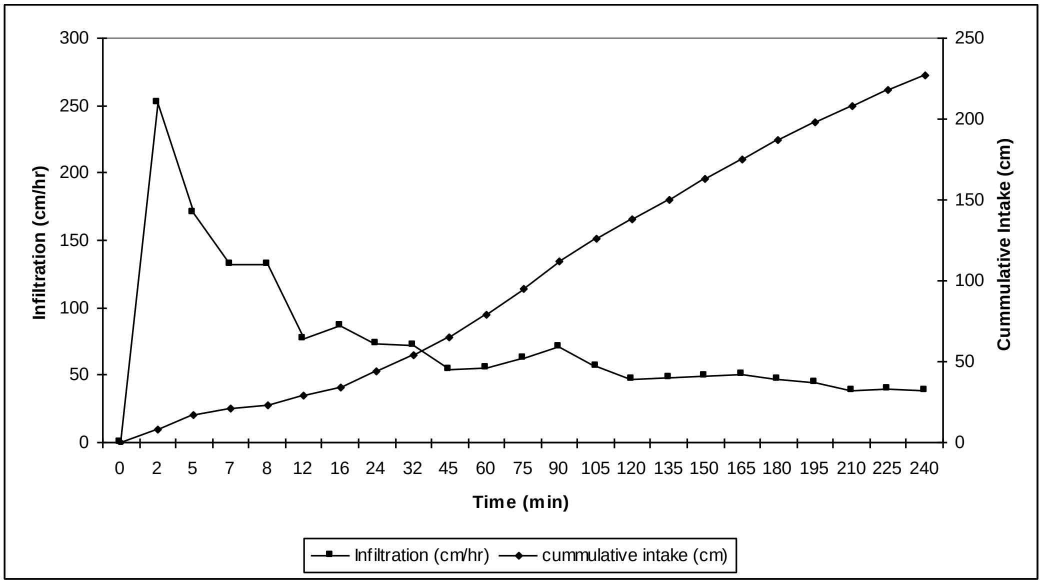
Infiltration for Gr1



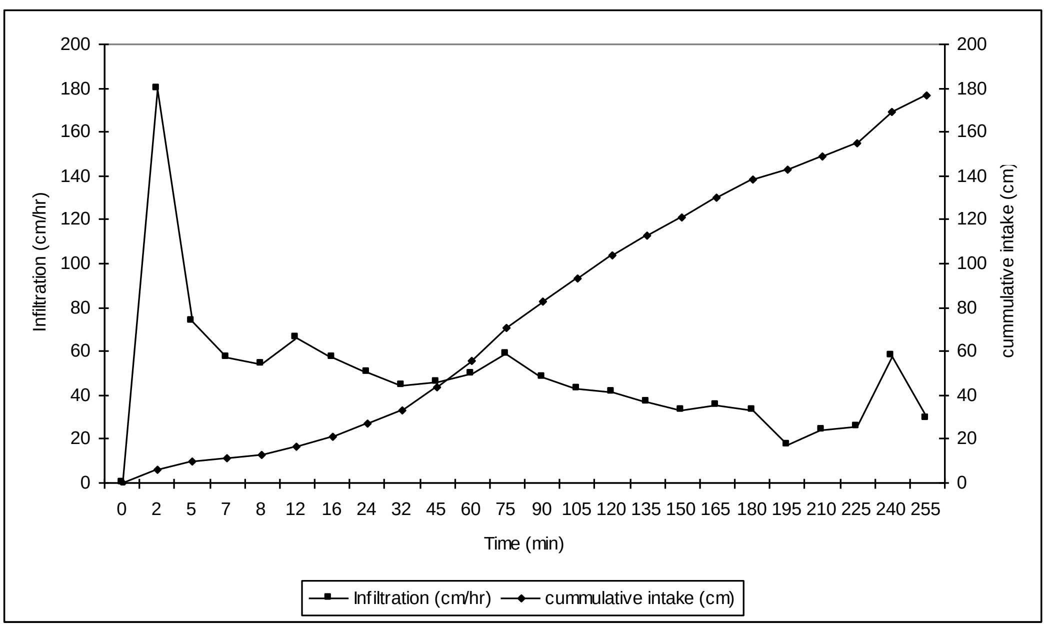
Infiltration for Gr2



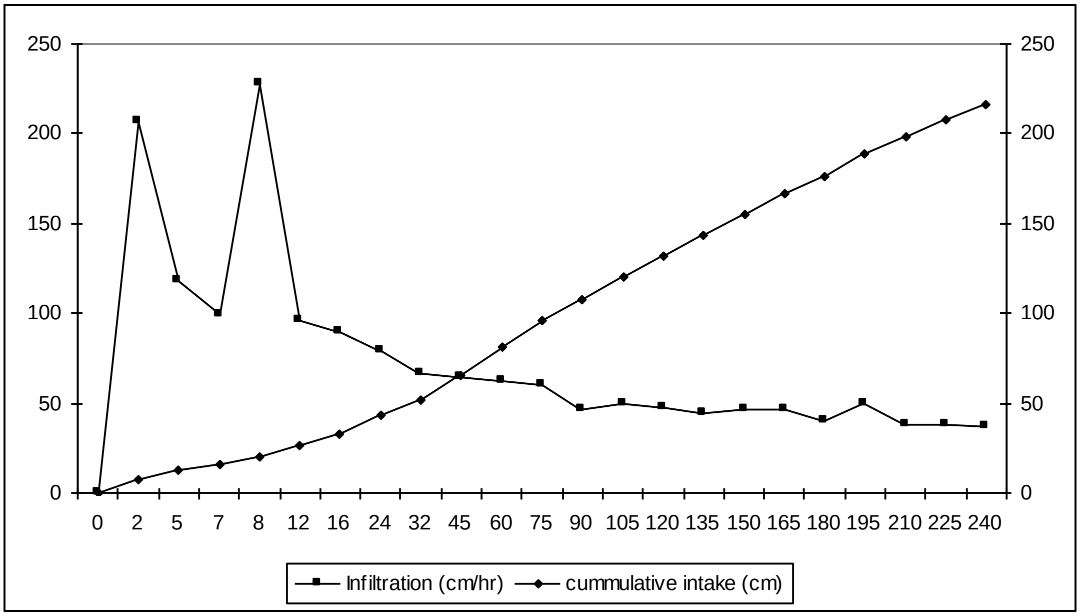
Infiltration for Gr3



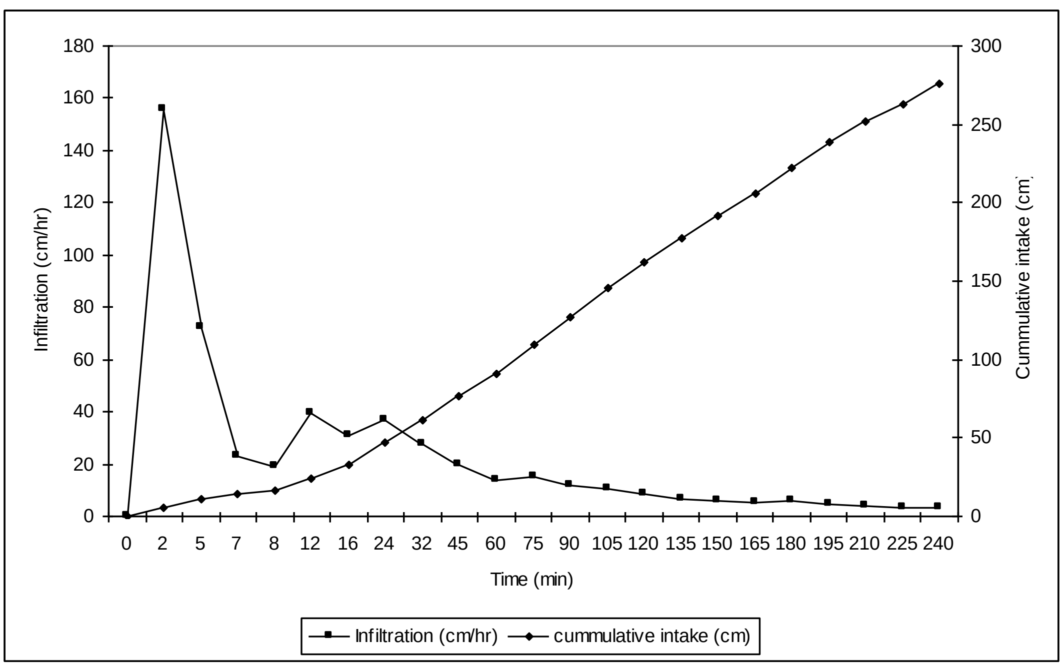
Infiltration for Gr7



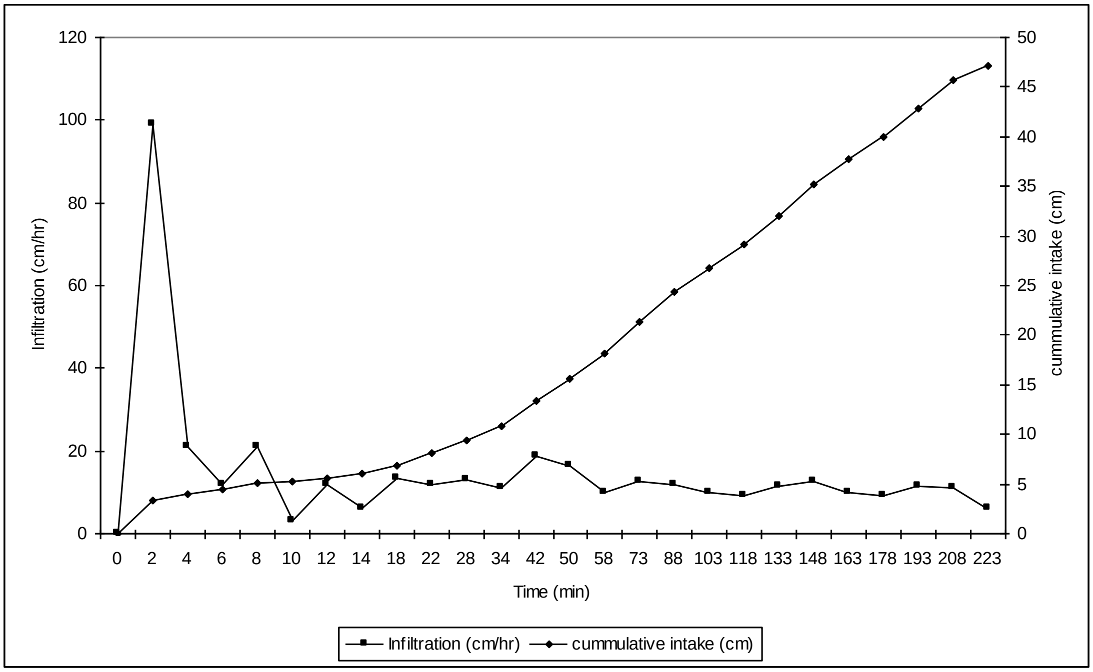
Infiltration for Gr8



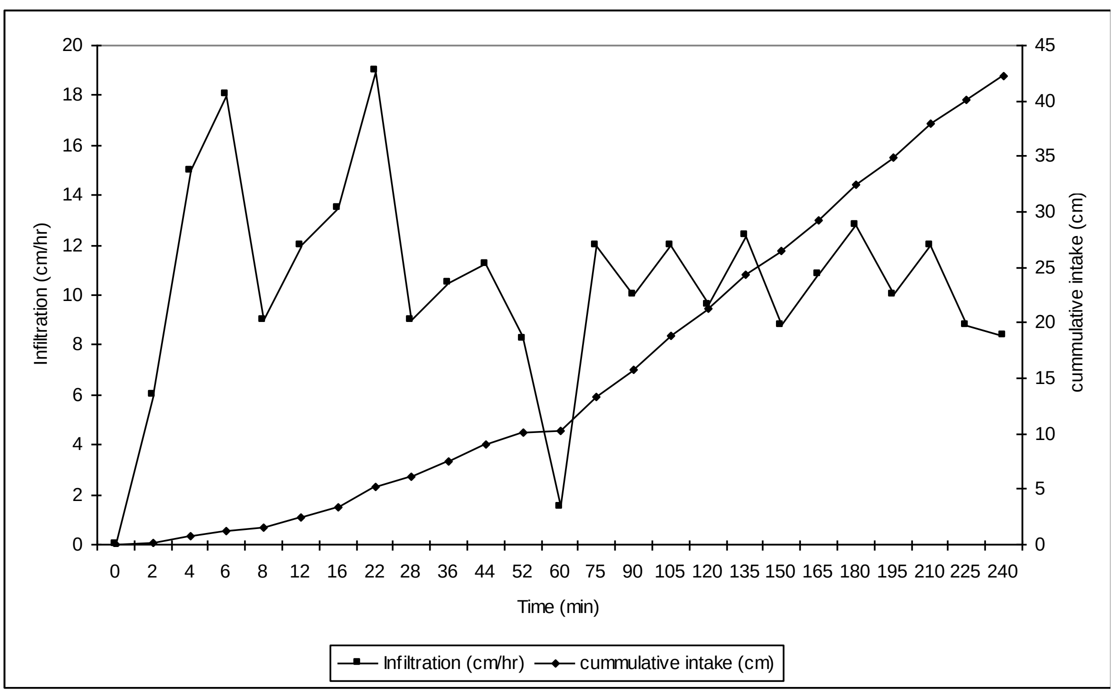
Infiltration for Gr 9



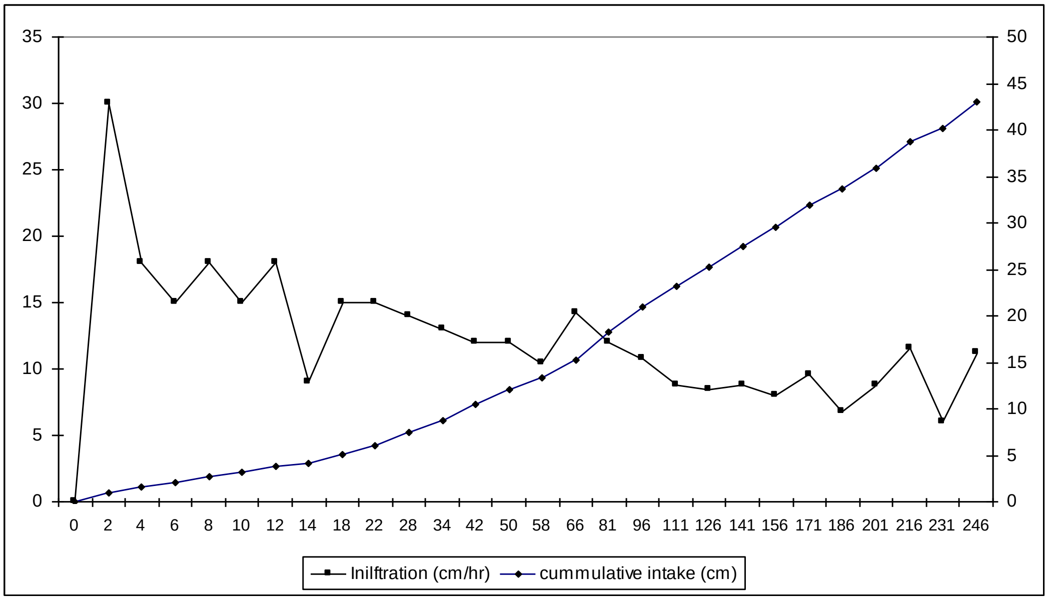
Infiltration for Gr10



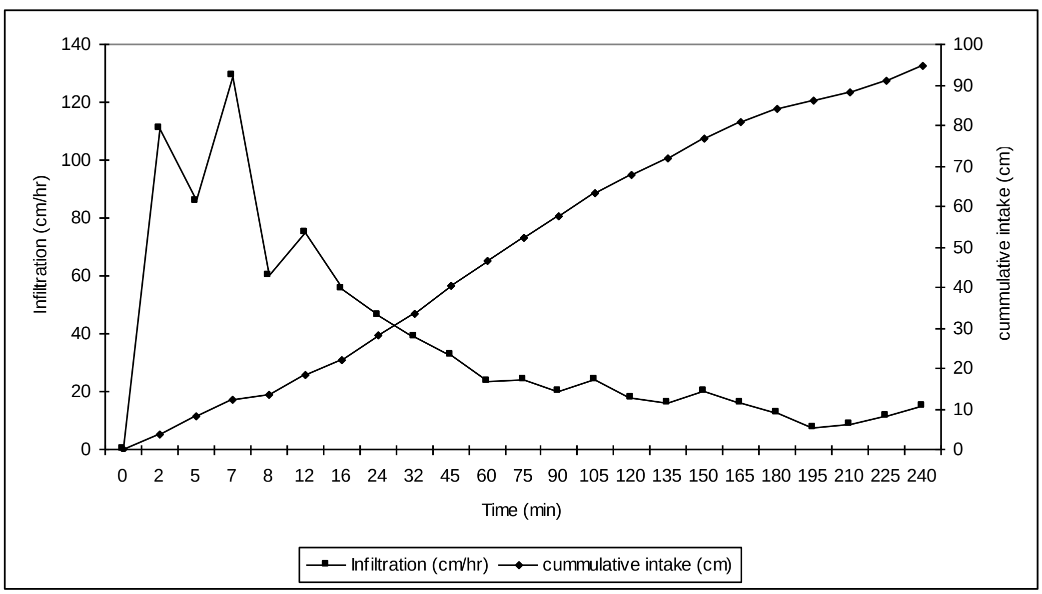
Infiltration for Gr 11



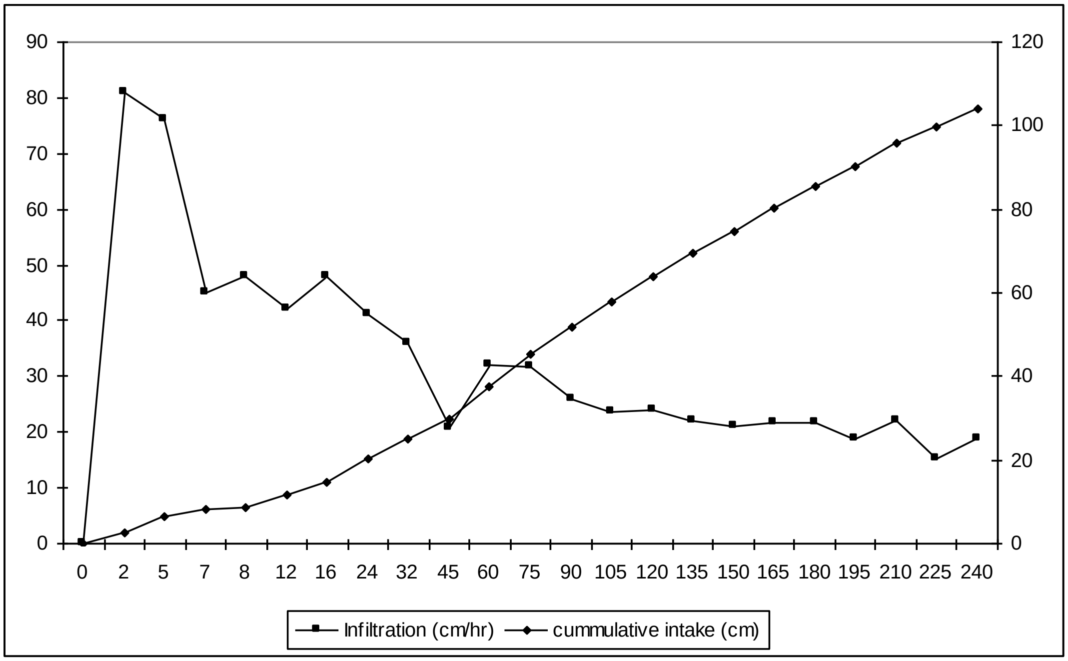
Infiltration for Gr 12



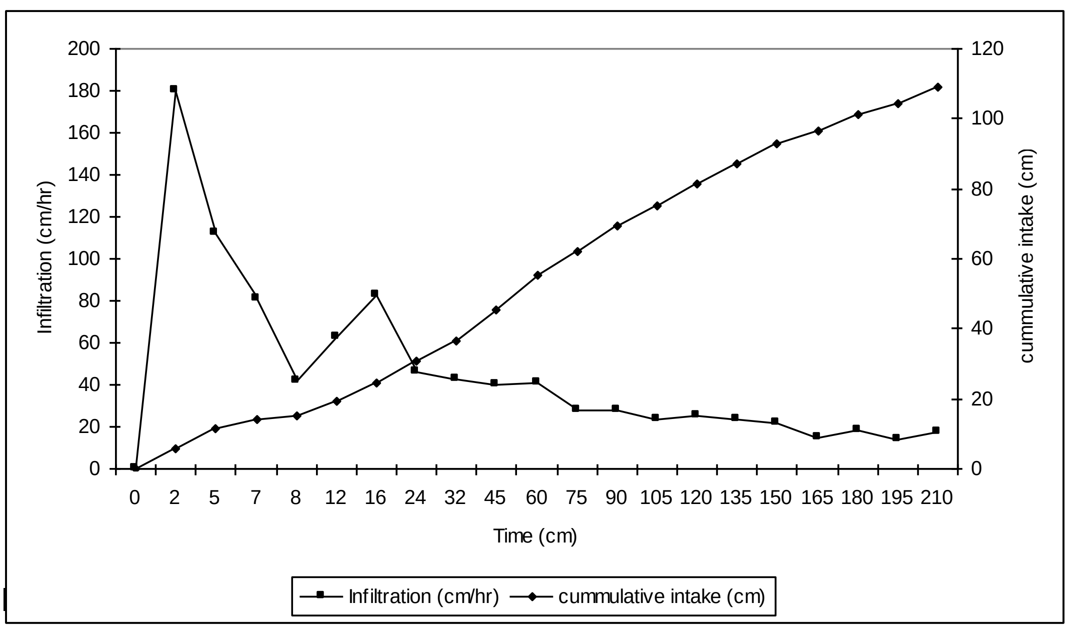
Infiltration for Gr 13



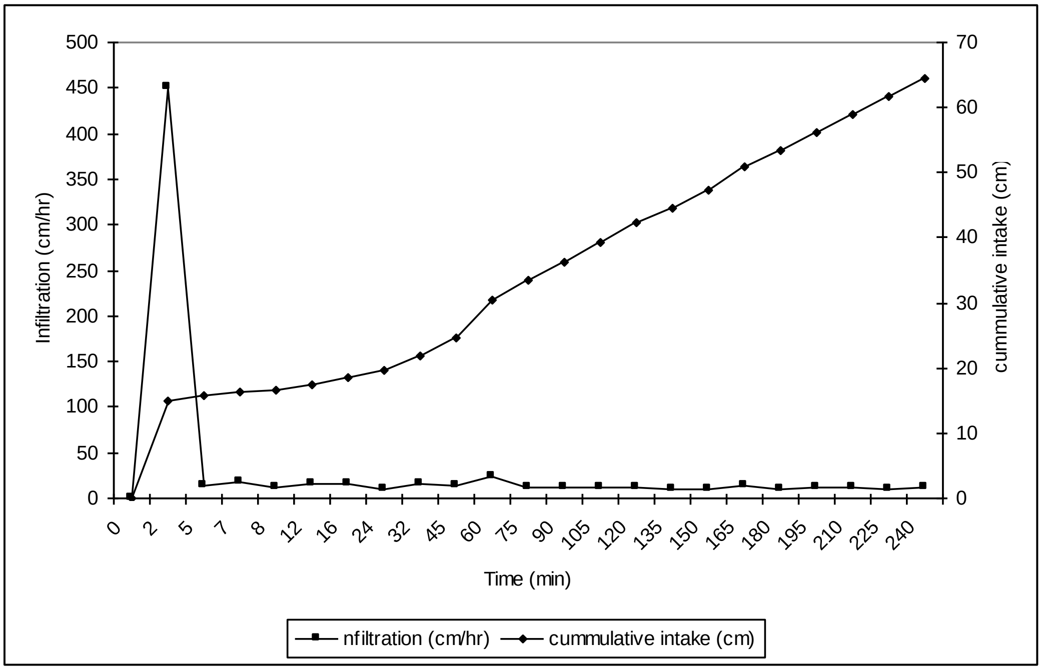
Infiltration for Gr 14



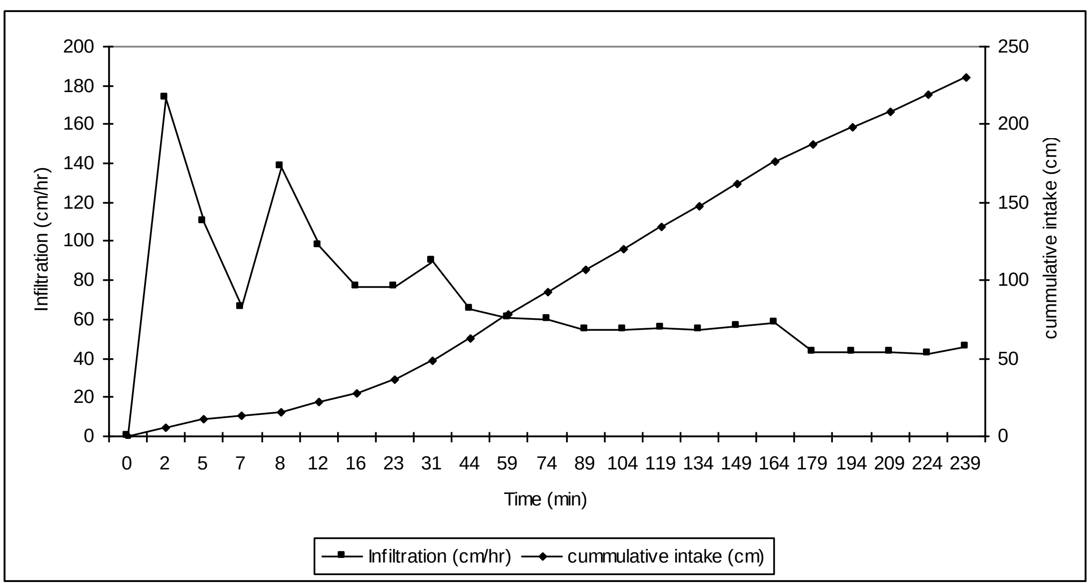
Infiltration for Gr 15



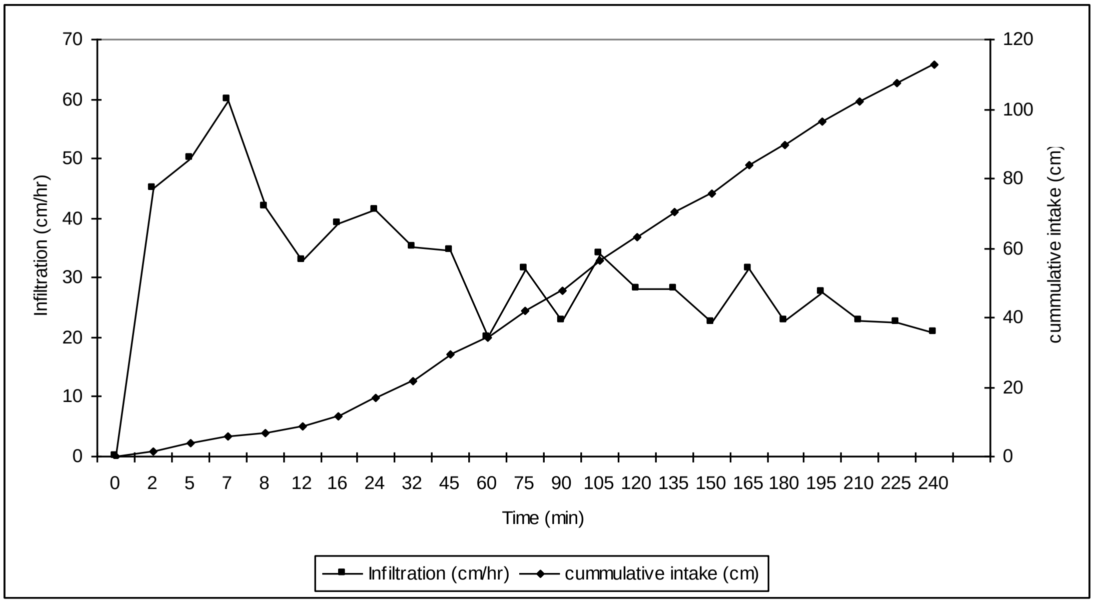
Infiltration for Gr 16



Infiltration for Gr 17



Infiltration Bfor Gr18



APPENDIX I

WEATHERING INDEX FOR THE SAMPLES

Sample	MnO	CaO	MgO	Na_2O	K_2O	Fe_2O_3	Al_2O_3	H_2O	Muira Index
Gr1	0.68	0.85	1.2	0.03	0.5	17.5	15.1	20.5	0.09
Gr2	0.55	0.29	0.6	0.02	0.35	15.1	19.4	29.8	0.04
Gr3	0.22	0.14	0.35	0.01	0.2	16.3	24.8	23.5	0.02
Gr7	0.56	0.18	1.4	0.02	0.66	14.9	15.4	23.6	0.07
Gr8	0.7	0.32	0.6	0.02	0.3	13.7	19.8	24.0	0.04
Gr9	0.23	0.32	0.29	0.02	0.29	14.8	22.3	25.3	0.02
Gr10	0.19	1.2	0.92	0.08	0.31	12.9	17.2	20.2	0.07
Gr11	0.17	0.24	1.04	0.09	0.56	7.8	18.1	31.5	0.04
Gr12	0.41	0.2	0.7	0.02	0.47	8.7	17.25	17.5	0.05
Gr13	1.0	0.64	2.6	0.04	1.0	13.9	15.2	27.3	0.12
Gr14	0.34	0.2	1.5	0.03	1.0	16.1	15.2	25.2	0.08
Gr15	0.5	0.3	0.73	0.02	0.6	14.8	17.5	24.6	0.05
Gr16	0.51	0.3	1.2	0.02	0.72	16.0	17.5	23.1	0.04
Gr17	0.4	0.1	0.3	0.02	0.21	11.4	20.7	24.8	0.02
Gr18	0.25	0.6	0.8	0.02	0.7	14.5	21.1	29.6	0.05
Basement Granite	0.03	0.96	0.25	3.36	4.98	0.3	13.95	0.39	0.67
Carbonatite	0.65	0.87	0.15	0.47	8.8	8.75	20.63	0.37	0.36
Carbonatite	0.06	1.7	0.48	0.83	9.8	11.63	18.23	0.4	0.43

APPENDIX J:

DAILY RAINFALL DATA COLLECTED FROM LOCAL RAINGAUGES BY FARMERS AT BUDUDA S.S FROM 2001 -2003.

Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2001	september	0	3.3	0	3.3	5.8	0	0	2.9	0	6.4		4	0	0	0	0	0	4.3	0	8	4.1	0	0	42	4	7.4	1.6	1.6	19.6	2.4	
	October	40.1	0	1.5	35.2	1.5	22	22.9	0	29.5	22.5	9.4	0.7	0	0	0	9.6	0	0	0	0	0	9.8	4.1	0	0	0	13.5	4.1	8.6	1.6	5.7
	November	4.9	18	1.6	13.1	7	34	0	27	43.4	9	1.6	0	0	1.6	2.5	14.7	0	0	1.6	4.9	9.4	2.9	0	0	0	0	0	0	0	0	
	December	0	2.5	2	52.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.2	0	0	0	0	0
2002	January	0	19.6	1.6	12.3	1.5	3.3	8.6	5.7	0	13.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	9	1.6	11.5	0	0	10.6	0	1.6	0	0	0	0	0	0	0	0	0	0			
	March	9.4	18.8	0	9	7.4	0	2.5	0	0	38.5	0	0	10.2	41.7	0	3.3	9	15	0	17.2	0	5.7	0	2	0	0	9	0	0	0	0
	April	0	0	0	0	0	8.2	0	0	0	0	3.3	2.5	12.3	3.3	36	0	8.2	4.7	1.6	5.1	20	19.6	0	0	29.4	4.3	0	0	18	19.6	
	May	0	7.4	0	0.8	3.3	0	63	0	32.7	0	0	0	5.7	0	9	0	0	10.2	39.3	31.9	8.2	17.6	0	0	9	0	9	9	0	0	7.4
	June	0	26.6	0	0	0	77	0	0	0	0	0	0	30	0	0	8.2	15.5	0	0	0	0	0	0	0	0	0	6.5	0	13.9	31.9	
	July	0	0	0	0	0	12	6.1	0	0	5.7	0	0	27	0	0	0	7.8	37.6	0	0	0	0	0	0	0	0	0	0	15.5	0	0
	August	0	13.1	4.9	0	0	24	0	0	7.8	0	0	0	0	0	0	0	7.4	0	0	0	30.3	2.5	7.4	0	0	0	0	15.5	0	7	8.6
	September	13.1	5.7	0	1.6	0	0	0	0	4.9	25.4	0	3.3	10.6	0	2.5	4.1	0	0	5.7	0	1.6	0	1.6	4.9	9.8	6.5	4.9	0	4.1	2.9	
	October	6.5	3.3	0	0	27	14	9.8	2.5	3.3	0	0	14	1.6	2	5.3	0	0	0	0	10.6	2.9	3.3	11.5	11	13.1	16.4	15.5	17.2	9.4	15.5	39.7
	November	0	0	40	4.1	4.5	5.7	6.8	0	2	2.9	3.4	0	25.4	0	1.6	7.4	10.6	0	3.3	0	0	0	6.5	1.6	0	0	0	0	0	0	
	December	0	0	0	0	0	0	0	0	11.5	1.6	4.1	2.9	0	0	0	0	6.8	0	49.9	1.6	19.7	7	6.5	14.3	0	0	0	4.3	13.9	4.5	0
2003	January	8.2	0	8.3	5.7	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21.3	3.3	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0		0	0	0	0	12.3	0	0	0	0	0	0	0	0	0	0	0	23.7	3.7	0			
	March	0	0	0	0	0	0	0	0	0	0	0	0	0	11.9	5.7	0	0	0	0	0	0	0	0	0	0	0	5.7	0	0	27	0
	April	0	1.6	2.9	2.9	0	0	0	0	0	0	0	0	3.3	2.9	36	10.6	8.2	0	20.5	6.1	12.3	9	0	58.9	9.8	12.3	31.9	6.5	0	0	
	May	0	10.6	0	18.8	19.6	0	7	33.1	0	4.1	0	4.1	0	12.3	0	0	0	0	0	0	0	0	15.1	0	10.6	14.8	6.5	0	19.6	1.6	20.5
	June	11.5	16.4	12	3.3	20.5	0	0	0	0	8.2	0	0	0	24.5	17.2	0	0	0	0	2.9	5.3	0	32.7	2.9	3.3	11.5	7.8	14.3	4.9	9.4	
	July	8.2	0.6	0	0	0	5.7	4.1	0	7	7.4	0	0	12.3	0	0	0	19.6	3.3	9.8	0	2.9	18.8	9	16.4	0	0	0	0	0	0	0
	August	0	0	0	0	27	8.6	11	0	2.5	0	0	0	33.6	0	2.9	0	6.5	0	1.2	3.7	0	6.1	16.6	0	3.4	0	0	3.3	3.3	3.3	22.1
	September	0	6.5	0	0	0	13	10.5	11.5	0	4.5	13.9	0	25.8	1.6	22.1	25.8	23.3	1.6	0	1.6	8.2	4.9	22.9	7.4	1.6	0	0	0	5.7	0	
	October	10.6	0	31	3.7	0	6.5	0	0	1.6	0	0	0	9.8	0	2	0	5.7	4.1	0	0	0	0	5.3	0	0	5.5	4	0	0	4.3	0