# NATURAL AND HUMAN FACTORS CAUSING LANDSLIDES AND THEIR SOCIO-ECONOMIC EFFECTS: A CASE STUDY OF KAIRO LOCATION OF MURANG'A COUNTY, KENYA

**BY**

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**A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF MASTERS OF ARTS IN GEOMORPHOLOGY UNIVERSITY OF NAIROBI**

**2014**

## DECLARATION

I declare that this project is my original work and has not been presented for an award of a degree in any other University.

Signature: ______________ Date ______________

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This research project report has been submitted for examination with my approval as the University Supervisor.

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## DEDICATION

This project is dedicated to my Family members.

## ACKNOWLEDGMENTS

It has been an exciting and instructive study period in the University of Nairobi and I feel privileged to have had the opportunity to carry out this study as demonstration of knowledge gained during the period studying for my master's degree. With these acknowledgments, it would be impossible to remember those who in one way or another, directly or indirectly, have played a role in the realization of this research project. Let me, therefore, thank them all equally.

First, I am indebted to the all-powerful God for all the blessings he showered on me and for being with me throughout the study. I am deeply obliged to my supervisor, Prof. George O. Krhoda for his exemplary guidance and support without whose help, this project would not have been a success. Finally, yet importantly, I take this opportunity to express my deep gratitude to the lasting memory of my loving family, and friends who are a constant source of motivation and for their never ending support and encouragement during this project.

**ABSTRACT**

Agriculture remains the mainstay of the economy of Muranga County. The soils are fertile and land productivity is high. Further economic growth and poverty reduction will be dependent on how land can sustainably support economic activities in the county. Landslides are very common disaster in Murang'a which impacts negatively on the socio-economic development of the affected inhabitants in various ways. Thus the general objective of this study was to examine causes and effects of landslides in Kairo location of Murang'a County, Kenya. The specific objectives of the study are: to determine the main factors responsible for causing landslides; extent of landslide threat on social economic and physical environment; and examine adaptation responses employed by farmers in landslide prone areas. This study has examined the man-made and natural factors causing landslides in Kairo Location targeting 100 households. A total sample of 30 farmers representing 30 households was selected. Further, the Divisional Agricultural Officer, Water Resources Management Authority and Environmental Officers were selected using purposive sampling. Both the interview guide and a questionnaire were employed as data collection instruments. Data was presented using frequency distributed tables, bar graphs, photographs and maps from various sources. Also content analysis was analyzed using qualitative techniques. From the study findings it was established that the main factors responsible for causing landslides in Kairo location of Murang'a County Kenya were heavy rainfall, human activities and steep gradient of slope. The findings revealed that, first, human activities that caused landslides include deforestation in general and removal of vegetation on slopes, specifically excavation of the toe slope, loading of the slope, defective maintenance of drainage systems, water leakages from water supply and terracing on the slopes. Second, heavy rainfall, geology, soil thickness, deep weathering, fluvial erosion of slope toe are the geomorphological factors that causes landslide in the area. Thirdly is that the socio-economic losses due to slope failures are great, ranging from destruction of infrastructure, displacement of residence, loss of property and siltation of rivers. Fourthly, the study established that farmers have adopted some responses in regard to landslides such as afforestation programmers, and adhering to warnings given by local government to re-locate to a safer ground. From the findings, the study recommends that there should be sustainable communication and education to farmers on effective ways to mitigate landslides, implementation of policies on settlements, and penalties curbing deforestation. Future researchers should investigate the influence government policies have on human activities in landslides prone areas.

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# CHAPTER ONE: INTRODUCTION

## 1.1Background of the study

Landslides are a complex natural phenomenon that constitutes a serious natural hazard in many countries (Brabb and Harrod, 1989). Landslides belong to a group of processes referred to as mass wasting. The term mass wasting includes a wide variety of slope movements such as falls, slides, solifluction, flows and creep. Types of landslides include deep-seated slides, rock slides, debris slides etc. (Varnes, 1978: Pierson and Costa, 1987; Hutchison, 1988: Cruden and Varnes, 1996; Hunger *et al*., 2001). Landslides are commonly associated with a trigger such an intense rainfall, a rapid snowmelt, or earth quake, Landslide areas geographically span more than eight orders of magnitude and landslide volumes more than twelve orders. Slope failures- ranging from single to tens of thousands occurring within seconds after earthquake trigger, hours to days after a snowmelt trigger, and days to weeks after an intense rainfall trigger.

Landslides are an important part of the natural landscape system in dynamic mountain environment. These landslides, or slope failures as they may be referred from time to time, serve as efficient mechanisms for detaching and mobilizing slope-forming materials into the fluvial system for eventual removal by channel flow processes. The release of sediments into the fluvial system may be highly episodic, with large rainfall or seismic events causing the release from the slope of sediment, which is then removed by subsequent large flow events of the associated river system, possibly in the form of 'sediment slugs'.

Most landslides require a triggering event to initiate movement. In many cases this is a high intensity and/or long duration rainfall event, and there are numerous well-documented examples of extensive landslide during, for example, monsoon rainfalls or the passage of tropical cyclones (Central Weather Bureau, 2004). Rainfall-triggered landslides are part of a natural process of hill slope erosion that can result in catastrophic loss of life and extensive property damage in mountainous, densely populated areas. In the United States, an average of 25 to 59 lives is lost each year, and annual property damage is estimated at $3.6 billion, in 2001 dollars (Gori *et al*., 2003). In Kenya, landslides occur mainly during the long or short rainy seasons at which loss of lives and damage to infrastructure has been noted (Ngechu and Mathu, 1999) Worldwide damage from natural disasters overall was estimated at $479 billion for the decade of the 1990s (Annan, 1999; O'Hare and Rivas, 2005). According to Haque and Burton (2005), the average annual damage costs had risen to $70 billion by 2000. McBean and Henstra (2003) estimate that weather-associated hazards contribute 80 percent of all the natural disasters. As global population expansion on or near steep hill slopes continue, the human and economic costs associated with landslide disasters will increase. The other main trigger for land sliding is the occurrence of a large seismic event (Keefer, 1984). The seismic activities associated with earthquakes may trigger extensive land sliding, sometimes at distances of more than 100 km from the epicenter.

Landslide hazard mitigation strategies generally involve hazard assessment mapping, warning systems, control structures, and regional landslide planning and policy development. Landslide hazard assessment mapping includes landslide inventory and susceptibility maps. Warning systems are usually based on networks of precipitation gauges linked by radio-or satellite telemetry to civil defense communication centers, and a broadcast communications system or network of warning sirens. Control structures are designed to stop, deflect of capture landslide debris before it reaches developed areas or near hill slopes. Regional planning and policy development uses landslide susceptibility and risk maps to guide planners in the determination of where infrastructure can be safely located. Planners and policy makers also depend on hill slope stability modeling approaches that can be used to estimate when and where hill slopes are likely to fail (Carrasco *et al*, 2003); McBean and Henstra, 2003).

Sustainable hazard mitigation links management of natural resources with local economic and social resiliency (Mileti, 1999; NRC, 2006). Education of the general public is key to social resiliency when a disaster strikes. The objective, to increase fundamental understanding of landslides and other hazards may be best achieved by targeting school-age children (Ronan and Johnston, 2003). All of these strategies require multi-disciplinary scientific and engineering approaches, and the political will take action at the local community to national scale. Unfortunately, landslide research efforts around the world are small relative to the economic costs of landslide damage, so the scientific and mitigation challenges are great (NRC, 2006; Keefer and Lars en 2007). The main goal of this research is to determine the causes and effects of landslides in Kairo Location of Murang'a County, Kenya.

Kenya has witnessed many rainfall triggered landslides (Karanja and Mutua, 2000. During the 1997-1998 El Nino events, most parts of the country received 2 to 12 times the monthly long-term mean rainfall amount that resulted in floods and landslides in various parts of the country (Ngecu and Mathu, 1999). Consequent impacts on water resources, agriculture, transport, health, and socioeconomic conditions were great. The estimated loss incurred by the agricultural sector alone was estimated to be about USD 236 million (Karanja and Mutua, 2000), one-tenth of the gross domestic Product. Landslides were triggered largely by long term human activities such as logging on slopes and vegetation gradation (Ngecu and Mathu 1999).

## 1.2 Statement of the research problem

Landslides impact negatively on the socio-economic development of the affected inhabitants in various ways. Farmers face challenges regarding sustainable food production in the context of uncertain conditions and disasters. Landslides among other disasters such as droughts, pests, and diseases have a tendency to reduce crop and animal productivity. In landslide-prone areas such as Kairo Location of Murang'a County, it is important for farmers to be equipped with knowledge about the natural and human factors causing landslides, the socioeconomic impacts of landslides, and mitigating responses. Local knowledge can reveal insights in resource and ecosystem management (Berkes and Folke 1998, Scott 1998). Such insights can be used to develop policies and community awareness programme to mitigate landslide hazards.

Disasters such as landslides have a tendency to stifle economic growth by diverting resources from productive sectors to relief rehabilitation. Landslides destroy homes, homesteads and social and physical infrastructures in the affected areas. As a result of landslide occurrences the society's assets are destroyed, their ways of life are affected and poverty becomes sustained. The local communities are very vulnerable to landslides denoting that they do not have adequate means or ability to protect themselves against the adverse impacts of landslides. To deal with the impact of landslides is to alleviate poverty and put the county on a sustainable development path. The present study will highlight the consequences of landslides and suggest policy direction in resolving the devastation caused.

Climate change is one of the greatest threats to humanity and has far reaching impacts on sustainable development and poverty reduction. The consequences of climate change include increased frequency and magnitude of extreme events (Government of Kenya, 2012) including floods, droughts and landslides. It is now known that not only rainfall intensity will increase in some parts of the country, but also flash floods will increase, partly as a result of climate change but also due to environmental degradation such as deforestation, soil degradation and land use changes. Resulting from these global changes, frequency and geographical spread of landslides will increase. Coupled with increased human activity in the County, the tendency is for the landslides to affect areas that presently are generally less vulnerable. Additionally, landslides monitoring and warning mechanisms will need to be put in place.

This study examined the man-made and natural factors responsible for causing landslides in Kairo Location, determine the socioeconomic impacts of landslides, and asses the adaptation strategies employed by farmers to mitigate the effects of landslides. The present study seeks to determine the causes and effects of landslide in Kairo Location of Murang'a County.

### 1.3 Research Questions

The study will be guided by the following research questions:

1. What are the main factors responsible for causing landslides in Kairo Location of Murang'a County Kenya?

2. What are the socioeconomic effects of landslides in Kairo Location of Murang'a County?
3. Which are the adaptation responses employed by farmers in landslide prone areas?

## 1.4 Objectives of the study

The general objective of the study is to determine the causes and effects of landslides in Kairo Location of Murang'a County, Kenya.

The specific objectives of the study are to:

1. To determine the main factors responsible for causing landslides in Kairo Location of Murang'a County Kenya.
2. To establish the effects of landslide on social-economic and physical environment.
3. Examine adaptation responses employed by farmers in landslide prone areas.

## 1.5 Hypothesis

**HI:** There is a significant relationship between rainfall, steep gradient, and landslide occurrence in Kairo location

**Ho:** There is no a significant relationship between rainfall, steep gradient, and landslide occurrence in Kairo location

## 1.6 Significance and Justification of the study

Landslides are very common disasters in Murang'a and other mountainous areas in Kenya. The devastation and loss of lives have been well documented but not investigated and resources inadequately allocated to reduce the risk. The agricultural sector in Kenya is under intense pressure to produce more food to feed the rapidly growing human population, produce adequate raw materials for the agro-industries and export to earn foreign exchange. This, coupled with the effects of human settlement, has led to land degradation, making some regions more vulnerable to landslides. No further land should be allowed to be wasted through landslide disasters.

Agriculture remains the mainstay of the economy of Murang'a County. The soils are fertile and land productivity is high. Further economic growth and poverty reduction will be dependent on how land can sustainably support economic activities in the County.

In Kairo Location of Murang'a County, most of the farmers depend on rain-fed mixed farming that is dominated by traditional technologies. The area is prone to rainfall triggered landslides, which have led to loss of life and damage to property. The study will benefit farmers and policy makers by suggesting measures that could be taken to address the problem of landslides in the country. The study findings will also contribute to the existing body of research on landslides, which is to benefit to future researchers.

**1.7 Limitations of the study.**

Agro ecosystems are complex adaptive systems in which humans are in an integral part (Roling and Wagemakers 1998, Levin 1999). Non- linear behavior and thresholds are inherent features of any geomorphological system (Levin 1999). Dynamics of this kind limit certainty and the ability to predict how a complex adaptive system will respond to change (Gunderson 1999). The research about landslide causes and effects require expensive experimental studies which will consume a lot of time and finances. Inadequate finances may inhibit data collection.

The research will not be in a position to control the attitudes of respondent during the study out of fear may choose to give wrong responses that will results in the study having inaccurate findings. However the respondents will be assured of privacy and confidentiality so as to increase accuracy of the findings.

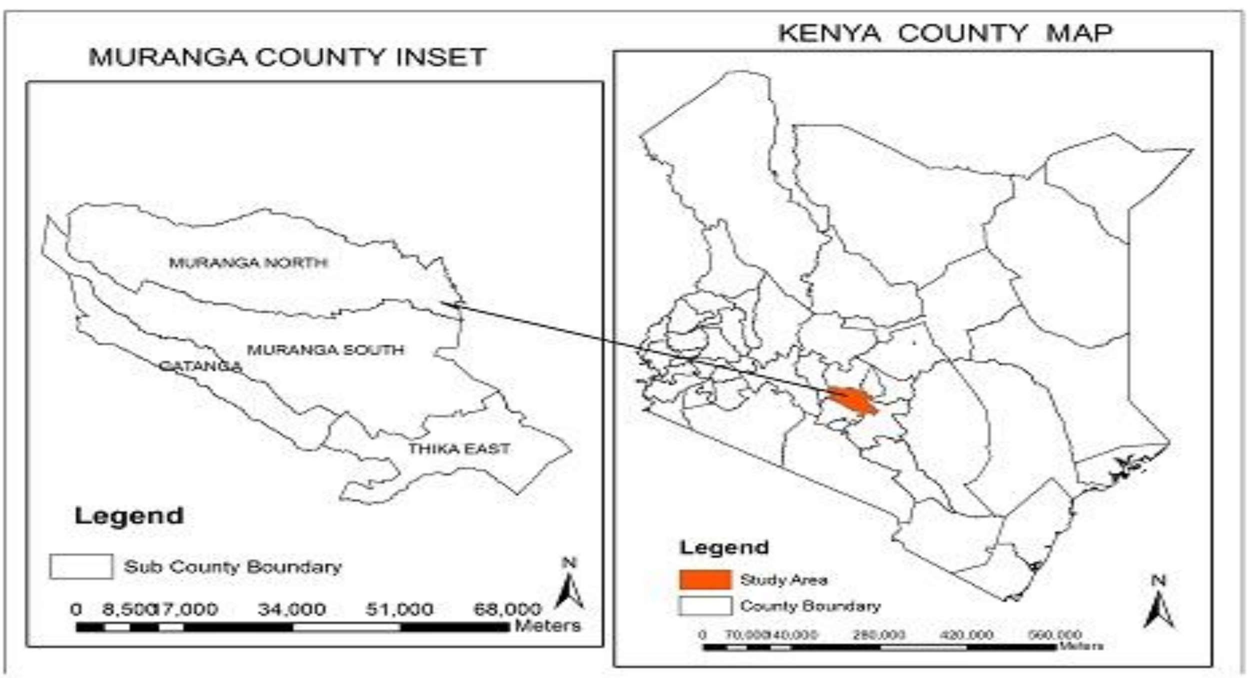
Weather conditions cannot be predicted and incase of heavy rainfall during the field study this may delay data collection. Lack of Aerial photographs as those available are 1: 50,000 taken year 2000, therefore not up-to-date.

## CHAPTER TWO: STUDY AREA

### 2.1 Geographical Location and Size

This study is based on the Murang'a County of Central region, the latter covers an area of about 2,150 $km^{2.}$ Murang'a County lies between latitude $0^0$, 34' South and longitude $36^0$ and 45' and $37^0$ 15' East. It borders Nyeri County to the North, Nyandarua to the West, Maragua to the South, Kirinyaga, Embu and Machakos counties to the East. The county's a total area is 930 $km^2$ and has four administrative sub-counties, namely, Kiharu, Kahuro, Kangema and Mathioya. There are 17 locations and 70 sub-locations. Figure 1 shows the map of Murang'a district.

**Figure 1: Kenya county map, Murang'a county inset**




Source: Researcher, 2014

The areas selected for the present detailed study in Kairo location were Irima. Nyarugumu, Ndunduini and Kamunjuini villages.

### 2.2 Physiography

The land rises gradually from an altitude of 914m in the East to 3,353m above mean sea level along the slopes of the Aberdares. The average land gradient

Slope can then be calculated using the slope formula:

$$\frac{\text{Vertical Distance}}{\text{Horizontal Distance}} \times 100 = \%\ \text{Slope}$$

Another way to write the slope formula is:

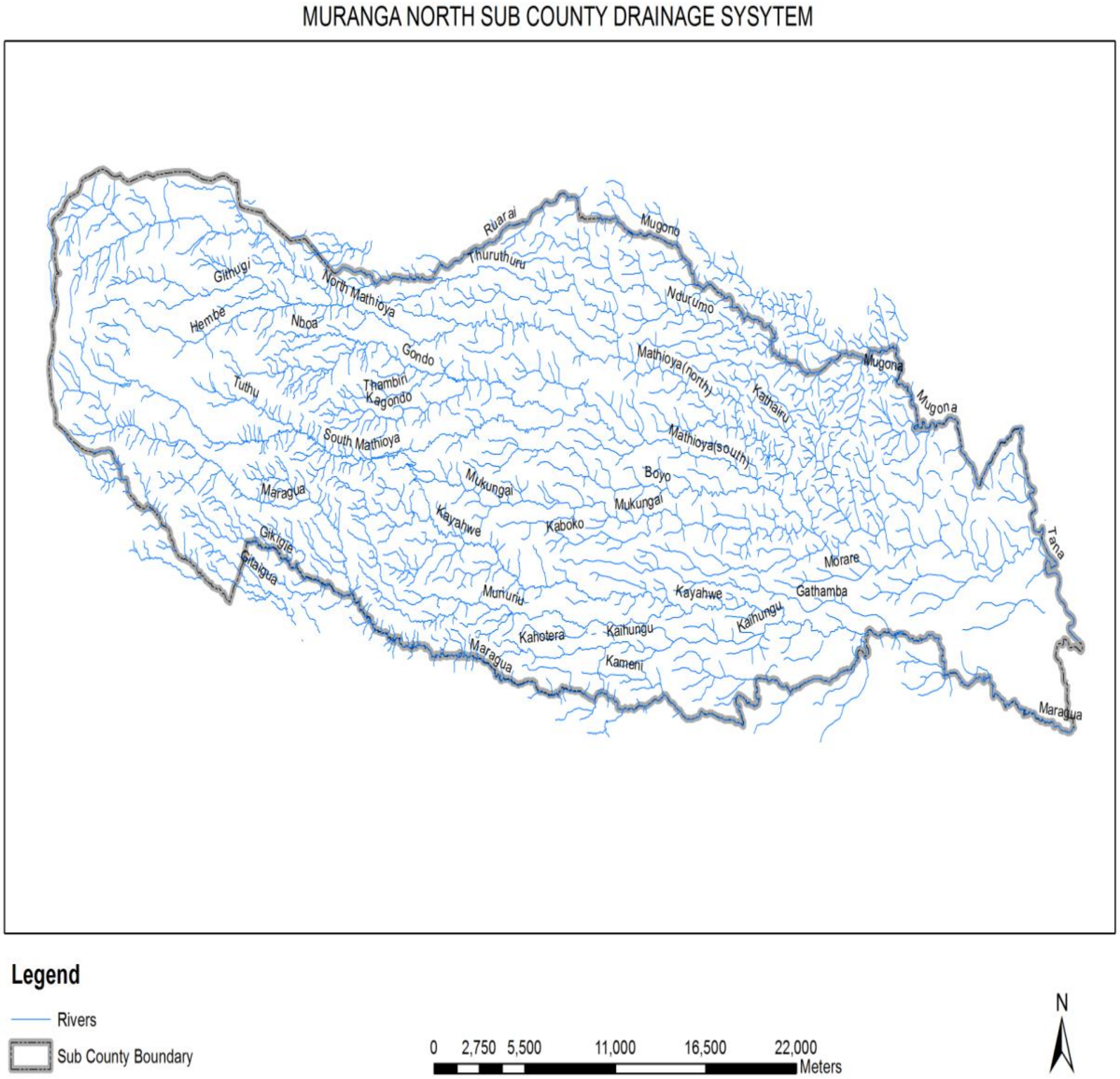
$$\frac{\text{Rise}}{\text{Run}} \times 100 = \%\ \text{Slope} = \frac{914 \times 100}{3,353} = 27.21\% \text{ or } 12^0$$

The topography of the highest areas to the West are deeply dissected and well drained by several rivers, which include Mathioya North, Mathioya South and Maragwa flowing eastwards to join the Tana River. More than 95% of the land is generally mountains landscape.

## 2.3 Drainage

Several rivers drain the Murang'a County among which is the Sagana and Mathioya which all drain in the Tana basin. Thika River which drains its water to Ndakaini dam and Chania to Mwagu Outfall are other main rivers.  Chania forms the boundary between Murang'a and Kiambu districts. The drainage system in the County and main catchments (Aberdare forests) is given in Figure 2.

**Figure 2: Murang'a North  sub County Drainage systems**




**Source: Water Resources Management Authority, 2006**

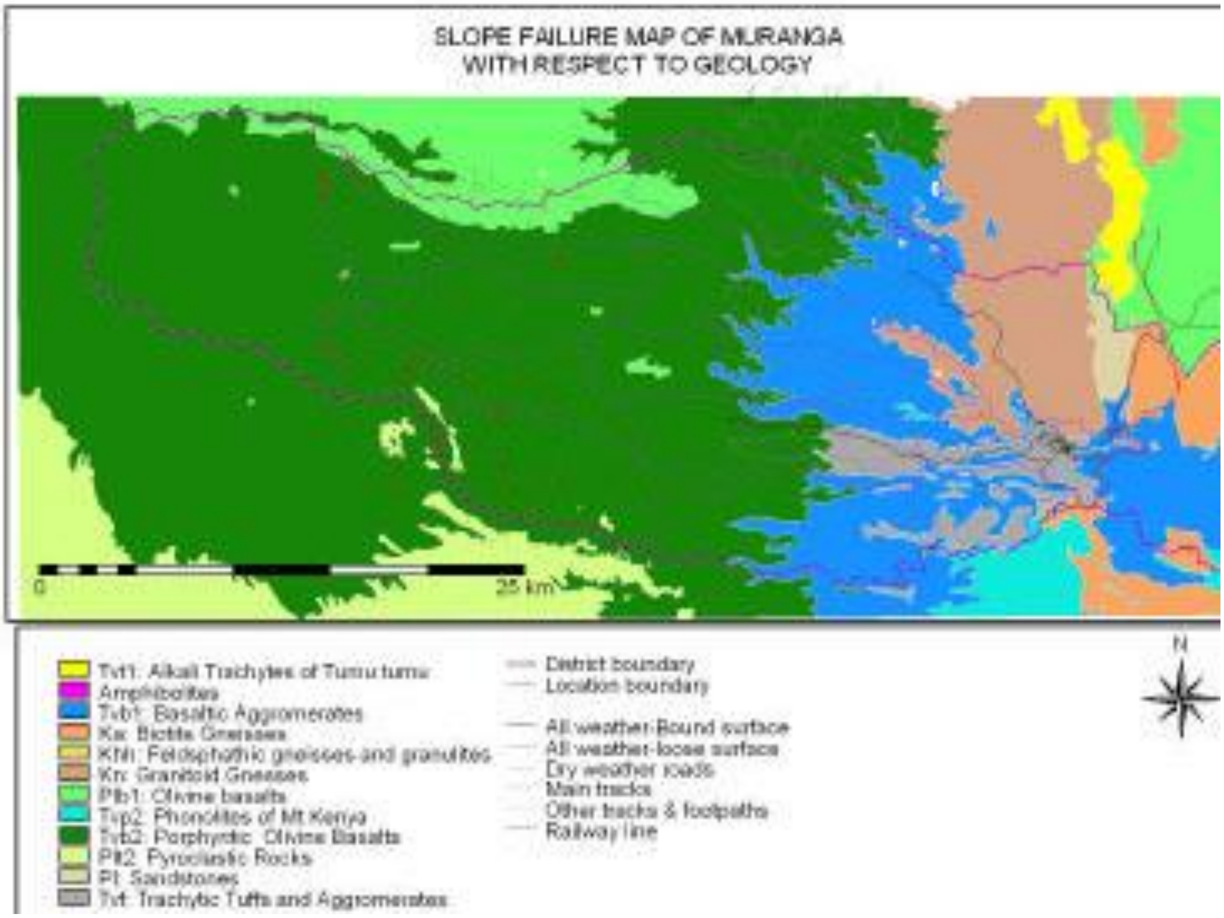
## 2.4 Climate

The climatic conditions of the study area vary from the equatorial climate in the western mountainous areas, sub-tropical type in the middle zone to the essentially dry eastern part. The county has two rainy seasons. The long rains start in March to May while the short rains start in October to November. The maximum average annual rainfall of between 1400 mm and 1600mm occur in high elevations while the low rainfall areas receiving less than 900 mm per annum . Rainfall in high and medium potential areas is reliable and well distributed throughout the year and is adequate for cultivation. However, on low potential areas rainfall is unevenly distributed and therefore unsuitable for cash crop. Temperatures vary with altitude. In the eastern lower areas the maximum annual temperatures range between $26^0$ C and $30^0$ C while minimum annual temperatures range between $14^0$ C and $18^0$ C. In the western area, which is mostly high altitudes, the minimum temperatures can be as low as $6^0$ C. Temperatures are moderate in the medium potential areas.

### 2.5 Geology

Rock types are an important factor in the triggering of landslides because in the landslide-prone areas such rocks are associated with deep weathering, which leads into a reduction in their strength. The most predominant geological formation is that of volcanic rocks. The rocks were formed during Pleistocene and Miocene times. The rocks include basalt and agglomerates. Basalt rocks are formed by the cooling and solidification of basic lava on the surface of the earth (geological map of Kijabe area).

**Figure 3: Geology of Murang'a**

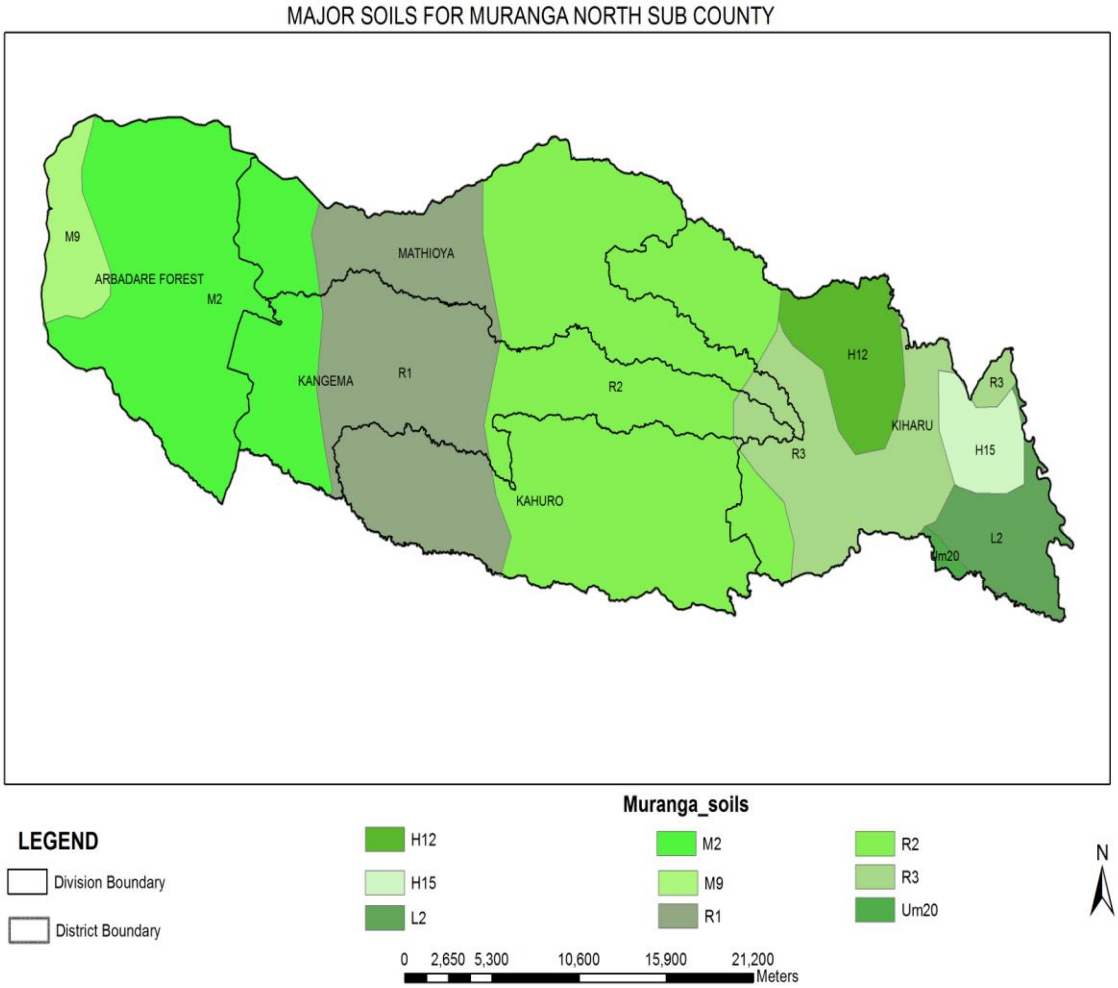



Source: Researcher, 2014

## 2.6 Soils

The predominant soils in Murang'a County are the deep and well-drained red/brown soils. These soils are loose and combined with the hilly terrain are easily eroded and sometimes are responsible for the landslides which are common in the County. Soil erosion is one major environmental problem in the district. Most of the land in the district is hilly with sparse vegetation. Rill erosion is very common in cultivated land while gully erosion is found in unprotected drainage channels, footpaths and culvert outlets. Landslides occur mainly on steep slopes where runoff is not well drained away.

**Figure 4: Major Soils of Murang'a County**




**Source: Kenya Soil Survey, Nairobi,** Muranga.

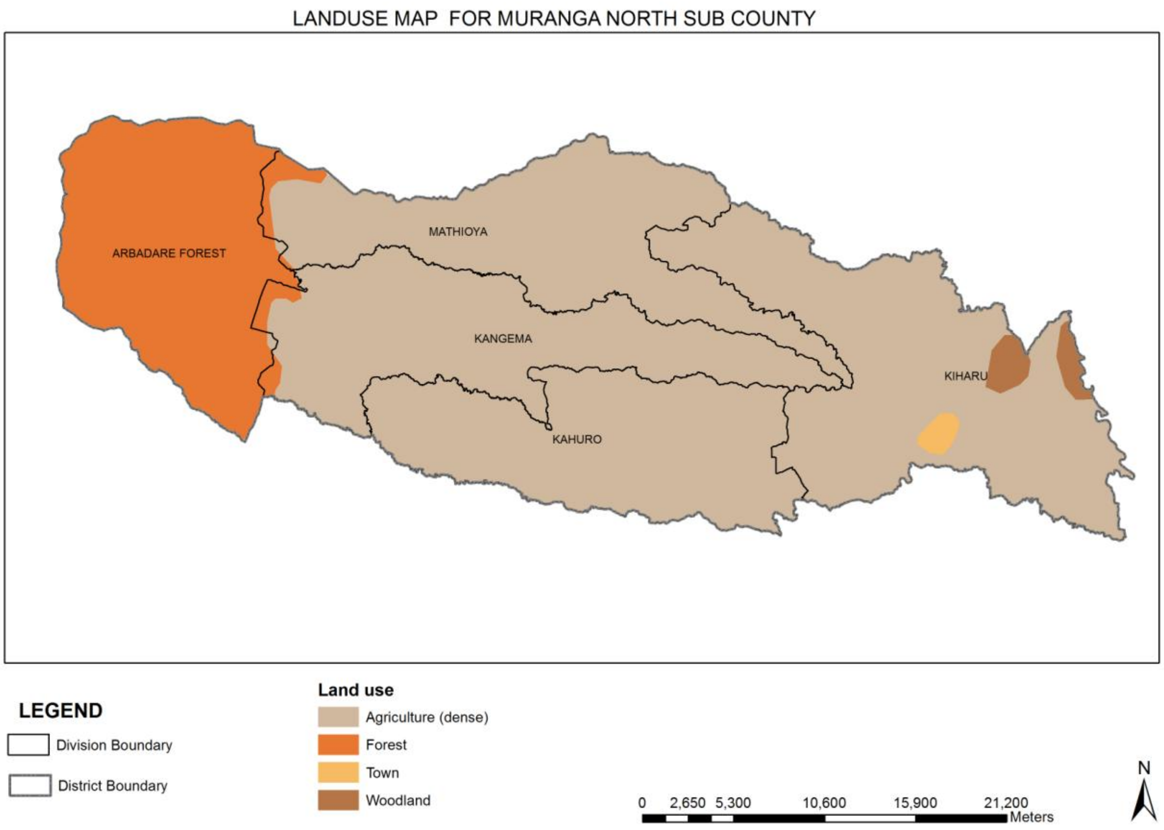
The soils are of variable fertility but their location is usually too cold, so much that there is little activity, (Sombroek et al 1982). At middle altitude top soils are in humid area of moderate to high fertility. There are often leached, acidic and shallow. Hill soils occur in the north and south-east parts of Murang'a and are of variable moderate to high fertility. On the eastern and south, the soils are of low fertility due to their non-volcanic origin. Soils on plateaus and low plains vary in fertility from moderate to very fertile.

## 2.7 Land use

Murang'a is considered as a high potential county with generally mixed Cropping. The county has a wide variety of land use because of its wide range of agro ecological zones that range from the highlands to lowland. The forests occupy the highest grounds while cash crops like tea, coffee and macadamia are in the higher zone. Horticultural crops and subsistence crops like maize and beans are found in the mid and lower zones of the County Agroecological zone (Farm management handbook, 2004).

The challenges in land use in the upper zones are continued forest excisions, illegal logging, encroachment and illegal cultivation, livestock grazing, landslides and quarries many of which have accelerated soil erosion.

**Figure 5: Land use map**




**Source:** Nation Media Group, Courtesy of Jennifer Muiruri, 23-08-2012

The district has a wide land use because of its wide Agro Ecological Zone range; from TA on the highlands to LM4 on the low lands. The forests occupy the highest grounds while cash crops like tea, coffee and macadamia follow the forests in that order.

Horticultural crops and Subsistence crops like maize and beans are found in the mid and lower zones of the district.

.The main crops grown in Murang'a can be categorized as; cash crops, food crops and horticultural crops. Cash crops are mainly the industrial crops like tea, coffee and macadamia. Food crops are mainly grown for subsistence while horticultural crops are largely for export market. Coffee production has been on the downward trend over the years due to poor prices at the international market. This has reduced tremendously the amount of fertilizers and agricultural chemicals being used by the farmers. World trend over the years due to poor prices at the international market. This has reduced tremendously the amount of fertilizers and agricultural chemicals being used by the farmers.

Yields of subsistence crops have also been on a downward trend because of the high prices of agricultural inputs. However production of horticultural crops has continued to rise because of high income and support to farmers by exporters with farm inputs.

**2.8 Population**

The population of Murang'a County is 348,304 (Central Burea of Statistics, 2009). It has a population density of 374 sq $km^2$ . the highest population densities are found in Kigumo, Muruku and Gatanga Locations of Murang'a Township. The lowest population densities are found in Kakuzi and Mitubiri location which are mainly large scale farming areas.

The County population growth rate is at 0.2 % per annum. (Muranga DEAP, June 2007).

**2.9 Socio-economic activities**

Agriculture is the economic mainstay of the County. Rainfall and topography are the limiting factors in agricultural production. In the lowland areas in Kiharu Division, the farms are relatively bigger in size ranging between 2-7 acres although the majority of the people are living below the poverty line. The farmers engage mainly in subsistence production. Dairy farming is also popular. In Kairo Division the larger part of the terrain is moderately steep and farm holdings range between 1-3 acres per household.

Kangema and Mathioya Divisions are generally have a steep hilly topography and enjoy a climate suitable mainly for tea production. The human settlements are found along the steep slopes and generally limited flatter areas. Majority of the people enjoy affluent living standards. Average farm holdings are very small with some households occupying less than an acre of land. Crop diversification is very limited due to unsuitable weather patterns.

The County has 792.6Km of road network. The railway length is 20km with one (1) station. Earth roads and rural access roads are major channels of runoff, which exacerbated by terrain and the loose nature of soil result to severe soil erosion and gullies This is depicted by the district social economic activities.

**2.10 Land Degradation**

The major source of energy in the County includes woodfuel, charcoal, kerosene and crop residue for majority of rural people. Land degradation has increased as a result of increased population growth, deforestation, energy demand, and poor agricultural practices (GOK, Muranga DEAP, and June 2007). With climate change impacts, farmers have intensifies land use and reduced fallow period. These practices have impact of occurrence of landslides. As a result large chunks of land are rendered useless after landslides thus threatening food security and livelihoods in general.

Soil erosion is a major environmental problem since most of the land in the County is hilly with sparse vegetation. Rill erosion is very common in cultivated land while gully erosion is found in unprotected drainage channels, footpaths and culvert outlets. Some of these drainage channels act as underground conduits for runoff thus causing landslides especially on steep slopes where runoff is not well drained away.

The Murang'a District on the eastern foot slopes of the Aberdare Range has high rainfall, intense population and intense farming. The area's soils are prone to landslides, exacerbated by the removal of forests and shrubs for farming (Feb 2003 image).

# CHAPTER THREE: LITERATURE REVIEW

## 3.1 Introduction

Landslides are not a new phenomenon in Africa. They have been reported in various countries including Cameroon, Kenya, Uganda, Rwanda, Tanzania, and Ethiopia (Moeyerson 1988; 1989a; 1989b; Davies 1996; Westerberg and Christiansson, 1998; Ngecu and Mathu 1999; Ingang'a and Ucakuwun 2001; Muwanga et al. 2001; Knapen et al. 2006). The East African region which includes Malawi, is a heterogeneous in terms of physiography, geomorphology and rainfall, and has a high susceptibility to slope movement. In every slope there are forces which tend to promote down slope movement and opposing forces which tend to resist movement. A stable slope is one on which the down slope shear stress is delicately balanced by the shear strength of the soil. Where this balance is upset and any form of trigger mechanism occurs, slope failure will occur.

The overall goal of the present study is to determine the factors that cause slope failure, and more specifically landslides and the measures that the local communities use to cope with landslide disaster. The high annual rainfall, high weathering rates, deforestation and slope material with a low shear resistance or high clay content are often considered the main preconditions for landslides (Knapen *et al*. 2006).

Between 1960 and 1980 the Muranga County experienced 40 landslides as shown in Table 3.1 below ( Muranga DEAP, and June 2007).

**Table 1:** A summary of Deaths & Destruction of Property Caused by Landslides in Central Kenya Between 1997 - 2003

| Year s | District | Location | No of deaths | Nature of Destruction and Displacement |
|---|---|---|---|---|
| 1997 | Muranga | Gatura | 0 | Roads/Farms |
| 1997 | Muranga | Muringa | 0 | 7 houses |
| 1998 | Muranga | Gatura | 0 | 400 people displaced |
| 1998 | Muranga | Gituamba | 1 | Farms/Homesteads |
| 1998 | Kiambu | Kijabe | 0 | Rail/Road |
| 2002 | Muranga | Ruri | 0 | Forest/Homesteads |
| 2002 | Muranga | Kiruri | 5 | Homesteads/road |
| 2003 | Kiambu | Ngegu | 2 | Farms/Homesteads |
| 2003 | Nyandarua | Sasimua | 0 | Sasimua dam |

## 3.2 Casual Factors of Landslides

### 3.2.1 Slope failures and landslides

Landslides are slope failures that are initiated by slippage as a response to the gravity along a well-defined planar surface due to reduces strength or increased stress (Ritter 1987) Starting from this general definition Terzaghi (1950) divided causes of landslide into external and internal causes. External causes do result in an increase of the shearing strength such as geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, drawdown, changes in water regime. The internal causes, on the other hand result in a decrease of the shearing resistance such as the progressive failure, weathering, and seepage erosion. He latter modified this classification of causes because there are a number of primary external or internal causes which may be operating either to reduce the shearing resistance or to increase the shearing stress (Varnes 1978). In addition, there are secondary causes affecting simultaneously both primary external or internal causes that tend to trigger slope failure. In other words, a great variety of slope failures reflects the diversity of conditions that cause the slope to become unstable and the geological and geomorphological processes that trigger the movement. It is therefore more appropriate to discuss cause factors and processes together.

Slope failure broadly describe as landslide is a consequence of a large mass surges down slope. They style of mass movement generally defined according to flow velocity, volume of the material involved shear rates and shear strength of the materials. The fluid and its interaction with the solid materials provide broader variations in its style. Experiences shows that landslides occurrences on hill slopes have very close relationship with availability of water. As a result, many varieties of landslides occur as a consequence of heavy rainfall in tropical and temperate climatic zones (Jacob and Weatherly, 2003).

### 3.2.2 Rainfall-Triggered Landslides

Landslide problem has been little researched on in Kenya and there is lack of information on rainfall threshold, nature of occurrence and characteristics which are vital information for GIS data base creation for easy landslide monitoring (Nyamai, C.M.1997) .Extraordinarily heavy rainfall between May 1997 and February 1998 due to the El Nino weather phenomenon caused major landslides in Kenya (Ngechu and Mathu, 1999) . On 10th November 1999, a landslide affected 356 km2 of arable land along Thika-Muranga Highway at Karugia.

Flow-like landslides triggered by rainfall occur in most mountainous landscape of the world. (Version, 2000). They pose significant natural hazards and have a high damaged potential (Brenner, 2003). There are many statistically meaningful analyses that have been published to demonstrate threshold value of rainfall and landslide triggering (Caine 1980; Glade at al, 2000: Wieczorek et al, 2000, Mikos, Cetina & Brilly 2004; Shakoor & Smithmyer 2005).

Water exerts a considerable influence on cohesion, strength and viscousity of soil materials and hence a powerful influence on slope stability. Crozier (1986) argues that low pressures cells particularly tropical cyclones are the major source of landslide – triggering rainstorms- because of their intensity. This is supported by Temple and Rapp (1972) who found  that the tropical cyclones were responsible for the extra ordinary heavy rainfall which in 1970 resulted in over thousands landslides at Mgeta Valley, Tanzania. When the rain water reaches the ground it starts to infiltrate, pore water pressure rises, and because of the loss of cohesion of the solid particles, their weight may be supported by pore water. The slope stability is endangered. A sudden rise of pore water pressure can be so great that the overburden of the soil and water effectively floats on the pore water beneath and the pore water will burst out of the voids. Such a burst will trigger slope failure. Pore water pressure may also rise if the ground water level rises after a heavy rainfall.

### 3.2.3 Weathering and bulk density

The down slope component of the gravitational force increases with increasing bulk density. Through weathering a gradual change in bulk density may occur over a long time. Slope materials in solution and suspension maybe transported laterally on or below the soil surface or vertically through the soil profile thereby causing dislocation of the center of gravity of slope section. Weathering may lead to an increase in porosity and permeability in coarse grained materials. Weathering may lead to increased water content causing a possible increase in pore-water pressure. Weathering increases infiltration which in turn increases pore water pressure.

### 3.2.4 Gradient and form slope

Steep slope are liable to instability since the down slope component of the gravitational force is greater on steeper slopes. Many authors including Birot 1960, O Loughlin 1981, Rosenqvist et al 1990 have argued that landslides are most common on steep slopes.
Gentle slope where surface and substance flow lines converge where infiltration is favored and drainage impended may experience an increase in pore water pressure which is conducive to the destabilization of slopes. Finlayson and Stathem 1980) Crozier (1986) argues that a dip outwards, towards the free face of a slope is likely to produce more unstable conditions than inward dip as joints between the strata comprises potential shear surface.

The form of slope may be altered by human activities or by natural processes. If for example a slope form is changed from convex to concave this will lead to a concentration of water flow and hence an increase in pore water pressure. (Van asch 1980) Evidence is that more landslides occur on concave slopes compared to conxex slope (Msilimba, G. 2002) .The present study examines the nature of slope on the sites that witnessed landslides.

**3.2.5 Influence of soil characteristics**

Soil is a complex of fine rock fragments and organic matter serving as medium for plant growth, and differentiated from its parent material by actions of various genetic and environmental influences (Muller and Oberlander, 1974) Soils are products of geology and climate. Through the processes of weathering, translocation and organic activity, soil characteristics especially soil profile is developed. The depth of soil depicts a balance between soil forming processes and soil erosion. Soil profile controls the tolerance of slopes to all other destabilizing factors. Crozier (1986) Crozier emphasizes that inclination and orientation of structural surface have the greatest effect on stability of slopes.

Soil characteristics include texture, structure, chemistry and colour. Soil texture determines the ability to absorb and store water, generally referred to as liquefaction. Liquefaction is defined as a condition when the soil momentarily liquefies and tends to behave as a dense liquid a condition which is required for landslides to occur. The most important textures that control liquefaction are sands and silts or combinations of both. Sand and silts or combinations are fine enough to inhibit rapid internal water movement, and coarse enough to inhibit rapid capillary action, while simultaneously displaying little cohesion (Bryant 1991; Msilimba 2002; Msilimba and Holmes 2005). Msilimba (2002) found that in all the units studied in Malawi, the soils contained a high percentage of sand ranging from 54% to 68%. Medium to fine sand was abundant and the mean percentage exceeded 38.66% of the total sample. Being unconsolidated, the angle of shearing resistance is low, and failure can occur at an internal angle less than that of the slope upon which the material rests (Finlayson and Statham, 1980) .The variation in stability in different pedagogical environment with similar slope properties reflects the variable characteristics of soils for example soil developed through weathering of volcanic ash, andosols are known to be sensitive to landside (Kipsanai, J. A.1986). Soils such as silt and clay are weaker and commonly have complex (colloids) or multiple planes of weakness (clay-humus complex) which enhance the occurrence of landslides. Soils with high clay content are known to swell when wet and shrink in dry weather and the swelling capacity increases with increasing surface area of the clay particles and with decreasing valence of the exchangeable cations (Krhoda, 2013)

### 3. 2.6 Vegetation and Land use

The importance of vegetation and land cover on the hydrological cycle is fairly well known. The vegetation and any other land cover characteristics determine the rate of rainfall infiltration into the ground, evapotranspiration and help in binding soil particles together and hence have some effect on stability of slope. On one hand the roots system of plants absorbs soil moisture and expires it to the atmosphere and lowers the water table. Deforestation therefore has a negative impact on infiltration capacity and soil development. It is however not known whether deforestation will contribute to severe landslides. After clearing of vegetation the sources soil humus and the role of tree roots will be eliminated.  Deforested areas also experience wide variations in temperatures and moisture contents thus causing heavy cracking of soils. Landslides are hence commonly attributed to the loss of support from a root system and deforested areas (Temple and Rapp, 1972).

### 3.2.7 Rivers

Muranga County has a rugged and hilly landscape interrupted by numerous streams. Hillslope angles adjust to reflect rates of channel incision at their base and that the specific slope angles in a landscape reflect a site of environmental properties (Strahler (1950). The total number or total length of stream channels per unit of area is referred to as drainage density and the higher the drainage density the higher the rate of sediment removal by stream channels. Rivers and streams undermine the toe of the hill slopes thus reducing slope stability. The relation between drainage density and slope angle for each watershed can be divided into two types: downward sloping and convex upward. Although previous studies suggested that drainage density positively correlates with slope angle if overland flow is dominant, such an upward sloping correlation seldom occurs in the study areas (Oguchi, 1997)

In many cases slope failures are triggered as a result of undercutting of slope by a river especially during a flood. This undercutting serves both to increase the gradient of the slope, and to remove toe weighting, which decreases stability. For example in Nepal this process is often seen after a glacial lake outbursts flood, when toe erosion occurs along the channel. Immediately after the passage of flood waves extensive landslides often occur. This instability can continue to occur for a long time afterwards especially during subsequent periods of heavy rain and floods events. The proportions of landslide susceptible areas are localized in steep headwater valleys, particularly at the heads of the channel network (Montgomery and Dietrich, 1994).

### 3.2.8 Seismic waves and vehicular tremours

Seismic waves and vehicular motions cause transitory stresses thus contributing to high shear stress. The passage of the earthquake waves through the rock and soil produces a complex set of accelerations that effectively act to change the gravitational load on the slope. For example, vertical acceleration successively increases and decreases the normal load acting on the slope. Similarity, horizontal acceleration induces a shearing force due to the inertia of the landslide mass during the accelerations. These processes are complex, but can be sufficient to induce failure of the slope. These processes can be much more serious in mountainous areas in which the seismic waves interrupt with the terrain to produce increases in the magnitude of the ground acceleration.

Vehicular tremours are known to trigger landslides and other mass wasting processes. Other factors being constant, development of slopes are dependent on friction only and therefore steep slopes should occur in dry climates while low slopes will develop in wetter climates according to Davis ( 1850-1934) cycle of erosion and revisions from Walther Penck (1988-1923) (Krhoda, 2013).

### 3.2.9 Liquefaction

The passage of the earthquake waves through a granular material such as soil can induce a process termed liquefaction, in which the shaking causes a reduction in the pore space of the material. This densification drives up the pore pressure in the material. In some cases this can change a granular material into what is effectively a liquid, generating ‘flow slides’ that can be rapid and thus damaging. Alternatively, the increase in pore pressure can reduce the normal stress in the slope allowing the activation of translational and rotational failures.

Some landslides quickly changed into mud/debris flows with increasing rainfall. The landslides involved curved surface ruptures and produced slumps by backward slippage (Davies 1996; Ngecu and Mathu 1999).

### 3. 2.10 Snowmelt

Although temperatures on the Aberdares Range may get to near freezing point, snow fall does not occur there. However in many cold mountain areas snow accumulates over the winter and melts over the summers. Snowmelt can be a key mechanism by which landslide initiation can occur, especially significant when sudden increases in temperature lead to rapid melting of the snow pack. The melt water can then infiltrate into the ground, which may have impermeable layers below the surface due to still-frozen soil or rock leading to rapid increases in pore water pressure, and resultant landslide activity. This effect can be especially serious when the warmer weather is accompanied by precipitation, which both adds to the ground water and accelerate the rate of thawing.
Melting snow seeping into disintegrating rock was reported to be responsible for a massive landslide that killed 83 people in a mining area near Lhasa, the Tibet autonomous region on March 29$^{th}$ 2013 (China Daily, 6$^{th}$ April 2013).

## 3. 3 Impacts of landslides

In most nations of the world, landslides have caused major socio-economic impacts on people, their homes and possessions, industrial establishments and lifelines such as highways, railways and communication systems. Social economic losses due to slope failures are great and apparently are growing as the built environment expands into unstable hillside areas under the pressure of expanding populations. Human activities disturb large volumes of earth materials in construction of buildings, transportation routes, dams and reservoirs, canals and communication systems. And thus have been a major factor in increases in damages due to slope failures.

Landslides are responsible for considerably greater economic and casualty losses than is generally recognized. They represent a significant element of many major disasters in which the magnitude of their effective overlooked by news media. For example the tremendous destruction and loss of life caused by 1970 Huascaran disaster in Peru, which killed some 20, 000 people is often referred to in publications that review disaster as an earthquake disaster, because the landslide was triggered by earthquake: this is in spite of the fact that the actual damage, destruction and casualties were directly caused by a huge, high – velocity debris avalanche.

Related to increases in population is the continuing high rate of deforestation due to logging, burning and development, a factor that increases landslide activity on the world's slopes. In the early 1990's the world resources institute estimated that the world tropical forest were disappearing at a rate of 16 -20 million hectares per year (Collier's Encyclopedia, 1997).

Landslide costs include both direct and indirect losses affecting private and public properties. Direct cost can be defined as the cost of replacement, rebuilding, repair or maintenance resulting from the direct landslide –cost damage or destruction to property installations (Schuster and Flemming, 1986; Schuster, 1996). All other cost of landslides are indirect like reduce real estate values in areas threatened by landslides, loss of tax revenue on properties devalued as a result of landslides, loss of industrial, agriculture and forest productivity, and of tourist revenue as a result of damage to land or facilities or interruption of transportation systems; loss human or domestic animal productivity because of death, injury or psychological trauma; and cost of measures to prevent or mitigate potential landslide activity. Landslide losses can be divided into cost of private and public entities (Fleming and Taylor, 1980). Private cost are incurred mainly as damaged land and structures, either private property or corporate industrial facilities. A destructive landslide can result in financial ruin for property owners because landslides insurance or other means to offset damage costs usually are unavailable.

Public costs are those costs borne by government agencies, national, regional or local. The largest direct public cost resulting from landslides most often have been for repairing or relocating roads and accessories structures such as sidewalks. Indirect public cost includes tax of revenues, reduction of transmission capabilities of lifelines, reduction of productivity of government forests. In the 20th century, the problem of deaths and injuries due to landslides was recorded high due to increase in populations in landslide prone areas, this trend will continue in the 21st Century. Varnes (1981) estimated that during the period 1971 to 1974 nearly 600 people per year were killed worldwide by slope failures. About 90% of this deaths occurred within the Circum-Pacific region.

## 3.4 Landslide mitigation measures

### 3.4.1 Profile of mitigation measures

Landslides can be predicted with reasonable accuracy except those that result from seismic waves. The geomorphological, environmental and human factors are fairly well studied. What requires further assessment will be the level of resilience of the people in case a landslide occurs. Mitigation is defined as sustained, deliberate measures implemented in advance to avoid or reduce the impact of hazards and impending disasters according to (Haque and Burton, 2005). Landslide hazard mitigation will be depended on actions that are carried out before the disaster occurs generally involving landslide mapping, construction of control structures, warning systems and regional planning. Most effective approaches include a combination of these strategies.

### 3.4.2 Landslide maps

As summarized by the National Research Council (NRC, 2003) landslide maps include maps that depict potential areas for landslide occurrence), susceptibility (likelihood of landslide occurrence), vulnerability (extent of potential loss), and risk (probability of harmful consequences). The list should also include inventory maps – which delineate landslide locations from single or multiple triggering events (Wieczorek, 1984). Inventory maps are basic data upon which other maps are developed. The development of landslide maps can be less costly than warning systems and control structures and the maps serves as important tools for planers and civil defense officials.

### 3.4.3 Landslide warning systems

Landslides warning systems provide a rapid means to monitor and communicate hazard information to vulnerable communities. Warning systems are used to mainly to protective lives, by indicating that landslides are likely to occur and provide time for notification and evacuation of vulnerable population. This systems however do not substantially reduced property damage (NRC, 2003). Furthermore despite their wide spread occurrence and potentially deadly nature, it remains difficult to predict precisely when where landslides are likely to occur mainly because of hill slope heterogeneity (Keefer and Larsen, 2007).

### 3.4.4 Control structure

In areas with high landslide hazards where population is dense or where property values is great, engineering solutions such as retention walls, sabo dams, and debris – flow catchments basins have been used to protect lives and property (Chan, 2000). A sabo dam is a small, low-head dam used on perennial stream channels to capture or slow the velocity of debris-flow materials. Retention walls stop, deflect or capture landslide debris before it reaches developed areas or near a hill slope. They are most commonly used at hillslope base to protect critical infrastructure (Turner and Schuster, 1996). Large debris - flow catchments basins are used for example in Los Angeles, California region where debris flow are common and property values are high. Control structures may lead to greater vulnerability by fostering new or additional development in or close to hazardous areas (Mileti, 1999).

### 3.4.5 Regional planning and policy development

Effective regional planning includes identification of potentially hazardous areas, the mitigation steps described above, and the development of policies and regulations to guide development in order to reduce risk. The planning and decision making is most likely to succeed if it includes states local government, as well as non-governmental and community organizations (NRC, 2003).

Sustained communication with and education of local citizens is necessary for implementation to be successful. Social political and cultural acceptance resulting from an interactive, participatory process involving local communities may produce the best outcomes with respect to mitigation, preparedness and recovery (Haque and Burton, 2005; NRC, 2006).

### 3.5 Conceptual framework

The objective of this study is to examine the man-made and natural factors associated with landslides in Kairo Location, determine the socioeconomic effects of landslides, and asses the adaptation strategies employed by farmers to mitigate the effects of landslides. Landslides occurrence is dependent on wide range of factors which may generally be considered under the dual category of geomorphological factors, environmental factors and human factors.

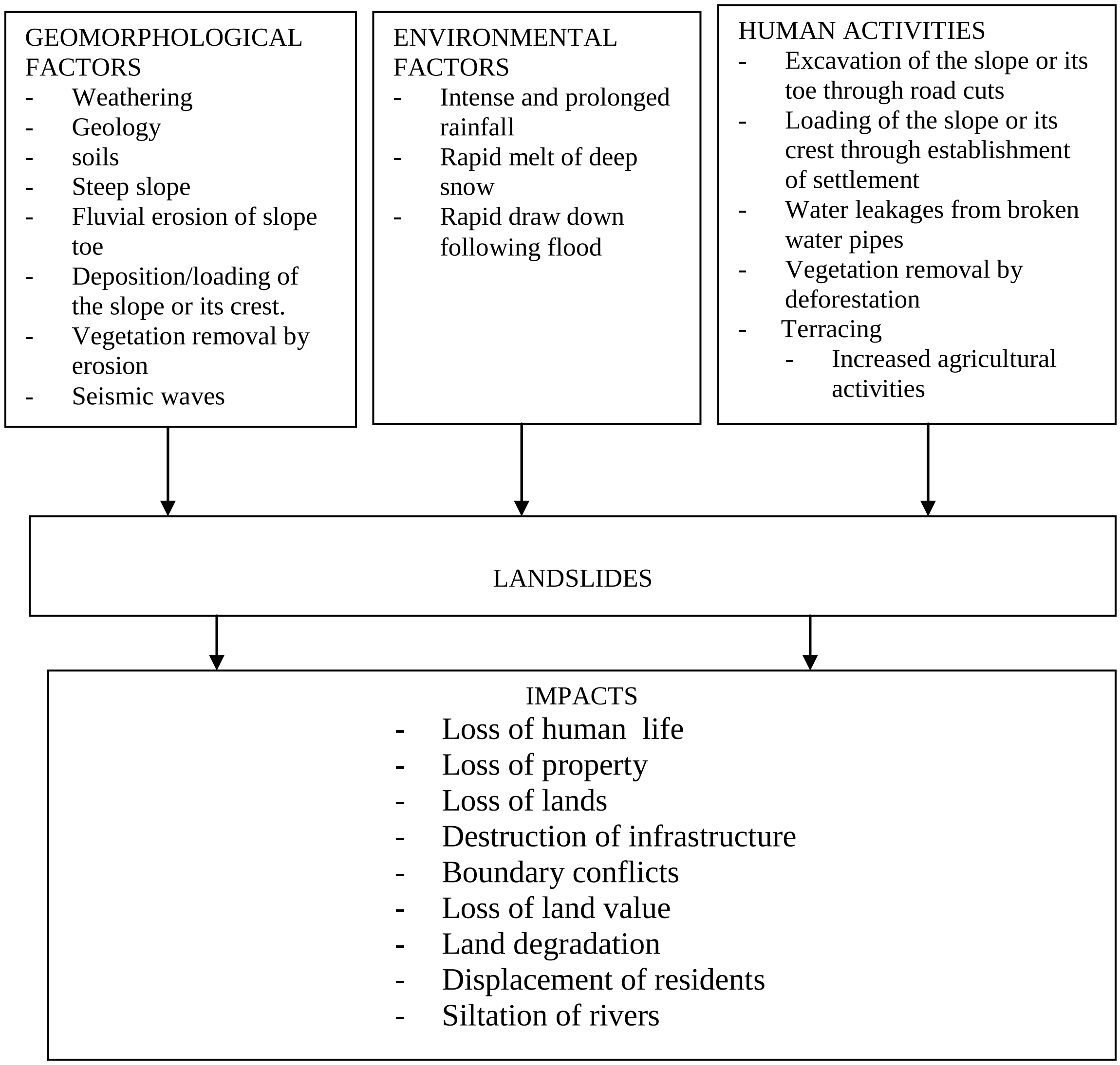
The geomorphological factors include weathering processes, geology/soils, geometry of the slope, fluvial erosion of slope toe, deposition/loading of the slope or its crest, vegetation removal by erosion, and transitory stresses including seismic waves and vehicular tremours.

Environmental factors include intense and prolonged rainfall or rapid melt of deep snow in case of snowcapped regions, rapid draw down following flood within stream channels.

Human activities include excavation of the slope or its toe, loading of the slope or its crest, defective maintenance of drainage systems, water leakages from water supply, vegetation removal by deforestation, and terracing.

Quite often these factors act in concert and therefore their relationships become very complex. The impacts of landslides include loss of lives, loss of farm lands, destruction of property, boundary conflicts, and degradation and loss of land value.

**Figure 6: Conceptual Framework Showing Natural and Human Factors Causing Landslides and Socio-Economic Impact**




**Source: Researcher 2014**

# CHAPTER FOUR: METHODOLOGY AND DATA ANALYSIS

## 4.1 Reconnaissance Survey

This study examined the man-made and natural factors associated with landslides in Kairo Location, determine the socioeconomic impacts of landslides, and asses the adaptation strategies employed by farmers to mitigate the effects of landslides. The survey was made within the study area. Geomorphologic investigation by design is a case study from which generalization could be made to other areas that demonstrate to poses the same physical characteristics.

The objectives of the study were to determine the causes of landslides in Kairo Location of Murang'a County, to establish the extent of landslide threat on social economic and physical environment, and to examine adaptive responses employed by farmers in landslide prone areas.

The field reconnaissance was established to visit the area and familiarize with the geomorphology of the County, take photographs, draw illustrations of the observed land disturbances. The depth, length, width, and slope angle of the individual landslides were measured.

## 4.2 Research Design

A research design is an arrangement of conditions for the collection and analysis of data in a format that combines their relationship with the purpose of the study to the economy of procedures (Chandran, 2004). It works as the master plan for the collection and analysis of data that aids in the answering of the research questions. Cooper and Schindler (2003), states that, a research design ensure that the study is relevant and applicable to the problem and its economical procedures for acquiring the information.

This research adopted a descriptive study design. It gathered information from Kairo location in Murang'a County. The information obtained provided details about the natural and human factors associated with landslides and their effects in Kairo location of Murang'a County, Kenya

### 4.3 Study population and Sample Size

Borg and Gall, (1996) defines a sample as a small proportion of a target population selected for analysis. Kairo Location has an area of 8.6 km2, target population for the study is 3,385 thus a population density of 394 persons per km2. The population has equal number of males and females. The number of households in the location is 100 households. The sampling flame included all farmers that constitute all the inhabitants of the location.

In addition, the Divisional Agricultural Officer, Water Resources management Authority and Environmental Officers serving in this county formed part of the study population.

Purposive sampling was employed, whereby first representative sub-zones will be sampled, after which farmers will be selected. A form of non-probability sampling in which decisions concerning the individuals to be included in the sample are taken by the researcher, based upon a variety of criteria which may include specialist knowledge of the research issue, or capacity and willingness to participate in the research. A total sample of 30 farmers representing 30 households was selected. However, all the County Heads of the above mentioned departments were interviewed and they were totaling to 10.

The advantage of purposive sampling is that the investigator is able to select respondents that are able to be mature and knowledgeable in the area of study. Of course the main disadvantage is that the selection of respondents depends entirely on the criteria set by the investigator and therefore the results are as good as the knowledge of the investigator. The investigator ensured that there was internal consistency in the selection process.

### 4.4 Collection of Primary Data

Slopes were measured to determine angles from field visits, samples of soils and rocks were collected.

### 4.5 Data analysis

Qualitative and quantitative data analysis techniques have been used to facilitate interpretation of data. Both secondary as well, as primary data were collected and analyzed. The secondary data was gathered from published literature and reports. Data from the key literature was collaborated by triangulation and further interviews of key informers. The secondary data included soil data, rainfall, temperature and evapotranspiration from Kenya Meteorological Department. Land use data was collected from published data.

The primary data, on the other hand, were gathered from survey carried using questionnaires to establish household characteristics and knowledge and frequency of landslides occurrences, land use, original angle of hill slopes before landslide incidence and estimates of landslide damage.

Administration of the questionnaire was done to the farmers to establish the landslide impact. A statistical package for the social sciences [SPSS] as a platform has been used to aid in computation of means and percentages as shown in frequency distributed tables, bar graphs and pie charts.

The data illuminated on the causes and effects of landslide in Kairo Location of Murang'a County.

# CHAPTER FIVE: DATA ANALYSIS AND DISCUSSION

This chapter presents the data and its analysis. Specific objectives were to determine the occurrence of landslides in Kairo Location of Murang'a County, Kenya; establish the extent of landslide risk on social economic and physical environment and examine adaptive responses employed by farmers in landslide prone areas.

## 5.1 Social-economic characteristics

The sample population for the study comprised of 40 respondents. They comprised of 10 Murang'a divisional Agricultural water and environmental officers and 30 farmers in Kairo location. Those who returned the questionnaires were 34 respondents bringing the response rate at 85%.

**Table 2: Response rate for the study**

| **Respondents** | **Sample population** | **Response rate** |
|---|---|---|
| Environmental officers | 10 | 9 |
| Farmers | 30 | 25 |
| Total | 40 | 34 |
| **Percentage** | **100%** | **85%** |

**Source: Author, 2013**

The table above indicated that the response rate for the study was 85% which was sufficient and representative of the entire population. According to Mugenda and Mugenda (1999), a response rate of 50% is adequate for analysis and reporting; a rate of 60% is good and a response rate of 70% and over is excellent.

The respondents were asked to indicate their gender and the results obtained were tabulated in a table of frequency and percentages. The results were as shown in the table below.

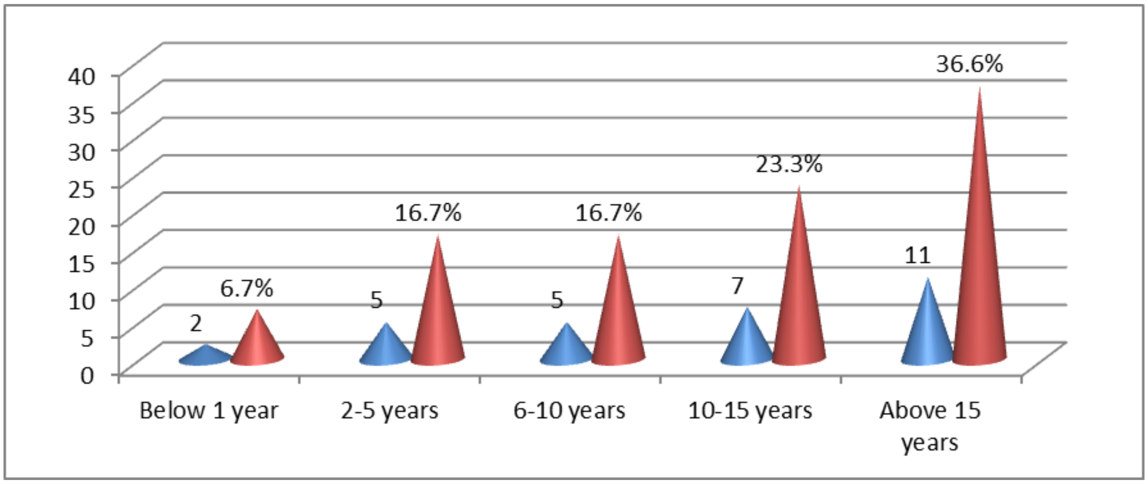
**Table 3**: **Gender of respondents**

| **Gender category** | **Frequency** | **Percentage** |
|---|---|---|
| Female | 18 | 60% |
| Male | 12 | 40% |
| **Total** | **30** | **100%** |

**Source: Author, 2013**

The study findings in the table above indicates that majority (60%) of the respondents were female while the male counterparts accounted for 40% of the respondents. The findings of the study therefore depicts that the mostly affected were females because majority were farmers.

**Figure 7: Years of residence**




Source: Author, 2013

Figure 10 shows that the majority of the respondents have lived for above 15 years as residents in Kairo location accounted for 36.6% and were familiar with disturbance of landslides .Those who had lived between 10 and 15 years accounted for 23.3% of the respondents; those who lived between 2 and 5 years to 6 and 10 years accounted for 16.7% of the respondents respectively. The residents who had been residents of Kairo location for more than 10 years were in a better position to discuss and give out information about landslides in the area.

**Table 4**: V**illage area**

| **Village** | **Frequency** | **Percentage** |
|---|---|---|
| Irima village | 7 | 23.3% |
| Nyarugumu Village | 9 | 30% |
| Ndunduini village | 6 | 20% |
| Kamunjuini Village | 8 | 26.7% |
| **Total** | **30** | **100%** |

Source: Author, 2013

The majority of the respondents were from Nyarugumu Village accounting for 30%, Kamunjuini Village for 26.7%; Irima village 23.3% and Ndunduini village 20%.

**Frequency of landslides in Kairo Location**

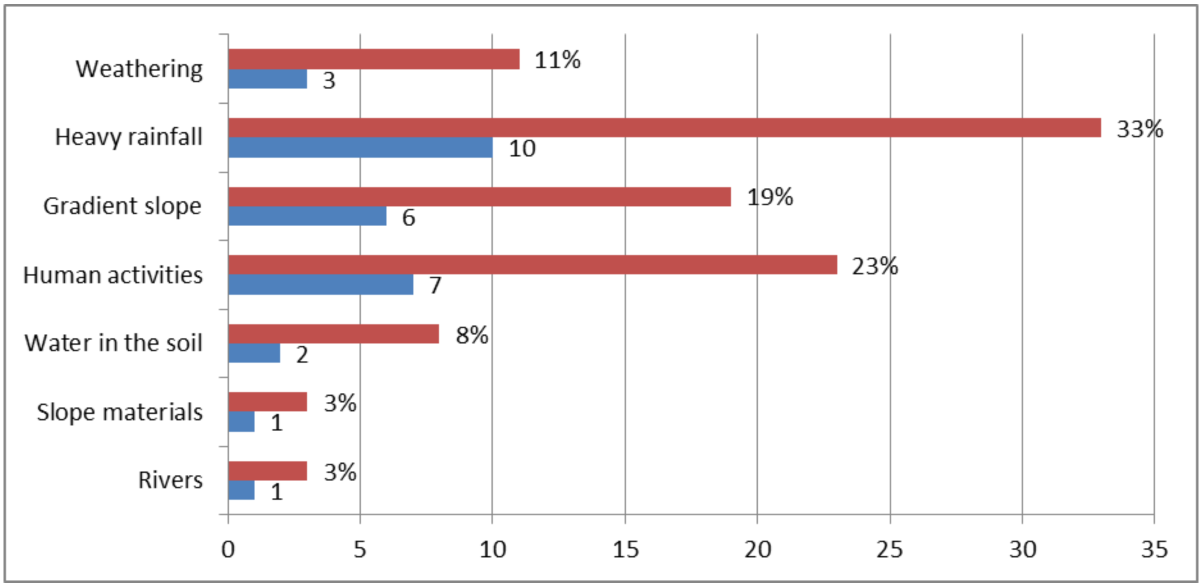
**Table 5**: **Frequency of landslides**

| | **Very frequent** | | **Frequent** | | **Moderate** | | **Less frequent** | | **Not at all** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Village** | **f** | **%** | **f** | **%** | **f** | **%** | **f** | **%** | **f** | **%** |
| Irima village | 8 | 26.6% | 10 | 33.4% | 12 | 40% | - | | - | |
| Nyarugumu village | 22 | 73.3% | 8 | 26.7% | - | | - | | - | |
| Ndunduini village | - | | 2 | 6.7% | 12 | 40% | 16 | 53.3% | | |
| Kamunjuini village | 5 | 16.7% | 14 | 46.7% | 11 | 36.6% | - | | - | |

Source: Author, 2013

The Nyarugumu village accounted for 73.3% response as the majority indicating that landslides in the area are very frequent. Nyarugumu village was more prone to landslides as compared to other villages. Ndunduini village accounted for 53.3% response as the majority indicating that landslides in the area happen less frequent. The cause of landslide was as a result of infrastructure development cutting almost the toe of the slope. Kamunjuini village accounted for 46.7% response as the majority indicating that landslides in the area occur frequently. Irima village accounted for 40% indicating that landslides in the area occur moderately.

**Figure 8: Factors causing Landslides**



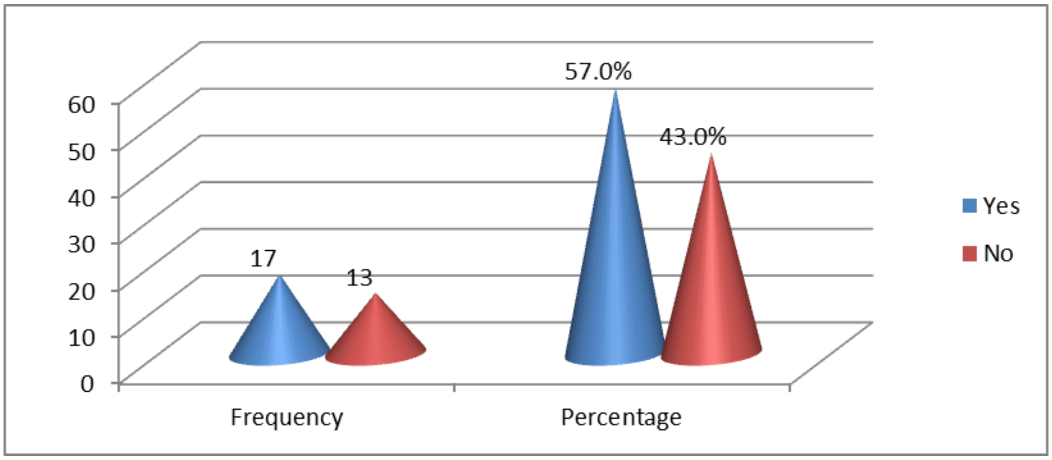

Source: Author, 2013

The main factors responsible for causing landslides in Kairo Location were rated as heavy rainfall of 1500mm. Human activities in the area also accounted for 23% while gradient of slope accounted for 19% of the response. Other factors that contributed to the cause of landslides in the area were: weathering; water in the soil, rivers and slope materials.

## 5.2 Farmers Knowledge on Human factors

The respondents were asked to indicate whether they are equipped with knowledge about the natural and human factors causing landslides.

**Figure 9: Farmers Knowledge on Human factors**




Source: Author, 2013

The findings found that majority of the respondents are equipped with knowledge about the human factors causing landslides in the area. About 57% were equipped with knowledge about human factors while 43% of the respondents were on the contrary. The gap between those who were equipped and those who were not equipped with knowledge was so small and this rose concerns as the results indicated that equal number of population may not be equipped with the knowledge about the natural and human factors causing landslides.

### 5.3 Human factors causing landslides

The majority of the respondents indicated that landslides were triggered largely by human activities such as logging on slopes, vegetation gradation, and terracing, defective maintenance of drainage and water leakages from water supply. Trees have some effect on stability of slope. On one hand the roots system reduces soil moisture and lowers the water table. On the other hand tree vegetation causes increased infiltration and shear stress causes root wedging. Deforestation has been followed severe land sliding. In Kairo location the removal of vegetation cover has contributed to the occurrence of landslide.

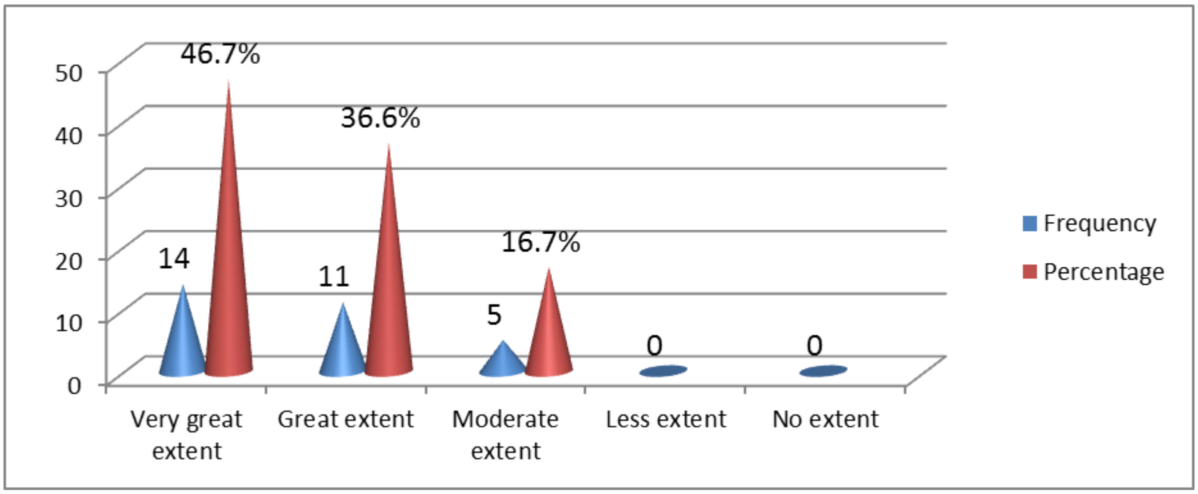
The findings of the study corresponds to the findings of Ngecu and Mathu (1999) that the major triggers of landslides largely contributed by human activities are logging on slopes and vegetation gradation. This supports the occurrence of landslides in Kamunjuini village where the main cause of landslides was leakage of piped water;

Ndunduini village where the main cause of landslides was development of road cutting across the slopes and Irima village where the main cause of landslides was terracing.

### 5.4 Socioeconomic and environmental impacts of landslides

The respondents were asked to rate the extent to which landslides impact socioeconomic and physical environment impacts in Kairo Location of Murang'a County. The results were obtained and shown in the figure below.

**Figure 10: Extent of the impacts of landslides on socio-economic and physical environment**




Source: Author, 2013

According to the study findings, the respondents rated the extent to which landslides impact on socioeconomic and physical environment in Kairo Location of Murang'a County. 46.7% of the respondents indicated that the impact of landslide on socio-economic and physical environment was to a very great extent, 36.6% to a great extent and 16.7% rated moderately.

The list of socioeconomic impacts include: catastrophic loss of life for people and livestock, extensive property damage of homes, possessions, infrastructure such as transport and communication systems and assets. While the physical impacts include: damage water resources, damage of vegetation and trees. In Kairo location where agriculture is a main economic activity, the estimated losses they encounter as a result of the aftermath of a landslide is to a great extent with other losing their livelihoods in the damage, loss of lives and lands, destruction of property, boundary conflicts and loss of land value.

The results were obtained and tabulated on a table of mean and standard deviation as shown below. The scores of ‘not true’ have been taken to present a variable which had an impact strongly disagree (S.D) and disagree (D) (equivalent to mean score of 0 to 2.5 on the continuous Likert scale; (0≤ S.D/D <2.4). The scores of ‘moderately true’ have been taken to represent a variable that had an impact to a moderate agree (M.A.) (equivalent to a mean score of 2.5 to 3.4 on the continuous Likert scale: 2.5≤M.A. <3.4). The score of ‘true’ have been taken to represent a variable which had an impact to a strongly agree (S.A.) and agree (A) (equivalent to a mean score of 3.5 to 5.0 on a continuous Likert scale; 3.5≤ S.A. /A <5.0).

A standard deviation of >1.5 implies a significant difference on the impact of the variable among respondents.

**Table 6: landslides on social economic and physical environment impact**

| No. | Statements | Mean | Std. Dev. |
|---|---|---|---|
| a. | Landslides play a major role in the evolution of slopes | 3.1087 | .75962 |
| b. | Landslides contribute to the loss of land value | 3.6348 | .92939 |
| c. | Landslides are commonly associated with boundary conflicts | 3.7957 | .87072 |
| d. | Rainfall-triggered landslides are part of a natural process of hill slope erosion that can result in catastrophic loss of life and extensive property damage in mountainous | 4.6870 | .50657 |
| e. | Landslides have consequent effects on water resources, agriculture, transport, health, and socioeconomic conditions | 3.6304 | .67355 |

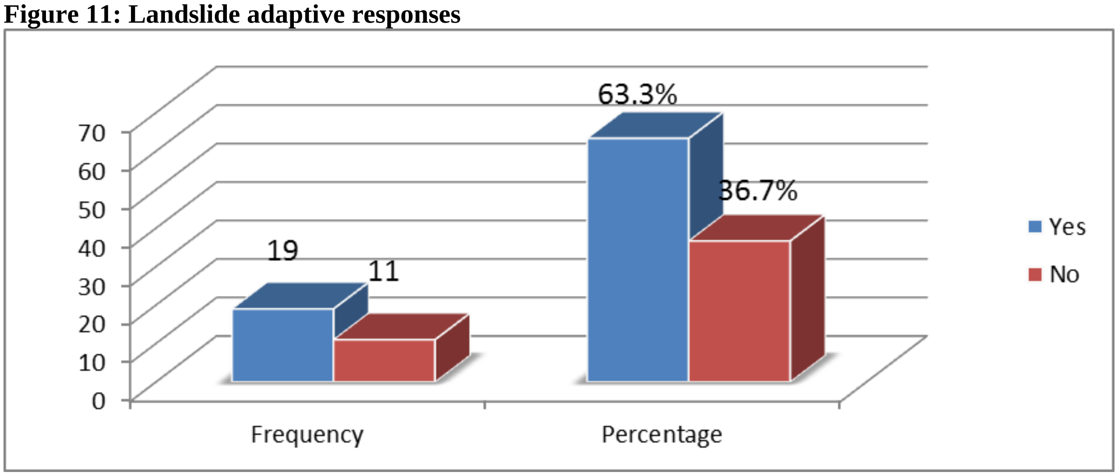
Source: Author, 2013

The respondents were asked to rate the given statements on landslides in the area. Landslides play a major role in the evolution of slopes had a (mean of 3.1087) indicating that the respondents moderately agreed. Landslides contribute to the loss of land value had a (mean of 3.6348) indicating that the respondents agreed. Landslides are commonly associated with boundary conflicts had (a mean of 3.7957) indicating that the respondents agreed; Rainfall-triggered landslides are part of a natural process of hill slope erosion that can result in catastrophic loss of life and extensive property damage in mountainous had a (mean of 4.6870) indicating that the respondents strongly agreed that landslides have consequent effects on water resources, agriculture, transport, health, and socioeconomic conditions had a (mean of 3.6304). The study deduced that landslides in Kairo Location have great impact on the social economic and physical environment.

### 5.5 Adaptation to landslides

The respondents were asked to whether they have adaptive responses they have accustomed to and the results were as shown below.

**Figure 11: Landslide adaptive responses**



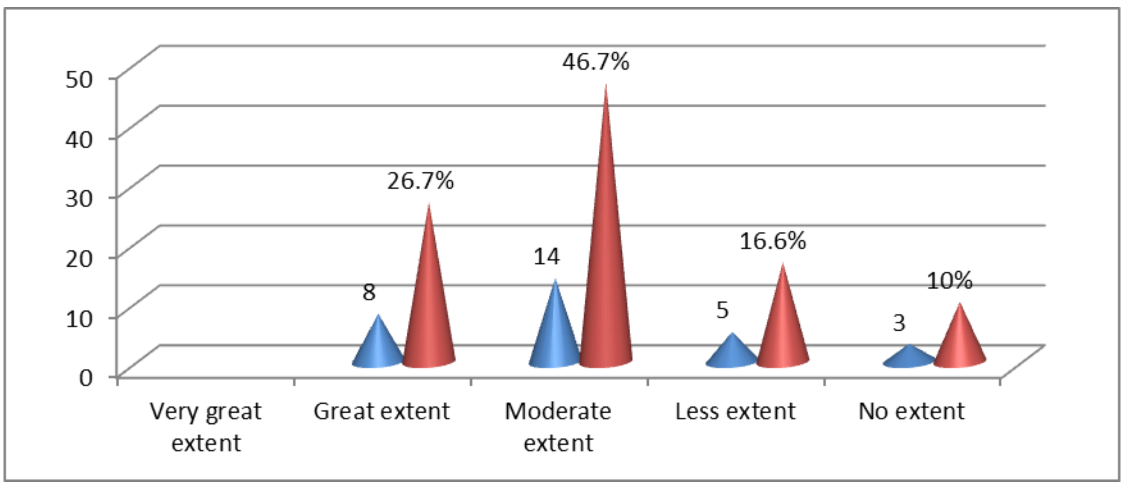

Source: Author, 2013

According to the results obtained in the figure above, the majority of the respondents indicated that farmers in landslide prone areas have adaptive responses they have accustomed to accounting for 63.3% of the respondents while 36.7% indicated that they did not have adaptive responses they have accustomed to.

The study also sought to determine the adaptive responses employed by farmers in landslide prone areas and the study established that meteorological department in Murang'a County has studied the rainfall patterns in the area and they know the amount of rainfall that would trigger landslides in the area. They give out warning to the residents considering the amounts of rainfall in the area. The farmers were made aware of the rainfall patterns in the area and they had basic knowledge on the use of rain gauge to measure the amounts of rain in the area. The farmers in the area were also aware that the cause of landslides in the area was infrastructure development at the top of the slope and development of piped water supply in the area. The local government sends out warnings to the residents and indicates that development is in progress hence indicating that the zone is a prone area to landslide and people should keep distance. The local government also discourages settlement of the residents at the top of steep slopes because they would likely be victims of landslides in the area. Landslides occurring in one area send out messages to other neighboring settlements in the area and people are evacuated earlier to avoid loss of lives.

The study sought to find out the effectiveness of adaptive responses that are employed by farmers in landslide prone areas. The results were as shown in the figure below.

**Figure 12: Extent of effectiveness of adaptation responses**




Source: Author, 2013

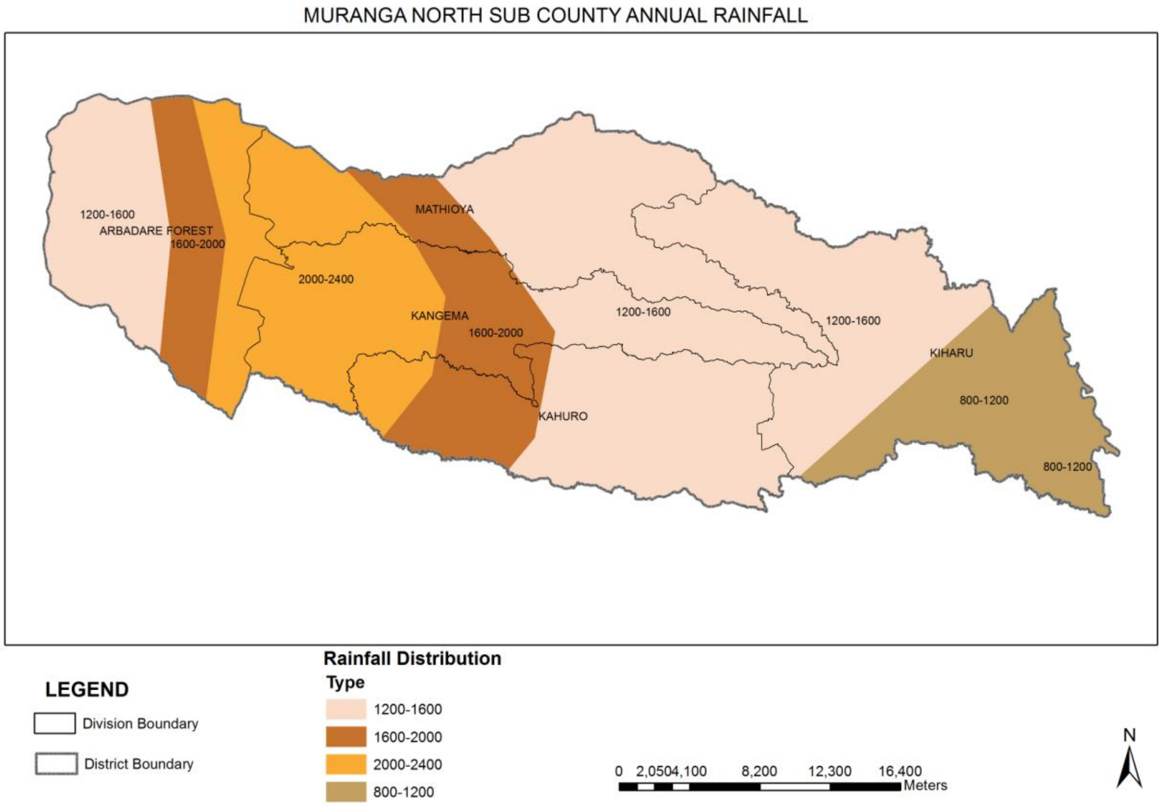
According to the study findings, the respondents rated the extent to which adaptive responses are employed by farmers in landslide prone areas. The results indicated that the majority of the respondents rated the extent to which adaptive responses are employed by farmers in landslide prone areas to a moderate extent accounting for 46.7%. Those who rated the extent to which adaptive responses are employed by farmers in landslide prone areas to a great extent were accounted for 26.7%, those who rated the extent to which adaptive responses are employed by farmers in landslide prone areas to less extent accounted for 16.6% while those who rated the extent to which adaptive responses are employed by farmers in landslide prone areas to no extent accounted for 10%. The study deduced that there is a need for the farmers to be equipped with better adaptive responses to avoid great losses.

## 5.6 Agricultural water and environmental officers

### 5.6.1 Amounts of rainfall that triggers landslides

The agricultural water and environmental officers were asked to indicate what amounts of rain are considered as a trigger to landslides. The respondents indicated high intense rainfall and heavy amounts of rainfall in mountainous landscapes is the main trigger of landslides in the area. According to Iverson (2003) flow-like landslides triggered by rainfall occur in most mountainous landscape of the world. There are many statistically meaningful analyses that have been published to demonstrate threshold value of rainfall and landslide triggering. These flow-like landslides pose significant natural hazards and have a high damaged potential. The respondents indicated that many varieties of landslides occur as a consequence of heavy rainfall in tropical and temperate climatic zones corresponding to the results obtained by Jacob and Weatherly findings. The amounts of rainfall recorded by the agricultural water and environmental officers in Kairo Location that trigger landslides were recorded at 1500mm-2200mm. The Highlands receive an average annual rainfall of over 1,000mm. The months of January and February and July to September are the driest, with an average rainfall of less than 30 mm each. The wettest months are April and May and October to November, with average rainfall of over 200 mm each month. During the hot months the temperature in the Highlands is about $25^{0}$C, while the temperature during the cool months is about $17^{0}$C. The district has two rainy seasons' i.e. Long rains (March-May) and Short rains (October –November). The highest potential areas receive an average annual rainfall of between 1400 mm and 1600mm. This finding corresponds to the Muranga County handbook on rainfall data in the area.

**Figure 13: Average Annual rainfall in mm Muranga County**




Source Kenya soil survey Nairobi.

## 5.7 Importance of landslides as natural landscape system

The agricultural water and environmental officers were asked to indicate why they thought landslides are an important part of natural landscape system in dynamic mountain environment. The respondents indicated that landslides are an important part of the natural landscape system in dynamic mountain environment as that experiences constant uplift. The slopes formed serve as efficient mechanisms for detaching and mobilizing slope-forming materials into the fluvial system, for eventual removal by channel flow processes. The aftermath of landslides create steep slopes and a shift of the ground and geographic soils that form dynamic environments especially in mountainous areas.

## 5.8 Measures and mitigation strategies

The respondents were asked to indicate the measures and mitigation strategies they take in creating awareness to the residents of the area about landslides in advance. Sustainable hazard mitigation is also a strategy that is used to manage the natural resources with local economic and social resiliency. Education is a fundamental key in understanding of landslides and other hazards prone to the area. The measures taken to create awareness of mitigation strategies include mapping of landslide inventory. Regional planning and policy development uses landslide susceptibility and risk maps to guide planners in the determination of where infrastructure can be safely located. According to Carrasco et al., (2003) planners and policy makers also depend on hill slope stability modeling approaches that can be used to estimate when and where hill slopes are likely to fail.

### 5.9 Control of human activities

The respondents were asked to indicate how they control human activities that lead to landslides in the area. The respondents indicated that human activities in the area that lead to landslides were under control by educating the residents of the dangers of human excavation of the slope, loading of the slope or its crest, defective maintenance of drainage systems, water leakages from water supply, vegetation removal by deforestation and terracing of the slopes. Through education the residents get to learn of the measures to be taken to secure and save lives and properties during a landslide and the residents get to be aware of the occurrence of a landslide in advance. The residents also learnt of the benefits of the practice of contour farming to prevent soil erosion, wind and water erosion of the geographic soil.

### 5.10 Adaptation strategies to mitigate the effects of landslides

The study sought to find out from the respondents some of the adaption strategies that are employed by local farmers to mitigate the effects of landslides. The respondents indicated that the adaptation strategies employed by farmers to mitigate the effects of landslides was afforestation practice that would help in the planting of trees and vegetation along the slopes to avoid heavy erosion. The farmers also practice counter farming method of agriculture cutting across the steep slopes. The adoption strategy that policies have developed is discouraging people from settling along the steep slopes and also at the bottom of such slopes by offering alternative land for living. The farmers have also developed adaptation strategies for developing drainage systems that drain water from the steep slopes to a river.

### 5.11 External and internal factors causes of landslides

The respondents were asked to indicate the external and internal casual factors that cause landslides. According to the study findings, the respondents indicated that the external factors lead to an increase in shearing strength that cause geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, drawdown and changes in water regime. The respondents also indicated that the internal factors lead to a decrease of the shearing resistance causing progressive failure, weathering, and seepage erosion. The study findings relate to the findings of Varnes (1978) who pointed out that there are a number of external or internal causes which may be operating either to reduce the shearing resistance or to increase the shearing stress. There are also causes affecting simultaneously both terms of the factor of the safety ratio. The great variety of slope movements reflects the diversity of conditions that cause the slope to become unstable and the processes that trigger the movement.

### 5.12 Observation of the slopes

Murang'a District is on the eastern slopes of the Nyandarua Range and it shows an increase in rainfall and in the length of the agro-humid period which is characteristic of increasing altitudes, due to the effect of the south-eastern trade winds. The annual average rainfall reaches a maximum of 2,700 mm at 2,500m. From this altitude up to the forest line and down to about 2,150m, it is so wet, cold and steep that the area is not recommended for agriculture (UH 0). A strip of UH 1 extends further down to the forest line and the $15^{0}$C isotherm, ( here due to heavy cloud cover exceptionally low at about 2, 050m) and generally known as the Sheep and Dairy Zone, though in view of the population pressure, vegetable cultivation would be more appropriate. The study area is concentrated on the next zone called Tea-Dairy Zone LH 1 that lies on the easterns slopes of Nyandarua Range.

The lower highland zone 1 (LH 1) Tea Dairy Zone has very good yield potential (av. over 80% of the optimum). In the first season of rain that normally starts middle of the month of March, the farmers grow peas, cabbages and lettuce. The second season of rains normally starts in the month of October and farmers grow peas. This yield varies over time depending on the level of potential with an average of 40-80% of the optimum rains.

**Table 7: rainfall Figure from Neighbouring Station**

| No. and altitude | Name of Station | Yr. of Rec | Kind of Rec | Annual rainfall mm | Monthly Rainfall in mm | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sept | Oct | Nov | Dec |
| 9036106 | Kanyenyeini | 35 | Av. | 2, 051 | 80 | 52 | 131 | 451 | 398 | 97 | 76 | 92 | 72 | 200 | 297 | 133 |
| 2, 005m | | | 60% | 1, 922 | 48 | 37 | 105 | 301 | 357 | 79 | 58 | 66 | 52 | 175 | 206 | 88 |

## 5.13 Landslide Occurrence in Kairo Location

**Photograph 1**

The photograph below shows the occurrence of landslide in Irima village located in Kairo location. The area has planted tea at the bottom of the slope and along the gently slope and the steep slope, trees grow naturally. The land is majorly used for tea growing, food crop forest and settlement. The type of soil in the area is of volcanic origin. The drainage of the rain water is at the bottom of the slopes where they are small rivers that are seasonal depending on the amounts of rainfall. The major cause of landslides in the area is the very steep slopes in the area that were measured to be approximately $45^o$ and the height of the slope was approximately 3meters. The latest occurrence of landslide in the area occurred in April 2013. This is the season of long rains and most probably that could have been a contributing factor to landslides accelerated with the very steep slopes in the area.

**Figure 14: The photograph showing the occurrence of landslide in Irima village located in Kairo location**

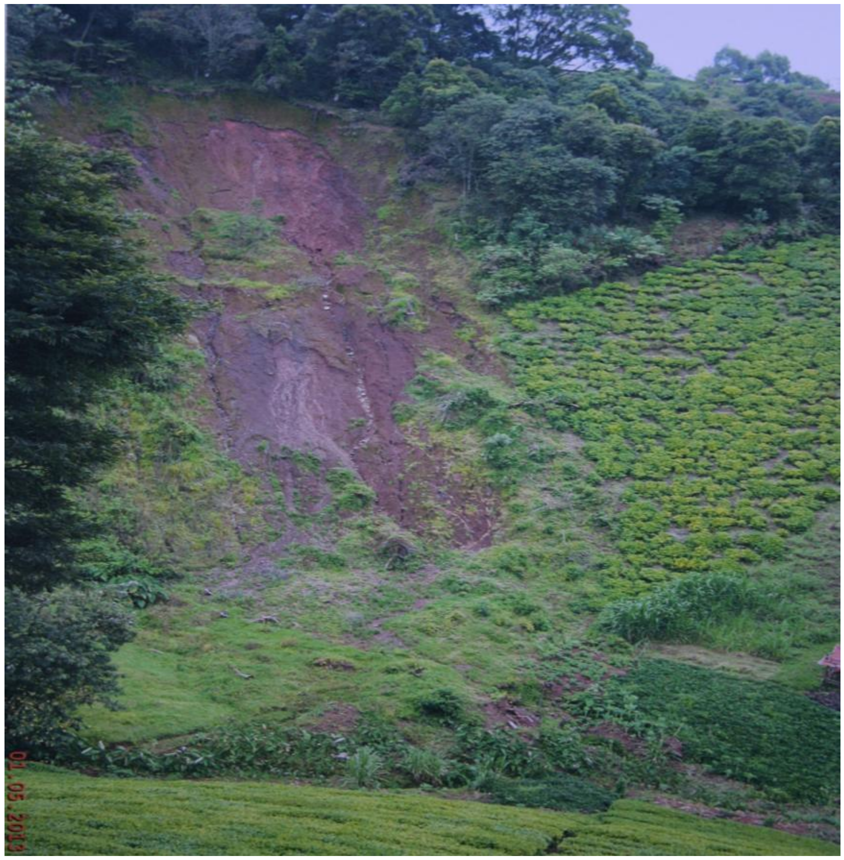


**Photo: November 2013**

**<u>Photograph 2 and 3</u>**

The photographs below show the occurrence of landslide in Nyarugumu Village at Kairo Location. The vegetation that is present in the area includes tea plantations, wild grass and trees that grow naturally. The land is majorly used for tea growing and food crop growing. The soil in the area is clay soil that is also volcanic in nature. The drainage of the area is at the toe of the slope where there is a spring that all the rain water drains. The volume of water differs depending on the season of long and short rains. The main cause of landslides in the area is very steep slopes that are convex shaped as shown in the photograph. This is followed by settlement at top of the slope and infrastructure development at the toe of the slope. The occurrence of landslides in the area is very frequent the latest landslide took place in April 2012 and March 2013 that is less than a year triggered by the very steep slopes and heavy rainfall.

**Figure 15: photographs showing the occurrence of landslide in Nyarugumu Village at Kairo Location.**

**Photo: November 2013**

Photograph 4

The photograph below shows the occurrence of landslides in Ndunduini village Kairo Location. The vegetation that is commonly found in the area is tea plantation and grass. The land is used for tea growing, crop growing and trees grow naturally. The soil present in the area is clay soil that is of volcanic origin. The area has emerging streams at the foot toe of the slope that join in River Mathioya where the rain water drains into. The main reason why this area is prone to landslides is because of the steep slopes. This is followed by the settlement at the toe of the slope and the infrastructure development cutting almost the toe of the slope. The current occurrence of the landslide in the area was in June 2012 which was triggered by infrastructure development cutting almost the toe of the slope.

**Figure 16: photograph showing the occurrence of landslides in Ndunduini village Kairo Location**


**Photo: November 2013**

**<u>Photograph 5</u>**

The photograph below shows the occurrence of landslide in Kamunjini Village in Murang’a County. The type of vegetation in the area is tea plantation and growth of eucalyptus trees. The land is majorly used in tea plantation and tree growing. The type of soil that is in the area is clay soil of volcanic origin. The main cause of landslides in the area is steep slopes and terracing. The other main reason that could trigger landslides in the area is infrastructure development at the top of the slopes. The latest occurrence of landslide recorded in the area was in April 2013 that was triggered by leakage of piped water accelerated by the long rains.

**Figure 17: photograph showing the occurrence of landslide in Kamunjini Village in Murang'a County**

**Photo: November 2013**

**Table 8: Summary of Landslide occurrence observed in Kairo location**

| **Village** | **Occurrence** | **Land use** | **Rainfall** | **Cause of Landslide** |
|---|---|---|---|---|
| Irima | April 2013 | Tea growing | 1500 – 2000 mm | Very steep slopes ($45^0$) |
| Nyarugumu | April 2012-March 2013 | Tea growing | 1500 - 2200 mm | Convex shaped steep slopes |
| Ndunduini | May 2012 | Tea growing Crop growing | 1500 – 2200mm | Infrastructure development cutting at the toe of the slope |
| Kamunjuini | April 2013 | Tea growing | 1500-2200mm | Leakage of piped water supply |

Source: Author, 2013

From the study findings landslides occurrences in Kairo Location are caused by high and intense rainfall, very steep slopes with convex shapes, infrastructure development cutting at the toe of the slopes and leakage of piped water supply and eroding of the toe of the slope by the river by the river Mathioya in Ndunduini village.

# CHAPTER SIX: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

## 6.1 Introduction

This chapter consists of the summary of findings, conclusion and recommendation of the study and there after the suggestions for further studies respectively.

## 6.2 Summary of Findings

The summary of the findings were done according to the specific findings of the study obtained in chapter five.

The study found out the main factors responsible for causing landslides in Kairo location of Murang'a County Kenya. The findings established that heavy rainfall, human activities and steep gradient slope as the main factors responsible for causing landslides in Kairo location. The study found out the human activities that caused landslides in the area of Kairo location as deforestation and removal of vegetation on slopes, excavation of the slope, loading of the slope or its crest, defective maintenance of drainage systems, water leakages from water supply and terracing on the slopes. The study sought to find out the socioeconomic impacts of landslides in Kairo Location of Murang'a County and it established that the socioeconomic losses due to slope failures are great and apparently are growing as the built environment expands into unstable hillside areas under the pressure of expanding populations and the human activities disturb large volumes of earth materials. The farmers in the area were also aware that the cause of landslides in the area was infrastructure development at the top of the slope and development of piped water supply in the area. The local government sends out warnings to the residents and indicates that development is in progress hence indicating that the zone is a prone area to landslide and therefore people should keep distance. The local government also discourages settlement of the residents at the top of steep slopes because they would likely be victims of landslides in the area. Landslides occurring in one area send out messages to other neighboring settlements in the area and people are evacuated earlier to avoid loss of lives.

The study findings proved the research hypothesis true that landslide occurrence in Kairo Location in Murang'a County is related to intense rainfall and steep gradient.

**Hypothesis**

**HI:** There is a significant relationship between rainfall, steep gradient,and landslide occurrence in Kairo location

## 6.3 Conclusion

From the study findings it was concluded that heavy rainfall, geology, soil thickness, weathering, steep slopes, fluvial erosion of slope toe and loading of the slope or its crest are geomorphological factors that causes landslide in Kairo location.

The study also concluded that human activities such as excavation of the slope through road cuts, loading of the slope or its crest through establishment of settlement, water leakages from broken water pipes, terracing, and increased agricultural activities have greatly contributed to the occurrence of landslides

Further, it was concluded that landslides in Kairo have adversely affected physical and social-economic environment through the loss of property, land degradation, destruction of infrastructure, and displacement of residents, boundary conflicts, and siltation of rivers.

The study concluded that trees have some effect on stability of slope. The trees have root systems that reduce soil moisture and lower the water table in the underground level while tree vegetation causes increased infiltration and shear stress causes root wedging. After clearing the sources are deprived of the tree roots through decomposition. Landslides are hence commonly attributed to the loss of support from a root system. An increase in population is the continuing high rate of deforestation due to logging, burning and development, a factor that increases landslide activity on the world's slopes. The study concluded that among all other counties in Kenya, Murang'a is a prone area of landslides leading with the highest number of history record of landslides in the country.

## 6.4 General Recommendations

The study recommends that sustainable communication through educating the residents of Kairo location should be the most effective way to mitigate landslides in the area. The study recommends policies to be implemented in controlling the high rising population that demands for more land hence forcing settlers to buy and settle in the steep slopes prone to landslides. The study also recommends that deforestation to have penalties that are answerable to the law because the trees and vegetation protect the land against soil erosion and avoid too much water accumulating underground forming water tables that weaken the ground makes it prone to landslides hence extensive afforestation programs should be practiced. In addition, engineering methods should be involved such as changes in slope geometry, control of ground pore pressure, and stabilization by building retention walls or anchoring.

### 6.5 Recommendation for Further Studies

The researcher recommends that policies should be developed in landslides prone areas in the protection of lives and livelihoods in Kenya. Finally the researcher recommends that future researchers should investigate on the influence government policies has on human activities causing landslides in prone areas.

# REFERENCES


Borg and Gall, (1996). An experimental investigation of post-earthquake travel behaviors: The effects of severity and initial location. *International Journal of Emergency Management, 6(1),* 14-32.

Brabb E.E. & Harrod B.L., (1989). *Landslides; Extent and Economic Significance .*A.A. Balkema Rotterdam.

Center for Hazards and Risk Research at Columbia University (2005). *Natural Disaster Hotspots—A Global Risk Analysis. Available from* Central Santa Cruz Mountains, California, in Debris Flows/Avalanches: Process.

Chan, (2000). Geohazard around the Michesi and Zomba areas. In the proceedings of the symposium on natural geological hazards in Southern Malawi, Zomba.

Crozier, M.J. Field, (1984). *Assessment of slope Instability, in: slope Instability, (Eds.).*

Cruden, D.M and & Varnes, D.J. (1996*). Landslides types and processes*. In A.K. Tuner.

Davies, T.C. and & Nyambok, I.O. (1992).*The Murang'a landslide, Kenya. Environmental.*

Finlayson CM, Storrs MJ & Lindner G. (1980). Degradation and rehabilitation of wetlands in the Alligator Rivers Region of northern Australia Wetlands Ecology and management 5, 19–36.

Fleming, R.W and & Taylor, F.A. (1980). *Estimating the costs of landslide damage in the* Flows, Geografiska Analer, 62 A (A (1-2), 23-27, 1980.

Geological Singleton (1993).*Survey, Zomba. ill slope stability and land use*. Water sources monograph series, No. 11, American Geophysical Union, Washington D.C.

Glade, T., (1998). Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. Environmental Geology 35, 160– 174.

Gori, M.; Carpenter, G. M. & Ottino, P. (2003). Spatial distribution and diet of the Neotropical otter Lontra longicaudis in Ibera Lake (northern Argentina). Acta Theriologica 48 (4):495-504.

Gunderson (1999). Keeping catastrophic change in context. In G. Gregory (Ed.), *Wellington After the 'Quake: The Challenge of Rebuilding Cities* (pp. 55-60). Wellington: Earthquake Commission and the Centre for Advanced Engineering.

Haque, C.E. and & Burton, I. (2005). *Adaptation options strategies for hazards and Vulnerability mitigation: an international perspective*, Mitigation and Adaptation Strategies for Global Change.

Haque, C.E. and Burton, I. (2005) *Adaptation options strategies for hazards and http://www.ldeo.columbia.edu/chrr/ research/hotspots/coredata.html. Links: Core Data Sets/Hazard Frequency and/orDistribution/Global Multihazard Frequency and Distribution (accessed 19 June 2007 and 12 December 2009).*

Hunger *et al*., (2001). Regional-scale GIS-models for assessment of hazards from glacier lake outbursts: evaluation and application in the Swiss Alps. *Natural Hazards and Earth System Sciences*, 3, 647–662.

Hutchison, (1988). *Analysis of Rock-Fall and Rock-Fall Avalanche Seismograms in the French Alps. New York: J. Wiley*.

Ingang'a and Ucakuwun (2001). Attributed works: Sketches showing the damage to buildings sustained in the 1848 Wellington earthquake. Reference number: PUBL-0050-01 *Part of:* An account of the earthquakes in New Zealand. Extracted from the New South Wales sporting and literary magazine and racing calendar. (Sydney, printed by D. Wall, 1848) (PUBL-0050).

Jakob, M. and Weatherly, H. (2003). *A hydro climatic threshold for landslide initiation on the North Shore Mountains of Vancouver*, British Columbia. Geomorphology, 54, pp. 137–156.

Johnston, D. M., Dolan, L., Saunders, W. S. A., van Schalkwyk, R., Killeen, C., Cousins, W. J., *et al.* (2009). *Disposal of debris following urban earthquakes: guiding the development of comprehensive pre-event plans.* Lower Hutt: GNS Science. GNS Science report 2009/33. 27p.

Karanja and Mutua, (2000). Using action plans to increase voluntary actions that reduce earthquake damage. *EQC Research Project 06-101*. Wellington: EQC Commission Research Foundation.

Keefer, D.K. and & Larsen, M. C. (2007). *Assessing Landslides Hazards, Science, 316, 1136-1138, 2007.*

Kipsanai, J. A. (1986). *Rural Housing Type Plans. Nairobi: National* Knowledge as adaptive management. *Ecological Applications* 10:1251-1262.

Knapen *et al*. (2006). Earthquake occurrence, experience and appraisal in Wellington, New Zealand. *Professional Geographer, 35(4),* 462-467.

Krhoda, (2013). *Landslides in densely populated county at the foot slopes of Mount Elgon (Uganda):* Characteristics and causal factors. Journal of Geomorphology 73:149–165.

Levin (1999). How information about building design influences causal attributions for earthquake damage. *Asian Journal of Social Psychology, 10(4),* 233-242.

McBean, G. and & D. Henstra (2003). *Climate Change, Natural Hazards and Cities. Toronto, Institute for Catastrophic Loss Reduction. Members of Congress." Prologue 28 (1996): 162-67.*

Mikos, M., Brilly, M., Fazarnic, R. & Ribicic, M. (2006). *Strug landslide in W Slovenia: a complex multi-process phenomenon.* Eng. Geol.83: 22–35.

Mileti, Dennis S. and Colleen Fitzpatrick. (1999). *Great Earthquake Experiment: Risk Communication and Public Action. Boulder, CO:* Westview Press.

Moeyerson (1988). A night of terror: Wairarapa's 1942 earthquake. Masterton, Wairarapa Archive. 99p.

Montgomery, D. R., and Dietrich, W. E (1994). A physically-based model for the topographic control on shallow landsliding: *Water Resources Research,* v. 30, p. 1153-1171.

Msilimba G, Holmes P (2005) A landslide hazard assessment and vulnerability appraisal procedure; Vunguvungu/Banga Catchmen Northern Malawi. Natural Hazards 24: 99 – 216.

Msilimba G. (2002) Landslides geohazard assessment of the Vunguvungu/Banga catchment area in Rumphi District, MSc. Environmental Science Thesis. University of Malawi, Zomba.

Muller and Oberlander, 1974). Geohazards in the Michesi and Zomba Mountain Areas in Malawi. Technical cooperation report No. 96. 20915.5, Depratment of Geological Survey, Zomba.

Muwanga et al. (2001). The significance of Wellington being the capital in a disaster. In G. Gregory (Ed.), *Wellington After the 'Quake: The Challenge of Rebuilding Cities* (pp. 15-21). Wellington: Earthquake Commission and the Centre for Advanced Engineering.

National Research Council (NRC) (2006). *Facing hazards and disasters: disasters: understanding Human dimensions, committee on disaster research in the social sciences: future Challenges and opportunities. National Research Council of the National Academies. The National Academies Press, Washington, D.C., 408.,pp, pp.*

Ngecu M, Mathu E (1999) The El-Nino triggered landslides and their socio-economic impact on Kenya. *Journal of Environmental Geology38: 277 – 284.*

NRC(National Research Council). (NRC)(2006). *Facing hazards and disasters :disasters: understanding Human dimensions, committee on disaster research in the social sciences*: future Challenges and opportunities. National Research Council of the National Academies. The National Academies Press, Washington, D.C., 408. pp., pp.

Nyamai, C.M. (1997) .Consultative group on international agricultural research, Technical Advisory Committee Secretariat, Food and Agriculture Organization: Rome.

Oguchi, T., (1997). *Drainage density and relative relief in humid steep mountains with frequent slope failure*. Earth Surface processes and Landforms 22, 107-120.

Pierson and Costa, (1987). *Erosion and deposition at Mt. Thomas, North Canterbury*, New Zealand, Earth surface processes pp. 227-247.

.

Ritter (1987).Survival confidence of New Zealanders in outdoor and post-earthquake situations. *Australian Journal of Emergency Management 24*, 38-43.

Roling and Wagemakers (1998). Listening to reporters or engineers? How instance-based messages about building design affect earthquake fatalism. *Journal of Applied Social Psychology, 37(9),* 1956-1973.

Rosenqvist *et*, *al*. (1990). Demographic and psychological Factors and Preparation for Earthquakes. PhD thesis, Victoria University of Wellington.

Shakoor, A.; Smithmyer, A.J. (2005). *An analysis of storm-induced landslides in colluvial soils overlying mudrock sequences,* southeastern Ohio, USA. Engineering Geology. 78 (3-4):257-274.

Strahler (1950 Bio-engineering for land reclamation and conservation. University of Albert Press, Edmonton.

Temple and Rapp (1972) - *Studies of soil erosion and sedimentation in Tanzania.* Geogr. Ann., 54 A, 34:110-124.

Terzaghi . K., (1950). *Mechanisms of landslides. Geological;Geological Society of America*. Engineering Geology.*United States, U.S Geaol. Survey* Circular 832, 21pp.

Van asch (1980) .preparation: survival activities and mitigation activities. *Environment and Behaviour*, *40(6)*, 798-817.

Varnes, D.J. 1978. *Slope movement types and processes*. In R.L. Schuster and R.J. Krizek (eds), Landslides: Analysis and Control. Transportation Research Board.

Vernes, *D.J (1978). Slope Movements and Types and Processes*. Landslides analysis Landslides analysis and control. Transportation Research Board Special Report, 176:11-33.

VersonVersion, (2000). *Roots in the Rotunda: Finding Biographic al Information about Former Virginia," edited by C. Evans, pp. 165-195.* Bureau of American Ethnology Bulletin.

Walther Penck (1988). Landslides in East African highlands, slope instability and its interrelations with landscape characteristics and land use. Advances in Geo-Ecology 31: 317 – 325.

Westerberg and Christianson,(1998).*Where two plates meet: Earthquakes. In Life on the edge:* New Zealand's natural hazards and disasters. The Encyclopedia of New Zealand, pp. 28-75. Wellington: David Bateman Ltd.

Wieczorek, G. F., (1987). *Landslides in East African highlands, slope instability and its interrelations with landscape characteristics and landuse.* Advances in Geo-Ecology 31: 317 – 325.

# APPENDICES

## APPENDIX I: QUESTIONNAIRE FOR FARMERS

**Instructions:**

(a) Give brief answers in the spaces provided.

(b) In the boxes given, please tick appropriately.

### A. General information

1. Indicate your gender

Male [ ] Female [ ]

2. How many years have you been a resident of Kairo Location?

a. Below 1 year [ ]
b. 2- 5 years [ ]
c. 6-10 years [ ]
d. 10- 15 years [ ]
e. Above 15 years [ ]

3. Indicate your village area

a. Irima village [ ]
b. Nyarugumu Village [ ]
c. Ndunduini village [ ]
d. Kamunjuini Village [ ]

**B. Occurrence of landslides in Kairo Location**

4. How frequent do landslides occur in the area?

a. Very frequent [ ]
b. Frequent [ ]
c. Moderately frequent [ ]
d. Less frequent [ ]
e. Not at all [ ]

5. What are the main factors responsible for causing landslides in Kairo Location of Murang’a County Kenya?

a. Weathering and bulk density [ ]
b. Heavy rainfall [ ]
c. Gradient slope [ ]
d. Human activities [ ]
e. Water in the soil [ ]
f. Slope materials [ ]
g. Rivers [ ]

6. Are farmers in the area equipped with knowledge about the natural human factors causing landslides?

Yes [ ] No [ ]

7. What are some of the human factors that largely contribute to landslides?
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................

**C. Socioeconomic impacts of landslides**

8. What extent do landslides impact socioeconomic and physical environment impacts in Kairo Location of Murang'a County?

a. Very great extent [ ]
b. Great extent [ ]
c. Moderate [ ]
d. Less extent [ ]

9. What are the socioeconomic impacts of landslides in Kairo Location of Murang'a County?

.......................................................................................................................................
.......................................................................................................................................
.......................................................................................................................................

10. What extent do you agree to the following statements have an impact on social economic and physical environment? Using a scale of 1 to 5 where **1= strongly disagree 2= disagree 3= moderate 4= agree 5= strongly agree**

| **No.** | **Statements** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| a. | Landslides are an important part of the natural landscape system in dynamic mountain environment as that experiences constant uplift | | | | | |
| b. | Landslides play a major role in the evolution of landforms | | | | | |
| c. | Landslides are commonly associated with a trigger, such an intense rainfall | | | | | |
| d. | Rainfall-triggered landslides are part of a natural process of hill slope erosion that can result in catastrophic loss of life and extensive property damage in mountainous | | | | | |
| e. | Landslides have consequent effects on water resources, agriculture, transport, health, and socioeconomic conditions | | | | | |

**D. Adaptive responses**

11. Do farmers in landslide prone areas have adaptive responses they accustom to?

Yes [ ] No [ ]

12. What are the adaptive responses that are employed by farmers in landslide prone areas?

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13. What extent do you rate the effectiveness of the adaptive responses that are employed by farmers in landslide prone areas?

a. Very great extent [ ]
b. Great extent [ ]
c. Moderate extent [ ]
d. Less extent [ ]
e. No extent [ ]

## APPENDIX II: INTERVIEW GUIDE

**Interview guide for agricultural water and environmental officers**

**Instructions:**

Give brief answers in the spaces provided.

1. What amounts of rain are considered as a trigger to landslides?

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2. Why landslides are considered an important part of natural landscape system in dynamic mountain environment?

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3. What are the measures and mitigation strategies taken to create awareness to the residents of the area about landslide in advance?

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4. How do you control human activities that trigger largely landslides?

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5. What are some of the adaptation strategies employed by farmers to mitigate the effects of landslides?

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6. What are the external and internal casual factors that cause landslides?

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