MAPPING LANDSLIDE SUSCEPTABILITY ALONG THE NANDI ESCARPMENT IN KABRAS DIVISION, KAKAMEGA COUNTY, KENYA

BY

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A THESIS SUBMITTED TO THE SCHOOL OF ENVIRONMENTAL STUDIES IN PARTIAL FULFILMENT FOR THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL STUDIES (ENVIRONMENTAL INFORMATION SYSTEMS)

UNIVERSITY OF ELDORET, KENYA

2016

DECLARATION

Declaration by the Candidate

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Declaration by Supervisors

This thesis has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

This work is dedicated to my entire family.

ABSTRACT

Slope failure may occur in hilly terrain due to a combination of factors like deforestation, heavy precipitation, slope steepness and gravity, land use and cover. Whenever they occur, they may result in loss of property and/or life. Therefore their frequency in any area may be high if all the factors that trigger them are prevalent. The main objective of this study was to determine the factors that influence the occurrence of slope failure over space and time and produce a landslide susceptibility map of the Nandi Escarpment in Kabras Division. It also presents the capability of a Remote Sensing and GIS based approach to mapping the susceptibility of hilly terrains, with the Nandi escarpment as a case, to slope failure. A slope failure susceptibility map to help in identifying strategic points and geographically critical zones that are prone to landslide risks was developed. The study involved generation of landuse/ landcover maps extracted from Satellite Images, which were taken in the years 1973, 1995 and 2006. SRTM DEM 90m was used in generating slope and contour maps of the area. Soil maps were obtained as secondary data from Moi University Soil Laboratory and Soil Survey of Kenya, while rainfall maps were obtained from the Kenya Meteorological Department (KMD). A slope failure risk map of Kabras region was produced by overlaying all thematic maps and analysis using GIS was conducted after assigning appropriate ranks and weights to respective variables. Focused interview groups were used in data collection and probing historical information on land use changes in the area. The result is a map showing zones with varying degrees of susceptibility to slope failure. It is opined that such a map will enable decision and policy makers to identify and implement suitable mitigation measures, with hopes of forestalling future losses in life and property in the area of study**.** Settlement should be limited to slopes of less than 24^0 since, according to this study, slopes higher than this are prone to sliding. Land use policy of Kenya should be revised so as to establish what activities to be conducted in the slopes of various degrees.

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ACRONYMS

AOI	Area of Interest
DDP	District Development Plan
DEM	Digital Elevation Model
GIS	Geographic Information Systems
GPS	Global Positioning Systems
IMG	Imagine
LULC	Land Use/ Land Cover
RCMRD	Regional Centre for Mapping of Resources For Development
RGB	Red Green Blue
ROK	Republic of Kenya
RS	Remote Sensing
SRTM	Shuttle Radar Topographic Mission
TIFF	Tagged Image Format File
UTM	Universal Transverse Mercator
WGS	World Geodetic Systems

DEFINITIONS OF OPERATIONAL TERMS

Angle of repose- the maximum slope angle at which a given unconsolidated material is stable.

Driving forces- Those forces that tend to make earth material slide.

Land cover-refers to natural vegetation, water bodies, rock, soil, artificial cover and other features that result due to land transformation

Land use- refers to man's activities and various uses which are carried out on land.

Landslide- a general term applied to a rapid mass wasting event, a mass movement which occurs suddenly when the delicate balance in slopes between resisting forces and driving forces is altered in favour of the latter.

Layer stacking-A function which different images representing different spectral bands are built into layers of one image file

Mass movement - the downward movement of rocks or soil as a more or less coherent mass.

Mass movement / wasting- the downward movement of earth material due to gravity

Mass wasting - any type of down slope movement of earth materials,

Mosaicking- Mosaicking is a process of joining two or more image files that have an overlap to produce one single complete image file of an area being analyzed.

Resisting forces- Forces that tend to oppose down slope movement of earth materials.

Shear Strength- the ability of a material to resist shearing stress

Shearing stress- Stress that tends to cause different parts of an object to slide past each other across a plane; with respect to mass movements stress tending to pull material down.

Slide- A form of mass wasting in which a relatively coherent mass of material moves down slope along a well- defined surface

Soil liquefaction-describes the behavior of loose saturated unconsolidated soils, i.e. loose sands, which go from a solid state to have the consistency of a heavy liquid, or reach a liquefied state.

ACKNOWLEDGEMENTS

First and foremost, I wish to thank God for gifting me with abundant life and good health. Thank you and glory be to your name for blessing my work.

Words fail me when I think of my supervisors. First, I thank Prof. Elias Ucakuwun of the Department of Environmental Earth Sciences, University of Eldoret and Prof. Gilbert Nduru of the Department of Environmental Studies, Karatina University for their keen interest in my work, and close supervision of this work. Their relentless encouragement, support and guidance right from the proposal writing are most invaluable to ever be forgotten.

I owe most gratitude to the entire staff of Regional Centre for Mapping of Resources for Development, Kasarani. They worked tirelessly to ensure that all the satellite images I required for this work were gathered, sometimes under very difficult circumstances. May God bless them abundantly.

To the School of Environmental Studies staff, I say thank you so much.

To my parents Mr. and Mrs. Ambrose Chepkwony, I say thank you for your financial support throughout my studies,

I am also greatly indebted to my husband Mr. Francis Tarus for standing patiently with me through all the stages of this work; His unfailing love, support financial assistance and prayers gave me the much needed strength, May God bless him abundantly.

I surely owe innumerable thanks to all my friends and classmates. They remained sweet to me and prayed for and with me till this manuscript is now accomplished

I cannot individually thank everyone who offered some assistance to me. To all I have not mentioned by name, please accept my most sincere appreciation for all that you ever did for me. Thank you and May God bless you exceedingly.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

According to the World Atlas of Natural Hazards (McGuire *et a*l., 2004), landslides are the most frequent and widespread natural hazard on Earth. They can occur on any terrain given the favourable conditions of soil or bedrock, groundwater, and the angle of slope. Landslides commonly occur in conjunction with other natural hazards such as rainstorms, floods, earthquakes, volcanic eruptions or tsunami. Every year landslide activity causes significant economic losses including losses of property as well as of human life in different parts of the world.

Landslides are mass earth movements, which occur suddenly whenever the delicate geomorphic balance of materials within slopes, between resisting forces, and driving forces is altered in favour of the latter (Marsh, 1991). Prediction of potential landslide areas has always been very difficult because of the complexity of the interacting factors, which are wide ranging. The factors that are usually related to landslides are soil type, rainfall, land cover, slope inclination, slope aspects, elevation, geology, land surface temperature, surface drainage and underground water dynamics.

Normally the causes of slope failure are determined by sampling all these factors from selected study sites. Often, the activities require much time and capital input, making landslide studies not only difficult but also a time-consuming job for a large area. By integrating relevant spatial data into a GIS as themes, the data can be easily overlaid and analysed to determine landslide risk areas.

Routine use of remote sensing data and GIS analysis can ease the monitoring of slope failure susceptibility. Landslide analysis is a complex analysis involving multitude of factors and it needs to be studied systematically in order to locate the areas prone to landsides.

Geographical Information System (GIS) is useful in the hazard mapping of landslides. One of its main advantages is the possibility of improving hazard occurrence models by evaluating their results and adjusting the input variables. Another aspect is the possibility to store, treat and analyse spatio-temporal data. GIS is an excellent tool to display the spatial distribution of landslides along with their attributes.

Slope failure occurs along river banks, hilltops, agricultural zones and along road construction zones. This results from the destabilization of the slope which results in reducing the resisting force and increases the driving force. Slope failure causes the destruction and losses to the environment, in that it leads to soil erosion, burying of vegetation and blocking of river channels.

In Kenya, as in other parts of the world afflicted by frequent occurrences of this environmental hazard, studies have been conducted to try to understand the causes of landslides and map susceptible areas.

Slope failure results in human and livestock fatalities and in the destruction of the landscape, structures, infrastructure and agricultural lands. Some of the effects of the slope failure are direct and immediate while others are indirect and may be long term. Damages caused by slope failure are estimated in millions of dollars annually while fatalities due to the same around the world are in thousands of people (Kozlovskii, 1988).

In the hilly region (e.gThe Nandi Escarpment), slope failure constitutes one of the major hazards that cause losses of lives and property. Due to the increasing population and scarcity of land, people in the study area have been forced to clear vegetation on steep slopes to create land to live on and for cultivation (unstable). They tend to destabilize the geomorphic stability of the slope by cutting into the slope to construct houses hence overloading the slope thus slope failure.

1.2 Statement of the Problem

The occurrence of mass movements in Kenya has become frequent and often disastrous to lives and livelihoods of affected populations as well as to the national economy and the environment.

Two landslides occurred at around 4:00am and 11:00am on 11th August 2007 at Khuvasali village and resulted in fatalities and heavy losses that indicate the underlying danger that awaits many other unsuspecting areas in Kenya with similar landscape and climatic conditions. In the area of study, many homesteads and economic activities still occupy hilly environments, while residents live in fear, yet there is no information on what potential danger they could be faced with and which areas are safe for settlement and their activities. For that reason there was an urgent need to study and identify potential areas where landslide hazards could occur and determine which areas are relatively safer for respective land uses. This study sought to use Remote Sensing, GIS analysis and accumulated knowledge to enhance the prediction of slope failure hazards in a manner that provides timely warning in the area.

1.3 Objectives of the Study

1.3.1. Main Objective

1. The main objective of the study was to develop a slope failure susceptibility map of the Nandi Escarpment within Kabras Division using RS and GIS.

1.3.2. Specific Objectives

i. To map land use and cover changes of the Nandi Escarpment within Kabras division from 1973 to 2006 using RS and GIS.

ii. To determine characteristics of soils, slope and rainfall amounts, respectively, in relation to the slope failure occurrence in the area of study.

iii. To develop a slope failure susceptibility map of the Nandi Escarpment within Kabras Division.

1.3.3. Research questions

i. What are the slopes angles?

ii. What is the rainfall distribution?

iii. What are the soil types within the landslide scar?

iv. Is slope failure related to vegetation cover?

1.4 The study area

1.4.1 Location and Size

The study was conducted in Kabras Division, Kakamega North Sub-County, Kenya. Kabras Division is one of the eleven Divisions in Kakamega North Sub-County. It is located roughly between latitudes 0^o15'and 0^o30'North and longitudes $34^o30^,$ and 35^o 30'East. The Sub-County borders Butere/Mumias Sub-County and Bungoma County to the West, Nandi County to the East, Vihiga County to the South and Lugari Sub-County to the North.

Nandi Escarpment forms a prominent feature on the eastern border of the Kabras Division with its main scarp rising from the general elevation of 1,700m to 2,000 m within one kilometre. Thus the study will only cover the Nandi Escarpment from East Kabras location to Shivanga location (see Figure 1.1).

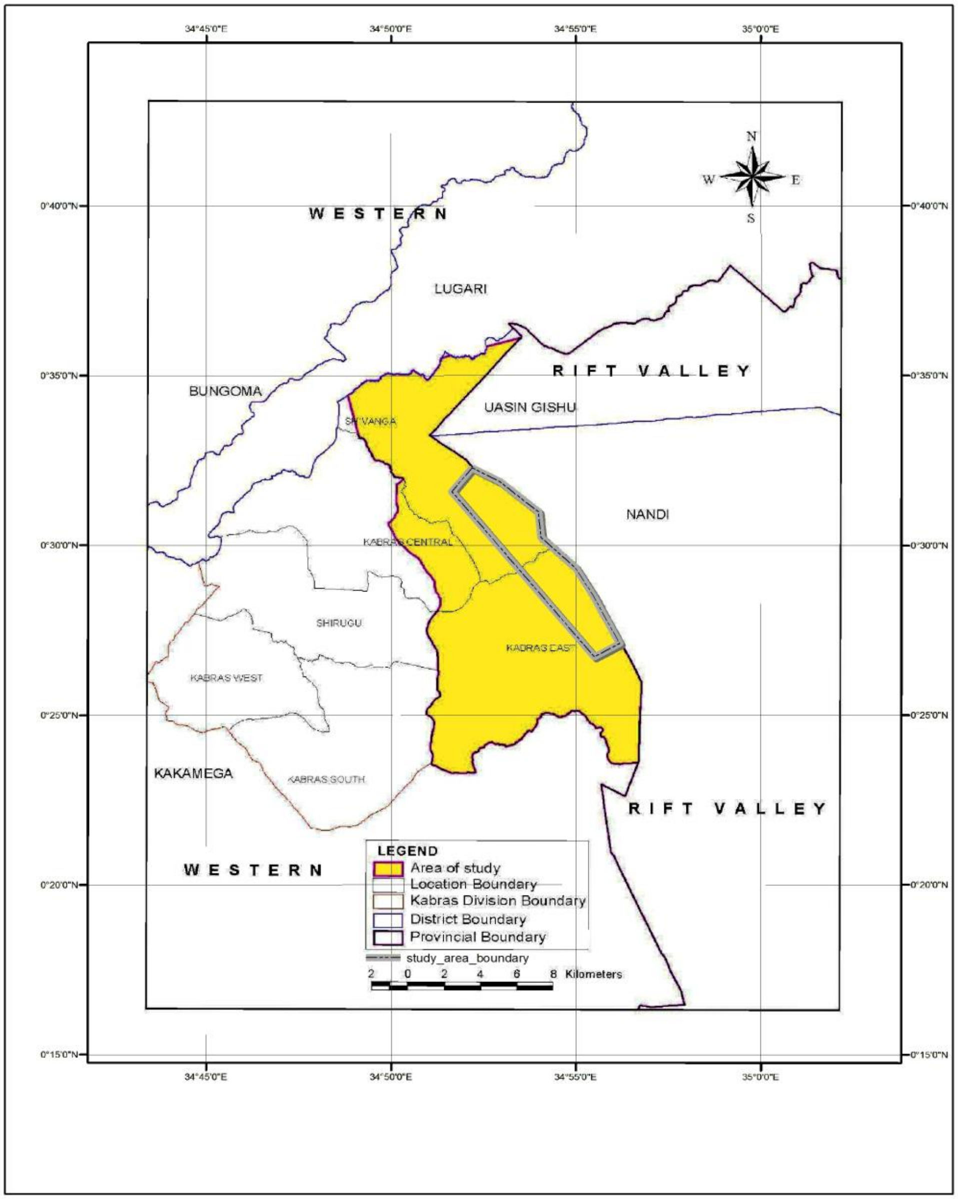


Figure 1.1: Map showing area of study.

(**Source:** Kakamega District Development Plan, 1994(modified)

1.4.2 Topography, Geology and Soil

The Nandi escarpment forms a prominent feature on the eastern borders of the division, with its main scarp rising from the elevation of 1,700 to 2,000 m. It has NNW trend and runs from about south of the Chavakali-Kapsabet road to around Webuye town. The escarpment rises over 1 km above the general elevation of the terrain to the west, making the escarpment slope very steeply to the west.

The Nandi escarpment forms the catchment zones for streams such as the Shitiya, Kabkalet and Nurungo, which flow westwards to form the Isiukhu River. Several small streams exhibit dendritic drainage patterns dissecting the peneplain surface often with steep erosional valleys (Republic Of Kenya 2002-2008),

The general geology consists of intrusive (mainly granite), Kavirondian sediments and Nyanzian volcanics all of Precambrian age. Over time rock weathering and vegetation cover have resulted in the formation of fertile soils. The Khuvasali area is on the Nandi Escarpment, hilly with steeply jutting slopes (Huddleston, 1975).

The heavy rainfall that Kakamega receives makes the soil vulnerable to mass wasting (Republic Of Kenya 2002-2008). Inganga *et al.*, (2001) concluded that soil with montmorilonite content has a high tendency to slope failure when moisture is increased.

1.4.3 Climate

The climate of the area is characterized by heavy reliable and well-distributed rainfall throughout the year. The pattern of rainfall is bimodal, falling in two peak seasons. The long rainy season lasts from March-June with peak in May while the short rainy seasons last from July to November with peak in September, other months receive normal rainfall with drier months being December, January and February. Lawrence (1986) reported a significant relation between rainfall and slope failure. High rainfall over a long duration provides a lot of water which infiltrate with time to increase soil water and the tendency of material to slide.

The average temperatures in Kabras vary between 18^0C and 20^0C. Low temperatures are usually recorded at night while very high temperatures are recorded during the day (Republic of Kenya, 2002-2008).

1.4.4 Population

Table 1.1 Sub-County Administrative Units

Division	Area (km^2)	No. of Locations	No. of Sub-location
Municipality	49.9	2	4
Lurambi	194.1	4	14
Navakholo	173.4	3	10
Kabras	424.2	6	24
Iileho	77.7	2	7
Shinyalu	332.6	4	16
Ikolomani	142.9	6	22
Total	**1,394.8**	**27**	**97**

Source: ROK, 2002-2008

During the Population and Housing Census 1999, Kakamega North Sub-County had population of 603,422 with an annual growth rate of 2.12 % compared to 488,352 in 1989, representing a growth rate of 2.98 % per annum. By the end of the plan period the population would have increased by 21 %, (Republic Of Kenya, 2002-2008). Land sizes are small, and continue to shrink with the swelling population.

1.4.5 Settlement Patterns

Most people tend to settle around and within the town and trading centers. Kabras had the largest number of people in 1999 (149,510). It has the least population density (352 per km^2) (Republic Of Kenya, 2002-2008).

1.4.6 Demographic characteristics

Kabras Division is inhabited by the Kabras and a few Kalenjins and Luos. The division is characterized by high birth rates and high population density with an average family size of 8 persons per household. These densities are among the highest in the Sub-County and in the republic thus creating pressure on the people to settle on steep slopes that are prone to sliding (Republic Of Kenya, 2002-2008).

1.4.7 Socio-Economic activities

A large part of Kabras Division lies within the lower midland zones which are characterized by sub-humid conditions and generally low fertility potential while some parts have very shallow soils. These factors have led to limited diversified agricultural economy. The area residents' predominantly grow maize as their food crop and sugar cane as their cash crop.

The land under gazetted forest covers an area of about 28,199.72 ha. Malava forest and Kakamega forest are covered mainly with indigenous forest. Illegal felling of tress for domestic use and systematic exploitation by saw millers without corresponding replanting program might leave the land susceptible to landslides and could lead to environmental degradation (Republic Of Kenya, 2002-2008). Tree roots are able to hold the soil firmly and take up a lot of water from the soil hence draining the excess water from the slope material (Nduru, 1995).

1.4.8 Infrastructure

The Escarpment is accessible from the Webuye-Kakamega road. Besides this tarmac road, other parts of the division are linked to neighbouring divisions and Sub-Counties by earth roads. This makes the area impassable during heavy rains. These diverse transports facilitate the inter-divisional, inter-Sub-County and rural to urban movement of people as well ad agricultural and consumer goods.

1.5 Scope of the Study

This study was designed to address factors which may act individually or jointly to cause slope failure in Nandi Escarpment. These factors included land use and cover changes, soil types, slope angle, and rainfall amounts and distribution. Although there are many factors which may act in combination to cause slope failure in Nandi Escarpment, the study will only use soil data, slope data, LULC data, and rainfall data.

1.6 Justification of the Study

From the study a slope failure susceptibility map showing zones with varying degrees of vulnerability to landslides was obtained. This contributed to knowledge required to propose and implement suitable mitigation measures, thus preventing loss of life and property along the Nandi Escarpment. The findings of the study will help in prediction of potential occurrence of slope failure in the future, which will enhance disaster preparedness. Researchers may also use the findings of this study as a basis for further research in related areas.

CHAPTER TWO

LITERATURE REVIEW

Many authors (Nduru, 1995; Varnes, 1996; Zabura, 1969; Inganga *et al*., 2001) agree that slope failures occur due to a combination of factors such as: high intensity and long duration of rainfall, steep slopes, disturbance of soil by cultivation, construction, mining and undercutting, removal of vegetation, earth quakes and jointing in rocks which make sliding easy.

The term “landslide” encompasses events such as rock falls, topples, slides, spreads, and flows (Varnes, 1996). A landslide is defined as, the movement of a mass of rock, debris, or earth downs a slope (Cruden, 1991). They are a type of “mass wasting” which denotes any down slope movement of soil and rock under the direct influence of gravity. The movement of soil and rocks may result from individual or joint effect of naturally occurring vibrations, changes in soil water content, removal of lateral support, loading with weight and weathering or human manipulation of water courses and the composition of the slope (Keller, 2002).

2.1 Landslide Hazard Maps

Varnes (1984) categorized landslide maps generally into the following:

Landslide inventory maps: This type of map shows the locations and/or outlines of landslides. A landslide inventory is a dataset that may present a single event, a regional event or multiple events. Small-scale maps may show only landslide locations whereas

Large-scale maps may distinguish landslides and classify different kinds of landslides and show other geological or geomorphologic data.

Landslide susceptibility maps: These types of maps usually divide the study area into zones according to different degree or level of proneness (susceptibility) to slope movement. Many susceptibility maps use a colour scheme that relates warm colours (red, orange, and yellow) to unstable and marginally unstable areas and cool colours (blue and green) to stable areas.

A landslide hazard map ideally indicates the probability of landslides occurring in a given area at a given time or with a given frequency. A hazard map, however, may be as simple as a map that uses the locations of old landslides to indicate potential instability, or as complex as a quantitative map incorporating probabilities based on variables such as rainfall thresholds, slope angle, soil type, and levels of earthquake shaking. Landslide hazard maps usually divide the study area into zones according to different levels of hazard to slope movement. They can also be called *landslide hazard zonation maps* (Varnes, 1994).

The other types of maps that include information on landslide types and features together with landforms and processes are ***geomorphological maps*** (and sometimes engineering geological maps). As far as landslide-related information is concerned, these kinds of maps are generally closer to the inventory-type of maps. However, some authors, such as Hansen (1984) also refer to geomorphic (or geomorphological) hazard maps when they include landslide hazard levels and other geomorphological features.

Landslide risk maps are however clearly distinguishable from all the above-mentioned maps, since they consider the exposure (or elements at risk) and vulnerability in addition to the susceptibility/hazard.

2.2 Causes of Slope Failure

Mass movement occurs whenever the downward pull of gravity overcomes the force, usually frictional, resisting it. The down slope pull tending to cause mass movements, called the shearing stress, is related to the mass of material and the slope angle. Counteracting the shearing stress is friction, or, in a coherent solid, shear strength. When shearing stress exceeds frictional resistance or the shear strength of the material, sliding occurs (Montgomery, 1989).

According to Griffiths (1999), landslide causal factors can be classified into two types: Preparatory factors and triggering factors. Preparatory factors make the slope susceptible to movement without actually initiating it, while the latter initiate movement. The trigger factor is an external stimulus that produces an immediate change in the stress-strain relationships in the slope, resulting in movement. The typical triggers are heavy rainfall or snow melt, earthquake shaking, volcanic eruption, erosion, or human factors. As the main factors that control slope failure, there are geological conditions, groundwater conditions, geomorphologic conditions, climatic factors, seismic activity, weathering, and man-made factors.

Slope failure can be triggered by high intensity and long rainfall duration, earthquakes, volcanic activity, changes in groundwater, disturbance and change of a slope by man-made construction activities, or any combination of these factors (Varnes, 1996).

Causes of slope failure are categorized broadly as internal (endogenic) factors and external (exogenic) factors. Internal factors commonly cited is increase in water-pore pressure or decrease in the cohesion of the slope material usually following heavy rainfall. External factors include disturbances such as earthquake shocks, vibration from vehicles and/or operation of heavy machinery in the vicinity, artificial increase in the slope angle, added weight on top of the slope, removal of lateral support from the toe of the slope and removal of vegetation (Alexander, 1992).

Nduru(1995) points out that, slope gradient, drainage density, soil texture, rainfall distribution, vegetation type and cover are major conditioners of landslide occurrence and that each of the parameters influence varies widely in space. Landslides occur during wet and dry seasons when they are caused by factors such as earthquake and poor surface and underground water drainage, steep slopes, high content of montmorillonite type of soil, high population density and overloading of the slopes (Inganga, 1995).

Zabura (1969) divides causes of slope failure into those that are due to disturbing forces and those that result from the weakening of the materials upon which the disturbing forces operate. If soil is completely saturated (for example, after heavy rainfall) the water exerts pressure within the pore spaces that tend to produce forces that push the grains apart. He also points out that when pore water pressure reaches high level in slope material, these materials may become unstable and lead to landsliding.

Zabura (*op.cit.*) adds that sliding of slopes is commonly caused by human activity and that "the diversity of forms and intricacy of interrelationships as well as the practical relevance of landslides can be recognized only by systematic and thorough study".

Zabura (op.cit.) adds that the variety of landslide types reflects the diversity of factors which are responsible for their origin. These factors are summarized as below:-

Changes in the vegetation cover

Inganga *et al*. (2001) and Ucakuwun et.al (2000) observed that the roots of trees maintain the stability of slopes by mechanical effects and contribute to the drying of slopes by absorbing part of the ground water. The cutting down of trees may cause instability of the slope and lead to occurrence of slope failure.

Land Cover Changes

UNESCO (1973) Muller et a*l*., (2002) Anderson *et al*., (1976) noted that current land cover information is essential information for a reliable environmental database. Land cover is the expression of human activities and as such changes with alteration in these. Hence, land cover is a geographical feature which may form a reference base for applications ranging from forest and rangeland monitoring, production of statistics, planning, investment, biodiversity, climate change, hydrology, to desertification control.

Change of slope gradient

Inganga (1995) concluded that change of slope gradient may be due to natural or artificial interferences for example change of slope gradient by mining may lead to instability and result in sliding of materials down the slope.

Rain water

Nduru (op.cit.) also observed that when the water penetrates the pores in soils, producing hydrostatic pressure, the increase in the pore water pressure induces a change of consistence which in turn causes a decrease of cohesion and internal friction. This may lead to sliding of material down slope.

Excess load by embankment, falls and water dumps

Ucakuwun *et al*., (2000) observed that excess load may increase shear stress and pore water pressure of clayey soils, which in turn decreases strength. When the shear strength reduces the slope material may slide due to the instability created.

Effects of human activity

Inganga *et al*., (2001), Nduru (1995) and Ucakuwun *et al*., (2000) point out that slope failure may result directly or indirectly from the activities of people. Slope failures can be triggered by construction activity that undercuts or overloads dangerous slopes or that redirects the flow of surface or ground water. Forest clearing may increase rate of surface water run-off or ground-water infiltration

People increase the risk of slope failure by modifying the landscape e.g. building on unstable slopes or in the path potential landslides. Unfortunately,such people are unaware of their exposure to slope failure risk.

Smith (1996), Pipkin (1994), Kozloskii (1988), Cooke and Doomkamp (1990), Keller (1982) have recognized, both empirically as well as from deductive evidence that slope failures are triggered by a combination of factors. The factors are commonly cited as increase in slope angle, high rainfall intensity, removal of lateral support at the toe of the slope, added weight at the top of the slope, earthquakes and other shocks and vibrations and vegetation removal.

Fitzpatrick (1983) noted the significance of clay in influencing occurrence of slope failures. He pointed out that soils containing montmorillonite minerals in the hot environments with alternating wet and dry seasons have been known to cause sliding. During the dry season the soil dries contracts and eventually develops cracks which may be over 10 cm wide on the surface and extend down for a meter, some of the upper horizon falls to the bottom of the crack where it stays until the wet season when the soil absorbs water and expands. High organic matter content also increases the water holding capacity of the soil. The water which accumulates underground leads to the occurrence of landslides by causing lubrication between the shear surface and the mass of debris on the slope.

Moore and Reynold (1989) who studied landslides in Canada refer to landslides as retrogressive slope failures, retrogressive because successive failures hit further into the landscape. They found out that wherever there are expandable clay minerals in the upper

cretaceous shales, slope failure can occur at relatively low slope angles of as low as 4^0. They realized that slope failure occurs frequently during periods of prolonged rainfall events. Other factors influencing the occurrence of slope failure include rock and soil type, drainage and the type of vegetation present. Landslide occurs when the driving forces exceed resisting force. In an example of a landslide, which occurred in South Africa, the colluvial soils involved were relatively thin and therefore became quickly saturated by the heavy rainfall. This is in contrast to observation by Ucakuwun *et al.*
(2002) that certain types of slope failures occur at the beginning of the rainfall season after a prolonged dry spell.

Inganga *et al*. (2001), in a paper on the rate of swelling of expansive soils, points out that none of the causative factors (heavy rainfall, artificial increase in the slope angle, removal of vegetation) on its own appears to be adequate to trigger slope failures. A combination of these factors is necessary to trigger a failure. Although this is the case, moisture saturation of the soil concerned always seems to be major factor. The soils in Nyeri County and other parts of central Kenya are frequently afflicted by the slump-type of land slide. Weathering of volcanic soils, over the years, produces deep profiles of brick-red latosols soil presumed to be rich in the montmorillonite group of clay minerals. The soil profiles are up to 5 m deep in these places. High relief rainfall associated with the windward sides of Mount Kenya and the Aberdares ranges here give rise to a dissected and rugged terrain of the Muranga and Nyeri Counties of central Kenya. These have one thing in common; they enable water to concentrate and infiltrate rapidly to deeper levels of the soil profile, resulting in landslides. Examples are landslides that occur on the down slope side of houses constructed on terraced surfaces, water leaking from an irrigation channel or a tank or water pipeline in Othaya Town, Kenya. Thus structures and infrastructure whose foundations rest in or above expansive soils suffer damages, often cracks and/or tilting them by the unstable soil they are in contact with.

Keller, (2002) point out that the following causes of mass-movement have been recognized. Absence of surface drainage and existence of channels or opening for seepage from internal sources greatly promote slope failures. This explains the frequent occurrence of slope failures during or after heavy or prolonged spells of rainfall. However rainfall duration and intensity are a major factor.

If the rocks are sheared and shattered, they will naturally become saturated with water. Their shear strength will consequently be less so that the driving force will overwhelm them, leading to perceptible sliding. Thus the degree of fracturing or jointing has a strong influence upon the shear strength of rocks.

Earthquake shocks, particularly those of shorter duration, acceleration of ground motion, tilt of the slope, modify the system of forces in a manner that driving forces get the upper hand. Thus the seismic shocks are the biggest trigger factor the extensive landslide caused by the 1950 earthquake in the eastern Arunachal Pradesh (India) bear eloquent testimony to this fact.

2.3 Classification/ Types of slope Failure

Slope failures can be classified according to a variety of factors such as material composition, and type and velocity of movement. The material involved in sliding includes soil, rock, and/or artificial fill. Common types of movement are creep, sliding and flow and fall (Nemčok 1982) or fall, topple slides (rotational and translational), lateral spreading and flow (Dikau *et al*., 1996). In a broad sense according to depth of the shear plane, landslides can be categorized as shallow landslides (<2 m) and deep-seated landslides (>10 m). Cooke and Doornkamp (1990) categorized landslides into active and inactive types; active types are those that occur frequently when triggered while inactive are those without recent experience of slope failure. In categorizing landslides, the material of which the landslide consists, the slope and location of the rupture or slip surface and the displacement or distance traveled during slide events are considered (Lundgren, 1986).

Faniran and Jeje (1983) classify mass movement based on the nature of water (or ice) present in the moving mass, the nature of the movement itself, and the speed of the movement. They came up with the following categories:

- Rotational slips: they include single rotational slip: multiple rotational slip in stiff and fissured clays, and in soft, extra-sensitive clay and clay flows; and successive, or stepped rotational slips.
- Translational slides: These include rockslides, block slides, slab or flake slides: detritus, or debris slides and mudflows subdivided into climatic and volcanic mudflows; bog flows, bog bursts; and flow failures subdivided into loess flow and flow slides.
- Falls: they include stone and boulder falls and rock and soil falls.
- Sub-marine slides: These include flow slides and unconsolidated clay slides.

Slope failures are commonly a complex combination of sliding and flowage. Important variables in classifying downslope movements are the type of movement (slide, fall, flow, slump, or complex movement), slope material type, amount of water present, and rate of movement (Keller, 2002).

According to Varnes, (1978), there are three common slope failure types (or slope movements). These are debris flows, debris and earth slides and rockslides.

Debris Flows — Debris flows are rapidly flowing mixtures of soil, rock particles and water. The soil mass that initially moves is usually a rocky, silt-sand mixture that is not highly plastic or cohesive (that means one that contains a lot of clay). The lower cohesion allows the soil to "liquefy" during heavy rains and move rapidly, up to 30+ mph down slope. (See figure 2.1)Once movement begins, there is often insufficient time to reach safety. Debris flows often originate in hollows on steep mountain slopes where thin (<6ft) soil overlies hard bedrock. The failed soil mass usually (though not always) travels down an existing drainage and accumulates into a lobe-shaped mass near the toe of the slope. Steeper slopes (>25-30 degrees) combined with a long run-out distance between the point of origin and the flatter toe-slopes create the potential for fast movement. Debris flows often originate in hillslope depressions, or hollows, near the headwaters of mountain streams. Often triggered by intense rainfall, debris flows typically follow mountain stream channels. Building homes or other structures at the base of steep hillslope (>30 degrees), especially near stream channels, increases their vulnerability to damaging debris flows.

Land-disturbing activity on steep slopes can also increase the likelihood of debris flows Ucakuwun et al. (2008)

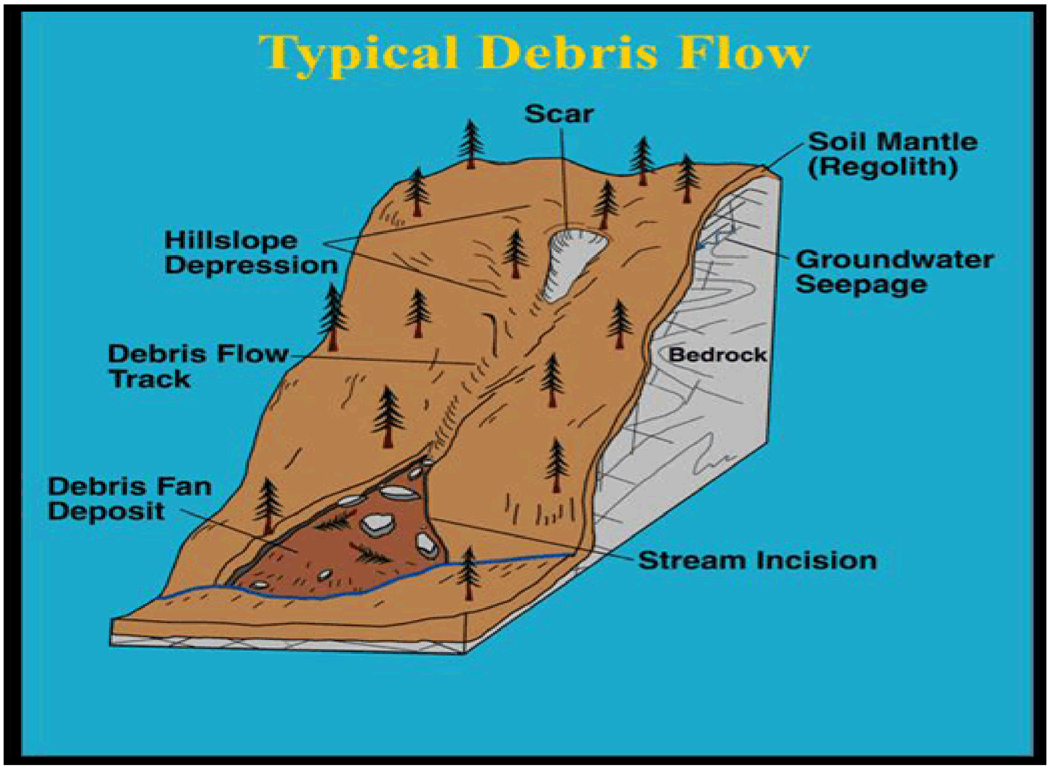


Figure: 2.1 Schematic of typical hillslope setting for debris flows.
(SOURCE: VARNES, 1978)

Debris or Earth Slides — Debris (soil-rock mixture) or earth (clay-silt soil) slides usually move at a slower rate than debris flows because the water content is too low for the mass to "liquefy". This can be due to the higher clay content of the soil that requires more moisture to liquefy. Movement rates are typically in the order of centimeters per day to meters per day, particularly during wet periods. During wet weather cycles, slides can be self-perpetuating. Initial movement opens tension cracks and scarps providing pathways for water to infiltrate deeper into the slide mass, thereby further decreasing the stability of the slope. Further movement widens existing tension cracks and scarps allowing more infiltration pathways, and so on. Shearing along the slide planes usually decreases the strength of the soil, a further destabilizing factor (Varnes, 1978).

Rock Slides and Rock Fall - Rock slides and rock fall usually occur along roadways, but can occur on any modified or natural rock slope. They can occur in conjunction with heavy rainfall, but often occur at other times, usually without notice. Freeze-thaw cycles and wedging by tree roots can loosen blocks of rock from a slope. A rolling and bounding basketball-sized rock can easily go through a roof. Rocks slide or fall because of pre-existing planes of weakness within the rock mass. Where these planes of weakness are inclined toward and intersect an excavated slope, the odds of a rockslide increase (Varnes, 1978).

2.4 Landslide and Mass Wasting Process

Keller (2002) defined sliding as the down slope movement of a coherent block of Earth material. Landslide is defined as the movement of mass of rock, debris or earth down a slope. Most landslides are small and slow, but a few are large and fast. Both may cause significant loss of life and damage to human property.

Mass wasting is a comprehensive term for any type of down slope movement of earth materials as landslide can also be defined as the downward movement of rocks or soil as a more or less coherent mass. Marsh (1991) describes landsliding as a mass movement which occurs suddenly when the delicate balance in slopes between resisting forces and driving forces is altered in favour of the latter.

2.4.1 Slopes and Landslide Occurrence

Slopes are the most common landforms on earth, and although most slopes appear stable and static, they are dynamic, evolving systems. Slopes are not generally uniform in their shape but are composed of segments that are straight or curved depending on the rock type and climate. Free-face slope is more common on strong and hard rocks or in arid environments where there is little vegetation. Convex and concave slopes are more common on softer or with a more humid wet climate where thick soil and vegetation are present. But there are many exceptions to these general rules, depending upon local conditions.

Materials on most slopes are constantly moving down the slope at rates that vary from an imperceptible creep of soil and rock to thundering avalanches and rock falls that move at tremendous velocities. These slope processes are one significant reason that valleys are much wider than the stream they contain.

Slope gradient varies widely in space and has a high influence on the location, type and magnitude of landslide occurrences (Swanson and Dryness, 1975). Sidle *et al.*, (1985) noted that steep slopes are most vulnerable to slope failure because gravitational force acts maximumly to the direction of the steepest slope. Thus gravitational pull makes it easier for shear stress to overcome shear strength of surficial materials on steep slopes than on gentle slopes (Larsson, 1986).

Robinson (1972) also observed that, landslides are common in areas of high amplitude of relief and steep slopes. He noted that, amplitude of relief greatly influences the energy of slippage at slope toe due to the weight of the overlying regolith.

In reference to Keller (2002), to determine the causes of landslides, we examine the slope stability which is expressed in terms of the forces that act on slopes. The stability of a slope expresses the relationship between the driving force, which moves earth material down a slope and the resisting force, which opposes such movement. The most common driving force is the downslope component of the weight of the slope material, including anything superimposed on the slope such as vegetation, fill material, or buildings. The most common resisting force is the strength or the resistance to failure by sliding or flowing, of the slope material acting along potential slip planes. Potential slip planes are geologic surfaces of weakness in the slope material, for example, foliation planes in a slope composed of schist, bedding planes in sedimentary rocks, and fractures in all rock types.

Slope stability is evaluated by computing a safety factor (SF), defined as the ratio of the resisting force to the driving forces. If the safety factor is greater than 1, the resisting forces exceed the driving forces and the slope is considered stable. If the safety factor is less than 1, the driving forces exceed the resisting forces and a slope failure can be expected. Driving and resisting forces are not static: as local conditions change, these forces may change, increasing or decreasing the safety factor.

Driving and resisting forces on slopes are determined by the interrelationships of the following variables:

- Type of earth materials
- Slope angle and topography
- Climate
- Vegetation
- Water
- Time

2.4.2 The Role of Slope and Topography

For dry, unconsolidated material, the angle of respose is the maximum angle at which the material is stable. This angle varies with the material, smooth, rounded particles tend to support only very low angle slopes, while rough sticky or irregular particles can be pilled more steeply without becoming unstable. Other properties being equal, coarse fragment can usually maintain a steeper or slope angle lager than fine ones (Montgomery, 1989).

Montgomery (*op. cit*) also adds that solid rock can be perfectly stable even at a vertical slope but may lose its strength if it is broken up by weathering or fracturing. Also in layered sedimentary rocks, there may be weakness along bedding planes, where different rock units overly imperfectly; some units may themselves be weak or even slippery (clay-rich layers for example). Such planes of weakness are potential slide or failure planes. All else being equal, the steeper the slope, the greater the shearing stress, and therefore the greater the likelihood of slope failure.

The hill slope angle, which is a measure of how steep a hill slope is, is usually called the slope. Slope affects the relative magnitude of driving force on slopes. As the slope of a hill or potential slip plane within a slope increases, the driving force also increases; therefore, landslides are more frequent on steep slopes. Steep slopes are often associated with rock falls and debris avalanches, which are the very rapid down slope movement of soil, rock, and organic debris (Ucakuwun, 2002).

Debris flows are the down slope flow of relatively coarse material; more than 50% of particles in a debris flow are coarser than sand. Debris flow can move very slowly or rapidly, depending on conditions. Debris flows, debris avalanches, and mudflows vary in size: they can be relatively small to moderate events, confined to a single valley of slope with a few hundred to hundred of thousands of cubic meters of debris (Keller, 2002).

(Inganga *et al*., 2001) argue that in areas where landslides of the rotational type occur and in areas with expansive soil problem, the presence or association with the montmorillonite group of clay minerals has been recognized. The rate at which a given soil swells is determined by the clay content, the desiccation level and the rate at which moisture saturated point and the rate at which moisture saturation point is reached, depending on the availability of moisture. When exposed to moisture, the clay absorbs moisture upto 30% of its dry volume-this is near the moisture saturation point (Chen, 1998).

2.4.3 Soil and Slope failure Occurrence

The effectiveness of the soil to transport water depends on the size and permanency of the channels. The size of the conduits depends on the size of the soil particles, the degree of aggregation between particles and the arrangements of particles and aggregates (Inganga

1995). Soil influence is determined by its mechanical, physical, chemical and mineralogical composition. Soil with high clay content has a higher tendency to slide when soil moisture is increased. This is mainly because clay particles are separated by pore water pressure thus reducing the soil cohesion and shear stress increases (Montgomery, 1989).

The dryer the soil becomes, the more the montmorillonite minerals loose their water content, and decrease in volume and therefore the more the soil develops deep-extending cracks. Therefore, when subjected to a certain amount of water, e.g. from a given amount of rainfall, the dry soil will take in the water more rapidly to deeper levels through the cracks. The rate of expansion of the soil at this depth will be quite high, leading to a trigger of a landslide. Examples are the slope failures which occur commonly in the tea plantations and other cultivated slopes (Inganga *et al.*, 2001).

2.4.4 Rainfall and Slope Failure Occurrence

The role of climate is important because it influences the amount and timing of water, in the form or rain that may infiltrate or erode a hill slope. Water can greatly increase the likelihood of mass movement, for example it can seep along bedding planes in layered rock, reducing friction and making sliding more likely. An increase in pore water pressure in saturated rocks decreases the rock's resistance to shearing, tending to cause sliding. The very mass of water in saturated soil may add enough extra weight, enough additional shearing stress, to set off a landslide on a slope that was stable when dry. Some soils rich in clays absorb water readily; one type of clay, montmorillonite, may take up twenty times its dry weight in water and form a very weak gel. Such material fails easily under stress.

Sudden, rapid slope failure commonly involves a triggering mechanism and heavy rainfall can be a very effective trigger, quickly adding weight, decreasing friction, and increasing pore pressure (Montgomery, 1989).

Lawrence (1986) reported a significant relation between rainfall and slope failure. High rainfall over a long duration provides a lot of water which infiltrates with time to increase soil water and tendency of material to slide. Terzaghi (1962) noted that many slope failures in time and space have a strong correlation to rainfall amount and distribution in the year.

Persistent hot and dry weather would give rise to a much desiccated soil condition. The desiccation level would be relative, varying from point to point depending on the vegetation cover and the clay content of the soil at that point and the duration of the hot/dry weather conditions. At the onset of rainy season, the desiccation levels are at the highest. The first torrential rains yield so much run-off that much of it also infiltrates the already desiccated soil to deep levels through the cracks. At a point where the clay (montmorillonite) contents is high, the volume changes due to water absorbed would be very high and rapid, increasing the trigger potential of a slope failure at that point. This would explain why most of the slope failures occur at or soon after the onset of the rainy season (Ucakuwun, 2002). As the rainy season progresses, the soils at deeper levels absorb moisture from above (Inganga, 1995). The concentration of water in slopes also makes them vulnerable to slope failure (Temple and Rapp, 1972).

Water can cause slope failure by contributing to spontaneous liquefaction of clay-rich sediments, or quick clay. When disturbed, some clays lose their shear strength and behave as liquid and flow.

2.4.5 Land use Types Distribution & Slope failure Occurrence

Keller (2002) observed that poor land use practices have led to an increase in landslides. Given the factors that influence slope stability, it is possible to see many ways in which human activities increase the rate of mass movements. One way is to clear away stabilizing vegetation. Construction of stepped home-building sites on hillsides is among the activities that can cause problems. Where dipping layers of rocks are present, removal of materials at the bottom ends of the layers may leave large masses of rock unsupported, held in place only by friction between layers. Slopes cut in unconsolidated materials at angles higher than the angle of repose of those materials are by nature unstable, especially if there is no attempt to plant stabilizing vegetation.

In addition, putting a house above a naturally unstable or artificially steepened slope adds weight to the slope thereby increasing the shear stress acting on the slope. Other human activities apart from agriculture, especially settlement, road construction and quarrying lead to undercutting of slopes, over steepening and removal of pre-existing geomorphic balance (Marsh, 1991).

Greenway (1987) noted that, the role of vegetation in slope failures is complex. Vegetation in an area is a function of several factors, including climate, soil type, topography, and fire history, each of which also influences what happens on slopes. Vegetation is a significant factor in slope stability for three reasons:

- Vegetation provides a cover that cushions the impact of rain falling on slopes, facilitating infiltration of water into the slope while retarding grain- by- grain erosion on the surface.
- Vegetation has root systems that tend to provide an apparent cohesion (like iron bars in concrete) to the slope materials, which increases resistance to landsliding.
- Vegetation adds weight to the slope.

In some cases, the presence of vegetation increases the probability of a landslide, especially for shallow soil slips on steep slopes. During wet months, plants take up water through the roots adding considerable weight to steep slopes thereby increasing the driving force. The plants also cause an increase in the infiltration of water into the slope, which decreases the resisting forces. When failure occurs, the plants and several centimeters of roots and soil slide to the base of the slope.

William and Pidgeon (1983) found out that vegetation influence varies with space according to their root systems. Tree roots bind the surficial material together and improve slope stability (Larson, 1986). Gray (1970) concluded that the effect of vegetation on pore water pressure depends on the amount and distribution of rainfall and species composition of the vegetation cover.

2.4.6 Effects of Vegetation Removal

Although vegetation does add weight to a slope its net effect is generally to stabilize slopes. Plant roots especially those of trees and shrubs can provide a strong interlocking network to hold unconsolidated materials together and prevent flow. In addition, vegetation takes up moisture from the upper layers of soils through transpiration and reduces the overall moisture content of the mass. Increase in shear strength due to moisture loss through the vegetation by transpiration also helps to dry out sodden soil more quickly (Montgomery, 1989).

Vegetation cover, allows deep infiltration but also serves to retain the moisture longer by shielding the ground from the direct sun‘s heat. By removing the vegetation, the soils are exposed to the heat and high loss of moisture as a result of high rates of evaporation from them. The desiccation level of the clays is higher at a given depth for a vegetated area compared to a bare area (Inganga *et al.,* 2001).

The New Vision, (1999) reported that, Vegetated slopes, even in very steep terrains such as the slopes of Mt. Kenya and Mt. Elgon in Uganda which also receive a lot of rainfall do not experience landslides. One of the local residents of the slopes acknowledged that planting trees on the slopes was the only solution to ending landslides. He further commented that he noticed that the neighbouring Mt. Elgon National Park did not experience landslides because the trees had been preserved.

Dunne (1979) stated that in Kenya, slope failures are rare in forested regions inspite of heavy rainfall and steep slopes because of the stabilizing role of tree roots. After vegetation is cleared, trees roots decay leading to the loss of their binding effect and consequent decrease in shear strength. When trees and other vegetation is removed this process stops, and the amount of water in the soil may increase. Wet slopes are more prone to slope failures than dry slopes. If trees are logged the roots may die and decay. When they do, the soil loses some strength because root systems bind the soil together. The combined effects of wetter soils and reduced soil strength as the trees decay result in more shallow landslides (Keller, 2002).

2.4.7 Population and Slope Failures

Due to population pressure, the land is intensively cultivated, including the steep slopes ($>30^0$) and settlements have often been built on terraces on the steep slopes. Structures and infrastructure whose foundations rest in or above expansive soil later slide because of the removal of lateral support for foundations at the toe of the slope and added weight at the top of the slope (Inganga, 1995).

High population density in Nyeri County has led to overuse of land, a factor which tends to increase the chances of material sliding because of heavy weight of the material on the slope (Inganga, 1995).

2.5 Remote Sensing and GIS Applications in Slope Failures

Remote sensing and GIS techniques play a significant role in slope failure susceptibility mapping. Landslide scar identification, which is a crucial parameter for any regional landslide hazard assessment, can be very well done particularly with aerial photographs. Coupled with aerial photos, GIS is an excellent tool to display the spatial distribution of landslides along with their attributes (Keller, 2002).

Nowadays satellite-based remote-sensing techniques have become more efficient tool for obtaining such information with less cost and time. Remote sensing has been used to study the characteristic properties of ground surfaces due to its advantage of broad area coverage and observation. The integration of GIS with RS technology plus thematic map data may greatly facilitate the assessment and estimation of regional slope failure hazards.

2.5.1 Landsat TM

Remotely sensed data (LANDSAT TM) has found specific application in documenting landscape change through surface erosion and in identifying causative factors in landslide events,(Lillesand and Kiefer, 2002; Singhroy and Matter, 2000).

2.5.2 Digital Elevation Model (DEM)

Blumberg *et al*. (2005) point out that, in February 2000, the Shuttle Radar Topographic Mission (SRTM) collected Interferometric Synthetic Aperture Radar (IFSAR) data from a remote sensing instrument mounted on a NASA space shuttle. It generated over 80% of the landmass of the Earth between 60^{o}N and 56^{o}S of the most complete high-resolution digital topographic database of the Earth.

SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGIA) and the National Aeronautics and Space Administration (NASA). These SRTM Digital Elevation Models (DEMs) are now being distributed by several agencies both public and private.

Digital elevation models and digital terrain maps (DTM) can be used to derive a wealth of information about the morphology of a land surface using algorithms traditionally used for processing raster data. DEMs are widely and readily available, these include satellite derived DEMs such as SRTM.

2.5.3 Shuttle Radar Topographic Mission (SRTM)

Shuttle radar topographic mission (SRTM) has created an unparalleled data set of global elevations that is freely available for modeling and environmental applications. The global availability (almost 80% of the Earth's surface) of SRTM data provides baseline information for many types of the worldwide research. The processed SRTM 90 m digital elevation model (DEM) for the entire globe was compiled by the Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) and made available to the public via internet mapping interface. This product presents a great value for scientists dealing with terrain analysis, thanks to its easy download procedure and ready-to-use format. However, overall assessment of the accuracy of this product requires additional regional studies involving ground truth control and accuracy verification methods with higher level of precision, such as the global positioning system (GPS). As of April 2004, 90 m resolution data were available for North and South America, Africa (Kenya), and Eurasia (Blumberg *et al*., 2005).

Terzaghi (1950) observed that with the increasing availability of high-resolution data sets, GIS, and computers with fast processing capacity, it is becoming possible to partially automate the landslide hazard and susceptibility mapping process and minimize fieldwork.

Current landcover information is essential for a reliable environmental database. Land cover is the expression of human activities and as such changes with alteration in these. Hence, land cover is a geographical feature which may form a reference base for applications ranging from forest and rangeland monitoring, production of statistics, planning, investment, biodiversity, climate change, hydrology, to desertification control. (UNESCO, 1973; Muller *et al*., 2002; Anderson *et al*., 1976).

The use of RS data can be classified for the various phases of slope failure study: detection and classification, monitoring, analysis and prediction in space and time of slope failures (Mantonvani *et al*., (1996).

Chowdry (1982) recommended that, GIS can be used to determine the slope stability. It is very convenient and easy to understand where prediction of failures can be seen on a single map. This makes the studies much more accurate. RS and GIS-based prediction modeling can be effectively used for slope failure hazard analysis.

Carrara *et al*., (1991) noted that regional predictive models generally attempt to identify where slope failure may occur over a given region on the basis of a set of relevant environmental characteristics. Under the assumptions that slope failure in the future will be more likely to occur under the conditions which led to past and present slope movements, these models provide information on potentially unstable movement.

Musaoglu *et al*., (2002) concluded that RS data can be readily merged with other sources of geo-coded information in a GIS. This permits the overlaying of several layers of information with the remotely sensed data and the application of unlimited number of forms of data analysis. On the other hand, the land cover data generated by a classification may be used in subsequent queries and manipulation of the GIS database.

Geomorphologists use aerial photographs to reveal slide scars. They are also familiar with the types of unfavorable geological conditions that commonly lead to instability and that can be detected by aerial photograph interpretation. Such unfavorable geological features are faults and shear zones and mylonite zones. These can be recognized by geological studies.

Larsson (1986) and Montgomery (1989) also recommend use of air photos and satellite imageries of high spatial resolution such as *System Probatoire d'observation de la Terre*

(SPOT) as tools in the study of landslide prone terrain. These can enable qualitative as well as quantitative analysis of landslides. But this can only be possible in conjunction with data collected in the field (ground truth) by conventional methods.

Sabins (1987) observes that individual landslide events are difficult or impossible to predict by remote sensing or other methods. This is because slope failures are caused by multiple factors, e.g. rainfall which varies over a short period of time. In this work, however, existing slides may be recognized on images. Sabins (*op. cit*) also emphasized the use of Infrared images to recognize damp ground associated with slope failure. They showed that evaporative cooling of the damp ground produces a characteristics signature on aircraft thermal infra red image. Satellite radar and side scanning sonar have also been used to study unstable terrain where slides occur.

Zabura (1969) divides the approaches to studying landslide into two. One technique is used by geologists while the other by engineers and engineering geologists. Geologists, according to Zabura (*op.cit*), study sliding phenomena as one of the significant exogenic denudation processes, with respect to their (landslides) origin, causes and the resulting surface forms while the engineers and engineering geologists investigate the slope instability from the point of view of the safety of the structure to be erected on them. They endeavor to ascertain in advance the proneness of the slope to sliding, to determine the maximum angle of the excavated slopes and to develop methods for reliable assessment of the stability of the slope, as well as the controlling and corrective measures needed. The best results of landslide studies can be achieved only by the combination of the two approaches. In this study, some knowledge of these two approaches has been applied.

Pipkin (1994) observes that the mechanism of slope failure can be classified broadly as slides or fall. The slide types are classified according to the shape of the slide surface as (i) slumps or rotational slides (ii) block slides or translational slides where slumps or rotational slides move on curved, concave upward slide surfaces and are self-establishing while block slides or translational slides move on inclined slide planes until they meet an obstacle or until the slope of the slide plane changes.

Keller (2002) emphasizes the time factor in contributing to slope failures. It is noted that the study of landslide must include historic study of the slope prone areas. A slope may become less stable with time and lead to increasing rate of creep until failure occurs. The safety factor of a slope might also decrease with time because of progressive wetting which causes a disarrangement of the soil particles in the slope, lowering the internal friction and strength of the slope materials. Therefore, slope design should include provisions to minimize processes that might progressively weaken slope material and lead to failure.

Unstable sedimentary deposits represent a major hazard in many localities throughout the world. There are a number of factors which can lead to the movement of these deposits and masses. Some of the more common factors are increases in water content, changes in the slope of the topography, geologic structure, excessive loading, and loss of vegetative cover, changes in the properties of the materials, shocks and vibrations. Final movement can be rapid and with little warning. In some cases, however, movement is slow and almost imperceptible (Montgomery, 1992).

2.6 Slope Failures in Kenya

In many parts of Mount Kenya region people have expanded their agricultural land by encroaching onto forest areas. This deforestation enhances the risk of landslides in these areas. In Murang'a County slope failures have in the past buried families, e.g. in Kanyanyaine (Nduru 1995).

Nduru (1995) carried out research and focused on evaluation of spatial variation in landslide potential within the South Mathioya Drainage Basin. His research objectives were to establish different zones of landslide potential, ranking them according to the likelihood of slope failure occurrence in each of them. His study was based on five parameters, slope gradient, drainage density, soil texture, rainfall distribution, vegetation type and cover. He concluded that all the factors are important conditions of landslide potential and incidence in space. The spatial distribution of landslide potential is thus strongly controlled by the slope-soil-rainfall-vegetation complex in the basin.

Inganga (1995) carried out research on landslides and their environmental effects in Nyeri County. His main objective was to find out the main factors which contribute to the high occurrence of landslides and to evaluate the effects of the landslides on the environment. He found out that slope failures in the study area were caused by earthquakes and poor surface and underground water drainage and overloading of structures on them.

Soil samples studied showed high bulk density, high plasticity and high clay content. The high content of clay, high population density and steep slopes are believed to contribute highly to the frequent occurrence of landslides.

Davies and Nyambok (1993) studied the Muranga slope failures which killed eight people on the 16th, May 1991. They carried out field measurements and laboratory analysis of the soil samples and recommended that serious threats from slope failures need to be considered when planning large scale developments and that a catalogue of landslides in Kenya be kept by local and provisional authorities, who should protect the public by zoning areas at risk as hazard lands.

The list of landslides, which have occurred, is long and the damage caused to the national infrastructure will take a long time to rectify. Research investigations have revealed that the landslides were a result of four major factors. The factors included geology and soil of the landslide prone areas, high relief, steep slopes with poor anchorage for slope stability, continuous heavy precipitation which resulted in over saturation of rocks and soils. The effects of the El-Nino triggered landslides in Kenya were enormous. Most of the El-Niño associated landslides in Kenya occurred in areas of high relief. Examples of slope failures experienced in Kenya in the past include: On 10th November- Thika- Murang'a highway at Karugia, on 3rd January 1998 along Embu – Meru highway, on 15th January 1998 along Thika – Garissa (Ngecu and Gaciri, 1995).

Three people were injured and more than 500 displaced following a massive mud flow on Saturday September 8th 2007 in Keiyo Valley in Rift Valley Province. An unknown number of animals were buried in the slides while several hectares of crop were destroyed. In addition six schools in the area have either been submerged by water or swept away by mudflow affecting more than 100,000 students. Transport operations along the Valley were also paralyzed after the Iten-Fluospar road was damaged by the mudflow. According to the area Sub-County Commissioner, these land-slides are a result of destruction to the vegetation along the escarpment, loosening the soil, i.e. through charcoal burning or engaging in agricultural activities along the escarpment (Saturday Nation August, 18^{th} 2007).

Heavy rains experienced in the Western parts of Kenya resulted in landslides affecting Khuvasali village in Kakamega North, Busia County and Kerio Valley. A total of eight people were killed and 49 families displaced in Kakamega north. Rescue operations were hugely hampered by the incessant rainfall (Sunday Nation, August 12, 2007). A massive movement occurred in Khuvasali village, on Kabasar Hills along the Nandi Escarpment, East Kabras location, Kakamega North Sub-County on Saturday night and killed over fourteen people and several people were injured and admitted at Malava Sub-County Hospital with multiple fractures and dislocation (refer to plate 2.2). It also destroyed property and vegetation. Data from Meteorological Department showed that the western highlands received slightly more rain than it normally does. The occurrence of the landslide was then attributed to the heavy downpour which had pounded the area for three consecutive days (Sunday Nation, August 12, 2007).

Ucakuwun *et al*. (2008a and b) carried out a study on the causes of slope failures in Keiyo and Khuvasali Escarpment in 2007. The investigations revealed that the landslides were a result of four major factors: the geology and soils of the landslide prone areas, high relief, steep slopes with poor anchorage for slope stability, continuous heavy precipitation which resulted in over saturation of rocks and soils. The researchers warn that due to the above abnormal rainfall and saturated soil, more landslides can be anticipated. As a safety measure, people living on lower slopes are encouraged to relocate to safer areas, not higher on the slopes.

Heavy rains and human activities have been cited as the major causes of landslides in most parts of the country. This has been observed in areas like Nandi, Kakamega, Keiyo, Baringo, Meru and Murang'a Counties.

Plate 2.2 Khuvasali Slope Failures which occurred on 11, August 2007, Length-200m, width- 100m, and gradient - 35^0 (Source: Author, 2008)

2.7 Conceptual Consideration

Slope failures have become one of the world's major natural disasters in the past few years. Predictions of potential slope failure areas have been very difficult because of the complexity of the factors involved and their relationship with each other which is wide ranging. The factors which are usually related to slope failures are geology, soil type, land surface, temperature, land cover, underground water level, slope aspect, slope inclination and elevation. Normally the causes of slope failures are determined by carrying out some sampling of the soil, rock, slope inclination, land cover, underground water level, geology, etc at the site. It is difficult and time consuming to do this in a large area from time to time but by integrating it in GIS, all the information can be combined, manipulated and analyzed to determine potential landslide areas.

CHAPTER THREE

METHODS

This research was based on a number of approaches to data collection and analysis. Problems encountered in the study area are also given. Data collection involved observation, photography and measurements. Focused interviews were also used to collect data related to the history, causes, effects and mitigation of slope failures.

3.1 Data Collection

3.1.1 GPS and Ground Truthing

A GPS instrument was used to obtain accurate coordinates of data locations for each LULC classes, for the creation of training sites and for signature generation in LULC image classification.

3.1.2 Slope

Using an inclinometer, slopes at various locations at the landslide scars and within the study area were measured; the slope was measured from top of the edge of the scar to the lower edge (toe). The values within the scar of the slopes were later used to recommend which areas are safe for settlement and which are most susceptible to slope failures. The steepness of slope would indicate how severe the slope failure was.

3.1.3 Soil samples

Soil samples were collected from the landslide scar and from the immediate surrounding area (within 50 m from the scar). Undisturbed (*in situ*) soil samples were collected using a soil auger and plastic pipes of diameter 53 mm and length 60 cm. The pipe was driven into the soil and soil collected. Disturbed soil samples were obtained by scooping soil from the scar and kept in a polythene bag which was sealed and labeled for subsequent laboratory tests. Atterberg limit tests (liquid limit, plastic limit and plastic index), determination of bulk density and texture analysis were the laboratory analyses and tests conducted at the Civil and Structural Engineering Department Laboratory, Moi University.

3.1.4 Pictures

Pictures (snapshots) were taken to illustrate some visual landslides aspect. These included pictures showing current land use and land cover, landslide scar, settlement in the areas, farming activities, vegetation type and the activities on the escarpment.

3.1.5 Satellite Imagery

Landcover/Land use information was obtained from satellite images taken in 1973, 1995 and 2006.

3.1.6 Focused Group Interviews

Focused group interviews were conducted for checking the reliability of the information collected. This helped in improving the quality of the data. The focused group interviews involved discussion with the youth, men and women who live along the Nandi escarpment. Leading questions were used to obtain information from them. Discussions were held in Kiswahili, however local language was used where some or all participants were illiterate. Through it, a wide range of data and viewpoints were concerning the history of the landslide occurrences were gathered as participants helped each other to recall, verify or modify a view point.

In addition, some farmers in the area were interviewed at random, to obtain information on the frequency and locations of landslides in the area.

3.2 Data Analysis

LAND USE

There was need to analyze the land use change that had occurred in the area around the Nandi Escarpment from 1973 to 2006 in order to find out the percentage change in vegetation and determine if the changes have increased or decreased. In actualizing this, supervised classification as well as change detection analysis was carried out on the satellite images.

The use of land use change detection tools which helps involve multi-temporal data sets, can help to discriminate different areas of land cover changes that have occurred between different years in an image (Lillesand, *et al.*, 2004).

3.2.1 Satellite Imagery

Three time series Landsat scenes of the same area of interest were acquired from the data archives at the RCMRD in charge of receiving, processing, geo-rectification, producing multiple sets of acquired data onto CD-ROM and distributing copies of CD-ROM to interested users. The satellite imagery was cloud free and was in GEOTIFF format.

Table 3.1 Satellite Images

IMAGERY YEAR	Satellite sensor	WRS Path/Row	Format	RESOLUTION	SPECTRAL BANDS	PROJECTION
01-02-1973	MSS	182/60	Geotiff	57 m	4	UTM 36N
02-04-1995	TM	170/60	Geotiff	28.5 m	7	UTM 36S
03-O2-2006	ETM+	170/60	Geotiff	30 m	8	UTM 36S

The acquisition dates for the Landsat data employed in the change detection process fall within an acceptable anniversary window February 1973 and February 2006. From the images (1995, 2006) and 1973 four and three land use/ land cover classes were determined respectively

Landsat imagery constitute the base data layer from which land-use/ land-cover maps were derived (Anderson *et al.*, 1976; Lillesand *et al.*, 2004) Manual and semi-automatic classification was carried out using Erdas Software The study area land use/ land cover database was clipped out and edited in Arc View and also reprojected to UTM (south) Zone 36 for further processing.

3.2.1.1 Image Processing

After acquiring the images in a data CD from RCMRD Geotiff format, they were unzipped and then imported band by band in GEOVIS environment where pre-processing was carried out.

The 1973 Landsat image was projected to the 36 North while the 2006 and 1995 were to 36South thus there was need for co-ordinate conversion in order for the Landsat image to be overlaid, manipulated, analyzed and aligned correctly with the rest of the mapping data, there was need to georeference, and reproject it to UTM zone 36 south with WGS-84 spheroid datum. This opportunity was also taken to resample the image pixel size from 28.5 m and 57 m to the more convenient 30 m to coincide with the 2006 imagery. Nearest neighbour resampling was selected due to quicker computer processing time as compared to other interpolation methods. This was done using GeoVIS software.

The data were imported into ERDAS Imagine for image processing. ERDAS had a distinct advantage over other image processing software available because of its compatibility with the Arc/Info GIS software. The bands were imported to ERDAS (1972, 1995, and 2006) so as to convert them to IMAGINE (img) format. Here layer stacking, subsetting images, image enhancement and image classification were performed. Stacking layers: Individual bands from the three images (1973, 1995, and 2006) had to be stacked together in order to obtain an image file with all bands in one image.

Subset of the study area: Since Landsat satellite images usually are larger images with different layers covering a large area therefore there was needed to reduce the size of the image to cover only the specific area of interest. This process cut out the preferred study area from the image into a smaller more manageable area i.e the Nandi Escarpment within the Kabras Division; this not only eliminated the strenuous data but also saved on the processing time and disk space. This reduction of data is known as sub setting. This was achieved using subset under data preparation in Erdas software.

The subset window was used to control the specific three images used for this analysis to ensure that they covered the same area the three images were cropped to the AOI. Image and edge enhancement: there are different ways in which an image can be enhanced which includes contrast stretching, histogram equalization, and standard derivation stretching. This technique helps to improve the quality of the image and increase the possibility of image interpretation they are only for visualization purpose (Sabins, 1996).

Histogram equalization was chosen as the image enhancing method. The darkest pixel is assigned the value 0 (black) while the highest value is assigned 255 (white) hence spreading the intensity values between 0 and 255, the histogram of the image were stretched between 0-255 to increase the grey scale levels.

Image classification: Classification of an image involves sorting the image pixels into a specific number of classes or categories based on the intensity value of the data file. Images can be classified in two ways; unsupervised and supervised classification. Unsupervised method is fast but does not give the exact classes that are required since it does not utilize training areas as its base for classification. In the Supervised classification the overall classification is automatically carried out by grouping all pixels in an image into land cover classes in which they belong, training areas are manually digitized for each class and the statistics of the training area are calculated deciding which raster cell belongs to which class (Lillesand and Kiefer, 2004).

Effective classification of Remote Sensing image data depends upon separating landcover types of interest into sets of spectral classes (signatures) that represent the data in a form suited to the particular classifier algorithm used.

Supervised classification nearest neighbour was performed on each of the three images using ERDAS IMAGINE software so used to come up with proper land use land cover.

Landsat imagery were loaded with band 4, 3, 2(RGB) to produce a false colour composite as well as the band combination 3, 2, 1 (RGB) to produce a true colour composite. Forest appeared red to bright red in the false colour composite image and green to dark green in the true colour composite. By viewing these different band combinations simultaneously, side by side in full resolution windows, vegetation patterns could be visually interpreted with relative ease.

Training sites: Training areas were developed manually around the Nandi escarpment and the areas developed were assigned classes in the signature editor in Erdas software.

Spectral signature: on completion of the training areas, pixels of the raster cells were automatically grouped together as one class by the Erdas software. The training sites made up different classes of the same feature which needed to be merged together to form individual classes.

The different single classes were assigned their corresponding landcover type and colours and saved so that they could remain permanently in the attribute table and can be assessed any time needed. Land use/ land cover map was obtained.

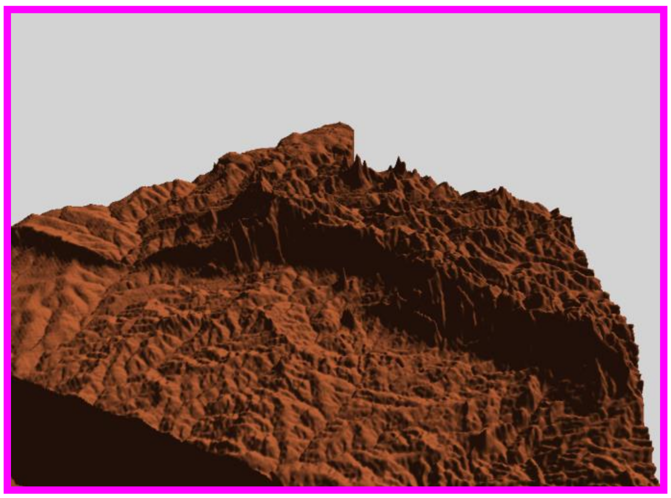
3.2 SRTM 90m DEM

This DEM is currently the most complete homogeneous 30 m and 90 m resolution of the world (Baghdadi et al., 2005). Because of the availability of the SRTM 90m DEM there was no need to digitize the contours from the 1:50000 toposheet which could be tiresome time consuming and less accurate.

The Shuttle Radar Topography Mission (SRTM) DEMs data were acquired from RCMRD, Nairobi in a CD form. SRTM image were in two formats, the grid and tiff format. The tiff format gives the height as a grey scale values ranging from 0-255. Grid format image was used because the height information can be extracted as (Z) values in meters. The DEMs for the project area were cropped from the N10E20 and S0E20 SRTM tiles. There was need to mosaic the two scenes before projection. The two scenes were mosaicked in ERDAS IMAGINE to obtain a single seamless image.

Since the SRTM image was in decimal degree and the Landsat image used was in UTM WGS 84 datum, it was necessary to project the SRTM image to UTM WGS 84 to make overlays possible. The grid image (SRTM) was opened in ArcGIS arcmap where Arc tool box facility was utilized to project this image. The projected image was opened in ERDAS IMAGINE for subsetting to the required AOI, after subsetting the SRTM image, the image format changed from the grid format (GRID) to (img). The image was interpolated using the surface tool in ERDAS to 20 m grid cells and contours generated at 20m interval. Finally the image was exported as a grid which both Erdas and Arc GIS could process. As a grid the image was opened in Arc View 3.3 for slope processing, the 3D analyst extension was used then slope was automatically generated after activating the 'Derive surface tool' and a slope map covering the AOI was obtained (see Figure 4.2)

In Erdas, the grid image was draped so that it could be viewed in 3D (DEM).The 2006 Landsat ETM+ was pansharpened since it had the panchromatic band eight, then it was overlaid on the draped DEM to allow for visual interpretation (refer to plate 2 and 3).



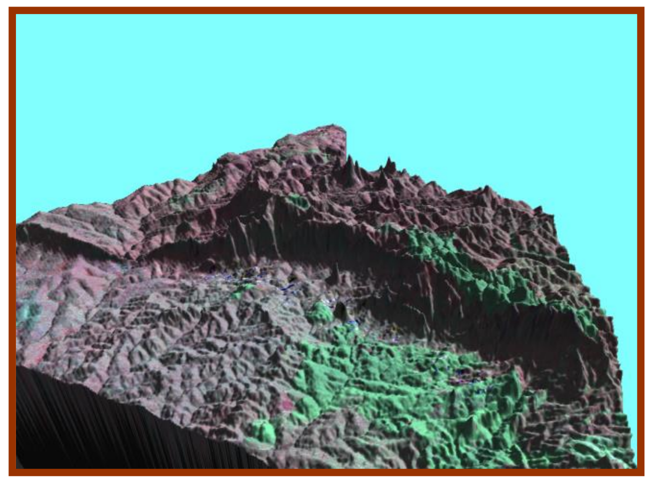


Plate 2 indicate the area of interest in 3 dimension view while Plate 3 is DEM that was draped on pansharpened Landsat ETM 2006 to allow further visualization. (Source: Author, 2008)

3.3 Soils Data

Laboratory analyses and tests conducted on the soil samples included, Atterberg limit tests (liquid limit, plastic limit and plastic index), determination of bulk density and texture analysis using standard procedures for example BS (British Standard) 1377 of

1975. The Atterberg limit of the soil consists of the liquid limit, plastic limit and plasticity index.

To add value to the data obtained from the field, Digital soil data were obtained from the Kenya Soil Survey. These data comprised 1:100,000 shape files and attribute data of the different soil types in Kenya (FAO/UNDP/Government of Kenya, 1988). The hydrological soil type attribute was created based on the infiltration rates of the different soil types based on textural rate of the different soil types. Using the AOI polygon, the study site was clipped out of the whole country data using Arc View and reprojected to UTM South Zone 36 for further processing.

3.4 Rainfall Data

In this study, the procedure outlined in McCuen (1989) was used to develop dimensionless rainfall distributions for the study area using rainfall data from the department of Meteorological Services (DMS). Rainfall actual and generated data from 12 stations that surrounds the study area were used to calculate average rainfall data. From the long-term rainfall data (1985 to 2006), the average rainfall for the rainy seasons (March-November) was calculated.

Rainfall data was obtained from RCMRD as Excel spread sheet, daily rainfall from 1985 to 2006 for twelve stations. Average monthly then average seasonal rainfall was calculated for the nine rainy seasons. The 1985, 1995 and 2006 averages were used. The stations and their mean rainfall were plotted in Arc view to obtain a layer of rainfall distribution.

Table 3.2:12 Stations and their Mean annual averages (mm)

RAINFALL_STATION	ID	LAT	LON	MEAN1985	MEAN 1995	MEAN2006
CHEBIEMIT AGRIC OFF	8935104	0.86700	35.5000	4.64	2.46	4.83
CHORLIM ADC FARM	8834013	1.03300	34.8000	3.03	4.03	4.80
ELDORET MET	8935181	0.53300	35.2830	3.27	3.41	4.21
KAIMOSI FTC	8934078	0.21700	34.9500	6.94	6.48	7.77
KAKAMEGA MET	8934096	0.26700	34.7500	7.42	6.66	7.67
KITALE MET	8834098	1.00000	34.9830	4.59	4.15	4.97
LUGARI FOREST STN	8934016	0.66700	34.9000	5.25	4.02	4.82
MUMIAS SUGAR	8934133	0.36700	34.5000	6.91	8.41	7.14
NZOIA SUGAR	8934183	0.56700	34.6500	7.20	6.06	6.44
BUTERE HEALTH CENTRE	8934182	0.21400	34.4990	6.79	5.22	7.44
PORT VICTORIA FOREST STATION	8934191	0.14634	34.0113	2.54	2.52	2.65
UHOLO CHIEFS CAMP	8934059	0.20225	34.3652	6.21	6.10	6.90

The locations of the rainfall stations were in decimal degrees, so there was need to project them to UTM WGS 84, so that it could be overlaid with other data.

It was necessary to interpolate the rainfall distribution into a grid since the rainfall distribution map showed the stations and the amount of rainfall they receive as a point data (X, Y, and Z-mean rainfall).

Using the area of interest polygon, the grid was cut to obtain rainfall distribution map for 1985, 1995 and 2006 (see figure 4.3).

3.5 Problems Encountered

There were different constraints to carrying out the studies. First, the 1973 and 1995 Landsat images had very low resolution, therefore land use/ land cover could not be identified clearly. Nevertheless, the results had to be treated cautiously. This problem was however addressed through ground truthing.

There was difficulty in mobility especially during the rainy season because the road network especially to the escarpment area is poor. Some parts have no roads at all. This made movement in the study area a night mare. These barriers were solved by using bicycles (bodaboda).

Lastly, collection and transportation of soil sample from the landslide scar was quite taxing since the slope was so steep and slippery because of the heavy rains that had pounded the area before. However this was solved by carrying small quantities in polythene bags down slope with the help of volunteered residents.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Observation

Field observations revealed that due to high population density, people have settled on slopes as steep as 38 degrees and artificial platform for construction of houses created to hold a house (Plate 4.5). The equilibrium of the slope is disturbed and overloaded; this may lead to sliding of lose materials. Water seeps through the upper side of the created flat surface thus accumulating below the building which eventually slides.

It was also observed that there is a basement rock that does not allow water to seep through hence flow as a river. The region is covered by dense network of streams and rivers originating from the Escarpment and flowing down slope forming a dendtritic pattern. The Nandi escarpment forms the catchments zone for such stream as the Shitiya, Kabkalet and Nurungo, which flow westwards to form the Isiukhu River. Several small streams exhibit dendtritic drainage patterns. It was also observed that people cut indigenous vegetation on the upper slope to clear the land for small scale farming, firewood charcoal burning and to be taken to Webuye Saw Mill which is a few kilometers from the escarpment (Plate 4.4 and 4.5). It was also observed that the natural stones on the ground are removed to create land for farming and construction. When the stones are naturally distributed on the ground, they hold down soil and when removed they de-stabilize the soil contributing to landslides.

Cutting of trees for charcoal burning was also observed in the area. This is an alternative source of income to the local people. The practice has contributed to acceleration of clearance of indigenous long rooted vegetation on the escarpment (Plates 4.6.1 and 4.6.2). There is so much gravel in the soil (Plate 4.1) thus it enhances the sliding because the soil is not cemented, and water coming from the slope seepS into the soil thus cohesive force is weakened.

A fresh landslide scar was observed in the area (Plate 2.2). This is clear evidence that the area is highly susceptible to landslideS all the factors that contribute to landsliding put together.

4.2 Soil

Averaged soil bulk density was 1140.91 kg/m^3. Liquid and plastic limit and plasticity index averaged 41.23, 21.33 and 20.33, respectively (Table 4.1).

Table 4.1 Soil test results

Sample No.	**Depth of Sampling in cm**	**Liquid limit (%)**	**Plastic limit (%)**	**Plastic index (%)**	**Bulk Density(kg/m^3)**	**Textural Classification**	**Grain size composition (%)**
KUV1	60	35	16.5	18.5	1060	Sandy loam	Sand:65 Silt: 20 Clay:15
KUV2	60	35	16.4	19.2	1060	Loam sand	Sand: 81 Silt:14 Clay:5
KUV3	60	51.5	24.3	31.4	1100	Sandy loam	Sand:81 Silt: 14 Clay: 5
KUV4	60	38.5	20.1	18.4	1220	Sandy clay loam	Sand:59 Silt: 20 Clay:21
KUV5	60	22.75	16.4	6.35	1200	Sandy loam	Sand:63 Silt: 24 Clay:13
KUV6	60	45.5	22.02	23.48	1230	Sandy loam	Sand:75 Silt: 18 Clay:7

KUV7	60	45.5	23.7	21.8	1200	Sandy loam	Sand:69 Silt:12 Clay:19
KUV8	60	50	24.2	25.8	1040	Sandy loam	Sand:71 Silt:16 Clay:13
KUV9	60	41	21.8	19.2	1050	loamy Sand	Sand:87 Silt:8 Clay:5
KUV 10	60	42	20.3	21.7	1120	Sandy	Sand:87 Silt:10 Clay:3
KUV 11	60	42.5	23.8	18.7	1150	Sandy clay loam	Sand:53 Silt:24 Clay:23

Sample No.	**% Sand**	**% Clay**	**% Silt**	**Textural class**
KUV1	65	15	20	Sandy Loam
KUV2	81	5	14	Loamy Sand
KUV3	59	21	20	Sandy Clay Loam
KUV4	63	13	24	Sandy Loam
KUV5	75	7	18	Sandy Loam
KUV6	69	19	12	Sandy Loam
KUV7	71	13	16	Sandy Loam
KUV8	87	5	8	Loamy Sand
KUV9	87	3	10	Sandy Loam
KUV10	53	23	24	Sandy Loam
KUV11	77	9	14	Sandy Loam

Sample No.	**Bulk Density (kg/m^3)**	**Liquid Limit**	**Plastic Limit**	**Plastic Index**
KUV1	1060	35.00	16.50	18.50
KUV2	1100	51.50	24.30	31.40
KUV3	1220	38.50	20.10	18.40
KUV4	1200	22.75	16.40	6.35
KUV5	1230	45.50	22.02	23.48
KUV6	1200	45,50	23.70	21.80
KUV7	1040	50.00	24.20	25.80
KUV8	1050	41.00	21.80	19.20
KUV9	1120	42.00	20.30	21.70
KUV10	1150	42.00	23.80	18.70
KUV11	1180	40.00	21.50	18.50
Average	**1141**	**41.30**	**21.33**	**20.35**

Atterberg Limits

Atterberg limits are used to estimate the plastic properties of soils; it consists of the liquid limit, plastic limit and plasticity index.

Liquid Limit (LL):- The minimum water content at which clay deforms under its own weight and changes into a liquid is its liquid limit.

Plastic Limit (PL):- is the minimum water content at which plastic deformation is possible. The plastic limit is less than 30% for all soils analyzed. Moreover Sample No 4 has surprisingly the lowest plastic limit of all the samples.

Plasticity index (PI):- is the difference between liquid and plastic limits, and represents the range of moisture content over which soil is plastic.

As moisture content increases, the consistency stage of a soil changes from solid state to liquid state passing through the semisolid and plastic states respectively. As the phase of soil water content advances from liquid state to solid state, the volume of the material decreases, the consistency changes from slurry to very hard while the shear strength increases.

The physical properties of most fine-grained soils, and particularly clayey soils, are greatly affected by moisture content (Earth manual, 1998). The moisture content of the soil samples taken from the field is determined using their liquid limit, plastic limit, and plasticity index. Observation of the result of textural analysis indicated that, the soils have a high percentage of sand, followed by silt then clay (Figure 4.1).

Soil consistencies

Sandy loams constituted 54.6% of the soil samples, loamy sand and sand Clay loam formed 18.2 % each, while the remaining 9% was sand. The presence of clay component in the soil as indicated in the textural analysis tends to cause swelling during the wet season and shrinking during dry season. This repeated change, apart from weakening shear strength, has a bearing on the formation of cracks in the soil during the dry season. The cracks tend to weaken the cohesion forces and lead to sliding. When it rains after a long spell of dry season, the cracks tend to facilitate rapid infiltration of water which act as a lubricant, leading to occurrence of landslides. During the dry season, as the temperature rises, cracks form in the soil and during the wet season they tap a lot of water, swell and act as lubricant for the sliding process (Inganga 1995).

Clayey soil has a high water retention capacity, which contributes to rapid increase in pore water pressure, thus it is highly susceptible to slope failures (Montgomery, 1989). Therefore areas covered by clay-sandy type of soil in the study area are more prone to slope failures than areas with loam soil.

Sandy soil liquefaction happens when the spaces between the grains of a sandy soil are saturated, i.e. completely filled up with water. When this soil is shaken the grains compact, squeeze together, and take up less space. Sandy soil liquefaction can also cause huge chunks of land to slump-slide in one piece down a slope (Montgomery, 1989).

From the pictures taken it is evident that the area has a high content of boulders, stones and gravelly clays as show in (Plate 4.1). The soils remain unconsolidated; also their water holding capacity is very high because of presence of sand and clay material in it. Thus it is evident that the area is highly susceptible to landslides other factors held constant.

PLATE 4.1 High amounts of gravel and stones in soil within the landslide scar in Khuvasali village (Kabras). (Source: Author, 2008)

The results showed that there is very low landslide susceptibility in areas covered by loam type of soil. Loam soils are more aerated and allow for water to infiltrate easily, therefore, pore water pressure in loam soil is low even when it rains, thus all other factors held constant loamy soils are less susceptible to slope failure.

In case loamy soil is underlain by clayey soils, their vulnerability to slope failure increases because of the clayey subsoil. But when clayey soils overlie loamy soils slope failures potential is greatly reduced since clay is less permeable, there is more runoff than infiltration. The water that infiltrates is held up in the clayey soil overlying the loamy one. Water does not percolate from the smaller clay particles into those of loamy layer.

The occurrence of slope failures is mainly due to the presence of a large thickness of loose soils, which when mixed with water, triggers the landslide. In the study area, based on the soils erodable nature, the soil is divided into four categories as follows: Sandy clay (Very highly erodable), sand (highly erodable), sandy loamy (moderately erodable) and loamy sand (poorly erodable). Thus, soil textures were ranked from the most susceptible to the least susceptible, following in order from number: 1, 2, 3, and 4, respectively.

Based on the Atterberg limits, bulky density and the soil texture the study area was categorized and ranked as follows:

Table 4.2: Influence of Soil Texture on Landslide Susceptibility

Ranks	Soil texture	Susceptibility
1	Very clay	Very high susceptibility
2	Sandy	High susceptibility
3	SandyLoam	Moderate susceptibility
4	Loamysand	Low susceptibility

Thus, the Soil map has got four categories and based on textural classification.

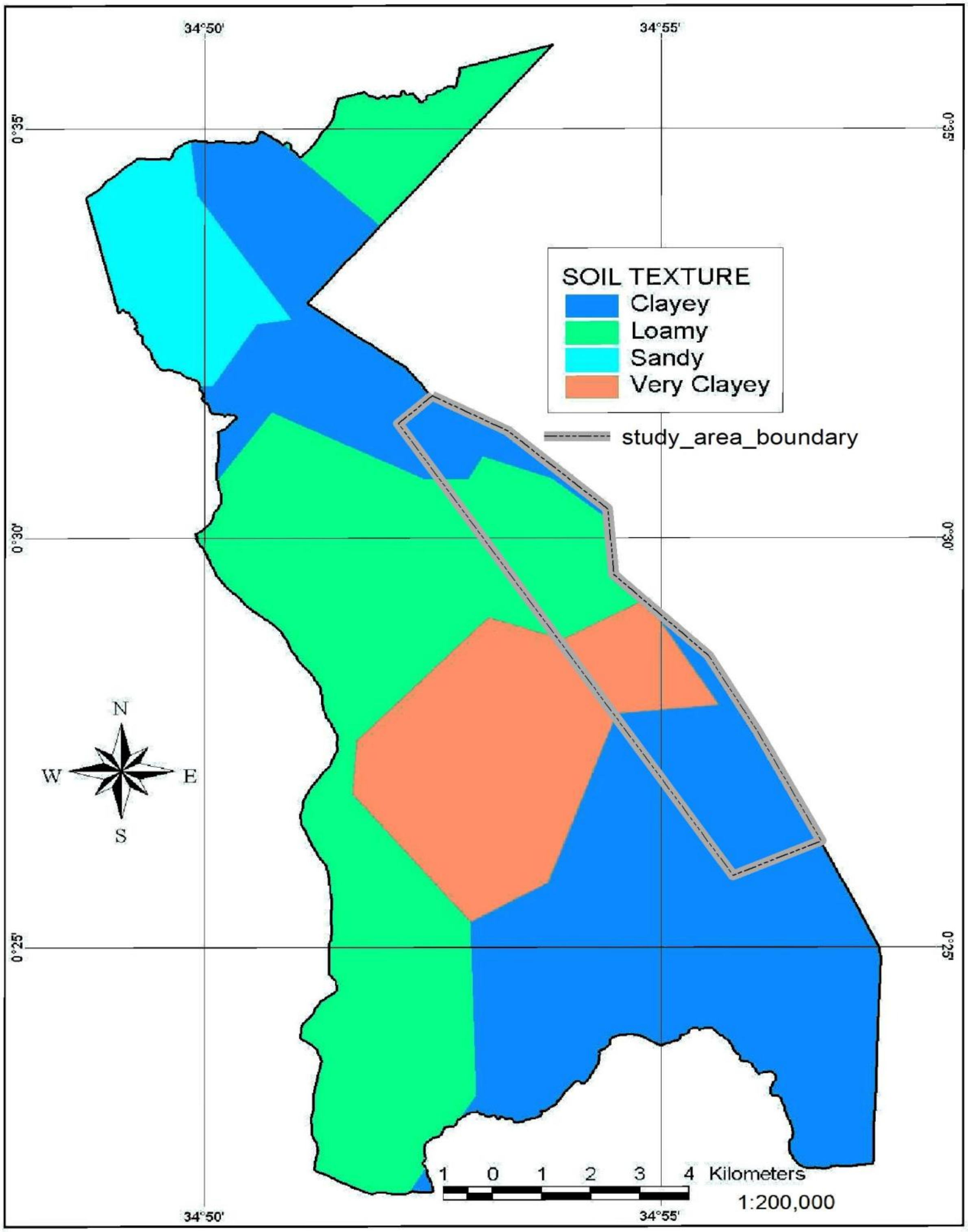


Figure 4.1: Textural Classification of the Soils of the Study Area.

(Source: Soil survey of Kenya; modified)

4.3 Slope

Sidle *et al*, (1985) pointed out that steep slopes are most vulnerable to sliding because gravitationnal force acts maximally to the direction of the steepest slope.

In the study area slope varies from 0^{o} to $>54^{o}$. The entire slope contour map was divided into four categories as follows:

Table 4.3 Slope Categorization/Classification in relation to Susceptibility to Slope Failures

Rank	Slope degree	classification	Susceptibility to slope failure
1	> 54^o	very steeply sloping	Very highlysusceptible
2	20^o - 54^o	steeply sloping	Highly susceptible
3	5^o - 20^o	moderately sloping	Moderately susceptible
4	0^o - 5^o	Flat -gently sloping	Low susceptibility

Thus, the slope contour map has got four categories and suitable ranks were assigned.

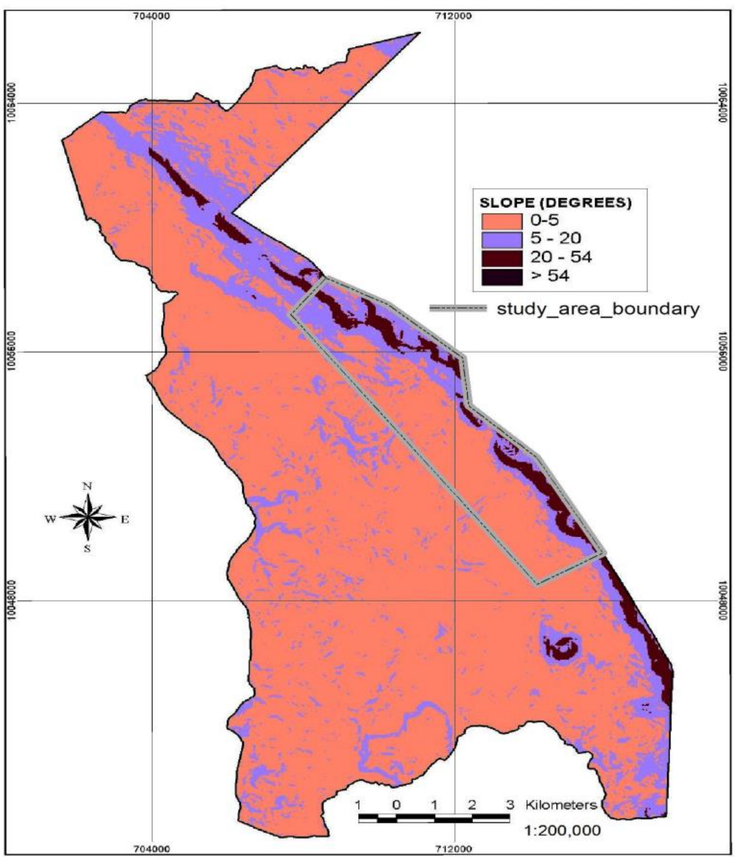


Figure 4.2: Slope Map derived from contours digitized from topographical map 1:50,000, modified. (Source: Author, 2008)

The result of this study within the range 5^o-54^o does not differ much from those obtained by Inganga (1995), Nduru (1995) who found out that slopes steeper than 24^o-55^o degree are more susceptible to slope failures. The critical slope for this study is 20^o-54^o degrees. Slopes above this critical level have a very high susceptibility to failures.

Therefore, the result of this study showed that the western side of the map can be classified as less prone to slope failures while the central and the eastern side may be classified as highly susceptible to slope failures (this is the section with the escarpment). This conclusion was arrived at by looking at many other factors. First the central part of the map is an escarpment with slope angle of about 20^o -54^o which means that the slope is very steep. The area has been inhabited by people who practice small scale farming, charcoal burning, therefore the soils are overworked and this may contribute to slope failures. It also receives about 1200 mm of rainfall annually. When all these factors are combined, the area is rendered highly susceptible to slope failures.

4.4 Rainfall

It is well known that rainfall is the most important and frequent trigger of landslides. It commonly contributes to the triggering of the landslides by means of infiltration into the slope cover, which causes an increase in the pore pressure value and a decrease in the soil suction value.

The climate of the area is characterized by heavy reliable and well-distributed rainfall throughout the year. The pattern of rainfall is bimodal, with two peak seasons. The long rainy season is from March to June with peak in May while the short rainy season is from

July to November with peak in September. Other months receive normal rainfall with drier months being December, January and February. Rainfall is high during the long rains. Most of the landslides occur during or towards the end of the long rains.

The landslide may have been triggered mainly by high rainfall. Rainfall of three consecutive days of the landslide was averaged and used as indicator of the effective rainfall which may have triggered the landslide.

For example, the record rainfall of 76.2 mm on the 11, August, 2007 in Khuvasali is believed to have triggered the landslide (Ucakuwun *et al*., 2008b).

Areas that receive over 2000 mm of rainfall annually are likely to experience landslide. When rainfall is high and well spread, the probability of high infiltration rate is high. Increased infiltration and percolation of rain result in increased soil moisture and hence high pore pressure. It is after a long duration of soil moisture accumulation that the pore water pressure builds up to a critical state where all other factors held, sliding is inevitable (Gray, 1970).

Areas which receive less than 1400 mm are less susceptible to landslides (refer to Figure 4.3). No landslides will take place unless pore water pressure reaches a critical point whereby soil particles can no longer withstand shear stress.

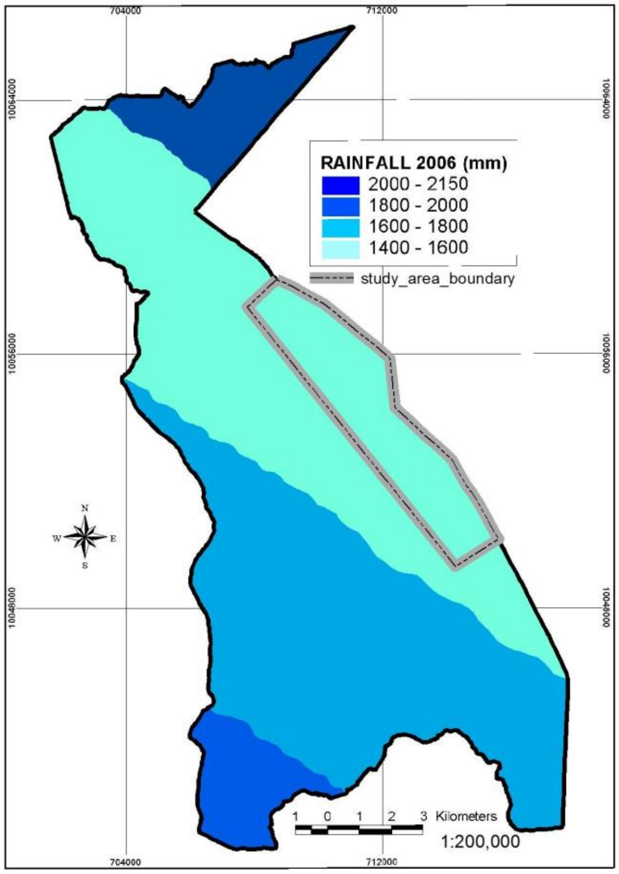


Figure 4.3: Rainfall Distribution Map of the Study Area isohyets; derived using data from 12 weather stations from 1985 to 2006. (Source: Author, 2008)

A fresh landslide scar was observed in the area of study (Plate 2.2). When the residents were asked what might have caused the slide, majority said heavy rains had pounded the area for three consecutive days. Another smaller landslide had occurred some few meters ahead where rocks and soil flowed to the road causing its closure. The local people's perception indicates that rainfall amounts and intensity are generally higher than they were in the previous years.

When heavy rains occur, the rain water infiltrates into the soil and groundwater table is raised. The pressure exerted by the water thus increases, causing the driving force to exceed the resisting force, hence resulting in a landslide.

In the scar it was observed that there were water springs which made the ground boggy and marshy (Plate 2.2). This means that drainage becomes poor and water collects in the depression thus increasing the likelihood of secondary slides.

The landslide scar (plate1.1) in the study area might have been caused by a combination of many factors, the main one being high amount and intensity of rainfall. Long duration of abnormal heavy rainfall for three consecutive days which pounded the area might have triggered this type of slope movement. The instability of the slope caused by construction and overworking of the soils was another contributing factor of the landslides (Refer to plate 4.4 and 4.5). The heavy rains might have caused the clayey sandy soil type to swell and absorb a lot of water causing the land to slide.

Table 4.4: Influence of Rainfall Amount/ Intensity and Landslides Potential

RANKS	**RAINFALL AMOUNT (MM)**	**SUSCEPTABILITY**
1	>2000	Very highly susceptible
2	1800-2000	Highly susceptible
3	1600-1800	Moderately susceptible
4	<1400	Low susceptibility

4.5 Land use/Cover

Land use/land cover of an area has direct or indirect influence in triggering the slope failures. Different types of land use /land cover types were identified in the study area such as settlements, agricultural farming, forest, shrub and grasslands (Fig 4.5)

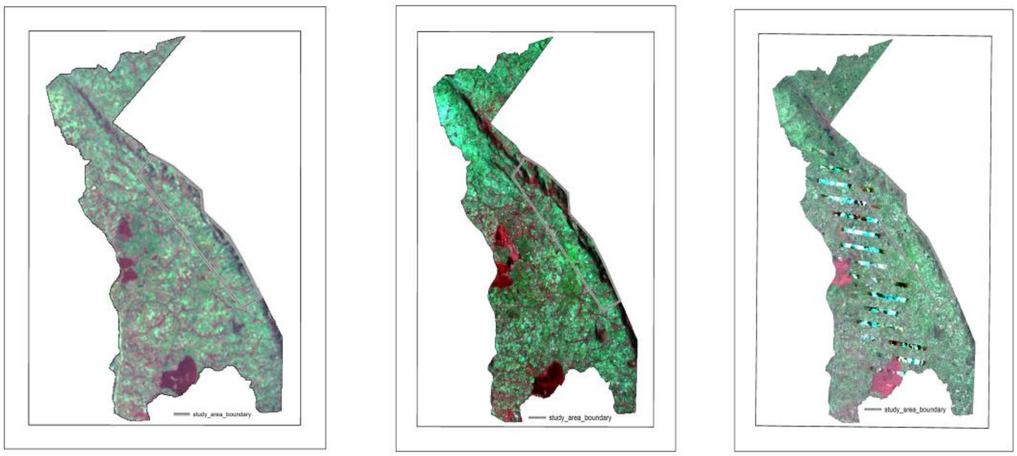


Figure 4.4 LANDSAT IMAGES (False Colour Composite, Band 4Red, 3Green, 2Blue showing landuse change for the years 1973, 1995 and 2006 respectively). (Source: Author, 2008)

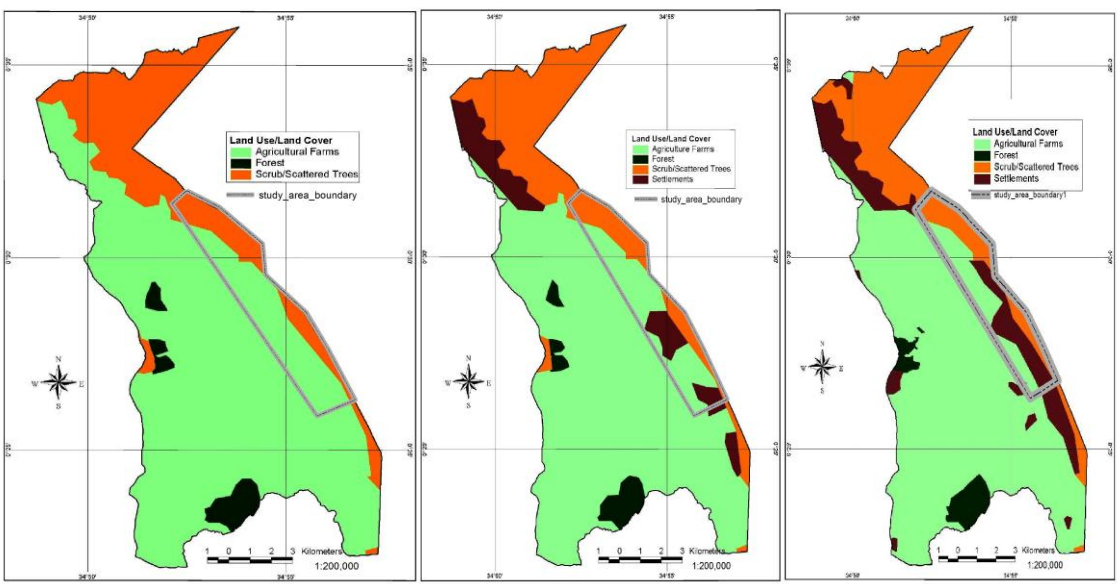


Figure 4.5: Land use/ Land cover Maps (1973, 1995, and 2006 respectively). (Source: Author, 2008)

Originally the Nandi Escarpment was covered by natural vegetation (forest) made up of indigenous trees (Plate 4.2). (“*mulomonyo” “Musyoma” “Musangula*”) shrubs and grasslands. At the time of this study some part of the escarpment was already exposed after cutting down of trees for cultivation. Vegetation cover was made up of cypress (exotic vegetation). This was also seen in the image as it appeared dark red in the false colour composite. Though the satellite image Landsat TM of 1973 had very low resolution and hence prone to errors it was treated cautiously. It was also evident from the landuse /landcover map, (Figure 3), that, there was no human settlement on the Nandi Escarpment and the area was then colonized by grasses, trees and bushes in 1973. From the interviews conducted, there was no report of landslide in the area except one in 1973 which resulted from heavy down pour. Forest trees and dense undergrowth tend to stabilize the soil because the tree root-system acts to increase the shear strength of the soil, thus preventing occurrences of slope failures. There was subsistence farming practiced but it was not intense as of today, thus there was no overworking and overloading on the escarpment hence no landslides.

After 25 years, i.e. in the 1995 LULC map obtained (Figure 4.5), it was evident that there was human settlement along the escarpment. People had started cultivation on the escarpment. This was also evident by bluish colour on the colour composite image. Also, it could be seen from the decrease in the edges of the forest. This means there was need for more land, thus people cut trees for settlement and cultivation. From the focused group interviews conducted it was during this time that the first landslide in the area was reported, though it is not clear as to the exact date when it occurred. This was also evident from an old scar along the Nandi Escarpment in Shivanga sublocation. There were no fatalities reported from the slope failure.

After only 11 years, it was observed that there was a drastic LULC change in the 2006 Landsat ETM image in which there was a further decrease in the forest cover. Increase of human settlement on the escarpment accompanied by intensive large scale farming. This was also evident in the satellite image (false colour composite) from regular shaped pink/light red colour parcels of land. It was evident by people living in on very sensitive area as high as 35^o -40^o which can lead to slide when all factors for landsliding are met (Plate 4.5). It is also evident that the forest cover has reduced drastically as compared to the 1973 image/map. The forest that covered the escarpment had been cut down to provide very productive farmlands; this was attributed to fertility of the “virgin” soil. There was high demand for timber to be used in the Webuye Paper Factory. This led to increase in the rate of tree felling for commercial purposes (refer to plate 4.6). There was also high demand from the Mumias Sugar Factory which accelerated tree felling along the escapement for sugarcane farming.

Forest trees offer stability to steep slopes by the binding role of their roots (Dunne, 1979). When forest is cleared, tree roots decay leading to decrease in shear strength of surficial materials and increase in landslide incidence. Through transpiration forest trees with deep roots deplete soil moisture to greater depths thereby delaying rise in pore water pressure during the rainy season. This upholds shear strength, which hinders landsliding.

Plate 4.2: Indigenous Vegetation from the slopes of Khuvasali. (Source: Author, 2008)

Small scale farming (maize) has the highest contribution to landslides. This is explained by the decrease of shear strength after tree roots have decayed. The soils in the escarpment have not been disturbed before, therefore they are "virgin" soils. The soils are fertile and have high productivity potential thus making them vulnerable to human interference.

Plate 4.3: Small Scale Sugarcane Plantation at the foot slopes of the escarpment. (Source: Author, 2008)

During the Population and Housing Census 1999, Kakamega North Sub-County had a population of 603,422 with an annual growth rate of 2.12 per cent, compared to 488,352 in 1989, representing a growth rate of 2.98 per cent per annum. By the end of the plan period the population would have increased by 21 per cent. Republic Of Kenya, (2002-2008). High population density leads to clearance of forest and settlement on slopes which makes them unstable and can result in occurrence of landslides. Satellite image of 1973 showed that there was no human settlement in the area before but the 2006 image showed that the escarpment has been inhabited. This means that the escarpment has been encroached. Field observation also revealed that there are human settlements on the Escarpment as steep as 55^o by terracing for construction of houses (Plate 4.4).

Due to population pressure, the land is intensively cultivated, including the steep slopes $>30^0$ and the settlements have often been built on terraces on these steep slopes. The combination of the steep slopes, high rainfall and poor land use practices have resulted in frequent landslide occurrences thus resulting in fatalities and destruction of property.

Due to intense land use and the nature of the topography (escarpment), houses are commonly constructed on steep slopes by terraces (platforms) on the slopes flat enough to hold a house (Plate 4.4 and 4.5). The equilibrium of the slope is thus disturbed and the construction is in fact an overload of the slope. Therefore, terraces are a potential cause of landslides in Khuvasali area.

This may cause an overload on the slope and impede free surface drainage. The house construction will tend to impede surface run-off such that the water seeps through the upper side of the created flat surface which leads to accumulation of water below the building and this may cause sliding.

Maize is the main food crop, however small pockets of out growers' cane farms were evident. Among other crops grown are sweet potatoes, cassavas, bananas cowpeas and beans. There are a number of domestic animals in each homestead which exerts pressure on land for grazing by competing with crops. To earn a living people sell sugar cane, charcoal and bananas, among other crops.

Human activities in the landscape are most likely to cause landslides in the area where high densities of people and supporting structures such as buildings (homes) exist.

PLATE 4.4: Intensive farming along the Nandi Escarpment enhances slope failure. (Source: Author, 2008)

Plate 4.5: Steep hillslope modification by human Settlement enhances slope failure. (Source: Author, 2008)

In many parts of the region people have expanded their agricultural land to create room for their farm crops. This deforestation means that trees can no longer stop the earth from sliding down hillsides.

Most of the landslides may occur due to exhaustive deforestation for the development of urbanization, plantation and sources of income. Thus, rainwater directly penetrates into the soil and causes landslides. This is also evident in the satellite imagery of 1973 that the escarpment was covered by forest thirty years ago and there was no human settlement on it. Republic of Kenya, Kakamega District Development Plan (2002-2008) indicates that,there is illegal felling of trees for domestic use and systematic exploitation by saw millers without a corresponding replanting program might leave the land susceptible to landslides and could lead to environmental degradation.

An observation made revealed that the main vegetation species in the area are indigenous hard wood trees (Plate 4.6.1 and Plate 4.6.2).Eucalyptus have deep and long roots which allow them to obtain nutrients beyond the scar, they also take up and use a lot of water from the ground. In so doing, the water in the scar is used up by the trees for growth (Inganga, 1995). Eucalyptus is used as way of draining away the water which collects in the escarpment during rainy season. The deep rooted tree is also known to increase the shear strength of the slope material. It also provides good quality charcoal, which burns for long hours, which makes charcoal burners to prey on it.

Most of the charcoal is sold to urban dwellers within Malava town and the rest to dealers who transport most of it to larger urban areas like Eldoret, Webuye, Kakamega and Bungoma. Despite the financial gains accrued, the practice has contributed to accelerated tree depletion in the Nandi Escarpment.

Plate 4.6.1 Cutting down of deep rooted Eucalyptus Trees which enhances slope failure on the escarpment. (Source: Author, 2008)

Plate 4.6.2 Charcoal burning a major cause of deforestation which enhances slope failure on the escarpment. (Source: Author, 2008)

The observation also showed that people in the area cut down deep and long rooted trees and instead plant shallow rooted trees like cypress and pine trees on the escarpment. Cypress trees have short and shallow roots (Inganga, 1995); thus the short roots cannot be used to increase shear strength of the slope material as in the case of eucalyptus. Also cypress cannot seep water from the escarpment in form of rain or springs that flow down slope. Thus they make the area more susceptible to landsliding.

Community opinion was also put into consideration (Plate 4.7). Information gathered through interviews and written reports showed that overpopulation and agriculture are the major force in land use change in the study area.

Plate 4.7: Focused group interview at the study area in Shivanga village.
(Source: Author, 2008)

Forest was taken to have the lowest effect in contributing to sliding and ranked number 4 while agricultural farming was ranked number 1 since it is highly susceptible follwed by settlement number 2 and moderate for scrub /scattered trees (Table 4.5). Thus areas with vegetation cover (forest) are less prone to landslide than areas where forest has been cleared for human activities (Inganga, (1995), Keller, (2002), Nduru, (1995).

Table 4.5 Influence of landuse/ Landcover on landslide potential

RANKS	LULC	SUSCEPTABILITY	
1	Agricultural farming	Very highly susceptible	
2	Settlement	High, susceptible	
3	Scrub/ scattered trees	Moderate susceptible	
4	Forest	Low susceptible	

Table: 4.6 Criterion Table for land slides susceptibility

THEME	RANK1	RANK2	RANK3	RANK4
LANDUSE	Agricultural farming	Settlement	Scrub/ scattered trees	Forest
SOIL TEXTURE	KUV(4, 11)	KUV10	KUV(1,5,6,7,8,12)	KUV(2,3, 9)
SLOPE(DEGREES)	$>54^o$	20^o -54^o	5^o -20^o deg	0^o -5^o
RAINFALL(MM)	≥1900	1450-1900	1201-1450	≤1200
SUSCEPTIBILITY	VERY HIGH	HIGH	MODERATE	POOR

Landslide susceptibility map was prepared by integrating the effect of various triggering factors. The susceptibility map divides the study area into four zones of landslide vulnerability i.e very high, high, moderate and poor. Thus, the landslide prone areas having four susceptibility zones were obtained as shown in Figure 4.5.

The four maps, which is land use/land cover map, rainfall map, soil map and the slope map were overlaid in Arc Map-Arc Info. Using the spatial analyst tools, the maps were added basing on four classes:

1. Very highly susceptible to landslide
2. Highly susceptible to landslide
3. Moderately susceptible to landslide
4. Lowly susceptible to landslide

Using the plus command, the maps were added to each other one at a time after which a reclass was done to get the final landslide susceptibility map ranked from the highly susceptible to poorly susceptible. The colour combination on the map is also based on the susceptibility of the area to the landslides. The RED represents/shows very highly susceptible, PINK shows highly susceptible, ORANGE, moderate and GREEN low susceptible areas (Figure 4.6).

Although landslides can occur anywhere, a combination of factors interact to bring about their occurrence (Goudie, 1981). Landslide will occur in an area as long as shear stresses due to one or more landslide factors overcome the shear strength of surficial materials (Costa and Baker, 1981). Therefore, when all things are constant areas with very steep slopes, very clayey soil types, high rainfall amount and highly cultivated-vegetated land are the highly susceptible to landslides and ranked No.1. This is evidenced by the Khuvasali landslide which occurred on cultivated lands, this is explained by decrease in shear strength after tree roots decayed.

Therefore in the study area, it was found out that there are more landslides likely to occur along the escarpment because of the steep slopes, very clayey textural soils and areas where trees have been cut for farming, evidenced by dark red in colour which was ranked No.1

In conclusion, areas with less than 1200 mm of rainfall, loamy type of soil but covered by trees, the area become less susceptible to land sliding hence colored green and ranked No.4. This is evidenced by low potential on upper part of the study area. This can be best attributed to the influence of the stabilizing role of forest trees (Beven, 1981) which cover the area. There are some areas with clayey type of soil but with vegetation thus landslide is minimal in these areas. This implies that for an area to be stable it should be covered by vegetation, preferably trees, scrub or deep-rooted crops like sugarcane or tea so that they assist to hold the soil together during heavy raining seasons. The stabilizing effect of trees is very important (Dunne and Leopold, 1978).

The distribution of landslide potential areas along the Nandi Escarpment in Kabras division as shown in figure 4.6 shows that the southern part of the study area is dominated by high and very high landslide potential, while moderate and poorly susceptible zones predominates the northern part. However, patches of each are found scattered in the area of study.

Thus the landslide susceptibility map indicates the whole study area was divided into four zones/classes as shown in Figure 4.6

LANDSLIDE SUSCEPTABILITY MAP OF THE NANDI ESCARPMENT ALONG KABRAS DIVISION.

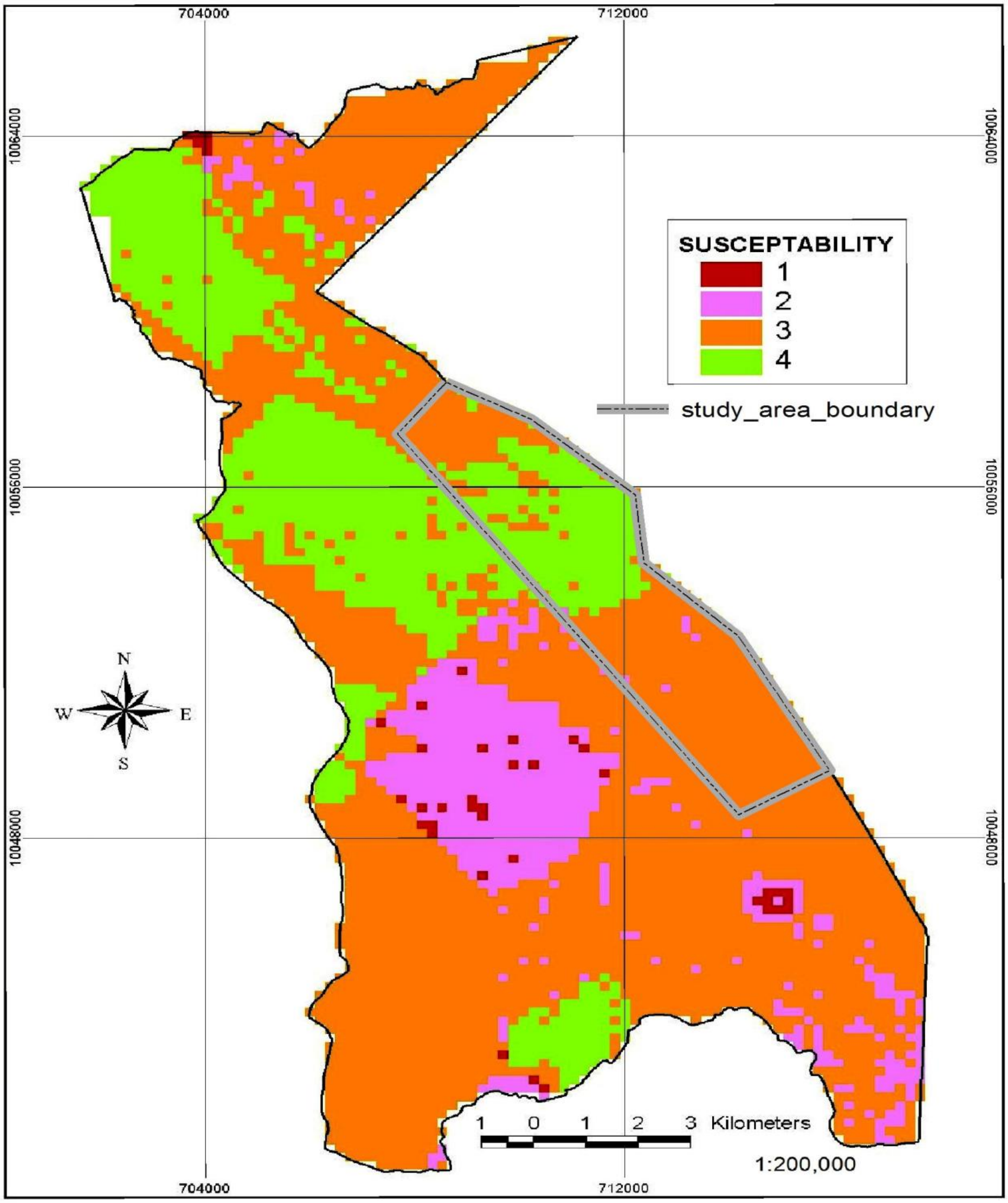


Figure 4.6: Landslide susceptibility map of the study area. (Source: Author, 2008)

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the findings

Besides the fact that steep slopes, high rainfall and typical soil properties and stratification may turn Nandi Escarpment into an inherently unstable area, human interference cannot be neglected. Whereas deforestation has reduced the stability of the shallow soils on the eastern slopes of the study area, the terracing of slopes, mainly for house building, are an important destabilizing factor for the western slopes. The growing population density not only increases the risk, but hampers the search for solutions for the landslide problem as well. Steep slope, intense human activity and clayey soils have strong influence on slope failures.

Taking all the factors into consideration and with the knowledge of slope failure in Khuvasali, slope was accorded the prime importance as the main cause of landslide. The thickness of the soil was considered next in importance as the soils were made mainly of sand and clay type. Under similar topographic conditions with similar thickness of soil and the amount and intensity of rainfall the susceptibility to slope failure is accelerated by human activity hence the land use practices adopted were also considered.

5.2 Conclusions

This study brings out the benefit of RS imagery and GIS techniques which play a significant role in mapping landslide susceptibility. Landslide identification which is a crucial parameter for any regional landslide hazard assessment can be very well done with

RS and GIS. GIS is an excellent tool for displaying the spatial distribution of landslides along with their attributes.

Landslide may occur where human activities such as deforestation and settlement interfere with the pre-existing slope balance. These human activities are important in evaluating slope failures potential for many places. Intensive small scale farming on the escarpment leads to cutting down of indigenous tress and shrubs hence decreasing the soil shear strength after the tree roots have decayed, exposing the soil to sliding.

Clay soil type is highly susceptible to sliding because of its elastic nature. It absorbs and retains a lot of water during heavy rains, hence expands resulting in sliding. The more the factors that enhance shear stress in the soil, the more likely the occurrence of land slide, i.e. the greater the shear stress the lower the shear strength thus the slope will slide. The study shows that remote sensing techniques when integrated with GIS can provide a useful tool to study potential landslide areas.

5.3 Recommendations

i. It is important to explore the use of alternative sources of remotely sensed data (satellite imagery) especially Quick Bird images which have a very high resolution (0.6 m).
ii. Settlement should be limited to slopes of less than 24^0 since, according to this study, slopes higher than this are prone to sliding.
iii. The government should encourage people to plant deep rooted trees and indigenous trees on steep slopes (of more than 24^0), because they have long root and are able to

hold the soil firmly and take up a lot of water from the soil hence draining the excess water from the slope material.

iv. Restraining structures should be constructed on the landslide prone and steep slopes on which people have settled, as protective measures so that chances of occurrences of landslide are minimized. These include cribs, gabions, buttresses, pilings, retaining walls and rock bolts (Inganga, 1995).

v. Landslides occur as a result of a combination of several factors. Planners should therefore address the issues of slope stability whenever they are implementing their development proposal.

vi. There are no clear government policies governing settlement and use of steep slopes. There is need for better policies. Land use policy of Kenya should be revised so as to establish what activities should be conducted on the slopes.

vii. Planting of exotic trees (cypress) should be discourage since their roots are shallow thus cannot hold the soil and do not have the ability to suck water from the soil which collect in the landslide scar.

viii. Deep rooted trees (eucalyptus and wattle) which take up a lot of water from the ground should be used for the rehabilitation of landslides so that the water which collects in the scars does not accumulate to cause secondary slides. The deep rooted trees also help to increase shear strength of the slope material

ix. Cutting down of trees (eucalyptus and indigenous trees) (see plate 4.6) for charcoal burning should be discouraged in the upper slope since instead the natural vegetation should be allowed to regenerate.

x. People living along the escarpment should be urged to avoid cultivating and felling trees on steep slopes.

xi. Risk and Vulnerability Assessment should be conducted along the Nandi Escarpment.

xii. National capacities to respond to major landslides are currently inadequate. In this regard, government authorities through the Ministry of Special Programmes should embark on a national preparedness exercise which involves both Government and non-government entities in strengthening structures and mechanisms for disaster management in the country.

xiii. The Ministry should organize seminars to sensitize and educate people on landslide mitigation measures in areas prone to the disaster across the country the department of Mines and Geology should respond to many landslide incidents for purposes of documentation and providing appropriate technical advice.

xiv. The Government policy on protected forest land areas should also be revisited to avert illegal land ownership in forested areas. The Government should highly consider resettlement of those people settled on mountain slopes

xv. Formulate strategies for early warning systems and their presentation, disaster preparedness based on the best available technical and scientific knowledge and monitoring in order to secure sustainable development.

REFERENCE

Alexander, D. (1992). *On the causes of landslides: Human activities, perception, and natural processes. Environmental Geology*: Water Science, Vol. 20(3):165-179.

Anderson J. R., Hardy E.E., Roach J. T. and Witmer R. E. (1976). *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*. Geological Survey Professional Paper 964. US Government Printing Office, Washington, USA.

Baghdadi N Cavalier S Chiles J.P., Bourgine B., Toutin, T.H., King, C. Daniel S. P., Perrin, J., and Truffert, C. (2005). *Merging of airborne elevation data and Radarsat data to develop a digital elevation model*. *Int. J. of Rem. Sen.* 26 (1) 141-166.

Beven, K. (1981). *Impacts and Management of steep lands, erosion*. In. Journal of Hydrology 20. pp 98-107

Blumberg, D., Bach, D., Weissel, J., Gorokhovich, Y., Small, C., and Balk, D. (2005). *The 2004 Sumatra tsunami event: Contribution of SRTM data to the Analysis of devastation*. *The Shuttle Radar Topography Mission—Data Validation and Applications*, Workshop, June 14–16, 2005, Reston, Virginia

Carrara,., Cardnalis, M., Detti, R., Guzzetti, F., Pasqui, V., Reichenbach, P. (1991). *GIS Techniques and Statistical Models in Evaluating Landslide Hazard in:* Earth's surface Processes and Landforms 16, 427 – 445.

Chen, F. H (1998). *Foundation on expansive soil*. P- 463. Elsevier, Amsterdam

Chowdry, R. N. (1982). *Slope Geology and Minerals, Slope Analysis*, 2nd edition. Elsevier Science Publishers

Costa, J. E. and Baker, V. R. (1981). *Surficial Geology* Oxford University Press. London.

Cooke, R. U. and Dookamp, J. C. (1990). *Geomorphology in Environmental Management*-410 P. Claredon Press, London.

Cruden, D. M. (1991*). A Simple Definition of a Landslide. Bulletin of the International Association of Engineering Geology*, No. 43, pp. 27-29.

Davies, T. C. and Nyambok, I. O. (1993). *The Muranga Landslide, Kenya. In: Environmental Geology*, journal, 21:1-3

Dikau, R., Brundsen, D., Schrott, L.and Ibsen, M. L. (Eds.) (1996*) Landslide recognition. Identification, movement and causes*, Wiley, Chichester, 251 pp

Dunne, T. and Leopold, L. B. (1978). *Water in Environmental Management* W.H. Freeman and Co. San Francisco.

Dunne, T. (1979). *Sediment Yield and Land Use In Tropical Catchments:* Journal of Hydrology 42 PP 281-300

Faniran, A. and Jeje, L. K. (1983). *Humid Tropical Geomorphology*. Longman London.

Fitzpatrick, E. A. (1983). *Soils: Their Formation, Classification and Distribution*. Longman, Hong Kong.

Goudie, A. S. (1981). *Geomorphological Techniques* Allen and UN.Win. London.

Gray, D. H. (1970). *Effects Of Forest Clear Cutting On The Stability Of Natural Slope in : Bull Association Of Engineering Geology 7. Bulletin Of The Association Of Engineering Geology* Vol.7 pp 45-66

Greenway, D. T. (1897). *Vegetation and Slope Stability In:* Earth Surface Process and Landforms Journal

Griffiths, J. S. (1999*). Proving the occurrence and cause of a landslide in a legal context. Bull. Eng. Geol. Env.*, 58: 75-85

Hansen, A. (1984). *Landslide hazard analysis. In: D. Brunsden and D.B. Prior (Eds.), Slope Instability.* Wiley, New York, 523-602

Huddleston, A. (1975). *Geology of the Kakamega District*. Report No. 28. Government Printers, Nairobi,

Inganga, S. F., Ucakuwun, E. K. and Some, D. K. (2001). *Rate of swelling of expansive soils: A critical factor in the triggering of landslide and damage to structures*. *Documenta naturae,* 136, p93-98.

Inganga, S .F. (1995*). Landslides and their environmental effects: A case study in Nyeri District, Kenya. M.Phil thesis, Moi University, Eldoret, Kenya*

Keller, E. A. (2002). *Environmental Geology* Charles E. Merrill publishers, Colombus, Ohio, USA

Kozlovskii, E. A. (1988). *Landslides and mudflows* Vol.1 236 p. UNESCO/UNEP Publication, Moscow.

Larsson, M. (1986). *Landslide in the Mountain Areas of Kenya: Comparative studies of different slopes within the Nyandarua Range. In, Soil and Water conservation in Kenya-proceedings of the third national workshop-Nairobi 6th-19th September 1986*

Lawrence, L. (1986). *Environmental Geology*. Prentice Hall, INC. New Jersey.

Lillesand T. M., Kiefer, R. W. and Chipman J.W. (2004). *Remote Sensing and Image Interpretation* (5th Ed) John Wiley & Sons, NJ, USA

Lundgren, L. (1986). *Environmental Geology*. Prentice-Hall International (U.K) London.

Mantovani, R. Soeters, C. J. Van Westen (1996). *Remote Sensing technique for landslide studies and hazard zonation in Europe: Geomorphology* vol. 15, pp.213-225

Marsh, W. M. (1991). *Landslide Planning: Environmental Applications*. John Willey and Sons Inc. New York.

McGuire, B., Burton, P., Kilburn, Ch., Willetts, O. (2004). *World Atlas of Natural Hazards*, Oxford University Press, 120 pp

Montgomery, E.W. (1989*). Environmental Geology*- Wm.C. Brown publisher, USA

Montgomery C.W. (1992). *Environmental Geology*- 466p Third Edition. Wm. C. Brown publisher Dubuque, USA.

Moore, D. M. and Reynold, R. C. Jr. (1989). *X-ray Diffraction and Identification and Analysis of Clay Minerals.* Oxford University press, New York.

Muller J. L. Pretorius C. and Vink, E. R. (2002). *The SADC Land Cover Database Project. Division of Water, Environment and Forestry Technology*, CSIR, Pretoria, South Africa.Press (N.Y)

Musaoglu, N. S., Seker, D. Z.and Goksel, C. (2002). *A Case Study of Using Remote Sensing Data and GIS for Land Management: Catalca Region, International Congress*, Washington, DC, USA.

Nduru G. M. (1995). *Evaluation of Spatial Variation in Landslide Potential within South Mathioya Drainage Basin, Kenya. M.Phil thesis, Moi University, Eldoret, Kenya*

Nemčok, A. (1982). *Landslides in the Slovak Carpathians.* Veda Bratislava, Slovakia, 319 pp (in Slovak with English summary)

Ngecu, W. M. and Gaciri, S. J. (1995*). Lithostratigraphy, provenance a facies distribution of Archaean Cratonic successions in western Kenya. Jour. African Earth Sci.*, vol.21, No.3, pp. 359-372.

Pack, R. T. (1985). *Multivariate Analysis of Relative Landslide Susceptabiloity in Davis County, Utah state university. Utah.*

Pipkin, B. W. (1994). *Geology and the Environment*, p.478 West Publ. Co., St. Paul Minneapolis, USA

Republic of Kenya, *Kakamega District Development Plan* 1994-1993. Nairobi: Government Printers

Republic of Kenya, Kakamega District Development Plan (2002-2008). Nairobi: Government Printers

Republic of Kenya (2004). National Policy on Disaster Management Revised Draft, Nairobi Kenya

Robinson, C. S. (1972). *Geological Geomorphical and Enginnering Investigation of the Loveland Basin Landslide*. Clear Creek Country, Colorado, USA, Geological Survey Prof. paper 673.

Shuttle Radar Topography Mission (2004). Retrieved October 25, 2004 from NASA: http://www2.jpl.nasa.gov/srtm /.

Sabins, F. F. Jr. (1987). *Remote Sensing: Principles and Interpretation*. 2nd Ed.W.H. Freeman and Company New York

Saturday Nation, August 8, 2007 p. 17

Scientific Data Purchase (SDP) (2004). Retrieved October 27, 2004 from NASA: http://www.esa.ssc.nasa.gov/datapurchase/default.aspx

Sunday Nation, August 12, 2007, p. 1, p.48

Swanson, F. J. and Dryness, C. T. (1975*). Impact of Clear cutting and Road Construction on Soil Erosion by Landslides in Western Cascade Range.* Oregon Geology 3 No.7:393-396.

Sidle, P. C., Pearce, A. J and O'loughlin, C. L. (1985). *Hillslope Stability and Landuse*. American Geology Union, Washington D.C. pp. 141

Temple, P. H. and Rapp. A. (1972). *Landslidies in the Mgeta Area, Wetern Uluguru Mountains, Geological Effects of Sudden Heavy Rainfall*. Geogafiska Annalla 54A (3-4): 157-193.

Terzaghi, K. (1950). *Stability of Steep Slopes on Soil Slippage by Pore Pressure Modification. In: Earth Surface Processes and Landforms Journal (JB GR B)*

The New Vision (1999). *The tragedy of Mbale Landslides-Special report*, p. 24 and p.29

Ucakuwun, E. K., Munyao, T. M., Simiyu, G. M.,Esipila, T. A. and Chepkosgei, E. (2008 a). *Mass Movement Occurance in Kipsaina-Kabokbok Area, Keiyo District, Kenya.* A paper presented at the 4th Moi University Annual Conference, held at Moi University, August 2008.

Ucakuwun, E. K., Munyao, T. M., Simiyu, G. M., Esipila, T. A. and Chepkosgei, E. (2008 b). *Landslide occurance in Khuvasali, Kakamega North District, Kenya*. A paper presented at the 4th Moi University Annual Conference, held at Moi University, August 2008.

Ucakuwun, E. K. (2002). *on the prediction of the slump-type landslides using Kenyan case studies.* Africa geoscience Review, Vol.9(4):397-400.

Ucakuwun, E. K., Some, D. K. and Esipila, T.A. (2000). *Assessing The Landslide Potential of the Eastern Slopes Kenya Side Of Mt. Elgon*. A Proposal for Research.

UNESCO (1973). International *Classification and Mapping of Vegetation.* Paris, France. 35 pp.

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

Varnes, D.J., (1996*). Landslide Types and Processes, in Turner, A. K., and R.L. Schuster, Landslides: Investigation and Mitigation*, *Transportation Research Board Special Report 247*, National Research Council, Washington, D.C.: National Academy Press.

William, A. A. B. and Pidgeon, J. T. (1983). *Evapotranspiration and Heaving Clays in South Africa Geotechnique* 33, 141-150.

Zabura, Q. (1969). *Landslide and their Control*. Elsevier publishing company, Amsterdam.