LANDSLIDE HAZARD ASSESSMENT IN KENYA

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JUNE 2011

DECLARATIONS

Declaration by student

This dissertation is my original work and has not been presented for degree in any other university and whatsoever

NAME……………………………………………………………………………………

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Declaration by University supervisor

This dissertation has been submitted for examination with approval as university supervisor

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ABSTRACT

Landslide problem has been little researched on in Kenya and there is lack of information on rainfall threshold, nature of occurrence and characteristics which are vital information for GIS data base creation for easy landslide monitoring. Landslide risk in Kenya is assessed in relation to region geology, soil type, rainfall density and slope gradient. Areas identified as being most risk are those affected by tectonic activities associated with the formation of Rift valley with deeply weathered volcanic nitisol soil and high to moderate mean rainfall attracting large human population settlement in these areas igniting landslides. Models of determination of physical factors directly or indirectly correlated with slope instability and selecting rating system according to hazard degree in an area need to be understood in which GIS can sustain effectively. Establishment of sensors with wireless connection (Bluetooth) in these fields is envisaged to monitor and warn on future occurrence.

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1.0 INTRODUCTION

Kenya is a region highly affected by landslides and mudslides. These landslides occur persistently and endanger the lives and livelihoods of thousands of households, most of which live in poverty. Long and heavy rain increase stream discharge in the zone generating landslides especially in highlands where the epidemic killed hundreds of people, thousands of animals and left many homeless. This has been documented in reports with Muranga having the highest number of occurrences since early 1960. landslide occurred in Mukurueni killing four people on September 1986 (Ngecu and Ichangi 1999).This was followed by disastrous one documented to have occurred on 15th of May 1991 killing eight people and destroying property worth more than 0.8million Kenya shillings (Davies and Nyambok1993). 1997 was the year when the disaster recurrence was high in Muranga, Mathoiya River broke its banks on 30th April sweeping through coffee plantations and taking lives of 11 people (Mwendwa and Njuguna, 2002). Rock falls occurred in Chesikaki destroying crop plantations and killing one person (Masibo 1998). On 16 March 1998 it destroyed a 2-km section of Masii-Makueni highway in eastern Kenya. The landslide also destroyed a major bridge on the highway, thereby cutting off communication between the two towns. The landslide occurred when River Tana swelled after heavy rainfall and its flood waters oversaturated the ferralsols which formed its banks and the surrounding region. The oversaturated ferralsols lost their shear strength and the landslide occurred (Ngecu and Mathu 1999). The onset of el-Niño in 1998 saw destruction of farm lands, railway lines, telephone lines, roads and ultimate deposition of earth material in dams hindering power generation causing losses of billions of US dollars (Ngecu and Mathu 1999). In the same year, failure in Kijabe area cost Kenya railways cooperation to loss over 90 million after their line was covered for more than 10 days. The new millennium was ushered in by Ndunyu Chege slide (Gatanga-Thika) causing loss of fertile soil (Kamunge and Kirembu 2002). 4th of May 2003 Sasamua dam in Nyandarua collapsed and after a week landslides occurred (Mwangi 2003). In March 2010 thousands of Kitony villagers in Marakwet spend their night in cold and 11 of them were killed together with thousands of animals.

Despite the immense losses and the recurrent episodes, no one has studied and compiled on nature of occurrence and characteristic in Kenya which is important in creation of GIS data base for easy monitoring thus compelling for the research.

1.1Research questions

- ❖ Which are the landslides triggering agents in Kenya?
- ❖ What are the characteristics of landslides in Kenya and their nature of occurrence?
- ❖ What is the degree of social and economic impacts of landslides in the country?
- ❖ Which are the suitable methods to control the disaster, existing gap in landslide prediction and how GIS can be used to map landsliding?
- ❖ What can be done to curb the disaster?

1.2. Objective

The main objective of this report is to;

- ➢ Study occurrence and nature/characteristic of landslides in Kenya.
- ➢ Study how GIS can be used to map landslides.

1.3 Methodology

The nature of occurrence of landslides in Kenya was determined through review of scientific papers and technical reports in departmental library and Mines and geology department (industrial area). How GIS can be used to map landslide and Mitigation measures were based on review of scientific papers around the globe.

1.4Significance of the study

There is need to curb loss of human life and property in Kenya by incorporation of modern technology in zonation of areas prone to mass movement, therefore GIS data base is necessary through the review since the technology has ability to warn on coming disaster if the parameters inducing failure are known and fed to system and method they can be analyzed be understood. Also existing gaps in landslide prediction need to be established and possible effective way of curbing the disaster need to be built up. Not least, an economical and effective method of preventing the disaster is required to avoid further acceleration in future. Generally, the research will be useful in disaster management in the country.

1.5 Justification of the study

With the current state of technology, landslide research and mapping in Kenya need to be taken to new level since the present is Key to the past.

1.6 Study area

The Republic of Kenya is located on the eastern side of Africa and is divided by the equator into almost two equal parts (Fig. 1). The country extends between latitudes $5^{0}30'$N and $4^{0}30'$S and longitudes $34^{0}00$E and $42^{0}00$E. Kenya has a total area of about 582000 km^2 with population density more than 32 million, majority living in poverty in rural areas. The country is divided into 8 administrative regions and total of 47 counties distributed in semi arid, arid, highlands and coastal region geographic zones.

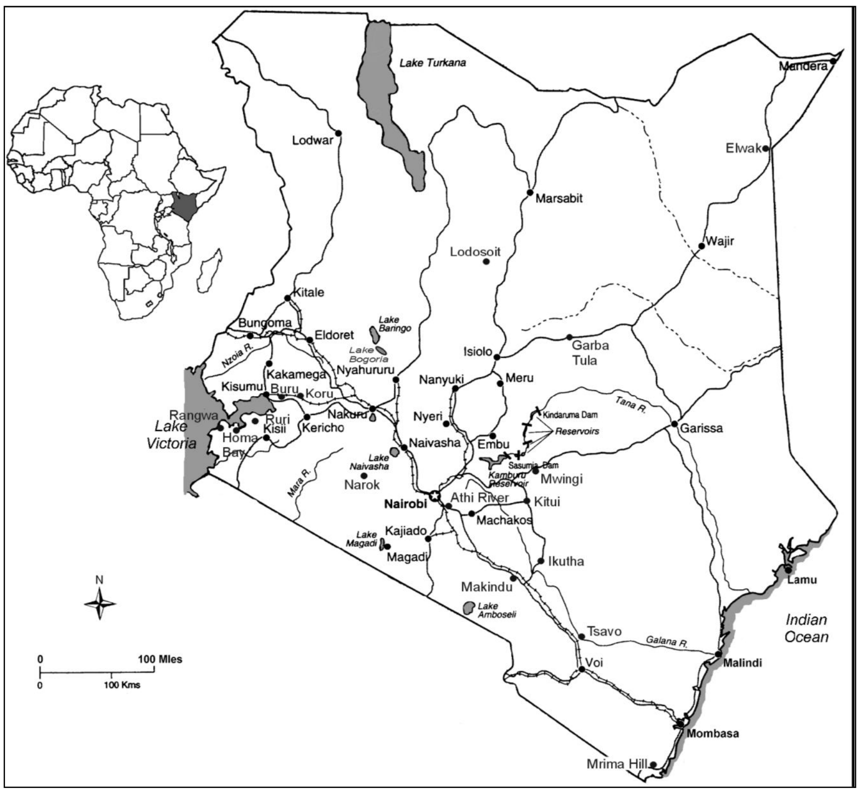


Figure 1.Map of Africa showing Kenya position courtesy of google earth.com

1.4 Regional geology

The main rock types making geology of Kenya include, the Achaean rocks of the Nyanzian and Kavirondian Groups, which are found in western Kenya, the Proterozoic rocks of the Kisii Group and the Mozambique Belt, the Upper Paleozoic rocks of the Taru Formation, the Mesozoic rocks of Maji ya Chumvi Formation, Mazeras Formation and Maheran Formation, the Cenozoic rocks of the East African Rift System including lava and pyroclastic flows, the Faratumu Formation, the Magari Formation and the Oloronga.

The Nyanzian and Kavirondian Groups form the Achaean greenstone belt of western Kenya. The Nyanzian Group is composed of metavolcanic rocks which range from tholeiitic basalts to calc-alkaline andesites, dacites and rhyolites. The group is unconformable overlain by the Kavirondian Group, which consists of greywacke, mudstone and conglomerates (Ngecu and Gaciri 1995).

The granite batholiths in western Kenya which include the Mumias and Maragoli granites are heterogeneous lithologies which vary from granodiorites, through adamellites to tonalites (Mathu and Nyambok 1993).

The Kisii Group is represented by a volcano sedimentary sequence that occurs in Kisii district of Kenya .This group represents marginal marine sediments and volcanic rocks of the original Mozambique geosynclinals basin (Mathu and Davies 1996). The rocks of the group were dated at 1.30–1.00 Ga (Cahen 1984).The Cenozoic volcanic rocks of the Rift Valley, include basalts, phonolites, nephelinites, trachytes and rhyolites. The phyroclastic rocks such as tuffs, agglomerates and ashes.

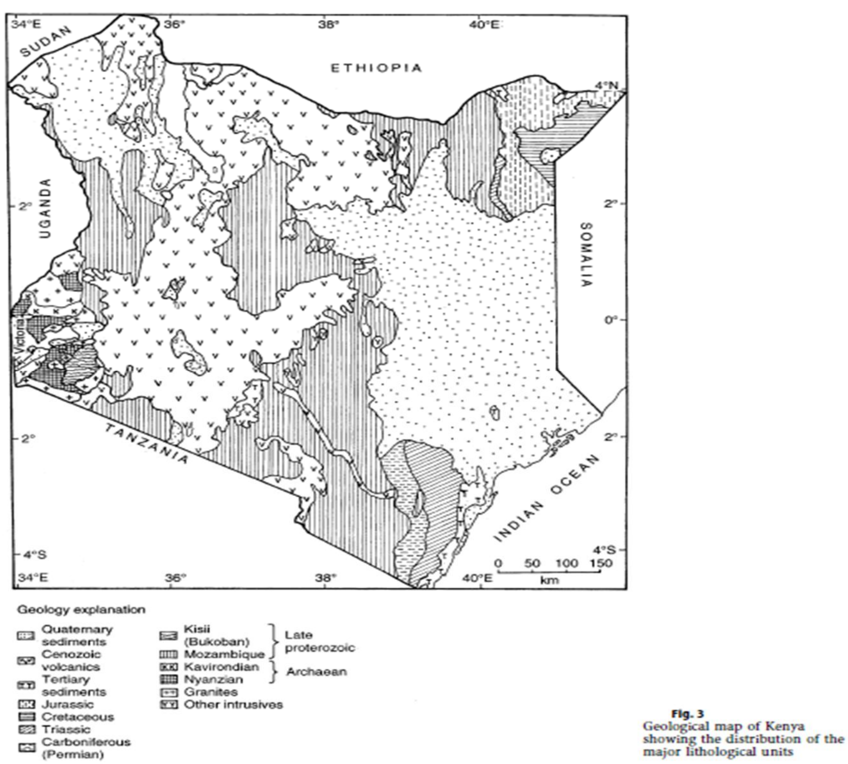


Figure 2.Map showing geology of Kenya modified from Ngecu (1999)

CHAPTER TWO: NATURE OF LANDSLIDE OCCURRENCE IN KENYA

The term landslide describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rocks, soils, artificial fills, or combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing in the study area. The various types of landslides can be differentiated by the kinds of materials involved and the mode of movement (Varnes, 1978). Other classification systems incorporate additional variables, such as the rate of movement and the water, air content of the landslide material. In Kenya, areas covered by andosol, lithosol ,nitosol and cambisol soil is found to be greatly affected(Rowntree 1989,Ngecu 1999,Mwangi *et al* 2003). Andosols occur in areas with steep slopes and high-rainfall intensities promoting excessive leaching of aluminium rich and start to fail on precipitation above 300mm/hr on slope angles above 22-36^0 as per Kamau 1981.
Andosol is porous with high water-storage capacity and a low bulk density(Gachene and G. Kimaru, Relma, 2003). Nitisols occur in highlands and on volcanic steep slopes in the central highlands of Kenya i.e Mt. Kenya, Abadares range ,Cheranganyi hills, and Mt.Kilimanjaro. They are developed from volcanic rocks and have high moisture storage capacity and aeration; the organic matter content, the cation exchange capacity and the percentage base saturation range from low to high.Nitisol have high clay content (more than 35%) and movement start at as low as 2^0 soldemly (Lewis1999) in Nyandarua. Nyandarua with Nitisol soil was unstable on slope angle's greater than 20 ^{0}(Rowntree 1989). The Kenya map below show area covered by Andosol,Nitisol,lithisol and combisol soil making up the sensitive soil.

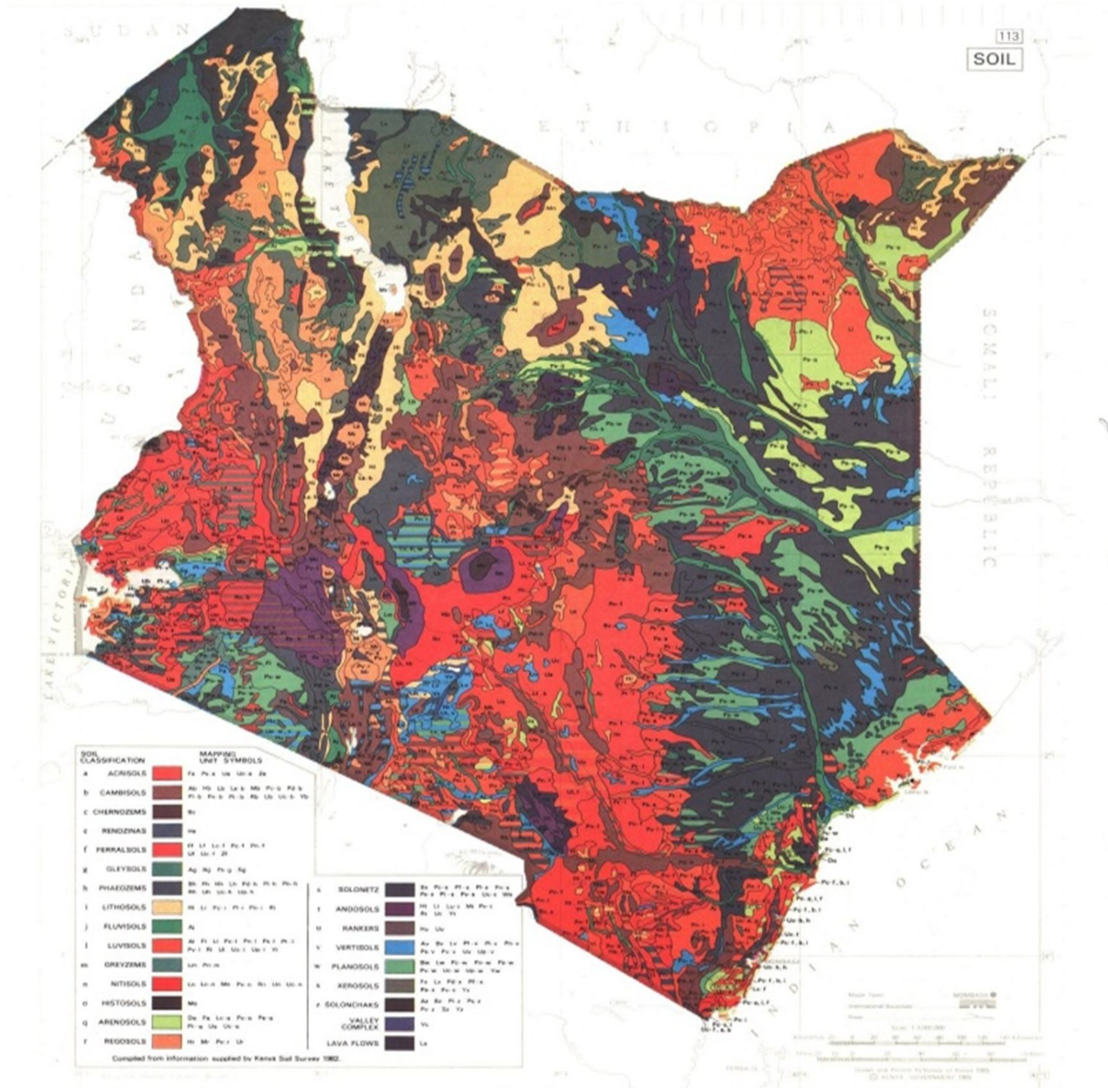


Figure 3 Kenya soil map courtesy of googlemap.com

2.1Characteristic of landslides in Kenya

Many types of mass movements are included in the general term “landslide", the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides experienced in Kenya are rotational slides and translational slides. Areas with steep slopes, high precipitation rates and deeply weathered volcanic soils are prone to landslides in Kenya. These areas make Tugen hills, Abardares ranges ,Mau escarpment Mt. Elgon,Mt. Kilimanjaro, Nyandarua and Muranga (Rowntree 1989).

2.2.1 Rotational slide

The surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (Njuguna and Mwendwa 2002). It occur in Ruiguta, Kagongo,Karicungo Ruambogo in Muranga at repose angle of 60^0 on weathered volcanic rocks soil on affecting depth greater than 15M. Occur on weathered volcanic materials yielding Nitosol soil which moved at surprisingly 2^0 at Nyandarua (Lewis 1999).

2.2.2 Translational slide:

It occurs in highly fractured pyroclastic or basalt(Mwangi *et al* 2003) in Nyandarua, also in Maringa area (Ngecu and Ichangi 1999). The mass moved along a roughly planar surface with little rotation or backward tilting. In Nyandarua (Lewis 1999), the soil profile investigations showed that the surface of rupture is the contact between residual soil and saprolite. Measurements indicate high rates of infiltration on topsoil (500-700 mm /hr) and low rates on an exposed saprolite surface (about 10 mm/hr). This implies that rainwater infiltrates rapidly, percolates to the cambosol boundary where it is effectively hindered and forced to take a lateral path down slope. Water flow at the cambosol contact reduces the stability of this layer making the steep slopes extra sensitive due to the increased speed of lateral percolation (Lewis 1999).

2.2.3 Rock Fall

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs. Along Kiruri –ichichi road in Muranga, Separation occurred along joints, and bedding planes. The movement was by free-fall and rolling for 15m blocking the highway (Mwendwa and Njuguna 2002). They are influenced by gravity, mechanical weathering, and the presence of interstitial water. It also occurred in Chesikaki area on the slope of Mt Elgon in 1997 where $100m^2$ boulders hit the ground and swept an area of $36000m^2$ after heavy precipitation (Masibo 1998).

2.2.4 Debris flow

A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilizes as slurry that flows down slope and normally less than

50% fine. It is caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes in Kijabe/Kiambu on 20th July 1998 where debris blocked culverts (Hussein 1998). The scenario also occurred in Chepkaigat hill (60^0) on 26th November 2006 and Chepchuru area in Nandi district (Lizunela 2006).

2.2.5 Mudflow:

A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt, and clay sized particles (Linuzela 2006). This occurred in Kerio Valley, Kitony village where the mud killed 11 people and covered thousands of animals and structures on March 2011.

2.2 Factors contributing to landslides

2.2.1 Geology and soil

The regional geology of an area is an important factor in triggering landslides because landslide-prone areas are associated with specific rock suites, which are normally deeply weathered, leading to reduction in their shear strength .Cenozoic volcanic rocks of the Rift Valley which readily weather to give thick soil profile, include basalts, phonolites, nephelinites, trachytes and rhyolites. The phyroclastic rocks such as tuffs, agglomerates and ashes are associated with both the large central type volcanoes (Mounts Kenya, Elgon, Kilimanjaro and the Aberdare Ranges) as well as the numerous central volcanic cones of the Rift Valley floor weathered easily to give andosol and Nitosol soil. Nitosols are formed after intensive weathering of basalt and basaltic agglomerates. They have a high clay content and moisture content of 38–62% and 49.5% respectively. The main clay minerals in the soil are kaolinite, illite, and montmorillonite. Nitosols have low bulk density which increases down the soil profile.

Table 1 Summary of landslides experienced from various literatures review

location	Landslide type	geology	Depth (M)	Elevation(m)	Repose angle(^{0})	Destruction caused	Rain intensity mm/hr
Mukurueini	Translation-al	volcanics	15	-	40	Farms and 4 lives	100
Kiharu Muranga	rotational	volcanics	20		60	Farms and 3 lives	-
Ruguita muranga	rotational	volcanics	5		60		
Gatanga	translation	Pyroclastics	11		60		200mm
Nyandarua-a range	Mud flow	volcanics	-	4000	2-60	Farm land	100mm
chepchuru	Debris flow	volcanics	-	1500	50	-	100mm
Kitony	Mud flow	volcanics	9	1500	-	Farms and 11 lives	-

2.2.2 Elevations and precipitation regime

Most landslides in Kenya occur in areas of high relief which receive high rainfall intensity encouraging weathering of regolith's to greater depth. The relief of Kenya is divided into four major zones which include, the Coastal and Eastern Plains, the Central and Western Highlands, the Rift Valley Basin and the Lake Victoria Basin(Ngecu and Mathu 1999).This zone vary in vulnerability to sliding as follows.

2.2.2.1 Coastal and eastern plains

The Coastal and Eastern plains which approximately cover one third of the country have an elevation which varies from 0 m at sea level to about 500 m at the hinterland coastal hills thus no observable landslide activity on them (Ngecu 1999). It receives an annual rainfall of about 1500 mm. The months of January and February, which are usually the driest, receive less than 10 mm of rainfall each. The months of April and May, which are the wettest, receive over 200 mm of rainfall each. The rest of the months in the year receive an average of 50–100 mm of rainfall each(Rowntree,1988, 1989,Ngecu1999).

2.3.2.2 Rift valley basin

The Rift Valley Basin runs approximately North-South along the 36^0E longitude and separates both the Eastern and Western Highlands. The basin is broadest in its northern part around Lake Turkana where it is about 300-km wide (Ngecu1999). It is narrowest around Lake Naivasha where it is only about 30-km wide. The highest elevation of the basin is 500 m above sea level occurs at its narrowest and middle zone which is enclosed by the Mau Hills in the west and the Aberdares Ranges in the east. There no intense landslide activity noted in these areas.

2.3.2.3 Eastern and Western highlands

The highlands have an altitude which varies from 1500 to 5200 m. The Western Highlands are marked by the Mau Hills (about 3100 m) which occur in the central part of Kenya. The Cherangani Hills (about 3400 m) and Mount Elgon (about 4300 m) fall in northern part of the country. The Eastern Highlands are marked by the Ndoto Mountains in the north while the Aberdare Ranges (about 4000 m) and Mount Kenya about 5200 m) mark the highest peaks in the central area of the eastern highlands. Immense landslide activities in this zone noted as Most of the Rivers in Kenya (accelerating agent), originate from this Highlands and form a radial drainage pattern increasing infiltration rate thus increased pore pressure (Mathu and Davies 1996). The Highland receives an average annual rainfall of over 1000 mm. The months of January, February and July–September are the driest with an average rainfall of less than 30 mm each. The wettest months are April–May and October–November with average rainfall of over 200 mm each month,(Ngecu and Mathu1999). Intense land sliding is observable in this zone during rainy seasons thus making the most risk zone.

2.2.3.4 The Lake Victoria Basin

The general elevation of the basin is between 500 m and 1000 m above sea level, it is not prone to the disaster though receive an average annual rainfall of over 1800 mm with the driest months receiving an average minimum of only 200 mm(Ngecu 1999).

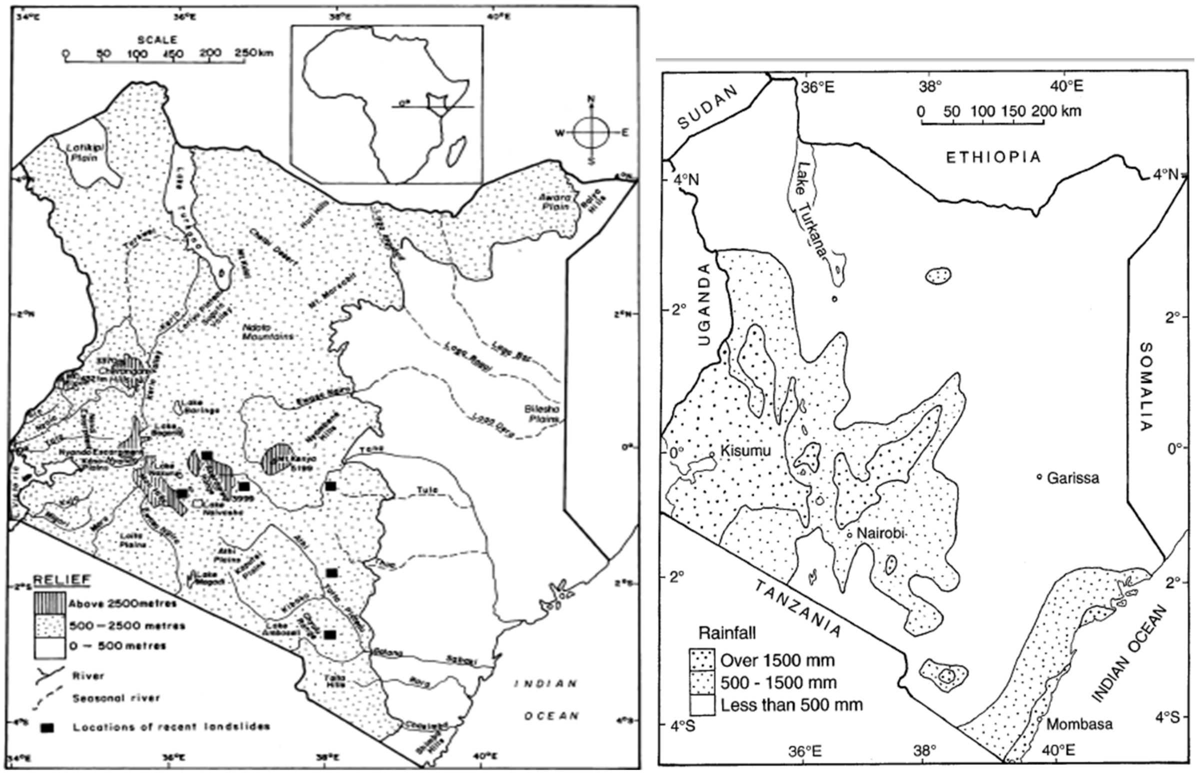


Figure 4:Maps of Kenya showing relief drainage and rainfall intensities in landslide prone areas(Ngecu 1999)

2.2.3 Seismic activities

Areas which previously experienced landslides, the population noted thunderstorm followed by shaking then subsequent mass movement down slope (Ngecu,Nyamai and Erima 2004, Lizunela 2006). This should not take little attention in landslide monitoring as seismic energy reduces soil confining forces. The seismic activity associated with the Cenozoic rift valley in Kenya generally consists of seismic events of magnitudes $M_L < 3$, whilst that associated with the western branch of the East African Rift System includes many higher magnitude ($M_s > 4$) events, indicating a difference in the manner of energy release between the eastern and western branches. The seismicity distribution derived from temporary local networks is primarily associated with the Kenya Rift and the east-west-trending Nyanza trough on the western flank of the Kenya dome. There is a scattered distribution to the east of the Rift, apparently originating in regions suffering recent volcanism and possibly associated with a shallowing of the lithosphere-asthenosphere boundary. The principal concentrations of activity are in the Nyanza trough, the Suguta valley and its continuation to the north into southern Lake Turkana, and in the Lake Bogoria region where the activity appears to be linked to the large-scale structural features of the Rift. The Figure below shows Mt Kilimanjaro having highest distribution of earth quake events thus making the landslide earthquake risk zone.

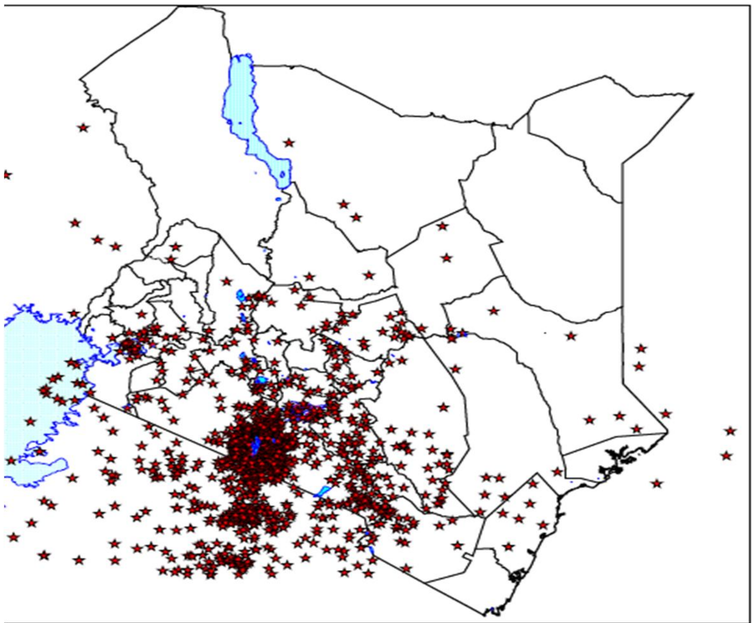


Figure 5 Earthquake distribution map in Kenya courtesy of Wayumba (2001)

2.2.4 Human causes

The landslides which occurred around Mount Kenya were caused by oversaturation of steep-sided man-made cuts between hills and road construction. The slope cuts reduced the confining pressure and the unconfined compression strength of the over-steepened slopes which supported the soil materials and consequently landslides occurred (Ngecu and Mathu 1999).

Ngecu and Ichangi (1998) noted vegetation in Maringa village had been largely destroyed by farmers in order to increase the cultivation hectareage and provide wood fuel. Remnants of natural vegetation, however, occur on few catchment areas and along the river banks thus no soil coercing forces. Sasamua dam draw down was as result of mans negligence in setting water body in weak collapsible soil. Generally for the all areas previously encountered the disaster has seen increasing population straining the ground with aim of economic benefits (Rowntree 1989).

2.3 Socio-economic impacts of landslides in the study area

The greatest socioeconomic impact of landslides is the loss of life, for instance, Gikondi village landslide killed 4 people, Gacharage slide killed 8 people and Maringa village landslide killed 11 people.

Another socioeconomic impact of landslides is the destruction of property and agricultural land. It is estimated that over 100000 US dollars worth of property including houses, coffee and tea plantations and domestic animals were destroyed by landslides between 1980-1997 in Muranga District alone (Ngecu and Mathu 1999).This was in addition to mobilization of several millions cubic meters of agricultural land from the original location to hundreds of meters down slope (Ngecu and Mathu 1999).

Socioeconomic impacts of landslides also arise from the destruction of roads. The Murang'a-Kiriaini highway is often impassable due to the sliding of deeply weathered volcanic soils which cover sections of the road. Another socioeconomic impact of landslides results from their contribution to river sediment loads. High river sediment load is a serious problem due to siltation of reservoirs which store water for hydro-electric power generation and for irrigation projects downstream (Nyambok and Ongweny 1979).

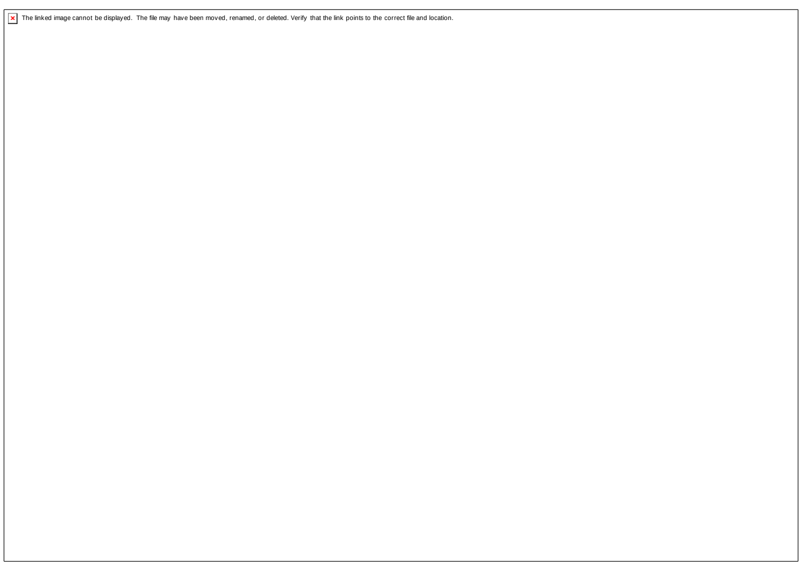


Figure 6 Residents view a house that was destroyed by mudslide in Mukurweini, Kenya (demotix.com)

CHAPTER THREE: USE OF GIS AND REMOTE SENSING IN MAPPING LANDSLIDES

Research on landslide in Kenya has been done by a number of scientist and rainfall determined to be the major triggering agent but its intensity threshold not determined in different materials in parts of the country! This should be factored in landslide assessment with creation of GIS data base to enable in zonation of disaster prone zones as applied in developed countries.GIS is computer based program which can sustain below effectively with availability of effective database (Popescue 2001).

- ❖ Modeling results
- ❖ Can perform spatial state of art i.e. drawing each sectorial research field both on simple data base and multiple maps.
- ❖ Perform system update and monitoring.

Landslides susceptibility mapping should focus on weight factor model (Sarkar 2002) which considers:

- Determination of physical factors which are directly or indirectly correlated with slope instability.
- Selection of rating system i.e. system of all instability factors and classes of each of them.
- Estimation of relative role of causative factors producing mass movement.
- Final classifying the surface according to different hazard degree.

The model involves bivariate statistical approach which is data driven applying Bayesian approach of prior and posterior probability to calculate individual weight of evidence. The prior probability of landslides in an area is calculated and used as the standard for calculation of weight by comparing class density with overall density (Susen *et al*, 2004). With this, binary class map displaying presence or absents of landslides is build up in which GIS and remote sensing technology can sustain effectively (Sarkar 2002, Guzzetti 2004).

Prior probability=Zone with slope failure/Total zone

This can be represented in terms of pixel i.e. p_{prior} =No of pixel with failure in an area /Total no of pixel present in the area.

Since the conditions are not uniform over whole area in terms of slope failure, conditional probability may decrease or increase depending on prevailing condition. In cross binary slope failure showing presents or absents of failure with each other, four possible results are:

- Presents of both failure and variable factor

- Presents of failure and absents of variable factor
- Absents of failure and present of variable factor
- Absents of failure and absents of variable factor

Slope failure	Variable factor	Variable factor
	presents	absents
Presents	• Pix 1	• Pix 2
absents	• Pix 4	• Pix 3

The susceptibility to slope failure thus can be expressed in terms of natural log of ratio of class density to the overall density in the area. With positive weight of evidence it will be expressed as W+ =in pix1/ (pix1+pix2)//pix3/ (pix3+ pix 4) while for negative will take W- =in pix 2/ (pix 1+pix3)//pix4/ (pix3+ pix4)

The positive weigh of evidence is measure of importance of the factors consideration influencing slope failure in area under investigation. Positive when the factor enhance slope failure, Zero when slope failure is independent and negative when presents of the factor reduces chance of slope failure(Mancini 2010, Lee *et al* 2007).

The contrast factor C is expressed C=w+ -W-. this expresses the correlation between the variable factor and slope failure of the area in which when it is C=0 it means w- and weight w+ have no association in common but occur by chance.

Creating weight maps for individual factor and combing them into overall weight map is obtained which can be subdivide into desired class each indicating relative hazard level (Popescue 2002) possible with use of GIS and remote sensing tool.

3.1 Required data base for GIS

Hazard GIS data base has been created with enormous success (Guzzetti2004).In creation of Azoires data base, several thematic data set were used with each set comprising several layers making up numerous data. The data base was set up in layer to allow constant update and input new detailed information without affecting logical structure of the data base. The data was grouped in set comprising basic monitoring and historic information as listed below.

3.1.1 Geographical and economic data set

This should include topographical maps (scale1:25000) with possible factor leading to vulnerability analysis i.e. roads, buildings water supply system, agriculture area, stream and rivers and population density(Mancini 2010). This information contained in the package can be updated always and represented as shown in Table below.

LAYER	DATA	Feature on map
Elevation contour	Major contour	Line
Rivers	Main river and stream	line
Buildings	Houses,schools,public buildings, hospitals and police stations	Points/polygon
Roads	Highways, main roads, footpath	line
Water supply	Lake, reservoir wells and dams	Points, lines
Agriculture activities	Type of plants and crops available	Point or polygon
Earth quake	intensity	points

3.1.2 Geodetic data set

This includes GPS readings and observation made during the field at that particular position (Guzzette2004, Mancini 2010).

3.1.3 Geologic data set

Cover descriptive data obtained during field survey i.e. lineament density, lithology, tectonic structures and erosion landform (Sarkar 2002).

3.1.4 Landslide data set

This should be defined to achieve information related to historical and contemporary slope movement as well as their impact which should be obtained from technological reports and recent mapped by uses of Arial photos and satellite imageries (Sarkar 2002, Guzzetti 2004). This can be represented as shown in the table below on Map

LAYER	DATA	FEATURE
Landslide event	Date, type of movement and triggering mechanism	point
Landslide scar	Maximum elevation, width, and perimeter area	Point/line polygon
Landslide impact	Total damages caused	point

3.1.5 **Ground water data set**

Water table variation with respect to precipitation with time should be fed to GIS (Guzzetti2004).

3.1.6 Metrological data set and rainfall-duration threshold

Rainfall intensity in landslide prone areas in hourly basis can be used to determine regional threshold. **Rainfall intensity-duration threshold as** Campbell (1975) postulated that infiltration of intense rainfall with time created perched aquifer with positive pore water pressure that reduced the effective strength of soil and initiate landslide. Identification of regional rainfall threshold to trigger landslide is statistical approximation of minimum rainfall condition to trigger mass movement in particular geological environment. It is possible to determine the trigger threshold for earth with homogeneous characteristic by comparing the degree of susceptibility to rainfall intensity (Caine 1980).

The threshold, fitted by inspection to the lower boundary of those points representing landslide-triggering storms, is expressed as $I = CD^{-B}$

Where: I= rainfall intensity in millimeters per hour,

D= duration in hours.

B and C=Constant representing shear strength of the soil and slope character A threshold fitted to the lower boundary of data points reflects the approximate minimal rainfall conditions necessary to trigger landsliding. Real time Rainfall data with landslide threshold should be incorporated to GIS landslide warning system to assist in detection as those operating in outside world which is not applicable in Kenya at now due to limitation of availability of rainfall hourly data.

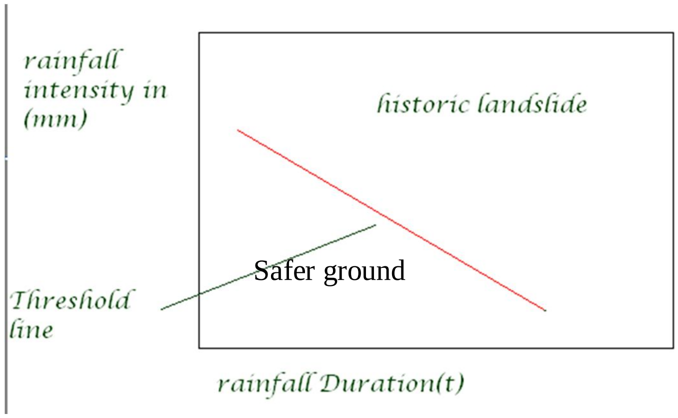


Figure 7 Rainfall duration threshold verses intensity

3.1.7 Soil mechanics data

This should cover soil for landslide prone area with their mechanical properties i.e. plasticity index, shear strength and thickness of weathered regolith.

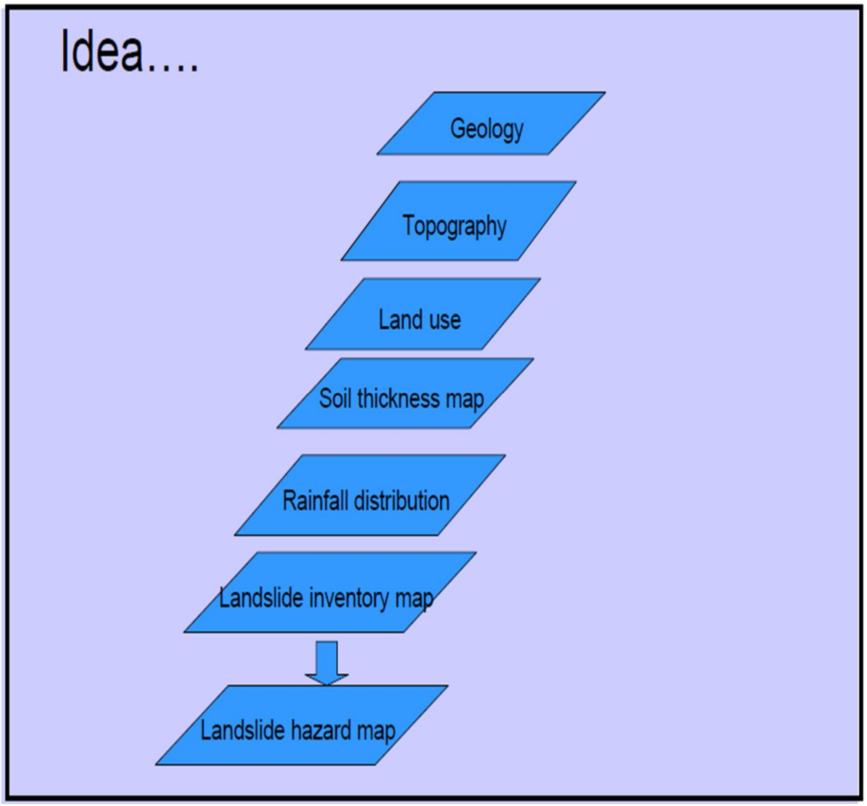


Figure 8 Factors to consider in development of GIS hazard map

In creation of landslide hazard map, the locals could be warned on coming disaster for decision making as GIS technology facilitates constant update, Modeling results, monitoring and perform spatial state of art thus on thresholds likely to cause movement, detection is enhanced.

CHAPTER ROUR: CONCLUSIONS

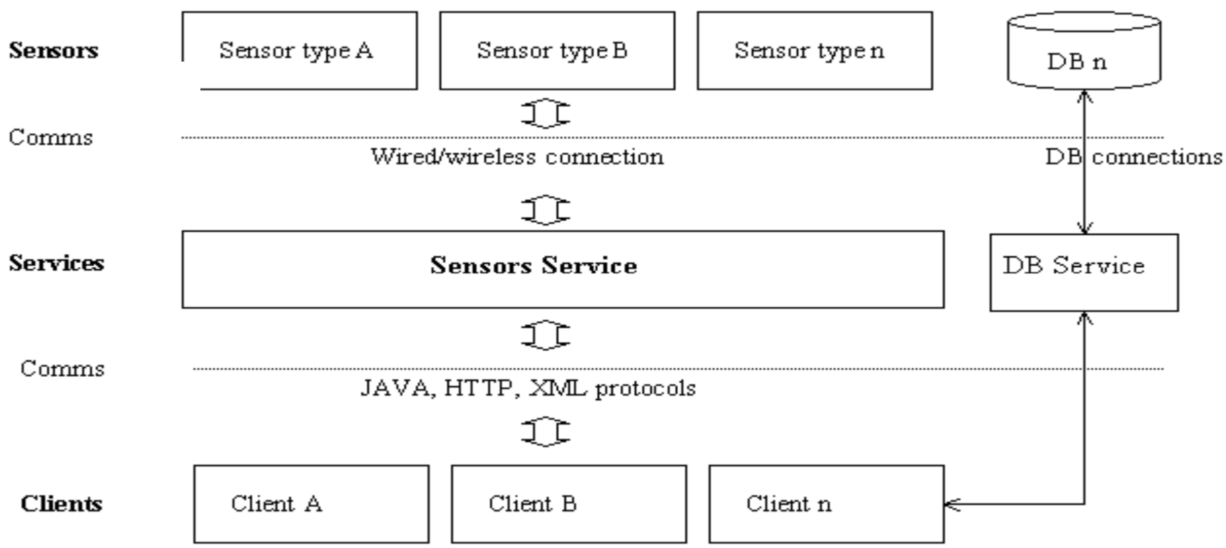
Landslides in Kenya are shallow (1-15m) rotational, translational, debris fall and mudflows occurring on slopes greater than 20^0 on intense rainfall with intensity threshold not determined. The volcanic rocks are the most susceptible due to the easy to weathering ability yielding clayey andosol, cambisol, nitosol and lithosol soil. The major triggering mechanism of landslide is rainfall and anthropogenetic activities increasing instability in steep slopes.

Remote sensing and GIS techniques greatly aid in the investigations of landslides, on both a local and regional scale and act as a boost if implemented in the Kenya. Although they do not replace fieldwork, interdisciplinary research strategies, and testing the reliability of landslide prediction models, remote sensing techniques do offer an additional tool from which we can extract information about landslide causes and occurrences. Most importantly, they greatly aid in the prediction of future landslide occurrences, which is very important to those who reside in areas surrounded by unstable slopes and thus should be used in analysis.

CHAPTER FIVE: RECOMMENDATION

- **Installation of permanent sensors in the field**

Number of extensometers observing the inevitable seasonal expansions and contractions of the joints and rainfall threshold measuring instruments (pluviometer) in build with Bluetooth and WINLAN to be set in field .The extensometer's daily measurements should be send regularly to a geological office for evaluation and if a certain threshold is reached or exceeded, an alarm is generated, in this case, in form of a short messaging service (SMS) and the roads near-by landslide active area are closed or villagers evacuated from the area. This avoids any danger to motorists or people on foot. The following is the frame work proposed to be established and desired to be developed by instruments making industry and disaster managers in the country.



Also rainfall intensity threshold should be determined and application of GIS technology for mapping as documented above should be used in the country.

- **Drainage control**

Drainage is often a crucial remedial measure due to the important role played by pore-water pressure in reducing shear strength. Because of its high stabilization efficiency in relation to cost, drainage of surface water and groundwater must be used; generally it is the most successful stabilization method to be used.

- **Vegetation planting**

Vegetation has a beneficial effect on slope stability by the processes of interception of rainfall, and transpiration of groundwater, thus maintaining drier soils and enabling some reduction in potential peak groundwater pressures. Except these hydrological effects, vegetation roots reinforce the soil, increasing soil shear strength while tree roots may anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching. A small increase in soil cohesion induced by the roots has a major effect on shallow landslides. The mechanical effect of vegetation planting is not significant for deeper seated landslides, while the hydrological effect is beneficial for both shallow and deep landslides.

- **Restraining work**

Modification of slope geometry is a most efficient method particularly in deep seated landslides in Kenya especially in Nyandarua where excavation of slope toe induced movement. Walls standing perpendicular to movement direction should be erected in this area though this may create eye sore to population in the ground.

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