COMPARATIVE FACTORS THAT INFLUENCE LANDSLIDE OCCURRENCE: APPLICATION OF GIS AND RAINFALL THRESHOLDS IN LANDSLIDE ASSESSMENT IN KENYA

KAHIGA EMILY WANGARI
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DECLARATION AND APPROVAL

Declaration by candidate

I declare that this is my own work and has not been presented for examination from elsewhere.

Name…………………………………………………………

Signature………………………………………………..

Date…………………………………………………………….

Approval by supervisors

I declare that this dissertation has been submitted for examination with my approval as the official University supervisor.

Name……………………………………………………......

Department of Geology

Signature……………………………………………………

Date……………………………………………………………..

Name…………………………………………………………….

Department of Geology

Signature………………………………………………………

Date……………………………………………………………

DEDICATION

I gladly dedicate this dissertation to my beloved Dad, Mr. Kahiga Julius.

ABSTRACT

Landslides are recurrent phenomena in Murang'a and Mt. Elgon Districts, causing loss of lives, property and fertile farmland. Despite the grievous danger posed, comparative studies of landslides in the two districts have neither been carried out nor has the use of state-of-the-art methods of landslide risk assessment been applied.

In this review paper, the factors influencing the occurrence of landslides in Murang'a and Mt. Elgon Districts have been comparatively studied in order to review how these factors influence landslide occurrence. The four factors discussed in depth include geology, topography, rainfall distribution, and soil-sediment characteristics. In the two districts, the four factors play relatively a similar role as far as landslide occurrence is concerned. Therefore, such comparative studies can be used to predict landslide vulnerability in different areas.

Two major techniques of landslide hazard assessment that is, application of GIS and rainfall thresholds, have been reviewed with an aim of boosting landslide research in the two districts. In the application of GIS in landslide assessment, creation of a standard GIS landslide database has been carried out in accordance with some successful GIS databases in the world. The database has been used to construct various landslide vulnerability maps for both Murang'a and Mt Elgon Districts.

A comprehensive review of landslide assessment using rainfall thresholds has been carried out. However, this method cannot be accurately applied in the two districts due to limitations of rainfall data (hourly rainfall data) due to lack of relevant instruments such as pluviometers.

ACKNOWLEDGEMENT

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I owe my sincere gratitude to the staff of Mines and Geological Department, Ministry of Environmental and Mineral Resources for their ready willingness to avail technical reports on landslides which were paramount in this project. Special thanks go to Judy who is in-charge of library.

Last but not the least, I thankfully register my overwhelming appreciation to my dear family and friends for their immense moral and financial support, it would not have been easy without you. God bless you all.

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LIST OF ACRONYMS

GIS – Geographical Information Systems.

UTM – Universal Transverse Mercator.

Km – Kilometre.

MEMR – Ministry of Environmental and Mineral Resources.

N – North.

Mt – Mountain.

SE - South East.

ºC – Degree Celsius.

Alt – Altitude.

asl – Above Sea Level.

US$ - American Dollar.

Kg – Kilogram.

Fig - Figure

cm² - Square Centimeter.

CHAPTER 1

INTRODUCTION

Landslide is the downward movement of slopes forming materials under the influence of gravity as described by Varnes (1978).

1.1 The Landslide Problem

Loss of human lives and destruction of property accompany every other occurrence of landslides which are very common in Murang'a and Mt. Elgon Districts. Some of the destructive landslides in the recent past are as follows:

On 10th May, 2010, a debris flow occurred in Cheptais area at GPS location 36N 0066112, UTM 0090562; elevation 1817 M asl., causing the death of two people and injuring five other family members, as well as destroying the home and crops, as reported in the Kenya Nation, Thursday, May 13, 2010.

On 30th April, 1997, a major landslide swept away 2 hectares of land, killed eleven people, and destroyed property worth thousands of dollars in Muringa village, Murang'a District, Ichang'i and Ngecu (1999)

On 15th May, 1991, a landslide occurred in Gacharage village, Murang'a District, killing eight people and destroying an estimated US$ 10000 worth of property, Nyambok and Davies (1993).

In May 2010, a landslide occurred in Chemma village, Sasura location, Cheptais district, at GPS location 36N 0666491, UTM 0091936, elevation 1913 M asl., displacing a section of banana plantation, a distance of about 100 M down slope into a valley, MEMR, Mines and Geological Department.

Still in May 2010, a rock fall/roll manifestations are observable in Nyatikongi village, Sasuri location, Cheptais district, where a huge boulder dislodged and rolled down slope for about 100 M, narrowly missing a home, with more potential rock falls, as explained by MEMR, Mines and Geological Department.

In the same area at GPS location 36N 066467, UTM 0092036, elevation 2OO1 M asl., a house was completely destroyed, household property including chicken buried by a debris flow, while two children were rescued with minor injuries, Maurice and William, 2010.

On 26th December, 1997, a major landslide occurred at Gatara village, Murang'a District, and swept away 8 hectares of land containing an estimated 50000 tea bushes, and killed three people, Mathu and Ngecu (1999)

On 17th December 1997, a rock fall occurred on the slopes of Mt. Elgon, Cheptais District. One person got injured, two houses, maize and coffee plantation got destroyed, Masibo, (1998)

The landslides generally caused loss of life as well as damage to homesteads, fertile farmlands, roads, railway lines, bridges, as well as destroying and displacing telephone and power lines. Heavy soil erosion and deposition in dams led to clogging thus interfering with power generation from the dams.

Despite the enormous effects of landslides, no much priority has been given towards identifying the active slide areas by using GIS and rainfall threshold techniques. Therefore, a landslide GIS data base has been proposed as an initial stage in application of GIS in landslide assessment. In addition, determination of rainfall thresholds using the intensity-duration method has been reviewed and proposed for assessment of landslides in Murang,a and Mt. Elgon districts. The plates below demonstrate some of the landslide episodes in Murang'a and Mt. Elgon Districts.

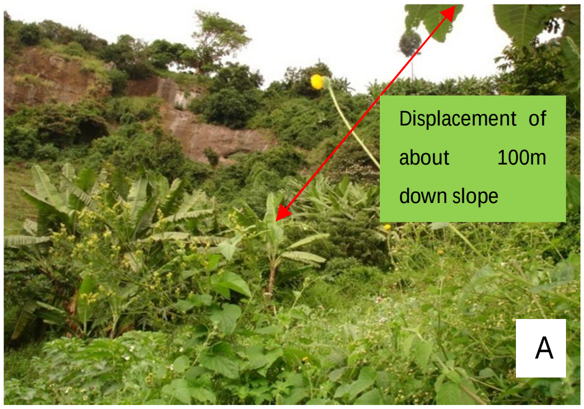

Plate 1. 1 ***Some of the landslide episodes in Murang'a and Mt. Elgon Districts:***

Source: Courtesy of Mines and Geological Department, 2010.

(A) A section of banana plantation that has been displaced for a distance of about 100 M in Cheptais District;

(B) A camp of some area residents who have been displaced as a result of a major rock fall in Cheptais District;

(C) A section of Murang'a District that was attacked by a major landslide;

(D) Neighbors ignorantly continue living in the landslide area in Murang'a District.

1.2 Objectives.

The main objectives of this project paper are:

1) To compare the areas prone to active slides based on the factors that influence the occurrence of landslides.
2) To review the influence of geologic setting, topography, rainfall distribution and soil-sediment characteristics on active slides.
3) To review the successful use of GIS and rainfall thresholds so as to use the two methods in landslide assessment in Murang'a and Mt Elgon Districts.

1.3 Methodology

The establishment of the detailed geology of the case study areas was determined through review of scientific papers on geotechnical reports from the Department of Geology, University of Nairobi and Mines and Geological Department. The influence of the various factors on the occurrence of landslides and identification of hazardous areas were based on scientific analyses of landslide occurrence from around the world. Internet sources were also greatly utilized.

1.4 General Overview of the Study Areas

Murang’a and Mt Elgon districts are closely related in terms of various factors such as population, location and climate as discussed below.

1.4.1 Location of the Study Areas

The Cheptais area falls within Sasuri Sublocation, Sasuri Location, Cheptais Division, in Mt. Elgon District. Mt Elgon is located in the extreme west of Kenya on the boundary between Kenya and Uganda; it forms the north western apex of the Kenyan highlands. It is bordered by Bungoma district to the south, Uganda to the west and Trans-Nzoia to the eastern and northern sides.

On the other hand, Muringa village is about 100 Km northeast of Nairobi and lies roughly in the northwest part of Murang’a District, (Ichang’i and Ngecu, 1999). Murang,a District (0º43´S 37º10´E) is situated about 90 Km NE of Nairobi.

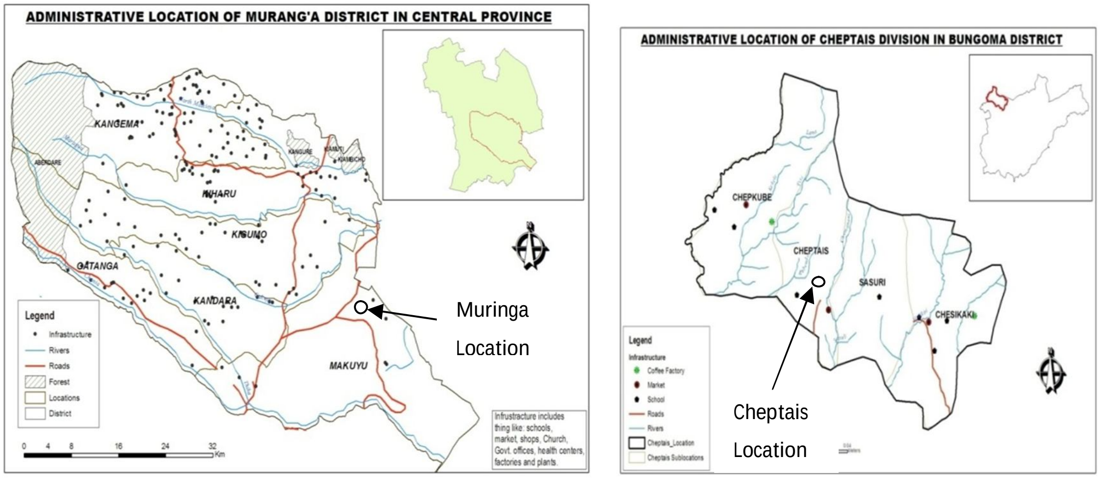

Fig 1.1 Geographical maps showing the location of (A) Muringa and (B) Cheptais Locations

Source: GIS laboratory, Department of Geology.

1.4.2 Population

Muringa area is populous and has a high population density of 600 persons per square km, (Ichang'i and Ngecu, 1999).

Cheptais area has a population of 56000 people (based on provincial figures of the 2008 population statistics), and has a population density of 1400 persons per square km, Mines and Geological Department.

1.4.3 Climate

Muringa area experiences a heavy rainfall of 1500-2000 mm annually, (Ichang'i and Ngecu, 1999). The maximum annual mean temperatures vary from 22°C to 26°C and minimum from 10°C to 14°C, Nyambok and Davies, 1993.

Cheptais area receives bimodal type of rainfall, with long rains starting in March to June, and short rains from September to November, ranging from 1500-2,100 mm per annum and fairly distributed all over the project area. The temperature decreases with altitude and ranges between 14ºC – 24 °C, (Maurice and William, 2010).

CHAPTER 2

FACTORS THAT INFLUENCE THE OCCURRENCE OF LANDSLIDES

2.1 Geology

Landslides are prevalent in volcanic terrains. Hutchnison (2000) explains that certain types of rocks such as high porosity deposits have a tendency to produce unusually mobile flows. Cenozoic volcanic rocks such as basalts, phonolites, nephelinites, trachytes and rhyolites. This is because pyroclastic rocks undergo rapid weathering. According to Lizunela, (2006), integrated chemical and mineralogical studies within weathered profiles are crucial to advance understanding of the nature and distribution of slip zones, which is of great importance to assessing landslide potential of weathered profiles. Furthermore, Hutchinson, (1988) demonstrates that many typical earth flows contain large percentages of gravel and coarser particles. Numerous field observations have shown that most landslides move predominantly by sliding along discrete shear surfaces. Ichang'i and Ngecu, (1999), explain that the Muringa landslide occurred due to rapid weathering of pyroclastic rocks thus creating a weaker regolith than the underlying better-cemented basalts. Therefore, geological setting plays a major role as far as landslide occurrence is concerned.

2.2 Topography

Landslides usually result where a slope has been greatly steepened, Edward and Frederick, (1976). Due to the steepened slope, soil erosion increases thus over-steepening slopes until they become unstable and collapse, resulting into landslides. Landslides have been described by Mathu and Ngecu, (1999), to result from high relief and steep slopes with poor anchorage for slope stability. According to Ichang'i and Ngecu, (1999), the Muringa village landslide was as a result of the high mechanically unstable slope. Larsson, (1986) observed that most slides occurred in terraced areas. Krauskopf, (1979), explains that on steep slopes, soil is washed away before the A and B horizons can be clearly differentiated unlike in lowland areas.

2.3 Soil- Sediment Characteristics

Soils differ in many ways: grain sizes, plasticity, composition, mechanical strength and permeability. The nature of the movement is controlled by the earth materials involved, Peter, (1970). Pyroclastic rocks such as tuffs, agglomerates and ashes weather under tropical conditions to produce thick soils with low shear strength and high clay content, Mathu and Ngecu, (1999). The resultant soils are nitosols and andosols, which exhibit high clay content. Clay particles have the ability to adsorb water and organic materials and so to become plastic. Clay minerals, once formed, do not change character readily but persist for long geologic periods, Frye et al, (1963).

The partly decomposed debris of rock weathering is subject to continued attack by the atmosphere and rain water percolating through it. Movement of water causes dissolved material and colloidal particles to be carried from one layer to the other. Thus, landslides result. Decay goes faster and penetrates more deeply in warm and humid climates, Krauskopf, (1979).

2.4 Rainfall Distribution

Rainfall is the most important trigger of landslides through infiltration into the slope cover. This increases the pore pressure value and decreases the soil suction value, Giannecchini, (2006). Iversion (1997) demonstrates that pore pressure is an important trigger of landslides. According to Crozier, (1989), excessive precipitation results into excessive infiltration and percolation into slope thus increasing pore pressure. Consequently, the intergranular forces along potential slide surfaces decrease. Thus, the surfaces are set in motion by the force of gravity. In addition, water also adds a considerable weight to a mass of material. The added weight in itself may be enough to cause the material to slide down slope, Edward and Frederick, (1976). Pore water pressure fluctuations are known to result to landslides as explained by Thampi et al, (1992). Kamunge and Kirembu, (2002) explains that the Meru recurrent landslides occur during rainy seasons, while Lawrence, (1986) describes the relationship of landslide activity and cumulative precipitation. Thus, landslides are more common during the storm periods.

CHAPTER 3

IDENTIFYING LANDSLIDE HAZARDOUS AREAS

3.1 Foreword

The research that has already been carried out on landslides in Kenya: Rowntree (1989); Nyambok and Davies (1993); Ichang'i and Ngecu (1999); Mathu and Ngecu (1999); Elizabeth Kamau (1999), has chiefly concentrated on the distribution of landslides in space and time, landslide triggering factors, and the socio-economic impacts. Although recent research works have involved the use of GIS in Kenya in regard to landslide assessment for instance, Maurice and William (2010); Kamunge and Kirembu (2002), the GIS zoning method is not yet fully exploited. In addition, no attempt has been made in determining rainfall thresholds for different parts in the country to enable early warnings. A landslide GIS data base has been used in landslide assessment worldwide: Kumar *et al.* (2002); Gemitzi et al. (2010); Gaspar *et al.* (2004); Acharya *et al.* (2005); Ayalew *et al.* (2005), with vast success. The author proposes the use of GIS data base and determination of rainfall thresholds using the intensity-duration method as basic methods for landslide assessment in Murang'a and Mt. Elgon districts. This will as well ensure an advanced landslide research.

3.2 Use of GIS in landslide assessment

GIS are computer-based systems with a high potential to archive, manipulate, analyze and display geo-referenced data (Aronoff, 1989). According to Peter, (2001), GIS is a computer-based system, comprising of a set of conceptual and physical data models together with analysis and output functions that, if necessary, are integrated with mathematical and geo-statistical models. In hazard assessment, GIS technology can support:

- Spatial state-of-the-art drawing for each sectoral research field both as simple data bases and as multiple maps.
- Modeling results i.e. a tool to feeding mathematical models.

- The hazard assessment derived form geo-statistics and spatial procedures that consider the spatial and temporal occurrence of a specific hazard factor.
- The specific risk assessment for each kind of risk spatially combining hazard assessment with economic evaluation of potential losses.
- The acceptable risk definition using evaluation models and simulations that the GIS can feed or support drawing the results.
- System update and monitoring.

3.2.1 Creation of a landslide GIS data base

Gaspar *et al.* (2004), explains the importance of landslide GIS data base by the creation of the Azores' data base. At the present, the computer-based system comprises of nine dynamic data sets, where elemental, historical and monitoring data are grouped in layers of first and second order. The AZORIS database is composed of several thematic data sets defined according to the type of information. Each set comprises several layers, which in turn can include numerous data. Due to the constant input of new and more detailed information, the system was built in such a way that data can become a layer and, thus, develop into a data set without changing the physical or logical structure of the database.

The available data is grouped in the nine sets:

- Geographical and socio-economic
- Civil protection
- Geological and geomorphologic
- Landslides
- Volcanological
- Seismological
- Geodetic
- Fluid geochemistry
- Meteorological

A similar system was adopted for a proposed landslide GIS data base and data sets related to landslides were created as following:

3.2.1.1 The geographical and socio-economic data set

Includes the topographic maps available for the areas of concern, and the basic data needed for vulnerability analysis. The most recent topographic data existing for all the landslide areas must be included in the 1:25 000 scale digital maps. Besides altitude, these maps incorporate additional information such as urban areas, roads and hydrology. The information contained in the package may be up-dated as required. Supplementary layers were added to the system, including counties and parishes administrative boundaries, population, energy and water supply systems, land-use classification and infrastructures for telecommunications. Table 3.1 below demonstrates an example of geographical and socio-economic data set.

Table 3. 1 ***Geographical and socio-economic data set.***

layers	**Data**	**Feature type**
Elevation contours	Major/minor contours, elevation points, geodetic vertices	Points and lines
Streams and rivers	Main rivers and streams, and their tributaries; seasonal rivers.	Lines
Buildings	Houses, historical monuments, schools, public buildings, churches, hospitals, cemeteries, police stations.	Polygons.
Roads	Highways, main roads, streets, forest paths, tracks, bridges.	Lines
Population	People, men, women, and families at location level.	Points.
Land use.	Urban areas, industrial areas, classified natural areas.	Polygons.
Telecommunication Systems and power lines	Tower antennas, telephone, and power lines.	Points, lines

Source: Modified from Gaspar *et al.*, 2004.

3.2.1.2 The geological and geomorphologic data set

Comprises descriptive and interpretative geological mapping surveys and aerial photo analysis (i.e. volcanic, structural and erosion landforms, litho logy and tectonic structures). Additionally, it contains analytical data germane to the petrography and geochemistry of samples related to the established geological units. In general, the data set contains information about the characteristics of the monitoring stations, their location and the existing data transmission facilities. See Table 3.2 below.

Table 3. 2 ***Geological and geomorphologic data set.***

Layers	Data	Features type
Litho logy	Basalts, trachyts, limestone, sandstones, alluvium, beach sand, beach gravel, clay	Polygons
Volcanic landforms	Central volcanoes, cinder cones, spatter cones, spatter ramparts, pumice cones, tuff cones, maars, domes, spines, lava flow fields, caldera rim, crater rim, pit crater,	Lines, polygons
Volcanic products and deposits	pumice, lava flows, tephra fall deposits, pyroclastic flow deposits, scoria flows, ignimbrites, block and ash flows, lahars, hydrothermal deposits	Polygons
Soils Stratigraphy Samples	Ages, dating methods, (id geology), sample reference number, geochemical analysis, petro graphicdata,	Points, polygons
Tectonic features	Faults Type, scarp faults, geometry, kinematics, age, dip, plunge, striations	Points, lines

Source: Modified from Gaspar *et al.*, 2004.

3.2.1.3 The landslide data set

It should be defined to archive information related to historical and contemporary slope movements, as well as their impact. Major historical events are being identified and catalogued based on a detailed study of old documents, while recent occurrences, with preserved scars, are being mapped using aerial photos. Layers for quantitative data related to the morph metric characteristics of landslide scars and associated deposits were also considered.

Table 3. 3 ***Landslide data set.***

Layers	Data	Feature type
Landslide events	Date, type of movement, main constituents, trigger.	Points

Landslide scar	Maximum and minimum elevation points, maximum width, average width, perimeter, area, landslide scar.	Points, polygons, and lines.
Landslide deposit.	Maximum width, average width, maximum length, average length, maximum thickness, average thickness, perimeter, area, volume.	Points, polygons, and lines.
Landslide impact	Deaths, injured, displaced people, damaged buildings, others	Points.

Source: Modified from Gaspar *et al.*, 2004.

3.1.1.4 Ground water data set

It is supposed to include the level of the water table and its variations in space and time with respect to precipitation and other factors.

3.1.1.5 Soil mechanics data set

The data set should include the types of soils in landslide areas, their mechanical properties such as shear strength and plasticity indices, and their clay contents. The spatial thickness of the weathered regolith is vital as far as this data set is concerned.

3.2.2 Results

The acquisition, storage and maintenance of all the above information, following a high criterion of quality, are critical to guarantee the accuracy and consistency of the GIS database through time. In this work, the structure and the data sets of AZORIS are presented, a GIS database for geological risk analysis in the Azores based on the ArcGIS® software from ESRI and installed over a Windows 2000® platform from Microsoft. When available, hazard and vulnerability data can easily be represented in a GIS and a great diversity of risk maps can then be produced following the implementation of specific predicting models. An example has been illustrated in the figure 3.1 below.

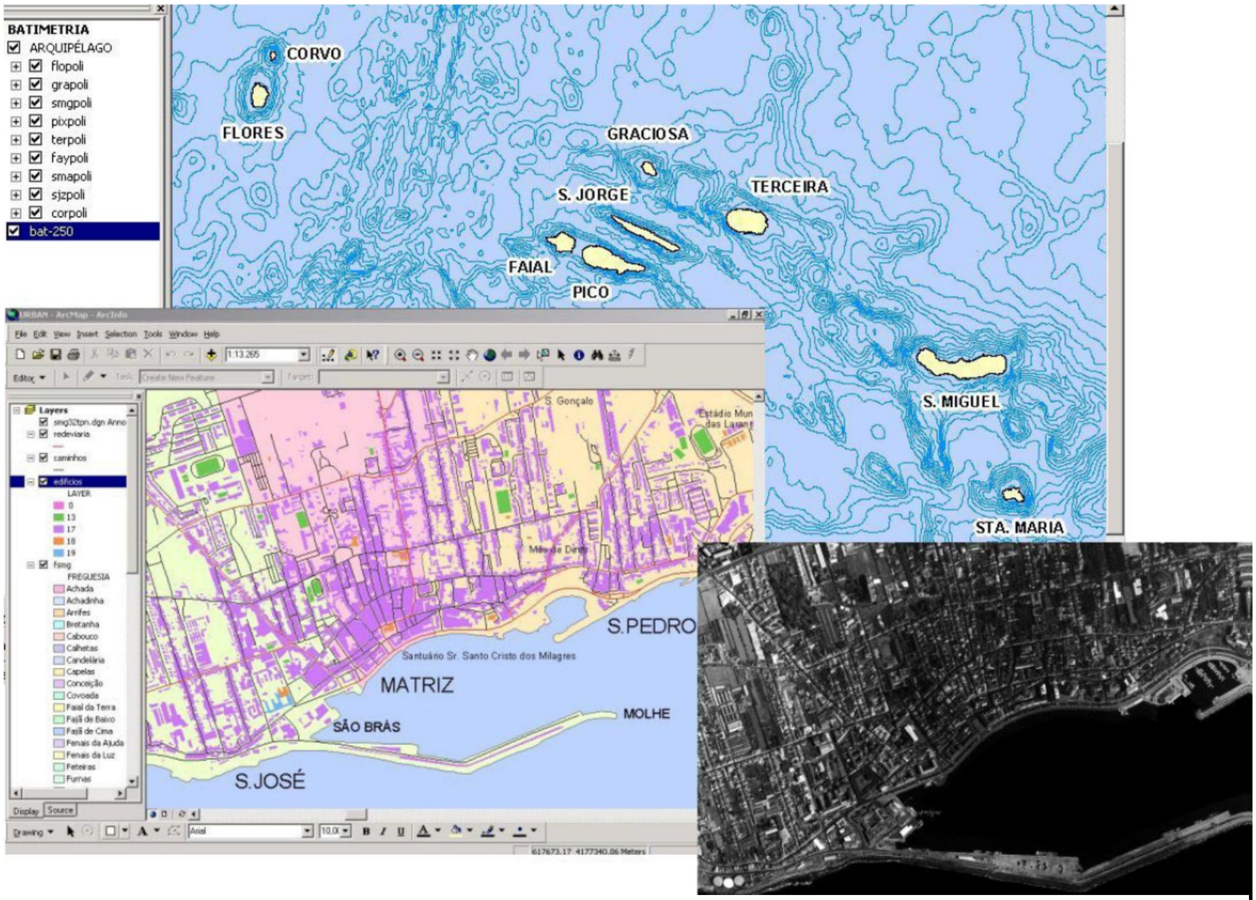

Fig. 3.1 AZORIS database includes geographical and socio-economic data for the Azores archipelago and municipalities.

Source: Modified from Gaspar *et al.*, 2004.

3.3 Use of rainfall thresholds in landslide assessment

According to Guzzet and Gerald (2006), the identification of regional rainfall thresholds for triggering shallow landslides represents in the broadcast sense a statistical approximation of minimum rainfall conditions for triggering landslides for a particular mix of regional geologic, hydrologic and topographic variables. Earlier, Campbell (1975), observed the relationship of high intensity rainfall in the triggering of shallow landslides, and theorized model which was a combination of rainfall intensity and duration. In addition, Caine (1980) utilized published data from worldwide examples where rainfall intensity and duration had been measured in association with the triggering of shallow landslides, to develop a minimum rainfall intensity-duration threshold for debris flows.

Matthias and Weatherly (2003), found that landslide initiation in British Columbia was dependent on the prior 4 weeks of rainfall, and Wioczorek (1987), observed that debris flows that started as landslides in a region of California did not occur until 280 mm of rainfall had fallen. Campbell (1975) and Gabet *et al* (2004) explain that slope steepness controls the daily rainfall necessary for failure. For instance, Larsen and Simon (1993), reported that short-duration, high-intensity storms triggered relatively shallow landslides; whereas the deepest landslides were triggered by long-duration, low-intensity storms.

Pedrozzi (2004), points out that it is possible to determine the trigger threshold for relatively small areas with homogeneous characteristics. By comparing the behavior of a landslide with the trigger threshold for the region, it is possible to determine the degree of susceptibility to rainfall of the landslide zone, (. This method is based on the correlation between rainfall and the landslide trigger and the parameters used are:

Average hourly rainfall intensity (mm/h) – I

Rainfall duration (h) – D

The results illustrated graphically are represented with two logarithmic scales so as to allow the correlation of different rain gauge stations.

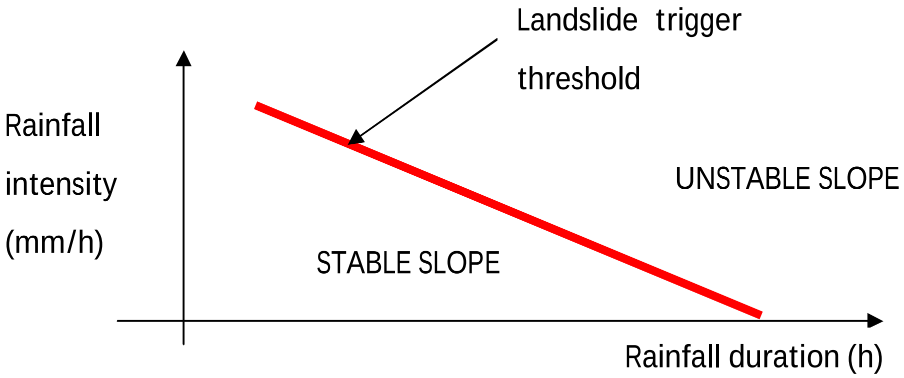

***Fig. 3. 2** A graph of rainfall intensity (mm/h) against rainfall duration (h).*

Source: Courtesy of Pedrozzi, 2004.

CHAPTER 4

ESTABLISHING LANDSLIDE PRONE AREAS

4.1 Comparing landslide prone areas on the basis of factors that influence landslide occurrence

4.1.1 Geology

Murang'a District comprises of Precambrian granitoid gneisses which form the basement rocks of the area. The gneisses are unconformably overlain by a thin layer of Pliocene Kapiti Phonolite which is overlain by a thick layer of basalt and basaltic agglomerates, which in turn are overlain by pyroclastic rocks. Mathu and Ngecu (1999) observed that the rocks are associated with the large central type volcanoes and volcanic rocks such as basalts, phonolites and trachytes. Murang'a area is rich in Rift faults and lineaments.

Similarly, Mt. Elgon District mainly consists of volcanic rocks that include agglomerate lavas, tuffs deposits and breccias of which the main constituent is mela-nephelinite lava with boulders frequently reaching very large sizes. Silicified fossil wood is common within the tuffs and they are cemented by calcite which enhances their quick weathering. In addition, the area is enriched with phonolitic-nephelinites as well as minor intrusions of Pre-Miocene Age, (Maurice and William, 2010). The area is highly jointed thus increasing the degree of disintegration as deduced from Mines and Geological Report (2010). See plates 4.1 below.

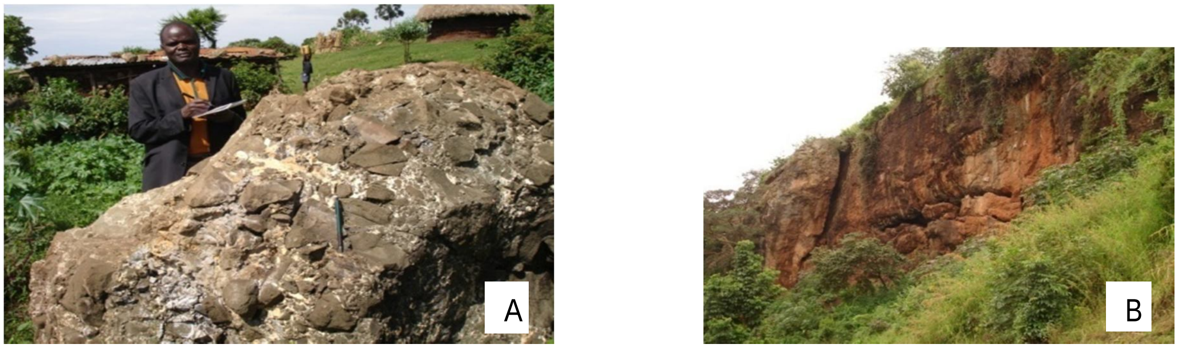

***Plate 4. 1** (A) A huge bolder in Cheptais area, whose cementing material is calcite; (B) a massive rock outcrop that has undergone weathering.*

Source: Courtesy of Mines and Geological Department, 2010.

4.1.2 Topography

Murang’a District is characterized by steep slopes as explained by Davies (1986). Ichang’i and Ngecu, (1999) observed that the area is characterized by east-west facing steep ranges which are dissected by numerous river valleys. Thus, the area is highly vulnerable to landslides as shown in the figure 4.1. According to Ichang’i and Ngecu (1999), the elevation of Muringa village is about 1800 M asl while Davies (1986) explain that the area having been located in the Eastern Highlands, as an altitude that varies from 1500 M to 5200 M asl. Nyambok and Davies (1993) observed that the area is highly undulating, rugged and crossed by numerous river valleys. As a result, most of the movements documented by Mwenda and Njuguna (2002) in Muranga are rotational slides.

Similarly, Mt. Elgon District comprises of a series of hills which are abruptly separated by deep gorges. Generally the terrain of the area rises from 1800 M to about 4100 M asl. According to Maurice and William (2010), the major land form is the Mt. Elgon, with steep undulating slopes, characterized by the presence of cliffs rising up to 7 M in height and dissected by deep gorges and V-shaped valleys and water falls. The plates 4.2 (A) and (B) below demonstrate the typical topography of Murang’a and Mt. Elgon Districts.

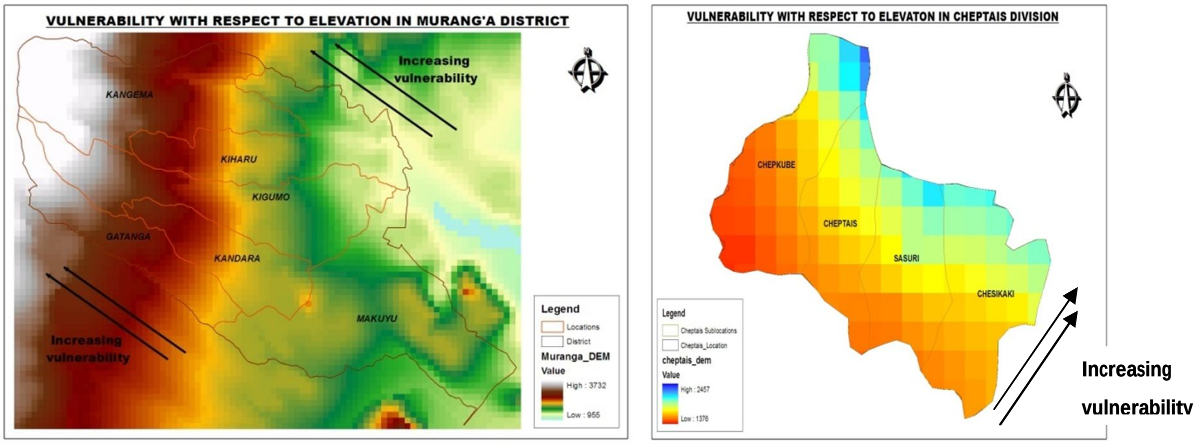

***Fig 4. 1** Maps of (A) Murang’a and (B) Cheptais Districts showing landslide vulnerability with respect to elevation.*

Source: GIS laboratory, Department of Geology

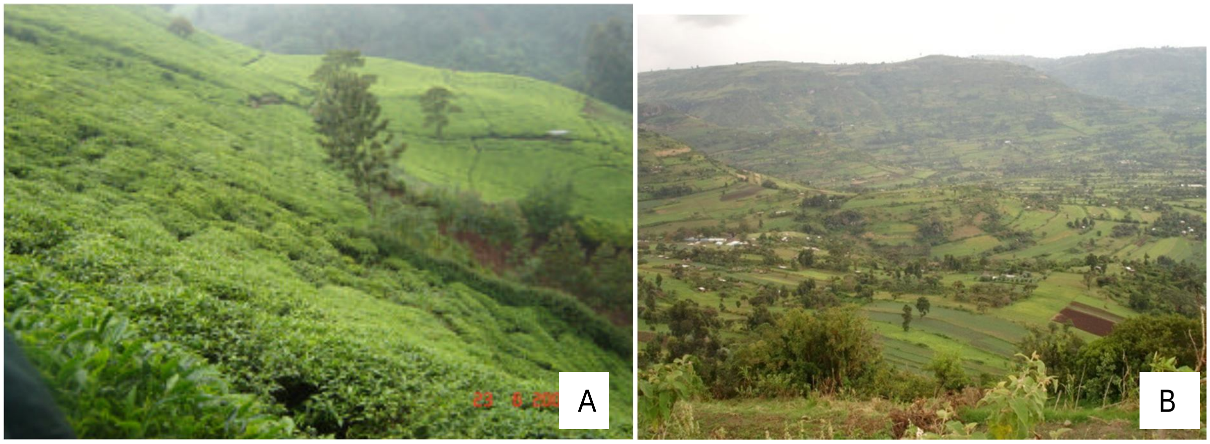

***Plate 4. 2** The rugged topography of (A) Murang'a and (B) Mt. Elgon Districts.*

Source: Courtesy of Mines and Geological Department, 2010.

4.1.3 Rainfall Distribution

Muringa area receives heavy rainfalls of 1500 mm to 2000 mm per annum as analysed by Ichang'i and Ngecu (1999). In total, Murang'a District receives an average annul rainfall ranging from 1000 to 2660 mm as demonstrated by Jacob (2010) in his study on landslides in Murang'a District. High rates of precipitation increase underground water, which in turn seeps into the impervious volcanic rocks, thus,causing landslides in Murang'a District as explained by Jacob (2010). Plate 4.3 demonstrates a section of Murang'a District underground water seepage.

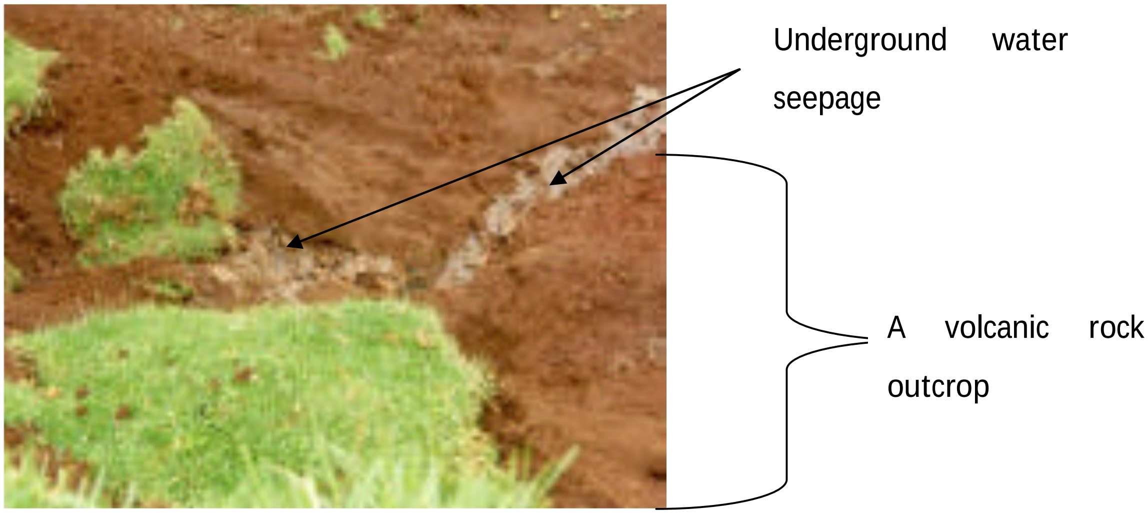

***Plate 4. 3** A section of Murang'a Distict showing underground water seepage.*

Source: Jacob (2010) Mines and Geological Department.

On the other hand, Cheptais area receives bimodal type of rainfall, with long rains starting in March to June, and short rains from September to November. The seasons are not very clear cut as the areas receives rainfall throughout the year, ranging from 1500-2100 mm per annum and fairly distributed all over the area. Table 4.1 demonstrates the rainfall distribution around Cheptais area.

***Table 4. 1** Rainfall Distribution around Cheptais area.*

	Name of Station			
Month	**Kapsokwony Chief's Camp Alt. 1829 M**	**Kimilili Forest Station Alt. 2073 M**	**Kimilili Agri. Office**	**Sirisia Alt.1615 M**
Jan	66	58	40	42
Feb	114	59	57	63
Mar	153	100	116	135
Apr	277	222	226	257
May	247	233	254	136
June	201	114	163	143
July	152	128	135	153
Aug	197	155	155	155
Sep	208	153	165	176
Oct	243	163	55	111
Nov	116	116	97	84
Dec	81	55	63	50
Maximum	277	233	254	251
Minimum	66	55	40	50
Mean annual	2054	1556	1627	1699

Source: Maurice and William, 2010.

4.1.4 Soil-Sediment Characteristics

In Murang'a District, the major types of soils are nitosols and andosols which are lateritic clayey soils resulting from the intense chemical weathering of pyroclastic rocks in the area. According to Ichang'i and Ngecu (1999), nitosol soils result from intensive weathering of basaltic agglomerates and have a high clay and moisture content (49.5%). The main clay minerals in the soil are kaolinite, illite and montmorilllonite. Andosols are friable when moist, relatively plastic when wet, and hard when dry. Additionally, they are poorly drained.

Further investigations on the index properties of soils from the landslide area were carried out by Nyambok and Davies (1993) and the results are as demonstrated in Table 4.2 below:

Table 4. 2 ***Index properties of soil samples from the Murang'a landslide.***

Sample	Particle size distribution (% of wet soil-weight retained)								Moisture content (%)	Atterberg limits		
Sieve No	7	14	25	36	52	100	200	+200		LL	PL	PI
1	9.40	1.60	1.40	0.90	0.80	2.80	0.80	82.30	49.5	78	57	21
2	1.90	2.00	3.00	2.40	1.00	2.70	0.90	86.80	41.0	79	57	22
3	0.60	0.70	1.50	1.30	0.70	2.50	0.80	91.90	42.2	82	62	20

LL, liquid limit; PL, plasticity limit; PI, plasticity index.

Source: Nyambok and Davies, 1993.

In Mt. Elgon District, the soils are derived from the volcanic ash and agglomerates. On the slopes, dark red friable clays are common, with deep humid top soil derived from the basement complex and volcanic rocks, and occur on flat topped ridges (1500-2000 M asl). The clay loams are found on the eastern foot hills (Government Report, 1999). Maurice and William, (2010) explains that dark red sandy loam soils in the lower parts of the Mountain, derived from basement complex and volcanic rocks and associated with pen plains between 300- 1800 M asl.

4.2 Creation of a landslide GIS database and delineation maps for Murang'a and Mt Elgon Districts

The database comprises of several dynamic data sets, where elemental, historical and monitoring data are grouped in layers of first and second order. In addition, the database is composed of several thematic data sets defined according to the type of information. Each set comprises several layers, which in turn can include numerous data. Constant input of new and more detailed information is expected. The system has been built in such a way that data can become a layer and, thus, develop into a data set without changing the physical or logical structure of the database. According to Lee and Talib (2005), the relationship between areas where a landslide has occurred and landslide-related factors is distinguishable. The available data has been grouped in a number of sets as demonstrated below.

4.2.1 The geological and geomorphologic data set

Comprises descriptive and interpretative geological mapping surveys and aerial photo analysis in both Murang'a and Mt. Elgon Districts (i.e. volcanic, structural and erosion landforms, litho logy). In general, the data set contains information about the characteristics of the monitoring stations, their location and the existing data transmission facilities as demonstrated by Tables 4.3 and 4.5 below. An ArcGIS® software from ESRI and installed over a Windows 2000® platform from Microsoft has been used to come up with a map showing landslide vulnerability with respect to geology and infrastructure of the area. See figures 4.2 and 4.3

***Table 4. 3** The geological and geomorphologic data set for Muranga district*

Layers	Data	Features type
Litho logy	Granitoid gneiss, basalts, trachytes, limestone, sandstones, clay, phonolite, pyroclastic rocks, lavas, tufus, breccias,	Polygons
Volcanic landforms	Central type volcanoes, rift faults, steep ranges, river valleys, , deep gorges, cliffs , lineaments	Lines, polygons
Volcanic products	pumice, lava flows, tephra fall deposits, pyroclastic flow deposits, ash flows,	Polygons
Soils	Friable nitosol and andosol soils, rich in content and poorly drained	Points, polygons

4.2.2 Geographical and socio-economic data sets.

Includes the topographic maps available for the areas of concern, and the basic data needed for vulnerability analysis. Besides altitude, these maps incorporate additional information such as urban areas, roads and hydrology. Supplementary layers were added to the system, including counties and parishes administrative boundaries, water supply systems and infrastructures. See Tables 4.4 and 4.6 below.

Table 4. 4 Geographical and socio-economic data set for Murang'a District

Layer	Data	Feature type
Roads	Main roads	Polygon, line
Infrastructure	Churches, schools, hospitals, markets	Dot
Rivers	Streams, springs,	Line
DEM	Elevation data	Line

Source: Topo index, 87/1, 87/2; scale 1:50000

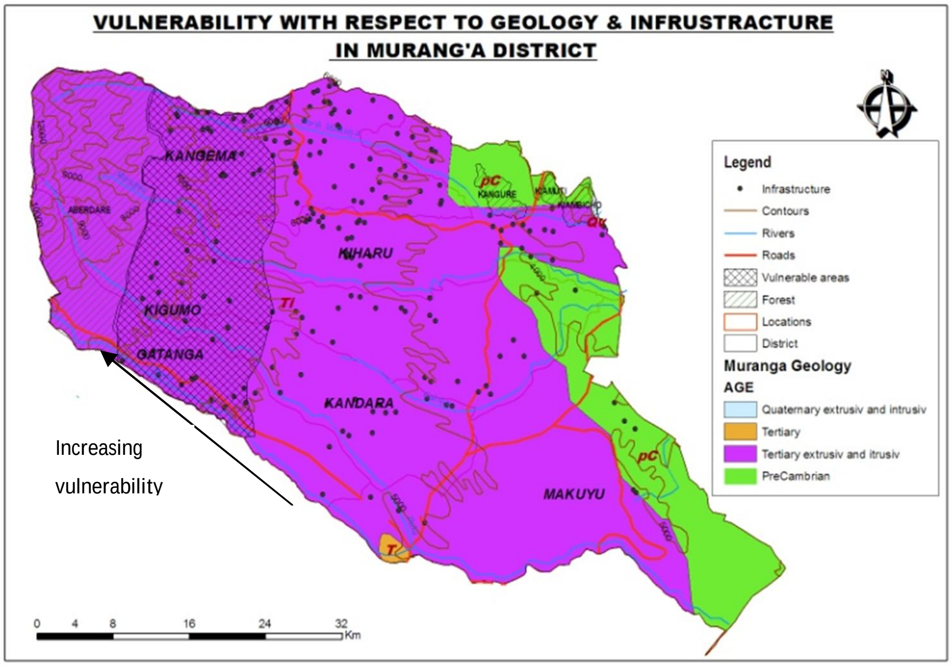

Fig 4.2 A map of Murang'a District showing landslide vulnerability with respect to geology

Source: GIS laboratory, Department of Geology

Table 4. 5 The geological and geomorphologic data set for Mt. Eldon district

Layers	Data	Features type
Litho logy	Agglomeratic lavas, breccias, tuff, phonolites, limestone,	Polygons
Volcanic landforms	Deep gorges, cliffs, water falls, series of hills	Lines, polygons
Volcanic products	pumice, lava flows, tephra fall deposits, pyroclastic flow deposits, ash flows, tuff deposits	Polygons
Soils	Dark-red friable clay soils, deep humid soils,	Points, polygons

Table 4.6 Geographical and socio-economic data set for Mt Elgon District

Layer	Data	Feature type
Roads	Main roads	Polygon, line
Infrastructure	Churches, schools, hospitals, markets	Dot
Rivers	Streams, springs,	Line
DEM	Elevation data	Line

Source: Topo index, 87/1, 87/2; scale 1:50000

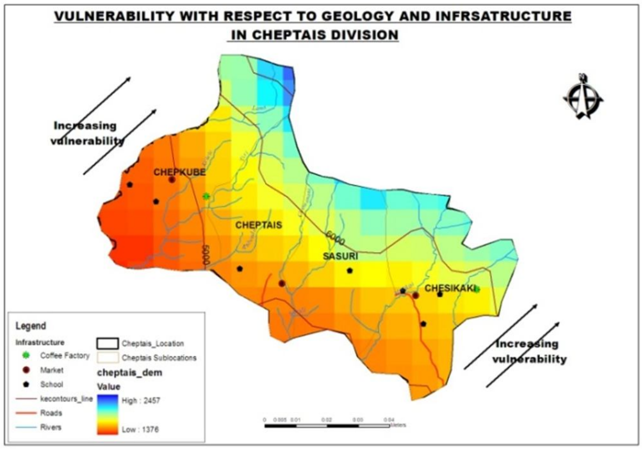

Fig 4.3 A map of Mt Elgon District showing landslide vulnerability with respect to geology

Source: GIS laboratory, Department of Geology

4.2.3 Soil mechanics data set

The data set includes the types of soils in landslide areas, their mechanical properties such as shear strength and plasticity indices, and their clay contents. In Murang'a and Mt Elgon districts, the prevalent types of soils are nitosols, andosols and friable red clay soils respectively. Table 4.7 demonstrates soil mechanics data for Murang'a district.

Table 4. 7 Soil mechanics data set for Murang'a district

Layers	Data		Feature type
Soil type	Andosols	nitosols	Polygons
Shear strength	0.04kg/cm²	0.5kg/cm²	Points
Bulk density	0.81-0.98m/cm³	1.02m/cm³	Lines
Compressive strength	1.05kg /cm²	1.2kg/cm²	Points
Clay content	40-45%	_	Lines

4.2.4 Landslide data set.

Major historical events are being identified and catalogued based on a detailed study of old documents, while recent occurrences, with preserved scars, are being mapped using aerial photos. The limitations to this data set for both Murang'a and Mt. Elgon districts is the insufficient quantitative data related to the morph metric characteristics of landslide scars and associated deposits. The only available data is tabulated as in Tables 4.8 and 4.9 below.

***Table 4. 8** Landslide data set for Murang'a district*

Year		1991	1997	1998	2002	Feature type
Study area	Layer	Data				
Gacharage -Murang'a	Landslide impact	8 people died; Houses and land destroyed	None	None	None	Points
Gaturi-Murang'a	Landslide impact	None	Roads, farms destroyed	3 people died; 400 displaced	None	Points
Muringa-Murang'a	Landslide impact	None	11 people died 7 homes destroyed	None	None	Points
Gituamba Murang'a	Landslide impact	None	None	Farms and homesteads destroyed	None	Points
Kiruri-Murang'a	Landslide impact	None	None	None	5 people died Homes and roads destroyed	Points

Table 4. 9 ***Landslide data set for Mt Elgon district***

Year		1997	2010	Feature type
Study area	Layer	Data		
Cheptais-Mt. Elgon	Landslide impact	1 person injured, houses and land destroyed	2 people died, 5 injured, Household property and land destroyed	points
Sasuri-Mt Elgon	Landslide impact	None	2 children injured, banana plantation Displaced, chicken buried	points

4.2.5 Ground water data set

It is supposed to include the level of the water table and its variations in space and time with respect to precipitation and other factors. The two districts have limited data on the measurements of the water level tables and its variations.

4.3 Use of rainfall thresholds in landslide assessment

The intensity-duration method is currently not applicable in Kenya due to data limitation. The rainfall data available is on dairy and not hourly basis. Utilization of this kind of data would produce huge error margins which would yield inaccurate thresholds.

CHAPTER 5

DISCUSSION CONCLUSION RECCOMMENDATION

5.1 DISCUSSION

There are various factors that influence the occurrence of landslides such as geology, topography, rainfall distribution and soil-sediment characteristics amongst others. The role of these factors is analogous in the areas that are prone to landslides. Landslides, for instance, are prevalent in andosols and nitosols-covered volcanic highlands of both Murang'a and Mt. Elgon districts. The major triggers of landslides in both Murang'a and Mt. Elgon districts are forerunner rainfall, tropical climate which favors deep weathering, as well as steep slopes. Therefore, such comparative studies are very essential in the prediction of landslide prone areas.

Landslide research in Kenya has chiefly concentrated on the distribution of landslides in space and time, landslide triggering factors, and the socio-economic impacts. Inadequate efforts have been given towards identifying the active slide areas by using GIS and rainfall threshold techniques, which have been used worldwide with enormous success. However, the intensity-duration method is not currently applicable in Kenya due to data limitations (hourly rainfall data and historical landslide data). The GIS database is considered to archive, manipulate, model and display spatial referenced data for risk analysis. The defined logical and physical dynamic structures allow the system to develop according to the collected and generated data keeping coherence and enlarging its capabilities. The maintenance of the database depends on the basic data update taking into account the main parameters that control changes in risk. A major step in the development of the system is related to the application of models for hazard and vulnerability assessment. This will lead to the definition of risk zones based on critical values that can be used for implementing alarm and warning systems and is of major importance for crisis management, for instance, landslides.

Rainfall data and daily sediment loads from a catchment are used to explore the effects of rainfall and hill slope characteristics on the initiation of landslides. It has been discovered that two distinct rainfall amounts, a seasonal accumulation threshold and a daily rainfall threshold, must be exceeded before landslides are triggered. To investigate the controls on these thresholds, a slope stability model that is driven by daily rainfall and accounts for changes in regolith moisture has been presented. Results from the model show a similar pattern of rainfall thresholds to the field data. It is concluded that slope angle controls the amount of daily rainfall necessary to destabilize a given hill slope and that the water storage capacity of the regolith determines the amount of seasonal rainfall needed to trigger a failure. Although the model does not duplicate all of the details of the land sliding record, it appears to define successfully the input parameters, both from the landscape and the climate, that control shallow slope failures.

5.2 CONCLUSION

The four major factors that cause landslides in Murang'a and Mt. Elgon are comparable and include: the geology, topography, rainfall distribution, and soil-sediment characteristics. Landslide research in Kenya has chiefly concentrated on the distribution of landslides in space and time, landslide triggering factors, and the socio-economic impacts. Therefore, the use of GIS in landslide assessment and use of rainfall thresholds in prediction of landslides will go a long way in advancing landslide research and risk assessment in Murang'a and Mt. Elgon districts.

5.3 RECCOMMENDATION

Landslide research and assessment in Murang'a and Mt. Elgon districts have lagged behind, thus new methods of landslide assessment have been recommended, that is, use of comparative studies of factors that influence landslide occurrence, the use of GIS in landslide assessment, and use of rainfall thresholds in prediction of landslides. Since the intensity-duration method is not currently applicable in Kenya due to data limitations (hourly rainfall data and historical landslide data), implementation of relevant instruments such as pluviometer is recommended. It is also recommended to ensure an improved landslide data storage, implementation and analyses.

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