AFRICA ENVIRONMENTAL REVIEW Journal
ISSN: 1727-8341
AER Journal Volume 5, Issue 2, pp. 303-326, Nov, 2022

RESEARCH ARTICLE

Available Online at *http://ojs.uoeld.ac.ke/index.php/aerj*

Mapping Landslide Susceptibility Along the Nandi Escarpment in Malava Sub-County Kakamega County, Kenya

E. Chepkosgei[1*], E. K. Ucakuwun[1] and G. M. Nduru[2]
[1]*Department of Environmental Earth Sciences, School of Environmental Studies, University of Eldoret, Kenya*
[2]*Department of Environmental Studies, School of Natural Resources and Environmental Studies, Karatina University, Kenya*
**Corresponding Author's Email: everlinechepkosgei@gmail.com*

Abstract

Landslides 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 disasters such as loss of property and/or life. The frequency of landslidesin 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 area of Malava Sub- County. 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 was used to help in identifying strategic points and geographically critical zones that are prone to landslide risks. The study involved generation of landuse/ landcover maps extracted from Satellite Images, which were taken in the years 1973, 1995 and 2006. SRTM DEM 90 m 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), Kakamega County. 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 groups discussions 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 and slopes steeper than 54^o was more susceptible to slope failures. 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^o since, according to this study, slopes higher than this are prone to sliding. There is need for Kenya ministry of lands and physical planning to ensure sustainable land use activities are conducted in the slopes of various degrees.*

Keywords: Landslides, Nandi Escarpment, Land Use, Slope Failure Susceptibility, Mapping

INTRODUCTION

According to the World Atlas of Natural Hazards (McGuire et al., 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 (Li et al., 2016; Cho, 2017).

Landslides commonly occur in conjunction with other natural hazards such as rainstorms, floods, earthquakes, volcanic eruptions or tsunami (Svalova et al., 2018; Kafle, 2017). Every year landslide activity causes significant economic losses including losses of property as well as of human life in different parts of the world (Haque et al., 2016; Zumpano et al., 2018; Lemenkova et al., 2012; Xu et al., 2017). 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 (Chen et al., 2021; Teshebaeva et al., 2019). Prediction of potential landslide areas has always been very difficult because of the complexity of the interacting factors, which are wide ranging (Korup & Stolle, 2014; Fan et al., 2014). 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 (Shit et al., 2016; Cervi et al., 2010). 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 manipulated to determine landslide risk areas. Routine use of remote sensing data and GIS analysis can ease the monitoring of slope failure susceptibility (Francioni et al., 2018; Ray et al., 2010). 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 (Jayanthi et al., 2016; Sharma et al., 2016; Ilies et al., 2020).

Geographical Information System (GIS) is a useful tool for mapping of landslides (Pradhan et al., 2011; Dahal & Dahal, 2017). 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 alongside their attributes (Chen & Li, 2020). Slope failure occurs along river banks, hilltops, agricultural zones and along road construction zones (Islam & Hoque, 2014). This results from the destabilization of the slope which results in reducing the resisting force and increases the driving force (Zieher et al., 2017). Slope failure causes negative environmental impacts which include; soil erosion, burying of vegetation and blocking of river channels (Bernatek-Jakiel & Poesen, 2018). In Kenya, as in other parts of the world afflicted by frequent occurrences of this environmental hazard, studies have been conducted to establishcauses of landslides and associsted map susceptible areas (Zhou et al., 2020; Mwaniki et al., 2015; Mwaniki et al., 2011; Ngecu et al., 2004). Slope failure results in human and livestock fatalities and in the destruction of the landscape, structures, infrastructure and agricultural lands (Msilimba, 2010; Gurung et al., 2013; Kamp et al., 2008). Some of the effects of the slope failure are direct and immediate while others are indirect and may be long term (Carey et al., 2021). 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 (Schuster & Highland, 2001; Yalcin, 2007).

In the hilly region of 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 for settlement and for cultivation. They tend to destabilize the geomorphic stability of the slope by cutting into the slope to construct houses hence overloading the slope thus facilitating slope failure. 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.

It has been noted that 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 study area, 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 risk 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. 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.

Study Area Profile

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 (Makokha, 2014). It is located roughly between longitudes 34º 30' and 35º 30' E and latitudes 0º 15' and 0º 30' N. 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 (Joseph et al., 2015). Nandi Escarpment forms a prominent feature on the eastern border of the Kabras Division with its main scarp rising from the general elevation of 1,700 m to 2,000 m within one kilometre (Gamba, 1991). Thus, the study will only cover the Nandi Escarpment from East Kabras location to Shivanga location (see Figure 1).

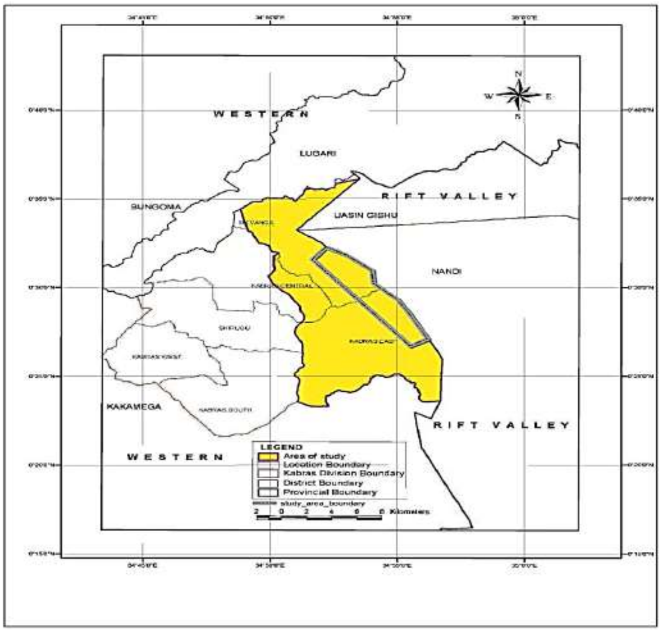

Figure 1: Map Showing Study Area.

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). 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). Inganga et al. (2001) concluded that soil with montmorilonite content has a high tendency to slope failure when moisture is increased.

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 starts from March-June with peak in May while the short rainy seasons begins 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).

Population and Settlement Patterns

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). Land sizes are small, and continue to shrink with the swelling population.

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 of 352 people per km^2 (Republic of Kenya, 2002).

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).

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). 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).

In terms of infrastrureThe 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.

METHODOLOGY

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.

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.

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 involvingliquid limit, plastic limit and plastic indexwere used to determine bulk density and soil texture at the Civil and Structural Engineering Department Laboratory, Moi University.

Photography and Satellite Imagery

Pictures involving snapshots were taken to illustrate some visual landslides aspect., which 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. Landcover/Land use information was obtained from satellite images taken in 1973, 1995 and 2006.

Focused Group Discussions

Focused Group Discussions (FGD) were conducted for counter-checking the reliability of the information collected. This helped in improving the quality of the data. The FGD involved interviews 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 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.

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

Satellite Imagery
Three (3) 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 as shown in Table 1.

Table 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 of February 1973 and February 2006. From the images (1995, 2006) and 1973 four and three landuse/landcover classes were determined, respectively. Landsat imagery constitute the base data layer from which landuse/landcover 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 landuse/landcover database was clipped out and edited in Arc View and also reprojected to UTM (South) Zone 36 for further processing.

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 36 South 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 also 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, which 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 was done 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. On 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 for visualization purpose only (Sabins, 1986). 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 was stretched between 0-255 to increase the grey scale levels.

Image classification involving sorting the image pixels into a specific number of classes or categories based on the intensity value of the data file was done. 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 to decide which raster cell belongs to which class (Lillesand et al., 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 in order to produce 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.

On the 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 entailed completion of the training areaswhere pixels of the raster cells were automatically grouped together as one class by the Erdas software. The training sites with different classes of the same feature 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 when needed. Land use/ land cover map was obtained.

SRTM 90 m 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 90 m DEM, there was no need to digitize the contours from 1:50000 toposheet which could be 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 value 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 extensionn was used then slope was automatically generated after activating the 'Derive surface tool' and a slope map covering the AOI was obtained. 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 overlaid on the draped DEM to allow for visual interpretation (refer to plate 1 and 2).

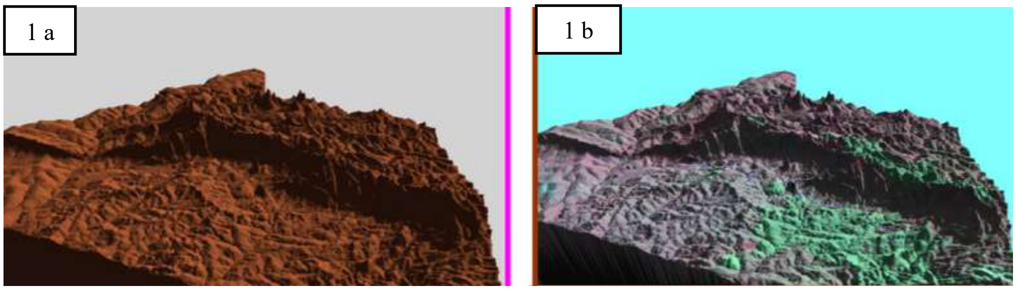

Plate 1: (a) indicates the study area in 3-dimension view (b) is the DEM that was draped on pansharpened Landsat ETM 2006 to allow further visualization.

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.

Rainfall Data

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 from the year 1985 to 2006, the average rainfall for the rainy seasons from March to November was calculated. Rainfall data was obtained from RCMRD as Excel spread sheet, daily rainfall from 1985 to 2006 for twelve stations. Average monthly and 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 2: Stations and their Mean Annual Averages (mm)

Rainfall_Station	ID	LAT	LON	MEAN1985	MEAN 1995	MEAN2006
Chebiemit Agric. Office	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 Factory	8934133	0.36700	34.5000	6.91	8.41	7.14
Nzoia Sugar Factory	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 Chief's 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 2).

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.

RESULTS AND DISCUSSION

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. The equilibrium of the slope is disturbed and overloaded, which 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 3). It was further 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 they are removed they de-stabilize the soil contributing to landslides. Cutting of trees for charcoal burning was again 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 1 and 2). There is so much gravel in the soil (Plate 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 1). This is clear evidence that the area is highly susceptible to landslides all the factors that contribute to landsliding put together.

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 3).

Table 3: 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 Clay:13
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

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): This 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): This 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 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 2).

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 (Zulkiflli et al., 2015). 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, and are 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 1). The soils remain unconsolidated as 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. 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 as 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 soil’s erodable nature, the soil is divided into four categories including: 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, 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 shown in Table 4.

Table 4: 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 as seen in Figure 2.

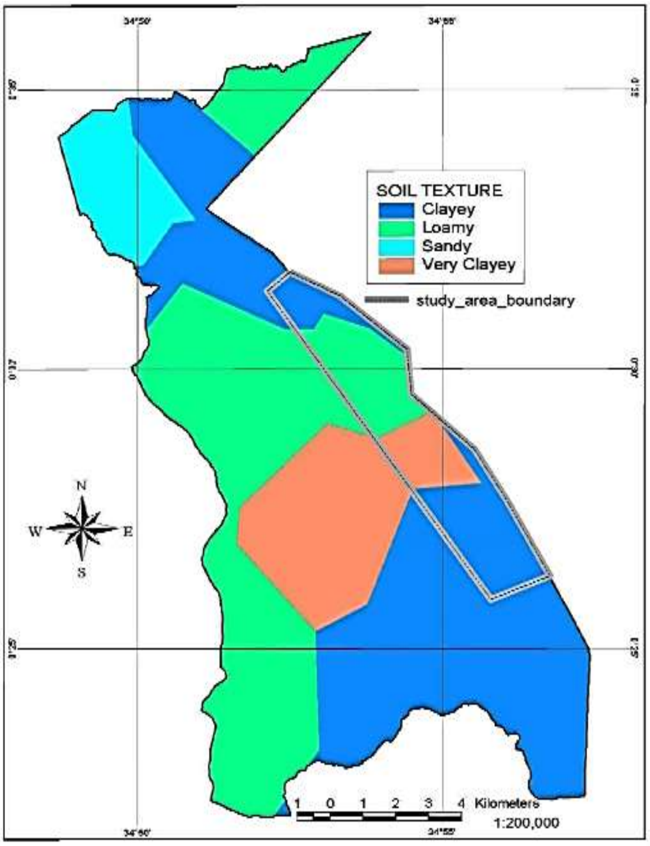

Figure 2: Textural Classification of the Soils of the Study Area; derived and modified from Soil Survey of Kenya.

Slope

Sidle et al. (1985) pointed out that steep slopes are most vulnerable to sliding because gravitational force acts maximally to the direction of the steepest slope. In the study area slope varies from 0° to >54°. The entire slope contour map was divided into four categories as indicated in Table 5.

Table 5: Slope Categorization/Classification in relation to Susceptibility to Slope Failures

Rank	Slope Degree	Classification	Susceptibility to slope failure
1	> 54°	very steeply sloping	Very Highly susceptible
2	20° - 54°	steeply sloping	Highly susceptible
3	5° - 20°	moderately sloping	Moderately susceptible
4	0° - 5°	Flat -gently sloping	Low susceptibility

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

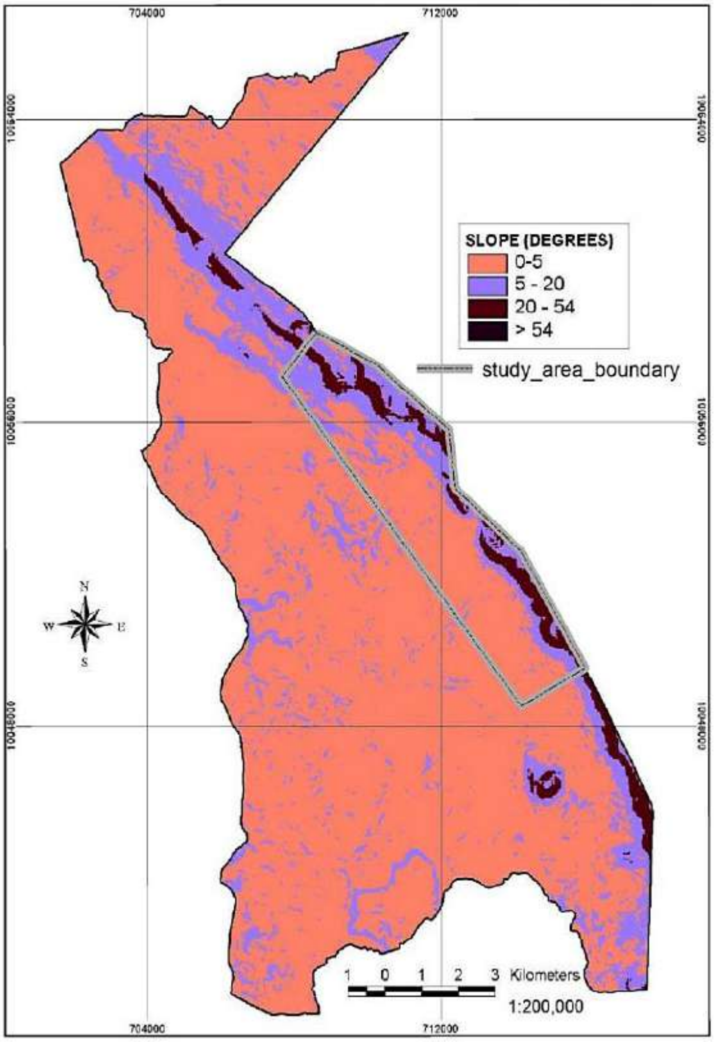

Figure 3: Slope Map derived from contours digitized from Topographical map 1:50,000.

The result of this study within the range 5°-54° does not differ much from those obtained by Inganga (1995), Nduru (1995) who found out that slopes steeper than 24°-55° degree is more susceptible to slope failures. The critical slope for this study is 20°-54° 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. As this is a 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°-54° which means that the slope is very steep. The area receives about 1200 mm of rainfall annually is inhabited by people who practice small scale farming and charcoal burning, therefore facilitating slope failures.

Rainfall

It is well known that rainfall is the most important and frequent trigger of landslides. It causes 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., 2008). 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). No landslides will take place unless pore water pressure reaches a critical point whereby soil particles can no longer withstand shear stress.

A fresh landslide scar was observed in the area of study (Plate 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 1). This means that drainage becomes poor and water collects in the depression thus increasing the likelihood of secondary slides. The landslide scar in the study area might have been caused by a combination of many factors, the main one being high amount and intensity of rainfall.

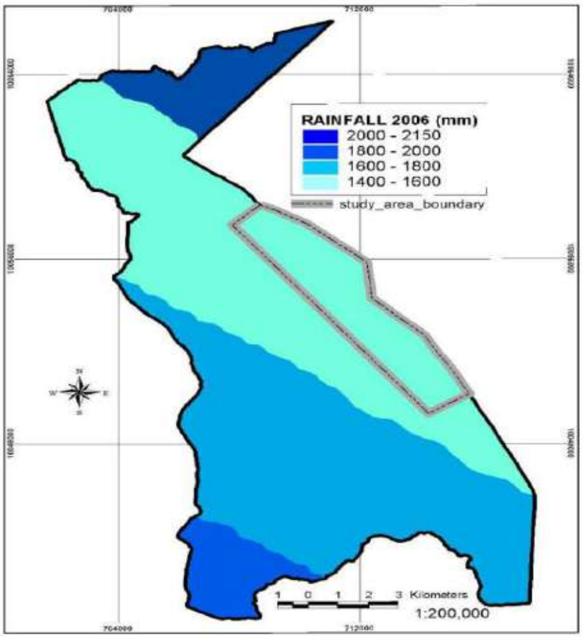

Figure 4: Rainfall Distribution Map of the Study Area isohyets; derived using data from 12 weather stations from 1985 to 2006.

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 (plate 3). 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 6: 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

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 5).

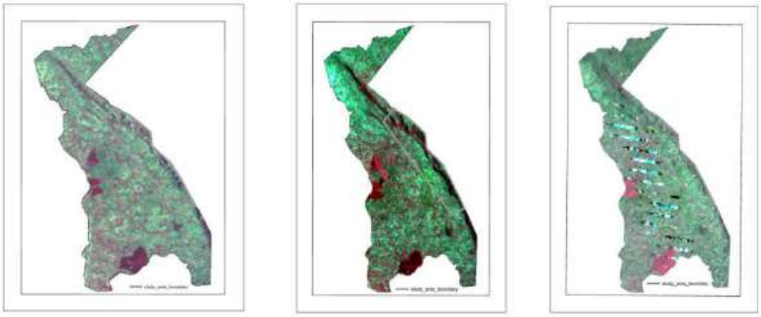

Figure 5: Landuse change maps for the years 1973, 1995 and 2006, respectively derived from LANDSAT IMAGES false colour composite, band 4 Red, 3 Green, 2 Blue.

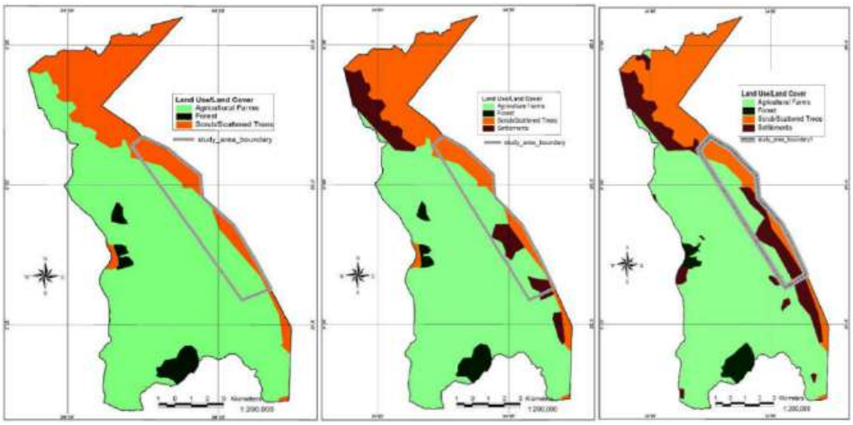

Figure 6: Land use/ Land cover Maps derived from Landsat images of 1973, 1995, and 2006, respectively.

Originally the Nandi Escarpment was covered by natural forestmade up of indigenous trees (Plate 1). (“*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 exotic trees such as cypress. This was also seen in the image as it appeared dark red in the false colour composite. Though the satellite image Landsat 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 6), 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, in the 1995 LULC map obtained (Figure 6), 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 FGD 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. 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, because of soil fertility or "virgin" soil. There was high demand for timber to be used in the Webuye Paper Factory leading to increase in the rate of tree felling for commercial purposes. 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. Small scale farming ofmaize 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 which are fertile and have high productivity potential thus making them vulnerable to human interference.

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%, 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). High population density leads to clearance of forest and settlement on slopes which makes them unstable and coul 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 and attendant enroachment of escarpment. Field observation also revealed that there are human settlements on the escarpment as steep as 55^o by terracing for construction of houses (Plate 3). Due to population pressure, the land is intensively being 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 leading to fatalities and destruction of property. Due to intense land use activitiespractices in the escarpment, the equilibrium of the slope is thus disturbed in. Khuvasali area causing an overload on the slope and impeding free surface drainage. The settlements on the slopes 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 causing sliding. Slope failure is also exercabated by crop farming involving maize, surgar, sweet potatoes, cassavas, bananas, cowpeas and beans together with rearing of domestic animals in each homestead.

Plate 3: Intensive farming along the Nandi Escarpment enhances slope failure as in 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 deforestation in an effort to create land for settlementand agriculture as sources of livelihoods and 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. According to Republic of Kenya (2002) 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 1). 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 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 accelerated tree depletion in the Nandi Escarpment.

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 that cannot contribute to increase of shear strength of the slope material as in the case of eucalyptus (Inganga, 1995); cypress roots cannot facilitate rain water to seep from the escarpment or springs that flow down slope and thus making the area more susceptible to landsliding. Information gathered through interviews and written reports showed that overpopulation and agriculture are the major forces in land use change in the study area. 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 followed by settlement number 2 and moderate for scrub /scattered trees (Table 7). 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 7: 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 8: 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; very high, high, moderate and poor. Thus, the landslide prone areas having four susceptibility zones were obtained as shown in Figure 6.

The four maps are 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 as seen inFigure 7. 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 kept 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 (Ucakuwun et al., 2008), which occurred on cultivated lands, as explained by decrease in shear strength after tree roots decayed. Therefore, in the study area, it was found out that there are more landslides which are likely to occur along the escarpment because of the steep slopes, very clayey textural soils and areas where trees have been cut for farming as 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 et al., 1978). The distribution of landslide potential areas along the Nandi Escarpment in Kabras division as shown in Figure 7 which indicates that the southern part of the study area is dominated by high and very high landslide potential, while moderate and poorly susceptible zones predominate 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 7.

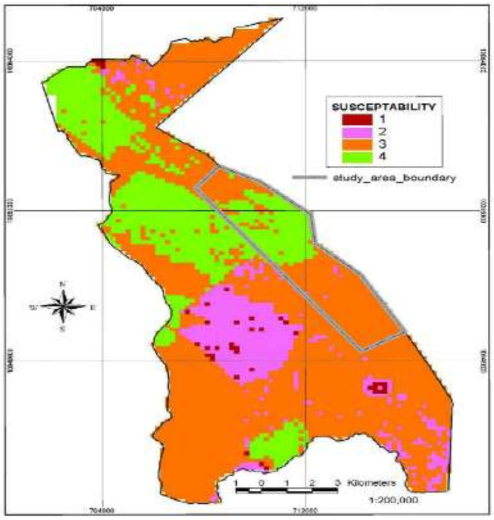

Figure 7: Landslide susceptability map of the Nandi Escarpment in Kabras Division.

CONCLUSION

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 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, and thus 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 resulting in sliding. The more the factors that enhance shear stress in the soil, the more likely the occurrence of land slide, as the greater the shear stress the lower the shear strength thus the slope will slide.

RECOMMENDATIONS

Based on the findings, the study made the following recommendations:

i) Settlement should be limited to slopes of less than 24^0 since, according to this study, slopes higher than this are prone to sliding,

ii) 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,

iii) 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.

i) 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

ii) 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.

iii) Planting of exotic trees (cypress) should be discouraged 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.

iv) Deep rooted trees such as eucalyptus and wattle take up a lot of water from the ground should be used to miligate against frequency 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

v) Cutting down of eucalyptus and indigenous trees for charcoal burning should be discouraged in the upper slope and natural vegetation should be allowed to regenerate

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

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

viii) 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.

ix) 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.

x) 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

xi) 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.

REFERENCES

Anderson, J. R., Hardy, E.E., Roach, J. T., & 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.

Bernatek-Jakiel, A., & Poesen, J. (2018). Subsurface erosion by soil piping: significance and research needs. *Earth-Science Reviews*, *185*, 1107-1128.

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

Carey, M., Huggel, C., Bury, J., Portocarrero, C., & Haeberli, W. (2012). An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. *Climatic Change*, *112*(3), 733-767.

Cervi, F., Berti, M., Borgatti, L., Ronchetti, F., Manenti, F., & Corsini, A. (2010). Comparing predictive capability of statistical and deterministic methods for landslide susceptibility mapping: a case study in the northern Apennines (Reggio Emilia Province, Italy). *Landslides*, *7*(4), 433-444.

Chen, H., Qin, S., Xue, L., & Xu, C. (2021). Why the Xintan landslide was not triggered by the heaviest historical rainfall: Mechanism and review. *Engineering Geology*, *294*, 106379.

Chen, W., & Li, Y. (2020). GIS-based evaluation of landslide susceptibility using hybrid computational intelligence models. *Catena*, *195*, 104777.

Cho, S. E. (2017). Prediction of shallow landslide by surficial stability analysis considering rainfall infiltration. *Engineering Geology*, *231*, 126-138.

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

Dahal, B. K., & Dahal, R. K. (2017). Landslide hazard map: tool for optimization of low-cost mitigation. *Geoenvironmental Disasters*, *4*(1), 1-9.

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

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

Fan, X., Rossiter, D. G., van Westen, C. J., Xu, Q., & Görüm, T. (2014). Empirical prediction of coseismic landslide dam formation. *Earth surface processes and landforms*, *39*(14), 1913-1926.

Francioni, M., Salvini, R., Stead, D., & Coggan, J. (2018). Improvements in the integration of remote sensing and rock slope modelling. *Natural hazards*, *90*(2), 975-1004.

Gamba, P. A. (1991). *Programmes on recipient communities: A case study of Kenya-Finland western water supply programme in Western province* (Doctoral dissertation, University of Nairobi).

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

Government Printers

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

Gurung, A., Gurung, O. P., & Karki, R. (2013). Improper Agricultural Practices Lead to Landslide and Mass Movementdisasters: A Case Study Based on Upper Madi Watershed, Nepal. *Emirates Journal of Food and Agriculture*, 30-38.

Haque, U., Blum, P., Da Silva, P. F., Andersen, P., Pilz, J., Chalov, S. R., ... & Keellings, D. (2016). Fatal landslides in Europe. *Landslides*, *13*(6), 1545-1554.

Ilies, D. C., Caciora, T., Herman, G. V., Ilies, A., Ropa, M., & Baias, S. (2020). Geohazards affecting cultural heritage monuments. A complex case study from Romania.

Inganga, S. F., Ucakuwun, E. K., & 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.

Islam, M. S., & Hoque, F. (2014). River bank erosion of the Surma River due to slope failure. *International Journal of Research and Innovations in Earth Science*, *1*(2), 54-58.

Jayanthi, J., Raj, T. N., & Gandhi, M. S. (2016). Identification of landslide-prone areas using remote sensing techniques in Sillahalla watershed, Nilgiris District, Tamilnadu, India. *Int J Eng Technol*, *3*(6), 1947-1952.

Joseph, O. N., Albert, O., & Byaruhanga, J. (2015). Effect of internal control on fraud detection and prevention in district treasuries of Kakamega County. *International Journal of Business and management invention*, *4*(1), 47-57.

Kafle, S. K. (2017). Disaster risk management systems in South Asia: Natural hazards, vulnerability, disaster risk and legislative and institutional frameworks. *J. Geogr. Nat. Disasters*, *7*(207), 2167-0587.

Kamp, U., Growley, B. J., Khattak, G. A., & Owen, L. A. (2008). GIS-based landslide susceptibility mapping for the 2005 Kashmir earthquake region. *Geomorphology*, *101*(4), 631-642.

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

Korup, O., & Stolle, A. (2014). Landslide prediction from machine learning. *Geology today*, *30*(1), 26-33.

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

Lemenkova, P., Promper, C., & Glade, T. (2012, June). Economic assessment of landslide risk for the Waidhofen ad Ybbs region, Alpine Foreland, Lower Austria. In *Protecting Society through Improved Understanding. Proceedings of the 11th International Symposium on Landslides and the 2nd North American Symposium on Landslides and Engineered Slopes. NASL.* (pp. 279-285).

Li, W. C., Dai, F. C., Wei, Y. Q., Wang, M. L., Min, H., & Lee, L. M. (2016). Implication of subsurface flow on rainfall-induced landslide: a case study. *Landslides*, *13*(5), 1109-1123.

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

Makokha, P. M. (2014). The place of home-based industries in rural Kenya's socio-economic progress: A case study of Kakamega County. *Journal of Economics and Sustainable Development*, *5*(28), 154-173.

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

Msilimba, G. G. (2010). The socioeconomic and environmental effects of the 2003 landslides in the Rumphi and Ntcheu Districts (Malawi). *Natural Hazards*, *53*(2), 347-360.

Mwaniki, M. W., Agutu, N. O., Mbaka, J. G., Ngigi, T. G., & Waithaka, E. H. (2015). Landslide scar/soil erodibility mapping using Landsat TM/ETM+ bands 7 and 3 Normalised Difference Index: A case study of central region of Kenya. *Applied Geography*, *64*, 108-120.

Mwaniki, M. W., Ngigi, T. G., & Waithaka, E. H. (2011). Rainfall induced landslide probability mapping for central province. In *Fourth Intern. Summer School and Conf., (JKUAT, Kenya: Publications of AGSE Karlsruhe, Germany)* (pp. 203-213).

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

Ngecu, W. M., Nyamai, C. M., & Erima, G. (2004). The extent and significance of mass-movements in Eastern Africa: case studies of some major landslides in Uganda and Kenya. *Environmental geology*, *46*(8), 1123-1133.

Pradhan, B., Mansor, S., Pirasteh, S., & Buchroithner, M. F. (2011). Landslide hazard and risk analyses at a landslide prone catchment area using statistical based geospatial model. *International Journal of Remote Sensing*, *32*(14), 4075-4087.

Ray, R. L., Jacobs, J. M., & Cosh, M. H. (2010). Landslide susceptibility mapping using downscaled AMSR-E soil moisture: A case study from Cleveland Corral, California, US. *Remote sensing of environment*, *114*(11), 2624-2636.

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

Sabins Jr, F. F. (1986). *Remote sensing: principles and interpretation*. Chevron Oil Field Research Co.

Schuster, R. L., & Highland, L. (2001). *Socio-economic and environmental impacts of landslides in the western hemisphere* (pp. 1-50). Denver (CO): US Department of the Interior, US Geological Survey.

Sharma, A. K., Parkash, S., & Joshi, V. (2016). Geographical Information Systems for Disaster Response and Management. *National Institute of Disaster Management*, *6*.

Shit, P. K., Bhunia, G. S., & Maiti, R. (2016). Potential landslide susceptibility mapping using weighted overlay model (WOM). *Modeling Earth Systems and Environment*, *2*(1), 1-10.

Sidle, P. C., Pearce, A. J, & O'loughlin, C. L. (1985). *Hillslope Stability and Landuse*.

American Geology Union, Washington D.C. pp. 141

Svalova, V. B., Zaalishvili, V. B., Ganapathy, G. P., & Nikolaev, A. V. (2018). Natural hazards and disasters in mountain areas. *Геология и геофизика Юга России*, (2), 99-115.

Teshebaeva, K., Echtler, H., Bookhagen, B., & Strecker, M. (2019). Deep-seated gravitational slope deformation (DSGSD) and slow-moving landslides in the southern Tien Shan Mountains: new insights from InSAR, tectonic and geomorphic analysis. *Earth surface processes and landforms*, *44*(12), 2333-2348.

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

Xu, X. Z., Guo, W. Z., Liu, Y. K., Ma, J. Z., Wang, W. L., Zhang, H. W., & Gao, H. (2017). Landslides on the Loess Plateau of China: a latest statistics together with a close look. *Natural Hazards*, *86*(3), 1393-1403.

Yalcin, A. (2007). Environmental impacts of landslides: A case study from East Black Sea region, Turkey. *Environmental engineering science*, *24*(6), 821-833.

Zhou, S., Zhou, S., & Tan, X. (2020). Nationwide susceptibility mapping of landslides in Kenya using the fuzzy analytic hierarchy process model. *Land*, *9*(12), 535.

Zieher, T., Schneider-Muntau, B., & Mergili, M. (2017). Are real-world shallow landslides reproducible by physically-based models? Four test cases in the Laternser valley, Vorarlberg (Austria). *Landslides*, *14*(6), 2009-2023.

Zulkiflli, A. B. (2015). Simulation of Slope Failure Induced By Rainfall on Clayey Soils. *Civil Engineering*.

Zumpano, V., Pisano, L., Malek, Ž., Micu, M., Aucelli, P. P., Rosskopf, C. M., ... & Parise, M. (2018). Economic losses for rural land value due to landslides. *Frontiers in Earth Science*, 97.