REMOTE SENSING AND GIS USAGE IN MAPPING VULNERABLE LANDSLIDE AREAS IN MURANG'A COUNTY, KENYA

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A PROJECT REPORT

Submitted to the Department of Geology and the School of Physical Sciences in partial fulfilment for the award of the Postgraduate Diploma in Natural and Environmental Disaster Management

APRIL, 2015

UNIVERSITY OF NAIROBI

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I declare that this work has not been previously submitted and approved for the award of a postgraduate diploma by this or any other University. To the best of my knowledge and belief, the project contains no material previously published or written by another person except where due reference is made in the project itself.

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Approval

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Abstract

This project presents the application of Geographic Information System (GIS) and Remote Sensing in landslide susceptibility mapping as one of the means for disaster management. A part of the Central Kenya region i.e. Murang'a County was selected for the project execution. Topographic maps, field data, Earth Explorer satellite data and other informative maps were used as inputs to the study. Important terrain factors contributing to landslide occurrences in the region were identified and corresponding thematic data layers were generated. These data layers represent the geological, topographical, and hydrological conditions of the terrain. Landslide characteristics in the study area were derived by using GIS analytical procedure. The procedure utilized the detailed spatial database of the area to integrate the evidence of the past slope failures and their causative variables for landslide occurrences. The resulting landslide hazard map delineates the area into different zones of three relative susceptibility classes: high, moderate, and low. The landslide hazard map was validated by correlating the landslide frequencies of different classes.

Key words: Geographic Information System (GIS), Remote Sensing, Hazards, Risk, Landslides, Vulnerability, Disaster, Disaster Management, Mitigation.

Table of Contents

List of Figures

List of Tables

CHAPTER ONE

1.0 INTRODUCTION

Space technology has made substantial contribution in all aspects of disaster management such as disaster preparedness, mitigation, response and recovery. The Earth Observation satellites which include both geostationary and polar orbiting satellites provide comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals and thus have become valuable for continuous monitoring of atmospheric as well as surface parameters related to natural hazards (Jeyaseelan, 2003). Advancements in the remote sensing technology and the Geographic Information Systems help in real time monitoring, early warning and quick damage assessment of both technological and natural disasters such as floods and landslides

Landslides are the result of complex interaction among several factors, primarily involving geological, geomorphological, and meteorological factors. The spatial information related to these factors can be derived from remote sensing data, ground based information, and several other data sources. Digital image processing of remote sensing data together with Geographic information systems (GIS) are very powerful tools for the integration of different types of data and for spatial data analysis. Efficient landslide susceptibility and hazard mapping can therefore be carried out by combining GIS with image processing capabilities for disaster management purposes.

The present project involves ascertaining the utility of remote sensing and GIS in spatial analysis and mapping of potentially vulnerable landslide areas within Murang’a County, Central Kenya region.

1.1 GOAL

The main goal is to map potentially vulnerable landslide areas in Murang’a which can be used for planning, monitoring, assessing socio-economic effects and for mitigation purposes.

1.2 OBJECTIVES

The major objectives are to use Remote Sensing and GIS techniques as a tool for:

1. Identifying and locating landslide areas in Murang’a County
2. Determining the relationship between instability factors and their ability to cause or trigger landslides
3. Developing landslide vulnerability maps showing areas susceptible to landslides

1.3 Problem Statement

Less has been done on analyses of landslide instability factors and updates of landslide inventory maps by GIS and remote sensing techniques. This project focuses on analysing particular factors that currently contribute, influence or trigger landslide occurrences in Murang’a County. Thus, the results obtained are used for mapping potentially vulnerable landslide areas hence landslide hazard maps which can be used for planning, monitoring, assessing socio-economic effects and for mitigation purposes.

1.4 Justification

The use of scientifically and technologically proven tools such as Remote Sensing and GIS have greatly been used in capturing, storing, retrieving, analysing and displaying of any geo-referenced data. They are known to have the capacities needed to generate and disseminate timely and meaningful information to enable individuals or communities threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

Landslides, among other hazards, are still major disaster causing geological processes which cause not only enormous damage to roads, bridges, and houses but also lead to loss of many lives within the country as well as globally. Better mechanisms are needed to be enforced to prevent, control, monitor and mitigate this hazard. This is in order to save lives and property getting lost now and often especially in most vulnerable areas.

This project is therefore worth pursuing as it makes use of Remote Sensing and GIS techniques in generating landslide vulnerability maps which can be used for analysing the causal factors of landslides with an aim of assessing and lessening vulnerability of people and property, wise management of land and environment, and improved preparedness for adverse events.

1.5 Definition of Terms

Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources (UNISDR, 2009).

Disaster Management

This includes the sum total of all activities, programmes and measures which can be taken up before, during and after a disaster with the purpose to avoid a disaster, reduce its impact or recover from its losses.

Geographic Information Systems (GIS)

This refers to a system of integrated computer-based tools for end – to –end processing (capture, storage, retrieval, analysis, display) of data using location on the earth's surface for inter-relation in support of operations, management, decision making and science.

GIS can further be summarised as tools for handling georeferenced data where a georeferenced data here refers to data that occupies space on the earth's surface and has actual location values.

Hazards

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009).

Landslide

A landslide is the collapse or movement of large amounts of land or rocks. The term 'landslide' includes all varieties of hill slope mass movements and can be defined as the downward and outward movement of slope forming materials including rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another (UNISDR, 2012).

Mitigation

Mitigation is the lessening or limitation of the adverse impacts of hazards and related disasters. The adverse impacts of hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions (UNSDR, 2009)

Remote Sensing

Remote sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyse the characteristics without direct contact (JARS, 1993).

Risk

Risk refers to the probability of harmful consequences or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable/capable conditions (UNISDR, 2009).

Vulnerability

The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an object or community to the impact of hazards (UNISDR, 2009).

CHAPTER TWO

2.0 REVIEW OF THE LITERATURE

In understanding the types, occurrence and causes of landslides in our study area, it is important that we first get the general information about landslides.

2.1 Occurrence of Landslides

Landslides usually occur on unstable, steep slopes. They can happen suddenly or gradually. Heavy rain falling in areas of unstable land, or on slopes which have been stripped of vegetation, is the most common trigger for landslides. However, earthquakes and human actions such as inappropriate farming activities have also caused landslides (UNISDR, 2012).

Slope saturation by water is a primary cause of landslides. This effect can occur in the form of intense rainfall, changes in groundwater levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers. Land sliding and flooding are also closely related because both are related to precipitation, runoff, and the saturation of ground by water (Ngecu et al., 2004). In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area (Gichaba et al., 2013).

Landslide prone areas include the following: - (a) Steep deforested slopes, (b) rainwater run-off areas and (c) areas with thick and loamy soil (UNISDR, 2012).

2.2 Types of Landslides

Landslides are classified according to their mechanisms (movement types) and the nature of the displaced material (material type), as well as information on their activity (state, distribution, style), i.e. the rate of development over a period of time (Dikau et al., 1996;

Cruden and Varnes 1996). Five principal types of movements are distinguished which include the following:

i. **Falls**

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs (Figure 2.1d). Separation occurs along discontinuities such as fractures, joints, and bedding planes and movement occurs by free fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water (Gichaba et al., 2013).

They are an abrupt movement of materials that become detached from steep slopes or cliffs, moving by free-fall, bouncing, and rolling (UNISDR, 2012).

ii. **Topple**

A slope movement that occurs due to forces that cause an over-turning movement about a pivot point below the centre of gravity of the slope. A topple is very similar to a fall in many aspects, but do not involve a complete separation at the base of the failure (Malet and Maquaire, 2008).

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (Figure 2.1e) Gichaba et al., 2013.

iii. **Lateral spreading**

A slope movement characterized by the lateral extension of a more rigid mass over a deforming one of softer underlying material in which the controlling basal shear surface is often not well-defined (Malet and Maquaire, 2008).

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain (Figure 2.1j). The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesion-less sediments (usually sands and silts) are transformed from a solid into a liquefied state.

Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often, the initial failure is a slump, but in some materials, movement occurs for no apparent reason. Combination of two or more of the types mentioned earlier is known as a complex landslide (Gichaba et al., 2013).

iv. Slide

This is a slope movement by which the material is displaced more or less coherently along a recognisable or less well-defined shear surface or band. Slide could be rotational (the sliding surface is curved) or translational (the sliding surface is more or less straight). In some cases a slide can change into a mudslide or slump-earthflow, especially on steep slopes, in highly tectonized clays or silt formations (Picarelli, 2001).

Although many types of mass movements are included in the general term 'landslide', the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides (Gichaba et al., 2013)

A: Rotational slide: more or less rotational movement, about an axis that is parallel to the slope contours, involving shear displacement(sliding) along a concavely upward-curving failure surface, which is visible or may reasonably be inferred' (Figure 2.1a)

B: Translational slide: The material displaces along a planar or undulating surface of rupture, sliding out over the original ground surface (Figure 2.1b).

A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass (Figure 2.1c).

v. Flows

According to Gichaba et al., 2013, there are five basic categories of flows that differ from one another in fundamental ways. They are described as follows;

a. Debris flow: A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilizes as slurry that flow downslope (Figure 2.1f). Debris flows include <50%fines. Debris flows are commonly caused by intense surface-water flow due to heavy precipitation that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist

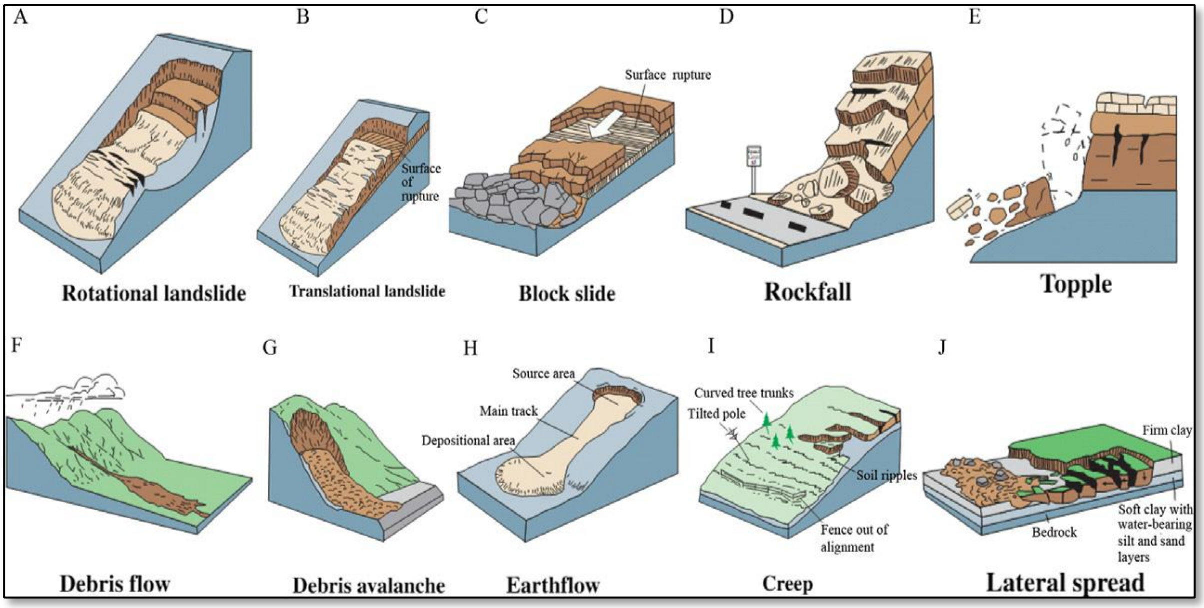

Figure 2.1: Schematic illustrations of the major types of landslide movements. Adapted from, Gichaba et al., 2013 Source: http://pubs.usgs.gov/fs/2004/3072.

of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies.

b. Debris avalanche: This is a variety of very rapid to extremely rapid debris flow (Figure 2.1g).

c. Earth flow: Earth flows have a characteristic 'hourglass' shape (Figure 2.1h). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible (Appendix 7.2; image 3).

d. Mudflow: A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50% sand-, silt-, and clay-sized particles. In some instances, for example, in many newspaper reports, mudflows and debris flows are commonly referred to as 'mudslides' (Appendix 7.2; image 1).

e. Creep: Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation but too small to produce shear failure.

There are generally three types of creep: (1) **seasonal**, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) **continuous**, where shear stress continuously exceeds the strength of the material; and (3**) progressive**, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (Figure 2.1i).

2.3 Causes of landslides

According to Gichaba et al., 2013, there are multiple types of causes of landslides in Kenya, which can be classified in two categories, namely, inherent and triggering factors.

The inherent (natural/human-induced) ones comprise:

a. Geologic Causes - Caused by weakness in the composition and structure of rock or soil;

- Weak or sensitive materials
- Weathered materials
- Sheared, jointed, or fissured materials
- Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, and contact)
- Contrast in permeability and/or stiffness of materials

b. Morphological Causes

- Tectonic or volcanic uplift
- Glacial rebound
- Fluvial, wave, or glacial erosion of slope toe or lateral margins
- Subterranean erosion (solution and piping)
- Deposition loading slope or its crest
- Vegetation removal (by fire and drought)
- Thawing
- Freeze-and-thaw weathering
- Shrink-and-swell weathering

c. Human Causes

- Excavation of slope or its toe
- Loading of slope or its crest
- Drawdown (of reservoirs)
- Deforestation

- Irrigation
- Mining
- Artificial vibration
- Water leakage from utilities

The main **triggering factors** include:

1) rainfall
2) earth movements
3) earthquakes, volcanism, faulting, and thunder
4) human activities such as clearing of vegetation, farming, undercutting, building, quarrying, blasting, construction, and other engineering works can trigger landslides

2.4 Landslides in Kenya

While much research has been done on landslides around the world, the landslides in Kenya have received relatively little attention (Gichaba et al., 2013; Davies, 1996; Westerberg and Christianson, 1998; Ngecu and Ichang'i, 1999; Ngecu and Mathu, 1999; Westerberg, 1999; Inganga et al., 2001; Knapen et al., 2006; Claessens et al., 2007). From the research done, the available landslide information is general covering the landslide events, their geographical locations and impacts of their occurrences. From the year 2002 to 2013 landslides have occurred in Kenya on 18 Counties with Murang'a leading with 7 occurrences followed by Baringo County with 6 occurrences while Mombasa, Homa bay, Laikipia, Bungoma, Kakamega, Kericho, Taita-Taveta, Makueni and Machakos have the least occurrences of one event each (NDOC, 2015; Appendix 7.1b).

Over the same period of 2002 to 2013, landslides had led to the loss of 97 lives, 149 people injured, 254 houses destroyed, 2908 people affected and 1031 relocated (NDOC, 2015; Appendix 7.1a).

2.5 Landslides in Murang'a County

Many landslides have occurred on the eastern foot slopes of the Aberdare ranges during the last 50 years. Between 1960 and 1980 about 40 landslides occurred in Murang'a in the eastern foot slopes of the Aberdare ranges. It is also estimated that in the last twenty years, landslides in Murang'a district caused the loss of over one million cubic meters of soil in an area of 30km^2 (UNISDR, 2012).

Basing on the research review done in Murang'a County, the available information entails some work done by Njagih (2005). It includes an inventory data sheet with landslide occurrences and their impacts in Central Kenya (Table 2.1).

Table 2.1: Landslides occurrences in Central Kenya from 1997-2003 and their impacts

A summary of deaths and destruction of property caused by landslides in Central Kenya between 1997-2003				
Year	**District**	**Location**	**Impacts**	
			No. of deaths	**Nature of destruction and displacement**
1997	Murang'a	Gaturi	None	Roads and Farms
‘’	Murang'a	Muringa	11	7 Houses
1998	Murang'a	Gatura	None	400 people displaced
‘’	Murang'a	Gituamba	1	Farms & Homesteads
‘’	Kiambu	Kijabe	None	Rail & road blocked
2002	Murang'a	Ruru	None	Forest & homestead
2002	Murang'a	Kiruri	5	Homes & roads
2003	Kiambu	Ngegu	2	Farms & Homes
2003	Nyandarua	Sasimua	None	Sasumua Dam

Source: *Njagi (2005)*
http://www.itc.nl/PDF/Organisation/UNU%20DGIM/item1840/21_09_2005_Landslide_hazard_mapping_in_Muranga.pdf.

Njagih's research data covered the years from 1997 to 2003. By then, Murang'a was considered as a district in Central Kenya unlike its current status of a County which has incorporated other districts namely, Maragua and Thika. This is then a clear implication that there is a large portion of the county that was not represented in his work. Additionally, since the year 2003 to the current year of 2015, Murang'a has further experienced landslide occurrences some of which have not been represented in his inventory data sheet thus a need to fill the gap left.

Other landslide occurrence incidences in Murang'a County are identified from the case studies and research work done by Ngecu and Mathu, (1999) and Ngecu et al., (2004). In their work we note that although landslides are primarily associated with mountainous terrains, they have also occurred in areas of surface excavations for highways, buildings and open pit mines. A good example is the Murang'a-Kiriaini highway which is often impassable due to the sliding of deeply weathered volcanic soils which cover sections of the road banks.

A major landslide, which occurred at Maringa village in Murang'a district of Kenya on 30 April 1997, indicated that apart from heavy rainfall, which characterised the later part of 1997, the geology, climate and soils of the area contributed immensely to the occurrence of the landslide (Ngecu et al., 2004).

On 10th November 1997, a landslide occurred along the Thika- Murang'a highway at Karugia, which swept away a one-kilometre section of the highway downslope. The landslide rendered about 356 km^2 of arable land useless in addition to cutting off road and other communications between Thika and Murang'a towns (Ngecu and Mathu, 1999).

On 26th December 1997, another major landslide occurred at Gatara village in Murang'a, which swept away an estimated 50,000 tea bushes in addition to killing three people who were buried while asleep in their house (Ngecu and Mathu, 1999; Ngecu et al., 2004).

CHAPTER THREE

3.0 METHODOLOGY AND DATA COLLECTION TECHNIQUES

3.1 The Study Area

3.1.0 Geographical Location

The study area is Murang’a County which is located in Central Kenya Region. It is bordered by Nyeri County to the North, Kiambu County to the South, Nyandarua County to the West and Machakos County to the East. The area lies below the Equator on latitudes between 0°34’S and 1°06’South and longitudes $36°42^{'}$ E and $37^{0}26^{'}$ East of the Greenwich meridian. It has an area of 2,527km2 (Figure 3.1).

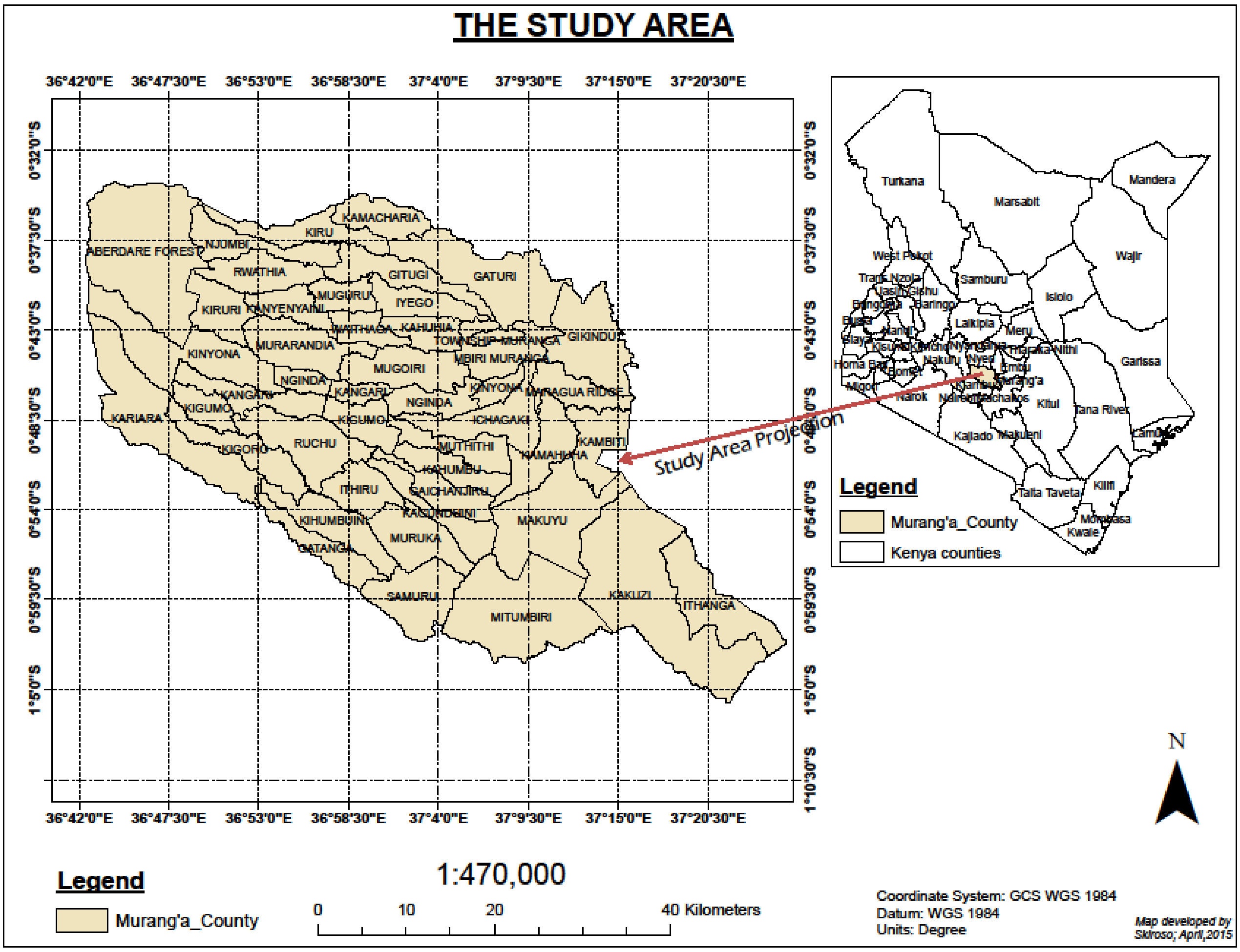

Figure 3.1: The study area of Murang'a County

3.1.1 Geomorphology

The land rises gradually from an altitude of 914m in the East to 3,353m above sea level along the slopes of the Aberdares. More than 95% of the landscape is generally mountainous. The area exhibits highly dissected and rugged topography in the West whereas it is gentle towards East of Makuyu division where the rivers dissipate into wetlands before discharging into Tana River (NEMA, 2006).

3.1.2 Climate

Temperatures vary with altitude. In the Eastern lower areas the maximum annual temperatures range between 26° C and 30° C while the minimum annual temperatures range between 14° C and 18° C. In the western area, which is mostly high altitudes, the minimum temperatures can be as low as 6° C. Temperatures are moderate in the medium potential areas (NEMA, 2006).

3.1.3 Rainfall distribution

There are two rainfall seasons i.e. long rains (March – May) and short rains (October - November). The highest potential areas receive an average annual rainfall of between 1400mm and 1600mm. Low potential receive rainfall of less than 900mm per annum. Rainfall in high and medium potential areas is reliable and well distributed throughout the year and is adequate for cultivation. However on low potential areas rainfall is unevenly distributed and therefore unsuitable for cash crop production (NEMA, 2006).

3.1.3 Drainage

Murang’a’s catchment rivers drain eastwards from the Aberdare ranges. The highest areas to the West have deeply dissected topography and are well drained by several rivers, which include Mathioya North, Mathioya South and Maragwa flowing eastwards to join the Tana River.

3.1.4 Soils

Highland areas have rich brown loamy soils suitable especially for tea, Coffee, maize and dairy farming. Soils in the lower areas are predominantly black cotton clay soils with seasonal impended drainage.

3.2 Materials and Methods

In addressing this landslide issue, the following methodology and activities were considered;

i. Identification of geographical location of Murang'a county;

   This was done using geo-processing tools in GIS whereby, Kenya's Counties shapefile was first intersected with Kenyan 1999 population census shapefile to obtain all administrative boundaries. The study area i.e. Murang'a County was then clipped out. Using its attributes and other GIS operations, an identification map was generated based on Murang'a's administrative Locations as projected from the large Kenya Counties map (Figure 3.1 above).

ii. The second phase entailed Looking at the past recorded data/inventory of landslide occurrences in entire Murang'a County from map interpretation supplemented by recorded data of specific event occurrences in the study area (Table 2.1). This led to developing landslide inventory maps showing the administrative locations and divisions. Data used was acquired from the DesInventar of Kenya National Disaster Operation Centre (NDOC) (Appendix 7.1a, b and c) and research work done by Ngecu and Mathu, 1999 and Ngecu et al., 2004. It was augmented by the use of GPS receiver coordinates, satellite imageries (Google Earth) and adoption of remote sensing techniques (Appendix 7.3).

iii. The third phase of methodology used was the analysis of the factors that determine the instability and the conditions under which different types of landslides occur.

These factors included;

- Slope
- Lithology and their characteristics
- Drainage patterns of the area
- Road networks
- Rainfall distribution, and
- Land use practices

The analysis was done using generated instability factor maps for each mentioned factor above. This was achieved by first overlaying factor-thematic layers obtained from geo-processed thematic maps of Kenya (Table 3.1; Appendix 7.4, 7.5, 7.6) and satellite imagery with Murang'a landslide events occurrence layer.

Table 3.1: Database used in generating factor analysis thematic maps

	DATA TYPE	**DATA DESCRIPTION**	**USE/PURPOSE**
1.	**Topographical Sheet**	Scale 1:50.000	Digitization
2.	**Satellite Data** ASTER GDEM2; ASTGTM2_S01E036 & 37 **Ke-srtm**	Aster Global DEM SRTM 1 Arc-second Global	DEM; slope angles and elevation depiction
3.	Kenya land use map		Land use classification
4.	Kenya Lithology		Lithology classification
5.	Kenya rainfall distribution		Rainfall distribution

Sources: *U.S. Department of the Interior U.S. Geological Survey (USGS) and International Livestock Research Institute (ILRI) –GIS Services*

The mapping inventory or databases of phenomena obtained shows;

- The spatial location of the phenomena, its location in time, and

- Set of attributes for description and valuation which includes number of deaths recorded, property destroyed, and number of those affected by that event at the time.

The basic GIS operations at this level included digitisation, clipping, image processing and overlay functions. Variables responsible for causing slope failures such as road and river networks were digitized from the topographical sheets (Appendix 7.7). Slope contours were generated by satellite image processing (Aster Global DEM) while other variables such as rainfall distribution, lithology and land use practices were clipped from the base thematic maps in the database (Table 3.1; Appendix 7.4, 7.5, 7.6).

The analysis was based on map observations and correlation of instability factors. Attributes of spatially located landslide events that had already occurred were analysed with the instability factors to obtain a relationship between landslide occurrence and causative factors.

It is by the analysis of above factors and terrain conditions in areas affected by landslides in the past or present that it could be possible to determine zones with similar characteristics i.e. landslide susceptible areas.

iv. The fourth phase of methodology used involved developing potentially vulnerable landslide map based on landslide instability factors. Landslide events that had previously occurred in the area were used as basic reference data. This included, Gikoe village, Kiambuthia, Kiruri, Karega area along Kaharati-Kangari road, Gathaithi, Murang'a- Kiriaini highway, Karugia, Gatara village, Muringa, Gatura, Gituamba, Ruru and Sasumua.

The variables for landslide vulnerability identification and derivation of its characteristics were obtained from the factors already analysed in methodology three above. Variable layers for slope failure identification such as slope contours, lithology, road and river networks were then overlayed with the shapefile layer of already occurred landslide events and by combining with Murang'a's administrative locations, potential vulnerability map was developed. The resulting map was further digitised and delineated into three different zones of relative susceptibility classes i.e. highly vulnerable, moderately vulnerable, and lowly vulnerable areas. This was validated by identifying and correlating the landslide relative frequencies of event occurrences.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter focuses on the results derived from the methodology used and the discussions are based on the analyses of particular factors that contribute, influence or trigger landslide occurrences in Murang'a County. The results obtained all point to the ultimate aim of mapping potentially vulnerable landslide areas thus leading to the development of landslide hazard maps which can be used for planning, monitoring, assessing socio-economic effects and for mitigation purposes.

4.1 Murang'a Landslide inventory Maps

The Murang'a landslide inventory maps (Figure 4.1, 4.2) were based on the administrative Location and Division boundaries of Murang'a County. The maps display researched and recorded landslide event occurrences from the year 1997 to 2013 on their spatial locations.

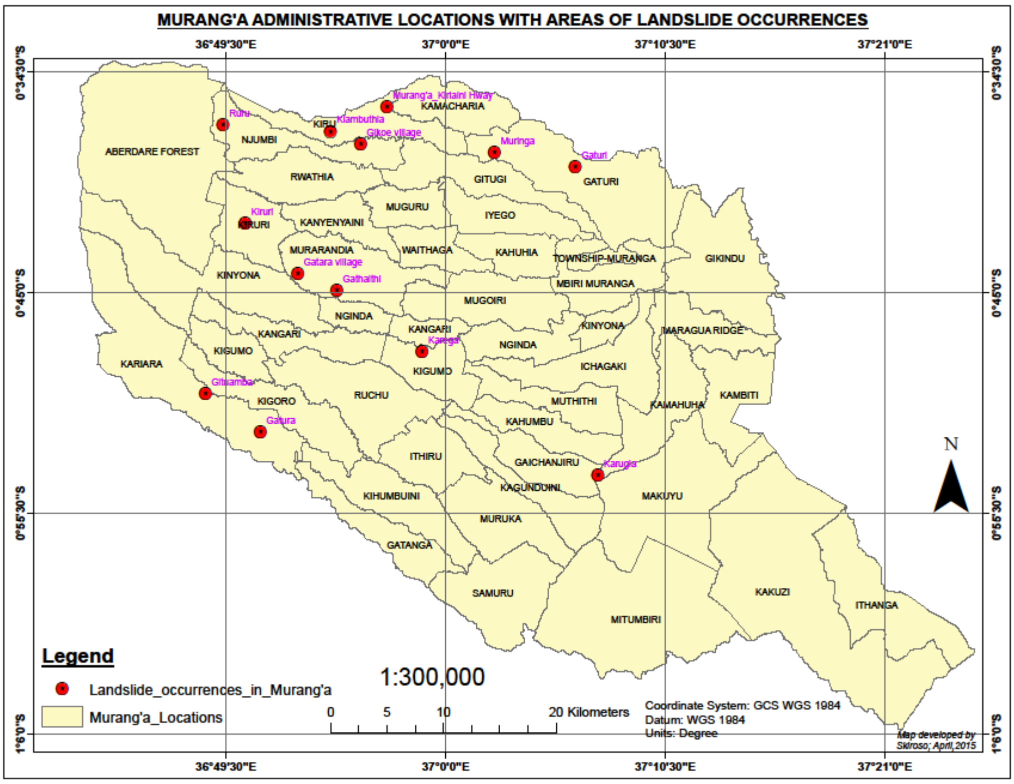

Figure 4.1: Murang'a Administrative Locations with landslide occurrence areas

From the above map it can be observed that landslides have occurred on eight administrative locations, five of which have each two recorded incidences while three have one incidence of landslide event. These locations are namely: Gaturi (2), Kiru (2), Njumbi (2), Murarandia (2), Kariara (2), Kiruri (1), Kigumo (1) and Gaichanjiru (1).

Landslide inventory map was also prepared based on Murang'a County administrative divisions with some of the variables responsible for landslide occurrences such as rivers, slopes (contours) and road network (Figure 4.2).

MURANG'A ADMINISTRATIVE DIVISIONS WITH AREAS OF LANDSLIDE OCCURRENCE

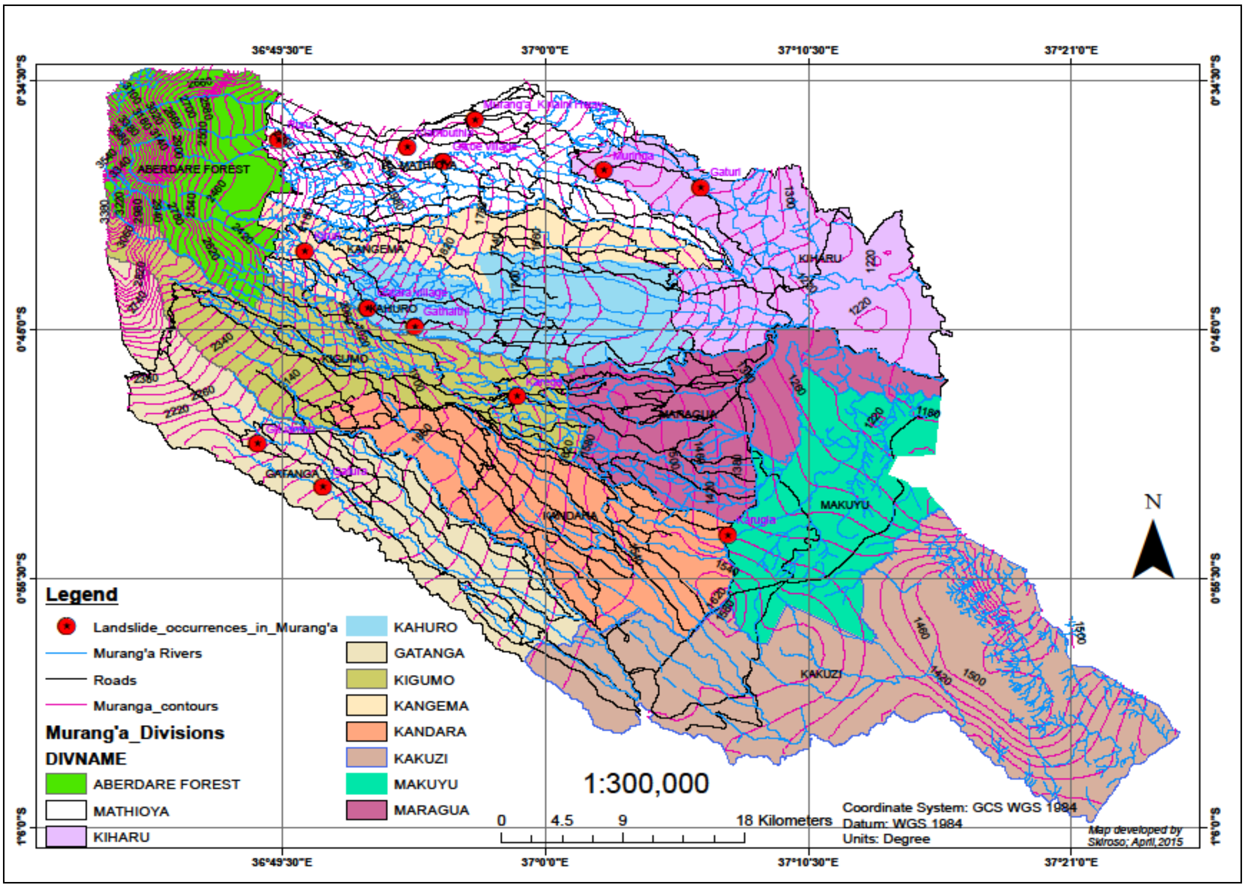

Figure 4.2: Landslide inventory on Murang'a administrative divisions

It is observable that from the administrative divisions in the map, landslides have occurred on 7 out of 10 divisions namely: Mathioya(4), Kiharu(2), Kahuro(2), Gatanga(2), Kigumo(1)

Kangema(1) and Kandara(1). All the 7 divisions are lying on steep sloping terrain indicated by close contours.

Mathioya division is much prone to landslides. It has more landslide incidences (4) than others. This is due to the presence of many river and road networks and rugged terrains that are known to trigger landslides. Maragua, Makuyu and Kakuzi divisions could be less vulnerable to landslides as there are no landslide incidences observed.

4.2 Landslide factor analysis

Factors that determine the instability and the conditions under which different types of landslides occur, or are triggered, were analysed using the landslide instability factor maps generated. The factors considered include:

- Slope failure
- Lithology
- Drainage pattern
- Road network in the area
- Rainfall distribution, and
- Land use practices

a) Slope failure analysis

Landslides are observed to have occurred on the slopes with contours that range between 1420m at Karugia and 2300 meters above sea level at Ruru. However, it can also be noted that most landslides i.e. 7 out of the 13 recorded, have taken place between 1820m and 2180 meters above sea level (Figure 4.3).

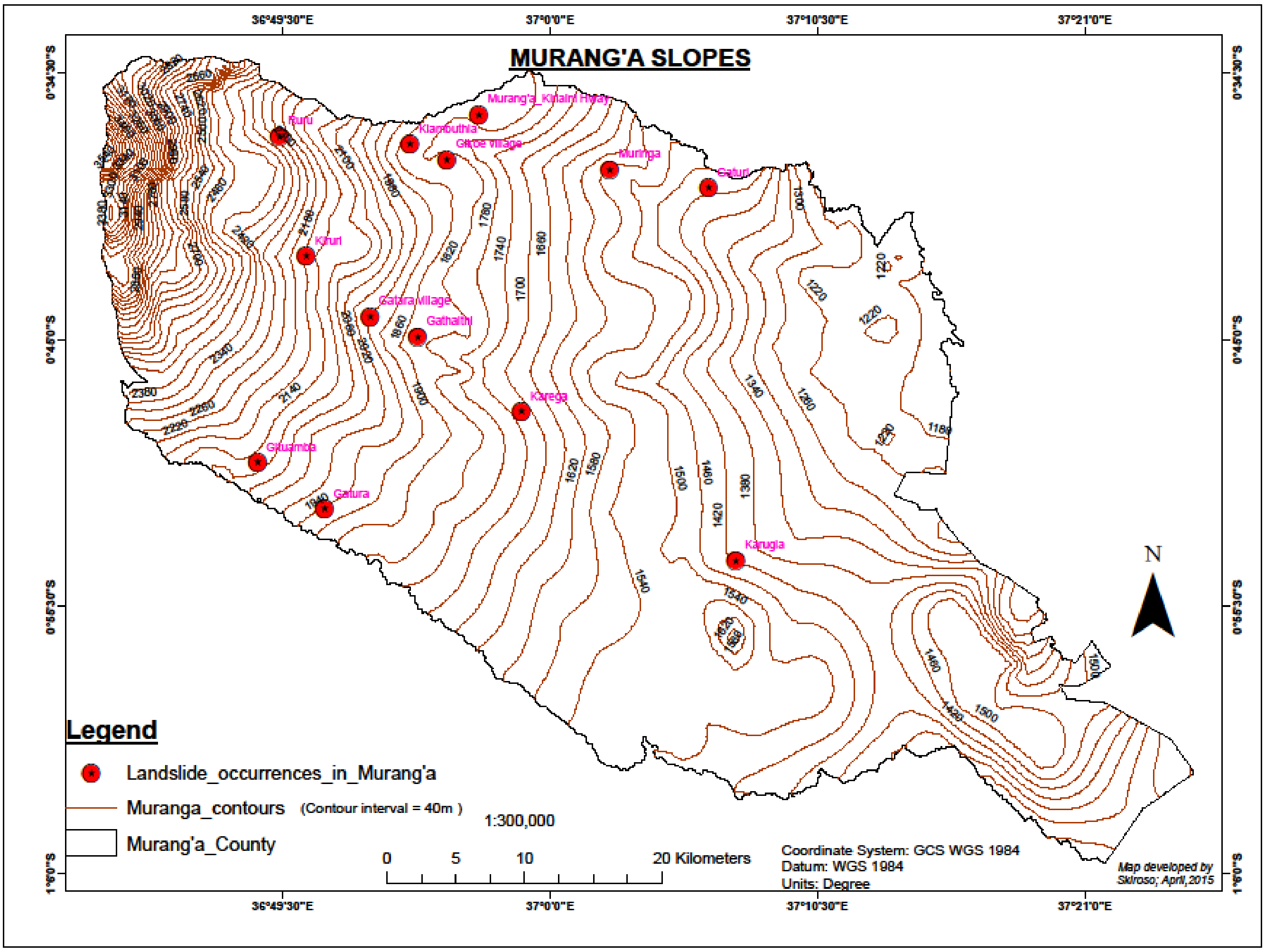

Figure 4.3: Murang'a Landslide slope analysis

The area characterised by contours close to each other indicate a rugged terrain surface with steep slopes.

A cross section was drawn on the map above represented by point A to B to further analyse the nature of slope in the County in relation to the occurred landslide events (Figure 4.4a and b)

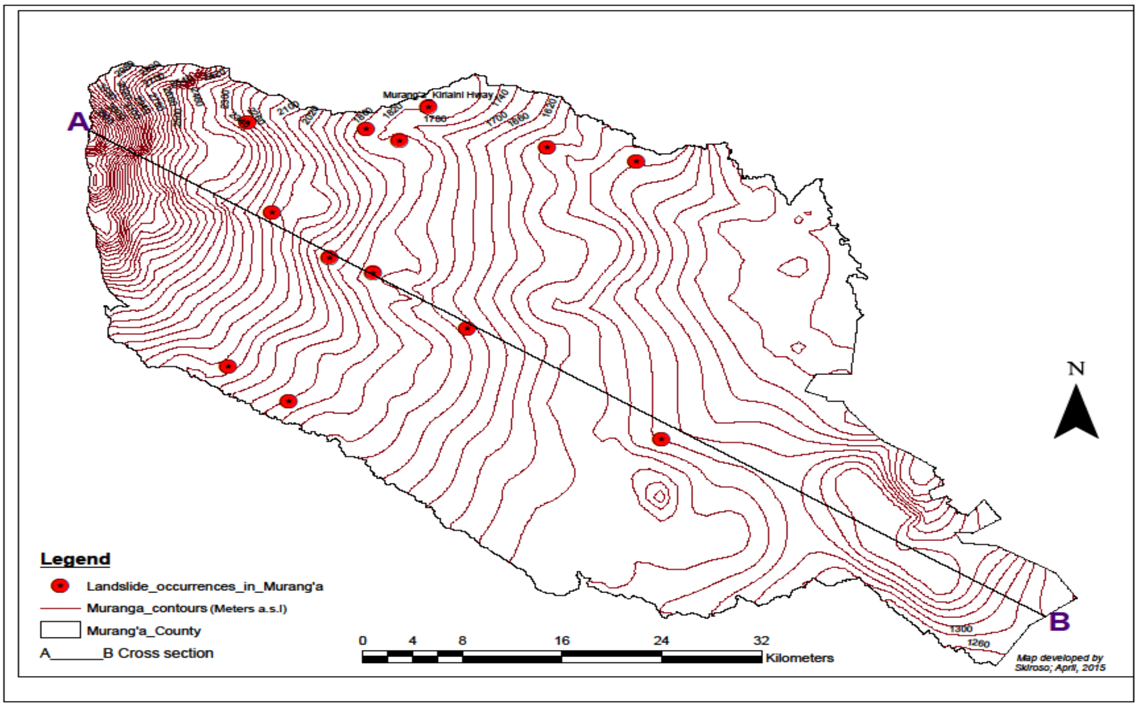

Figure 4.4a: A cross section (A to B) over Murang'a County

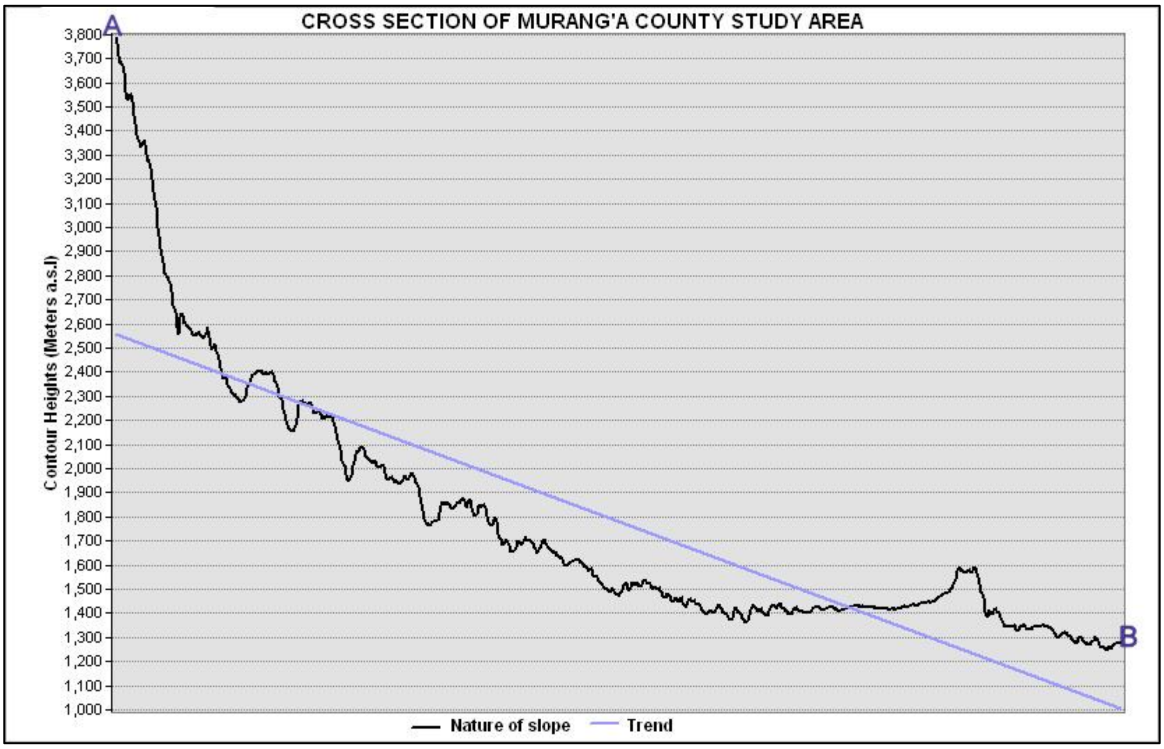

Figure 4.4b: Results of cross section done over Murang'a County

From the cross section above, we can observe that the terrain where the trend line cuts i.e. section identified by slope contours ranging from 1400m to 2400m, is highly rugged especially to the western side to which the land rises. This is also the section where all the landslides recorded and mapped above have been experienced.

It is also observed that landslides at Ruru (2300m), Kiruri (2180m), Gituamba (2140m), Gatara and Gatura(1940m), Kiambuthia (1860m), Gikoe and Gathaithi (1820m), and at Karega (1700m), all have taken place on V-shaped gullies identified from the cross section above.

From these observations it is evident that slope failure likelihood is very high at this region which when combined with other instability factors such as heavy rainfall and little steep slope disturbance either by ground tremors or human activities such as farming and constructions, will highly increase the propensity of landslide occurrences.

On analysing the same slope using a geo-processed digital elevation model map shown in Figure 4.5 below, landslides have been noted to occur in different elevation stratas.

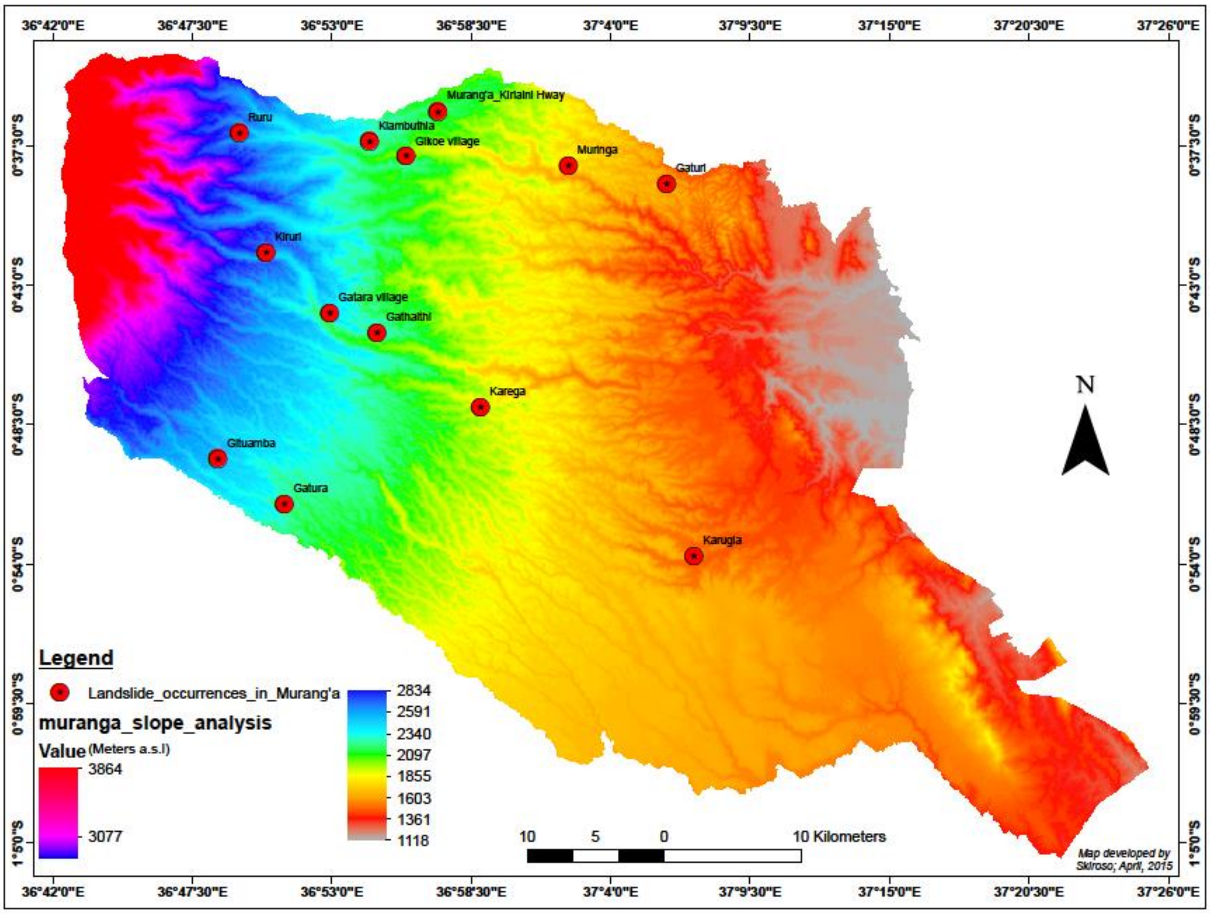

Figure 4.5: An overview of how Murang'a land slopes. Modified from USGS http://earthexplorer.usgs.gov

Murang'a land is observed to be steeply sloping from North Western side marked by colour red to South Eastern side marked by orange colour. The western part is seen to be highly dissected with several ridges down slope. It is along these ridges that rivers are also observed to be flowing through as seen in the drainage map below (figure 4.6) indicating that those areas have valleys. Landslides tend to occur along these ridges on the slopes characterised by green and turquoise blue colour with contours ranging from 1740m to 2300m a.s.l. thus intensifying the analysis done using the cross section and Murang'a slope map above.

b) Drainage system

Rivers in Murang'a County drain their water from the slopes of Aberdare Ranges downstream towards the eastern side of the county into Tana River. The highest areas to the West of Murang'a County have deeply dissected topography and are well drained by several rivers, which include North Mathioya, South Mathioya and Maragua, all flowing eastwards to join the Tana River. The drainage system in the slopes is very intense and characterises a region most prone to landslide occurrence as shown in Figure 4.5 below.

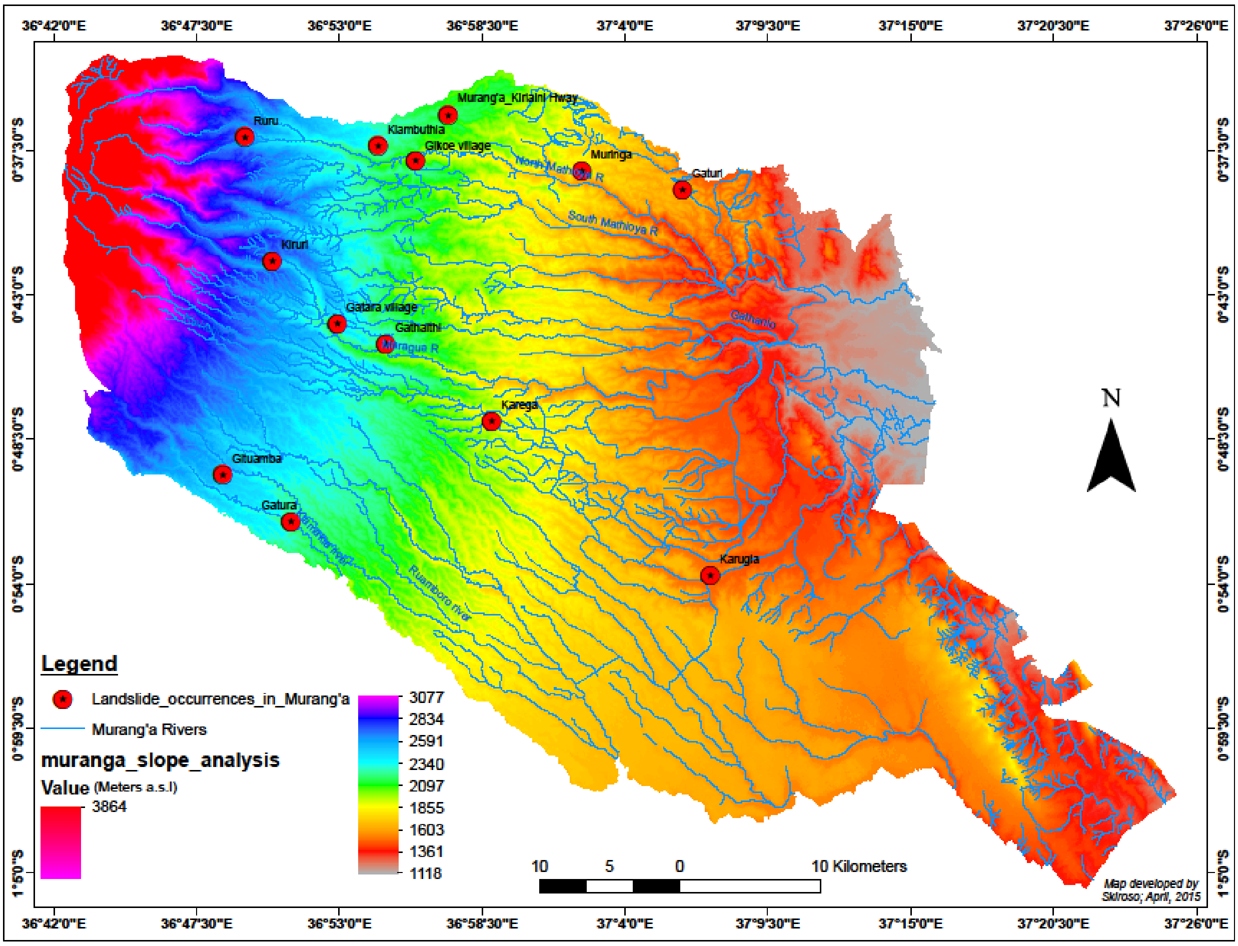

Figure 4.6: Murang'a County drainage system analysis

There is correlativity between landslide occurrences and the influence of rivers on the sloping ground. With increased water volume from heavy downpour, the streams and river channels identified by ridges and troughs on the above figure 4.5 become swollen with water. This water has got high pressure on the steep slopes and thus as the rivers flow downstream, they heavily erode their banks weakening the cohesion of rocks and soils around and along their channels. Water then saturates the rocks and soils in the area making them loose and cohesion less. When coherent material, either bedrock or soil, rests on materials that has started liquefying, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow.

Under these conditions and Murang'a County land being mostly mountainous, debris flow (figure 2.1f) and mudflow (Appendix 7.2; image 1) are the most experienced type of landslides.

c) Road network

Road network constructions, for example, earth roads and rural access roads within Murang'a County are major channels of runoff. These roads have been constructed on the mountainous regions and on steep slopes as evidenced by Figure 4.6 below. This kind of constructions definitely interrupts and disturbs the slope angles and removes vegetation cover e.g. trees which have been holding the rocks and soils together. With heavy and continuous rainfall experienced on these regions, the grounds around and along the roads are exacerbated by slope failure and the loose nature of soil. This results to severe soil erosion, gullies, rock falls and mudslides in the region. Good examples are the landslides that occurred in Thika-Murang'a highway at Karugia on November 1997 which swept away a one-kilometre section of the highway downslope; Murang'a – Kiriaini highway, and Karega landslide along Kaharati-Kangari road which took place on November, the year 2011.

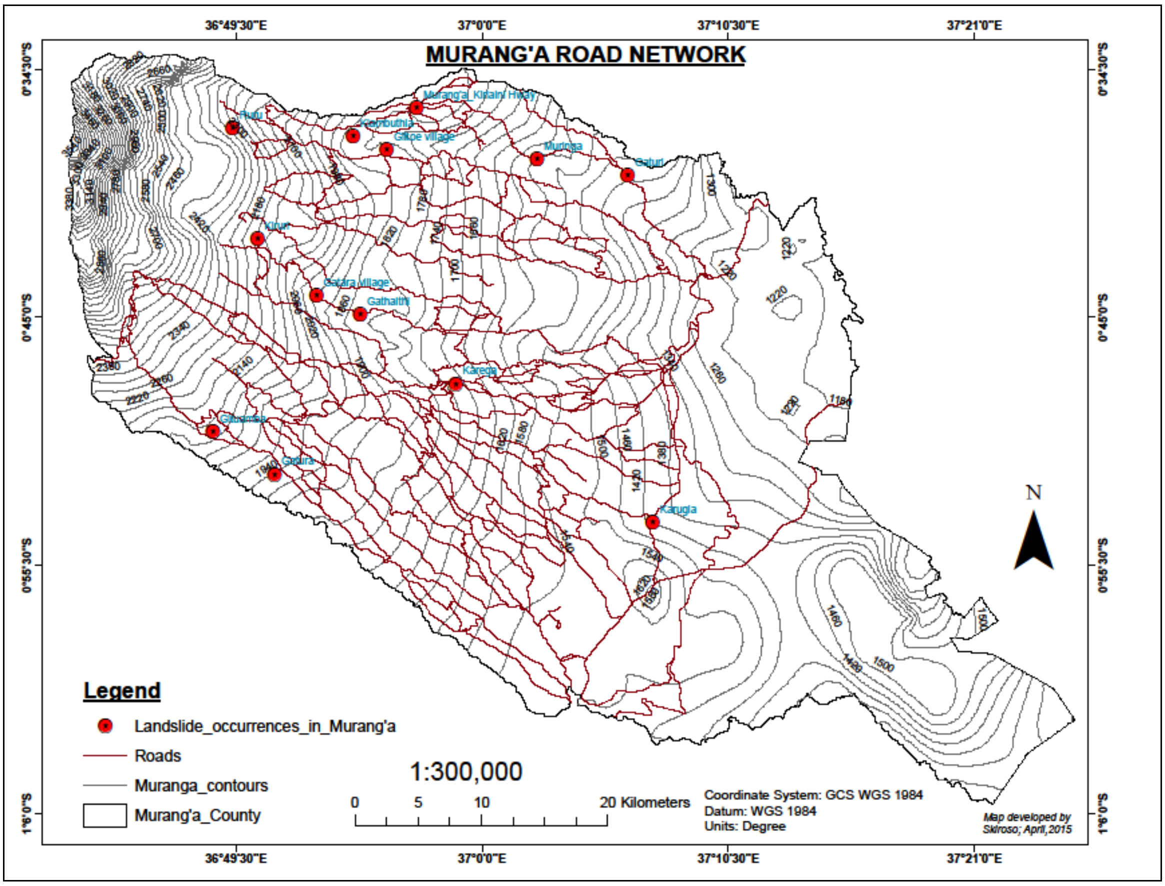

Figure4.7: Murang'a County road network's influence on landslide occurrences

From the given figure above, we can deduce that areas identified with human activities such as construction of roads and communication lines especially in mountainous areas and on steep slopes, are likely to succumb to gravity when compact rocks are disturbed and the soil becomes too wet to hold together. These areas then become potentially vulnerable to landslides.

d) Rainfall Distribution

Murang’a County normally experiences two rainfall seasons i.e. long rains from March to May and short rains from October to November (NEMA, 2006). Basing on the analysis of research data collected (Appendix 7.1b and c; Ngecu and Mathu, 1999; Ngecu et al., 2004), 7 out of 13 recorded landslide events occurred between the months of October and December from the year

1997 up to 2013. The areas affected over the mentioned period include; Gikoe, Mukima, Gathaithi, Kiruri, Karega, Gatara village and Karugia. On the other hand, Landslide event occurrences at Maringa, Gikoe village-Njumbi and at Kiambuthia are recorded to have taken place between the months of April and May, the years 1997, 2009 and 2013 respectively. Additionary, from Figure 4.7 below, most of these landslides are noted to be occurring in regions experiencing high rainfall ranging from 1600mm to 2400mm annually.

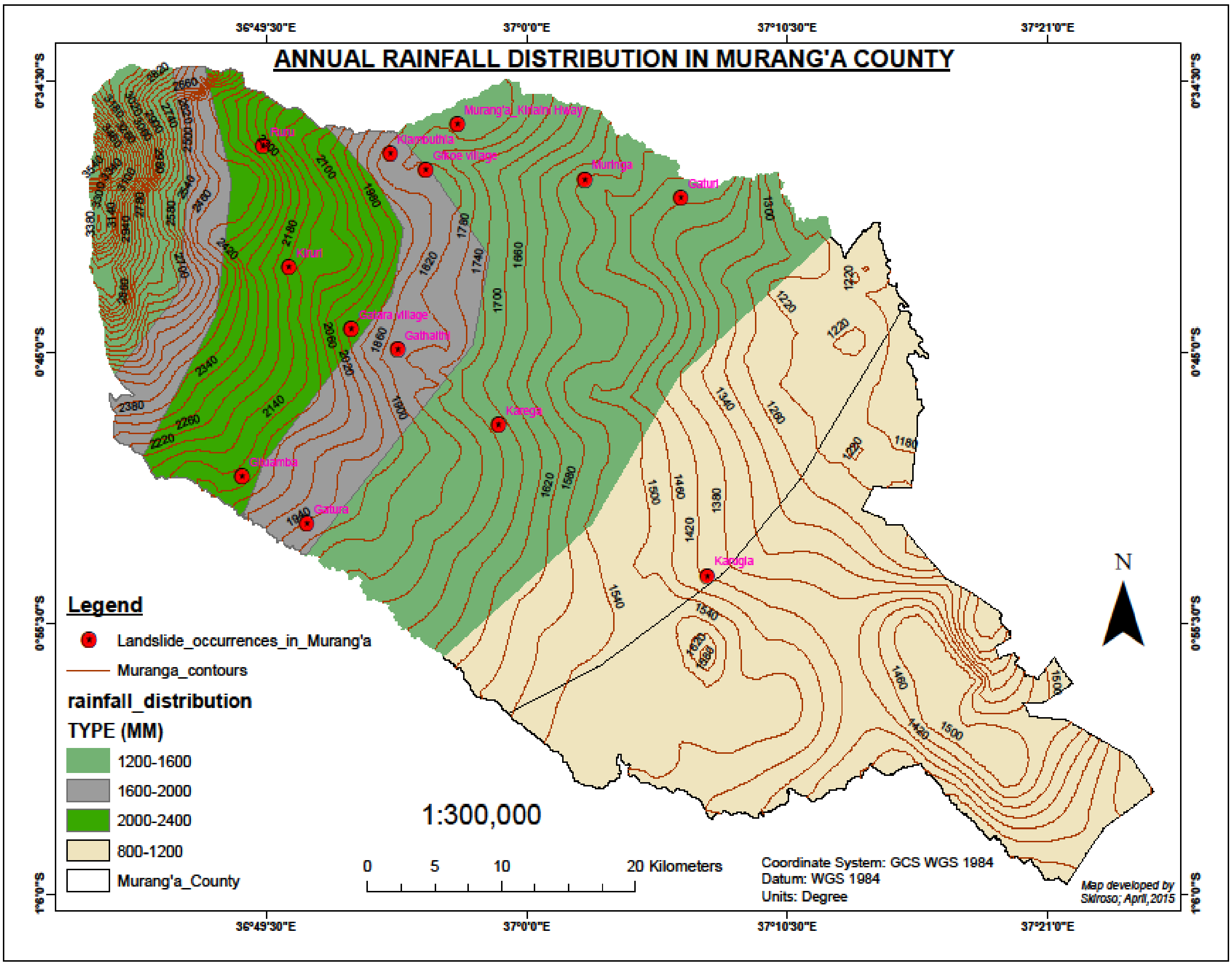

Figure4.8: Annual rainfall distribution and its implication to landslide occurrence in Murang'a County

It is therefore evident that Murang’a County seriously experiences landslides during most rainy seasons.

This high rainfall experienced over the identified regions on the map above greatly impacts the stability of the slopes making the soils and sediments more saturated with water hence losing their coherence. This then results to occurrences of slides which can take different forms e.g. mudflow, debris flows and slump-earthflows (Appendix 7.2; image 2, 4 and 5). Borrowing from Ngecu et al., (2004), constant rainfall over long periods causes mass movement of soil, rocks and debris. The sediment material flow downwards and splashes at the opposite slopes of the ridges thus destroying crops, plantations and houses during the event. The debris then cover the opposite slope and some, dam the river valley. Due to the rising water pressure, the dam collapses and the materials are washed downstream destroying houses, bridges and roads alongside other properties.

e) Lithology

From the observations made in Figure 4.8 below, 9 out of 13 recorded landslide events were experienced in lithological areas with pyroclastic unconsolidated rock, while the other remaining four occurred on areas classified with basaltic lithology.

Areas covered with pyroclastic unconsolidated rock receives high amount of rainfall as earlier noted and at the same time they are characterised with steep slopes and highly dissected terrain. The rock already being unconsolidated, undergo massive weathering with the action of water and warm temperatures.

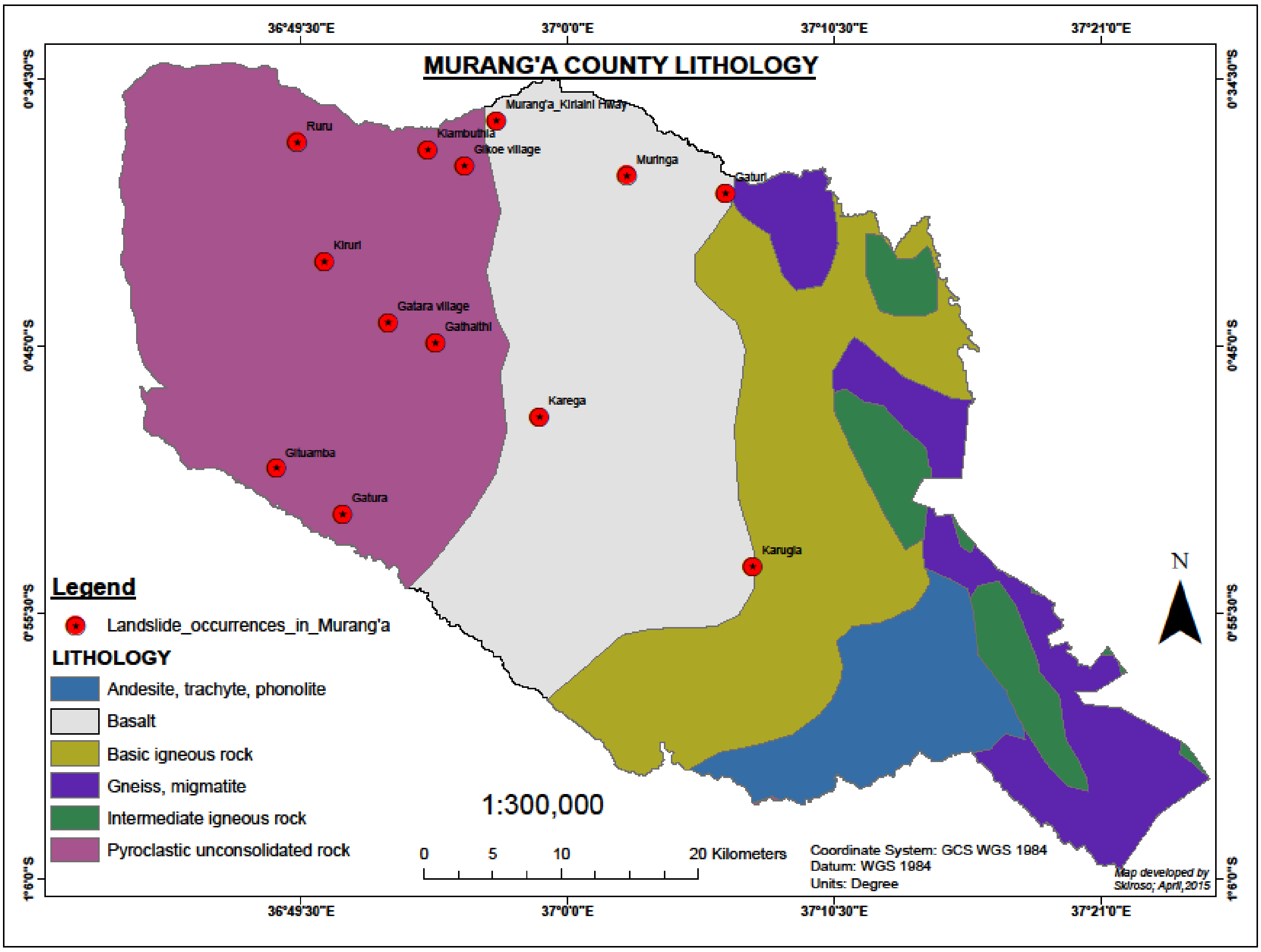

Figure4.9: The lithology of Murang'a County and its implications on landslide occurrence in the area.

Deeply weathered pyroclastic rocks under warm and wet climate create a regolith which is weaker than the underlying better-cemented agglomerate. The landslides thus occur when the weathered pyroclastic regolith on a highly unstable slope become saturated after a heavy rainstorm and then slide over the more stable agglomerate.

Basing on a case study done by Ngecu and Ichang'I (1999) on landslide that occurred at Gatara village on 26th of December 1997, the landslide occurred when highly permeable Miocene pyroclastic rocks resting conformably over impervious tertiary basalt agglomerates and tuffs became saturated after continuous heavy rainfall. At the contact between the two formations, the pyroclastic material became detached and slid down the slope.

From the above analysis and observations we can infer that landslides have a high propensity on pyroclastic unconsolidated rocks which after being saturated by heavy rainfall, they lose their cohesion hence flow over the consolidated basalt rocks at their line of contact.

On the other hand, when basalt rocks are exposed to heavy rainfall constantly, the rocks become oversaturated and easily fracture along lines of weakness. Block slides may thus be experienced on these regions.

Additionally, the occurrence of earthquakes and/or earth tremors in steep landslide-prone areas greatly increases the likelihood that landslides will occur. This may be due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water (Gichaba et al., 2013).

Widespread rock falls may also be caused on basalt grounds by loosening of rocks as a result of ground shaking which is caused by human activities such as blasting and farming.

f) Land use practices in Murang'a County

Most parts of Murang'a County is put under agriculture especially the central area with dense agricultural practices and sparse agricultural practices to the south eastern region of the county as shown on Figure 4.9 below. In areas where agricultural practices are dense, landslide occurrences are shown to have been high especially to the western side of the map on the slopes adjacent to Aberdare forest.

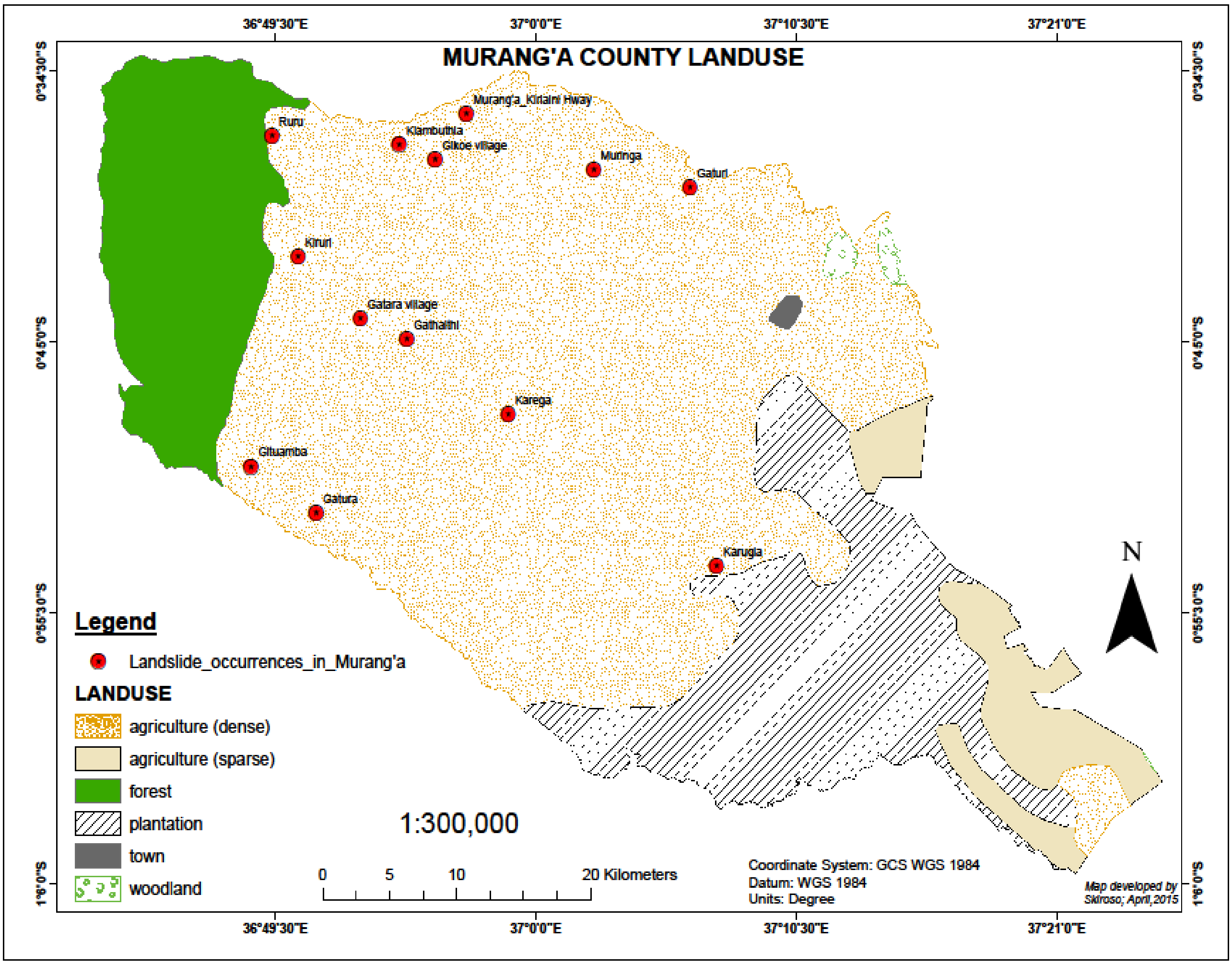

Figure 5.0: Land use practices in Murang'a County with Landslide event occurrences in various parts of the County

From the map above, we can depict that expanded agricultural lands for crops and deforestation on mountain regions are likely to destabilize the already fragile slope hence making the region potentially vulnerable to landslide occurrence.

A driving force behind unsustainable land-use practices is the population growth and density in the areas bordering the mountainous regions. For example, high population makes families in most areas clear existing vegetation and over cultivate their plots to maximize crop yield. It is generally noted that farming practices that do not allow the land to lie fallow from time to time are among the main causes of landslides (Gichaba, et al., 2013).

4.3 Potential Vulnerability map

With the analysed instability factors and observations above, a final potential vulnerability map was developed showing areas susceptible to landslides. Murang'a County was zoned into three major relative susceptibility classes i.e. highly vulnerable region, moderately vulnerable and lowly vulnerable (Figure 4.6).

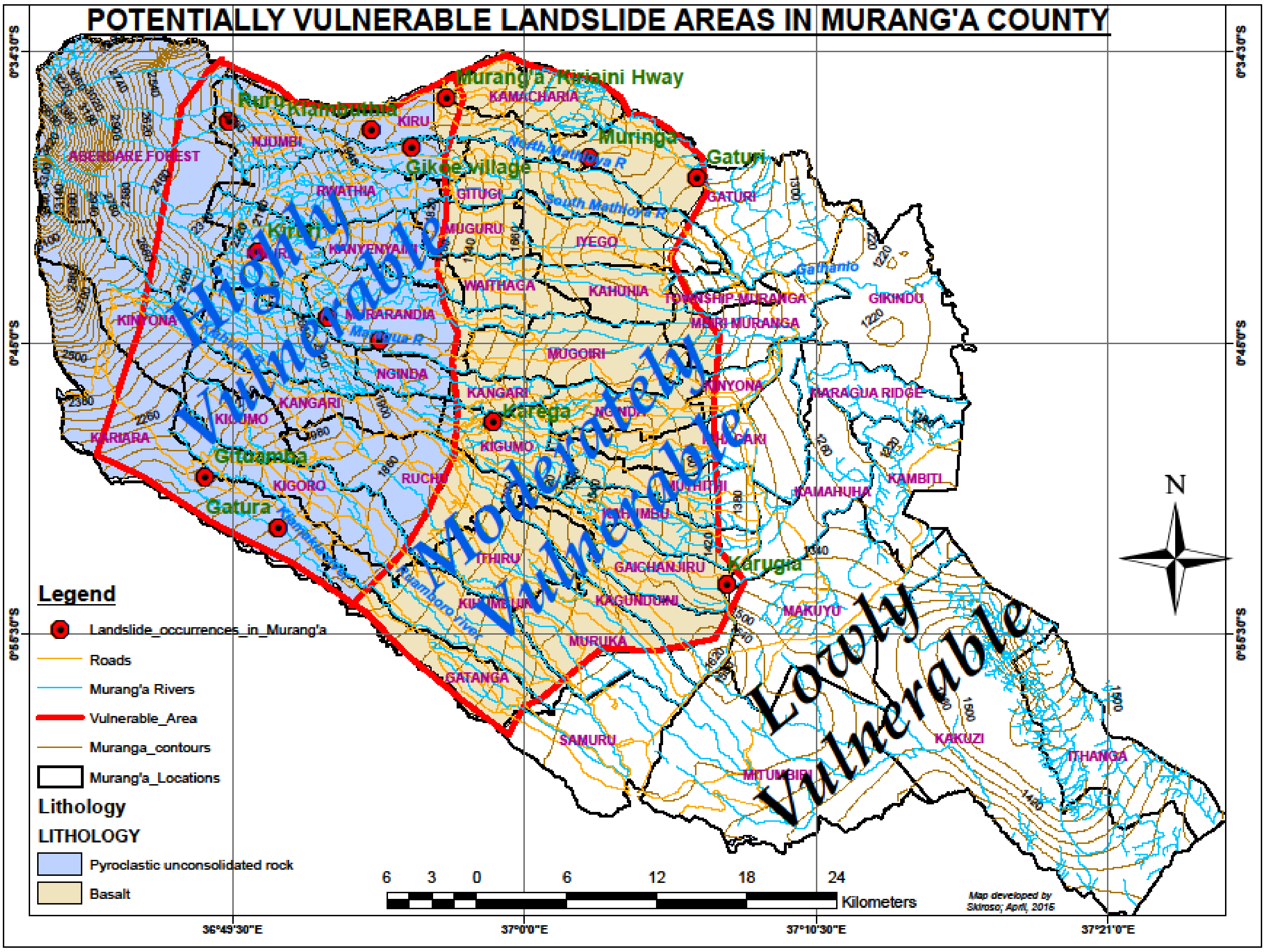

Figure 5.1: Classification of Murang'a County according to its potential landslide vulnerability

From the map, areas such as Ruru, Kiruri, Gatara, Gathaithi, Gituamba, Gatura, Kiambuthia and Gikoe are highly susceptible to landslides because they lie on highly dissected and steep sloping areas receiving high amount of rainfall (above 1600mm annually) and their lithology comprises pyroclastic unconsolidated rocks which easily gets dislodged and flows down slope once oversaturated. We can also observe that in the zone classified as highly vulnerable, there are 9 out of 13 recorded and mapped incidences of landslide occurrences in the entire Murang'a County which is a 69.2% representation.

Areas with basaltic rock type such as Muringa, Gaturi, Karega and Karugia are moderately susceptible to landslides. There are 4 out of 13 landslide event occurrences observed in the mentioned section which also represents a 30.8% of recorded and mapped landslide events in the entire Murang'a County. Basaltic rocks being consolidated, their rate of weathering, disintegration, fracturing and losing coherence is moderately slow as compared to other areas affected by the same instability factors hence few landslide events experienced in that section.

There is a very low likelihood of experiencing landslides in areas receiving annual rainfall of less than 1200mm with slope contour heights below 1400m. These areas are further characterised by gradually sloping terrain to the lowlands of Murang'a County in the East as shown by the contours, land use practices here are represented by sparse agriculture, plantation and few parts with woodland, dense agriculture and Murang'a town to the North East (Figure 4.5 above). This region include administrative Locations namely: Samuru, Mitumbiri, Makuyu, Kakuzi, Ithanga, Kamahuha, Kambiti, Maragua Ridge,Gikindu, Kinyona, Mbiri Murang'a, Township-Murang'a, and eastern parts of Ichagaki and Gaturi. In the then mentioned areas, there has not been observed any landslide event occurrences. The section was thus classified as lowly vulnerable.

4.4 Limitations

Vulnerability maps are limited to determining the spatial likelihood of landslide occurrence on given areas of interest or study. They have the challenge of determining exact dating of events as they occur in real time.

Digitization of topographical sheets for Murang'a area was cumbersome and time consuming especially to the Eastern side of Murang'a County where the topographical sheet were blurred (Appendix 7.7). Additionally, there is a lack of current/revised digital maps which can be directly used in ArcGis software to obtain results needed.

Aerial photographs and Remote sensed imageries for Murang'a County landslide occurrence analyses were inadequate thus some up to date information on the nature of land, environment and climatic changes were difficult to find.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusions

In conclusion, landslides are a major potential hazard affecting Murang'a and many other parts of Kenya and therefore more joined efforts are needed to prevent, prepare, respond and mitigate these hazards. It is of concern that we embrace the use of technology in curbing this problem in a timely and efficient manner so as to save many lost lives and our country's resources as well. The use of Remote Sensing and GIS has thus proved to be very efficient in handling this matter at hand as evidenced by the results obtained in this project report.

The hazard maps generated, analysed and discussed in chapter four, can be put to use in handling landslide related issues with the ultimate aim of disaster risk reduction and management. For instance;

Areas in Murang'a County that receive annual rainfall ranging from 1600mm to 2400mm, having steep slopes of 280m gradient with dense agricultural land use practices, intense drainage system and with road networks especially on high terrain regions and lithology comprising pyroclastic unconsolidated rocks, are potentially vulnerable to landslides. These areas should be carefully monitored especially during the rainy seasons of March to May and October to early December.

Necessary actions and preventive mechanisms should be applied to these potentially vulnerable areas to put it under control. These may include but not limited to; putting up early warning systems, ground monitoring and rock observations for cracks along lines of weaknesses, banning of deforestation and clearing of vegetation on steep slopes, advising farmers against bad agricultural practices such as over cultivation, together with increased sensitization of Murang'a people on various ways of conserving and managing the environment. This will highly help in preparing, preventing and mitigating the impacts should the extreme event occur.

Moreover, relevant disaster management bodies and organisations at the County and National level such as the Kenya Red Cross and National disaster Operation Center (NDOC), can make use of the vulnerability maps for organising relief priorities more effectively and for quick decision making in planning rescue operations and evacuation routes in the event of landslides.

The maps can also be employed in early warning and assessment programmes to evaluate the increasing vulnerability of human society due to widespread environmental and climatic changes in order to emphasize the need for sound integrated environmental management, selection of best activity patterns based on vulnerability zones and to provide early warning of emerging threats for preparedness and response.

5.2 Recommendations

Basing on the research work done, project results and conclusions made above, the following recommendations are worth noting;

First, an up to date landslide-reporting database/ inventory of landslide occurrences and their attributes need to be established at the County level and by relevant authorities and organisations e.g. The Kenya National Disaster Operation Centre and The Kenya Red Cross Society. This should be where all the data collected would be stored and analysed and then the end product packaged for dissemination. It will greatly help in research work, data analysis and in enhancing objectiveness.

Secondly, the use of aerial photographs and remote sensed images are very useful in real time monitoring of environmental and climatic changes. Their frequent capture and usage will aid us develop more reliable, up to date and quality maps with the help of Remote Sensing and GIS tools. Therefore more efforts and resources should be allocated on these fields to enable us get time to time imagery especially those with landslide incidences for necessary action on affected areas or Counties.

Thirdly, it will be of great importance that more research be carried out to develop a comprehensive understanding of landslide processes and triggering mechanism. People should then be advised on proper land use practices especially on potentially vulnerable zones and on what to do to mitigate impacts should the extreme events occur so as to save lives and property.

Finally, it will be recommendable that a comparative landslide factor analyses be carried out with other Counties and potential vulnerability maps be generated to help landslide susceptible Counties in planning, monitoring, assessing and for general preparedness, prevention and mitigation purposes.

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7.0 APPENDICES

APPENDIX 7.1a

Data collected from National Disaster Operation Center (NDOC), Kenya

Disaster events affecting Kenya from the year 2002 to 2013 and their impacts

Event	Deaths	Injured	Missing	Houses Destroyed	Houses Damaged	Victims	Affected	Relocated	Evacuated
DROUGHT	0	0	0	0	0	14970	6812154	0	0
EPIDEMIC	223	464	0	0	0	0	1691	0	0
EXTREME RAINS	0	0	0	0	3	622487	0	0	0
FLASH FLOOD	11	2	0	539	0	0	15000	835	1775
FLOOD	696	93	11	21408	7733	305	925298	22822	2647
FOREST FIRE	0	0	0	0	0	0	0	0	0
LANDSLIDE	97	149	4	254	2	0	2908	1031	0
MUDSLIDE	5	0	0	0	0	0	80	0	0
PLAGUE	0	0	0	0	0	0	0	0	0
STORM	5	0	4	0	0	0	0	0	0
SUBSIDENCE	1	1	0	0	0	0	0	0	0
THUNDERSTORM	25	18	3	1	1	0	3	0	0
WINDSTORM	0	0	0	6	10	0	36	0	0
TOTAL	1063	727	22	22208	7749	637762	7757170	24688	4422

Source: *National Disaster Operation Center (NDOC) (27/22015); DesInventar/Disater Mngt/data/muranga land slide.*

APPENDIX 7.1b

Landslide event occurrences in Kenya from the year 2002 to 2013

Event	County	Division	Date	Location	Deaths	Houses Destroyed	Affected
LANDSLIDE	MURANGA	MARAGUA	04/12/2011	karega area along kaharati-kangari road			
LANDSLIDE	MOMBASA	CHANGAMWE	25/10/2011	Gana Hola village	1		
LANDSLIDE	MERU	ABOTHUGUCHI CENTRAL	11/11/2010	Nkubu, Ngirine village	1	1	
LANDSLIDE	KEIYO-MARAKWET	TOT	30/04/2010	Kitony & Chetundu villages in Endo - Kaben location	12	150	900
LANDSLIDE	HOMABAY	KASIPUL	07/04/2010	Obisa Sub location, West Kamagak			184
LANDSLIDE	MURANGA	MATHIOYA	07/11/2008	Gikoe village	1	1	11
LANDSLIDE	MURANGA	MATHIOYA	07/11/2008	Mukima		1	4
LANDSLIDE	MURANGA	KAHURO	03/11/2009	Gathaithi sublocation of Kahuho division, Nyagathia village	1		
LANDSLIDE	WEST POKOT	CHESEGON	13/11/2008		8		
LANDSLIDE	LAIKIPIA	RUMURUTI	30/08/2010	Marmanet Scheme Water Supply			
LANDSLIDE	NYERI	MATHIRA	02/05/2010	Mathira		7	
LANDSLIDE	NYERI	MUKURWE-INI	05/05/2010		2		100
LANDSLIDE	BUNGOMA	CHEPTAIS	11/05/2010		3		21
LANDSLIDE	KIRINYAGA	NDIA	03/05/2006	Kiangai Village		1	7
LANDSLIDE	KAKAMEGA		11/08/2007	Khuvasali area	8		
LANDSLIDE	KEIYO-MARAKWET	TOT	26/05/2010	Kaben location	14		
LANDSLIDE	WEST POKOT	CHESEGON	30/11/2008	Chepkokogh location	11		
LANDSLIDE	KERICHO	KIPKELION	31/12/2003	Kokwet	4		
LANDSLIDE	KEIYO-MARAKWET	CHEPKORIO	31/12/2003	Kocholwo location	3		
LANDSLIDE	BARINGO	SACHO	31/12/2002	Timboiywo area			
LANDSLIDE	BARINGO	SACHO	31/12/2003	Timboiywo area			
LANDSLIDE	BARINGO	SACHO	31/12/2004	Timboiywo area			
LANDSLIDE	BARINGO	SACHO	31/12/2005	Timboiywo area			
LANDSLIDE	BARINGO	SACHO	31/12/2006	Timboiywo area			
LANDSLIDE	BARINGO	SACHO	31/12/2008	Timboiywo area			
LANDSLIDE	MURANGA	KANGEMA	01/10/2009	Kiruri location			
LANDSLIDE	MERU	IGEMBE CENTRAL	31/12/2002	Maua	4		
LANDSLIDE	MAKUENI	MBOONI	31/11/2010	Kithungo location	1		
LANDSLIDE	TAITA-TAVETA	WUNDANYI	11/12/2007	Mbale location	3		
LANDSLIDE	KEIYO-MARAKWET	TOT	02/05/2010		10		
LANDSLIDE	KIRINYAGA		12/06/2012	Kirinyaga, Wanguru, Togonye Village, Kambori Seasonal Stream	1		
LANDSLIDE	KISII		18/05/2010	Nyamisieka and Chinche villages		37	
LANDSLIDE	MURANGA	MATHIOYA	01/05/2009	Gikoe village - Njumbi	1	5	
LANDSLIDE	KEIYO-MARAKWET	SOY KEIYO	08/01/2013	KOCHOLWO,SIMIT,KAPSOGOM,TORO,TUMO,KIBARAGOI,SEGO	5	51	
LANDSLIDE	MACHAKOS	YATTA	14/04/2013	Mavoloni	3		8
LANDSLIDE	KISII		14/04/2013	Bogichoncho, Nyasasa and Kabiero villages			1000
LANDSLIDE	WEST POKOT		13/05/2013	Chongis, Losa, Tapach, Tokwopogh and Kaptirpai			673
LANDSLIDE	MURANGA		31/04/2013	Kiambuthia Sub-location			

Source: *National Disaster Operation Center (NDOC) (27/22015); DesInventar/Disater Mngt/data/muranga land slide.*

APPENDIX 7.1c

An extract of landslide event occurrences for Murang'a County

Serial	Event	County	Division	Date	Location	Deaths	Houses Destroyed	Affected
3064	LANDSLIDE	MURANGA	MATHIOYA	07/11/2008	Gikoe village	1	1	11
3067	LANDSLIDE	MURANGA	MATHIOYA	07/11/2008	Mukima		1	4
3089	LANDSLIDE	MURANGA	KAHURO	03/11/2009	Gathaithi sublocation of Kahuho division, Nyagathia village	1		
4193	LANDSLIDE	MURANGA	KANGEMA	01/10/2009	Kiruri location			
4480	LANDSLIDE	MURANGA	MATHIOYA	01/05/2009	Gikoe village - Njumbi	1	5	

Source: *National Disaster Operation Center (NDOC) (27/22015); DesInventar/Disater Mngt/data/muranga land slide.*

APPENDIX 7.2

Photographs of landslide areas in Murang'a County

Image 1: landslide which swept away a house in Kahuro village in Murang'a district. The mudslide is said to have occurred after nightlong rains.

Posted on Wed, 04 Nov 2009 00:51:18 -0800 by Kenya Citizen TV; Source: http://topicnow.info/topic/muranga-mud-slide/

Image 2: The havoc El Nino rain caused in Murang'a with heavy rains and landslides; A 13 year-old girl died in the mud as a landslide hit her home in the area, destroying her home on 03/11/2009. Source; http://www.demotix.com/news/el-nino-rain-cause-havoc-kenya#media-172030

Image 3: Landslide in Kandara, Murang'a County

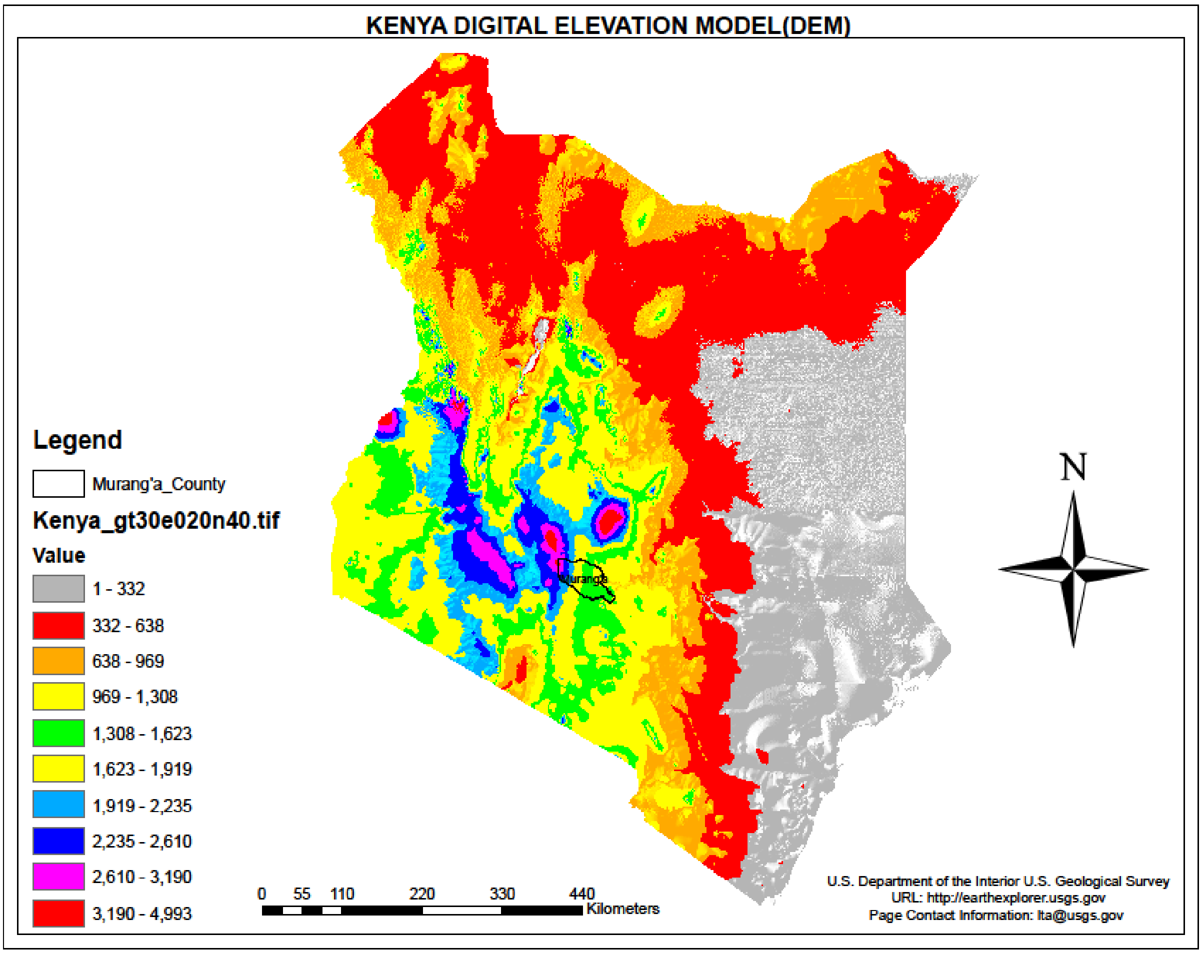
Image 4: a landslide which has swept away a tea farm in Gathaithi location of Murang'a District, barely a month after a woman perished in a similar incident. Posted on Fri, 25 Dec 2009 03:34:47 -0800 by NTV Kenya http://www.ntv.co.ke Source; http:// article.wn.com/view/2011/08/01/

Image 5: The havoc El Nino rain caused in Murang'a with heavy rains and landslides 03/11/2009. Source; http://www.demotix.com/news/el-nino-rain-cause-havoc-kenya#media-172030

Image 6: Landslide in Murang'a, Central province on 3rd November, 2013 Source: http://www.demotix.com/news/el-nino-rain-cause-havoc-kenya#media-172033

APPENDIX 7.3

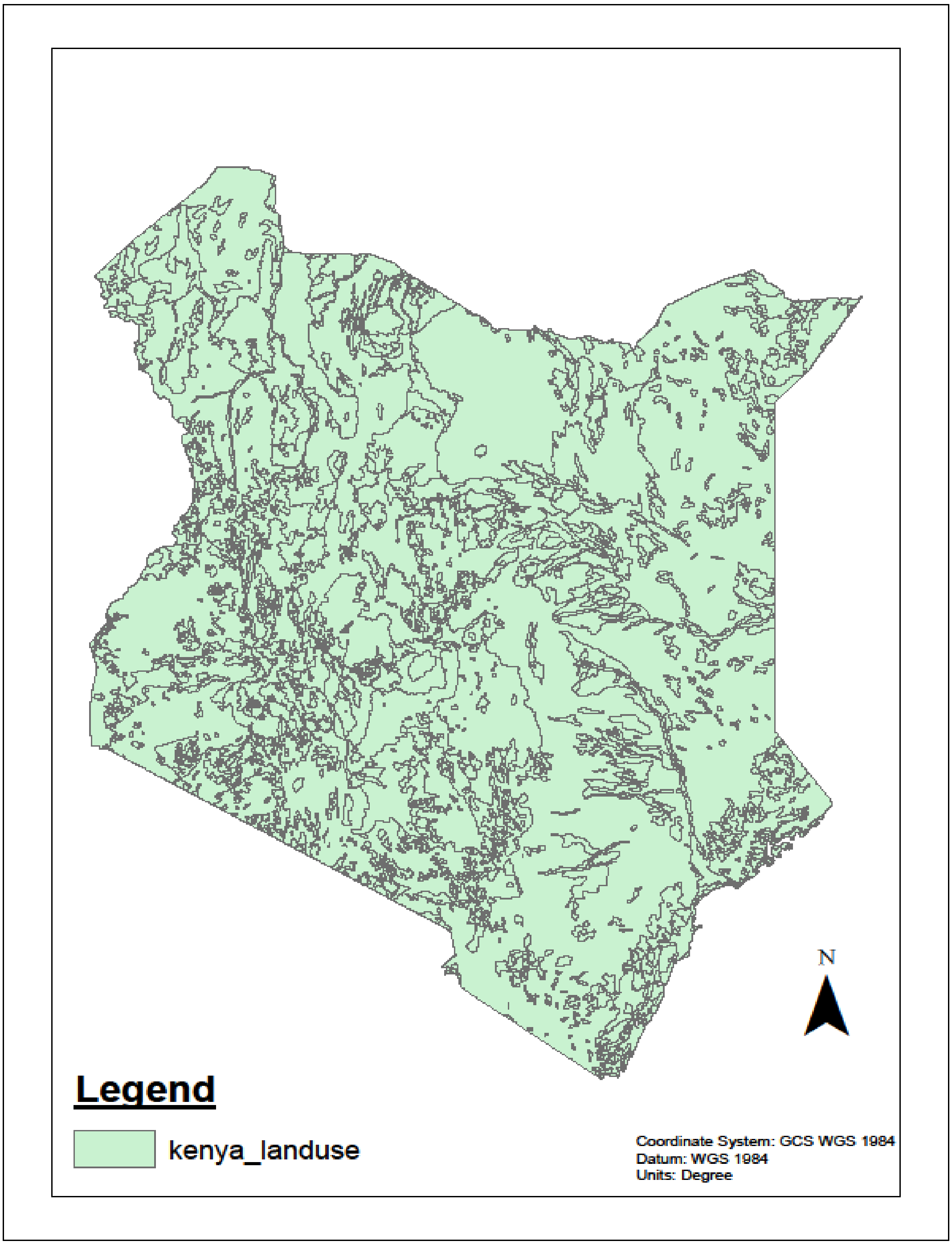
Kenya's Digital Elevation Model (DEM) used in extracting the slope levels as used in Murang'a landslide project.



Source: U.S. Department of the Interior U.S. Geological Surveys; Gt30e020n40.tif Accessed (6/03/15) from http://earthexplorer.usgs.gov

APPENDIX 7.4

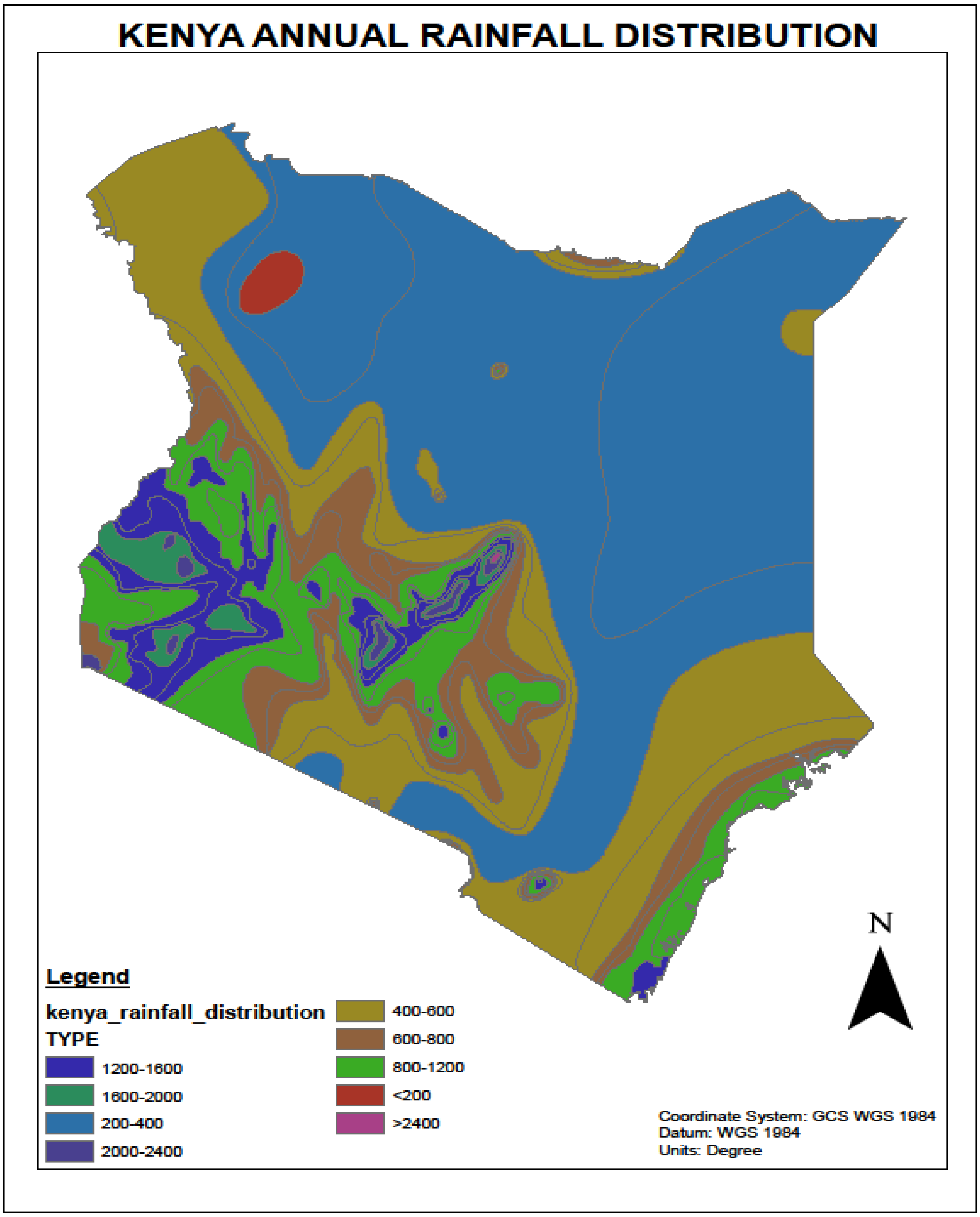
THE KENYA LAND USE MAP USED IN CLASSIFICATION OF MURANG'A COUNTY LAND USE PRACTICES



Source: International Livestock Research Institute (ILRI) –GIS Services. Accessed (18/03/15) from: http://192.156.137.110/gis/search.asp?tbCountry=&tbCoverage=&tbLayer=&tbFeature=&tbTheme=&opCoverage=&opCountry=&opLayer=&opTheme=&opBoolean=&display=Brief&rgone=1&rgtwo=201

APPENDIX 7.5

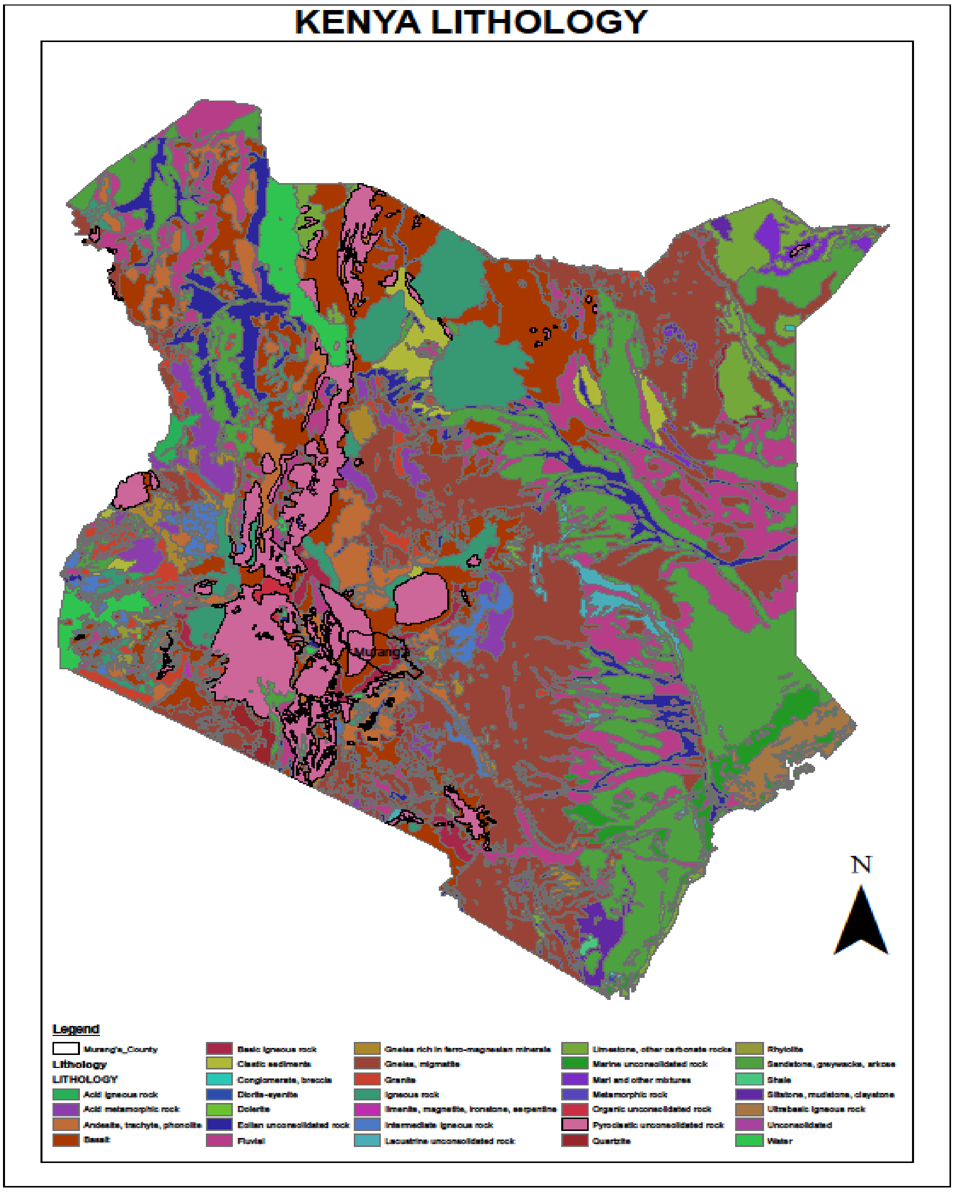
KENYA ANNUAL RAINFALL DISTRIBUTION GEO-PROCESSED TO EXTRACT MURANG'A COUNTY ANNUAL RAINFALL DISTRIBUTION MAP



Source: International Livestock Research Institute (ILRI) –GIS Services. Accessed (18/03/15) from: http://192.156.137.110/gis/search.asp?tbCountry=&tbCoverage=&tbLayer=&tbFeature=&tbTheme=&opCoverage=&opCountry=&opLayer=&opTheme=&opBoolean=&display=Brief&rgone

APPENDIX 7.6

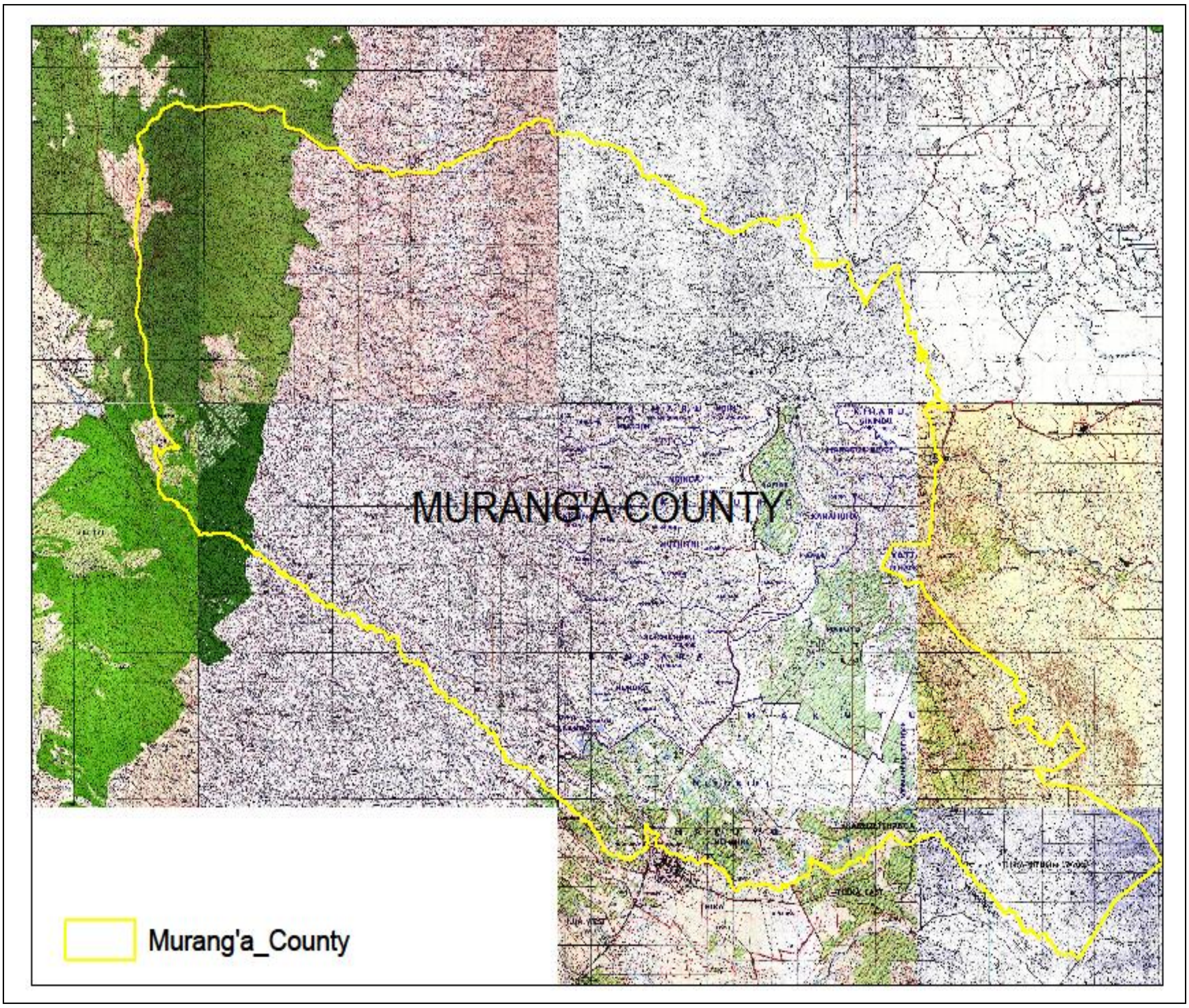
KENYA'S LITHOLOGY GEOPROCESSED TO EXTRACT THE LITHOLOGY OF MURANG'A COUNTY



Source: International Livestock Research Institute (ILRI) –GIS Services. Accessed (18/03/15) from: http://192.156.137.110/gis/search.asp?tbCountry=&tbCoverage=&tbLayer=&tbFeature=&tbTheme=&opCoverage=&opCountry=&opLayer=&opTheme=&opBoolean=&display=Brief&rgone=1&rgtwo=201

APPENDIX 7.7

TOPOGRAPHICAL SHEET MAP USED FOR DIGITIZATION OF LANDSLIDE INSTABILITY VARIABLES ON MURANG'A COUNTY.



Source: International Livestock Research Institute (ILRI) –GIS Services (Compiled at the GIS lab, Department of Geology, University of Nairobi)