INFLUENCE OF LAND USE ACTIVITIES ON GEOMORPHIC PROCESSES IN RUPINGAZI WATERSHED, EMBU COUNTY, KENYA

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A Thesis Submitted to the Graduate School in Fulfilment of the Requirement for the Award of the Degree of Doctor of Philosophy in Geographical Sciences of Chuka University

CHUKA UNIVERSITY

NOVEMBER 2021

DECLARATION AND RECOMMENDATIONS

Declaration

This thesis is my original work and has not been presented for the award of a diploma or conferment of a degree in any institution.

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Recommendations

This thesis has been examined, passed and submitted with our approval as the University supervisors.

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ACKNOWLEDGEMENTS

All good things and rewards come from God. I thank the Almighty God for His blessings. I am grateful to my supervisors, Professor Adiel Magana of Chuka University and Dr. Joseph Muthike of South East Kenya University for their invaluable help, guidance, and counsel that helped immensely in shaping my thoughts and work.

My gratitude also goes to my friends and colleagues in the Faculty of Humanities and Social Sciences, Professor Colomba, Professor Stephen K. Wambugu, Dr. Moses Kathuri, Dr. Paul Kamweru, Job Mulati and Purity Rima of Chuka University who spent their time with me, including the cartographers and the GIS experts. My thanks also go to those who were always there for me, even at their own sacrifice; my brothers Robert Kariuki for his hard work, devotion and being a handy field assistant, and to my brother Eugenio Ireri for taking time to read my work.

My joyful gratitude goes to the members of my family for continuous support and concern about my work and its progress at every stage of the way. My heart-felt gratitude goes to my spirited students who gave me the good reason to go on. My thanks also go to all those in the communities within the Rupingazi watershed who very resourceful respondents. Am grateful to them for allowing me to set and access sampling stations on their farms.

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ABSTRACT

Landforms are part of every part of the earth. The study aimed at finding ways by which land use activities contribute substances which effectively influence changes in landform along the Rupingazi watershed in Embu County, Kenya. The main objectives of this study were to assess the influence of agriculture, urban settlements, mining and abstractive activities on landform dynamism in the context of geomorphic parameters of denudation, and to determine their impacts. This was done by considering geomorphic processes such as weathering, erosion, deposition and mass movement. The study was guided by the theoretical framework of the nine-unit slope model suggested by Doornkamp and King; that an initial landform in a climatic and geological region evolves through geomorphic dynamism on varying slope forms. From this notion, the conceptual framework was developed on the assumption that the same denudational processes are operational on Rupingazi watershed and form the relevant variables: Crop farming, livestock rearing, urban settlements, abstractive and mining activities were the independent variables; climate and rocks as the intervening while the geomorphic processes were the dependent variables. Applied Research design, both quantitative and descriptive was adopted for the study. Data was collected from 21 sampling stations (SS) fixed through stratified systematic point sampling. Observations and field measurements on various land uses were used to obtain data. Satellite data and images were also used to compare with field observations. In addition, water and soil samples were collected for further analysis to corroborate field observations. The soil samples were tested for soil pH, porosity, organic contents and main chemical elements. Farming practices influenced geomorphic processes in that there was a very strong positive correlation (coefficient of 0.91) between the angle of farm slope and the distance of soil moved downslope when tilling. On average soils moved the furthest (123 cm) when tilling was done on farms with slope of 26^0 while tilling on farms with a slope of 6^0 caused soil to move by about 70 cm. Further, use of hand hoe moved about 800 kgs of soils materials in one season per acre. An African mole rat (mainly found where there was farming of napier grass and sweet potatoes) loosened about three kilograms of soil materials. On less steep paths (8^0), 1.8 m^3 of soil was moved while 9.36 m^3 of soil materials on slopes of about 22^0 was moved as result of livestock. All urban centers are located less than three kilometers from the Rupingazi river. Organic and solid wastes associated with urban settlements were found in sampled waters of the Rupingazi river. An increase of 50% of PO_4 and NO_3 was observed in sampled waters. The Mg was no increases by 92.3%. Surface run off from these settlements accelerated the impact of erosion and weathering. More than three quarters (76.7%) of the abstractive activities are in the lower reach of the River Rupingazi between SS 16 and 21. Mining and abstractive activities breakdown rocks, thereby accelerating geomorphic processes. Regolith development on any slope plays an important role in the slope evolution because it affects such bedrock characteristics as the strata dip (angle and direction) rock joints, and the effect on the weathering rates and amounts. The study recommends concerted effort and environmental education to control human activities along the watershed to ensure the landform equilibrium in the Rupingazi watershed. Further studies can be carried out to examine and determine the influence ecological zones on the geomorphic processes.

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ABBREVIATIONS

ACZ	-	Agro-climatic zone
AEZ	-	Agro-Ecological Zone
CIDP	-	County Integrated Development Plan
EPA	-	Environmental Protection Agency
GEMS	-	Global Environmental Monitoring Systems
GIS	-	Geographic Information System
NEMA	-	National Environment Management Authority
SPM	-	Suspended Particulate Matter
SS	-	Sampling Station
UNEP	-	United Nations Environment Programme

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CHAPTER ONE

INTRODUCTION

1.1 Background Information to the Study

The earth's crust comprises of numerous varieties of rocks, which are continuously changed through endogenic and exogenic geomorphic processes. Geomorphic processes are events that alter the earth's physical land surface features. The landforms on the earth including rivers, beaches, sand dunes, hills, plains, among others (Hugget, 2011). These landforms are the easily visible features and occur everywhere on earth. However, according to Hugget (2011), landforms vary in size and their lifespan. Morphologically, landforms can be considered from three facets: firstly, configuration (size and form as described by geometry variables), secondly constitution (physical and chemical as seen in the material property variables) and thirdly, mass flow (Strahler, 2013).

The evolution of a landform is the continuous oscillation of altering processes, which take very long geologic times and operate upon the landform for as long as the active altering agents, mainly denudational, have the potential energy to propel the process. Consequently, a new pace and process replaces the earlier ones, and therefore impose new rhythms in the changing processes. These new phases therefore, become the stages in landform development. Landform evolution (the continuous development processes), results from changes in slopes and rock cycles (Plummer *et al*., 2001). In all cases, the morphology of landform changes is through the alterations of slopes angles. The changes occur through weathering, erosion and deposition of transported rock debris so that the new materials form a new landform surface (Yates *et al.,* 2014). These changes are collectively known as landform evolution dynamisms and are processes, which cause progressive changes in topography. As rightly observed in the basic dictum by geomorphologists (the present is the key to the past), the old landforms can be studied as being guided by the present processes (Hugget, 2011).

Landforms on the earth's surface have been changed naturally through various geomorphic processes including the various and varied active agents of weathering, erosion, deposition and earth movements (Duff, 2012). Additionally, these geomorphic processes can be affected by anthropogenic activities through their

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influence on the rates of weathering and erosion. This is why Gregory (2006) observed that both natural causes of landform evolution and human modification of landforms and drainage channels have significant impact on the existing landforms. Therefore, human activities are significant in geomorphology studies as envisaged in the study.

Land use is the surface utilization of all developed and vacant land on a specific point at the given time and space. The effects of land use by man on the environment are some of the pressing issues to policy makers, researchers and land managers globally (Rutherford, 2004). Since 18th century, anthropogenic land use has increased by about 48% and thus greatly reduced the natural ecosystems (Lawrence & Chase, 2010). Land use for agriculture accounts for half of the habitable land globally, while forests occupy 37%, 11% is shrub land and grasslands, 1% freshwater and 1% is built environment (Ritchie & Roser, 2013). These different land use systems have different impacts on the earth's geomorphic processes. Nepal, for example, is very susceptible to soil erosion mainly accelerated by slope failure, landslides, and debris flows (Joshi *et al.*, 1998).

Studies in United States' Rocky Mountains, South Africa, Britain, and Australia, Prosser (2012) have significant examples over a long period of investigation into the evolution of landforms. In those studies, rock types are the significant factor in landform development. Equally important are the climates prevalent upon those rocks and the environments upon those places that help to regulate, modify and set pace for weathering and erosional processes according to the geological set up. The role of vegetation in providing humic acids and preserving moisture for geomorphic activities results in different landform evolution (Lane, 2017).

Forming part of the geomorphology are slopes. Slopes are salient landforms, which vary in steepness; from those that have very high gradient (more than 45^0) to those that are almost level (0^0-2^0). Weathered materials (soil and saprolite) cover most slopes but some land surfaces are covered by the parent rock (Gumisiriza, 2014). Rupingazi watershed in Embu County Kenya has a variety of landforms. The materials covering these landforms are subjected to weathering and denudation processes. Therefore, these geomorphic processes would determine steepness of

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slopes. Gumisiriza (2014) argues that materials on a relatively level ground require some external energy to move while regolith on a sloping surface or land moves by gravity. It is this gravity, which subjects regolith to shear stress. However, to attain slope stability, shear resistance counters the shear stress on the slope. Therefore, should the shear stress overcome shear resistance, then slope failure would occur in form of materials movement at different rates.

Land use activities in Rupingazi watershed include agriculture, extraction of natural resources, urban settlements and roads. Agricultural land use accounts for 83% of the Rupingazi watershed land use, while urban settlements occupy a small proportion of the land but contribute the bulk of the substances, which affect the geomorphic processes (County Government of Embu, 2014). All those activities cause soil and rock alterations, which may lead to landform changes as complementing the natural geomorphic processes (Waters *et al.*, 2014). This is because eroded materials, both solid and in solution, chemical inputs from farms and settlements can influence geomorphic processes by chemical reactions. Thus, the study sought to establish the influence of these land use practices on the characteristic topography and geology of the Rupingazi watershed and ultimately the developed soils and drainage systems.

1.2 Statement of the Problem

Rupingazi watershed has experienced geomorphic processes stimulated by all the interactions on land both from natural and anthropogenic activities. In geologic time, the Rupingazi watershed is not only critical to the livelihoods of residents but also as a pointer to the future land morphometry of Embu County. The watershed has been subjected to tectonic activities and earth movements. These activities may have led to numerous geomorphic phases of denudation and landform conformities and disconformities, which have resulted in adjustments in the initial primary landforms, and later on by the secondary landforms resulting from erosion and deposition. Various land uses including farming activities, urban settlements, quarrying activities and other development activities have been intensified in the Rupingazi watershed.

Studies carried out on Rupingazi watershed have largely focused on the influence of farming activities on the water quality and socio-economic impacts. There is no available literature that discusses the influence of the various land uses on geomorphic

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processes on the watershed. To develop appropriate intervention measures and policies related to sustainable land use in the watershed, the contribution of the human directed activities on landforms on the watershed needs to be evaluated. This need motivated the study.

1.3 Broad Objective

The study assessed the influence farming practices, human settlement and infrastructure to geomorphic impacts on the basis of three drainage and geomorphic sections of the Rupingazi watershed, Kenya.

1.4 Specific Objectives

The study endeavoured to achieve the following objectives:

i. To assess the influence of farming practices on geomorphic processes in Rupingazi watershed, Embu County Kenya.
ii. To establish the influence of urban settlements on the geomorphic processes in Rupingazi watershed, Embu County Kenya.
iii. To establish the influence of quarrying and abstractive activities on geomorphic processes in Rupingazi watershed, Embu County Kenya.

1.5 Research Questions

Based on the above objectives, the following research questions were examined:

i. What is the influence of farming practices on geomorphic processes in Rupingazi watershed, Embu County Kenya?
ii. What is the influence of urban settlements on geomorphic processes in Rupingazi watershed, Embu County Kenya?
iii. What is the influence of quarrying and abstractive activities on geomorphic processes in Rupingazi watershed, Embu County Kenya?

1.6 Justification of the Study

Studies carried out relating to drainage basins on the changing nature of watershed (Getis, 2005; Goudie, 2000; Miller *et al.,* 2010; Prosser, 2012; Yang *et al.,* 2016) indicate the significance of inputs, in form of materials and human activities as important tools in changing the morphometry of the slopes, valleys and channels. There are studies on the direct human input in transforming the river landscape and on

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human role in changing the river channel through utility-need modifications (Gregory, 2006; Kang *et al.*, 2010; Rasmussen, 2015; Saigo, 2007). Any new processes introduced onto the geo-environmental sites, topography, or any geomorphological characteristics, impose direct influence on the rates and types of weathering. This ultimately influences drainage, and land use patterns, resulting in influencing changes on different landforms (Doherty & McDonalty 1999; Donohue *et al.,* 2006).

In Rupingazi River basin, studies have been carried out on water quality and land use (Olayide & Koome, 2018; Shohei, 1987; TNC, 2015), but with no specific and significant study for this watershed on the impact of land use on geomorphic processes. There are also no available specific studies on chemicals input in relation to land use and geomorphic processes. There is also no direct enquiry on what would result from water and effluent retention by soil vital to the soil development and landform behaviour. This study has tried to establish that land use, and not exclusively the natural cycle of denudation, change the rates of landform development. This examination will therefore shift the conceptual emphasis of landform development rates from solely climatic influence to include the significance of land use on substance contribution that have an influence on geomorphology.

The peculiarity and unique characteristics of landforms and their diversity require investigation and quantification. Their influential link to landform dynamism justifies the choice of this study location. Since landforms are made of slopes of varying gradients, it is important to evaluate these slopes through angle consideration, lengths and equilibrium. This will help to find their changes and project their dynamism in order to enable assessment of the changes caused by different land uses and ultimately how the land uses induce those dynamisms (Price *et al*., 2011).

Agriculture is the main land use in the Rupingazi catchment (Njeru, 2020). Therefore, this study enhances the knowledge base on the inputs from agricultural land use and other land uses as they influence landforms. The study findings are important to extension workers and planners involved in the conservation of riparian zones of the Rupingazi watershed. Ultimately, this will enhance conservation and sustainable land use without negatively influencing the rocks and soils. Engineering activities such as hydroelectric power (HEP) project will benefit from the assessment of the current

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corrosive and erosive land use activities. This is because various land uses contribute differently to siltation of dams and corrosion of the plants' equipment thereby affecting their maintenance and their life span (CRED, 2019). Policy makers, planners and environmentalists will find these study findings helpful in enhancing sustainable development by avoiding land use activities, which induce degradation of installations and land. The study will enable planners to make changes which can help to regulate, and in selecting inputs in land use activities and maximise on available resource-utilization. It will enhance a balance between economic gain and an equitable environment quality and avoid negative impacts from land use such as erosion and mass failure (Langat *et al.,* 2019).

1.7 Scope of the Study

The study was conducted in Rupingazi river catchment in Embu County. The 800 km^2 watershed is about 65 km long and traverses through parts of Embu North, Embu West and Mbeere North Sub Counties. The study focused on land use activities such as crop farming, livestock farming, human settlements, rural and urban, economic, infrastructure activities. These activities were examined and their influence on denudation processes, slope stability and equilibrium the watershed in Embu County, Kenya. These land use activities were evaluated as per the four agro-ecological zones found within the watershed (Jaetzold *et al.,* 2006). The agro-ecological zones were as follows: The Lower Highland Zone 1, LHI an area yielding high quality tea; the Upper Midland Zone 1, UM1 characterized by coffee and tea production; the Upper Midland Zone 2, UM2 characterized by coffee and fruit growing and the Upper Midland Zone 3, UM3 which is a marginal coffee zone and more suitable for maize and sunflower.

The watershed was divided into 21 systematically located data collection stations (SS), distributed over the watershed, and arranged from the river channel to the top of the spurs with 7 significant points, (1, 4, 7, 10, 13, 16, 19) located at the channel. The investigation on the present conditions of the landforms spans from the year 2014 to 2020.

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1.8 Limitations of the Study

Limitations are factors or restrictions to the progressive achievements of the objectives of this study. Progressive assessment of the spatial changes in the topographical evolution parameters may not be captured in the study timeline and requires continuous and future monitoring and research. The samples tested in the field and laboratories only pertain to the periods of sampling, and are limited in ascertaining the past or precisely projecting the future trends. The data collection method, however suitable, might have spatial limitations in that not every representative point may be included. Due to variations in the stimuli to geomorphic parameters, the results and findings may not be replicated in all places in the watershed.

1.9 Assumptions of the Study

The study assumes the following:

i. Rupingazi River watershed undergoes the natural process of weathering, erosion and deposition, and that land use activities modify the rate, pace and the extent of the geomorphic processes.
ii. Rupingazi River watershed was affected by natural and human activities in both rural and urban areas, all of which are related to each other because they are in the same topographical setups.
iii. The farming practices within the farming belt are similar for different farmers.

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1.10 Operational Definitions of Terms

The following are the operational definitions of terms used in this study in order to accurately identify the variables and asses them:

Anthropogenic: Relating or resulting from human influence upon the natural world; land use by humans affecting the landforms and how they evolve measurable parameters in form of stimulation of geomorphic changes.

Colluvial Deposits: Sediments eroded from the hill slopes and valley side which accumulates at the base of the slope but not delivered directly to the channel and form the lowest element of slope where some sampling stations (SS) are located and enable assessment of the contents of deposited substances.

Denudation: Result of the processes of weathering, erosion and deposition that add or sculpture the surface of a landform and alter the surface that may result from land use activities and assessed through erosion indicators such as gullies, rills, tree-root exposure and turf rolls.

Drainage: The movement of water from one place to another: the controlled movement of rain water or other waters through planned paths in order to avoid erosion or destruction of landforms or artificial installation both in urban and rural areas.

Evolution: Induced processes by which new or different developments result or cause gradual change in the angles of slope of any landform and assessed through measurement of slope repose changes and through slope reconstruction.

Fluvial: The physical interaction of flowing water and the natural channels of rivers and streams where such process changes the river channel morphometry resulting from added substances or activities from land use.

Geomorphic: Relating to the surface of the earth or relevant to the geomorphology of an area, or as part of geology that examines the formation of and the features of the earth's surface; the application of those processes.

Geomorphic Processes: Processes which alter the surface of the earth which are measurable through movement of materials such as sediment deposits or removal of materials by erosion and mass failure.

Groundwater: Where surface runoff from various sources which add water of different properties to the ground water storage through infiltration and percolation after precipitation, which can be analysed to indicate added

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substance, where added water or chemicals may stimulate weathering or movement.

Interception: Precipitation water held by vegetation before getting to the ground which accumulates to cause changes in the rocks, soils and on landforms, where spring and tributary water is part of other water sources in the watershed and compared to the river or rain water.

Landform: A conspicuous topographic feature on the surface of the earth with defining height, spread and slopes; the major part of assessment in this study.

Land Use Activities: Pertaining to the occupation of the surface such as areas occupied by forests, urban settlement, agriculture or any other use that contributes to processes of denudation change.

Plume: The spreading or fanning out of a flowing substance so that it disperses on the surface and fans out and percolates to depths as it flows and progressively occupies wider spaces, useful in the assessment of agent distribution.

Pluvial: Activities related to precipitation such as rain-wash, sheet-wash and rain-drop impact which effect change to the land slope angles; where analysis of such materials' movement acts as indicators of processes over the slopes.

Slope: The flanks of a valley or landform which is the main surface of an eroding land. The zone of soil and rock loosening by weathering processes where transportation of material by gravity down the gradient to the river channel or plain. It is measurable as gradient in degrees and as a component of a landform.

Watershed: The region of a drainage basin draining into a trunk river: a sub-basin so that the valleys and the interfluves upon which this study assesses the land use inputs.

Weathering: The production of rock debris through agents of the weather and forms the major assessment point for changes on the landform through the land use inputs.

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CHAPTER TWO
LITERATURE REVIEW

2.1 Slope Evolution

Every type of landform is part of a slope of some magnitude measurable as gradient and length and therefore makes up topography of varying gradient and amplitude. Erosion exposes a new erosion surface to the agents of denudation. The river basin morphometry is a result of the sculpturing by the fluvial processes. These processes result in the development of the two river profiles: cross and long profiles (Acreman, 2014). They are relevant in the continuous evolution of the basin; the cross-profile or short profile from the top of the spur through the channel to the crest on the other spur, and the long-profile which is the cross-section of the channel bottom or bed from source to mouth, also called longitudinal profile or thalweg (Twidale, 1998). The said parameters form the basis for landform evolution. Rivers are the dominant agent for shaping the landforms whether in hot or cold geographical places, and through their valley development and evolution, landforms are reshaped by rivers. Rivers are characteristically perennial, seasonal, intermittent or episodic. Of geomorphological significance is that in all cases, rivers sculpture the landscape and create new landforms through erosion, transportation and deposition (Twidale, 2005).

The concept of landform evolution is an expression of progressive changes in topography from an initial morphology as an essential part of process geomorphology. Variation in the discharge of the river changes the nature of the load transportation system from saltation to traction load and therefore affects the channel corrasion and deposition dynamism. In turn, this alters, at the time, the channel roughness, and on land the surface configuration (Allison, 2002). These measurable parameters are the interplay between the water flow in a channel or on land and the roughness of the surface, which cause the alteration of processes of the stream flow as turbulent flow. These ultimately initiate the generation of the eddy currents, which directly enhance hydraulic lift to energize the load transfer. A similar process causes ripple deposits on land and reduces the land surface roughness, altering the generated water energy and affecting the fluvial and colluvial processes.

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Most of the land use activities affect the land surface configuration. Such processes as river bluff slumping can offset the balance and the stability of the whole slope and the slope angle-of-stand or repose, causing mass failure as observed by (Doherty, 1999). In areas of clay soils, infiltrating water often develops underground or sub-surface tunnels in the process of through flow and by this event induces mudflow and sliding on steep slopes (Zhang, 2012).

The concept of slope evolution is rooted in the Davisian cycle of erosion, Penck and King as pointed out in (Duff, 2012), with chronological connotation, yet when considered seriously the erosion process is not cyclic in that it does not repeat or re-start at a point as does the hydrological cycle as argued out clearly by (Sparks, 1985). The interruptions, due to changes in the climatic conditions, may not strictly be a starting point for a new cycle but is a change in the rates of the processes. Climatic changes lead to interruptions and modification of the land-forming dynamics and a start of a new phase of slope surface evolution.

The Davisian model lays the foundation for the more analytical, statistical and numerical approach, and therefore overshadows the chronological theory of youthful, mature and old stages in rivers and landform evolution. Due to the approach and methodology, the cycle concept of Davis has degenerated into a dogma and paradigm for general denudational theories and processes (Nicholas *et al.,* 2019). James Hutton had postulated this idea under the concept of Uniformitarianism. In support and regard to the Davisian concept, the temporal aspect in the evolution of the landforms is paramount in order for the rocks to be effectively altered. The interaction between rocks and climate in geological time is an important factor in landform evolution. Therefore, changes in their rates result from endogenic and exogenic activities, which include land uses. This formed the basis of the study. Such a notion points out to the more rapid landform-changing processes of mass failure, mass wasting and mass movements (Lane, 2017). The term mass movement strictly involves movement by material from the slopes through gravity only, but this process also includes movement of the materials where there is water and clay, as envisioned in the study.

Mass movements vary according to the condition of the slopes, rocks and climate, and are classified as flows, slips, and slides and *en bloc* fall and can take different time

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scale so that some are rapid while others such as soil creep are very slow. Studies have been carried out on mass movement triggered by air trapped within and beneath weathered material in Australia and the effects of tunnelling by burrowing animals (Twidale 1998; 2015). Farming being a major land use in the study area, the study sought to examine the influence of farming on the geomorphic processes. Expansion and contraction of clay soils in particular, causes heaving which triggers micro slippage and creep in form of puffs or turf rolls and depressions called *gilgai* (Montgomery, 2019). Since Rupingazi watershed has deeply weathered volcanic rocks with clay at the base of the weathering mantle and with adequate precipitation, the study sought to establish the distribution of mass movements in the whole catchment area.

2.2 Geomorphic Processes and Landforms

Worldwide, the rocks are central in studies on landform changes. Slopes and amplitude are important features of landforms. Jones (2012) points out that rock utility is the basis upon which human activities alter the nature of the natural environments. The various land uses alter the nature of the drainage basin morphometry by inducing weathering and erosion to the resultant slope changes and denudation. These are driven by overland flows of water and transportation of materials. This is why the urban and rural areas require planning for all the infrastructures such as, roads, residential spaces and agricultural land use in order to avoid undesirable events caused by landform-changing dynamism (Yang *et al.,* 2016).

The climatic anomaly reflects on the vegetation characteristics affects land use and the contribution to the geomorphic dynamism in weathering rates and types. This is comparable to the present landform studies of the basin vis-à-vis similar landforms in other parts of the world. Similar studies outside study area point out the related works and indicate the knowledge gaps that exist that this study has endeavoured to fill in regarding influence of land use on denudation processes in Rupingazi watershed. Planning is the only way to ensure that drainage, roads and sewerage problems of the urban environments do not alter the nature of the landform-changing processes at rates and in ways that alter them negatively or affect natural and agricultural outputs. Chemicals get into the environment through many ways and from many sources with land use activities contributing the bulk of it from both urban and rural areas. This

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specific problem was not covered in earlier studies carried out (Lane, 2017; Lind, 2016; Van Leeuwen, 2017). This gap fuelled this study.

Such case studies provide significant insight into the complex relationship between the various characteristics of rocks, weathering, erosion, mass movement and human land use inputs and their impact on the landform evolution. The human response to different landscapes in the world is reflected in agricultural systems, leisure, settlements, road constructions and other engineering projects and extraction of natural resources such as mining and quarrying (Piatek *et al.,* 2009). These conditions provided by the nature of the landforms help to explain the location of human land uses such as coastal settlements, spring line settlements, location of industries; including modern hazardous industrial locations as nuclear and other modern industries, which have significant effect on the rocks and geomorphic processes (Baird *et al.,* 1992; Shaw, 2008).

The importance of the rock structures and type shows sufficient evidence of lithological variations, which cause variations in the geomorphic and human responses (Siddan, 2016). This partially explains why landforms developed on sandstones, granite, limestone and basalts under different climatic, topographic and land use conditions evolve significantly differently. For instance, granite weathering in Dartmoor produces moors and tors, while similar granites in Tanzania produce tors and inselbergs. The case of the Idanre Hills 5^0E 7^0N in western Nigeria, is another granitic region in which the landform development is influenced more by the climatic conditions of high temperatures and high rainfall (1,600 mm), with a four-month period of no rainfall and with the mountainous topographical influence (Grapes *et al.,* 2008; Siddan, 2016).

Human activities in this high-density populated region have removed over 30% of the vegetation cover, which was originally rainforest, leaving extensive patches of Savannah and bare rock all of which have accelerated weathering and erosion (Grapes *et al.,* 2008). Here inselbergs and tors have developed in which the composition and structure of granites has influenced the resulting landforms and their formation processes. Spacing of joints and the intensity of their formation in different parts of the 320 km ranges, influenced landform changes (Grapes *et al.,* 2008). The Idanre

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studies contributed significantly in quantifying the meaning of the concept of joint density and its influence on the rates of weathering and erosion.

All these activities are based on the geology of the place including the rock types, their structure and texture. The rock-forming minerals and composition have varying susceptibility to reactivity and decomposition, and therefore set the rates of weathering. The rock type, rock hardness and their tenacity to different external and internal forces were considered in the study in relation to geomorphic processes. The resulting landforms are ultimately the result of geomorphic response to weathering and erosion and the land use processes, which sculpture and evolve the landforms (Duff, 2012; Huggett, 2019). Vital process in the evolution of the landform is the effect of overland water flow in the development of gullies.

In different parts of the world, slopes on landforms respond in different ways to the effect of surface runoff. For instance, in the United States, the Tennessee Valley Authority was established to restore degradation of land due to erosion resulting from severe gully erosion on farmlands. Similarly, Aix-en-Provence in Southern France provides and contributes to evidence of the worldwide activities of landform sculpturing by intensive gullies (Huggett, 2019).

Gullies are also generally accepted as providing processes under which landforms evolve through relatively small but cumulatively significant land sculpturing geomorphic process of denudation (Summerfield, 2013). The model of gully landscape evolution involves periods of slope stability when there is little rainfall and a period of instability, which occurs when slope-grading processes follow. Studies of slopes in southern Europe by Goudie (2001) and Grapes *et al.,* (2008), show that the slopes seem to be undergoing episodes of accelerated erosion through gulling. The studies indicate conclusively that this pace change is due to the critical shift in the way slope systems respond to new environmental changes brought about by human interference.

Studies in basin hydrology by Smith (2000) and Shaw (2008), have underlined the processes, which lead to environmental changes, and the problems in river basins, while Duff (2012) emphasizes the impact on the river basin environment. However,

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this study did not to apply such findings and consider the specific problems arising from the various land use methods. Some of the contributions to the landform dynamisms are not directly seen as significant in effecting changes on the landforms as indicated by Getis (2005), but numerical analysis points out their significance (Acreman *et al.,* 2014). The study on Rupingazi watershed quantifies the significant role played by land use events and their consequences on geomorphic landform changes through addition to, or removal from rock-forming minerals.

According to County Government of Embu (2014), some areas in the watershed have lost most of their vegetation, leading to accelerated rate of erosion and landform changes. Probably the need for more land in agriculture, roads and urban settlements has caused removal or replacement of natural vegetation for new land uses. In some areas of the watershed, farming is done directly to the riverbanks, and the suggested cure is planting of buffer zones with bushes, grass or tree thus inducing accelerated recovery and changes in fluvial processes and basin morphology (Collins, 2004). The methods of slope management and conservation of riverine forests or riparian strips of a 10-meter belt at the banks were used in parts of River Tana basin. This method was considered suitable and therefore adopted in this study (Ongwenyi *et al.*, 1993). Many methods have since then been suggested including implementation of buffer strips, contour budding, contour ploughing, cover crops, gabion, wind breakers, mulching, reforestation and others. All these methods are suggested in order to reduce the impact of human land use on the landform changes (Langat *et al.,* 2019).

Due to the varying demand on the land utility in different parts of the world, the influence of climatic factors and the economic state, watersheds have been utilized differently. The effects of such choices have necessitated studies on the impacts of those activities. From such studies, for instance D'Ambrosio (2017) suggested making two levels for entrapping the soil on the river banks through the two-stage ditch in Michigan. In these studies, the interactive consideration of land use and geomorphic processes is scanty. The current study examined in details the interaction of various land uses with geomorphic processes.

Introduction of a substance to land or water causes change in the physical, chemical and biological characteristics on a landform, which subsequently triggers short-and

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long-term changes in the development of that landform. Therefore, its rate of development is slowed down, accelerated or changed completely when climate changes. Substances in the environment in dosages that overwhelm the natural sinks of purification or recycling processes would be regarded as pollutants (Waugh, 2016). Rivers, rocks, soils, the animal and plant habitat are very sensitive to new mediums introduced into them or into their environment so that they duly effect changes on their processes' trend, functions and structure. Frey (2001) and Gregory (2006) consider the impact of added input to an environment and point out that this can only be investigated through identifiable inputs by the land uses. The inputs from various land uses in Rupingazi watershed have been examined.

Water is the universal solvent capable of transmitting volatile substances to or from the environment to another, which in turn effects changes on landforms structures and their evolution rates. Water can transmit substances in both solution and solid forms. These wastes can be carried away as garbage, dissolved chemicals, acids, and other washouts on to the surface or into the sub-surface, to the rock systems and ground water storage. Due to the wide spectrum of land uses, it is difficult to monitor and control amounts and routes of these substances. There are, however, ways that enable relatively accurate monitoring of such systems. For example, Dudgeon (2007), suggests the use of such operations as the comparative changes and differences in the water and soils constituents and their behaviour at specific points and time. This method was adopted on this study watershed so that water contents could be monitored through analysis of samples at points upstream and downstream of substances source points. Effluents and washouts carried as overland flow in the rural and urban areas infiltrate and percolate and significantly plume out to wide areas and spread the chemical and non-chemical substances (Waugh, 2016).

Although water has the ability to clean itself as it flows through rocks, it also distributes the substances it carries. The problem of pollution or substance input into the geologic system is observed if the water is abstracted for use before that process of self-purification is completed. Water pollution and substance contribution to the geomorphic impactive processes can be examined at four levels: as a physical agent, a chemical conveyer, a bio-potential medium and nutrients pool. All these levels affect the geomorphic processes (Zhang *et al.,* 2010). This is why the study examined river

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Rupingazi that flows through urban areas where substances are likely to be added to the watershed through human activities and ultimately affect the repose angle of the slopes

The initial slopes over which the rivers flow is provided by the earth dynamics, which produce landforms such as volcanoes upon which rivers carve their drainage basins. Within the river basins, valleys and drainage systems evolve and are modified by the climate, which determines the precipitation. This in turn affects the geological structure and also controls the rates of weathering and erosion as it depends on the rocks' hardness, tenacity, chemistry, solubility, porosity and topography. Further, Rasmussen (2015) asserts that the sculpturing of river valleys takes advantage of the joints and other structural weaknesses in rocks to shape their courses depending on the agents of weathering. This study took into account the structural state of the rocks and their influence on the evolution of landforms from the dip to the strike and the valley limps to the channel. In the United States, studies have taken considerable investigation processes, and have indicated and evaluated modification of river channels. In the low lying agricultural dominated lands, by the use of two-stage ditches, natural channels are modified, where an inner terrace is made, and a second bench is also made, so that vegetation growth is enhanced and surface runoff is drastically reduced (D'Ambrosio, 2017).

Works on specific rivers by Plummer *et al.,* (2001) and Allen (2008) indicate that valleys develop by active removal of material such as rock debris, which is carried away by streams, and surface runoff to the lower reaches of the slopes and rivers. Where there are temporary points of deposition along the long and short profiles of the river valleys, and where the conditions of the gradient, discharge and valley width are affected by the capacity and competence of the river, bars and braids develop. These events constitute the major agents of excavation of those valleys through their erosive power. In this regard, it was important in this study to examine the reasons why water is so important in the landform development and evolution on all parts of the watershed. This pluvial process was examined and considered as important in this study because earlier studies had ignored this process.

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There are very few recording stations for rainfall in the Rupingazi watershed. However, the study had assessed the impact of the pattern of discharge and recharge in the basin as an input into the geomorphic processes. The patterns of rainfall, its intensity and duration are important in predicting catchment discharge, load generation, interception and water flow, as regards the lag-time and in the erosive rates. For example, the rainfall pattern and variation in the last sixteen years is an indicator of the variation in the nature of land use and erosion activities. Another important aspect of landform dynamism is the soil as the broken state of rocks (Barnaby, 2011).

Water, the most abundant substance on earth is the principal constituent of all living things; even in the driest parts of the world, there is water in the atmosphere, in the soils, in the rocks and as groundwater. This implies that water is available for the landform changes, which can be observed, or those which take place unperceptively as indicated by Armstrong (2004). The study showed that fluvial processes are a common concern in all geomorphologic related processes and relevant to a basin land use activity from the arrival of water at the land surface as precipitation, to its eventual loss by evapotranspiration and by surface and sub-surface flow to the ocean. This study on Rupingazi watershed has considered the flow of water originating from different land uses in order to assess the significance of addition or removal of substances on a landform.

Smith (2000) considered case studies on the design of the channel network and riverine morphometry as being affected by human activities. This study has found it necessary to consider the important role of the available water in the watershed in order to relate it to the calendar of the land use, especially in agriculture and the related agricultural industries as a gap in the knowledge of landform evolution. This has been done considering the water balance in mind, which is a concept basic to the hydrologic science and as an expression of the hydrological cycle for an area of land surface in terms of conservation of water in order to help in the understanding of geomorphic dynamics (Pickering, 1994; Vijay *et al.,* 2016).

Forested areas have been shown to have a greater interception loss than in places where there are adjacent grasslands due to the greater aerodynamic roughness of the

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forest. In connection to this fact Gregory (2006) considers the riverine vegetation as being mainly due to the greater water availability and efficient transfer of water from its surface to the atmosphere. This also affects the rates of infiltration, which depend on the intensity of the input and the initial moisture conditions of the surface soil layer.

The surface runoff on the slopes alters landforms through sapping; a process of valley side or scarp recession through undermining of the underlying less-resistant materials; and includes spring sapping where ground water outflow result in headward erosion and the extension of the river source upslope so that the valley morphometry changes by slope decline, or by parallel slope retreat. Recent studies by Maurizio (2019) have, by data analysis, pointed out that man influences the valley evolution processes through the above-mentioned dynamism; but the extent of such human influence has not been quantified in many parts of the world, including this study area. However, this study has examined the influence of human activities on the evolution processes.

The movement of the water through rocks and soils is due to temperature difference and the chemical concentration of solutes, or osmotic potential of the soil water. This is an important factor where there are washouts from different sources such as land use activities in the processes of landform changes (Maurizio, 2019). This forms a gap in the knowledge of the impact of both the contribution and the result of land use on landforms. In this case five factors influence geomorphic dynamisms and landscape evolution. These factors are first, climate, where temperatures and rainfall and their characteristics had apparent significant effects on chemical weathering rates; where water is the major reagent in weathering processes. Second factor is site, which is the nature and condition of topography and the drainage system with the contributions, which help in the distribution of chemical substances. Third, vegetation and animal influence, which can be classified as biotic factors. The presence of forests, grasslands or bare land surface, influence the geomorphic processes by what they provide as materials agents such as the organic acids (Clarke, 2002). The influence of these factors on the geomorphology of the Rupingazi catchment area were extensively examined.

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2.3 Mass Movements as Agents of Landform Evolution

All the processes, which displace and relocate any type of materials within any media down slope, are called mass movement. Slopes create landforms and topography, but every landform evolves through two erosional slope forms: the primary erosional slopes, which are developed by the vertical and lateral sculpturing by rivers and their drainage systems, and the secondary erosional slopes, which are developed through weathering and erosion of all surfaces (Baird *et al.,* 1992; Stefano *et al.,* 2016). The down-slope movement of the weathered rock debris shapes and modifies slopes in all parts of the world, but in different ways and at varying rates, as propelled by the climate and rock systems.

Due to the variety of rocks and rock formations in the world, and due to different geomorphic processes, mass movements tend to vary in all parts of the world. Mass movements are classified into falls, slides and flows, and relate to the weathering degree of material and water contents (Lind, 2016). New erosional land surfaces result from two processes: first, after denudational processes new landforms result from both processes of denudation, degradation and aggradation. The newly exposed surface is actualized by climatic changes. Second, changes in continental landforms results from tectonic activities including uplift, subsidence, emergence, warping, tilting and volcanism (Rasmussen, 2015).

The vertical sculpturing of the river valleys' slopes and the riverbed initiate slope instability. This has to be counterbalanced by the movement of the materials at the base and top of the slope when they are in a state of imbalance and therefore those slopes begin to grade anew. This process causes modification of the slope by wearing back by either retreating where it maintaining the same shape and angle, parallel retreat, or it may fall and reduce the gradient by slope decline according to Davis, Penck and King respectively, at a pace set by the prevailing agents (Christopherson, 2016; Morisawa 2001; Nicholas *et al.*,2012).

The impact of the raindrop on the wet soil can have very serious effects in dislocating materials to lower levels downslope to varying degrees according to the gradient, Krhoda (2015). Recent studies have shown that up to 250 tonnes of soil per hectare may be shifted in a heavy rainstorm. This is also because thousands of millions of

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raindrops strike a hectare according to Ramesh (2017) and Duff (2012) at velocities of up to 30 kilometres per hour. The finest materials of the top soil are transported to lower levels of the slope by forming a thin sheet of muddy water spread evenly over the slope. This is known as slope-wash, and a little lower on the slope, water concentrates into trickles and rills as rill-wash. The rates of soil movement are accentuated by human interference on the natural cover and displacement of the soil. This happens through tillage, deforestation and breaking up of protective turf by ploughing as conceptualized by Nicholas *et al.*, (2012). Such influence has been examined in the study area on slopes steeper than 35^0 and exemplified for other places in the watershed.

The downslope migration of the weathered rock mantle, the regolith, is related to the displacement of the bedrock as falls, slides, flows and creep. It may further be distinguished as soil flow, landslide, block slides, debris slide, slumping, debris flow, debris avalanches, rock fall, rock avalanche, slab failure, wedge failure, planar slide and soil creep. Notably, any of these processes can be triggered by excess water, which originates from drainage from towns and other land uses (Barry, 2005). These geomorphic phenomenal influences are evident in many parts of the world and have been examined in this study.

Different processes may shape and reshape the extent and length of any of the slope facet according to the agents of erosion and climate. Therefore, different climates produce, repeat or eliminate some of the facets while others may be developed or undeveloped. Significant too, are the granular soil movements on the slope in form of soil creep and solifluction exhibited by turf-rolls on the lower side part of stone outcrops on the slope. These movements may cause the bending of the trees near their base as and therefore these influences were investigated and related to the angles of slope evolution. Stefano *et al.*, (2016) indicated that different geological and climatic factors have a crucial role in mass failure, internal friction in the material and the angle of the shear planes have to be considered as significantly important factors in the events. This would also indicate the likely new erosion surface after the failure, with new structures, which could change the class of the slope from convex to concave, or in time form a straight slope.

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Soil creep is also a common process in the upper Rupingazi. Creep is the sum effect of innumerable tiny displacements of grains and particles propelled by gravity through rain-splash and rain-wash and by surface runoff (Duff, 2012). Downslope movement of particles is also accelerated by expansion and contraction and through soaking and drying. Due to humidity and temperature changes, and by the growth and decay of tree roots, and also from the filling in of cracks and spaces made by burrowing animals, besides the impact of the trees as they swing in the wind. These processes are aided by the methods of tillage, so that calculations on the rates and amounts of displaced of soil according to the angle of slope and the implement employed can point out the significance of farming and the shifting of top soil in a specified area and duration (Joshi *et al.,* 1998).

The soils on a slope indicate the balance between removal by erosion and its accumulative formation, and this determines the rate of the development of the soil profile and the soil catena and slope form (Allen, 2008). The same agents that cause soil creep also cause slow creep of screes known as talus-creep, which create colluvial deposits. Where the surface has a strong vegetation cover, the water movement rates are reduced, so that each type of vegetation cover has varying conservative ability.

The equilibrium of slopes and the angles that result are variables of the rates of weathering and of removal. In essence, two limiting factors can be identified; First, weathering-limited slopes where rocks are resistant to weathering and therefore the rate of weathering is low and so is the rate of material transportation. Second, transport-limited slopes where the rates of weathering are high, but the capacity of erosion to remove and carry away materials is low although the rocks are weak or unconsolidated. In such situations, the free-face of the slope is absent. The three slope models developed (the slope decline, slope replacement and slope retreat) as slope evolution by Davis, Penck and King, reflect the variables and agents active on different slopes (Nicholas *et al.,* 2012). The processes leading to these classifications of slopes are controversial and this study tries to mitigate these factors and concepts by delving into the probable geomorphic processes.

The stability of the slopes is important in all aspects of applied geomorphology as regards infrastructures and other installations so that the mechanism of slope failure

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and the different types of movements on those slopes determines their morphometry and their everyday utility. Different processes produce different slope forms, so that the analysis of slope processes and the alterations of those slope forms depend on the changes or/and momentum of the processes (Brooks, 2011). For example, different climatic conditions within the same basin will produce differences in forms and rates of change and therefore process-response system result. This puts into consideration slow and fast processes, which have different degrees of change according to the degree of wetness and on varying angles of slopes. These events were compared and examined in areas of different rock types along the Rupingazi watershed. For example, heaving of small parts on the land surface due to differences in heating resulting from aspect or due to partially exposed parts of the rock-forming minerals in response to albedo. These factors play small individual roles but cumulatively the results are significant. As explained and analysed by Sparks (1986) as well as Vijay (2016), the internal properties of the material; its structure, texture and water content influence the pore-pressure and cause displacement and deformation which initiates landform changes.

2.4 Role of Weathering in Geomorphic Processes

Weathering is the total effect of all the various sub aerial processes that co-operate in bringing about the decay and disintegration of rocks (Summerfield, 2013). This is most useful in the assessment of the weathering influence imposed on landforms by the inputs of land use. The dominant type of weathering is directly related to the prevailing climate and topography, which proportionately affects the effect of gravity, subsequently affecting weathered material displacement.

Worldwide, rates and degree of weathering also vary according to the rock distribution and the dominant types of weathering. For example, the weathering in Highlands of Scotland of the sandstones exposes weaknesses, which are affected by the presence of freeze-thaw. However, weathering of the same type of rock in Mozambique produces inselbergs landscape. On the other hand, granites weather into exfoliation domes and perched blocks in Matopo Hills of Zimbabwe (Selby, 1995). Similar features with exfoliation domes have been observed in Embu County particularly in Ishiara. Since the study area covers some drier parts where the climatic conditions oscillate between wet and dry, the weathering products at most places is

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the duricrusts, made of reddish leached soils which also form ferricretes, commonly called murram (Waters *et al.*, 2014).

Weathering can be categorized into the physical, mechanical and chemical. Notably, the processes, which cause physical changes, do not necessarily fall under mechanical processes. They can be distinguished as two different processes unlike the analogical assumption that there is physical or, instead of physical and mechanical weathering (Begueria, 2006). The products of both forms of weathering may be somewhat similar but the processes are distinctly different. Mechanical processes include freeze-thaw, pressure release, and salt crystallization. Action of roots, burrowing animals and human activities, can be termed as biomechanical, while the physical include insolation or thermal impact, which causes expansion and contraction, or heat weathering and wetting and drying (Begueria, 2006). These processes prepare the rocks for removal by the agents of transportation, which strip off the materials from the surface and change the landforms slope angles, different land uses stimulate some of these processes (Jones, 2012).

The chemical weathering processes act on the weathered and the non-weathered rock materials through the processes of oxidation, reduction, carbonation, hydration, and hydrolysis. In addition, the action of cheluviation, which involves elements such as magnesium, iron and aluminium being released by organic acids particularly from clays, thus being washed away or re-deposited deeper into the regolith and the bedrock which; essentially is part of the biochemical weathering. Due to the diversity and the interactivity of the different processes, as pointed out by Summerfield (2013), weathering processes in most of the land forming processes are affected by the weathering activities. These activities are in turn propelled by the prevailing climatic conditions so that there is dominance of particular processes but no isolation or exclusion of other processes. It is necessary to draw clear lines to delineate the levels of weathering dominance investigated in this study for slopes, with peculiar characteristics such as asymmetry of slopes in different locations of the same river valleys.

Erosion as a geomorphic process which transports materials, from the points of in situ stance, to new locations as propelled by the available energy of the erosional agent

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such as running water and mass failure (Armstrong, 2004; Tyler & Spoolman, 2010). Erosion by running water includes the surface runoff on the valley limps, which erodes loads of materials as colluvial and fluvial deposits. In all parts of the world, rainfall provides the necessary water to move materials, while the quantity of materials moved by the running water depends on the underlying parent rocks. Additionally, their rate of weathering could be limited by slope and vegetation. Although rivers are partly fed by groundwater in form of base flow, a lot of water comes from melting snow in a case such as the Rupingazi area. Erosion is therefore the major agent of fluvial landform sculpturing and evolution in all landforms.

River basins in any part of the world develop in two stages that overlap. These initial erosion stages can be classified as primary erosional slopes curved by the rivers, glaciers, winds or ocean waves and currents according to the structure of the rocks (Strahler, 2013). The second type of erosion is termed secondary erosional slope because of weathering and consequent erosional surface and earth movements. The third (tertiary) classification, considered in this study to be inclusive, is the weathering and erosion of the secondary new erosion surface resulting from anthropogenic influence (Dudgeon, 2007). The anthropogenic influences include agricultural, economic activities such as quarrying and engineering, related to infrastructures and superstructures. Such influences have been extensively covered in the study on Rupingazi watershed.

2.5 Role of Drainage Input in Geomorphic Processes

In hot and humid parts of the world, studies on land forming processes have mainly concentrated on the drainage systems' morphometry and utility. This is because rivers have very significant input into the majority of the human activities in these areas. To this approach and in connection with landform evolution, there has been added, appropriately, material movements in the basins and sediment yield in the inclusive study of fluvial geomorphology. This approach has been applied in case studies in Britain, Germany, USA, Japan, New Zealand and other places of the world (Prosser, 2012).

In all cases, the initial relief has to be subjected to geomorphic processes over considerable geologic period. The relief of a place is made up of geological

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formations and structures, which have different levels of resistance and reactivity to various climatic elements and human input at varying periods and intensities. Geomorphic processes are subject to the intervening presence of vegetation cover or absence thereof. The hydrological factors also control the landform evolution in that the relief relates to the base level of erosion and the drainage network characteristics such as the drainage density (Clarke, 2004). In Africa, land use methods have changed and generally shifted from the traditional simple hand tools to the use of modern implements in agriculture and extraction of natural resources such as forest, minerals and construction materials. Due to the variety of rocks in Kenya, volcanic to sedimentary and mixture of metamorphic rocks at varying degrees coupled with a very wide climatic spectrum and land uses, landform evolution has become very complex (Collins, 2004).

This has been apparent in the development of flood plains even in the upper reaches of the Rupingazi watershed in such places as Kiandari, and Ndunda. These drainage features influence and are themselves influenced by sediment movements and their yields, which ultimately affect the river channels. Lastly and probably most portent is the human influence on the landform according to the management or mismanagement through land use.

The major distributor of chemical substances in water is effluents from domestic and economic activities in urban areas where the concentration and amounts are high. Dust and smoke from human and natural sources also have an input in changing the rates and types of weathering in different weather conditions that affect the atmosphere, the earth’s surface and the nature of geomorphic trends influence the landforms. Soil characteristics such as the levels of acidity affect microorganism activities, which are agents of soil development (Gurnell, 2012). When these properties change or when altered by the presence of new chemicals added to the medium, changes also occur in the soil development rates. Gas emissions from industries, vehicles, domestic activities, petroleum product spills and disposal of waste products are also important contributions as agents of changes on landforms. There are fugitive emissions, which are pollutants that do not happen through the general methods and include dust from the soil when eroded, mining, rock crushing and construction sites (Miller, 2010).

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Poorly maintained or poorly planned drainage systems in urban areas become a hazard when they destroy infrastructure in both urban and peri-urban environments (Lind, 2016). Unfortunately, most of the sustainable urban planning is rarely implemented. Road planning is an important component of the smooth running of the urban areas, where this should be related to the relative location or centre of high population, commerce, industry and transport. Adequate drainage is the most important element in the road construction. The engineers should select the storm-design for the high-volume runoff or highest water overflows in the natural or artificial banks of the channels on the normally dry land as the gauging parameter (D'Ambrosio, 2017; Salter *et al.*, 2000).

Housing in the urban areas complicates the drainage due to the high interception by the roofs. This essentially complicates discharge from towns' paved surfaces because water runs into shallow gutters and into inlets of underground drains which are often blocked on the onset of the rain season due to the solid waste materials swept from the surface (Langat *et al.*, 2019). While these solid materials are part of the garbage in many places in towns, collecting the garbage and litter before the onset of rains would greatly ease the problem of blockage (Smith, 2000). This problem is directly linked to this study because there is inadequate knowledge about the said linkage of garbage generation and drainage blockage and injection of substances into ground and onto the surface.

Urban drainage requires an efficient system of water transmission from all parts of a town. This would avoid flooding, overflowing or damaging of the infrastructure by the water from precipitation or accidental spillage of water within the urban area where infiltration is minimized by surface paving (Gregory, 2011). Such flowage therefore alters the slope by changing the momentum of the active processes so that the rural areas have a spill over effect on towns next to them depending of the location and situation. The drainage system can, in modern urban areas, be extensive, and therefore expensive.

2.6 Influence of Farming Practices on Geomorphic Processes

Farming as a land use practice greatly depends and influences the geology of a place including the rock types, their structure and texture. It is therefore important to

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examine influence of farming activities on the geomorphic processes. Tillage practices, cultivation methods and cropping systems influence environmental processes within agroecosystems (Njeru, 2020). Farming being a major land use in Embu County, this study examined the influence of farming activities on the geomorphic processes along the Rupingazi River.

Broken state of rocks (soil), is a primary resource in farming and it is also an important aspect of landform dynamism (Barnaby, 2011). The rock-forming minerals and composition have varying susceptibility to reactivity and decomposition, and therefore they set the rates of weathering (Hugget, 2019). Therefore, the development and movement of soil is fundamental in geomorphology because it indicates landform changes (Hugget, 2011). Soil development, is the progressive change in the soil characteristics, as it depends on the climate, parent material (rocks), topography, vegetation, soil organisms, other biotic activities and time duration of that development.

The changes taking place in the soil horizons over time are the soil's development processes and are landform-changing processes (Brunsden, 2001; Strahler, 2013). The soil formed and the resulting landforms are ultimately the result of geomorphic response to weathering and erosion. This may be triggered by the land use activities, which sculpture and evolve the landforms (Duff, 2012; Huggett, 2019). These parameters determine the soil types and the soil reactions to the effects of drainage and the added substances, which come from different land uses. All these ultimately modify the responses in the slope development processes and the catenary systems characteristics.

As soil develops and provides nutrients and fertility, the soil development rates become synonymous with rock disintegration and creation of new soils and rocks (Thompson & Troeh, 2009; Ramesh & Darius, 2017). Soil requires moisture to hold it together and as a medium to transmit nutrients for plants, and therefore the moisture contents can change the response of the soil to other introduced stimuli in different ways; noting that soil is not passive to the added chemical substances and gases from the environment.

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One of the effects of farming practices is increased soil erosion. Soil erosion has caused landslides on the steep slopes of Mt. Elgon (Obua *et al.,* 2004). Similarly, Ramsey (1986) found that farming practices influenced geomorphic processes in Himalayas. In Nepal, three quarters of the landslides were associated with inappropriate farming practices (Laban, 1979). Human activities in Idanre Hills 5^0E 7^0N in western Nigeria, a high-density populated region have removed over 30% of the vegetation cover, which was originally rainforest, leaving extensive patches of Savannah and bare rock all of which have accelerated weathering and erosion (Grapes *et al.,* 2008). The study therefore examined the widely practiced farming practices along the Rupingazi catchment with a view of examining their influence on the geomorphic processes.

Kitutu (2002) in her study in Manjiya County observed that the intensity of land sliding had increased over the years because the area had been cleared off the original forest cover and turned into farmlands. However, in her study she noted that the need for farming land had pushed people to settle on steep slopes that accelerated geomorphic processes. Use of land for farming on such slopes without appropriate soil conservation practices may contribute to slope instability. As observed by Knapen *et al.,* (2006) and NEMA (2007), intensive cultivation on concave slopes changes the hydrological conditions of the soil by enhancing saturation. This triggers debris flows in case of high rainfall intensity. However, in their study, they did not focus on the steepness of the slopes but the current study has related the geomorphic processes with steepness of slopes.

Tillage as an activity in land use influences landform evolution according to the nature of the implement used on the land. Therefore, tillage as farming land use activity is significant because of its effect on soils structure. In all cases of tillage:

i. Soil is turned over, so that aeration occurs and the inner layers of the soil are exposed to the elements of weathering and erosion. This action affects the microorganisms and the humus as a chemical colloid (Njeru, 2015; Njoroge, 1999).
ii. Tillage mixes the nutrients, induces new chemical changes in the rocks, and may affect the soil porosity and mineral distribution.

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iii. Loosened soil particles are easily removed, and when they settle down, the texture of the soil changes so that infiltration and surface runoff are affected either through creation of spaces by altering porosity or clogging and surface seal.
iv. Use of heavy machinery has the effect of compaction of the soil and reducing the pore spaces and causing soil clogging and making it hard for roots to penetrate the soil and so increasing surface runoff.
v. In pastoral land use such as is practiced in the lower watershed agro ecological zone, the animals have the same effect of compressing and compacting the soil (KIOF, 1999; Njoroge, 1999).

In their study on the local people's perception of geomorphic processes Obua *et al,* (2004), observed that people believed landslides occurred during the wet seasons and were mainly triggered by intensive cultivation. Gumisiriza (2014) in her study of effects of geomorphic processes and land use activities on slope stability in Mount Elgon Uganda established a positive relationship between intensive farming activities and geomorphic processes. In addition, she found that half of the landslides' scars were found where there was cultivation.

Crop production mainly relies on rainfall. According to Gumisiriza (2014), water plays a great role in influencing the intensity of weathering. While weathering disintegrates rocks during the dry months, rainwater exerts pressure on the already loosened rocks, which eventually move down the slope. This indicates the potential of rainfall as a trigger geomorphic process as noted in Mount Kenya (Westerberg, 1999). Such influence of rainfall was noted in Norway (Rice, 1977).

Livestock farming by way of overstocking and overgrazing accelerates soil erosion by their action of clearing vegetation, as was observed by Wessels *et al* (2007) in South Africa. The increased surface erosion has both on-site effects related to the loss of topsoil and off-site effects associated with downstream siltation (Mol & Ouboter, 2004; Miserendino *et al.*, 2013). It can also result in hydrological modification (impact on rivers and streams due to physical disruption of banks and vegetation) and general destruction of vegetation (Sindling, 2003).

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Vital process in the evolution of the landform is the effect of overland water flow in the development of gullies. In different parts of the world, slopes on landforms respond in different ways to the effect of surface runoff. For instance, in the United States the Tennessee Valley Authority was established to curb and restore degradation of land due to erosion resulting from severe gully erosion on farmlands. Another relevant investigation is in the case of the Aix-en-Provence in Southern France, which provides and contributes to evidence of the worldwide activities of landform sculpturing by intensive gullies. Gullies are viewed as providing processes under which landforms evolve through relatively small, but cumulatively significant land sculpturing geomorphic process of denudation (Summerfield, 2013).

Lack of soil water conservation measures on steep farmlands would accelerate soil erosion (Njeru, 2020) and that may lead to development of gullies. The model of gully landscape evolution involves periods of slope stability when there is little rainfall and a period of instability, which occurs when slope grading processes follow. Studies of slopes in southern Europe by Goudie (2001) and Grapes *et al.,* (2008), show that the slopes seem to be undergoing episodes of accelerated erosion through gulling. The studies indicate conclusively that this pace change is due to the critical shift in the way slope systems respond to new environmental changes brought about by human interference.

Studies in basin hydrology by Smith (2000) and Shaw (2008), have underlined the processes, which lead to environmental changes, and the problems in river basins, while Duff (2012) emphasizes the impact on the river basin environment; but this study has deemed apt not to apply such findings and consider the specific problems arising from the various land use methods. Some of the contributions to the landform dynamisms are not directly seen as significant in effecting changes on the landforms as indicated by Getis (2005), but numerical analysis points out their significance Acreman *et al.,* (2014). The study on Rupingazi watershed quantifies the significant role played by land use events and their consequences on geomorphic landform changes through addition to, or removal from rock-forming minerals.

Water is a universal solvent capable of transmitting volatile substances to or from the environment to another, which in turn effects changes on landforms structures and

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their evolution rates. Surface run off from farmlands may contain agrochemicals and fertilizers used in crop production. The dissolved chemicals in the surface run off from farmlands may react with rocks downslope, which are part of the landforms. These agrochemicals and other chemical substances cause change in the physical, chemical and biological characteristics on a landform by triggering short-and long-term changes in the development of that landform (Frey 2001; Gregory, 2006).

However, it is difficult to monitor and control amounts and routes of these substances in surface run off because they are from diverse sources. There are, however, ways that enable relatively accurate monitoring of such systems. For example, Dudgeon (2007), suggests the use of such operations as the comparative changes and differences in the water and soils constituents and their behaviour at specific points and time. This method has been employed in this watershed study so that water contents can be monitored through analysis of samples at points upstream and downstream of substances source points. Effluents and washouts carried as overland flow in the urban areas infiltrate and percolate and significantly plume out to wide areas and spread the chemical and non-chemical substances (Waugh, 2016).

Farming activities such as growing of crops may attract certain burrowing animals such as moles. According to Twidale (1998) mass movement triggered by air trapped within and beneath weathered material in Australia affects tunneling by burrowing animals. This parameter was examined in this study because agricultural land use induces these processes. Expansion and contraction of clay soils in particular, causes heaving which triggers micro slippage and creep in form of puffs or turf rolls and depressions called gilgai (Montgomery, 2019).

Any river basin and its morphological evolution depend on the management of the basin concerning control of water and soil movement, the presence and amount of vegetation. The stability of any landform and its rates of change are dependent on the frequency of changes, the intensity, and the dominance of any specific processes in the environment (Saigo, 2007). Vegetation holds the soil through the root systems and helps to maintain the moisture by reducing evaporation through the shade cover.

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Since there are various and intensive farming practices carried out on slopes along Rupingazi River, the study reasonably examined the influence of such practices on the geomorphic processes in the catchment.

2.7 Influence of Chemical Fertilizers on Geomorphology

Soil profiles develop from long periods of rock weathering complimented by organic materials water and gases. Soils comprise of up to 92 elements, but out of these, only 16 are necessary for growth (Trenkel, 2002). Fertilizers are chemical elements added to the soil to enhance crop yield. In this study, a number of questions must be considered: What is the effect and influence of chemical fertilizers on the rocks and the geomorphic processes, which affect landforms? How much fertilizer is necessary? The purposes for using fertilizers are to supplement the natural soil nutrients, to recharge the soil with the lost nutrients taken by the crops as they grow or what is lost through erosion or leaching in order to maximize crop yield. So, is fertilizer use beneficial to the soil or necessary? Has that necessity been a result of soil analysis to ascertain the requirement? Are there residues that affect the soil and change the soil composition and influence geomorphic activities?

Fertilizers used in the proximity of the rivers are likely to be washed into the rivers, changing the composition of the water and influencing the fluvial processes. The use of the modern fertilizers has spanned the last 150 years. International Fertilizers Industry Association (Trenkel, 2002) warns that fertilizer use must take into consideration the nutritional requirement of animals and human beings consuming the crops. Over 90% of the farmers in Embu County use fertilizers without any soil analysis and with no extension work experts' advice (Njeru, 2020; Shohei, 1987). Such use of fertilizers may increase the range of toxicity to the plants and pass it to consumers (Njoroge, 1999). Most important minerals as plant nutrients provided by the rocks are carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus, but these vital elements could become inaccessible through chemical reactions, which create stable compounds from them.

Thompson and Troeh (2009) argue that as soil develops and provides nutrients and fertility, the soil development rates become synonymous with rock disintegration and creation of new soils and rocks. In the Rupingazi watershed, the natural development

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of soil has resulted in the soils, which reflect the minerals present in the rock-forming minerals, but in order to enhance soil fertility; in most cases without analysing the chemical properties of the soils, farmers have used fertilizers, that are likely to affect the geological and geomorphic processes.

In addition, the built-up areas, both paved and loose surface parts of towns, are also routes for water and materials swept by agents of transportation and ultimately deposited into rocks, soils, rivers, and on various surfaces. By inference, every part of the watershed affects every other part of it. Development of soil as viewed, in this study, is part of the landform development stages since it alters slope morphometry (Van Leeuwen *et al.*, 2017). While this is the general aspect of soil development, the impact of the influence of added chemicals as agents of weathering and erosion are important parameters of geomorphic processes.

However, they have not been specifically integrated into landform changes in previous studies conducted in Rupingazi watershed. It is important that the overview of the research area with its interactive factors be intrinsically related to the drainage and gradient of both the river and human habitat in many sites. These interfaces of variable interactions affect the physical environment in which geomorphic processes, which are rarely noticeable. This could also affect the rocks below the surface and the soils on these surfaces. However, there are visible indicators as tree-root exposure, animal trucks or trails, footpaths, roads and the resulting mass movements (Yang *et al.*, 2016).

Minerals required in small, but necessary quantities are sodium, manganese, potassium, calcium, iron, magnesium, chloride, iodine, cobalt and baron. These minerals are released from the rocks through weathering and erosion. This provision of minerals underlines the importance of the influence of various land uses. Some of these chemicals may only be useful for specialized plant functions such as allelopathy or those short-term chemical responses that are defensive to the plants in order to inhibit growth of potential competitors, but extra supplies harm the plant or remain unused, yet they affect landform dynamism (Zang *et al.*, 2012).

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2.8 Influence of Human Settlements on the Geomorphic Processes

Human settlements that include construction of houses and related infrastructure such as roads are responsible for some slope instability (Gumisiriza, 2014). According to a study by Wemple *et al* (2000) on forest roads and geomorphic processes interaction in the western Cascade Range of Oregon in USA, they found out that roads functioned as both production and depositional sites for mass movements as well as fluvial processes. They further noted that debris slides from mobilized road fills were a dominant process of sediment production from roads. According to Gumisiriza (2014) hanging walls along the roads that have not been protected by concrete or vegetation cover, are prone to landslides. Gumisiriza (2014) further argues that buildings on sloping grounds may cause cracks due to overloading of the steeply inclined slopes. Such cracks were common on slopes inclined at 30^0 and covered by shallow loam-clay soils.

Where land use is mainly under human settlements and particularly the urban settlements paved areas exist which reduces water infiltration thus increasing surface runoff. This surface run off coupled with pollution from the urban ecosystems needs to be examined, as envisioned in the study. Water pollution and substance contribution to the geomorphic impactive processes can be examined at four levels; effect on microorganisms, example sewage, as a physical agent, by being a heat carrier, third as a chemical conveyer, and fourth as bio-potential medium and nutrients pool, all of which affect the geomorphic process. This is why the study examined Rupingazi River, which flows near urban areas. This is of geomorphological significance because Zhang *et al.,* (2010) observed that substances added to a watershed through human activities ultimately affect the repose angle of the slopes. The substances are carried in surface run off containing pollutants.

The surface run off from the garbage dumps, especially during rain periods, seep into the soils and rocks through infiltration then percolate and effect changes on those surfaces. Whipple (2004) indicates that the in wash of fine particles carried in suspension by infiltrating water can clog the rock and soil pores, and therefore lower infiltration rates so that chemicals, which are generated by human land uses, change the state of the water and soil. These substances affect ecosystems and the geomorphic processes. When the garbage decays and decomposes, it generates

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chemicals, gases and heat, which affect the environment and atmospheric characteristics (Miller, 2010). Studies on soil pH in specific land uses have been found to influence environment by changing the soil and rock in their functions by causing weathering (Armstrong, 2004; Brabb & Harrod, 1989).

Kang *et al.,* (2010) examined the effect of effluents, particularly sewage where the process of nitrification-denitrification occurs. These processes contribute to the inputs of geomorphic dynamism. For example, the process of denitrification removes plant nutrients in the sewage as a tertiary process. In the process of nitrification-denitrification, nitrates are removed when ammonia nitrogen is converted into nitrates by microorganisms and therefore biologically converted to nitrogen gas. Another method applied to the effluents called ammonia tripping removes ammonia gas by a physicochemical process. These changes and additions of substances to the land and water directly affect geomorphic processes of weathering. The study examined water and soil samples from the areas covered by surface run off from towns to analyse the chemicals therein.

Municipal solid waste (MSW), often-called garbage or trash (Miller & Spoolman, 2010), is another significant contributor to the changes on landform dynamisms because of the substances generated by garbage from different sources. Garbage is a difficult problem to control, and areas of high human concentration are areas of high garbage generation. The towns are the major sources of solid waste and holding points, which are also great contributors and providers of chemical effluents that contribute to geomorphic changes in the rock substratum, drainage, soil structures, and biochemical processes (Waugh, 2016).

Garbage made up of unsorted materials can produce very complicated chemical and gaseous products so that any imbalance in the six main bacterial systems in the soil and water caused by chemical additions, could affect other cycles such as nitrogen circulation from air to plants and back. If one or a combination of the chemicals should poison the nitrifying bacteria on a worldwide scale, the air would become unbreathable according to Yang *et al.,* (2016). Such statements as this summarize the impact of human predicament on the environment utility, which influences landform evolution (Price, 2011). This view propelled this study to examine the influence of

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urban settlements and the associated infrastructure on geomorphic processes and in particular through surface run off.

2.9 Influence of Quarrying Activities on Geomorphic Processes

Mining involves the extraction of mineral resources from the ground for various economic reasons (Windalund & Ohlander, 2014). While the extraction of minerals would obviously bring economic opportunities, it portends several environmental challenges to the regions where they take place (Banez & Ajon, 2010). Studies have conducted to examine the impact of quarrying, noted its adverse effects on farming and settlement (Rodrigues & Lima, 2012). For instance, the scooped soil and soapstone fragments are dumped near the carving sites thus creating mounds of debris on a landscape (Tilji, 2018).

Where heaps of debris accumulate as a result of mining activities, geomorphological processes including rock cycle and denudation may occur thus resulting in new landforms (Rodrigues & Lima, 2012). In addition, the heap is easily eroded because it is unconsolidated and the steep nature of its slope accelerates the rate of soil erosion processes besides changing the original appearance of the landscape. As erosion occurs, the land is left bare thus being exposed to more weathering and mass movement activities. For instance, a study by Wahome (2013) found out that the exploitation of soapstone loosens the top soil cover and even weakens soil colloids thereby making those areas susceptible to erosive processes. This then results in erosion, which is the removal of top soil or break up of rocks by water, wind or ice.

Quarrying activities, according to Walker *et al*., (2003) not only change the physical landscape, but also the ecological relations in an area where they occur. The cumulative effects of environmental disturbances caused by quarrying activities trigger geomorphic processes like weathering and erosion (Gale *et al*., 2001; Gathuru, 2012). According to Gathuru (2012) weathering forms the basic component in the denudation of landscape. Veldkampa *et al.,* (2012) further note that the loosened rocks particles and remnants of mineral ores left as residues around mining sites may rapidly move down slope as mass movement when they are saturated with rainwater. These moved soils and remnants of quarrying activities from the upper parts of the slopes to lower levels may cover the productive top soil in the lower areas (Ferrai &

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Guiseppi, 2011; Tilji, 2018). The study thus sought to examine the influence of quarrying, mining and abstractive activities on the geomorphic processes in Rupingazi watershed.

Mining and quarrying activities may require clearing of vegetation. This may lead to loss of original vegetation and biodiversity. The clearing of vegetation and quarrying activities accelerate erosion. Where open cast mining is done, four distinct types of erosion are commonly found: Terrace, gulley, sheet and rill erosions (PIDS, 2012). Sheet and rill erosion develop into gullies when no conservation measures are adopted. These gullies with steep sided scarps and flat funnel bottoms develop on exposed steep slopes. The movement of soil materials by gravity downslope is faster on a steeper slope than on a gentle slope. Accordingly, massive landslides may occur on such steep slopes if the area receives high rainfall amounts (Obwori *et al*., 2012).

The disturbance produced by one slope failure often leads to the weakening of adjacent areas, particularly on the upper part of the back-slope, resulting in the development of cracks that decrease shear or tensile strength and allow the entry of water into weakened zones between blocks (Varnes, 1984). These weakened zones often constitute the plane for further mass movements from the summit of the pit. Since the study area is characterized by steep slopes and receives high amount of rainfall, the study sought to examine geomorphic processes as influenced by land uses across the watershed.

Notably, quarrying affects the stability of the surface material, which may result in direct movement of material while others create favourable conditions for other geomorphic factors to exert their influence (Ferrai & Guiseppi, 2011). Thereafter abandoned and unmanaged abandoned quarry sites contribute to dereliction. This is why Akanwa *et al*., (2016) is emphatic that quarrying causes major environmental degradation as evidenced by increased erosion, sedimentation and loss of aesthetic value of the site where quarries exist because the original landform is permanently changed. In fact, excavated sites become derelict (Upkong, 2012) and even Davids (2007) referred to open quarry pits in Hungary as landscape scars.

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In approving most of the Environmental Impact Assessment (EIA) on quarrying activities, National Environment Management Authority (NEMA) recommends that these effects may be mitigated and possibly maintained at tolerable levels. This can be done by employing responsible operational practices. Further, in managing the solid wastes from some towns and cities, some authorities have turned the open pits as dumpsites. The exerting pressure of the heaped wastes combined with the regular movement of heavy trucks ferrying wastes of different chemical compositions may trigger geomorphic processes. Although the overburdening and by products of quarrying activities, may not be easily quantified (Banez *et al*., 2010), the study evaluated the influence of quarrying and abstraction of clay on geomorphic processes in the study area.

2.10 Role of Climatic Factors on Landform Changes

The phenomenon of climate change is a worldwide event and affects the study area like any other place. Climate change is a measurable increase in the temperatures of the earth from its average as regards the atmosphere, oceans and land masses. Greenhouse gases retain radiant energy heat that causes the greenhouse effect (Christopherson, 2008; Miller & Spoolman, 2010). The result, through scientific measurements, has been that global average sea levels have eustatically risen by between 0.1 and 0.2 meters during the twentieth century due to melting ice and water expansion due to temperature increase. Precipitation has increased by 0.5% to 10% per decade in the twentieth century and has, over that general increase risen by a further 0.2% to 0.3 % per decade over the tropical land area between 10^0N to 10^0S. On the local scene, Mt. Kenya snowline has retreated by about half a kilometre in the last 70 years, according to Time-Life (2014). These changes have to be considered as agents of geomorphic changes in the watershed and as affecting the water systems and supply of the whole catchment area of Mt. Kenya and therefore the Rupingazi watershed.

In this section the relationship between the different factors, influencing geomorphic processes have been reviewed. Conclusively therefore the knowledge gap which this study has tried to fill is the lack of information on the balance between the expected geomorphic processes and the human inputs into those dynamisms which alter the

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pace of those systems, as stipulated in the Davisian cycle of erosion (Zang *et al.*,2012).

2.11 Theoretical Framework

In the last 150 years, studies by scholars worldwide on the development of the slopes have evolved in phases into a theoretical model whose elements keep changing as the variables change. This is a Dynamic Model. From the simple four-element framework, the waxing, free, constant and the waning slope into the hypothetical nine-unit land-surface-slope model. The model has been summarized into crestslope, backslope and the footslope, each comprising three units from the crest to the river channel (Doornkamp & King, 1971; Sparks, 1986; Strahler, 2013; Stefano *et al.,* 2016 Vijay, 2016).

Dynamic Models, are characteristically subject to changes in time. The nine slope units can be summarized as follows:

Unit 1: Zone of pedogenetic processes associated with vertical subsurface soil water movement: the interfluve.

Unit 2: Mechanical and chemical eluviation by lateral subsurface water movement; the seepage slope.

Unit 3: Zone of soil creep: Terracette formation. Convex creep slope

Unit 4: Zone of fall, slide, chemical and physical weathering. Fall face.

Unit 5: Section of transportation of material by mass movement: flow, slide, slump and creep. Terracette formation, area of surface and subsurface water action and transportation to midslope.

Unit 6: Area of redeposition of material by mass movement and some surface wash, fan and cone formation. Creep, solifluction and surface water action; colluvial footslope.

Unit 7: Alluvial deposition; processes resulting from water action: Alluvial toeslope.

Unit 8: Zone of corrasion, slumping and fall. Channel wall.

Unit 9: Transportation of material down valley by surface water action: periodic aggradation and corrasion. Channel bed.

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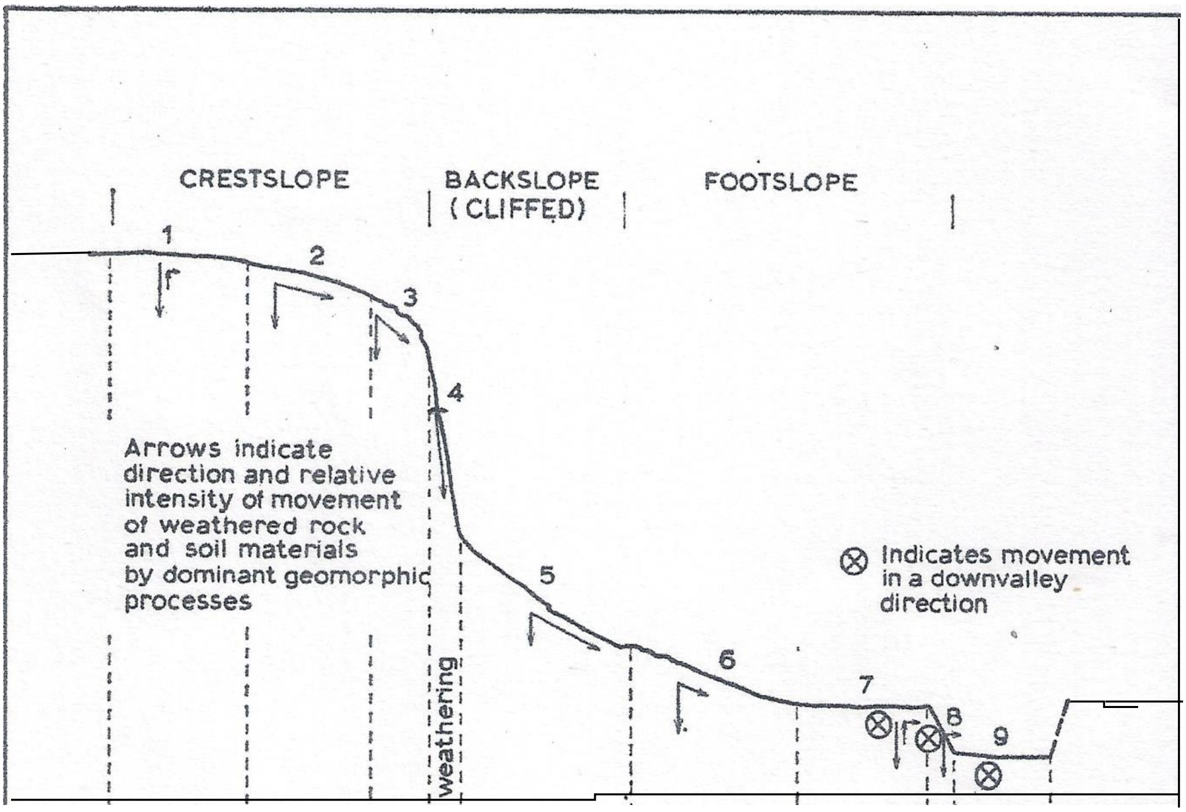

Figure 1. Surface Model. Source: Doornkamp and King (1971)

The model is called 'predominant contemporary geomorphic processes' and forms an idealized likely slope according to rock influence and climatic propulsion. Crestslope: this comprises three distinct action parts, called unit (1) The areas of dominant infiltration in which the weathered mineral materials percolate and moves vertically into the soils inducing such pedogenetic processes as leaching and minerals transfer in the soil horizons. In this section the solid materials are *in situ.* Unit (2) combines vertical and lateral mineral movement through percolation and removal of minerals in solution form or eluviation. As the slope gradient increases to unit (3) both lateral and vertical debris and minerals movements occur. The significant process here is the force and effect of gravity on the weathered material and through solifluction and soil creep dynamism. In this section of the slope, land use activities influence the changes and development of the slope as they affect these processes.

Backslope: with further gradient increase, it is difficult for the weathered material to stabilize in its two facets, unit (4), here there is downslope movement of weathered materials from chemical, physical and mechanically weathered materials, hence the term fall-face which is a belt of mass movement, where the cliffs develop. Unit (5)

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denotes the constant upper slope from where the debris is transported through flow and mass movement such as slides, slumping and creep, and so rest here. The amount of water flowing over and through the material at this point is important to the dynamisms, which move both the minerals in solution and solid materials.

Footslope: this section extends to the river channel, from (unit 6) which is an extension of the constant slope but here redeposition of materials from the upper part (unit 5) occurs. Here, surface relocation of materials takes place and infiltration and mass movement in form of creep, sheet or surface wash are active. Unit (7) is next to the channel and here is where alluvial deposition occurs and where the colluvial materials in some slopes is deposited as colluvium materials or colluvium, which originate from the slopes but does not reach the channel. It is a zone of vertical and lateral mineral and water movement. Unit (8) is the bluff or river cliff, which is the part of the channel affected by river erosion processes such as corrasion, cavitation and slumping where materials move both vertically as solution and laterally by flows and falls. Unit (9) is the river channel where processes of load transportation by water occur and where gradation, aggradation and degradation may operate by oscillation. According to Huggett (2011), the system of naming the hillslope elements has changed from Wood in 1942, Ruhe in 1960, Savigear in 1965 and Dalrymple *et al* in1968

The above description of the facets of slopes can be identified in the landforms of the Rupingazi watershed in varying extends. The analysis of the slope dynamism due to land use is the basis of this study as the theoretical framework to enable the establishment of landform development as influenced by land use. Yates *at el*., (2014) considers the seasonality and the resulting variations in spatial relationship between agricultural and other land uses and indicates that land use significantly contributes to stream nutrient and chemical concentration in the soil and in the rivers. What then changes the facets from the ideal model?

The Penck, Davis and King's model of slope development and evolution are the direct result of climate, dominant geology and topography (Kirkby, 1969; Thornes, 1983). That may explain why some facets are repeated, eliminated or modified according to the locational factors, besides the other factors of rock and climate and now the

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contribution from land use. Van Leeuwen *et al.,* (2017) relate land use and soil activities and the mineral stratification at different depths. This helped examine the influence of land use practices on geomorphology as envisaged in the study.

The landform development theories have evolved at the same pace as the development of the geomorphic thought as emphasised by Holt-Jensen (1982). The landforms are ultimately summarized into slope forms, which result from the interaction and oscillation of geomorphic processes in geologic time. This study has found it appropriate to adopt the most inclusive of the landform models. The reason for this choice is that while different parts of the world have unique landform-creating slopes; a broader view of an all-inclusive slope consideration is necessary in order to appreciate the possible slope alternatives that may result, although not all the unit facets are represented in a particular landform. This approach opens the way for projections and likely slope development in changing conditions of landform development in the ever-changing conditions in the world (Robert *et al.,* 2016; Siddan 2016). From the broad ideas relating to landform development, the conceptual framework has been developed in order clarify the interactive variables of this study.

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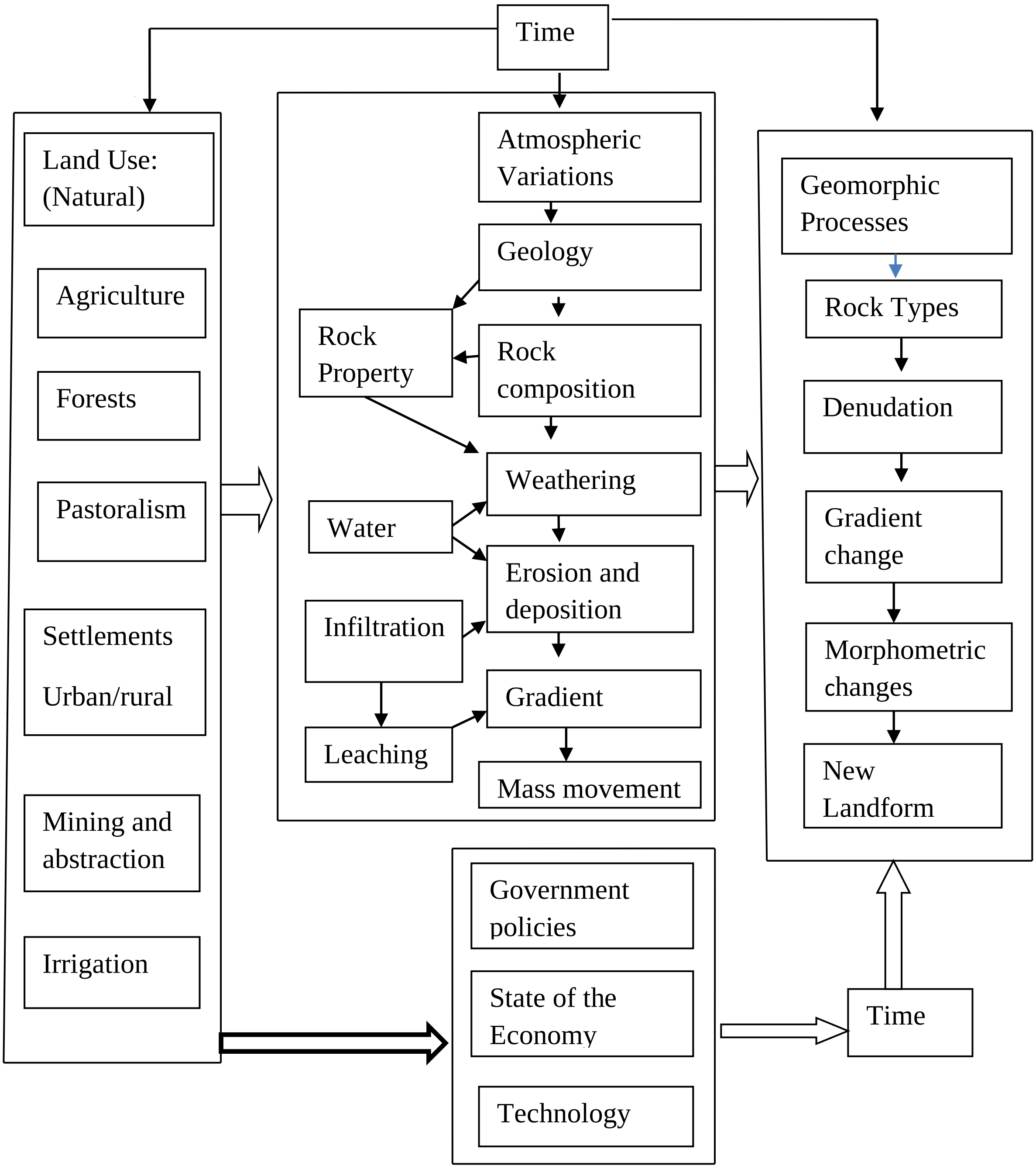
2.12 Conceptual Framework

From the study objectives guided by the literature reviewed relating to geomorphic processes, the conceptual framework (Figure 2) has been developed in order clarify the interactive variables of this study.



Independent variables intervening variables Dependent variable

Figure 2. Influence of Land Use Activities on the Geomorphic Processes in Rupingazi Watershed

This study has six independent variables, which are all under the umbrella land use. Field (2012) uses an alternative term, Predictor Variable for the same. The variables

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contribute in influencing, to varying degrees, the geomorphic processes. First, farming process has the effect of changing the land surface when different methods of farming, ploughing and tillage are used. The different inputs, which enhance production, do at the same time, impact on the response of the geology and soils. Those same inputs also become new stimuli to the landform changes. Second, the forests have the dual effect of influencing the rates of water flow through interception, which enhances lag-time for surface runoff and infiltration. They modify erosion and evaporation rates; but at the same time creating conducive condition for chemical weathering, biological (bio-mechanical) weathering due to the abundant presence of plants and animals (McTavish & Herman, 2014).

Third; pastoralism influences landform changes through direct removal of vegetation and the direct erosive effect by the animals. Fourth, settlements in both rural and urban areas directly change the landform through planned landscaping and therefore interfering with the natural drainage forms. Besides providing the medium for the transmission of materials and chemicals from numerous and varying routes, its input to landform change may be substantial. Irrigation also affects landform-changing processes through diversion and introduction of water to new places, enhancing infiltration as irrigation water becomes a surface storage and a provision for water supply to the soils and rocks.

The intervening variables, affect the independent variables to bring about the outcomes. In this study, they are the climatic factors, which affect the geology of the watershed according to the time of operation. This may be influenced by the intervention from the Government policies, the state of the economy and the technology applicable in the study area as observed in County Government of Embu, (2014). The effects of these variables are responsible for the results; the dependent variables, which Field (2012) calls the Outcome Variables in the end, part of the conceptual framework. These parameters had to be tested in this study and the knowledge gap that this study has endeavoured to fill.

This conceptual framework is important in the understanding of the levels of environmental attention to landform responses from land use inputs. The inputs have significant economic drive for the people, authorities and the environment. These

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activities influence and determine the surface and slopes' stability because they are components of landforms and their changes affect the Rupingazi watershed. This affords the spatial and temporal state of the framework that lays the background for the adoption of the theoretical framework (McTavish & Herman, 2014).

Since landforms may be of igneous, sedimentary, metamorphic or any set of mixed rock forms in origin, the weathering processes start when the rock breaks down according to the type and pace of decomposition followed by generation of rock mantle as assisted by various agents including man; resulting in erosional dynamic changes on the slope gradient hence altering the landform. In time a new landform evolves and sets its own pace and equilibrium where the development of a new landform begins, and the cycle sets a new pace according to the active and changing media and degrees of intensity of processes (Bierman & Montgomery, 2019).

The role of weathering as a process precursor to the process of denudation has been shown to be pivotal to the landform development. The presence of urban settlement as a land use has notable influence on geomorphic processes through its input in the drainage system within the urban areas, their periphery rural areas and the river systems (Huggett, 2019). This operates by contributing chemicals and other substances, including garbage with its rich source of substances, to the general environment. The literature review has also enabled the development of the conceptual framework related to the nine-unit slope model, which has steered this study.

CHAPTER THREE
METHODOLOGY

3.1 Study Location

The Rupingazi River watershed is in Embu County and forms part of Mt. Kenya River catchment system (Figures 3 and 4). It is located to the south of Mt. Kenya between 37°17' East and 37°30', 0°10' South, 0°40' South, and a trend of NNW-SSE.

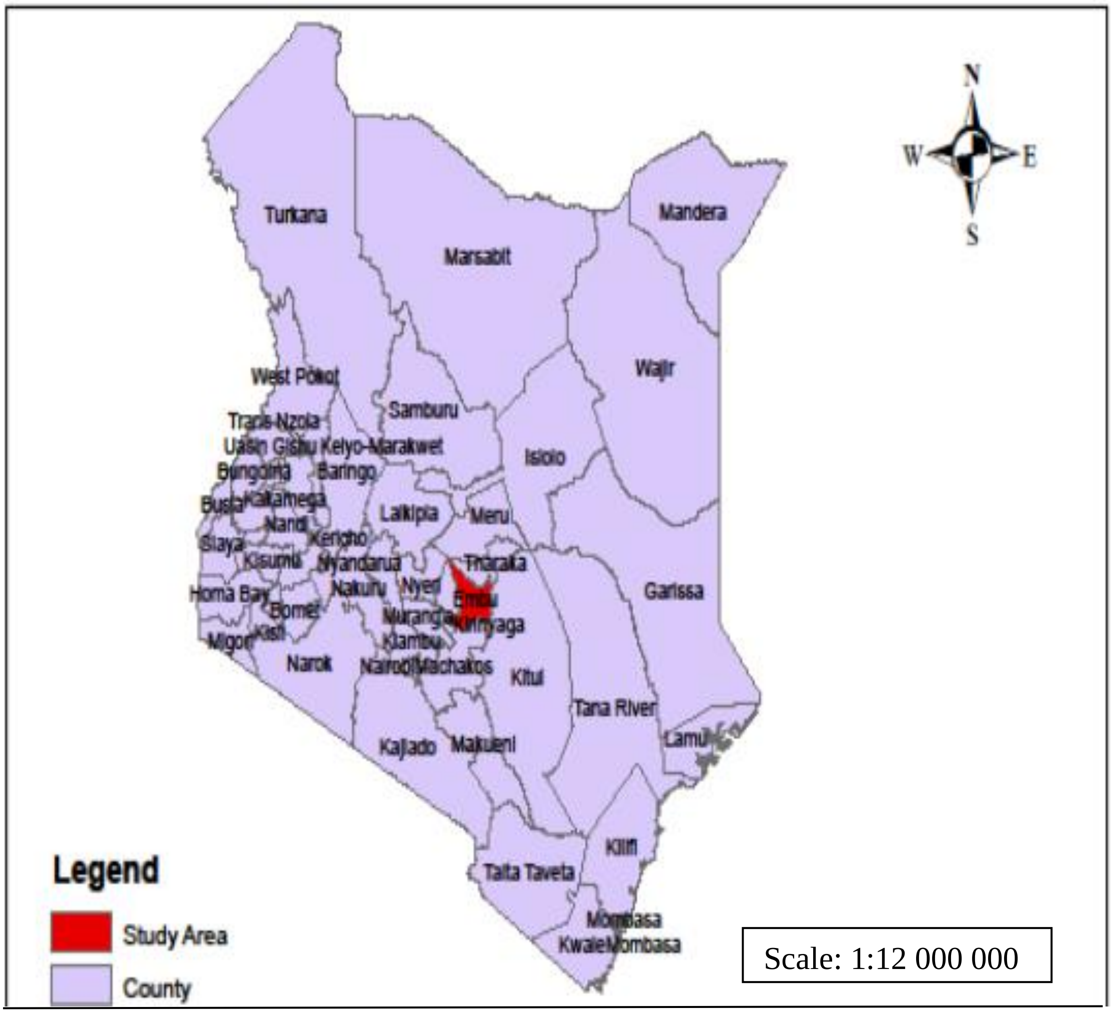

Figure 3. Map of Kenya Showing Embu County

Rupingazi watershed is about 65 kilometres long and covers an estimated area of about 800 square kilometres (CIDP, 2014). The river originates from Mt. Kenya Glacial Lake and Forest, one of the largest water towers in Kenya.

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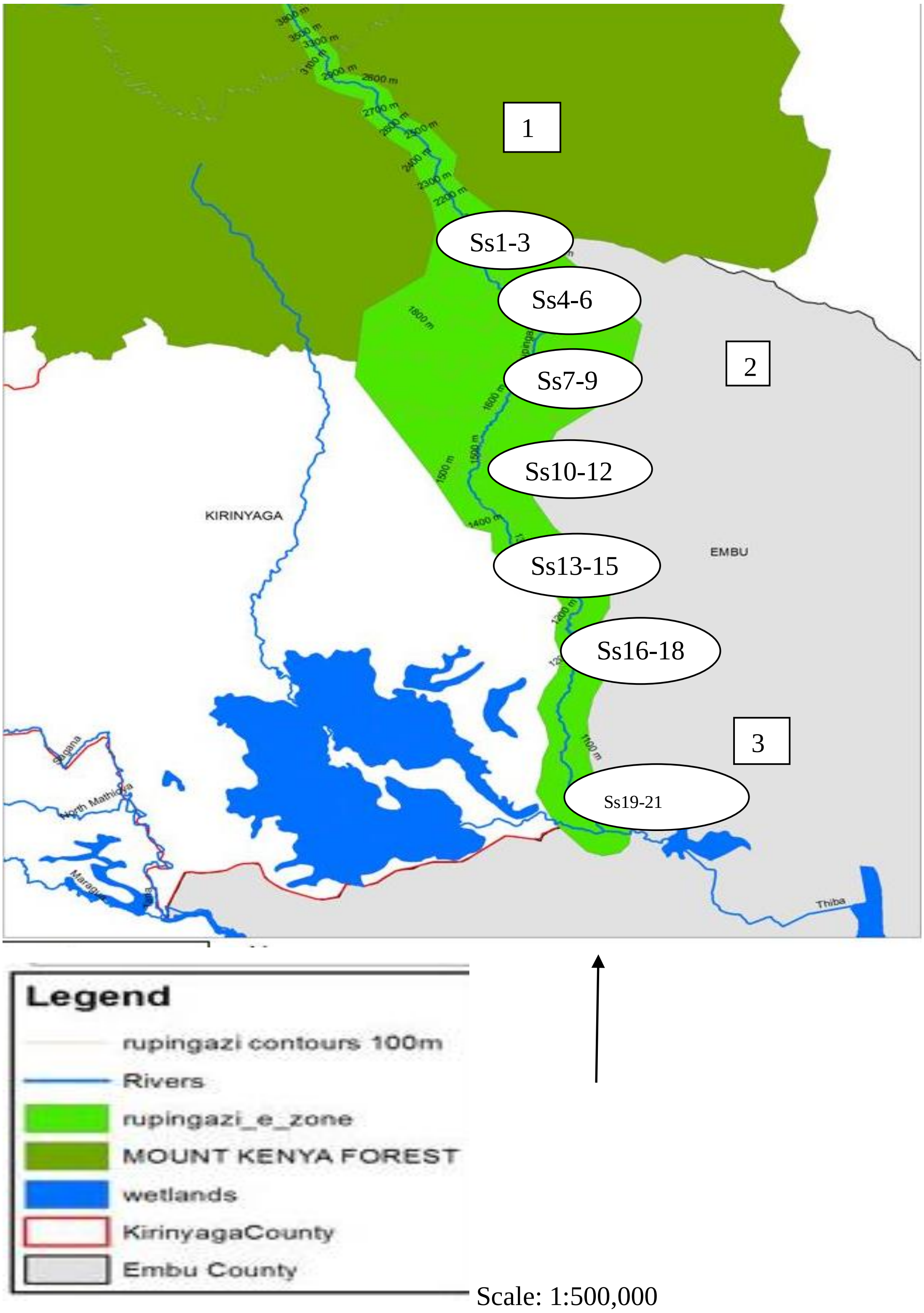

Scale: 1:500,000

1 = Alpine, 2= Highlands, 3= Lower zone, (37017,37030’ E. and 0010’,0040’

<u>Figure 4</u>. Location of Rupingazi Watershed and the Topographical Divisions

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3.1.1 Climate and Agro-Climatic Zonation

Rupingazi watershed predominantly experiences a bimodal rainfall pattern with the long rains falling between March and May, while the short rains fall between October and December. The watershed receives an annual rainfall of between 500 mm and 2,000 mm. This amount of rainfall decreases from north to south as the gradient changes from 5,000 m in Alpine zone to just below 1,000 m in the dry Mbeere region (Van Leeuwen *et al.,* 2017). However, some areas around Mt. Kenya (areas above 1700m in altitude) have tri-modal pattern, (March, July and November) which have a peak in April/May (CIDP,2014). Temperatures across the Embu County average at 20.7^0c with a maximum of 27.1^0C in February/March to a minimum of 12^0C in July (MoLAF, 2016). The topographic and climatic factors demarcate the different agro ecological zones (AEZ) which cover the upper reaches of Rupingazi river mountain zone, the middle or second zone centred about Embu Town, to the third lower reaches centred around Gachoka.

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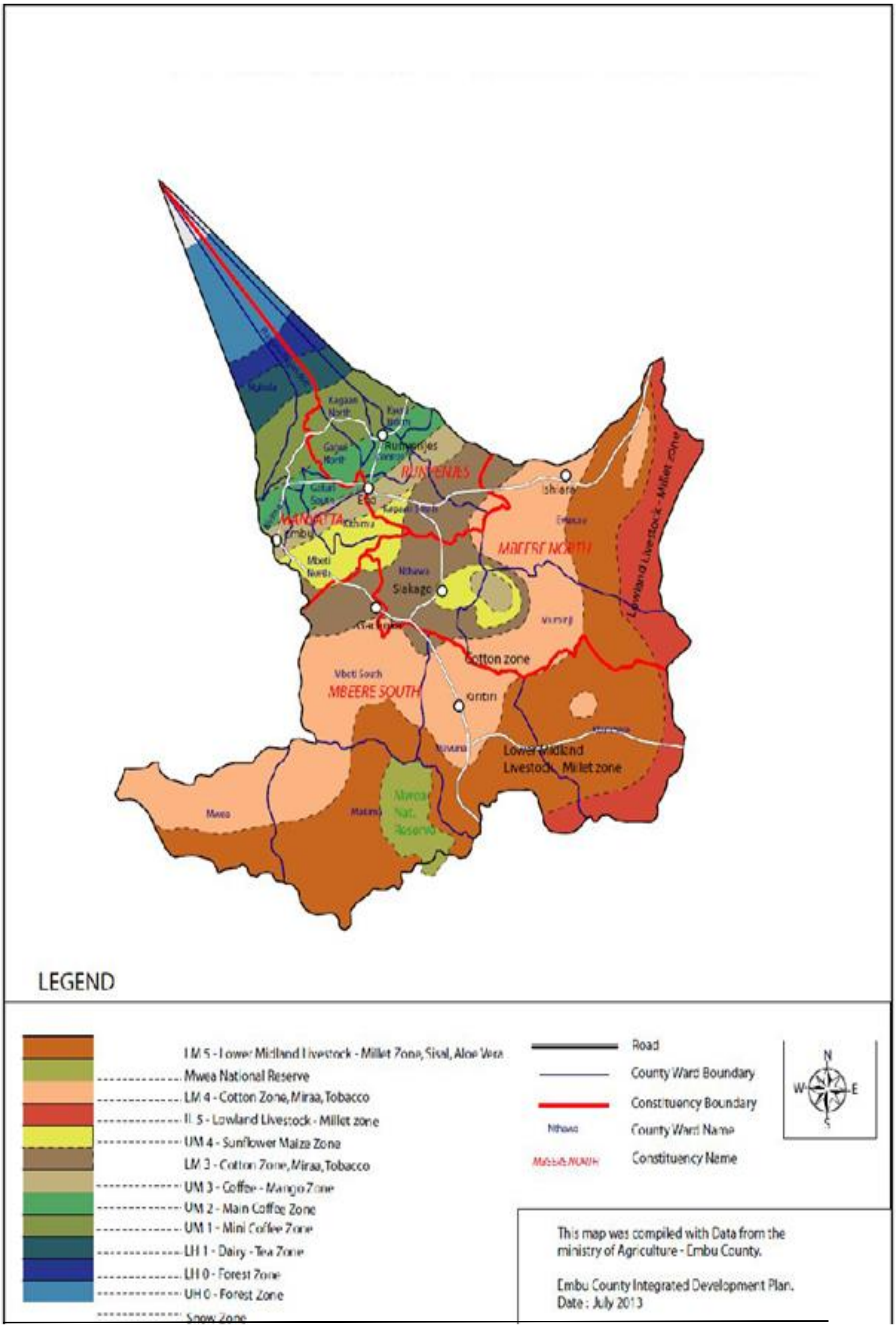

Figure 5. Agroecological Zones of Embu County (Embu County Government 2014)

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Agro-ecological Zoning (AEZ) refers to the division of an area of land into smaller units, which have similar characteristics related to land suitability, potential production and environmental impact. It is a land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use. The essential elements in defining an agro-ecological zone are the growing period, temperature regime and soil mapping unit. The AEZ of the study area are as indicated in Table 1.

Table 1: Summary of Agroecological Zones of Embu County

Ecological zone	Description	Soils	Rainfall (mm)
TA0	Rocks& Glaciers	(M)Mountain slope soils	1600
UH0	Forest zone	(M)Mountain slope soils	1800
LH00	Forest Zone	(Mv)Volcanic soils	2200
LH1	Dairy-Tea Zone	(U)Upland soils	1800
UM1	Mini Coffee Zone	(R)Upland soils	1600mm
UM2	Main Coffee Zone	(RB &H) Upland & Hill soils	1500mm
UM3	Coffee, Mango Zone	(L) Plateau Soils	1400mm
LM3	Cotton, Miraa, Tobacco	(LB)Plateau soils	1200
LM4	Sunflower, Maize Zone	(P) Plain soils	1000
L5	Livestock, Millet	(Pd)Plain soils: dissected plains	900
LM4	Cotton, Miraa, Tobacco	(Pd1) Dissected plain soils	800
1M5	Livestock, Millet, Sisal, Aloe-vera	(PdC & LB) Plains and plateau soils	700

Source: (CIDP 2014)

3.1.2 Topography and Vegetation

Rupingazi watershed is an area of radial drainage with most streams flowing into the Tana River (CIDP 2014). It has four tributaries forming its sub-basins namely Kavingaci, Thambana, Kanjikeru and Kiye. Thiba River, which is the main tributary of Nyamindi, joins Rupingazi River (Jaetzold *et al.,* 2007) at the lowest station of this study (SS19). This area therefore covers the whole area drained by Rupingazi river system through one outlet at the confluence.

The study area has seven agro-ecological zones, ranging from UH_0 (upper highlands which is wet and steep making forest growth the best land use in the zone), to UM_4 which is a dry land livestock-millet zone. In this watershed, each ecological zone supports and determines the nature of the environmental characteristics with peculiar

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responses concerning rocks, soils, topography and land use (CIDP, 2014). This has augmented and formed the basis for the locations of the study's 21 sampling stations (SS).

3.1.3 Soil Forming Factors in the Study Area

Soil is the medium for plant growth. The general characteristics of soil types and their distribution in the Rupingazi watershed have a close relationship with its physiography. Soil is the dynamic natural agent on the earth crust, which is composed of minerals and organic materials and living forms, in which plants grow. The Nyandarua and Mt. Kenya ranges have influenced the soil types and the agroecology of the study area (Ouma *et al.,* 2002). The study area is dominated by humic nitisols that are very deep and well drained.

The geology is mainly volcanic rock and ash and some old metamorphic rocks (Schoeman, 1952). The volcanic rocks in the area are related to the Rift Valley development during the Pliocene time and dated from 3.5 to 2 million years. Three phases of deposition by this volcanism can be distinguished. The first phase was during the main activity of Mt. Kenya. This phase took place during the upper Pliocene time. In this period phonolite and lahars flows were deposited in the area. These form the plateau level in the area which borders the basement system belt. The second phase was during the activity of the parasitic cones in the north eastern side of Mt. Kenya during the Plio-Pleistocene time (Jaetzold *et al.,* 2007).

Parasitic cones are cone-shaped accumulation of volcanic material forming from fractures on the side of a volcano because the sides of the volcano are unstable. The lava flows during this time consisted of lahar and basalt. The third, recent phase was during the Pleistocene time and is also related to the activity of the parasitic cones of Mt. Kenya. Lahar, tuffs and volcanic ashes were deposited during the time especially in the river valleys. Therefore the volcanic rocks related to the Mt. Kenya series are mainly lahars, phonolites, tuffs, basalt and volcanic ashes (Jaetzold *et al.,* 2007; Schoeman, 1952).

The soil pH in the Embu County ranges from strongly acidic (4.6) to slightly alkaline (7.7). However, most of the farms are acidic with varying acidity levels (NAAIAP,

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2014; Njeru, 2020). The soils in the LM zones have been observed to have low soil organic carbon (0.47% of total organic carbon) while those in the UM_1 and UM_2 zones have been observed to have as higher soil organic carbon of 3.67% of the total organic carbon (NAAIAP, 2014).

3.1.4 Dominant Soil Types in the Study Area

In Rupingazi River catchment, the dominating WRB (IUSS Working Group WRB, 2015) rreference soil groups (RSG) are: Nitisols, Ferrasols, Regosols, Vertisols and Phaeozems (Figure 6.). This is according to the 1:1 M KENSOTER map and database (Dijkshoorn, 2007). The western part is relatively humid with lower temperatures. Low rate of mineralization of organic matter, strong leaching and eluviation give rise to humic topsoils, and mostly acid soils with low base saturation like Andosols, Umbrisols and Alisols. Andosols which are mainly found in high elevation, humid zones of Mt. Kenya region are intermediary weathered compared to soil types in the middle and lower zones of the study area.

In the middle elevation, the rainfall and temperatures are moderate. Hence less leaching and moderate organic matter decomposition resulting in well structured, drained and deep soils evidenced by presence of Nitisols. Nitisols are deep, well-drained red tropical soils with diffuse horizon boundaries and a sub-surface horizon with more than 30 % clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedric ('nutty') elements. The genesis of Nitisols includes ferralization which result in loss of silica (Si), formation of kaolinite and accumulation of sesquioxides. The angular shinny peds are a result of nitidization caused by micro swelling and shrinking and pressure regulating clay particles in the form of ped faces. Bioturbation by ants and earth worms homogenizes soils (Driessen *et al.,* 2001). Rejuvenation of Nitisols through deposition and enrichment of volcanic ashes has been reported (De Wispelaere *et al.,* 2015).

Ferrasols are associated with high rainfall and very old (Tertiary) land surfaces (Jones *et al.,* 2013). They are strongly leached soils that have lost nearly all weatherable minerals over time. As a result they are dominated by stable products such as aluminium oxides, iron oxides and kaolinite which give Ferralsols strong red and yellow colours. Ferrasols are mainly found in the middle zones of the study area. The

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effect of past climate, alternating of dry and wet spells give rise to pisoplithic material as evidenced by presence of Plinthosols in the lower semi-arid zones.

Young soils like Cambisols show incipient subsurface soil formation on alluvial plains and shallow Leptosols which are mainly found in areas with basement rock. Presence of Regosols in the eastern semi-arid zones is evident due to extensive erosion and accumulation especially in the mountainous terrain. Regosols are weakly developed mineral soils in unconsolidated medium and show only slight signs of soil development. They are commonly found in extensive eroding lands such as mountains or desert areas where soil formation is generally absent or moderate (Dijkshoorn, 2007; Jones *et al.,* 2013).

Vertisols are mainly found in the lower landscape positions that are periodically wet in their natural state. Vertisols are clayey soils that exhibit wide crack which open and close periodically upon drying and wetting. This is caused by the presence of montmorillonite clay mineral, which takes up water when it becomes wet (swells) and releases the water again upon drying (shrinks). Phaeozems have a thick dark coloured surface layer which is rich in organic matter (De Wispelaere *et al.,* 2015; Dijkshoorn, 2007). This soil type was found mainly in the north eastern part of the study area where rainfall is adequate and grass for grazing livestock is the main land use practice.

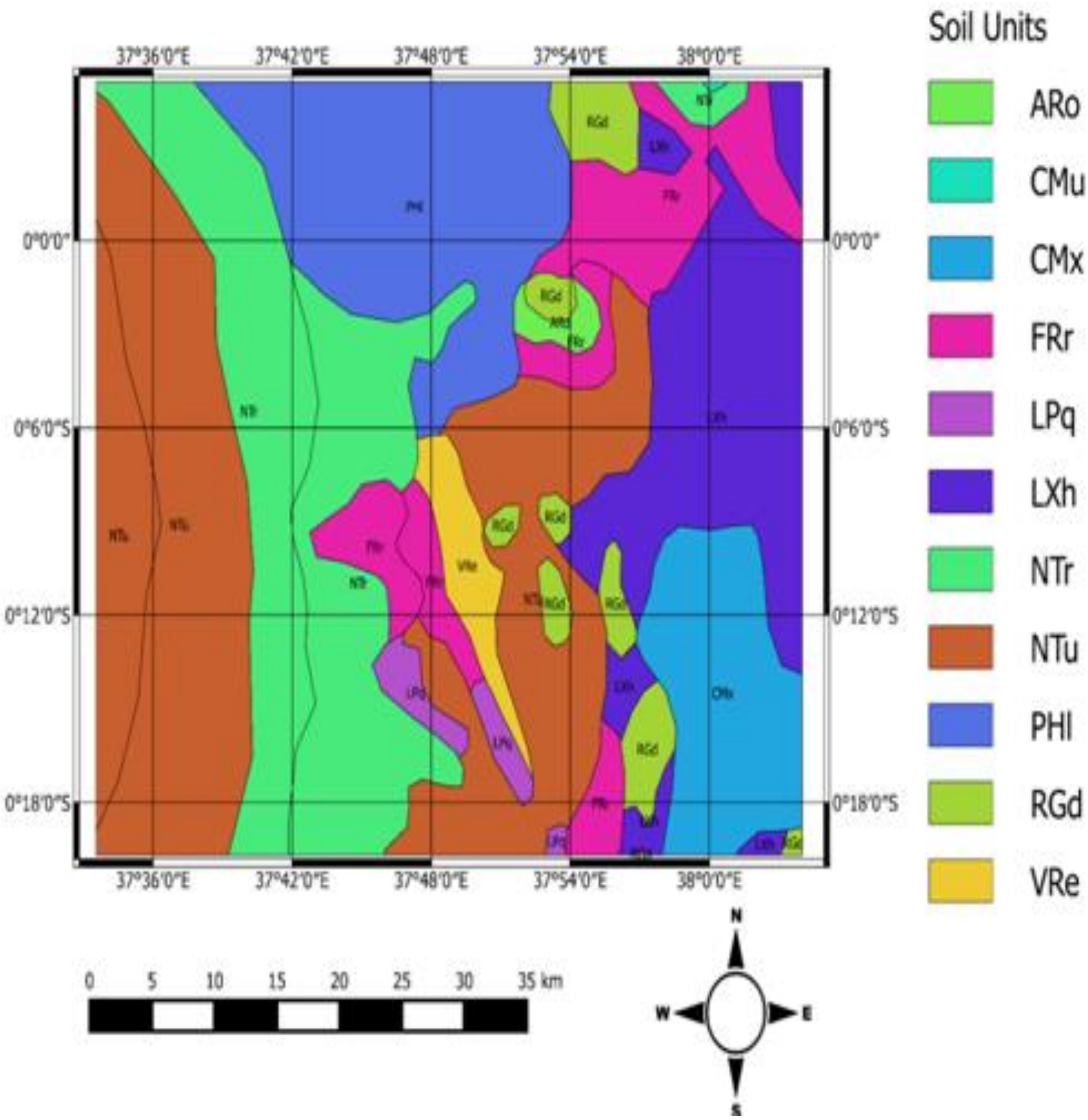

Figure 6. KENSOTER Soil Units for the Study Area (Dijkshoorn, 2007)

KENSOTER soil units descriptions (indicated by the dominant soil types)
ARo = Ferralic Arenosols; CMu = Humic Cambisols; CMx = Chromic Cambisols; FRr = Rhodic FERRALSOLS; LPq = Lithic Leptosols; LXh = Haplic Lixisols; NTr = Rhodic Nitisols; NTu = Humic Nitisols; PHI = Luvic Phaeozems; RGd = Dystric Regosols; VRe = Eutric Vertisols.

3.1.5 Soil Analysis

Two important characteristics of soil directly affected by land use require special attention in the contribution to geomorphic processes. These are; (a) soil porosity and soil (b) bulk density (Thompson & Troeh, 2009).

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Soil porosity is a major factor in the rock breakdown and weathering since porosity determines the capacity of the soil to hold water, gases and the minerals therein. The pores also affect the probable organic and chemical cycling and breakdown of the rock-forming minerals. In any field, porosity can be measured by taking four operational steps:

i) Take a sample of soil of known volume. Weigh the sample (W1)
ii) Place the sample in de-ionized water for about 12 hours
iii) Weigh the sample after the immersion period (W2).
iv) Use the formula given below to calculate porosity (P):

$= \frac{W2}{W1} - \frac{W1}{W1} x100.$ (Thompson and Troeh 2009)

This calculation gives the percentage pore volume of the soil sample. The above operation is, in effect, a measure of the water uptake by the soil or rock, and therefore an easier way to assess porosity. An alternative method has been carried out as shown below.

i) Cut a block of rock or soil and calculate its volume (V)
ii) Take a known volume of water in a container, e.g., one litre
iii) Place the block into the containers and let it soak (W)
iv) Absorbed water enters the pores (P). Porosity can be assessed through the displacement or by measuring the difference in the water volume after the removal of the rock, (the soil is difficult to remove, but since its external volume is known, therefore the displacement method is suitable), and calculated as below (Thompson & Troeh 2009).

$$P = \frac{W}{V} x100$$

Where;

P is the pore space,

W is water absorbed into the pores, hence pore volume

V is the volume of the block.

Soil bulk density is the relationship between the weight of a soil sample divided by its volume and given as g/cm^{-3}.

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The purpose for knowing the bulk density of the soil is threefold:

i) To assess the proportion of mineral content in the soil
ii) To assess the proportion of organic matter, and
iii) To assess the degree of soil compaction.

Geologically, the rocks of the crust (SIAL) have a specific gravity of 2.5 g/cm^3 (Duff 2012) but if this characteristic is altered, it greatly influences the soil and rock. This process is stimulated by the land use methods such as tillage, digging, ploughing and the general utilization of the soil. Land management can be altered or modified so that the rates of infiltration and porosity are affected Getis (2005). The microorganisms in the soil are a significant agent of weathering; therefore, changes in soil structure and affect landform evolution paces. In most soils, the organic matter has a specific gravity of about $0.5g/cm^3$. Any type of land use, other than none interference with the earth's surface, affects the crumb structure of the soil. Soil crumbing increases with depth in the soil, while the soil organic matter decreases with depth. Crumb structure is improved by the use of organic fertilizers, but not chemical fertilizers. The chemical fertilizers may contain chemicals in excess of what the soil requires so that they may become toxic or form unusable stable substances, which are not utilizable by plants (Thompson & Frederick, 2009).

3.2 Laboratory Analysis

Besides the tests that can be carried out in the field such as pH and infiltration, laboratory tests provide a direct indicator of the present substances and amounts and their sources. Therefore, the purpose of each analysis relates in specific ways to the objectives of the study in order to assess the contribution and influence of those measurements from the land use processes to the geomorphic dynamisms. Each analysis is an indicator of source of materials or chemicals. Additionally, by comparing different sections on the same slope, it helps to clarify the effect and influence of the added substances on rocks or soils. For example, the pH changes in a set of sampling stations (SS) from crest to the river channel provides an indicator of the substances' increase and influence (Thompson & Frederick, 2009). The soil and water samples were analysed at Chuka University Laboratories. The laboratory analyses relate to water and soil samples collected from identified specific points of study. All the materials and chemicals, except colour, electric conductivity, pH and

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turbidity are measured in milligrams per litre or expressed in parts per million. In order to assess the influence of the land use inputs, comparisons and differences in the quantities are made.

3.2.1 Colour

Colour in water analysis is reported in Hazen units. This was measured using Lovibond Nessleriser Colour Comparator. The determination of colour is based on the comparison of the water sample and a column of colours rated from 0 to 500. The standard is made from 1gm of cobalt and 1.245gm of potassium chloroplatinate to which is added 100ml of concentrated hydrochloric acid. The mixture is then diluted with one litre of distilled water. Colour is derived from dissolved or suspended particulate matter, which is an indicator of added substances to pure water. The colour is a result of both organic and inorganic substances. Colour is closely related to turbidity, which is measured using Turbidity metre: Turbidimeter HACH, model 2100A. Turbidity is generally the colour or hue or opaqueness of the water due to suspended matter. Like the colour, turbidity is an indicator of substance contents in water. Further analysis helps to point out the sources of those substances as a result of erosion or dissolved substances (Price *et al.*, 2011).

3.2.2 pH of Samples

This is measured using a pH metre PYE model 79. This is a measure of hydrogen ion concentration. Water has a nonhydrated hydrogen ion, H_2O which is the same as H^+ OH^- when ionized. When water is neutral, the H and OH are the same. The pH is lower in an acidic solution and higher in a basic solution. It is noteworthy to know that the pH in a water sample may change during storage so it is best to measure the sample immediately. Field analysis was carried out at the sampling station and compared with laboratory results.

Acidity and alkalinity are usually denoted by their pH. The pH is a scale of the measure of acidity or alkalinity which quantitatively measures the concentration of hydrogen ions in a solution ranging from 1 to 10^{-14}gram equivalent per litre of water and given in a scale, (generally called chart), ranging from 0 to 14. For clarity, water is neutral as stated above, therefore it is at the midpoint of that scale, 7, and therefore it is at 10^{-7} or a pH of 7. Any substance with a value below 7 is acidic while values

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above 7 are bases. The pH levels are important in the chemical reactions, which are involved in the rock weathering processes (Plowright, 2012).

The state of the pH affects the ability of water to conduct electricity. This an indicator of the substances dissolved in water, which may be taken from the soils away from the river channel. Electrical Conductivity Measuring set model MC-1mark V was used. Conductivity is the ability of a substance to conduct an electric current. This is considered in specific conductance per centimetre and it is a reciprocal resistance, which is reported in ohms or microhms; neutral water has less than one ohms. Conductivity is due to dissolved substances in the water. This measurement is a good indicator of added substances in water. The laboratory results for different locations are a good pointer to the sources of the substances.

Soils were air-dried and ground through a 2mm sieve. A mixture of soil and distilled water in the ratio of 1:2.5 and 0.01 M $CaCl_2$ 1:2.5 using suspensions in water. The mixture was then swirled. The soil pH was determined using a pH meter (EYELA model pH M2000) as recommended by (Okalebol *et al.*, 1993).

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Table 2: Summary of Data Collection Procedures

Items	Instrumentation	Process	Remarks/Results
Slopes	Clinometer, tape measure, ranging poles	Hind and foresight angles averaged	Angles of slope, segments demarcated
Soil pH	pH-kit, universal indicator solution	Solution in water and the litmus indicator. Colour chart	pH recorded
Soil infiltration per minute	Soil in a funnel with a paper filter.	Water poured in to filter through; five minutes	Water collected and measured @mm. per minute
Water	Containers (sample bottles)	pH measured organic matter, mineral contents	Laboratory analysis for properties
Tillage soil displacement	Digging implements	Movement at different gradients	Distances moved measured
Gullies	Tape measure, rope, metre rule	Rope across the gully, depth measured to find the volume of lost soil, paths, tree-root exposure	Estimated loss per period of time
Vegetation		Estimate as %	Cover estimates

To determine the impact of flowing water on slopes, on the channel and the banks, and other fluvial events, the colluvial materials at the bottom of the slopes and pediments, the assessment and reconstruction of slopes was done in order to evaluate past slope forms and present operational geomorphic processes. Assessments included ergodic or location-for-time substitution, where material is transported, fabric analysis done to show where particles impended in the soils indicate the direction of solifluction to affirm the direction of material transportation by erosion.

Tree-root exposure was considered an important way to signify the general result of denudation in any location. Tree stems bent at or near the bases and leaning fence poles are physical indicators of soil creep. Turf rolls and strata distortion are good indicators of material translocation. Slope correlation data enables comparison of slopes in different agro-ecological belts. This was done by comparing the cross section and profile of a site slope to the nine-unit slope elements. Eroded materials, both solid and in solution, chemical inputs from farm and settlements which may influence geomorphic processes were an important variable. These substances are

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inputs into the lithosphere while sediments and effluents from source and non-source origin also alter the rates of denudation on geological formations and affect slope dynamism (Price *et al.,* 2011).

To investigate the effect of water yield from the built-up areas, roads and other surfaces, measurements of gullies was deemed the best method. Presence of water features such as springs and ponds were also considered as points of modified geomorphic processes developed from their microclimatic conditions, or as indicated as areas of eutrophication. The methodology of data collection is summarised in Table 6 and Table 8.

3.2.3 Chlorides

Chlorides are measured with a Chloride Metre. Chlorides are measured as acids and domestic water is treated using chlorine. Addition chlorides come from chemicals generally used for osmotic regulation in some crops and as a basic substance in fungicides. Addition of chloride and chlorine is a continuous contribution from domestic activities. Another present contribution into the soils and rocks are the fluorides. Fluorides are measured with Ionalyser Specific ion metre and reported in parts per million (Simon & Collison, 2002). Domestic use of fluorides in urban area is continuous contributor to the contents of fluorides in soils and water from dental care such as fluoridated toothpaste in the fight against dental caries.

3.2.4 Potassium and Sodium

These are determined and measured with a Flame Photometer, model 407A.These chemicals are contributed by fertilizers from which residues are washed out by rain into the water systems, especially rivers. Potassium and sodium as fertilizers can be used interchangeably by plants fertilizers and are very commonly used in farms. According to the International Fertilizer Industry Association (2002), the use of fertilizers has to balance between three levels: deficiency, when there is need for added nutrients in form of fertilizer application in the soil; optimum levels, which can only be measured through soil analysis; and excesses, which introduce different levels of toxicity in the soil. In the area of study, there are, virtually no such mechanism for assessing such level to create equilibrium.

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3.2.5 Biochemical Oxygen Demand (BOD)

This is Biochemical Oxygen Demand, which is measured by AZAD. This is a measure of the amount of oxygen required to remove organic matter from the water in the process of decomposition by the aerobic bacteria. This measure provides the degree of organic pollution in water. The levels of BOD determine the levels of eutrophication in lakes and rivers. The added organic materials from land use are therefore indicated by this analysis. An important phenomenon is the TDS. This denotes the Total Dissolved Substances. This is a measure of ions and cations reported in terms of the elements in water such as iron. Acidity is not included in this measurement. To ensure accuracy, the TDS is usually compared with the evaporated residue. In streams, the TDS relates to the land use activities in the valleys and other substance sources, including urban drainage (Hanwell & Newson 1993).

3.2.6 Hardness

This can generally be considered as the readiness or reaction of water with soap. This is measured by the process of titration of a standard soap solution as the old method, while the new method of chelation using disodium salt of ethylenedia-minetetra-acetic acid is quantitative. Hardness is a parameter of water quality affected by amounts of dissolved minerals especially calcium and magnesium, particularly as bicarbonates chlorides, sulphates and ferrous oxides. These minerals are abundant in water runoff and effluent from construction sites, and from domestic activities. This section serves the purpose of clarifying the link between land use and its contribution to the agents, which directly affect the geomorphic processes (NEMA, 2017).

3.3 Socio-Economic Characteristics

According to the 2009 national population census, Embu County had a total population of about 516,212 in 131,683 households, forming 1.3% of Kenya's population. The County's population density averages about 210 people per square kilometer (GoK, 2018; KNBS & ICF Macro, 2010). Although the County is characterized by a rural settlement, population density in the urban area is higher than in rural areas. The settlement pattern in the study area is greatly determined by rainfall patterns, farm productivity and socioeconomic activities (MoLAF, 2016).

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Agriculture is a major land use activity and the main economic activity for the people in the County and particularly provision of food. More than 80% of the working labour force in the county is involved either directly or indirectly in the agricultural sector (MoLAF, 2016). Rain fed crop farming covers about 30% of the County's total land. Of this, 77% is under food crops while the remaining 23% is under cash crops (GoK, 2013). Due to continued land fragmentation, the average household farms size was 1.98 acres for small-scale farmers and 7.4 acres for large-scale farmers. More than 60% of these farmlands were fully adjudicated and had title deeds (KNBS, 2006). Majority of the farming households in Embu County, practice mixed farming, where they rear livestock and grow crops (GoK, 2013). However, most households get the highest on-farm income from crops, followed by livestock production (GoK, 2014)

According to CIDP (2019), there are several small-scale quarrying and abstractive activities along the Rupingazi watershed. There are patches of ballast rocks along the watershed. These abstractive and quarrying activities in the area remain largely uncontrolled.

3.4 Research Design

This is an applied research study with the aim of solving a problem, providing guidance and alternatives for policy decisions. The study employed qualitative and quantitative approach methods at four levels in order to obtain the relevant data. The primary data collected from the field through direct observation and measurements for such aspects as slope gradient and topographical structures and the secondary data, were obtained from documental background to the study, County Government. The experimental operations, physical and chemical parameters were undertaken in the field in which experiments intended to evaluate such parameters as soil pH, infiltration rates, slope gradient and water action role as factors in geomorphic landform evolution. These data collection processes were done at the sampling stations, SS, from the channel and along the strike of the slope at specified points selected as representative sample stations. The stations were chosen through stratified sampling method at intervals of 10 km on average, and in consideration to the agro-

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ecological zones and required data. Angles of slope and other topographical gradients were assessed and measured using clinometers, pantometers, and tape measures.

This study adopted a multi-point descriptive and quantitative survey design encompassing longitudinal and cross-sectional analysis to assess land use practices and their influence on geomorphic processes. According to Bryman and Bell (2007) a longitudinal design allows a researcher to repeat the observations of the same variable over time. Therefore, the contribution of an individual item (land use) over the outcome some specific events can be examined. For example, tillage was assessed and its influence on soil movement on slopes examined (Kothari, 2004). This made the research design appropriate for the study.

Since the study examined several variables existing at the same time and collected data related to multiple variables with a view to establish possible relationships, Bryman and Bell (2007) recommend this design. Moreover, Kothari (2004) argues that descriptive cross sectional research design allows for use of observation sheets and collection of samples as was envisaged in the study. The design was suitable because it was not restricted to fact finding but led to formulation of knowledge and examining how land uses influence geomorphic processes. The descriptions involved parameters such as soil pH, infiltration rates, slope gradient and water action role as factors in geomorphic landform evolution. The design was suitable for the study because it suffices in fact finding and allows sufficient interpretation. Additionally, the parameters examined were not being manipulated but were carefully and completely observed as advised by Good (1992).

3.5 Sampling Procedures

The Rupingazi watershed was divided systematically by a set of grids (of 5 km), using systematic sampling method, and therefore at least 10 km, apart. Further, every area was allotted three points for data collection as point sampling. Points with relevant information such as vegetated areas on different slopes which are non-point source stations, and points of special geomorphic interest such as landslides were used.

The second step in establishing the sample points was choosing specific points within the grid squares but along the river channel. Along certain points such as catenary

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systems or substance plumes, transects were established. Where necessary, for comparison, or in a place lacking of contrasts or where the need to get average data was necessary; random points were chosen. Assessment of such a parameter as soil loss from gullies along certain land uses were chosen using random numbers design to obtain points on the surface and measurements and calculations carried out (Appendix 2 and Table 5).

Compass was used to select distance against a fixed direction using random numbers. This was made possible by taking angles and distances selected using the random numbers from 0-360 (Appendix 2). These methods have the advantage of a more complete coverage of the area of study since every part is reasonably represented.

Study stations' locations were fixed and identified using Garmin GPS-MAP 64s through the satellite and Google maps app. To obtain relevant information, Rupingazi River was divided into Study Sampling stations (SS) locations that were identified first, using GPS. After the appropriate locations were identified at the river channel, (1, 4, 7, 10, 13, 16, and 19), two other stations were fixed along the transect at mid-slope and at the crest. The second step was categorisation by the interactive aspects of topography, geology and agro-ecological zones, the most suitable points on the transect. Every three related points (by location) form the sampling unit of the sampling frame. Different methods of data collection, besides direct observations, measurements and experiments were carried out. Pseudo–experiments in the field were carried out where measurements were taken in order to establish significance levels of the data collected through repeated measurements. Controlled experiments were also done in the field where some investigations were carried out under artificially controlled conditions, for example, infiltration rates, percolation and plumage of effluents and tillage methods (Barnaby, 2011; Plowright, 2012; McTavish & Herman, 2014).

The landforms within the watershed include all topographical features, which are under the influence of varied aspects of land use. The study incorporated the drainage system assessments and urban settlement land use. This therefore included Embu town, Manyatta, Kianjokoma, Kanja, Mutunduri, Kibugu, Don Bosco and Gachuriri which form the major sampling stations (SS) points. These stations also make up the

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study population for investigation of this study, therefore constitutes 21 stations, as indicated above, one at the river channel and two stations related to it as an extension from the channel to the crest of the spur. The choice of these stations was done with consideration to the study watershed and the agro-ecological zones, Shohei (1987), within the 65 km length of the watershed. An average width of 10 km. making up an area of approximately 800 km^2. Points of investigation were identified in order to make the coverage more representative so as to yield appreciable data. As suggested by Booth (2003), Barnaby (2011) and McTavish and Herman (2014), the larger the sample size the better it is, in order to determine the true representation of the population. The sample stations form the largest adequate population.

This method also generates secondary sampling stations, which, when necessary, are fixed using the Bretschko 0-360 Random Numbers which represent $0^0$to 360^0 (Appendix 2). To generate a new SS, a random number is taken, where the first number represents the direction to be taken for fixing a new point and the second number chosen indicates the distance to be taken to the point where the extra point is to be fixed. This procedure was repeated over if more than one SS are required.

Through systematic and point sampling method, 21 major stations were fixed (SS) within the watershed at appropriate data yielding points of the watershed which is mainly in Embu and slightly touches Kirinyaga counties. At these stations, measurements and experiments were done to collect primary data on slopes gradients, weathering, erosion and deposition indicators. Soil and water samples were collected from the stations for laboratory analysis.

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The distribution and location of the sampled stations is summarised in Table 3.

Table 3: Location of Sampling Stations

Station name	Station number	Altitude	GPS	Agro-ecological zone (after Shohei 1987)
Kathangariri (Kiandari)	SS1-3	2,320m	S 0^0 21' 43 47 E $37^0$32'92.63	Forest, dairy, tea, fodder, vegetables
Kairuri	SS4-5	2,057m	S 0^0 23'45.34 E $37^0$34' 39.32	Forest, dairy, tea, coffee
Ndunda		1,879m	S 0^0 25'53'78.05 E $37^0$30'52.65	Coffee, dairy, mixed farming
Embu-Kathita	SS6-9	1,331m	S $0^0$31' 52.21 E $37^0$26'50.30	Coffee, dairy, mixed–crop farming
Embu-Dallas	SS10-12	1,315m	S 0^0 32 50.40 E 37^0 27'20.20	Coffee, dairy, pastoralism, cereal
Don Bosco (Riamangeta)	SS13-15	1,254m	S 0^0 34' 49.12 E $37^0$29' 19.5	Maize, cereals and pastoralism
Ngomano (Gachuriri)	SS16-21	1,069m	S 0^0 54'51.47 E 37048'52.66	Cereals irrigation pastoralism & khat, (mirra)

Information on Table 3 shows that the location of SS 1-4 is in the Upper reaches of the drainage system: SS 5- 15 are in the Middle of the drainage system and SS 16-21 are in the Lower reach of the drainage system of the watershed. These fall within the agro ecological zone (AEZ).

3.6 Research Instruments

The main instruments employed were: clinometers, pantometers, tape measures, pH-kit, sample bags and bottles for water samples besides equipment for digging, cutting and scooping. The points were identified, as indicated using a Garmin GPS-MAP64s and Arc GIS, Landsat imagery and Google Earth app.

3.7 Validity of the Research Instruments

Validity is the meaningfulness and accuracy of inferences given by a study in relation to the actual phenomena studied or to be studied (Borg & Gall, 1989). For content validity, the researcher sought the input of supervisors and experts in environmental studies at Chuka University. The experts evaluated the applicability and appropriateness of the contents, clarity and adequacy of the items on the observation

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schedule. This followed the advice of Borg and Gall (1989) that the validity of an instrument can be improved through experts' judgement

3.8 Reliability of the Research Instruments

Reliability is a measure of the extent to which random errors are involved in the measurement processes in the data due to unknown factors, McTavish (2014). Most data used in this study is primary data collected in the field, and therefore with minimal degree of risk of bias. The collected data was subjected to tests of significance using standard methods stated above as was deemed apt and as exemplified by Booth *et al* (2003); McTavish (2014). Data in the field and observation was taken more than once to ensure reliability.

3.9 Data Collection Procedures

Data was collected at the established stations, which were distributed within the study area. In nature, certain data is only obtainable when rare events occur such as earthquakes, storms and so on. In the case of this study, some data was collected at specific occurrences when specific events relevant to the study presented themselves as significant source of data, for instance landslides or slope failure, which can only be evaluated during the specific instances. The presence of microclimates resulting from such physical phenomenon as springs and ponds was also noted in this study. At a sampling station centrally located at the river channel, two or more secondary sampling points were identified at midslope and the crest of the spur. These were selected with consideration to altitude, GIS location, soil sample, vegetation, weathering, erosion and other relevant measurements.

3.10 Observation

Using an observation schedule (Appendix 14, 15), effects on geomorphic processes associated with land uses were recorded. The researcher focused on features such as gullies, cracks on the ground, tree-root exposure, tilted trees bases, footpaths by animals and arrangement of rock layers on quarry slopes. Photographs of such features and evidence of geomorphic processes were captured using a digital camera.

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3.10.1 Field Measurements and Samples Collections

In order to evaluate the influence of denudation on landform evolution, measurements of soil loss on slopes by assessing tree-root exposure, gully sizes, turf-roll and the place of eroded materials. Soil pits were used in catenary assessments and throughflow in different parts of the watershed identified according to the established stations (Plate 11). Pedatic processes included measurements of infiltration rates and field capacity. These measurements enhanced calculations on soil bulk density at different locations and correlation of spatial variation done.

3.10.2 Soil Sampling

Random Soil samples were taken along the Rupingazi watershed considering factors such as the topography, drainage conditions, farm management practices and cropping systems, as advised by NAAIAP (2014). Ten soil cores were pulled per samples taken in a systematic grid pattern using a graduated soil auger. The soil samples were taken from a 30 centimetres depth, which was considered ideal since it covers the depth of most farmed crops in the area. The soil cores were combined in a large plastic container to form a soil composite, which was thoroughly mixed. Soil samples weighing 500 grams of soil were measured, packed and labelled by site location.

3.10.3 Laboratory Soil Measurements

The packed soil samples were taken to the laboratory and tested for soil pH, porosity, organic contents and main chemical elements. In this section, the conventional soil properties analysis using the wet chemistry methods, are highlighted. Sample pre-processing before analysis is explained. First all soil samples were air-dried then large clods were crushed and sieved using a 2 mm sieve. The samples were analyzed for the following parameters with the respective methods following the recommendations of Van Reeuwijk (2002).

i) pH–potentiometrically measured in the supernatant suspension of a 1:2.5 soil: liquid (H_2O) mixture.
ii) Cation Exchange Capacity (CEC)-Ammonium acetate method (Van Reeuwijk, 2002)
iii) Na, K, Ca, Mg and Al following Mehlich 3 extraction.

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iv) Soil organic Carbon (SOC) and total nitrogen (TN) following thermal oxidation (Baldock & Skjemstad, 2008 Soil organic Carbon (SOC) and total nitrogen (TN) following thermal oxidation (Baldock & Skjemstad, 2008).

Table 4: Data Collection Methods

Data	Extra data	Source
QGIS	Landsat imagery	Satellite data and field measurements
QGIS Slope gradient measurements	3DEM Soil samples GIS Overlays	
Erosion gulley Landslide	GIS Overlays, soils and water samples	QGIS overlays
QGIS overlays	Slope gradient measurements,	Field measurements
Slopes	Soil samples; slope angles	Samples of soil and water
Slopes and soils Water samples	Field analysis; infiltration and pH	Measurements

The field measurements and analysis were compared with the laboratory results for better understanding of the data. It was found out that there was very little difference in the results. Climate data was secondary data provided by the Embu Meteorological Station. Data collected from the field involved different procedures as summarized in Table 4.

Table 4 was an important tool in regard to site finding verification. This was done using the data sheet (Appendices 13 and 14). The analysis of slopes and the ensuing erosion are observed in the field but require the corelation in regard to soil movement. For example, in sampling station 5, the use of the use of QGIS overlays enabled time-sequence development of soils, infrastructure and vegetation for varying periods within the timeline of this study. In sampling station 4, the GIS overlays were the best way to reconstruct the shifting characteristics of the river channel and the evolution of the river cliff (bluff). The combined investigation of GIS overlays and field measurement complement each other in affirming the data and the reconstructed geomorphic processes.

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3.11 Data Analysis

The study sought to answer three research questions and data was analysed using the statistical procedures indicated in Table 5.

Table 5: Summary of the Variables and Statistical Procedures

Research Question	Independent Variable	Dependent Variable	Statistic
i) What is the influence of farming practices on geomorphic processes in Rupingazi watershed, Embu County Kenya?	Crop farming Livestock farming	Geomorphic Processes	Frequencies Percentages
ii) What is the influence of urban settlements on geomorphic processes in Rupingazi watershed, Embu County Kenya?	Urban and rural settlements	Geomorphic Processes	Index of Dissimilarity
iii) What is the influence of quarrying and abstractive activities on geomorphic processes in Rupingazi watershed, Embu County Kenya?	Abstractive and quarrying activities	Geomorphic Processes	Frequencies Percentages

The data collected from the field observation sheets was edited immediately. The collected and data and was examined and organized in terms of its completeness, comprehensiveness, consistency and adequacy. The organized data was then coded and entered into the Census and Survey Programme (CSPro) for further cleaning. The cleaned data was then imported in a computer for analysis using the Statistical Package for Social Sciences (SPSS) version 22 for windows. The data was organized and analyzed according to study variables and research specific objectives

The data was analysed for measures of dissimilarity, relationships and measures of dispersal, and presented in maps, diagrams, charts, graphs, photographs and other prescriptive reports. To evaluate the influence of erosion on landforms, the slope angles and the deposited materials and the removed material was correlated. They were also reconstructed by measuring the erosion indicators such as gullies and tree-root exposure, footpaths (Appendices 1,18; Tables 6 and 8). Additionally, animal

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trails were also examined especially where ranching was practised. The data used to elaborate the analysis is part of the primary data collected in the field for this study.

3.12 Ethical Considerations

Ethics is the code of conduct or expected behaviour while conducting research (Mugenda & Mugenda, 2003). Prior to data collection, the researcher sought clearance from Chuka University's Research Ethics Committee and later obtained authority to conduct the study from NACOSTI. The purpose of the study was explained to the owners of the land in which the stations were established. In the whole process of data collection, the researcher and the trained research assistants observed all applicable research ethics and particularly established rapport with all the people in the field in an effort to win their trust. Confidentiality denotes the researcher's ethical obligation to keep the respondents' identity and responses private (Plowright, 2012). Therefore, the respondents were assured that the information collected on their properties would be treated with confidence and that it was to be used for academic purposes only. All works other than the original primary data have been acknowledged. The research took due respect to people and the environment.

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CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Influence of Farming Activities on Geomorphic Processes

Farming is the predominant land use in the Rupingazi watershed. The study examined farming practices under crop production and livestock rearing. The results are presented and discussed hereunder:

4.1.1 Influence of Crop Farming and Geomorphic Processes

In crop production, several activities are involved. However, since tillage practices involve disturbance of soils on farms, the study endeavoured to establish the influence of tillage on the geomorphic processes. In order to assess influence of tillage on slopes, six marked points (half a meter apart) were chosen on the same slope with similar soils but at varying angles of slope according to the angles forming the elements. A stretch of land three meters wide along the contour line was chosen at points with the gradients 6^0,16^0, $19^{0,}$ 22^0 and 26^0. The three meters were divided into 50 cm portions. Using the same digging implement, the portion was dug once along a set line and the distance moved by the displaced soil measured and recorded. The results were presented in Table 6.

Table 6: Distance of Soil Moved in Tilling Land

Angle of Slope	Distance of Moved Soil at Various Points (cm)						Average Distance moved (cm)
	Point 1 (at 50 cm mark)	Point 2 (at 100 cm mark)	Point 3 (at 150 cm mark)	Point 4 (at 200 cm mark)	Point 5 (at 250 cm mark)	Point 6 (at 300 cm mark)	
6^0	80	54	70	65	85	67	70.2
16^0	80	90	70	80	80	80	80
19^0	90	93	90	70	100	100	90.5
22^0	100	120	124	130	110	125	118.2
26^0	112	126	124	128	132	116	123

Information on Table 6 shows that tilling the land using a hoe at a slope angle of 6^0, the soil moved the least (54 cm) at point two (100 cm mark) but the tilled soil moved a distance of 85 cm at point 5, which was the greatest at that slope angle. On average, tilling land on a slope angle of 6^0 caused soil to move by about 70 cm. Tilling land at 16^0, caused soil to move 70 cm at point 3 but moved the furthest (90 cm) at point two.

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On average, tilling land at angle of 16^0 displaced soil by 80 cm from the original point of the soil. At point four, soil moved by 70 cm when tilling was done on a farm with slope angle of 19^0. However, soil moved the furthest (100 cm) at both the fifth and the sixth points when tilling on farm with an angle of slope of 19^0. Evidently, tilling using a hoe on farm slope with angle of 19^0 caused the soil to move by about 90.5 cm.

Tilling using a hand hoe on a farm with slope angle of about 22^0, caused the soil displacement downslope by about 118.2 cm. At this slope angle, soil moved the furthest (130 cm) at point four while soil moved the least (100 cm) downslope at the first point. At the first point, soil moved the least (112 cm) distance while it moved the furthest (132 cm) at the fifth point, when tilling on a farm with a slope angle of 26^0. It was at this slope angle that the soil moved the furthest, with an average distance of 123 cm, when a hand hoe was used for tilling.

To establish the relationship between the angle of farm slope and the distance of soil moved when tilling, a Pearson correlation test was performed. A correlation coefficient of 0.91 was obtained, indicating a very strong relationship between the angle of farm slope and the distance of soil moved downslope when tilling. That implies that as the angle of slopes increased (became steeper) the further the tilled soils moved. Therefore, tilling on very steep slopes moved soil the furthest while the tilled soil moved minimally on gentle slopes. Given that tillage is carried out about four times a year (before planting and during weeding for two seasons), the cumulative effects of the moved soil would be of significance to geomorphologists.

Each time a hoe is pushed or rammed into the ground, a mass of soil the depth of the length of the hoe and its width is lifted and shifted downslope. Field observations established that for every hit on the ground with the hand hoe, an average weight of two kilogrammes of soil was shifted downslope. If hand hoes (with average width of 25 cm) were used to dig a 100-metre-wide farm, then one can establish the total amount of soil moved. To dig the width of the farm implies 400 hits by the hand hoe (100x100/25). If a single hit by a hand hoe moves about two kilogrammes of soil, then by digging a strip along the 100 metres wide farm would move 800 kilogrammes of soil materials (400 hits multiplied by 2 kilogrammes) in one season and shifted downslope a distance corresponding to the gradient Table 6. Therefore, continuous

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cultivation on such farms would move tonnes of soil. This indicates the influence tillage has on geomorphology. This agrees with the findings of Mainuri and Owino (2014).

Tillage and the movement of soil contribute to geomorphic dynamism. This is because tillage and resulting removal of regolith expose a new erosional surface for weathering. In addition, the eroded materials change the morphometry of the land surface so that the angle of slope changes. Moreover, where the eroded materials finally rest, changes occur in the angle of repose and the rates of weathering. This happens by either preserving the rock below it or introducing materials, which change the rates of the active type of weathering and erosion. Besides, if the eroded materials reach the river channel, they alter the fluvial processes by increasing the rates of erosion. This is so because the capacity and the competence of a stream change simultaneously as the channel roughness and other parameters change. This is consistent with earlier findings by other studies (Gregory, 2006; Gumisiriza, 2014; Waters *et al.*, 2014).

Table 7: Main Crops Grown in Rupingazi Watershed

Crop	Percentage (%)
Napier grass (*Pennisetum purpureum*)	23.2
Sweet potatoes (*Ibomea batatas)*	12.3
Maize (*Zea mays*)	16.4
Beans (*Phaseolus vulgaris*)	12.8
Arrow roots (*Maranta arundinacea*)	16
Bananas (*Musa spp*)	15
Tea (*Camellia sinensis*)	4.3

The study further sought to establish the main crops grown on farms along the watershed. The results are as presented in Table 7.

In crop production, several activities are involved. However, since tillage practices involve disturbance of soils on farms, the study examined tillage practices to establish its influence on the geomorphic processes. In order to assess influence of tillage on slopes, six marked points (half a meter apart) were chosen on the same slope with

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similar soils but at varying angles of slope (gradient) according to the angles forming the elements

According to the information on Table 7, napier grass was the most common (23.2%) cultivated crop along the Rupingazi watershed. This fodder crop was mainly grown on terraces to stabilize the terraces. Similarly, the sweet potatoes cultivated on farms acted a good cover crop and may have enhanced soil water conservation by reducing soil erosion. Since the households within the catchment area rely on *githeri* (mixture of maize and beans), this partly explains the common occurrence of maize and beans on farms. Arrowroots were mainly cultivated on swampy areas and wet river banks of the watershed. These observations on common crops in the study area compare favourably with earlier findings of Njeru (2020).

Crops are of significance in geomorphology because of their role in soil water conservation and soil erosion. Soil without vegetation cover is prone to effects of soil erosion as seen on Plates 12, 19, 21 and the impact raindrop (Plate 24). Cover crops such as sweet potatoes and beans reduce the impact of surface run off hence reducing the amount of soil that would otherwise be carried downslope by running water (Njeru, 2020). Where this soil is deposited and accumulates, it changes the slope of the section. As Duff (2020) explains, creep would occur as a result of many small displacement of particles and grains that are moved by surface run off and propelled by gravity. Similarly, as the soil is moved downslope, the underlying layers of soil are exposed to more agents of weathering. If the soil erosion occurred on a steep slope, gullies are likely to develop. Gullies are viewed as providing conditions under which landforms evolve through relatively small, but cumulatively significant land sculpturing geomorphic process of denudation (Summerfield, 2013).

Cultivation of certain crops may indirectly affect the geomorphic processes within where they are grown. For example, cultivating crops such as sweet potatoes and napier grass in the study area was found to attract burrowing animals such as squirrels and moles. Evidence of molehills and soil moved can be seen in Plate 1.

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Plate 1. A Mole-rat Hill on Napier Grass *(Pennisetum purpureum)* Farm at Mutunduri.

Information on plate 1, shows moulds of soils, an indicator of the African mole rat (*Tachyorytes spp*). This subterranean rodent with a body length of 15 to 30 cm weighs between 150 and 560 grams. These moles are significant because they not only eat roots of cover crops but also make burrows on farmlands. In making their burrows, used for habitat and in searching for food (comprising plant roots, tubers and bulbs), the resulting tunnels can be as extensive as 300 meters. The burrowed depth is 10 to 25 cm below the land surface but may be layered so that the deeper layers form the habitat, food stores and places for excreta.

The mole rats breed very fast with a gestation period of one month and can have a litter of 1 to 5. The moles therefore contribute to biomechanical weathering by way of the influence of their activities on denudation (Encyclopaedia Britannica, 2011). The average diameter of the burrow is 10 to 15cm. Field observations established an average number of five to ten moles in an acre farm.

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To explain the influence of these moles on geomorphic processes on farms where they occurred, estimates of moved soils were made. Field measurements of the shifted materials showed that each molehill averaged 3 kg in weight. The number of molehills depends on the size of the burrow and the number of mole rats. On average, with a burrow length of 100 meters, about 5,000 kg of soil would be loosened and put on the surface to be eroded. Therefore, an acre of land with 10 moles will loosen and make ready for erosion at least 50 tonnes of soil. There can be more soil moved especially where farmers opt to eliminate the moles by digging in order to manually remove the moles from their burrows. When the burrows collapse or if the rodent dies the same volume of rock material must be shifted to fill in the burrows. In addition, the air trapped inside the burrows may trigger mass movement as observed by Twidale (1998) in Australia. This makes farming a significant contributor to landform change induced indirectly by burrowing animals.

Where farming is carried out close to the riverbanks (Plates 2, 17, 20, 21), only a vegetated buffer zone and trees can mitigate the effect of erosion. The right middle ground (Plate 2) is the corresponding point; the bench left on the opposite side of the river by erosion during flooding. This is another point at which grading is initiated after flooding event, when the ability of floodwater deeply erodes the riverbanks. Here a nearly two-meter bluff has been excavated on the left bank and deposition of material on the opposite bank, slip-off slope occurs. The slopes on either side have to grade to the newly set repose so that the left bank has to grade itself to the new base level which is two meters lower than previously. In Plate 2, the left bank has to grade to the new higher level by depositing material as it starts the new grading by aggradation up slope.

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Plate 2. Buffer Zone at the River Bank, Kiandari (in the Foreground is the Slip-Off Slope or River Beach, 2018)

The limit of the farming towards the riverbanks marks the average flood water height. Evidence of slumping and cavitation is clearly seen on the bluff at the bend in form of material accumulation and slip-off slope (river beach) on the right bank. These materials will be the first to be washed away by the next floodwater and therefore accentuate further slope instability and this agrees with Gregory (2006). The farming on the banks contributes in the supply of alluvial and colluvial material through the frequent digging by the tradition method of pulling the soil down slope, thus accelerating the slope grading process. The significance of this process has been noted as important in the slope grading and evolution process. The valley at this point is asymmetrical (as on Plate 17 except being of the opposite bank) and the left bank has an extensive flood plain while the right bank is steep and straight to the riverbank.

The combined activities of the natural momentum set by geomorphic processes as propelled by factors of climate and rock systems, which affect the valley morphology, depend on the effectiveness of weathering and of erosion dynamics and land use

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inputs (Krhoda *et al.*, 2015). Where the lower part of the slope erodes faster than the upper portion, steep slopes develop, for example in the Kairuri and Kathangariri areas. On slopes where the upper part of the valley slope is eroded faster than the lower portion, the slope declines; this could occur where the rate of removal by erosion is slower at the base of the slope due to presence of vegetation. These processes have been identified in other areas as has been observed in Itabua, southeast of Embu town. Differences in topography may also occur on the limp or slopes of the same valley due to the direct microclimatic effects of aspect according to the alignment of the valley and the dominant direction of the wind, which controls the characteristics of the raindrop impact and the angle at which they strike the slope during rain storms

Another significant cause of slope failure is the human input, the land use, in form of contour irrigation. This is a method of diverting the river water by cutting a canal at a point upstream of the area intended for irrigation so the water flows along the contour line. In order to get a water head and irrigate the points further downstream instead of pumping water uphill from the river, the method is used in many spots on the riverbanks. Generally, the water is directed along the contour lines on the strike of the spur and takes advantage of gravity (Acreman *et al.*, 2014). However, it also introduces a lot of infiltration, which, if constant and continuous on the slope, changes the water content in the soil, increases the soil pore pressure and induces mass failure. This event caused a very large landslide two kilometres upstream from the Rupingazi Bridge after a canal had, by this method, diverted the water along the spur to the town of Murinduko (Appendix 19).

Parallel to the contour irrigation canal mentioned above was a road running along the summit of the spur. The two kilometres canal run along the deeply weathered volcanic rocks underlain by clay: this forms an ideal condition for mass failure in form of a landslide as explained below, as supported by Knapen *et al.,* (2006). The significant point in this landslide was that it blocked the river and created a temporary dam for seven hours. The new reservoir which was formed, broke through its dam, eroding the river channel, offsetting the slope equilibrium, and initiating a new set of erosion cycle (Appendix 19).

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The water diversion from the channel to the dry slope limps introduces extra water to the soils and rocks with the effect of changing the surface and sub-surface characteristics. The changes affect the slope stability and, as demonstrated by roadside slumps during the rainy seasons at different scales, as also found by (Whipple, 2004). This is an event related to the geological conditions of the rocks such as the degree of weathering and soil depth. Such a human input is demonstrated by two case studies; on the Rupingazi River in Njukiri forest some years back, and a resent case on the Kavingaci River where a landslide was induced by seepage of water from the interception in a construction site at Kianjokoma.

From such activities as use of agricultural fertilizers, inputs of component chemicals and other operational inputs or other modifying inputs to geomorphic processes are agents of weathering. Erosion and deposition, which are denudational, are therefore landform-changing processes, while the climatic inputs are basic conditions for slope change. Human activities are therefore, affirmed to have influence on geomorphic processes. The study affirmed that vertical sculpturing of the slope and valley bottoms undercutting could trigger mass movement and general slope failure. In addition, human land use induces biomechanical activities by animals. This view was also espoused in earlier studies (Baird *et al.,* 1992; Gregory, 2006; Mc Knight, 2005; Thornes 1987; Thornes, 1994).

4.1.2 Influence of Livestock Farming on Geomorphic Processes

As is the characteristic of most households in the study area, they not only grew crops but also reared livestock (cows, goats, sheep, pigs, poultry and bees). This observation of on variety of livestock reared in the study area, agrees with earlier studies (Njeru, 2020). However, this study examined the influence of the most commonly reared livestock including; cows, chicken, goats and sheep. This is because even if cows and other livestock graze on a wide area, they tend to use the same path often causing trails. These trails are of significance in geomorphology (Plate 3).

Estimates of soil lost from the footpaths created by livestock as they were moved to specific grazing and watering pints along Rupingazi watershed were made. The approximate volume of materials moved was obtained by multiplying the average cross-section area by the length of the segment. The results obtained are presented in Table 8.

Table 8: Volume of Soil Lost from Livestock Trail

Segment	Gradient (^{0})	Length (Metres)	Width (Metres)	Depths (Metres)	Volume of soil moved M^3
1	8	10	0.8	0.15	1.8
2	9	10	1.4	0.19	2.28
3	11	10	1.2	0.24	2.88
4	18	10	2.2	0.38	4.56
5	22	10	2.4	0.78	9.36

Information on Table 8 shows that approximately 1.8 m^3 of soil was moved where the livestock trail had a gradient of 8^0; 2.28 m^3 in volume was moved on a slope of 9^0, 2.88 m^3 on a slope of 11^0 while about 4.56 m^3 of soil materials was moved where livestock trail had a gradient of about 18^0. Where the livestock's trail gradient was 22^0, about 139.86 m^3 of soil materials was lost. Therefore, as the gradient increased along the livestock's trail, so did the amount of soil materials move downwards. Therefore, the footpaths became deeper indicating more materials moved by agents of erosion.

As Trimble and Mendel (1995) argued, cow hooves can reshape the surface of the land where they frequent as evidenced by the paths or the trails. This is because the paths created are the most conspicuous manifestation of direct force of livestock on land. The impact of soil loss is much felt when the livestock move up the slope. Due to frequent use by the livestock, the soils on these trails are compacted and become less permeable. As water passes over these less permeable trails, there is bound to be more surface run off since water does not infiltrate. This results in more erosion. Thus, as Cooke and Reeves (1976) observed, the running water could trigger gulley development on the lower side of the slope. However, as observed Howard and Higgins (1987), saturated soils are not prone to deformation because the pore water helps in retaining soil structure. Therefore, these trails on the upper side would contribute fluvial that would influence the geomorphology on the low-lying areas.

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Plate 3. Erosion by Livestock at a Watering Point, Gachuriri (SS19)

In addition to compaction, grazing on sloping lands enhances meso-micro climate relief (Trimble & Mendel, 1995). That is, differential compaction enhances the surface roughness. This may be due to soil differences (for instance deep vs shallow) or obstructions to compaction such as a flat rock lying horizontally within the soil profile. Compaction greatly limits penetration of water and air to plant roots thereby reducing plants' vitality. This leads to grass changing from the perennial to annual (Kinucan & Smeins, 1992) and other grasses adapting to the changes by becoming shallow rooted instead of being deep-rooted (Naeth *et al*., 1990). Observable effects of grazing have been reported in earlier studies (Blackburn *et al*., 1982; Kauffman & Krueger, 1984; Lull, 1959; Naeth *et al*., 1990; Tollner *et al*., 1990). The combined effect of compacting and grazing may further reduce the density of grass cover. Reduced density cover of grass and related phytomass by grazing livestock production implies reduced soil organic matter and consequently diminishing soil fertility. The soil structure is reduced because of reduced soil organic matter. This would further expose the soils to agents of erosion.

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4.2 Influence of Urban Settlements on the Geomorphic Processes

The study sought to establish the distribution of urban centres and their proximity to the Rupingazi River. The results obtained are presented in Table 9.

Table 9: Distribution of Urban Centres in the Study Area

Sampling Station	Urban centre	Approximate Distance from Rupingazi River (Km)
1	Kiriari	0.5
	Kathangariri	2.0
	Kianjokoma	2.0
	Manyatta	3.0
2	Kairuri	0.3
3	Kirigi	2.8
	Kibugu	1.6
4	Mutunduri	2.3
5	Kangaru	1.4
6	Embu Town	0.2
9	Don Bosco	1.3
20	Gachuriri	0.8
21	Gachoka	3.3

According to the information on Table 9, thirteen urban centres are found along the study area. The closest urban centre to the Rupingazi river is Embu town which is about 0.2 km away, while Gachoka is the urban centre that is the furthest (3.3 km) from the river. Three urban centres (Gachuriri, Kairuri, and Kiriari) are located less than a kilometre from the river; another three urban centres (Kibugu, Kangaru and Don Bosco are located between a kilometre and two kilometres from the river. Station one has four main urban centres including Kiriari, Kathangariri, Kianjokoma and Manyatta; while station three has two urban centres (Kirigi and Kibugu). Stations two, four, five, six, nine, twenty and twenty-one have an urban centre each.

The aerial image of the Rupingazi River and the urban settlement of Embu town is as shown on Plate 4.

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Plate 4. Urban Settlements of Embu Town SS 10-15 (Landsat imagery. Google Earth App Arc GIS)

The sections of Embu town and Kangaru markets have urban contribution of drainage water into the Rupingazi River from the interception of all forms. Urban settlement is one of the major land-uses along the Rupingazi watershed. Development of soil as viewed, in this study, is part of the landform development stages since it alters slope morphometry (Van Leeuwen *et al*., 2017). While this is the general aspect of soil development, the impact of the influence of added chemicals as agents of weathering and erosion are important parameters of geomorphic processes. These parameters have not been specifically integrated into landform changes in previous studies of this watershed and that the overview of the research area with its interactive factors is intrinsically related to the drainage and gradient of both the river and human habitat in many sites. These interfaces of variable interactions affect the physical environment.

The topography of the lands in the two urban centers allows surface majority of run off to end up in Rupingazi River. Since most of the areas in the urban centers are paved or have concrete, there is increased surface run due to reduced infiltration. Direct injection of urban drainage, solid waste, chemicals, industrial by-products and wastes from informal sector, including car wash and garages and other contributors eject matters into the river and the other parts of watershed through surface run off. The built-up environment with both paved and loose surface parts of towns, can be

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viewed as the routes for water and materials swept by agents of transportation and ultimately deposited into rocks, soils, rivers, and on various surfaces. By inference, every part of the watershed affects other part of it. This is why Gurnell *et al*., (2012) opine that accelerated surface run off (because of impermeable concrete surfaces) within the urban settlement would be of significance in geomorphology studies.

Even where cover crops are cultivated, other underlying factors may influence geomorphic processes within a given area; surface runoff, throughflow, rainwash, and biomechanical processes as viewed in Plates 8, 11, 13 and Plate 16. These include the influence of urban input in geomorphic processes was the influence surface runoff and infiltration in Kianjokoma landslide.

Plate 5. Kianjokoma Landslide (2018) (GPS -0.389249, 37.500165)

Mass movements have great sculpturing effect on the valley and topographical evolution particularly when and where the balance of the slope gradient is affected by undercutting by man or by erosion processes such as in flood time or sliding as in the case of Kianjokoma landslide (Plate 5). There are two distinct points significant to the slope evolution; the bench left by the flood which forms the point of slope instability and the point at which the slope grading starts. There are two important primary indicators of mass movements or mass wasting. First, there are scars on the slope, which create points of rock instability, which are points of new grading processes. Second, are the points of accumulation of material at the point of repose of the shifting materials. Significantly, the two instances alter the landform. At the head of the slide are long large cleavages along which the next failure will be initiated (Plate 7).

Plate 6. Time-line Sequence of Land Use Input to Kianjokoma Landslide, 2005-2018

The interplay between water inputs through land use in the role of Kianjokoma slide is an important contribution to the geomorphic dynamism to be considered. Saturation of clay by water results in thixotropic characteristic. Clays can be classified into two groups: clay minerals and 'non-clay minerals. The clay minerals have the characteristics, which give the clay its plastic property. The non-clay minerals are those, which are accessory in nature, which is provided by the environment.

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Clay minerals have notable important characteristics relevant to mass failure in the presence of water. Most kinds of clay have platy layers in their formations. As the final products of weathering, clays are fine grained. When mixed with water, clays attain varying degrees of plasticity Gurnell (2012). They are chemically hydrous silicates, mainly of aluminium oxide (Al_2O_3) and magnesium oxide (MgO). In the case of Rupingazi watershed the clays are provided by the weathering of the rock-forming minerals of the basin which are mafic in composition. Although they have a high content of silicon (SiO_2), they have less than 50% of silica and high content of iron oxides, (FeO and Fe_2O_3). Mafic component strictly implies the presence of magnesium and iron) In some places, the rocks have considerable amounts of calcium (CaO). The significance of the rock composition is in its reaction to what is added into it through land use activities. Acreman (2014) points out the impact of such an addition.

This is a state in which any level of vibrations causes a substance to change its form and structure. It is a reversible behaviour of a mineral when shaken or disturbed but reverses on standing. However, this state can be attained by addition of water. It is a similar process to the behaviour of quicksand, which is a mixture of sand and water. The Kianjokoma slide, attained this state due to excess water in the clay, and unique to this mass failure was sliding, slumping and the lamina flow of the material in which tea bushes were carried away without a rotation motion and turbulence.

Generally, most landslides occur on slopes of between 40^0 and 50^0, but in areas where earthquakes occur and the right conditions prevail, they can occur on gentler slopes of less than 30^0, as in the case at Kianjokoma. Here, water from the construction site, residence and road drainage into the tea bushes over the point where a spring of water lay below the tea bushes triggered the slide. Clay clearly formed the base upon which the event occurred (Plate 11). Vegetation stabilizes the slopes, although the roots have a limit in depth at which they can reach, and therefore on very deeply weathered rocks, certain vegetation may not stop landslides.

Due to human or natural changes in the slope material property, conditions of frictional resistance and material weight changes the internal cohesion and form, such that the imbalances resulting propel mass failure. Incidental or deliberate erosion and

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excavation increase the shear stress within the slope repose, ultimately causing mass failure especially when the base of the slope is undercut. It is true that through human activities such as land use, such trigger events are not conceived, but geomorphic processes respond to those stimuli irrespective of whether they are intentional or accidental. Why then do some slopes fail while others with greater propensity to failure stand? This is because shear strength is not uniform on any slope so that some parts are more prone than others due to their internal stress levels and their geomorphic characteristics which can be modified by land use activities, including internal weakness and water contents which affect the frictional resistance of the materials.

Plate 10. Cleavage Lines at the Head of the Slide at Kianjokoma

The information demonstration in Table 10 indicates the progressing events resulting from the water input of water into the soil and soil substratum. At the head of the slide are a series of wide fissures along which the next slumps will occur, (Plate 7) particularly the areas of high infiltration

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What, then, is the mechanism for the occurrence of a landslide? The rocks' degree of weathering and the amount of water in the weathering mantle also determine the stability of the resulting slope. In the Kianjokoma slide, the materials dislodged by the slide were moved about 220 m and dug a furrow with a flat clay surface of 35m, a depth 1.5 m. This translates to an estimated volume of 102,000 tons of soil moved.

Plate 8. Slump and Slide in Kianjokoma Landslide (2018) (GPS -0.389249, 37.500165)

In the event of Plate 8 the induced geomorphic process demonstrates the dual movement of the mobilised weathered rocks and soil due to the instability resulting from landform instability. Weathered material that rests in situ finds its own angle of stand and stabilizes to create a slope, but clay particles are very small and can find their way through the pores of permeable rocks to the top of the unweathered rock where they form a thin layer of platy clay materials. When water enters clay micelles, they swell and the water acts like ball bearings.

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As a result, the frictional resistance at the bottom of the slope is overwhelmed by the force of gravity. This is also accelerated by the extra weight of the water and assisted by the slippery clay base. The landslide occurs therefore after infiltration and the saturation of the weathered materials.

Plate 9. Water Erosion During the Kianjokoma Landslide

Clay materials are often seen as the base of through flow at the channel. In areas of clay soils such as in this watershed, infiltrating water often develops underground or sub-surface tunnels in the process of through flow (Plate 11).

Plate 10. Lower End of the Slide (from the Opposite Side of the Valley)

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This induces mudflow and sliding on steep slopes such as Kibugu, Kianjokoma and Kiriari. This action relates to the type of land use and the instability induced in different parts of the valley, which, through excavating at the valley base and the adjacent slopes, changes in the morphometry by change in the slope angles results.

Plate 11. Throughflow in Clay at Kiandari

In weathering processes, rock systems and vegetation play an important role in modifying erosion rates, but vegetation may not stop a landslide. Tree roots hold the soil together so that there is a direct relationship between the amount and type of vegetation and the holding capacity of that vegetation which affords a degree of pseudo-stability. First, the amount of vegetation determines the concentration of the roots and therefore the stability of the weathered mantle. Second, the type of vegetation determines the depth to which the roots can hold the weathered material. Some trees have very deep root, which reach the bedrock and may considerably stabilize the slope, while shallow rooted trees and grasses may have little effect as it is with the case of tea bushes in the Kianjokoma slide. Notably, very deep tree roots cause breaking of bedrock and therefore contribute in loosening the rock mantle, and creating routes for water to reach the clay layer (Plate 9, Plate 10 and Appendix 19).

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Plate 12. Weathering by Tree Roots

A landslide may be induced by under-cutting at the base of the slope especially when floodwater erodes the river channel or extends to the flood plain. The undercutting may induce degrading of the slope and cause slumping. Slumping involves the tearing away of wedges of slope material involving a rotational movement so that the base of the sliding material is concave to the sky. In such cases, the required slippage plane is formed by the underlying clay, this agrees with findings of Lane (2017).

It is also important to take into account the chemical weathering in the lower layers of soil and the subsoil where minerals are deposited by infiltration and leaching processes. These chemicals may form solutes utilizing the situation provided by the groundwater or intermittent rainfall. Slides may be grouped (besides landslides and slumps) into block slides, debris slide (Huggett, 2011).

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Plate 13. Slope Failure at Kathangariri, (2018) (-0.415941, 37.461400).

Overall, the probability of slope failure is a function of the relationship between the initial angles of slope, the nature (characteristic property) of the weathered materials, the angles of repose (considering any undercutting as inductive to mobility) and the water content. This concept must be considered to be at variance with the other inclusive factors such as levels of weathering, aggradation and land use (Goudie 1990; Gurnell *et al.*, 2012; Lane 2017; Murray & Paola, 2003). The general view that slope failure occurs on slopes of the angle-range between 32^0 and 40^0 is a concept that may not be construed to be universally applicable since slopes at much higher gradient stand. Similarly, those at lower angles fail according to the individual site conditions; the amount of material was 2,690 kg and a 2 km-stretch of the road, there were three similar failures for the rainy season. At the river banks, slopes on either side have to grade to the newly set repose so that the left bank has to grade itself to the new base level which is two meters lower than previously. The right bank has to grade to the new higher level by depositing material as it starts the new grading by aggradation up slope.

The combined activities of the natural momentum set by geomorphic processes as propelled by factors of climate and rock systems which affect the valley morphology depend on the effectiveness of weathering and of erosion dynamics and land use

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inputs. Where the lower part of the slope erodes faster than the upper portion, steep slopes develop, for example in the Kairuri and Kathangariri areas. On slopes where the upper part of the valley slope is eroded faster than the lower portion, the slope declines; this could occur where the rate of removal by erosion is slower at the base of the slope due to presence of vegetation. These processes have been identified in other areas as has been observed in Itabua, southeast of Embu town. Differences in topography may also occur on the limp or slopes of the same valley due to the direct microclimatic effects of aspect according to the alignment of the valley and the dominant direction of the wind, which controls the characteristics of the rain drop impact and the angle at which they strike the slope during rain storms

In considering landslides, it is necessary to understand the nature of the weathered material and the role of vegetation in the stabilizing of the slopes. Weathering on rocks progressively reduces rock mass to smaller particles as it progresses. The final product of weathering is clay, which contains silica; and usually the crustal rocks have a high percentage of silicon. As observed in earlier studies (Allison, 2002; Baird *et al.*,1992) observed, similar to the findings of this study, clays and kaolinite are the last products of weathering and main requirement for landslides.

In this section, it has been affirmed that addition of water to the clay where weathering system has the affinity for mass movement will be triggered by land use activities. Presence of vegetation has a conservative effect on erosion to a limited level. This is because. Due to the limited in depth to which tree roots can penetrate the soil layer certain vegetation as tea bushes may not stop slides and slumps. Vegetation also helps in breaking parent rocks as a weathering process. Contour guided irrigation introduces water on the slopes and helps in causing mass failure. A buffer zone of vegetation at the riverbanks inhibits loss of soil, and therefore land use, which removes riparian vegetation, induces changes in geomorphic dynamism (Mc Knight, 2005).

From such activities as use of agricultural fertilizers, inputs of component chemicals and other operational inputs or other modifying inputs to geomorphic processes of weathering. Erosion and deposition, which are denudational, are therefore landform-

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changing processes, while the climatic inputs are basic conditions for slope change. Human activities are therefore, affirmed to have influence on geomorphic processes.
The study affirmed that vertical sculpturing of the slope and valley bottoms undercutting could trigger mass movement and general slope failure. In addition, human land use induces biomechanical activities by animals. This view was also espoused in earlier studies (Baird *et al.,* 1992; Gregory 2006; Mc Knight 2005; Thornes 1987; Thornes, 1994).

4.3 Surface Runoff and its Influence on Geomorphic Processes

One of the major routes for transmitting materials and chemicals contributed to the geomorphic dynamics is overland flow of water. Surface runoff, alternately called overland flow takes materials in solid and solution state from the surfaces it passes over. Erosion causes changes in the rates of weathering and physically transforms the landform through degradation and aggradation. These processes can be exemplified by looking at the data of discharge and the load yield from Rupingazi and its tributaries, Table 10. It is important to note that any activity, which causes materials and chemicals to be moved or transported from one place to another, constitutes landform evolution process (Huggett, 2011). As the seasons change every year and climatic changes occur, the amounts of eroded materials deposited in rivers or carried on the land surface changes in amounts. Kiye starts in the Mt. Kenya Forest and is located to the east of Rupingazi and west of Kavingaci. It flows through areas with forest vegetation where the concentration of organic matter is high and this may partially explain the high contents of NH_4CO_2 and O_2.

The yielded amounts of materials are indications that there are changes that occur in the watershed even within a very short time, as there are changes in the oscillations of the seasons. Further changes occur on the land surface as dictated by climatic changes such as global warming and in the end, the landforms. There is also a clear indication from the data that the changes in the amounts of precipitation are significant to the contribution of materials and chemicals from the land use, both onto the land and into the rivers. Although the amounts of materials added to the rivers come from the watershed, considerable amounts can be directly associated with two sources; the natural systems brought about by physical and chemical geomorphic activities, and secondly the human contribution. Kiye is a smaller tributary which passes over an area of higher land use intensity (80% of the land is under agricultural land use) and has higher precipitation (over 1,200 mm). Kavingaci, like the Rupingazi, flows mostly over basalt bedrocks and therefore any chemicals other than those weathered from basalts are from different land use sources.

Table 10: Load Production for Kiye, Kavingaci and Rupingazi Rivers

Elements	Kiye Average ppm	Tonnes	Kavingaci Average Ppm	Tonnes	Rupingazi Average Ppm	Tonnes
Turbidity	-	-	-	-	5	
E.C.	59		36		62.5	
pH	7.0		6.5		6.95	
Colour	5		<5		8.3	
HCO_3	39.0	1.46	22	0.16	40.0	16.44
CO_3	-	-	-	-	-	-
Cl	3.0	0.11	1.0	0.01	5.5	2.26
SO_4	-	-	1.3	0.01	-	-
NO_3	0.5	0.02	0.55	0.001	-	-
NO_2	Trace	Trace	-	-	Trace	Trace
F	0.2	0.01	0.23	0.001	0.15	0.06
Na	6.0	0.22	4.5	0.03	7.0	2.88
K	3.5	0.13	1.1	0.01	0.5	0.21
Ca	4.0	0.15	1.6	0.01	4.8	1.97
Mg	1.0	0.04	-	-	0.75	0.31
Fe	0.01	0.001	0.1	0.001	0.1	0.001
NH_4	0.24	0.01	-	-	-	-
Pb, Cu, Zn	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$CaCO_3$	14.0	0.52	4.0	0.03	17.0	6.99
TDS (180^0)	70.0	2.62	40.0	0.29	45.0	18.50
CO_2 free	6.0	0.22	5.0	0.04	3.0	1.23
SiO_2	20.0	0.75	15.0	0.11	20.0	8.21
O_2 absorbed	1.4	0.05	0.9	0.01	0.78	0.23
Discharge	0.43		0’08		4.76	

Source: Embu Water Station, 2019

Information on Table 10 shows other parts in the basin and helps to explain the amounts of different substances in the Rupingazi River and that these substances have run over wide areas of the watershed. The nature and types of substance contribution in July and September 2016 vary in amount and type according to the nature of land use. Water analysis relates to the established Water Gauging Stations on Rupingazi River, identified as 4DC3, Kiye 4DC3US Kavingaci 4DC3KIR and Rupingazi 4DC4RN by Embu Water Supply. The contribution includes daily load of TDS and

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chemicals contributions, which can be considered as the indicated water content analysis in Table 11.

The water samples were from some areas, which are intensely farmed, (c90% of the land is under agriculture on steep slopes (Plate 18 in the periphery of Embu town). This is a significant finding in that all the values in regard to chemical contents are higher than even those of the main river, except for SS13 which is at the point where the sewerage water enters the main river. Contribution from this area is clearly a result of land use, (market gardening, urban settlement and sewerage), and this data shows a 531% higher NO_3 than the next highest value from SS14 lower downstream. The pH value corresponds to the chemicals added to the pure water, and it is an indication of the contribution into the water. It is also important to note that these samples were taken during the dry period when, expectedly, the contribution was low because of less surface runoff water flow into the stream.

Turbidity as a measure of the colour hue, which causes opaqueness of the water and Kiye, shows a high turbidity of 11.05 only comparable to water sample W5L14 which is the left or lower part of the entry point of the sewerage water into the main river. Conductivity in sampleWR4T, which is 119.0, surpasses by far the next highest value of 87.9 by 26.1%. The significance of this finding is that although the stream passes through areas of intensive farming it also passes through residential areas while the sample WRH6 is 15 km downstream on the main river in an area of farming and irrigation along the river shown in Plate 19 where soil sample SR6.3 was taken. The higher chemical contents in the water, Cl, PO_4, NO_3 and SO_4 indicate the contribution from land use including residential contribution, which affords comparable values such as those of WRH6, which show the cumulative addition along the watershed to 50km downstream.

The Plate 19 (right foreground) left bank, shows the location of SS 13 and the drainage channel of the sewerage plant for Embu town into the Rupingazi River. It also shows the intensity of the agricultural and human settlement land uses, removal of vegetation, including riparian gulley vegetation and the effect of eutrophication. The Kathita confluence from where the water sample was taken is shown in left background (confluence). Kavingaci is shown on the eastern side. Three points at

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which soil samples were taken are approximately at equidistant points from the crest at the point below the sewerage plant at the dirt road shown in Plate 4 (SS 13, 14 and 15).

At SS13, the water samples were taken at the point of entry of the sewerage water into the river from the upper and the lower points of the confluence shown in the right foreground. The water samples afford a significant comparison where the water from the Embu sewerage treatment plant empties into Rupingazi River.

Samples WR5R and WR5L14 were taken from the confluence of the treated sewage water (which flows as a permanent stream) and the main river and it is a perpetual supplier of the contents of the sewerage water into the river. Sample WR5R was taken on the right side of the entry point that is upstream of the point where WR5L14 was taken on the left side just below the entry point. Eutrophication is an indicator of the added substances into the water.

There is a difference in the pH of the water, so that the value is reduced by the water from the sewerage plant but the turbidity increases from 6.50 to 9.00, indicating a colour change in the water after the addition of sewerage water. Conductivity increases by 13.95% on the downstream point of the water supply from the sewerage plant; an indication of additional chemicals in the river water from the sewerage. Cl value increases by 6.9% while there is an increase in TDS of 8.8% on the lower side of the entry point. Significant increase in PO_4 of 367% shows the enormous contribution into the river water from this point source. The nitrates increase by 259%, but SO_4 cannot be detected after the sewerage water; an indication of a chemical reaction as a pointer to what additives into the geomorphic systems can do.

Two agro-ecological zones, the middle, inclusive of Embu town, and the lower zone at Gachoka/Gachuriri are sections of intensive farming and irrigation near the low gradient river valleys. Pastoralism and other varied land use and their contribution indicate very significant addition of agents to the geomorphic dynamism. While Plate 9 shows the western side of Embu town and part of Kirinyaga, both areas have high intensity of agricultural land use and erosion. The old abandoned road runs parallel to the river and on the upper slope, which has been under farming for very long time,

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and the collapsed embankments of the road has a surface which is strongly fluted and forms points of slope instability where small ‘fans’ have developed through active slope grading, Plate 4. Both valley side areas are on the slopes where vegetation has been extensively removed.

The section of Embu town has urban contribution of drainage water into the river from the interception of all forms. Direct injection of urban drainage, solid waste, chemicals, industrial by-products and wastes from informal sector, including car wash and garages and other contributors eject matters into the river and the other parts of watershed. The nature of the topography prohibits construction of buildings due to high gradient but the steep slopes form an easy path for solid materials and effluents from the town where poor management of farming are inductive of severe erosion (Plate 19). Any fertilizers applied on the farms on slopes easily washes away into the ground and overland to the river. Farming on the right bank, Kirinyaga, has high population and the small size of the farms is an indicator of the intensity of agricultural land use. Intensive land use requires heavy inputs of supplements in form of fertilizers and chemicals both for nutrient supply and for crop protection; inputs such as insecticides, pesticides and weed retardants.

Therefore, the lower and middle reaches of the watershed with varying climates, besides being intensively farmed, varies both in gradient and input which facilitates varying response to such processes as infiltration, percolation, and the nature of the and surface runoff. Information on Table 15 and Table 16 show water deficiency for most part of the year, hence the need for irrigation. The high evaporation is a prerequisite for leaching. In this lower section, the water and the soil properties indicate the land use contributions as being a factor of climatic dictation. Evidence from the water samples WR5R (upstream) and WRH6 (downstream) shows a pH reduction as an indicator of increasing water acidity but a slight reduction in turbidity, (due to flocculation), yet there is a significant increase in conductivity of 36.3%. This indicates an increase in chemical contents in the water as contributed by the intensive use of chemical fertilizers and other enhancing or inhibiting substance in agricultural practice.

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Another significant indicator of substance addition is the increase downstream of TDS (52.9%) as further evidence to support the conductivity; the fall in turbidity is a result of greater flocculation which accounts for reduced turbidity. The changes in the content of PO_4 is also statistically large at 50% while enormous change in NO_3 alludes to the great use fertilizers in the lower section as at an increase of 285.2% and 137.6% in the SO_4, another major ingredient of fertilizers.

A comparative analysis of the soils of the two middle sampling stations SS 14 and SS 15 helps to underline the contributions to the geomorphic dynamisms. Geomorphic processes signify progressive changes in time and in certain direction in time: for example, deposition on a slope increases from the top of the spur crest to the valley bottom. It is of significant extent that from the highest part of the slopes, chemical values increase progressively to the channel area which indicate significant cumulative changes from 5.87 (at altitude of 1315 m.), 6.47 (at altitude 1309) and 6.69 (at altitude of 1283). The progressive change in pH indicates that there is change in the soils resulting from progressive change in the chemical contents contributed by the relevant land uses and more so because of substance content change from point SS.7 to SS 10.

Mg contents increases from the highest part of the slope to the river channel by 444.3%. Such a drastic increase in chemical content contributes greatly to the geomorphic processes. As regards P, there is a 1,413% reduction from the highest point to the valley bottom. The contents of N increase from the top of the slope by 23%. To establish a pattern of change resulting from the land use, a significant change from the top of the slope to the bottom indicates a reversal in the contents of P and N. The pH increases by 18.6% from top to bottom while Mg increases by 92.3%. The sample SR6.1 was taken from a non-cultivated crest with bushes and thin soil underlain by laterites. P content was 5.18 mg/l and the midway point on the slope was cultivated and irrigated, the value was 29.86 mg/l, a 476.5% increase. At the bottom of the valley, the value was 41.4% increase over the middle point of 38.7%. Clearly, the portion where agriculture was practiced could be associated with increase of the chemicals. The soil samples were taken at the points with notable activities, where the gradients and the altitudes and GPS locations are indicated, and this affirms the contribution from land use activities.

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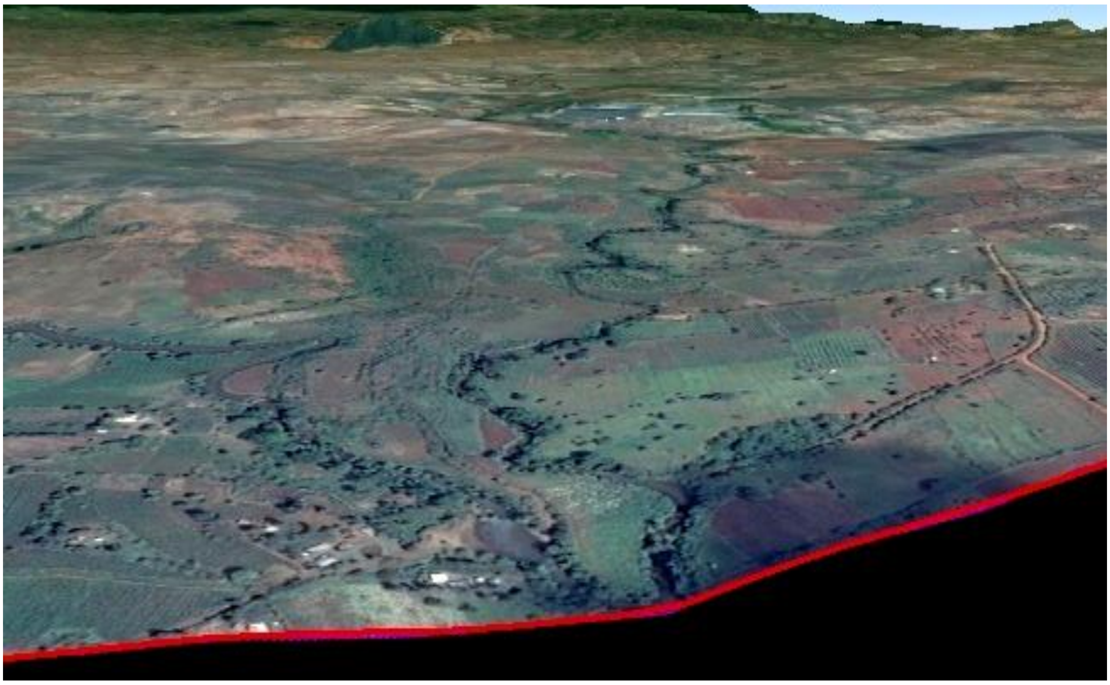

Plate 14. Valley Cross Profile at SS 19-21 (Google Imagery CNES/ airbus 2018)

While the slopes are important, the nature of the chemical substances and sediments produced through surface runoff play a major role in the transmission of rock changing elements. The soil samples at SS 16-18 at Don Bosco (Riamangeta), shows significant differences because of differences in the land use practices. Station 17 is located in the dry agro-ecological zone where farming for most farms is done on irrigation. From the crest to the riverbank, (SS18 to 16), the pH increases from 6.74 to 7.00 to7.99 as the farming activities intensify (Plates 21 and 22).

The land is under crop all year round with farmers using petrol driven pumps to produce such crops as maize, potatoes, tomatoes, various vegetables and khat (*Catha edulis* also called *mirra*) the farmers use large amounts of fertilizers, insecticides and pesticides. The contents of Mg are relatively low at the crest at 470mg/l and increase in the farmed section to 851.25mg/l and 903.75mg/l an increase from the crest by 92.3%. A similar trend is evident with the P contents where it increases from 5.18mg/l to 29.86mg/l to 41.4mg/l; is an increase of 699.2%. A clear case of land use contribution is in the geomorphic dynamism indicated by the percentage of the N decrease from the scrubland to the cultivated areas. Different parts in the watershed

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yield varying substances the contribution to the influence on the geomorphic processes. Irrigated

Information on Table 1, Figures 5, 6 and 8, indicate intra-disparities within the agro-ecological zones due to varied land uses induced by topography and vegetation, which makes the yields different. In order to assess the contribution of land use to geomorphic dynamisms it is important to consider the inevitable fact that landforms respond to weathering, erosional and depositional activities to change those landforms. These changes are what constitute landform evolution and therefore in assessing contribution it is apt to know the likely and actual sources of the agents that effect geomorphic dynamics. Many studies cited in this study use similar methodologies (Lane, 2017; Simon & Collison, 2002; Withers & Jarvie, 2008; Piatek *et al.,* 2009; Stefano *et al.,* 2016). There are important factors to consider in the assessment of the contributions; the natural sources, additions by or through land use and the time of the year concerning climate as indicated by the chemical in-depth overview of apparent sources.

It was necessary to consider that the significant indication in the water analysis as only the net balance on the budget of land use contribution into the geomorphic dynamism. Allison (2002) agrees with the findings of this study that tracing the sources of the chemical substances, it would be unrealistic to assume that the substances are produced and then they enter the river systems. If this were the case, then there would be direct dumping of the substances into the rivers.

The fact is that the substances get into the environment mainly through non-point sources, en route surface, and ground runoff. There is therefore a complex transmission system of the material, which implies also both short-and long-term delivery system of the substances. The short-term system implies when the materials are delivered quickly after the rains by surface run off or by throughflow into the rivers. The long-term implies the delivery of the substances after some storage in the ground water or as base flow into the rivers. In this study it was found that pluming of substances, solid or liquid was a major factor in distribution and as Armstrong and Botzler (2004) affirm that any of these routes the resident time of the materials in both short and long terms, substances have time to react with the rock-forming minerals

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and influence the pace of the geomorphic dynamism. This is the easiest way to trace where the extra amounts of chemicals originate from.

Calcium comes naturally from limestone and calcareous sandstones. But human contribution is significant. According to Barr (2017) sources which relate to human activities or land use are found in construction industry where large amounts of cement and sand are used and where the source of the two products are generally away from the area where they are used. Calcium is an alkaline earth element and the fifth most abundant element on earth constituting 3.64%. It does not occur in a free state naturally. As calcite ($CaCO_3$) it is found in limestone, chalk, marble, dolomite, egg shells and gypsum.

Calcium oxide (CaO) known as lime or quicklime is used extensively as building materials and as a fertilizer. Calcium carbide (CaC_2) and calcium cyanamide ($CaCN_2$) are used as fertilizer components (commonly called CN), while calcium hypochlorite ($Ca(ClO_2)$) is widely used as a bleaching powder. Calcium Sulphate: ($CaSO_4$) is a naturally occurring salt, and when it is dehydrated it is called gypsum ($CaSO_4.2H_2O$). Uncalcined gypsum is used in making soil correctors, while calcined gypsum is used in making tiles, laths and plasters. In agriculture, Calcium phosphates, $Ca_3PO_4)_2$ are used in manufacturing fertilizers (Njoroge, 1999).

For example, a soil sample collected and analysed in the laboratory in September 2017 from Kangaru market in the northern periphery of Embu town, as a pilot soil analysis from a site where there are both residential and farming land uses indicated progressive increase in soil pH towards the areas of garbage and litter increase. Near the residential area the sample pH progressively changed from 4.9 to 6.2. That was likely due to the washouts from the residence and the additional runoff of the residue from the interception water on roofs. The sample also shows a clear value difference in the chemical contents of soil calcium in horizon A as 9.8% and 2.4% for the B-horizon. These figures point out to the weathering of buildings or material substances introduced through land use, considering that calcium carbonate forms the major component of cement. In the sample, the nitrates decreased with depth from the surface from 0.8% in the A to horizon 0.08% in the B-horizon. In this sample too, phosphorus was low, and so were the organic matter probably because the area has

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been under cultivation for a long period without allowing much of vegetation growth or its residue. Such trends were found to be true in the study on urban geology (Bathrellos, 2007).

It is important to note that commercial farming returns very little of organic material to the soil because every part of the plant is utilized, as pointed out by Thompson & Troeh (2009), who noted that one of the important factors to consider in connection with soil development is that soil inherits hundreds of different minerals from the environment besides the parent rocks. Thus, the anthropogenic activities have introduced to the environment numerous substances, which are assimilated into all the landforms within the watershed, in rural and urban areas. As a result, the substances end up onto the land surfaces and into rivers of the watershed to become part of the soil and landform development agents.

Another chemical of importance is manganese, which comes mainly from the soils. Manganese is not common in igneous rocks, which are dominant in the upper Rupingazi watershed. Church (2002) relates urban settlements and riverine However, manganese occurs more widely in the sedimentary rocks of the lower Rupingazi. Different land uses and other utilities contribute to the geomorphic dynamisms as indicated by the soil analysis. In the crust, manganese occurs as manganese dioxide (MNO_2) which is useful in steel manufacture. Manganese monoxide (MnO) is used as the starting material for manganese salts and as a fertilizer and also as a reagent in textile printing. This is the major source of land use contribution in the watershed in form of manganese dioxide (MnO_2) which is used as a cathode in electric dry cell. Manganese sulphate ($MnSO_4$) is added to soil to promote plant growth and is useful in the manufacture of paints and varnish driers. The wastes and by-products of their use in the urban areas is a significant contribution. Manganese chloride ($MNCl_2$) is used as animal feeds additive, while potassium permanganate ($KMnO_4$) is used in disinfecting, deodorizing and bleaching. There are also other significant contributors.

Aluminium is one of the most abundant minerals in igneous rocks occurring as aluminosilicates in feldspars and in micas. In soils aluminium is found in clays and further weathering produces bauxite, the hydrated aluminium oxide, and iron-rich laterites found especially in the agro-ecological zone designated 3. Land use

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contributions emanate from the use of the aluminium products including mining and gem prospecting. Land degradation discussed by Chisholm (1997) agrees with the findings of this study in relation to the surface run-off accelerated by mineral and gem prospecting. The gems prospected include crystalline aluminium oxide (AlO_2): emery, corundum, sapphire, topaz and garnet, which are exploited in the lower region of the watershed. In doing so, many rock materials are shifted changing the nature of the landforms by creating areas of slope imbalance, which trigger new dynamics. In other areas isostatic changes are induced either through overloading resulting from deposition or offloading through removal and erosion in mining (Plate 15 and Plate 36).

An important salt to consider is aluminium potassium sulphate, also known as potassium alum or potash alum. The alums have many uses, which are useful in the production of medicines, textiles and paints. Alum is commonly used to flocculate water or sedimentation for urban use and thereafter transmitted for the various utilizations. The expansion of water supply in the watershed is a major contributor of the mineral. Hydrated aluminium chloride, also called aluminium chlorohydrates ($Al_3.H_2O$) is used as antiperspirants or body deodorant. These chemicals and materials end up as contributions to the rhythm of the landform development and therefore induce changes because their containers and the residues are ejected into the environment.

In regard to the geology of the watershed, iron, is the third most abundant mineral after aluminium and silica in igneous rocks. Iron makes 5% of the earth’s crust and forms 35% of the elements of the earth, and the igneous rocks have an average of 5% iron contents. In the building industry ferric oxides have a series of uses because of their pigments which range from yellow to red (commonly called ‘oxides’) used to stain cement. Chin (2006) considers such land use as transforming of landscape. They have their use in cosmetics too and some of these chemicals are washed into the soils or are carried as surface runoff. When reacted with sulphuric acid two compounds form; ferrous sulphate available in two forms as hepahydrates, $FeSO_4.7H_2O$ and ferric sulphate, $Fe_2(SO_4)_{3,}$ which are used in the making of inks, fertilizers and pesticides.

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These compounds also form iron alums, which are used as coagulants in water purification and in sewerage treatment. The iron compounds are also used as mordant (fixatives) in textiles and printing. With chlorine, iron forms a number of industrial products such as ferric chloride, $FeCl_3$, a yellow-green deliquescent (moisture absorbing) crystals and its hydrated form, $FeCl_2.4H_2O$, used in the dye industry, while the $(Fe(CN_6)_4)$ forms a deep blue colour (Prussian blue) used in paints, enamels and lacquers. All these products eventually find their way into the rocks and rivers via surface runoff.

Crustal rocks have the silica, also called silicon dioxide, as the single most abundant substance, which forms 59% of the mass of the earth's crust and 95% of rock constituents of all rocks. Quartz is the most abundant of its forms and least soluble in water and therefore most utilized in construction industry as building sand. It is also the most extracted rock material with the result that the activity creates slope instability. The weathering of silica-rich rocks provides the silica for soils and for solutions. Silica is a basic constituent of sandstones and slowly dissolves in groundwater to form the necessary cementing medium in sedimentary rocks and in the formation of quartzite which have a wide variety of uses including abrasion and ceramics.

The findings of this study agree with the observations made by Bland and David (1998) and Baldock and Skjemstal (2008). From their studies, they found that many chemicals influence weathering due to their variety and ambivalent sources. The nitrates are obtained from the atmosphere through lightening and from the igneous rocks. However, the nitrates in form of ammonium salts, NH_4NO_3, are widely used as fertilizers and explosives. Both farming and mining are common in the Rupingazi watershed. The commercial grade of the salt is about 33.5% nitrogen, which is utilizable by plants and therefore forms a common nitrogenous component in fertilizers. Ammonium nitrates are highly soluble in water and are therefore used as solvents and in this regard, they are easily carried by rain and distributed over the land surface and directly affect the rock structures and soil reaction and formation.

The purpose for the samples in Table 10 and Table 11 was to show the variation of the contents of minerals in the water as transmitted by the land use changes even

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within a very short period of time. The samples were taken within a frequency of ten days. The table reflects the changing human activities in the watershed and the influence of weather conditions. For example, July is a period when the weather is cold and precipitation is in form of drizzle. May had 12.35mm falling in 14 days with an intensity of 0.8. Therefore, with the 14 rainy days the geomorphic processes were affected differently by the amount of rainfall and the temperatures. In August the dry spell started, but also denoted the eventual through flow of chemical substances after a lag time created by the interception of those substances by the soil and rocks. This is what may have led to the increase in pH, HCO_3, SO_4, Na, NO_3, Ca, reduction of hardness as a result of reduced surface runoff, an increase in iron due to higher temperatures. Induced greater oxidation of iron in rocks, increased its conductivity, EC, resulting from higher concentration of minerals as the water amounts decrease and in turn an increase in TDS. August is harvest time in this agro-ecological zone.

Even at such a short span of time as two months, the amounts of substances introduced into the rivers are significant. For example, the bicarbonates increase as the rainfall increases by 8.3%. Nitrates increase from zero to 0.5. The sulphates increase by 233%, Sodium increases by 100%. Due to the addition of organic materials in the water, oxygen contents fall by 40% while the TDS increases by 27.3% and so does the conductivity increase as a result of addition of substances in the water.

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Table 11: Water Analysis as at July/August 2017 (Embu Water Supply)

Element	10th July	20th July	30th July	10th August
Colour	<5	<5	<5	<5
pH	7.2	7.3	7.1	7.3
HCO_3	24	22	24	26
CO_3	Nil	nil	nil	Nil
Cl	1	3	3	5
SO_4	1	1	1.2	4
NO_3	Trace	nil	trace	0.5
NO_2	Nil	nil	nil	Nil
F	0.1	0.1	0.1	0.1
Na	4	4	4.1	6
K	1	1.2	1	2.5
Ca	2.2	2	2	2.5
Mg	2.4	2	1.5	Nil
Fe	0.1	nil	0.2	1.3
NH_4	Nil	nil	nil	Nil
$CaCO_{3\ hardness}$	14	13.5	14	6
CO_2	2	1	1.2	2
SiO_2	15	15.4	18	20
O_2	1.0	0.9	0.9	0.6
TDS	44	44.5	48	60
Turbidity	Nil	5	nil	5
EC	35	39	40	50

The changes cited here is an indication of the contribution made by natural activities such as rainfall and surface run off on farms and more significantly by the land use activities such as farming, run off from settlements, the use of manure and chemical fertilizers in the agricultural activities. The analysis of individual element is a strong indicator of the significant contribution that influences geomorphic processes from land use activities. Overland flow is the most effective way through which chemical substances are spread over the watershed. The work of Tilji (2008) on the effects of soapstone mining in Kisii had similar findings in regard to overland flow. The role of surface runoff in the distribution of produced materials by land use activities is very crucial in supplying chemical substance to the soils, rocks and to cause erosion and deposition, which alter the slopes and ultimately change any landform’s pace of evolution or denudations.

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4.3.1 Influence of Abstractive Activities on the Geomorphic Processes

To examine the influence of abstractive activities on geomorphic processes in the study area, the study sought to find out the types of these abstractive activities. The results obtained are presented in Table 12.

Table 12: Abstractive Activities on River Rupingazi Catchment

Sampling Station	Type of Abstractive Activity	Number of Sites	Percentage
1-9	None	0	0
10, 11 and 12	Murram	3	3.9
	Building stone	4	5.2
13, 14 and 15	Building stone	8	10.4
	Murram	3	3.9
16, 17 and 18	Sand harvesting	5	6.5
	Building stone	6	7.8
	Murram	13	16.9
	Brick making	4	5.2
19, 20 and 21	Sand harvesting	12	15.6
	Building stone	6	7.8
	Murram	10	13.0
	Brick making	3	3.9
Total		77	100

Information on Table 12 shows that in stations 1-9, there were no abstractive activities. This implied that no visible sites associated with murram extraction, quarrying or sand harvesting were observed in these stations. This is because the stations 1-9 are found in the upper reach stage of the river where minimal weathering of rocks had occurred. In addition, the main economic activities in these stations were crop farming. This observation agrees with earlier study findings by Njeru (2020) and Nyakundi (2019).

About 9.1% of all abstractive activities in the study area were found in stations 10, 11 and 12. However, murram excavation represented 3.9% of the abstractive activities in stations 10-12 while quarrying sites for building stones formed 5.2% of the activities in the three stations. Building stones were the main abstractive activities (10.4%) done in stations 13, 14 and 15, while 3.9% of these activities involved murram extraction. More than a third (36.4%) of the abstractive activities were found along stations 16,

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17 and 18. Murram excavation was the main (16.9%) while brick making was the least (5.2%) practiced abstractive activity in these 16, 17 and 18 stations.

At stations 19, 20 and 21, were 40.3% of all abstractive activities with sand harvesting being the most common (15.6%) activity in the three stations followed by murram excavation (13%), quarrying for building stones (7.8%) and the least common was brick making accounting for 3.9% of all abstractive activities in the lower reach of the River Rupingazi;76.7% of the activities are between SS 16 and 21. In the whole study area, murram excavation was the most common abstractive activity accounting for more than a third (37.7%) of all activities. However, excavation of the murram was limited to the lower reaches of the River Rupingazi where it was readily available. Blasting of building stones and ballast was common in almost all the stations, thereby accounting for 31.2% of the abstractive activities in the study area (Tilji, 2008). Blasting of rocks for construction works was common because of the even distribution of outcrop rocks along the study area. The distribution and occurrence of the abstractive activities were consistent with the characterisation of the soil and rock types that are found along the study area. This distribution also agrees with earlier observations by CIDP (2014).

In quarrying, sand abstraction and removal of overlying material, the process of off-loading causes heaving of layers of rock isostatically as in or where a large rock is exposed by removal of top soil becomes an outcrop and exfoliation results. Evidence of exposed rocks can be seen on Plate 15, Plate 27, Plate 28 and Appendix 15.

Plate 15. Exfoliated Rock at a Quarry (Effect of Off-Loading) near Don Bosco, 2018

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For construction materials, all regions of the watershed have abstraction of stones, sand and other materials. In these areas, whether those quarry sites active or have been abandoned, the slope balance is offset and therefore landform evolution is initiated. Weathering has the ability to change the rock characteristics, alter the regolith, and change the soil structure. In the lower reach of the watershed, where rainfall is low and the periods of high temperatures are the norm, and the topography is also low, laterites develop through the repeated process of leaching. Laterites must not be a term assumed to represent all the weathering processes in hot humid climates. In the case at the lower zone of the Rupingazi watershed, irrigation has influenced the formation of laterites. The soils in this area have considerable amounts of quartz, kaolinite and contains some amounts of aluminium and manganese, they are at the same time very rich in iron and ranges in colour from yellow to red. They also contain some amounts of aluminium and manganese (TNC, 2015).

The two ideal conditions for laterite formation are met in this area of the watershed. Here too, due to the soil characteristics of good drainage, which is conducive to rock decomposition, there is mineral mobility, the ultimate cause of leaching. The second ideal condition is the climatic factor of pronounced seasonality of rainfall and pronounced periods of drought. This condition affects the level of the water table, causing it to fluctuate and the dissolved minerals to move by capillarity. Due to its high demand in the building and construction sector, sand harvesting extraction affects the equilibrium of slopes and the landforms from which it is harvested. The lower Rupingazi watershed forms a major zone of sand harvesting for eastern Mt. Kenya region. In this region riverbank slumping and cavitation is common. Where the sand is harvested, rough roads are constructed to the riverbanks and therefore aid soil erosion.

Mining of building stones affect slope stability because slopes are induced to adjust when their angle of repose are thrown out of balance through quarrying activities including blasting of the stones. The vertical sculpturing of the watershed surfaces and the river valleys' slopes are pivotal points in landform development since they form the base level for landform evolution. As supported by findings of Stefano *et al.*, (2016) the riverbed erosion initiates slope instability, which has to be counterbalanced

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by the movement of the materials at the base and top of the slope. When erosion effects acceleration or deceleration of geomorphic changes, grading process of the topography begins anew. This process causes modification of the slope by wearing either retreating where it maintains the same shape and angle, parallel retreat, or it may fall and reduce the gradient by slope decline process. This analogy explains the different varieties of slopes in the watershed which have developed at paces set by the prevailing physical agents and as influenced by land use activities in agreement with Smith (2000) in regard to triggering hazards.

4.4 Rock Structure and Weathering

In the context of this study any process that causes decomposition of rock by altering the characteristics of the material constitutes is weathering. Land use processes always expose rock-forming minerals to the elements and agents of weathering, whether in the form of exposing rocks themselves as in the case of quarrying, removal of vegetation, removal of soil layer through ploughing and tillage or by adding chemicals to the rocks and to the soil. These findings are similar to those of Rodrigues and Lima (2012) in Brazil. By these and other activities weathering is enhanced. Weathering is more sensitive than commonly believed. For example, since a rock is an assemblage of minerals in form of either elements or compounds any one of the minerals removed or weakened by any land use process such as digging, breaking or reacted upon chemically by an added chemical, including fertilizer products, weakens the whole rock. This happens because the minerals in rocks are intrinsically connected to each other at all times (Huggett, 2011).

The structure of any rock predisposes it to any inputs of chemicals, temperatures and moisture. Weathering has a domino effect on the rock-forming minerals. For instance, a chemical substance from the fertilizers comes in contact with a rock containing calcite reacts with it to form a powder, a bi-carbonate. The bicarbonate formed thereof is washed away by infiltration or surface-runoff to other places where it changes the form of another rock by forming a cementing agent, while the scar left on the original rock starts a modified geomorphic process. Such a web of interactivity is unperceivably in operation on rocks of all forms whether consolidated or in granular form at all times; even the more resistant rocks like quartz will differentially weather if it harbours other minerals, Plate 31, Plate 33. The rock structure is also significantly

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affected when land use activities remove or loosen materials from the top of the rocks, whether by deliberate operation of mining and quarrying or by inducing severe erosion (Ramesh & Darius, 2017; Rasmussen, 2015).

In quarrying, sand abstraction and removal of overlying material, the process of off-loading causes heaving of layers of rock isostatically as in or where a large rock is exposed by removal of top soil becomes an outcrop and exfoliation results. For construction materials, all regions of the watershed have abstraction of stones, sand and other materials. In these areas, whether those quarry sites active or have been abandoned, the slope balance is offset and therefore landform evolution is initiated. Weathering has the ability to change the rock characteristics and the regolith thereby changing the soil structure, as found in many parts of the world and widely exemplified by Prosser (2012). In the lower reach of the watershed, where rainfall is low and the periods of high temperatures are the norm, and the topography is also low, laterites develop through the repeated process of leaching. Laterites must not be a term assumed to represent all the weathering processes in hot humid climates. In the case at the lower zone of the Rupingazi watershed, irrigation has influenced the formation of laterites. The soils in this area have considerable amounts of quartz, kaolinite and contains some amounts of aluminium and manganese, they are at the same time very rich in iron and ranges in colour from yellow to red. They also contain some amounts of aluminium and manganese.

Leaching causes the soils to become hardened irreversibly into a layer comprising iron oxides in the upper part after exposure to the air. This hardened top layer is what is strictly called laterite. Two types of laterites are recognizable in the area around Gachuriri. The primary laterites developed in situ and the secondary laterites developed from materials transported from somewhere else, such as materials deposited by surface runoff aided by land use activities; ploughing and digging. This was found to correlate positively with earlier findings by Price *et al.*, (2011).

The two ideal conditions for laterite formation are met in this area of the watershed. Here too, due to the soil characteristics of good drainage, which is conducive to rock decomposition, there is mineral mobility, the ultimate cause of leaching. The second ideal condition is the climatic factor of pronounced seasonality of rainfall and

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pronounced periods of drought. This condition affects the level of the water table, causing it to fluctuate and the dissolved minerals to move by capillarity. The large numbers of livestock also directly contribute to landform changes through biomechanical weathering (NEMA, 2017).

Summarily, the weathering process in different parts of the watershed have been directly influenced by land use activities such as agriculture, urban settlements and by abstraction processes of sand harvesting and stone quarrying. Addition of chemicals from agricultural mining and other sources affects the rates of weathering processes. The addition of water through irrigation induces leaching and the formation of laterites, which are processes of landform development similar to the impactive effects observed by Mossa and James (2013).

Mass movement, also called mass wasting, is a geomorphic process in which rock debris, top bedrock and soils shift downslope. Landslides are a significant dynamism in geomorphic processes of landform evolution worldwide (Maurizio, 2019). Weathered materials or rock mantle is usually *in situ* where it forms and attains a dynamic equilibrium in regard and response to gravity. The material attains a slope angle of repose according to the nature and composition of the materials and therefore an angle of stand is attained and must be maintained because any alteration on that slope results in regradation and any removal of material from any point on that slope causes imbalance. Such events induce new grading processes and new slope form. The lower the angle of slope the more stable the slope is. Yet material movement may be triggered internally in the weathered rock mantle, the regolith, by either vibration, as in an earthquake, or by addition of weight caused by introduction of water or lubrications at the base or up slope of the weathering front, thus creating internal pore pressure which therefore induces mobility (Vijay, 2016).

Soils are a product of rock weathering, and transportation by mobile agents such as running water, winds and glaciers. Soil development process is a geomorphic process. Soils in the whole watershed are as varied as the rocks, climate and the intensity of the weathering processes, and according to topography and land use. The soil analysis was done for the purpose of assessing the differences in the soil composition at different points along the slopes in different parts of the watershed for the purpose of

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assessing the contribution of land use activities to the environment and ultimately to the geomorphic processes. What was significant about the soil was not the formation process but the stimulant imposed on the processes by substance input as indicated by (Thompson & Troeh, 2009).

This natural land use significantly preserves the landforms from rapid denudation. The soils in the agro-ecological zones 1, 2 and 3 have been developed from olivine basalts and volcanic ashes. They are deep dark brown but shallow where there are rock outcrops such as Kairuri and Kathangariri. The soils are very friable and therefore easily erodible when left bare. Characteristically these soils are humic acidic soils. As the slope gradient fall in such locations as those found in Kiandari, away from the forest but where tea grows on the steep slopes, which are also marginal coffee areas, colluvial plains develop. The soils are better drained. The soils here are histosols loam, clay loams, and andosols, as in Kianjokoma. The catenary system of this tea zone varies from very deep on the concave slopes to very shallow on convex slopes where outcrops appear as seen in Figure 6.

At the highest altitudes on the mountain are the alpine soils generated through freezing and thawing processes and comprise of scree, fluvial and glacial deposits. Evidence of solifluction is apparent in the greyish soils. In other areas, thin reddish-brown soils are found on steep slopes while in the valleys peaty soils develop. Lower altitudes are forested and have reddish-brown soils with clay, which become sticky when wet as discussed by Meadows and Lin (2016). These soils develop differently in different parts of the world according to the climatic zonation. The difference in the soil composition induces different deficiencies in plant nutrients and therefore varying substance inputs. Therefore, inputs from agricultural activities are important inputs to the geomorphic processes as indicated by the changes in the chemical contents in the soils for different land uses.

In most of the middle zone (2) where the vegetation is transitional between forest and savannah, the soils are deep and reddish-brown in colour. In the poorly drained areas such as the valley bottoms, the soils are the colluvium soils and dark clay soils (grumusols). While the soils of the highest altitude, are very deep and well drained dark-reddish and brown in colour, rich in ferromagnesian mineral and organic matter.

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The soils in the in the drier agro-ecological in the lower zone (3), are developed from the basement rock systems are complex being mainly developed from gneisses. They are shallow dark brown to red brown. These soils are classified as regosols. In the same region, the colluvial-derived soils are deep and sandy, and therefore classified as arenosols. They are dark brown to yellowish brown in colour.

In the lower agro-ecological zone, the soils are developed from quartzite. These soils are in areas of gentle slopes where there is excessive drainage and are dark-reddish brown in colour. They have high contents of iron and are therefore classifies as ferralsols. In all the areas, the soils show marked changes and differences with depth and location on the slope.

Table 13: Soil Analysis by Depth at Kangaru (2017) Field Reference 135/2-6

Horizons	A1	B21	B22
Depth in cm.	0-30	30-60	60-100
Texture	C	C	C
Sand 2.0-0.05mm	5%	3%	5%
Silt 2-50microns	12%	16%	10%
Clay 0-2microns	73%	81%	85%
pH- H_2O	6.3	6.6	6.6
EC-H_2Omho	0.15	0.16	0.09
pH-KCl	5.3	5.6	6.2
C	2.18%	0.67%	0.55%
N	0.28%	0.10%	0.08%
Cation exchange pH8.2	22.4%	18.8%	18.6%
Exchangeable Ca	11.2%	10.6%	11.3%
Exchangeable Hg	2.4%	2.8%	2.4%
Exchangeable K	1.88%	1.80%	1.75%
Exchangeable Na	0.50%	0.30%	0.40%
Base saturation	71.6%	82.4%	79.8%
Exchangeable Al	0	0	0
Kaolinite	100%	100%	100%
Available P ppm	9		

The analysis of the soil by depth shows the effect of infiltration, plume and the effect of tillage, which affects the whole soil profile. It can also be compared to findings by Langat *et al.*, (2019). Major inorganic components of soil are sand, silt and clay. Sand as distributed by percentage and increase by depth and in the order of 5%, 3%, 5%. Silt 12%, 16%, and 10%, and clay 73%, 81%, and 85%. The vertical distribution of sand and silt is a reflection of a long history of soil formation. These include such

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processes as weathering, erosion and deposition besides burrowing animals and microorganisms as they aid in soil development; including land use. The clay distribution is an indication of the general behaviour of clay.

Clay is very fine and is the final product of weathering. Clay tends to, in a sense, precipitate through the pores as water runs through permeable rocks and soil and creates an ideal condition for landslide by settling at the point where its movement is inhibited by porosity. At that point therefore, it develops a layer that swells when wetted, becomes impermeable and slippery (Kitutu, 2006). Drying and of clay may not necessarily cause slippage, but excessive water can induce slippage and flow as in the case of Kianjokoma slide where the excess water had virtually become a continuous flow even two weeks after the slide. At the point of the slide, slip, slump and flow resulted in laminar flow of the mud, which was carrying tea bushes without rotating and transplanted the bushes at the point where the flow stopped. The flow resulted in a wide completely flat surface of about 50 meters, Plate 12. Plate 6 shows the sequence of land use activities, settlements, leading to the landslide.

The factors, which affect weathering, are temperatures and humidity and these two factors directly affect rain erosion. Infiltration is affected by the nature of the surface such as water deficiency, which raises the capillarity potential (pE), and the presence of cracks and fractures on the characteristics subsurface. The percolating water affects and promotes instability of the weathered mantle. In turn, such tendencies are instrumental to mass erosion and that interstitial rain-wash and raindrop impacts are ever-present agents depending on vegetation and land use. For example, an interlacing of grass roots protects the soil from failure; yet such a mat such as that provided by the tea bushes may not be effective if there is an underlying layer of clay. When there is poor surface cover of vegetation a uniform surface layer is constantly being removed through slope-wash (Hiscox, 2009).

It difficult to measure the changes in every part of the watershed, but in the study area, two distinct observations explain the slope morphometry in the upper and lower regions of the watershed. The upper region comprises the Kathangariri –Embu town section and the second portion is from Embu town to Gachuriri where the SS19 is situated on such varying slopes with similar findings in Mt. Elgon by Gumisiriza

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(2014). This points out to specific factors such as presence of soils from freezing zone to soils developed in hot semi-arid regions; but the changes in slope on Rupingazi watershed relate to amounts of rainfall, land use and rock characteristics such as permeability and chemistry.

The Kathangariri–Embu section is characterized by deeply weathered volcanic rocks that produce deep soils but receive higher rainfall. Where the slope gradients are higher than 25^0, rain wash is one of the dominant types of erosion depending on the surface cover and land use influence. Here, soil creep, slumps, and sliding maintain slopes at the same angles and any changes exhibit parallel slope morphometry change.

In the Embu-Gachuriri low gradient, the rainfall amount received is lower and the soils and the weathering mantle is developed on the basement sedimentary and metamorphic rocks with sandy and clay fabric. Due to the lower gradient from 25^0 to 8^0, infiltration is much higher and at the same time, due to higher temperatures, laterites develop and the slopes show characteristics of slope decline.

Soil analysis, of the soil from Embu town west of the sewerage plant, shows the pH at the three the points on transect which were taken from the highest point of the slope towards the river channel. The gradual increase in the soil pH from the crest is an indication of accumulation of chemical substances. In the same order, the magnesium increases from the crest to the river channels. The characteristics of the contents of the Phosphorus indicate that there are specific activities in agriculture in the second point, while the nitrogen as the soil sample analysis for SS19 shows the same trend.

Soil samples in the SS 16 transect are in an area of intense agricultural activities. The values of the pH increase from the crest to the river from 6 to about 9, which is a significant indicator of the input by the land use activities. In the same way, the magnesium and phosphorus increase in the same way while the Nitrates decrease in the same way from the crest to the bottom of the valley.

From the rainfall data, it is clear that this agro-ecological zone has bimodal climate with low rainfall (short rains) from October to December and the long rains from March to May. It is a zone of pastoral dominance and of quick growing cereal crops.

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New land use activities include sprinkler irrigation near the rivers (note the amaranth farm Plate 24 and Plate 25), the round patterns scattered in the farms are ponds for water storage used for irrigation. Immediately to the left of this farm rows running parallel to the river indicate the khat (*Catha edulis* and local name *mira*) plantation also under irrigation. The soil pH changes from 7.0 at the crest to 7.6 half way the slope, (150m), to 8.5 at the riverbank. This change results from the chemical washout from the farms as supported by the soil analysis.

Soil erosion can be viewed as the effect of moving water on a soil surface, thus washing it away. Interception (the retention of precipitation by vegetation before it reaches the ground surface as compared to the through fall), is important in that intercepted precipitation has a regulating and modifying effect upon the water flow. Its availability for geomorphic processes is significant because the intercepted water is able to take or wash away any chemical substances on the vegetation such as the sprays on crops.

Patterns of rainfall intensity and duration are also important in predicting catchment discharge and the water availability in dealing with floods, droughts, surface runoff, groundwater storage and recharge, soil storage, soil erosion and the ways they affect the agricultural land use calendar. As regards environmental flows, Acreman *et al.*, (2014) emphasize the importance of water flows in the environment to the distribution of agents, which changes the quality, and reactivity of minerals carried by water. Landforms respond to the flow and amounts of water on the land, but such a response and the flow are controlled by vegetation interception. Christopherson (2008) indicates that interception, which depends on the intercepting media, is important in regulating the rates and effectiveness of the rainfall and erosion rates.

These parameters and inputs modify landform dynamics and are considered as being significant factors in the meteorological events and inputs of temperatures, moisture and winds. This study puts into consideration the role of water flow and vegetation. This is a low-lying land where superimposed profile Plate 26 from where irrigation and chemicals modify the geomorphic dynamism so that the practice of irrigation alters the water contents of the soil and creates a microclimate. This is for economic

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purposes but it contributes to the changes in the weathering processes and the movement of the nutrients in the soil.

Loss of water through deep percolation may be caused by irrigation. This affects the bedrock and the addition of chemicals supplied by the fertilizers accelerates weathering. The percolation is accompanied by transfer of minerals and nutrients, which induces leaching. Leaching makes soils more acidic and the acidic conditions cause more leaching because more cations are released through acidic weathering. An important factor was found at the edges of the two farms, which are divided by a road, which ends at the river's edge that a thin layer of murram (laterites) has developed along the road. Leaching is therefore a contribution of land use activities. Leaching results from loss of soluble substances and colloids from the top layer of the soil (eluviated layer) to the deeper layer (illuviated layer). This process deprives soils of nutrients and leaves insoluble substances such as quartz and iron hydroxides, aluminium and manganese, hence the laterites (Frey, 2001).

4.5 Influence of Human Activities on the Slope-form Changes

The nine-unit slope model finds its major anomalies in specific-process-response slopes such as the glacial slopes of Mt. Kenya or any other slope on varying landforms. The elements at the top and at the bottom of the slope vary according to the pre-existing slopes. For example, the formation of a corrie leading to the creation of an arête would show a variety of possible slope profiles pivoted at the top of the back wall. The threshold of the corrie at its base where there could be a tarn behind it or none at all, depending on the glacial processes and gradient. Anomalies also develop where there are sudden changes in the slopes such as landslides.

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Plate 16. Slope Failure (near Embu town) -0.524221, 37.437832) (2017)

Therefore, the previously developed profiles change and so different forms of slope start. This could occur due to natural or by land use assistance. Imbalance resulting from road cutting at the base of the slope caused the trigger-effect that forced the slope to grade according to the new repose. This phenomenon was examined by Douglas and Lawson (2015) in Britain Slope analysis is complex and requires many numerical inputs and consideration of numerous operations. For example, in calculating the amount of material moved on this slope it was necessary measure the height, breadth and depth (30x156x67 respectively) of the dislodged material, which gave 313,560 m^3 or approximately 7,890,000 kg of rocks. Slope profiles in this study relate to the nine-unit model, and provide information about angles along the measured lengths of slope within the rivers´ short profiles and the long profile in relation to the whole watershed.

Surface measurements of the slope are important, but as regards geomorphic processes the rocks and their weathering and the resulting weathering mantle, or regolith, is more important. The rock debris varies according to the position on the slope and in turn affects the catenary system on any slope from the flat areas, the slope crest, to the riverbank. Analysis of the slopes in the watershed sampling station

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indicates that many valley and slope varieties can be represented in a relatively small area, whether it is away from the river channel or along the valleys. This, by implication, the consideration of the parent rock below the mantle may not conform to the surface morphometry of the slope due to the mantle mobility on the slope (Acreman *et al.*, 2014; Church, 2003).

The only way to assess the rock set up is by analysing the depth of the debris at different unit of the slope to reach the solid rock. Therefore, the amount of regolith on different slope elements is of great influencing role in the understanding of the slope evolution. According to the agro-ecological zones of this watershed, it is difficult to know at present precisely the relationship between the climate and the slope form development. Yet, what are important are the daily climate changes, the oscillation thereof, and the resulting microclimates, which may result naturally or by land use induction. In this regard, slope aspect, which is measurable in relation to the grid north, is an important variable.

Regolith development on any slope plays an important role in the slope evolution because it affects such bedrock characteristics as the strata dip (angle and direction) rock joints, and the effect on the weathering rates and amounts. The regolith can shield the rock from weathering by shielding it from weather elements or facilitate weathering process by keeping the rock moisture. Land uses and the chemical additives from different sources directly modify all these variables as also found out by Lane (2017). If the slope profile of different slopes in the watershed were to be superimposed on the nine-unit slope model represents, the differences would reflect the effects of climate, gradient, geomorphic processes, initial landform and past land uses.

Some notable inconsistencies show geomorphic slope facets, which have been modified, exaggerated or eliminated. Crestslope: units 1, 2 and 3 form one facet of a gradient varying from $2\text{-}4^0$ which form the crest of the spur. This is the zone of rainwash and although most of these portions of the slope are vegetated, they are the only point at which the roads are constructed. The presence of the roads changes the sheet wash to gully erosion as the drainage water consolidates into rills, which wash the steep slope at unit 4 which are over 30^0. Unit 4 segment is a modified unit 5,

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which is generally steeper and extends to the riverbank. This slope form eliminates unit 6 and 7, and the resulting straight slope, with minor convex and concave segments develop. These modified sections have no significant breaks of slope and therefore transmit materials directly into the channel. Most of these steep slopes are asymmetrical and forested or cultivated with tea bushes, Plate 17, Plate 18.

Plate 17. Asymmetric Valley, Kiandari (GPS -0.416100, 37.463824) (2019)

The rate of infiltration is least at the crest where the soils are compact and clogging of soil pore spaces is a result of interception, leaf drip and through fall from the tall trees.

It is significant by observation to note that the valley at this station is asymmetrical in form and the flood plain oscillates from left to right according to the rock systems and river erosion. On the asymmetric slopes, weathering, erosion, deposition and mineral movements and therefore the geomorphic dynamisms are different on the two slopes; and as expected the land uses differ. For example, the wide flood plain is utilized for vegetable growing while the steeper slopes are taken by tea, maize fodder and forests. Due to these differences the contributions of chemical agents to the rocks and soils vary in amounts and frequency.

The slope, Plate 25, shows the extension of the slope unit 4 elimination of unit 5 and 6 but extends unit 7 to the channel. The average angle of the extended unit 4 averages

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32^0. Although this is an area of deeply weathered volcanic rocks, the resulting soils on the slope element are relatively thin, and therefore frequently expose rock outcrops where erosion and land use aid the soil removal. The extended colluvial plain averages 170 m. This portion of the slope is utilized for crop farming, fodder and mainly vegetable farming. An assessment of the infiltration rate in the field shows a pattern of high rates at the crest, 5.5ml, in the middle as 0.9ml per minute about 80 meters from the crest to a very high infiltration rate on average for the plain as 12.5ml, a general indication of sediments and soil structure.

The pH indicates uniformity on the steep slope of 7.5 but increases in the plain to 8.5 on some of the steep slopes where farming of tea is practiced. In other slopes forests predominate and the water movement and erosion dependent on the gradient. On some of these very steep slopes, tea bushes commonly slump especially next to the roads, (Plate 13). Soil is deep, but the plant roots are limited in depth and form a shallow mat on top which becomes unsupported when the materials at the base have no frictional resistance at the bottom such as at the road or where also deep undercutting occurs through erosion or land use. At the road where the tea plantations are uphill from the point of undercutting, the new base level for grading sets and the retreat of the whole slope to the top of the spur is triggered, and new geomorphic processes operate to make new slope facets.

The soil analysis shows changes in the contents of minerals in response to both infiltration and surface runoff even on almost straight slope, the same under same land use, but the changes are significant. The causes of the differences in pH values are the contributions by the land use activities. It is expected that there would be changes along the slopes in any topological changes but the concentrations or removal of chemical substances is accentuated by land use activities so that on this slope, the pH changes downslope, from 6.47 to 6.69. Magnesium changes from 668 mg/l to 1673.75 mg/l, an indicator of chemical inputs while the contents of phosphorus drastically increased from 0.495 to 3.84 due to the use of phosphate fertilizers. Changes in the nitrate contents, usually modified by natural processes, clearly shows an increase downslope from the spur

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How do such changes affect and modify the geomorphic processes in time? The modifications that result from such additions is a matter that can be quantified in time. This can be done in view of acceleration or deceleration rate and pace of changes in geomorphic processes as indicated in the slope evolution analysis through soil chemistry. The mechanisms of soil erosion and slope failure on any slope involve complex interactions of landform-altering processes including the changes in the structure and texture of the weathered rock material and the soils and supported by events in Plate 6, Plate7, Plate 9, Plate 11 and Plate 12. The slope failures can be associated with certain conditions on the ground, climate and land use contribution, but whatever the trigger mechanism, landform changes are initiated by some event which could be geomorphic or anthropogenic. Plate 6 shows the physical developments in settlement, farming and drainage in 2005, 2008, 2012 and 2018 to show the impact of human activities as input into geomorphic landform evolution.

After the rain period the ground develops cracks, which then become the points at which surface runoff water enters transmitting both the water and materials. Miniature mass failures at the cracks shift the slope surface mart of soil and debris. Miller *et al*., (2010) consider the combined effects of natural and human-induced geomorphic impacts on the environment and agree that human input strongly influences geomorphic events in both short and long-term through sequences similar to those discussed in this section.

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Plate 18. Land Use on Steep Slopes, Kathangariri

Continuous wetting and drying enhances downslope movement of the soil and weathered layer of rock. This process of infilling of the cracks by the soils, stones and vegetation materials pushed down the slope alters the slope form each time the process is repeated, so that the surface morphometry changes. In such slopes as these, it is important to relate the physical characteristics of the mantle to the downslope shift of the materials by creep or failure. The weathered mantle is usually anisotropic so that there are areas of strength and others that are weak. This points were confirmed by Krhoda *et al.,* (2015) near Ngong Hills in a study that linked geomorphic events, fluvial processes and human activities. An increase in weight due to addition of materials or water or if materials such as rock fragments or soil particles enter the weak points such as cracks, they induce plastic or viscous flow. The triggered dynamism will depend on such factors as slope characteristics, weathered mantle characteristics, geological characteristics below the mantle, climate and presence or absence of vegetation.

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Movements within the materials mass occurs when the new applied weight causes frictional resistance in the material against gravitational force to be exceeded. This important factor helps to explain why any offsetting of the dynamic equilibrium on slopes usually follows heavy rainfall or addition of water. At first, water as moisture increases cohesion, but when saturation occurs, it reduces the shear strength of the material and failure occurs. The bulk size of the moving material is commensurate with the mantle thickness, and that the shear stress caused by the extra weight in the weathered mantle increases faster than, and even reduces, cohesion and frictional resistance. Knapen *et al.,* (2006) found through data results that support the conclusion made in this study in regard to landslides and high population. The water content in a weathered mantle such as soil affects the pore water pressure and the chemical structure in the material.

The process of increase or decrease in shear strength of the materials on a slope that keeps it stable on the valley limp is also a variable of the throughflow in the soil. Water flows through the interconnected pores, a process that enhances percolation, permeability and natural piping of flowing water through percolines. Depending on the location of the majority of the percolines in relation to the mantle stratification, a zone of high concentration of percolines becomes the likely zone for mass failure. Once such a point effectively causes mass movement, a multiplier effect occurs on the whole slope so that a process of grading starts above and below that point. This delicate quasi-equilibrium on the slope can be offset by land use activities so that cumulatively small but numerous failures in the weathered mantle control the slope form creating new segments or eliminating others from the theoretical slope model. This approach also used in the study by Simon and Collison (2002) found out that the mechanism of fluvial activities affects the stability of the river banks where vegetation is affected.

Internal changes in the chemical systems in the weathered mantle brought about by materials introduced into the mantle through land-use cause changes in the materials' structure. This affects plasticity and rheidity of those materials so that internal frictional resistance to gravity and the slope stability are affected. The process eventually changes the slope, in time, from a soil surface to a talus slope (taluvial), and eventually into a rock slope because the finer particles are easily washed away.

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The top convex slope is formed due to rainwash, action of pressure release, but may also be induced by soil creep and followed downslope by rills where the slope is generally straight. Convexity is also a result of accumulation of scree from the rainwash originating from two sources converging so that any cracks developed or earlier rills parallel to the strike of the slope enhance deposition and therefore a change in surface configuration.

Observations on most movements indicate that as the material fails, any of the categories of movements; slides, flows and heave can operate on the landform. A clear distinction has to be made between slide and landslide. Sliding mainly involves dry materials and the movement is rapid while a landslide is slow with a uniform velocity and sometimes intermittent, with a distinct sliding surface and may include rotational slips, or a combination of those movements at different points in the event. In the cases of Kathangariri and Kianjokoma, human input was responsible for the slope failure due to the excess water directed into the tea bushes just above the spring point, and wide cracks remain at the head of the slide where further sliding can be initiated.

The process in general also relate to the significant contribution by the burrowing animals which shift a lot of soil and rock debris as they make their burrows and when the burrows collapse the soil shifts into those gaps. Also significant is the impact of range animals, including chickens in the farms, which continuously shift materials on the surface or bring others from below the immediate surface layer. In the places located in the second agro-ecological zone, the landform shows a decline in the angles of slope with little variation in the slope form on both sides of the river. Major modification is on unit 3 and 4, which have been modified by erosion and deposition as represented by the superimposed profile (Plate 23).

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Plate 19. Slopes in the Second Agro-Ecological Zone (GPS -0.530814, 37.446048) Right bank is in Kirinyaga County

The floodplain in the middle ground is a result of erosion and weathering in the foreground and alluvial deposits. The calculation of the soil loss from the footpath shown in the background, from the house in the left background to the stream at the right middle ground was 272.5 m^3or 68,125 kg of soil (Table 8). Differences in the gradient denote varied rates of material movements. The procedure involves subdividing the transect into segments with approximately similar dimensions of three equidistant points across the gulley, and measuring width depth, and length of the segment. The example below is for the livestock drinking point at SS19 at the confluence of Rupingazi and Thiba. The volume of material is obtained by multiplying the average cross-section area by the length of the segment.

The intensity of the land use has progressively become high, and so have the varieties of the land uses. This a representative example of the slopes, and the two valley limbs show contrasting land uses. The left bank shows a high percentage of bare land

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surface, except for the fodder crop, napier grass *(Pennisetum purpureum).* In the middle ground it shows raw of maize. This area is highly cultivated without much effort to control erosion. Erosion gullies start very high up the slope as seen in the foreground, Plate 19, on such a slope the assessment of the degree of material movement shows great variations. Erosion has also stripped off much of the soil to expose rock outcrops

On this slope, the supply of most of the water that causes erosion is from the intercepted water by the urban infrastructure since this region is at the edge of Embu town. Infiltration on this side of the valley is low, the soil is compact and surface runoff is usually very high. The river gradient falls by 64 meters from 1331m to 1283m between the stations SS10 and SS 13. This gradient fall enhances the flow of substances, which enter the watershed from different land uses.

In consistence with SS 13, location S-0.0^0.32' 50 40, E37^0 27' 2020, there are in this station as in others study points, three points of assessment. On the left bank, the first point was next to the sewerage treatment plant. The first point from where the samples were collected, RS5.1, was at the road just below the sewerage at a point just before the bend on the road at an altitude of 1315m. The soil infiltration rate was 5.5, its average pH was 8.0, and the soil properties were as follows: at point 1, (sample RS 5.1) the spill over and overflow from the surface runoff from the open-air garage, roads and sewerage plant. The sample was collected from a garden next to the road.

The second point, RS 5.2, was at the point halfway (200m) downslope, lowest residential area, at an altitude of 1309 and location, S .$0^0$32' 58 1 E 37^0 27'13 8. This was at a point where farming has been carried out for a long time and the ground was bare except for the vegetation along the drainage channel for the sewerage to the river. The average infiltration was 0.6ml/minute and the pH., was 7.0 and the area suffers from extensive sheet and gully erosion with gullies as wide as three meters and a meter deep. The characteristic of the soil shows significant changes in the chemical contents. The third point, RS 5.3, was at the river, location of this point S 0^0 33 00 9, E 37027' 11 1 and an altitude of 1283 m. The preliminary soil infiltration was 15ml/minute while the pH was 8.5. The major characteristics of the soil were

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progressive changes of the chemical content characteristics according to the nature of its location.

The slope is represented in Plate 20, and the findings, which relate to the inputs to the geomorphic dynamism show that the pH on that slope increase from 5.87 to 6.69. This is a clear example of systematic change in the contents that alter the chemical component in the soil resulting from cumulative changes in the contents as it corresponds to land use activities. What is the state of geomorphic dynamism? Rocks and soils are sensitive to any such change, and the microorganisms, which assist the geomorphic processes, respond accordingly to any new stimuli resulting from chemicals, which alter the acidity levels (pH), either in rocks or soils. On this slope too, magnesium, phosphorus and nitrates, in response to the chemical contents from land use change, from the point at the top of the slope to the river bank.

For SR6 sample, collected from SS16, SS17 and SS 18, the results reflect the same trend; confirming that land use contributes substances, which alter the structure of the soil according to land use activities. The relationship between the locations of the SR5.1 (SS16) in the contents of phosphorus as compared to the other two locations. The content is 116.2 mg/l (at the banks) as compared points (SS17) and (SS18) as 9.9 mg/l and 7.68 mg/l. This enormous difference relates directly to the presence of intense irrigation, and the progressive decrease in the contents affirms the significance and the contribution of that activity to any weathering process on that slope.

There are slight differences between the field analysis and the laboratory results of the soil characteristics. This closeness assists in affirming the significance of the land use inputs at the source points (SR5,1-3 for SS13-15 and SR6,1-3 for SS 16-18).

Table 13: Infiltration Rates and pH at SS 13 &16

Field reference	Infiltration rates	pH
SR5.1	5.5 ml/minute	7.5
SR5.2	0.6 ml/min	6.0
SR5.3	15 ml/min	7.5
SR6.1	0.9 ml/min	6.0
SR6.2	6.2 ml/min	7.0
SR63	1.0 ml/min	7.5

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Nitrogen is another plant nutrient present in sewage in form of ammonia. Ammonia is toxic to fish but it has another effect on the water composition; it creates oxygen demand in the water where it is deposited. The reason why eutrophication as seen in Plate 10 occurs is because nitrates and phosphates, besides other nutrients contained therein, promote it. Apart from construction and road cutting, the intensity of human activities dominates the area including the town sewerage at the right foreground.

Plate 20. Intense Vegetation Removal and Eutrophication at Sewerage Plant (SS 13 to SS 15)

Information on Plate 23 shows how multiple human activities contribute to changes in the geomorphic activity as confirmed by eutrophication along the exhaust channel. Any sewerage treatment involves the process of denitrification, which removes the organic nutrients from the sewage. This includes removal of phosphorous found in organic compounds where the process of chemical precipitation does this operation. Also, note the new settlement and landscaping to the left background.

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The low gradient of the area induces fast infiltration and high evapotranspiration. This has two results; higher water demand and therefore irrigation and greater input of fertilizers and chemicals into the soils.

Plate 21. Intense Land Use in Lower Thiba/Rupingazi (2018)

Information on Plate 21 shows that the slopes in the lowest altitude have unique properties in that this section is very low in its gradient (on the ground one may not know there is a river until one gets there). This is an area of basement rocks, which are metamorphic, rocks overlain by younger volcanic rocks (Plate 31 and Plate 32). The soils are rich in mineral contents because of their paragenesis. The topography therefore has a slope unit sequence of 1, 2, 6, 7, 8 and 9 (Figure1). This arrangement pre-empts the nature of infiltration and surface runoff. The surface runoff is minimized by the slope, while infiltration and leaching predominate the pedatic processes

A combination of slope-form and climatic factors such as precipitation amounts and the intensity of irrigation, Plate 20 and Plate 21 show that both banks of the river have

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intensive farming and the density of water storage points (shown in Plate 22 by the round depressions combined with the piping systems for irrigation.

Plate 22: Lower Reach of the Watershed; Location of SS 19, Ngomano (at the confluence) -0.0545147, 37.0485266 (2017)

The slopes in this section are at very low gradient and one may not know there is a river until one gets there. Plate 22, while Plate 23 shows the superimposition of the slopes in this agro-ecological zone against the nine-unit slope model. This is an area of basement rocks, which are metamorphic, overlain by volcanic rocks. The soils are rich in mineral contents as a result of their paragenesis. The oscillation of the hot and cool, wet and dry seasons has the same effect in the production of materials, chemicals and non-chemical products generated by different land uses.

Four sets of climatic categories can be delineated from the rainfall data (Appendix 9, 11, 12).

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December to February: hottest period of the year with very little rainfall, with no period reporting a hundred millimetres of rainfall in the period between years 2000 and 2015

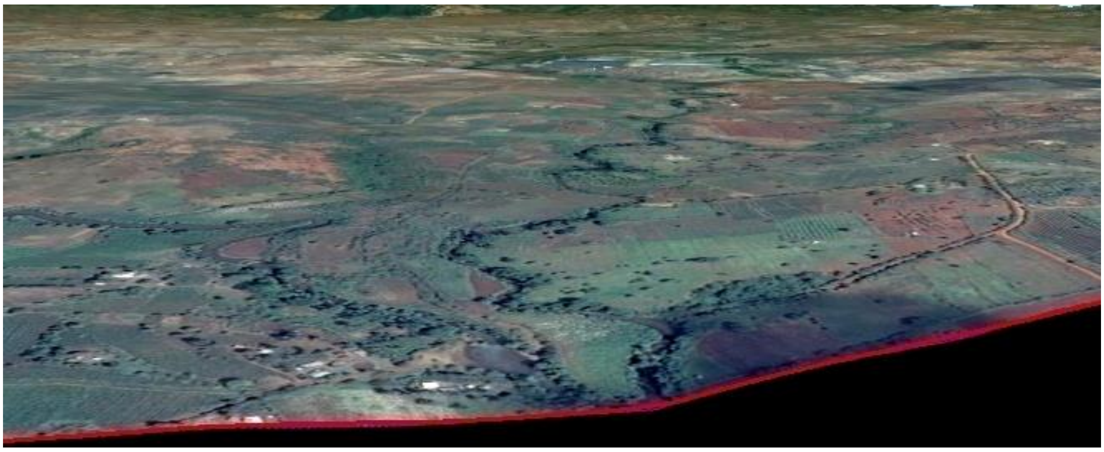

Plate 23: Superimposed Profile of the Slope; Lower Reach of Rupingazi at Ngomano, Gachuriri (Arc GIS)

In this agro-ecological zone there is water deficit to run rain-fed agriculture, hence the need for irrigation. The effect of inadequate water on dry soil at high temperature is the induction of soil leaching as one of the geomorphic process. The second effect of irrigation is the introduction of water into the soil and rocks at relatively high temperature increases the rates at which weathering occurs.

The third factor is the use of chemicals on the farms and the residues from such use. During the dry time of the year in this ecological zone, there is scanty vegetation so that the irrigated land provides the so classified pests to invade those farms. This requires large amounts of pesticides and insecticides and this contributes chemicals into the geomorphic dynamism.

The second season: March to May is the wettest season with three months of rainfall characterized by high intensity. For example, April 2014 had a rainfall of 486 mm. Under the conditions of the previous months, the high intensity rainfall has low infiltration rate particularly after a month of rainfall. Two important results, which directly affect geomorphic process, are apparent. First, high surface runoff carries loads of soils to the lowlands, changing the topography and modifying the soil properties. Second, the high amounts of water transfer minerals and agricultural inputs into the soil and rocks by eluviation and plume out significantly, modifying

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geomorphic processes of weathering and changing the groundwater properties. This event ultimately affects weathering and minerals removal or accumulation. These processes are repeated in the seasons that follow.

June July and August are months devoid of effective rainfall, but September to November are low rainfall months. These seasonal changes are more effective in the light of the high content of rock-forming minerals in the country rocks, which are sedimentary and metamorphic. The complexity of the mineral contents results in as complex reactivity in the rocks and in the soils of this zone.

4.6 Denudation Process

Land use varies according to the agro-ecological and agro-climatic zones which are determined by climate and altitude. These two factors directly affect the geomorphic dynamisms in any landforms. They influence weathering types and rates, erosion and deposition (Twidale & Campbell, 2005). Some of the ecological zones are non-agricultural as exemplified by the snow-caps of Mt. Kenya and the related forested high altitude. These natural land uses have their modifying effects on the geomorphic processes and lie at elevations of between 5,000 metres and 3,000 metres and are therefore dominated by steep slopes, narrow V-shaped valleys and fast flowing streams.

The highest agro-ecological zone lies in the highest altitude of the watershed, (just below the Alpine Mountain zone), by altitude lies between 3,000 m and 2,000 m, where tea, coffee, maize and beans are the dominant crops in addition to bananas and fodder crops for dairy animals. The next agro-ecological zone lies between 2,000m and 1,500m is in the middle reach of the basin. From the altitude of 1,500m to 1,000m (in the lower reach of the watershed) is an area of low rainfall where cereals such as millet and sorghum and root crops are cultivated. It is also the zone dominated by pastoralism. There is a general decrease in rainfall from north to south due to the increase in the distance from Mt. Kenya’s orographic effect and the reduction in altitude, which raises the temperature.

Virtually 80% of the country lies in the semi-arid to very arid zones (ASALs), which are predominantly inhabited by the pastoralists and agro-pastoralists. Kenya's ASALs

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also support more than 50% of the country's livestock population. The distribution of study sampling stations is according to the agro-ecological zones, which are designated alpine (1) middle (2) and lower (3) according to climate and altitude, Figure 3. It is important to know that there are no real edges of the ecological belts because their boundaries are determined by numerous factors such as altitude, topography, geology, hydrological inputs and aspect.

The land use types in the watershed are related in their collective influence in their chemical and non-chemical substance contribution within the agro-ecological zones and therefore have direct bearing on watershed and contribute to both the physical and biotic parts of the geomorphic dynamisms and the ecosystems Van Leeuwen *et.al*. (2017). The contributions with greatest influence, for example, are urban settlements, infrastructures, dams, irrigation and greenhouses, which are just a few of the major land uses. Wherever and whatever types of land use are, their contribution to geomorphic dynamisms is inevitable because they all have output and by-product which include waste materials and chemical substances

4.7 Ambient Climatic Characteristics and Slopes Mass Movement

Different geologic and climatic factors have a crucial role in mass failure. Therefore, it was apt in this study to point out that the slope failure concept can be predicted by considering the initial slope, the medium added into the mass of weathered rock, angle of slope of the topography, the likely effect on internal friction in the material and the angle of the shear planes. These components of the materials help in triggering mass failure. This would also indicate the likely new erosion surface after the failure. This notion can be applied to any slope to estimate the propensity for the slope to failure. This was generally found to agree with study findings on mass movement in East African Highlands (Westerberg, 1999).

The climate is one of the pivotal factors in landform evolution and a driver in the geomorphic dynamism such as weathering, erosion and deposition. The position of the Equator and the presence of Mt. Kenya induce respectively convectional and orographic phenomena in the watershed resulting in the imposition of a Modified Equatorial climate, described as ‘highland sub-tropical’ climate (Ojany & Ogendo, 1973). The rainfall periods are March to May with maximum in April as dubbed long

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rains, and the period October to December described as the short rains with the peak rainfall in November.

This trend indicates that there are periods in the year when the increase of the climatic activities and human land use intensify. The graphs Figures 6 and Figure 8 relate to the rainfall amounts and the rainfall intensity for Kairuri for 2012-2015. Figure 7 compares the rainfall variation over the last fifteen years. This significantly compares with rainfall of the same station in the years 1973-1976 (Figure10), and its intensity, (Figure 7, Figure 8, Table 15 and Table 16). Five factors have interwoven acted upon the landforms of the watershed. First, the time factor, 40 years of changing climatic events acting upon the landforms with varying intensity and impacts. Second, the changing patterns of rainfall total and the apparent shift in the seasonality of the rainfall. Third factor is the intensity of the rainfall and the changes in the seasonality of it. Fourth, land use changes in time and the technologies as regards inputs and the human population changes, fifth, water sample between the 1970s and 2010s show remarkable difference in constituents.

Information on Table 14 shows that the rainfall trends were as they were described as "rainfall throughout the year". This climatic characteristic is emphasized by the graphs. It is important to consider these climatic trends as significant in regard to changes in geomorphic dynamisms as both natural trends and human inputs have changed in time. This data also emphasizes the apparent significant trends in climate, where every three to four years form a distinct cycle. This cycle at present elicits compensatory activities to combat the negative climatic conditions and therefore induce inputs that contribute to the impact on geomorphic dynamisms such as those resulting from irrigation and fertilizers use in agriculture.

The general nature of the rainfall characteristics is bimodal with the first peak being March to May and the Second peak from October to December. There is clear indication that from 2003 and 2007 there are variation in totals and in the shift in the peak months. In 2003 the early peak was in May and the late peak in October in 2006 early peak was in April and the late peak in November. In 2007, early peak was in May and the late peak in October. The four years, 2003- 2007 were the wettest year (Figure 8).

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The years 2008 to 2012 were years of unpredictable and unreliable rainfall with very dry period between June and October. The impact of these trends resulted in greater use of artificial watering of the crops and ultimately more inputs into the geomorphic systems in the watershed. The trend of rainfall reduction continues to 2016, but a portrayal of very clear overview of the nature of the irregularity and unreliability of rainfall. In 2013 and 2016 there was a shift of the higher rainfall from March to May, while in 2015 the higher rainfall fell in the October and November.

The changes brought about by the seasonal shifts in precipitation affect discharge; in particular, the simple river regime. The changes help in mounding the channel and in turn the valley and slope morphometry. Any change in the channel has a domino effect on the rest of the basin. For example, an increase in overland flow during high precipitation increases both the capacity and the competence of the flowing water so that for the particles of the same size the competence increases with the sixth power of the velocity. Shaw (2008) had projected by the Hjulstrom's curves; that a threshold for erosion or deposition is set by the critical velocity able to move a static particle, known as the erosional velocity.

It is not possible in this study to analyse the changing trend in the global climate change but it is necessary to point out some local trends in relation to the global conditions. The rainfall only creates a broad picture of likely extent of the impact of weathering and erosion processes. The geomorphic processes are not uniform either. It is generally understood that the climate of a place is the average of the elements (Siddan & Subramanian, 2016). In the same way a close look at the precipitation from the graphs indicate why it is difficult to ascertain the extent of geomorphic processes, yet the extent the processes occur can be assessed individually and at the time of the event such as flooding, mass failure or drought.

From the point of view of the rainfall intensity as a rough estimate of the intensity of geomorphic processes, the wettest years out of the 14 years were 2006, 2007, 2012, and 2015 while the least wet years (below average) were 2005, 2009, 2014 and 2016. It is noteworthy that although the amounts of total rainfall differ in different agro-ecological zones, the characteristics of the rainfall are similar.

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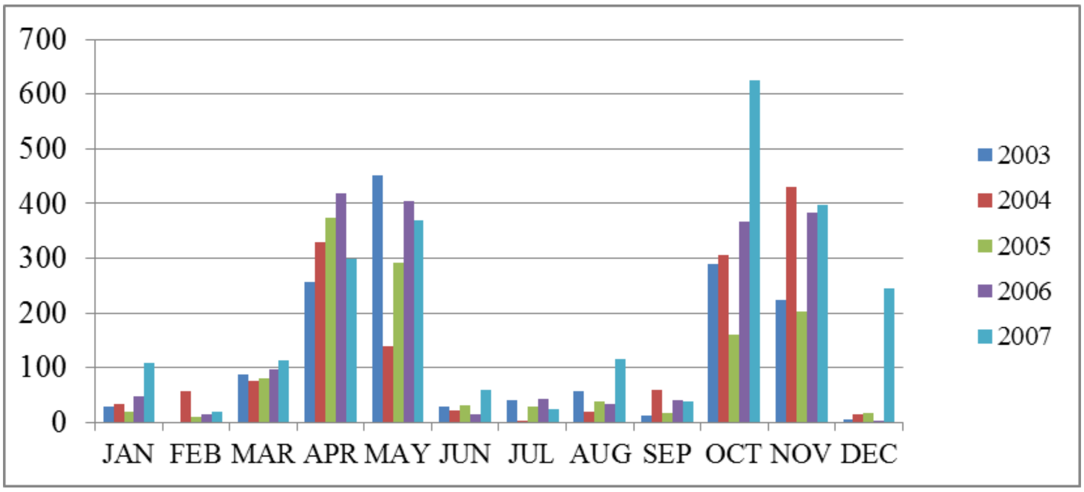
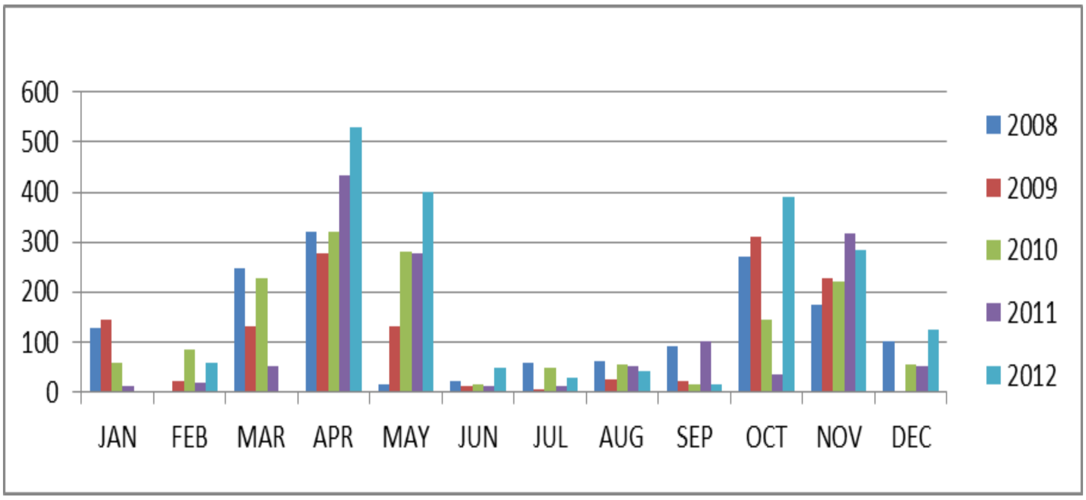
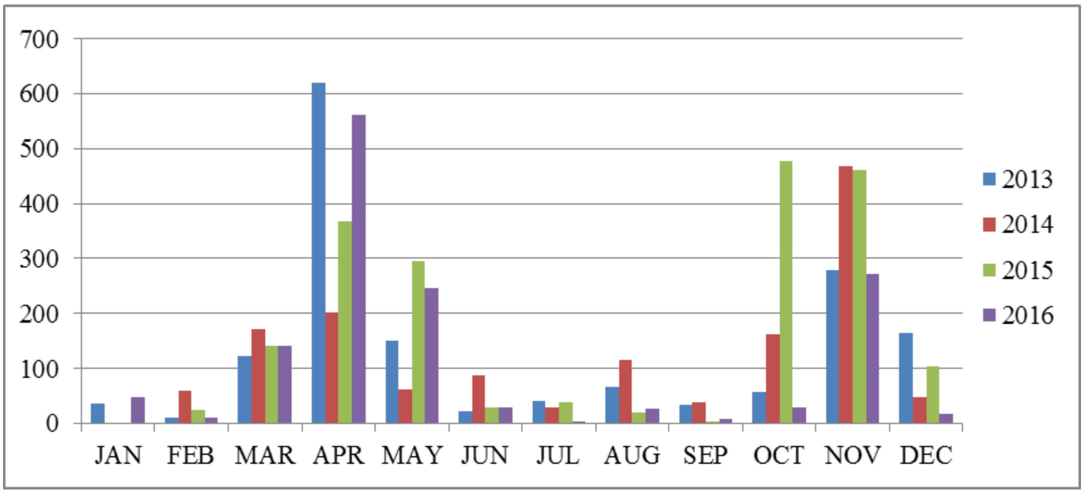


(a)



(b)

Figure 7. Rainfall in mm, 2003-2016.



(c)

Figure 7. Rainfall in mm Received in the Rupingazi Watershed between 2003-2016

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The influence of the amounts and duration of rainfall have significant contributions to the geomorphic dynamics as exemplified by looking at two stations in different agro-ecological zone: Irangi in the high-altitude zone 1 and Kairuri in zone 2. The amounts and intensity directly affect the aspects of:

i. Land use activities including chemical inputs,
ii. Precipitation, input or lack of it as it affects geomorphic processes,
iii. Rates of substances transportation on the slopes, in the soils and rocks,
iv. Modification of the geomorphic processes in time according to effective inputs.

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Table 14: Rainfall Amounts and Intensity at Irangi and Kairuri for the years 2014, 2015, 2016

2014		Irangi		2014		Kairuri
Month	Amounts mm.	Duration days	Intensity mm.	Amount mm.	Duration days	Intensity mm.
Feb	2.74	3	1.0	4.5	5	1.0
Mar	1.75	3	0.7	3.09	3	1.0
Apr	19.90	11	1.8	39.86	18	2.5
May	46.76	28	1.8	22.18	13	1.7
Jun	7.19	8	0.6	1.10	3	0.3
Jul	21.65	28	0.8	4.48	4	1.1
Aug	17.23	17	1.0	6.59	17	0.4
Sep	5.12	6	0.8	6.44	8	0.8
Oct	21.20	9	2.3	18.02	7	2.5
Nov	36.45	12	3.0	21.53	15	1.5
Dec	4.72	8	0.8	13.12	14	0.9
Rainy days		133			107	
2015						
Jan	1.65	3	0.7	0,05	5	0.01
Feb	12.55	4	3.0	26.50	3	9.0
Mar	18.13	5	3.6	19.40	4	4.8
Apr	13.65	26	0.5	12.26	17	0.7
May	5.13	11	0.5	10.45	6	1.7
Jun	4.17	7	0.5	1.70	5	0.3
Jul	12.88	15	0.8	2.35	6	0.4
Aug	1.23	10	0.1	6.53	13	0.5
Sep	1.18	7	0.2	5.53	6	0.92
Oct	36.50	7	5.1	2.25	8	0.3
Nov	13.26	11	1.2	16.07	16	1.0
Dec	4.03	5	0.8	8.00	4	2
Rainy days		111			93	
2016						
Jan	1.04	5	O2	0.28	2	0.15
Feb	5.72	8	0.6	1.28	4	0.32
Mar	8.00	5	1.6	15.11	7	2.1
Apr	15.75	8	1.9	24.20	5	4.8
May	12.35	14	0.9	27.02	17	1.6
Jun	6.97	10	0.7	3.95	8	0.5
Rainy days		50			37	

Irangi is located ten kilometres to the northeast of Kairuri 260m higher in altitude. In 2014, Irangi had 133 days of rain while Kairuri had 107 days. In 2015 Irangi had 111 days of rain as compared to 93 days at Kairuri. This notable difference in rainy days'

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results in differences in other weather elements, land use and geomorphic dynamisms and therefore varying impact on the landform evolution.

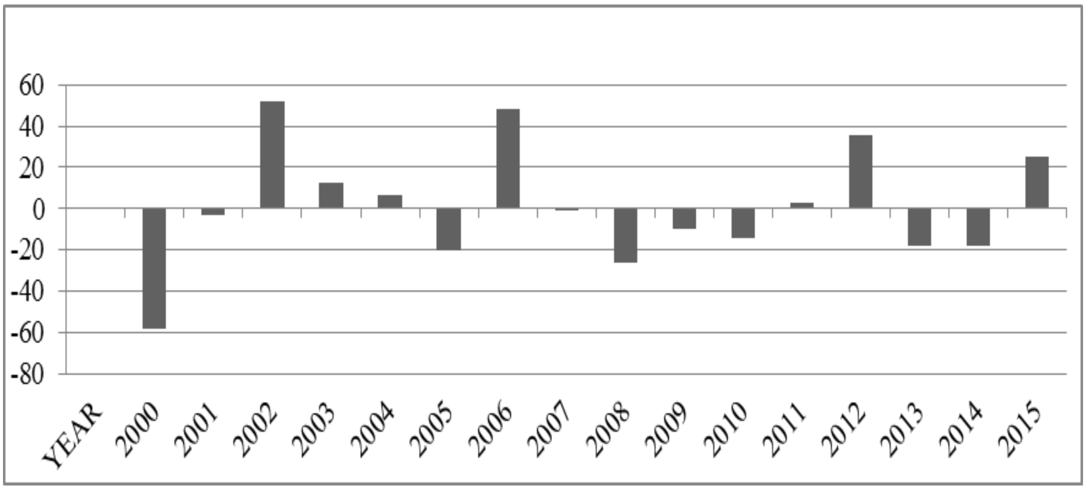

Figure 8. Rainfall Dispersion: The mean (=0) is 1,290mm

The years chosen in the graphs represent years of high rainfall, drought and shifting seasons. The usual pattern of rainfall in this region is one of higher rainfall in the March-May season, yet in this period, there is a clear shift in the higher rainfall occurrence to October-December. The excessively high rainfall for 2002 caused flooding and a lot of riparian agricultural activities were washed away indicates the levels to which such discharge can influence landforms, Figure 7.

Rainfall is a significant variable in landform evolution as can be deduced from Davis, Penck and King models. On the impact of rainfall on landform evolution, Duff (2012), says that the surface erosion results from the cooperation gravity with weathering agents. This cooperation of relates directly to rainfall variation, amounts and intensity. The interstitial rain-wash and slope-wash contribute to the soil and surface flowage such as creep of water in the interstices carrying substances from land use into the soils and rocks, causing changes in geomorphic operations. Where the rainfall amounts are higher, the initial rain-wash develops into rill-wash which forms efficient agents of transportation of any surface materials and chemicals originating from land use. These combinations of human contributions to geomorphic processes results in effective landform evolution.

This has been shown in Plate 15 where erosion has stripped off the soil layer and has exposed a new erosion surface comprising of the bedrock where livestock takes water.

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Global changes in global climate are also reflected in the watershed. The rainfall only creates a broad picture of likely extent of the impact of weathering and erosion processes. The geomorphic processes are not uniform either. It is generally stated that the climate of a place is the average of the elements. In the same way a close look at the precipitation. Information on Figure 7 and Figure 8 indicate why it is difficult to ascertain the extent of geomorphic processes, yet the extent the processes occur can be assessed individually and at the time of the event.

The factors, which affect weathering, are temperatures and humidity and these two factors directly affect rain erosion. Infiltration is affected by the nature of the surface such as water deficiency, which raises the capillarity potential (pE), and the presence of cracks and fractures on the characteristic subsurface (Ramesh & Darius, 2017). The percolating water affects and promotes instability of the weathered mantle. In turn such tendencies are instrumental to mass erosion and that interstitial rainwash and rain drop impacts are ever-present agents depending on vegetation and land use. For example, an interlacing of grass roots protects the soil from failure. When there is poor surface cover of vegetation a uniform surface layer is constantly being removed through slope-wash, and slope failure (Plate 9 and Plate 16).

It is difficult to measure the changes in every part of the watershed, but in the study area, two distinct observations explain the slope morphometry in the upper and lower regions of the watershed. The upper region comprises of the Kathangariri –Embu town section and the second portion is from Embu town to Gachuriri where the SS19 is situated.

Information on Figure 8 shows the dispersion of rainfall within the years 2000 and 2015.Taking the rainfall for Embu as an example the graph shows very inconsistent rainfall pattern and a regular but unpredictable oscillation of rainfall from the general average of 1,200 mm per year. How do the geomorphic dynamics react to these changes? Seven years out of the sixteen years have rainfall below the average. This was a period of higher temperature and reduced moisture available for chemical weathering and reduced erosion but a period of likely acceleration of physical weathering. In this period the geomorphic activities veer from the seven years of more

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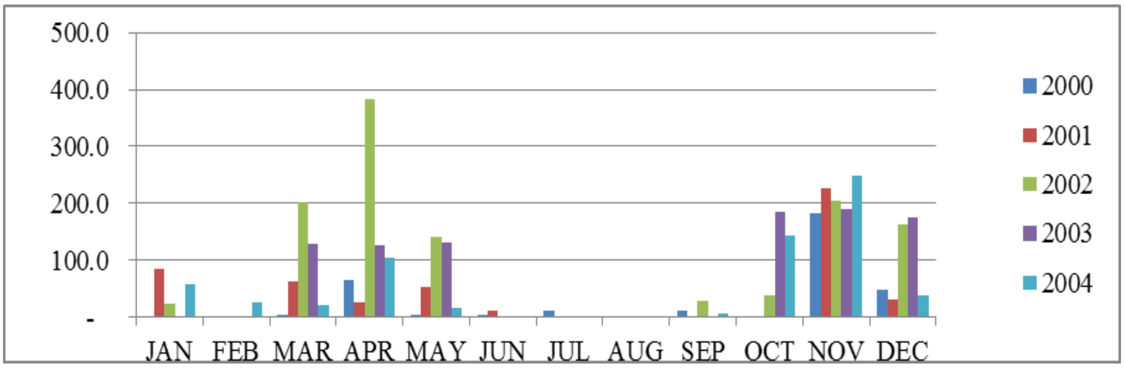
than average rainfall when there is recharging of the groundwater and provision of water for chemical weathering and accelerated erosion by surface runoff and solution.

These changes in the climatic pattern also contribute variously to the geomorphic activities since these same changes necessitate human land use activities to change and to be modified as the climate dictates. The temporal factors in geomorphic terms imply periods of different inputs, processes and corresponding landform evolution.

The intensity and change in rainfall totals are events, which affect human activities and affect variably on the landform responses. For example, high intensity rainfall spells greater raindrop impact on the land. Raindrop impact inevitably changes the landform through denudation. The impact of the raindrop depends on the nature or state of the land surface and rainfall characteristics. The rain drop in a storm can strike the same spot over thirty times, each time causing a miniature crater and scattering soil particles in different directions, but mostly the movement of the particles is affected by the gradient of the ground so that the slope propels the grains in the direction of the dip.

On a surface covered by vegetation, the impact is modified so that the contribution of landform-modifying materials depends on interception and land use. The raindrop has significant impact on the surface. Information on Plate 24 illustrates the effect of resistant objects on the surface and in turn, the necessity to use land uses that conserve the cohesion of the soils. Rain drop impact has significant contribution to landform evolution even where there is relatively dense vegetation, which furnishes an example of different ways of land use so that it clarifies the significance land use contribution as depending on how the land is utilized.



(a)

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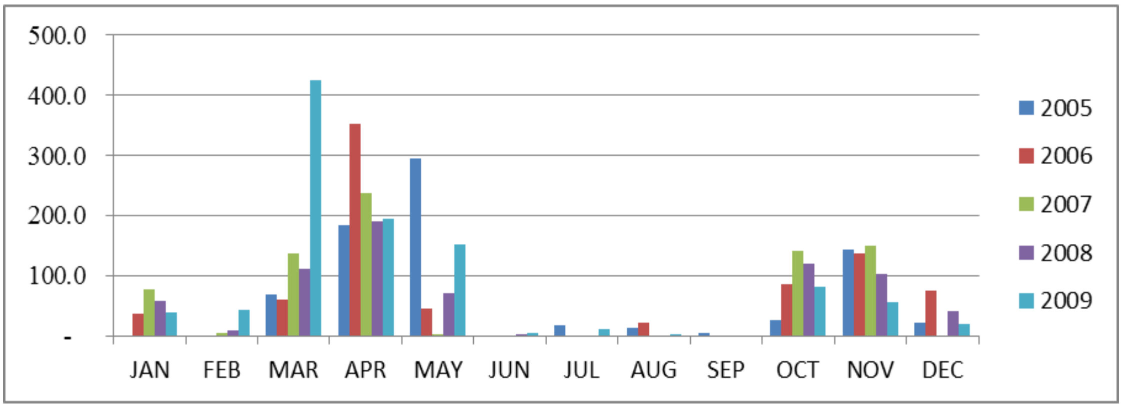
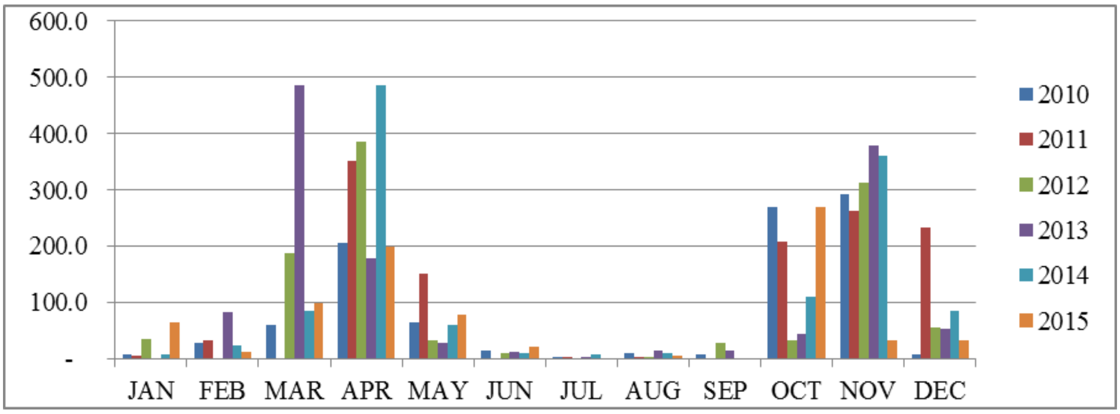


(b)



(c)

Figure 9. Rainfall 2000-2015 Compared to Indicate Variability

In this respect, land use activities loosen the particles making them easy to remove by erosion agents, including raindrop impact, sheet wash and rills have the influence on land surface have therefore been evaluated for this watershed. This has been to some degree measured and quantified in this study through field experiments and surface particle displacement and flow.

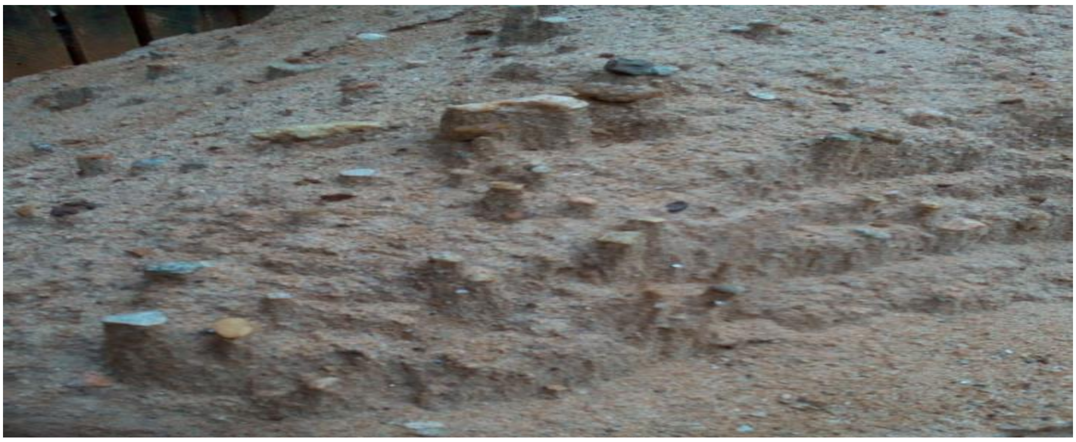


Plate 24. Rain Drop Impact on Loose Surface at a Residential area Gachuriri, (SS21)

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Raindrop impact is also found on Plate 24, Plate 25. Three points stand out from this example; the foreground, middle left and right grounds and the background with varied land uses representing variations in land use contributions to geomorphic dynamism. Plate 2, Plates 12, 13, 16 show the impact and contribution of land use to landform evolution by man.

The foreground is the edge of a farm, which is limited in its extent by the slope and therefore left furrow where at this edge, the slope element is concave; showing the deposition of material from the farm and the effect of vegetation in reducing erosion. This land use method indicates the conflict between conservation of soil and food production. The farmer is generally oblivious of the impact of erosion on the farm and as the crop yields fall, he goes for the alternative of using fertilizers, which introduce chemicals to the geomorphic systems.

The middle-left ground shows the floodplain at the confluence of two streams where farming benefits from the deposition of colluvium from the slopes. The area has been over-cultivated and has become a new erosion surface, and lack of trees indicates the vulnerability of the land to surface runoff.

The middle right ground shows a good sustainable utility of the land which reduces erosion and provides food crops and fodder by the use of terraces, (although the upper part of this farm is utilized in a similar way as in the farm in foreground). The background indicates variations in land use so that activities, which conserve the soil, are practiced while in other places vegetation has been removed while in other places the land is furrow. Such areas show contrasting results in the assessment of their contribution to geomorphic dynamisms so that variations in soil and water analysis would indicate minute differences in very close proximity.

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Plate 25. Effect of Sheet Wash, Raindrop Impact and Terracing on Various Surfaces and Varied Land Uses (2018)

That phenomenon impacts directly and affects the nature of the land surface as a result of the land use such as bare, cultivated, ploughed, plantation, scrub, or forested. These activities are the human and physical contribution to landform dynamics. These same slopes can be viewed in geomorphological light. The shifting nature or characteristic in land uses implies changes in their intensity in time, for example in the last forty years, cultivation methods and the land use in agriculture have become more sedentary and in effect concentrated in innovation for higher yields from both the farms and livestock. This has, inevitably induced greater use of chemicals in most land uses including greater use of wider varieties of fertilizers, pesticides, weedicides and growth inducing chemicals.

Mixed activities on slopes of different gradients cause as many responses to geomorphic dynamisms as there are the variety of activities. In the example of slopes

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shown on Plate 25, the foreground shows a bench developed at the point where cultivation is limited by the slope gradient but where the vegetation significantly controls the downslope movement of the soil. Here two other conflicting systems are in operation: due to the climatic conditions of medium precipitation of the lower middle ecological zone. On Plate 25, the slope development is transport limited in characteristic. In the right middle ground, the terraced slope shows two clear slope elements, the upper concave slope developed as a result of the modification of the upper, (not fully shown), convex waning slope of the crest. This is an area of debris accumulation and infiltration and therefore minimal surface runoff. The second element is a convex slope made up of more resistant rock from where material derived from the upper slopes, drifts to the spur below, or into the stream beyond to form the pediment slope of colluvial material near the confluence of two streams.

In the background, farms form the patches of more exposed surfaces where erosion if fast due to the methods of land use and the gradient. In all the three described areas of the photograph, human contributions are apparent; positive and negative to the rates of geomorphic dynamism such as terracing, tree growing and cultivation on steep slopes. Plate 25 is therefore a good example of good and bad land use methods and both affect geomorphic rate of evolution. It is typical of the middle agro-ecological zone. These analyses material movements indicate the progressive and active processes due to changes in inputs into the rocks and soils, hence landform evolution.

The significant point in the role of soil in geomorphic dynamism relates to soil texture. If weathering or land use systems cause the soil to become fine at the bottom of the valley, experiments have shown that the internal friction decreases and the slope angle changes. This is similar to considering the different angles of repose of materials of different sizes. The changes in the amounts of materials' input, their distribution, frequency and intensity denote the important geomorphic parameter that, for example, the water supply, amounts and the periods of retention spell the duration and intensity of geomorphic activities such as weathering, erosion and deposition.

The changes in the climate relate directly to the pluvial, alluvial and fluvial activities in the watershed. These parameters undergo oscillation processes according to rates and amounts of modification. The effects of slope and soil development result from

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the interactivities of the natural and human activities on the landforms. This can be seen in the nature of the water contents and particularly the turbidity of the river as shown in Table 11.

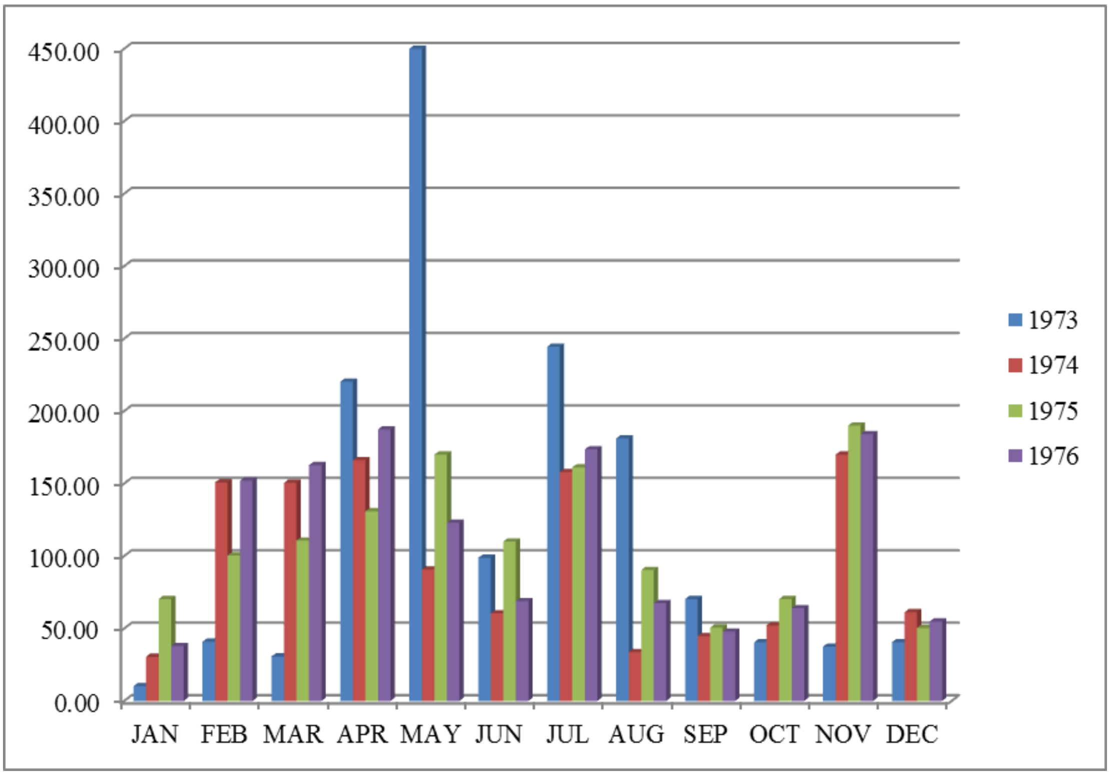

Figure 10. Rainfall 1973-1976 (Source: Embu Water Supply)

Comparing four-year changes may look rather inadequate, but the clusters used in this study help in the in-depth view of longer periods, and is also a pointer to the trends that may compel the land use activities to be altered as the changes in the climatic pattern do. A clear case is comparison of the disparity between Figure 10 and Figure 11 Clearly, such drastic change in the pattern of rainfall implies not only climatic changes but also land use and geomorphic processes

The two graphs and their rainfall intensity show a clear change in the behaviour of the rainfall and therefore evidence of climatic deviation and change

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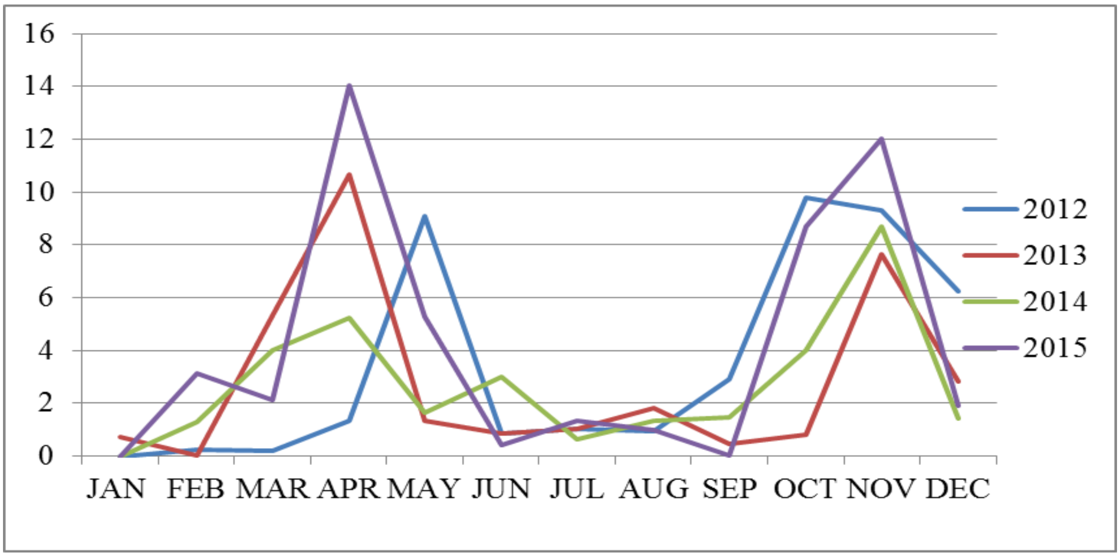

Figure 11. Superimposed Rainfall Pattern Profiles, 2012-2015.

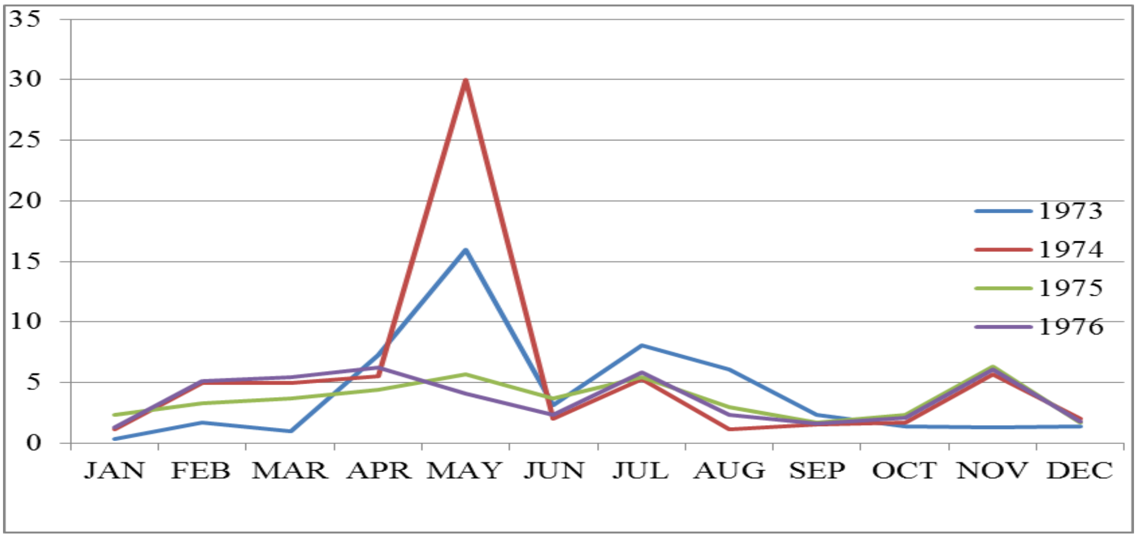

Figure 12. Superimposed Rainfall Pattern Profiles, 1973-1976

The mode of rainfall has changed from a rain regime of rainfall throughout the year to a clear bi-modal regime with notable drought periods. The bimodal regime is clearly represented by the above exhibits of a swing back and forth within the months of the seasons. The trend in Figure 12 indicates that despite the high peak such as in 1974, the distribution of rainfall in the period was better throughout the year without periods of very low rainfall.

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It is important to make a quick comparison of the two extreme stations of the watershed in order to grasp the disparity in the rainfall; Irangi to the north and Gachoka to the south, Table 14 and Table 15 respectively for the year, 2015.

Table 15: Rainfall, its Duration and Vegetation

	Irangi	Gachoka
Total Rainfall (cm)	1,243.6	813.7
Rainy months (over10 cm)	12	9
Rainy days	111	73
Vegetation	Forest	Scrub

This climatic anomaly, which also reflects on the vegetation characteristics, in effect affects land use and the contribution to the geomorphic dynamism in weathering rates and types.

4.8 Geological Impact

Landforms are a result of the interaction between endogenic and exogenic processes on the country rocks, referred to as geosystems by Christopherson (2008). The changes on those rocks relate directly to their response to climatic elements which control their evolutional changes such as weathering, erosion and deposition. In the context of this study the additional substances on the same rocks and the amounts of those added materials have influence on the rates of those processes Rupingazi watershed is part of Mt. Kenya suite comprising igneous rocks mainly phonolites and basalts in the highlands, while in the lowlands are the basement rocks which are overlain by both sedimentary and metamorphic rocks. Earth movements have distorted the rock-formation and in places caused faulting as shown in Plate 27, Plate 28, Plate 29 and Plate.33.

The variety of rock structures and their reaction to varied geomorphic processes is reflected in the reaction of any types of the rocks in any place and climate where the effect of off-loading has resulted in the fracturing of the rocks Plate 15. The impact of these rock-changing events influences the topography, rock structures and alters the rock type. It is also clear that differential weathering and erosion are a reality below and on the surface soil, Plate 27, Plate 28. Regarding any landscape, an erosion surface is a remnant of phases of development in succession, where many processes

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were involved and therefore appreciated as being a result of multi-phases and as being polygenetic. The complexity of the said polygenetic processes depends on the geology, geologic time, and the characteristics of the rocks, which determine their resistance; tenacity, solubility and their affinity to all weathering agents a principle enhanced by David (2007). This characteristic is called the geological framework.

The middle zone of the watershed (Figure 5), is at the margins of the Mt Kenya volcanic flow where snouts of the lava flow extend on the watershed and are exposed along the river valleys. Differences in the geologic distributions in the watershed are reflected in the variety of soil types, which develop from them. Rupingazi watershed has a complex geological system as was analysed by Schoeman in the 1950s and 1960s and by Baker in1968 (Ojany & Ogendo, 1973).

In the lower Rupingazi watershed, the distribution of the volcanic rocks shows irregularity in distribution. In some areas earth movements have created areas of disconformity so that minor folding and faulting have been exposed by erosion and road cutting (Plates 30). It is therefore an inferential geomorphic fact that any chemicals on such complex rock-forming minerals directly affects the weathering processes. The age of the phonolites system is of the Upper Pliocene age. For example, Thiba Rupingazi confluence area, (SS, 19) (Appendix 17), the basalts have been exposed by the river erosion, Plate 26, Appendix 6. These are on the basement systems of the end tertiary age and therefore belonging to the Pliocene age.

In this lower region, the metamorphic gneisses and schists of the basement have been exposed and form some of the outcrops as indicated in Plate 3, Plate 32 and therefore form the foundation of the younger volcanic and sedimentary rocks. Some of these rocks are being exploited as building material. While quarrying and sand harvesting are useful economic activities, these processes expose rocks (forming new erosion surfaces) to further weathering and slope imbalance. Consequently, resulting in rock isostatic readjustment after a rock formerly buried deep in the ground are exposed by off stripping of the layers of rock that have been extracted for building in stone quarry and other forms of mining in the lower ecological zone at Gachuriri or where the river has exposed the rocks (Plate 34 and Plate35).

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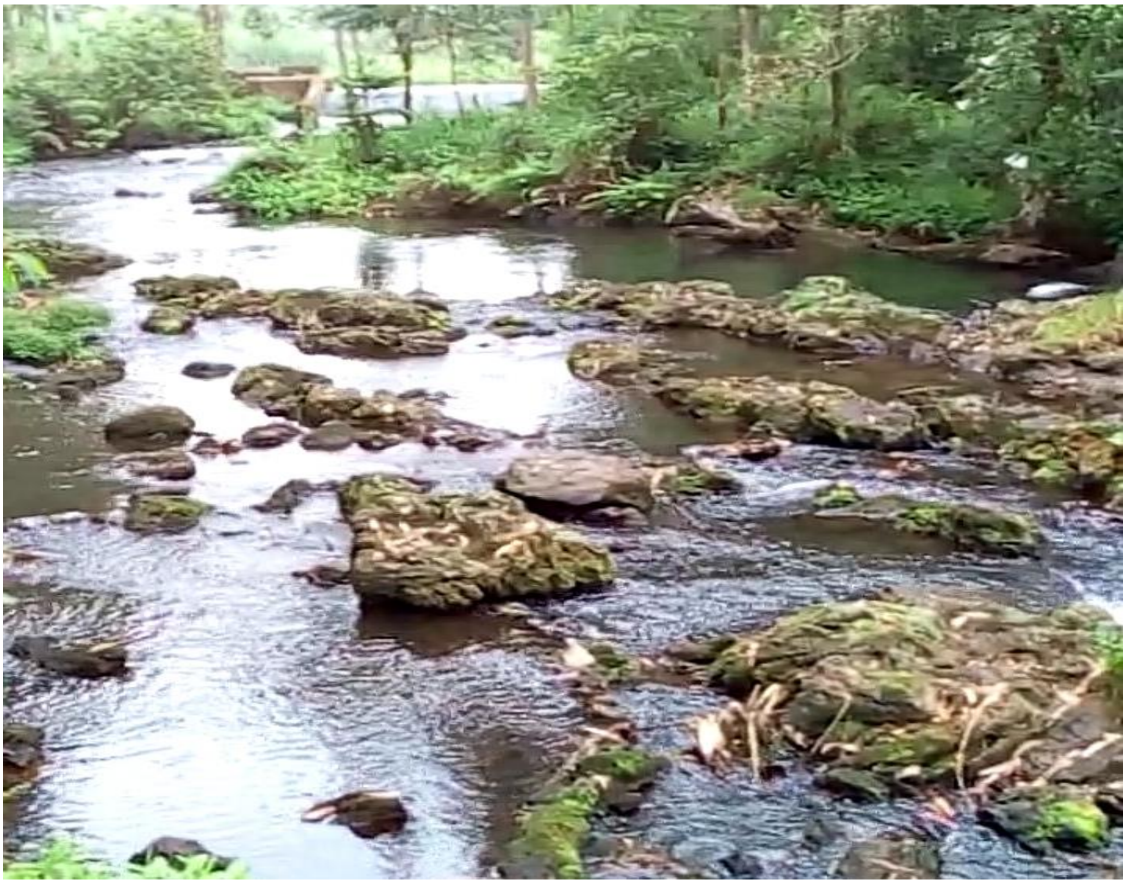

Plate 26. River Erosion (-0.551921,37.462128) (Downstream Kairuri Water Intake, 2018)

Besides such exposure of rock to the weathering agents, weathering result through quarrying, the mining industry as a land use, which loosens, in places, many tonnes of rock fragments it breaks to smaller pieces through blasting by explosive methods. Such processes cause rocks to weather faster, erode faster and offset the angle of repose of the slopes. Blasting itself can cause liquefaction, induce rheidity in the surrounding environment and add residual explosive chemicals into the geomorphic systems.

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Plate 27. Disconformity: Igneous, Sedimentary and Metamorphic Rocks and Faulting and Folding in the Same System (2018)

The extent and intensity of the land use can be seen from Plate 20, Plate 21 and Plate 22. Agricultural activities have removed most of the vegetation and exposed the soil surface to elements of weathering and erosion and also exposed the volcanic rocks.

Plate 28. Differential Weathering and Erosion on Landform Development, (2019)

Two striking geomorphic conditions, which are directly affected by the elements of climate to influence the landform changes, are the vegetated and bare surfaces. The rainfall amounts in different sections of the watershed have varying impact and degree

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of landform modification according to land use activities and surface runoff. The valley limps' gradients are affected by the scouring and abrasive force of increased water flow as the sheet-wash changes to rills then to gullies when water accumulates after precipitation. Altitude, gradient and the climate are significant factors in delineating areas of the watershed where human activities are curtailed by those conditions.

Phonolites, Plate 32, comprise any extrusive igneous rocks, which are rich in nepheline and potash (various potassium compounds) and feldspar. They are fine grained. The related extrusive volcanic rocks, the basalts, are low in silica contents. Basalts are dark in colour and comparatively richer in iron and magnesium. Some have large crystals such as the olivine basalts, augite and feldspars. These are the more common rocks in the Mt. Kenya region, which are mainly alkaline (Plate29, Plate 33).

Any human activity, which alters the size or adds to the acceleration of rock decomposition by altering the material through addition or subtraction of some component material, contributes to geomorphic dynamism. Even where very resistant rocks such as quartz are exposed for some time to chemical substances the rock-forming minerals may be selectively but effectively removed. The piece of quartzite shown in Plate 30 was found in a weathered part of a drain outlet from three effluent sources converging and swiping over it: kitchen, washroom and washing machine detergent.

This is just one of the many examples of landforms (of whatever magnitude), which are actively being shaped and reformed by land use inputs into the imperceptible, but, ever-active geomorphic processes. Where this process develops eddy currents which cause the whirling of the water with the load it carries, pot holes develop and eventually offset the micro slope stability of the potholes and the river banks and so inducing the wet-bank slumping (Plate 4 and Plate 29).

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Plate 29. Mt. Kenya Flood Basalts in Rupingazi Watershed Near Don Bosco (GPS - 0.576203,37.479448)

Areas of mixed rock formations such as sedimentary and metamorphic rocks are more affected by introduction of chemical elements from land use due to the wider spectrum of likely encounters of volatile chemicals available in the composition.

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Plate 30. Weathering of Quartzite through Human Input (2019)

The Mt. Kenya volcanic suite is about 8,400 square km (2,700 square miles) and has a diameter of 104 km (65 miles) and Rupingazi watershed is within it. In the lower Rupingazi/Nyamindi /Thiba, phonolites, agglomerates and metamorphic rocks are common in this section as found at the confluence of Rupingazi and Thiba Rivers, Ngomano-Kiumbu. Rupingazi River originates from the snow lake, Carr Lake. It is also common to encounter pyroclastic materials, and volcanic bombs, Plate 31, Plate 32. These agglomerates and pyroclasts are the erosional vulnerable weaker parts of the riverbank and bed and are the points at which potholes develop.

These sections also relate to the topography, another determinant factor of the agro-ecological zones. The watershed topography resulting from geologic formation can be subdivided into four belts from the mountain as the altitude decreases downstream. First, the areas higher than 3,000m above sea level where the topography is ragged with the highest stream density and therefore very numerous small valleys and ridges resulting from spring sources and spring sapping, where the general gradient is about 1:30.

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The second belt overlaps the first so that characteristically the area is highly dissected and the slopes angles exceed 40^0 while in some sections the slopes reach 60^0. In the situation of Embu town, the valleys open out by slope decline forming convex elements at the crest of the spurs to the river where they are either straight or concave with little flood plains. Within the middle part of the slope, they are concave in form, as in Don Bosco area slope profile, this is the third section.

Plate 31. Accessory Pyroclast at Gachuriri

The intensity of irrigation and the high population livestock have affected the soil and exposed the bedrock to form rock outcrops of volcanic, metamorphic and basement sedimentary rocks. The fourth zone extends to the Rupingazi-Thiba confluence where in some areas the angle of slope is less than 5^0 and maximum 14^0 and the river is encountered at the point of the break of slope created by the river flood system when the river swells to the level above two metres level from the dry period wetted perimeter.

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Plate 32. Phonolites and Agglomerates at Gachuriri Confluence (2018)

Near the banks of the rivers where farming utilizes river water, and where large herds of livestock graze and drink, the surface cover of vegetation has been removed and rock outcrops have been exposed and exfoliated. Surface run off and gullies eroded by animal hooves accelerate removal of soil and rock debris.

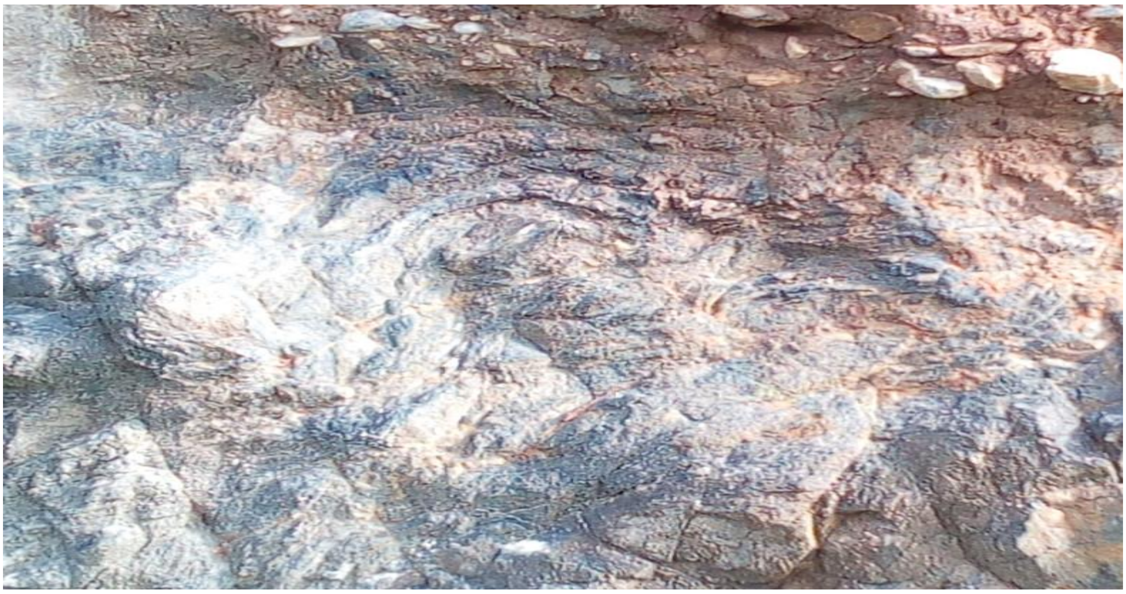

Plate 33. Rock Folding at Kiringa at a Quarry, (2018)

The Rupingazi/Thiba basalts found in the higher altitudes of 3,000m are primarily grey olivine basalts. In areas of sedimentary rocks, soils developed from them overlie the older phonolites. These sediments are derived from their sources in the upper

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regions of the watershed. The valleys have changed from very steep and typically asymmetrical forms with characteristic steeper eastern unilinear and the western steeper flunks with wide floodplains, although they may alternate in their form. As a land use, road cutting directly affects the slope equilibrium of any landform. All landforms are made up of different rock-formations and therefore the geologic background is an insight into all the geomorphic processes of the watershed.
road.

4.9 Role of Clay in Slope Failure

Clay minerals have notable important characteristics relevant to mass failure in the presence of water. Most kinds of clay have platy layers in their formations. As the final products of weathering, clays are fine grained. When mixed with water, clays attain varying degrees of plasticity Huggett (2011). They are chemically hydrous silicates, mainly of aluminium (Al_2O_3) and magnesium (MgO). In the case of Rupingazi watershed the clays are provided by the weathering of the rock-forming minerals of the basin which are mafic in composition, and although they have a high content of silicon, (SiO_2) they have less than 50% of silica and high content of iron oxides, (FeO and Fe_2O_3). (Mafic component strictly implies the presence of magnesium and iron) In some places, the rocks have considerable amounts of calcium (CaO). The significance of the rock composition is in its reaction to what is added into it through land use activities.

Clays can be classified into two groups: clay minerals and ‘non-clay minerals. The clay minerals have the characteristics, which give the clay its plastic property. The non-clay minerals are those which are accessory in nature, i.e., provided by the environment. The interplay between water inputs through land use in the role of Kianjokoma slide is an important contribution to the geomorphic dynamism to be considered. Saturation of clay by water results in thixotropic characteristic, Plate 8. This occurs when any level of vibrations causes a substance to change its form and structure. It is a reversible behaviour of a mineral when shaken or disturbed but reverses on standing. However, this state can be attained by addition of water. It is a similar process to the behaviour of quicksand, which is a mixture of sand and water. The Kianjokoma slide, attained this state due to excess water in the clay, and unique

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to this mass failure was sliding, slumping and the lamina flow of the material in which tea bushes were carried away without a rotation motion, turbulence.

Generally, most landslides occur on slopes of between 40^0 and 50^0, but in areas where earthquakes occur and the right conditions prevail, they can occur on gentler slopes of less than 30^0, as in the case at Kianjokoma. Here, water from the construction site, residence and road drainage into the tea bushes over the point where a spring of water lay below the tea bushes triggered the slide. Clay clearly formed the base upon which the event occurred (Plate 7). Vegetation stabilizes the slopes, although the roots have a limit in depth at which they can reach, and therefore on very deeply weathered rocks, certain vegetation may not stop landslides. In the case of the Njukiri forest slide in another part of the watershed, deep tree roots were limited by the great depth or thickness of the weathered volcanic rocks, but in the Kianjokoma slide the tea bushes and the few grevillia trees offered no resistance to the moving soil and rock mantle.

Due to human or natural changes in the slope material property, conditions of frictional resistance and material weight changes the internal cohesion and form, such that the imbalances resulting propel mass failure. Incidental or deliberate erosion and excavation increase the shear stress within the slope repose, ultimately causing mass failure especially when the base of the slope is undercut. It is true that through human activities such as land use, such trigger events are not conceived, but geomorphic processes respond to those stimuli irrespective of whether they are intentional or accidental. Why then do some slopes fail while others with greater propensity to failure stand? This is because shear strength is not uniform on any slope so that some parts are more prone than others due to their internal stress levels and their geomorphic characteristics which can be modified by land use activities, including internal weakness and water contents which affect the frictional resistance of the materials.

4.8 Index of Dissimilarity

The index of dissimilarity has been used to compare the distribution of any two related variables. For example, it has been used to compare the changes in the distribution of pH in different sampling stations.

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Table 16: Tabulation for Calculation of Index of Dissimilarity

SS	SR5 (x)	SR6 (y)	x-y
1	5.87	6.74	0.87
2	6.47	7.00	0.53
3	6.69	7.99	1.30
			2.7÷2=1.83

To compare the pH variation in SR5 and SR6 the formula for the index of dissimilarity for the data, Table 15, can be used as follows:

ID= 1/2∑ [x-y]   (source: Barnaby &Cleve (2011)

Therefore, the dissimilarity between SS5 and SS6 is 1.83. This result points the difference in the two stations and therefore implies that the activities in SR6 have contributed 1.83 higher values.

In summary, the location of the study watershed is unique in its geographic perspective in that it traverses the climatic characteristics from the Alpine snow-covered zone to the semi- arid Tropical climate and vegetation. Rainfall ranges from just over 2,000 to 600mm, while the temperatures range from below freezing point to the high of 30^0C. The geology of the watershed is also very vastly represented, from purely volcanic rocks to the complex metamorphic rocks of the lower reaches. The combination of climate and geology produce a complex system of soils in the whole watershed. This combination propels the various land uses according to the optimum conditions and the modifications that can economically fit in the various land uses.

Topography, climate and the geomorphic processes are pivotal to mass movement, slop equilibrium and landform changes. The agro-ecological zones dictate the different land use activities. These land use activities have been shown to contribute substances and conditions which influence geomorphic processes of denudation and alteration of the slope morphometry. The combination of these factors, including urban settlements have indicated that the slopes in all the parts of the watershed can be modified by inputs from land use activities.

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CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The objectives of this study were: to assess the influence land uses on geomorphic processes with reference to denudation. To find ways in which land use activities such as crop farming, quarrying, settlements and livestock contribute and add substances, which influence geomorphic processes. Additionally, landform change in three drainage reaches of Rupingazi watershed was examined to evaluate the extent to which land use activities in the watershed influence slope stability and mass movement. These are viewed in the context of different agro ecological zones within the three sub-divisions of the watershed: according to the research questions in section 1.5.

In order to assess these geomorphic parameters, the basic operational theory was the nine-unit slope model by Doornkamp and King (1971) which formed the theoretical framework of this study.

5.2 Major Findings of the Study

Land use activities have contributed to landform dynamisms of denudation and landform evolution, the study found that land use activities vary greatly according to the agro-ecological zones in different reaches of the watershed. Agricultural land use involves digging, ploughing and other tillage methods, which generally disturb the land surface and structure of the soil so that greater aeration occurs. This process introduces extra gases to the soil and into the rocks and therefore enhances chemical weathering. This process also affects the normal amounts of such gases as carbon dioxide and nitrates, especially from ammonia, when humus is exposed to the weather elements.

The process of agriculture moves materials according to the slope gradient and the implements or machinery used to move materials in farming requirements and therefore contribute to the process of erosion and deposition which effect denudation. This activity also directly affects the angles of slopes as the soil and rock materials are shifted, this ultimately results in slope repose angle modification and that of the whole

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slope. Agricultural land use adds chemicals to the soil and rocks through the use of organic and inorganic fertilizers. These chemicals change the chemical structure of the soils and modify the rates at which geomorphic processes operate, and therefore are a major contribution and influence landform development. Chemicals are also introduced into the soils and rocks in form of insecticides and pesticides and their residues modify geomorphic dynamism.

The rearing of livestock contributes to physical weathering and erosion when large herds are reared and their hooves break the rocks and remove vegetation. Livestock also affects the nitrogen cycle and increase ammonia into the atmosphere, thus making a contribution that has influence to the geomorphic processes in the environment. This study found out that domestic animals, including range chicken move enormous amounts of loose material and can browse on grass to the level of removing it. On farms, heaps of manure or waste materials such as garbage are quickly spread out far and wide by chicken.

In this study the rates of infiltration at different points along the slope surface indicate the significance of the rates of infiltration as an indicator of soil structure and soils response to water. The hydraulic characteristics of the soil are also important where these characteristics include the effects of rain-splash which often causes clogging and surface seal, surface storage or where there are large cracks in the soil surface faster flow, all of these modify infiltration rates and surface storage Water supply in excess of infiltration capacity of the soil flows as overland flow or surface runoff where the depressions become surface storage, so that saturated surface generates more surface runoff.

From urban areas are important sites for non-point and point sources of materials, which modify the geomorphic processes. For example, urban areas have unique exotic drainage system, which reduces infiltration but generates a lot of surface runoff. These phenomena collect many chemicals from many sources within the urban areas are continuous processes, which continuously add different chemicals to the rocks and soils, and therefore affecting and influence the geomorphic dynamism. For example, oils, discarded metallic materials and effluents, including sewerage, domestic wastes and garbage, which are rich in chemical substances, contribute to the geomorphic

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dynamisms at various points of landform development. Further, urban systems are not harmonized to the intended plans that are laid down as rules and order which could apply to all parts, therefore the contribution from urban land uses cannot be regulated in their outputs so that their influence is most evident due to the varieties land uses and alternatives.

Land use activities have influence on the processes of weathering, erosion and mass movement, this study has found influential contribution of land use activities which modify and effect change that influence the pace or alter the erosional, weathering and mass movements. Human land use activities, through their inputs such as water in the weathered rock influences mass movement such as landslides and mass failure.

Through direct alteration on the land surface by direct removal, addition and dislocation of the material, landforms are altered. Through land use activities such as digging, landscaping in urban settlements and shifting of earth materials by quarrying and changes in drainage systems including irrigation, and other land uses, the rates of landform development are affected. Landforms also evolve as the rain water volumes increase from sheet to rills, and eventually gully erosion. Landforms do change differently where this water movement may be altered through land uses, which induce changes on the natural systems such as canals. Human land uses add materials and different chemical substances, both organic and inorganic to the landforms and these alter the rates of denudation

Notable in the Rupingazi watershed was mass wasting and mass failure as evidenced by downslope movement of weathered material and soil on a slope due to the force of gravity. This is a geomorphic process, but land use contributes to this process through interference with the balance of the material on the slope and how it rests upon it and therefore its angle of repose being changed. Mass movement has been shown to be in many incidences to be a direct influence of the contribution of land use activities apart from natural occurrence. The Kianjokoma landslide was mainly a result of extra water in the soil from the construction site and surface drainage from paved surface. It was further established that land use through fluvial dynamism or other mass movement is significant in effecting changes on slope angles.

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Slopes are subject to continuous modification of their elements and segments as they grade themselves in response to removal or addition of materials. Slope elements are concave, convex or relatively straight, but those reposes are altered by land use activities as man utilizes the land, and a result different modifications and changes occur:

5.3 Conclusions

The study has drawn attention to the role of different land uses in contributing materials and chemicals, which are agents of geomorphic activities. They alter the fluvial landforms through rock breakdown and aggradation through slope change and failure, landslides and other mass movements; their inductive activities and their magnitude as they affect landforms according to different locations and land uses in different agro-ecological zones. The human-induced processes are contrasted with the natural rates through literature, measurements, observations and experiments. This study has assessed the unique, specific problems for, and to, landforms dynamism due to land use in this watershed and provides information on the contribution from both rural and urban land uses and their problems to drainage and landforms. It forms a model that can be used to gauge, assess and evaluate other similar or different watersheds.

Based on the three study objectives, the study makes the following conclusions:

i) Livestock rearing and crop farming in the watershed contribute and influence the geomorphic dynamism within Rupingazi watershed.
ii) Urban settlement and related infrastructure, by enhancing surface run off and wastes produced from the settlements, influence the development and evolution of the valleys and their slope-forms;
iii) Abstractive and mining activities greatly influence geomorphic processes within the Rupingazi.

The present trends in land use can be better managed for better sustainability for the sake of the stability of the landforms. There is also knowledge gap relating to the use of chemical fertilizers and the soil stability and utility which require further research.

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5.4. Recommendation for Further Research

The following are areas of geomorphic interest that standout as controversial and inadequately analysed and are recommended for further research.

i) Inference making methods into slope evolution based on observation yield inadequate data. For, it is very rare that actual observations of the actual events can be done in the like manner where the actual occurrence such as the Kianjokoma land slide. In this case, the recommended way forward is to develop government policies that will establish stations for observation where data can be recorded continuously, for example on areas of possible mass movement, tectonic activities, creep and solifluction.

ii) Further research should be done to find out the significance on the interchange of variables in landform evolution, for example whether form of the slope can induce progressive change or if progressive change can cause form change in the land form

iii) The government should ascertain the significance of land use intensity in relation to changing land use patterns. This would help relate development policies to demographic dynamics and land carrying capacity for sustainability without degrading the environment.

iv) The cause-effect statistics on slope profiles are based on probability and assume that the present slopes are in equilibrium without consideration for any exogenic or endogenic inputs such as rock weathering below the regolith and weathering mantle and their induced changing rates, due to inputs from land use.

v) Many land evolution factors require quantification. Therefore, research should be carried out on the impact of specific land uses on geomorphic processes over longer periods.

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APPENDICES

APPENDIX 1

EROSION IN TEA BUSHES: FOOT PATH, KIANJOKOMA

(GPS -038940,37.50095)

APPENDIX 2

RANDOM NUMBERS 0-360

245	290	240	180	275	55	270	120	295	10	65	355
360	350	175	115	35	85	220	135	180	45	55	10
25	320	60	290	140	250	120	290	340	135	65	195
180	210	210	230	65	280	320	75	25	70	250	80
260	165	210	345	270	265	85	260	275	205	70	255
305	330	220	290	30	170	310	305	50	220	35	200
50	130	210	170	50	105	260	80	335	300	345	95
10	220	215	220	145	130	140	335	35	280	75	210
255	165	290	150	330	70	125	340	175	110	80	320
110	265	120	185	205	40	245	345	290	90	350	320
180	185	45	285	305	180	325	120	200	275	15	95
315	275	350	55	295	25	355	200	135	15	360	325
250	120	175	40	215	10	235	265	100	240	140	265
105	35	55	70	50	35	200	205	90	135	10	135
355	215	135	140	95	210	270	175	340	165	280	140
245	345	240	130	115	95	30	35	165	210	285	75
280	5	265	175	310	70	315	335	155	65	50	285
340	340	265	345	0	185	165	160	50	120	330	335
70	10	180	220	330	40	25	115	305	90	285	70
245	315	295	230	285	60	295	10	110	55	345	230
350	340	270	115	45	270	315	240	140	265	220	55
340	95	355	155	135	80	25	50	320	65	260	170
65	235	95	265	355	210	190	185	175	235	145	305
345	50	290	70	260	265	250	260	330	105	220	200
285	260	290	55	170	265	190	200	65	275	115	285
195	170	330	125	105	305	345	330	20	130	65	210
15	350	315	305	305	225	190	115	245	190	195	40
145	0	10	310	105	310	140	255	110	350	335	300
250	225	10	135	130	155	165	215	95	125	15	110
130	205	180	255	360	45	285	130	355	100	35	235
35	310	275	5	55	130	90	345	115	50	225	230
115	335	215	175	35	290	150	295	325	65	280	215
50	300	5	235	5	340	245	25	260	70	350	315
15	5	60	150	5	195	230	15	305	290	30	10
340	80	45	355	145	30	255	355	115	65	350	245
340	280	330	270	155	5	340	75	80	100	185	50
195	85	140	340	110	20	60	115	295	235	40	180
180	120	110	110	230	115	90	330	5	255	180	245
80	50	100	180	75	135	270	150	285	215	55	330
240	275	335	190	40	100	230	90	340	180	15	25
320	55	10	315	75	170	160	115	335	175	305	210
25	125	190	260	10	230	155	270	310	345	220	20
55	350	340	315	345	145	80	300	235	160	315	225
0	55	165	245	300	40	195	135	140	50	45	330
80	230	85	270	310	105	75	95	280	270	320	240
130	110	290	215	330	105	140	105	295	5	25	55
295	355	120	75	60	245	40	120	210	230	305	65
110	210	30	120	60	200	340	250	85	310	330	280
260	190	300	315	55	310	10	305	25	140	110	215
305	200	135	345	290	225	50	150	315	0	180	355
105	295	5	5	125	350	250	130	130	215	25	260
95	80	50	235	0	95	125	205	270	280	270	170
265	105	310	185	290	360	355	240	195	325	320	305
105	25	205	325	275	250	155	25	160	290	160	85
125	220	255	125	145	255	305	135	180	295	110	85
75	220	150	20	240	330	170	10	95	195	65	300
150	170	130	65	60	140	185	85	90	335	275	80
295	195	175	40	280	335	70	65	175	30	180	100
45	315	320	160	235	200	80	180	100	140	265	285
35	55	240	350	185	320	115	35	10	110	75	115

Random Numbers 0-360 (Adapted from G. Bretschko 1997)

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APPENDIX 3

WEATHERING OF VOLCANIC TUFF

PIAI Embu (-0.52874,37.327648)

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APPENDIX 4

STRUTURE OF VOLCANIC TUFF *(NDARUGO*)

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APPENDIX 5

WEATHERING OF A ROCK BY PLANT ROOTS

At Kairuri (0.532875,37.362436)

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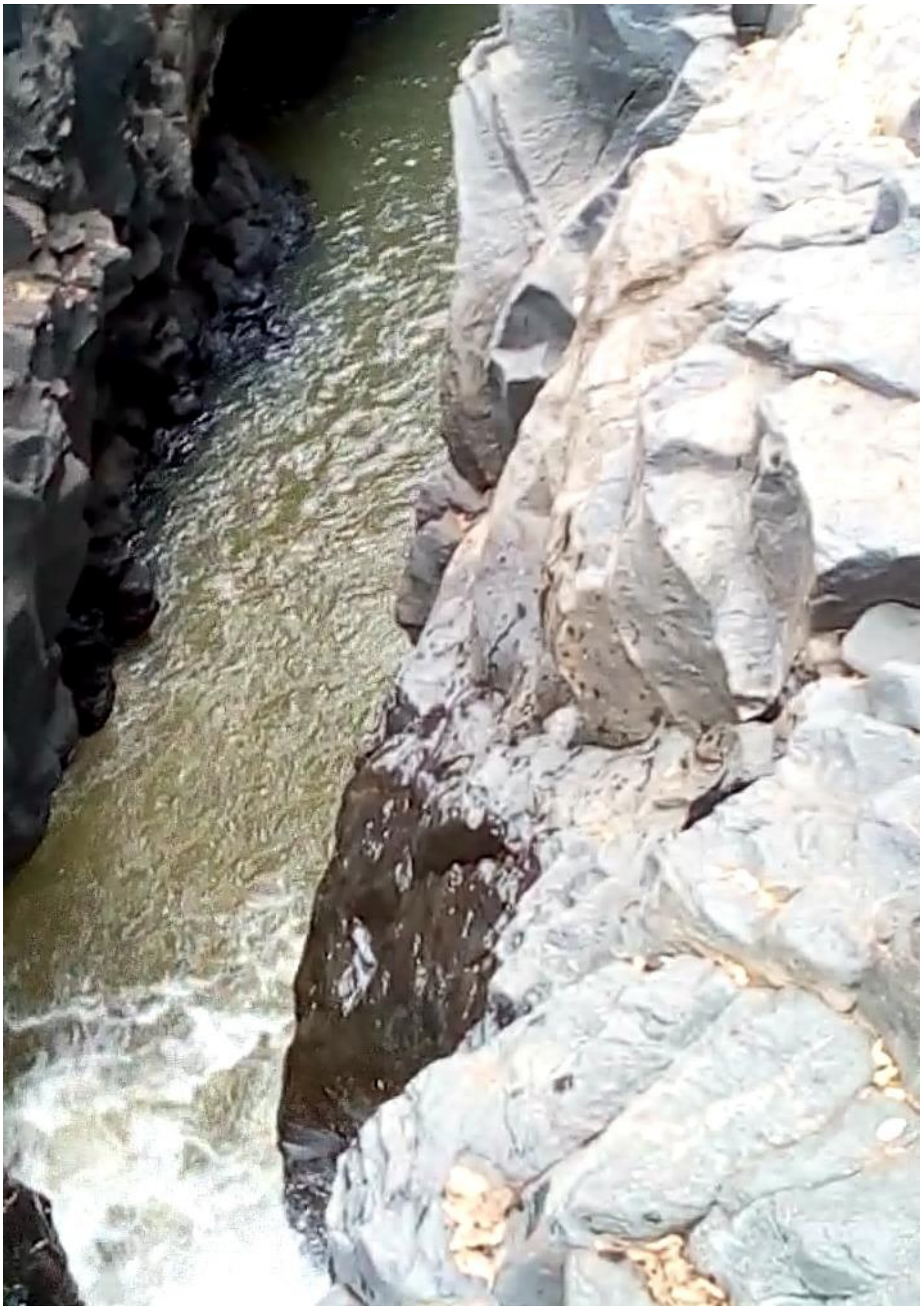
APPENDIX 6

FLUVIAL PROCESSES



Middle reach, (Don Bosco), Rupingazi River (2018)

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APPENDIX 7

RUKURIRI STATION RAINFALL (EMBU MET. STATION)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003	30	0	88.2	255.7	450.8	28.7	41.2	58.5	12.9	289.1	224	6
2004	34.5	57.6	75.4	330	138.8	21.2	3.3	19.3	60.6	305.9	429.8	16
2005	20.6	11	81.3	373.4	291.4	31.1	29.8	39.8	18.1	160.3	203	17
2006	49	16	98.1	419.7	405.6	15.9	43.3	33.9	40.9	366.9	383.4	3
2007	110	20.9	113	298	369	60.5	24.7	117	38	625	398	246
2008	129	0	246	322	14	22	59	62	90	270	175	101
2009	146	20	130	277	130	12	5	26	20	312	229	0
2010	59	86	229	319	282	15	49	54	16	144	222	56
2011	13	17	53	434	278	11	12	53	101	34	318	50
2012	0	58	0	530	399.6	48	26.7	41.5	14.5	389.9	284.4	126
2013	36.5	10.7	123	620	151	21	40	67	32.9	57.8	279	16.4
2014	0	60	172	201	62.2	86.7	29.6	116	39	163	469	48
2015	0	24.9	141	368	295	29	38	19	1.8	477	460	103
2016	48.8	11.5	142	561	247	28	4.3	26	8.3	30	272	17

APPENDIX 8

RAINFALL TOTALS AND INTENSITY 1973, 1974, 1975, EMBU MET STATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1973	10.2	40.9	30.7	220.3	480.6	98.8	244.4	181.2	70.3	40.5	37.5	40.5	1,495.9
Int.	0.3	1.7	1.0	7.3	16.0	3.1	8.1	6.1	2.3	1.4	1.3	1.4	Av.4.2
1974	30.5	150.8	150.5	166.1	90.7	60.5	158.0	33.7	44.8	52.2	170.0	61.2	1,169.0
Int.	1.1	5.0	5.0	5.5	30.0	2.0	5.3	1.1	1.5	1.7	5.7	2.0	Av.3.2
1975	70.3	100.4	110.6	130.9	170.0	110.0	161.2	90.3	50.6	70.3	190.0	50.4	1,305.0
Int.	2.3	3.3	3.7	4.4	5.7	3.7	5.4	3.0	1.7	2.3	6.3	1.7	Av.3.6
1976	37.9	152.1	162.7	187.4	123.0	68.9	173.6	67.5	47.8	64.0	184.1	54.8	1,323.8
Int.	1.3	5.1	5.4	6.2	4.1	2.3	5.8	2.3	1.6	2.1	6.1	1.8	Av.3.7

APPENDIX 9

GACHOKA STATION RAINFALL (IN MM)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	-	-	4.0	65.0	5.1	4.0	12.5		11.5	-	181.6	48.1
2001	85.0	-	62.5	27.0	54.0	11.5	-		-	-	227.5	31.4
2002	24.5	-	202.0	383.1	140.0		-		27.5	38.5	205.5	163.5
2003	-	-	127.5	125.5	130.0	-	-	-	-	185.0	191.0	174.0
2004	59.0	25.7	21.5	103.5	15.5	-	-	-	6.0	143.6	247.3	37.5
2005			69.0	184.0	295.0		18.0	12.5	4.5	25.0	142.5	21.5
2006	36.0		60.5	353.5	44.5			21.0		85.0	136.0	75.5
2007	77.0	4.0	136.6	236.8	1.0					141.0	150.5	
2008	57.0	3.5	111.0	191.0	70.0	3.0	-	-	-	119.0	102.5	42.0
2009	39.5	42.9	425.0	194.5	151.0	4.0	11.0	1.5	-	80.5	55.0	20.5
2010	3.0	27.0	61.0	206.0	65.0	15.5	1.0	9.5	6.5	270.5	291.5	6.5
2011	4.5	32.5		351.5	152.0		4.0	2.0		207.5	262.5	234.0
2012	36.0		187.0	386.0	32.5	11.0	-	2.0	27.5	33.0	313.0	56.0
2013		33.0	485.5	178.0	28.0	12.5	1.0	14.0	14.0	43.5	379.0	53.0
2014	7.0	24.0	85.5	486.5	59.0	11.0	8.5	10.0	-	110.5	361.1	85.5
2015	64.5	12.5	98.7	198.5	77.5	20.5	-	5.5	-	269.0	33.5	33.5

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APPENDIX 10

RAINFALL TOTALS AND INTENSITY: 2012, 2013, 2014, 2015, EMBU MET STATION (CM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2012	0	7.3	5.4	40.6	272.9	25.7	30.7	28.7	87.0	293.3	279.9	187.7	1,259.2
Int.	0	0.24	0.18	1.35	9.10	0.86	1.02	0.93	2.90	9.78	9.33	6.26	Av.3.5
2013	21.7	0.10	159.2	300.0	40.2	26.2	30.2	54.3	13.1	23.7	229.7	84.6	983
Int.	0.72	0.01	5.31	10.67	1.34	0.87	1.01	1.81	0.44	0.79	7.66	2.82	Av.2.7
2014	0	39.3	119.6	157.4	49.9	89.8	18.5	40.4	44.4	120.8	260.5	42.9	983.5
Int.	0	1.31	3.99	5.25	1.66	2.99	0.62	1.35	1.48	4.03	8.68	1.43	Av.2.7
2015	0	94.4	64,1	420.9	158.4	12.8	40.4	29.1	0.6	261.4	360.6	56.9	1499.6
Int.	0	3.13	2.14	14.03	5.28	0.43	1.35	0.97	0.02	8.71	12.02	1.90	Av.4.2

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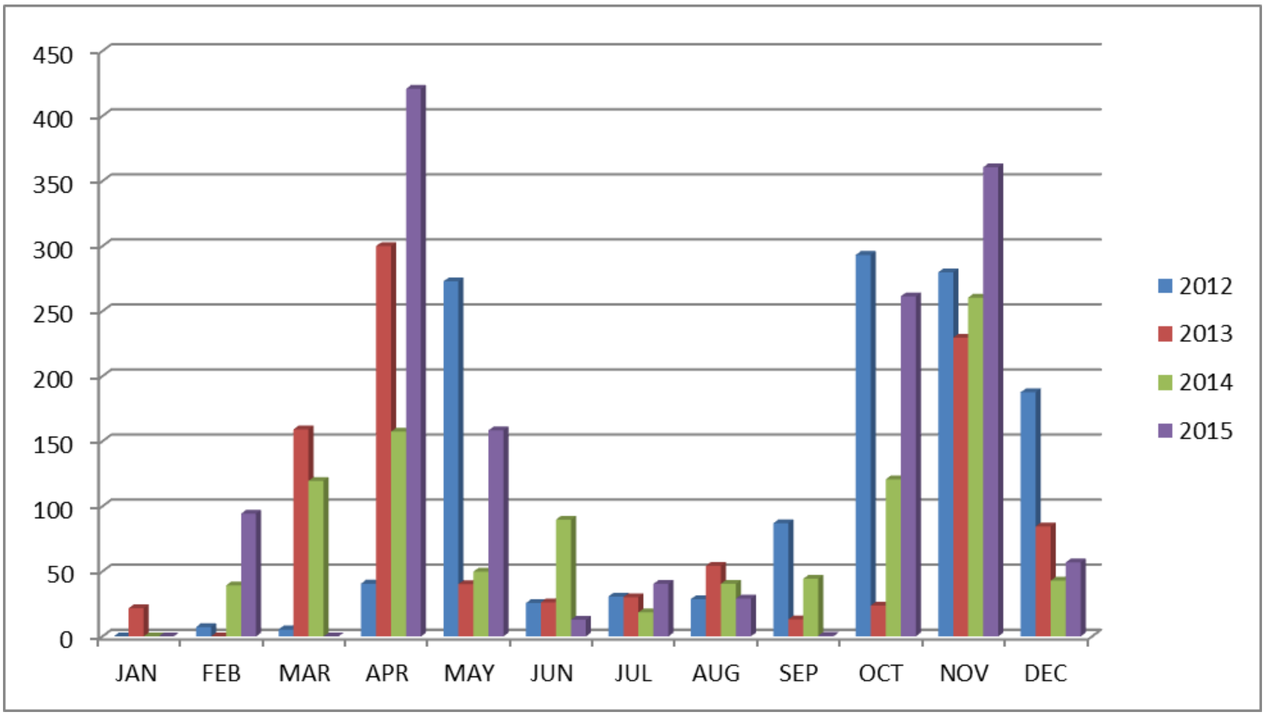
APPENDIX 11

RAINFALL AMOUNTS BETWEEN 2012-2015



APPENDIX 12

MONTHLY RAINFALL FOR EMBU METEOROLOGICAL STATION: 2000-2016

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Mean	Deviation
2000	-	-	15.90	60.10	24.50	21.10	25.00	22.80	29.40	40.50	198.10	61.70	499.10	41.59	(58.41)
2001	108.60	31.90	119.40	312.40	146.80	30.50	29.40	18.50	3.70	51.90	283.40	29.50	1,166.00	97.17	(2.83)
2002	25.90	17.00	94.60	320.70	273.00	15.30	19.00	54.50	37.10	173.40	150.40	142.4	1,823.30	151.94	51.94
2003	-	-	66.70	314.30	316.70	10.60	14.90	101.20	52.50	202.20	174.40	93.60	1,347.10	112.26	12.26
2004	32.60	54.40	234.70	152.60	62.90	20.90	3.80	15.50	38.00	238.40	372.20	49.80	1,275.80	106.32	6.32
2005	3.40	1.00	21.90	238.80	247.00	31.70	36.00	47.10	22.30	168.10	129.90	5.00	952.20	79.35	20.65
2006	15.30	24.00	177.20	184.80	269.80	22.70	23.50	19.80	80.10	225.20	446.10	291.1	1,779.60	148.30	48.30
2007	66.90	-	73.70	260.50	177.10	9.90	33.40	45.70	18.90	323.80	125.70	57.40	1,193.00	99.42	(0.58)
2008	67.00	-	164.70	340.00	13.30	20.60	51.40	20.90	1.80	99.00	99.50	2.00	880.20	73.35	(26.65)
2009	116.30	10.20	84.50	199.00	162.90	14.40	3.70	13.70	8.70	239.00	183.90	43.30	1,079.60	89.97	(10.03)
2010	18.60	117.50	188.30	223.60	223.30	19.90	26.80	48.80	5.40	13.90	114.20	23.00	1,023.30	85.28	(14.73)
2011	12.40	17.80	44.60	264.00	196.10	7.50	8.80	29.80	100.6	262.50	224.30	68.20	1,236.60	103.05	3.05
2012	-	7.30	5.40	406.40	272.90	25.70	30.70	28.00	87.00	293.30	279.90	187.7	1,624.30	135.36	35.36
2013	21.70	0.10	159.20	300.00	40.20	26.20	30.20	54.30	13.10	23.70	229.70	84.60	983.00	81.92	(18.08)
2014	-	39.30	119.60	157.40	49.90	89.80	18.50	40.40	44.40	120.80	260.50	42.90	983.50	81.96	(18.04)
2015	-	94.00	64.10	420.90	158.40	12.80	40.40	29.10	0.60	261.40	360.60	56.90	1,499.20	124.93	24.93
TOTAL	488.7	414.50	1,634.50	4,655.50	2,634.8	379.6	395.5	590.1	543.6	2,737.1	3,632.8	1,239.1	19,345.8	100.76	

`

APPENDIX 13

DATA SHEET 1

POINT SOURCE CONTRIBUTION ASSESMENT

LOCATION...……………….. DATE……………….

Segments	Segment length	Description	Surface cover	pH	Porosity	Infiltration	Sample #	Remarks
A								
B								
C								
D								
E								
F								

Data sheet 1

`

APPENDIX 14

STREAM CHARACTERISATION

STREAM:____________________________ LOCATION:___________________

DATE: ____________________________GPS______________________

1. Predominant land use by %

Rain forest [ ] Dry Forest [ ] Savanna [ ] Scrubs [ ] Residential [ ]

2. Vegetation Cover

Bare [ ] Plantation [ ] Grass [ ] Other.[ ]

3. Erosion

Sheet [ ] Rill [ ] Gully [ ] Biotic [ ]

4. Physical characteristics of the Stream

Mean Width [ ] Mean Depth [ ] C Section Area [ ] pH [ ] Discharge [ ]

	Common	Dominant	Absent	Sparse
Animals				
Plants				
Human				
Other				

Bank Characteristics	%	Load	%
Bluff		Float	
Slip-off		Suspension	
Cavitation		Traction	
Potholes		Bed	

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APPENDIX 15

EXFOLIATION RESULTING FROM WEATHERING IN THE DRIER ZONE OF THE WATERSHED

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APPENDIX 16

CONTRIBUTION OF AGRICULTURAL CHEMICAL INPUTS

Crop	Hectares	Agro-Eco. Zone	Conservation	Chemical inputs
Maize	30,920	1,2,3	2	5
Sorghum	1,535	3	1	1
Pearl millet	1,295	3	3	1
Beans	22,105	1,2	3	4
Cow peas	2,620	3	2	3
Green grams	875	3	3	3
Sweet potatoes	620	2,3	3	1
Cassava	1,225	3	3	1
Irish potatoes	2,565	1,2	3	4

Contribution of Agricultural chemical inputs (Source EIDP 2014)

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APPENDIX 17

CONFLUENCE, THIBA (LEFT) RUPINGAZI (RIGHT)

`

APPENDIX 18

EROSIVE IMPACT OF LANDSLIDE

`

APPENDIX 19

TRANSFORMING IMPACT OF MASS MOVEMENT

APPENDIX 20

RESEARCH AUTHORIZATION

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471, 2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref. No. **NACOSTI/P/19/17989/28690**

Date: **7th June, 2019.**

Paul Njue Nyaga
Chuka University
P.O. Box 109-60400
CHUKA.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Assessment of the contribution of land use activities to geomorphic processes in different agro-ecological zones in Rupingazi watershed, Kenya."*** I am pleased to inform you that you have been authorized to undertake research in **Busia County** for the period ending **6th June, 2020.**

You are advised to report to **the County Commissioner and the County Director of Education, Busia County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

BONFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Busia County.

The County Director of Education
Busia County.