AN ASSESSMENT OF THE INFLUENCE OF SLOPE SEGMENTS ON SOIL PROPERTIES IN THE MUA HILLS, MACHAKOS COUNTY

Muthui Elizabeth Wangari

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DECLARATION

This project is my original work and has not been submitted for the award of any degree in any other University.

Signed………………………………… Date……25/08/2020….…………..

Muthui Elizabeth Wangari

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The project has been presented for examination with my approval as University supervisor.

Signature……… Date…25/08/2020.……………………

Dr. Shadrack Kithia

Department of Geography and Environmental Studies

University of Nairobi

Dr. John Nyangaga

Department of Geography and Environmental Studies

University of Nairobi

Signature - Nyangaga. Date -------25.08.2020-------------------

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ABSTRACT

As a factor that is involved in soil formation, topography mediates the interaction of soil and geomorphological processes on a hillslope and this essentially influences the soil properties in a location. Soil properties of depth and texture are not randomly distributed and in a local setting where soil forming factors are fairly constant, soils have a close relationship with topography and geomorphic setting. The objective of this study was to investigate the spatial distribution of soil properties of depth and texture in relation to slope position. Soil depth influences soil moisture storage and texture is a key soil property that influences water drainage and susceptibility to erosion.

The soil depth as a measure of erosive geomorphic process was thinnest at 15cm on the transportational slope and thickest at 244cm on the toeslope. Clay soil composition was at an average of 4% along the slope with the highest clay composition being recorded on the river channel at 8% while silt soil composition was at an average of 30% along the slope, with the highest concentration of 47% being recorded on the river channel. The river was a seasonal channel and at the time of this field work, it was dry. Sand soil composition was generally high along the hillslope with an average of 58% along the slope, with the backslope having the largest sand content at 77%. The highest concentration of gravel was on the transportational unit at 45%.

Stratified sampling technique was applied to identify the seven geomorphic units used in the study. From the seven identified geomorphic units, purposive sampling method was consequently applied to choose the twenty sampling points which were deemed to be inclusive of the study population. The study findings indicated that the soil properties of depth and texture had been influenced by the slope position in the Mua Hills. The thinnest soils were in the middle steep slopes, which also recorded the coarsest soil textures. To this, it is recommended that when soil property variations are matched to the slope segment on the hill, then it is possible to conduct area specific land management on similar landscapes.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The intent of this study is to give an assessment of the influence of slope segments on soil depth and texture in Mua hills, Machakos County. This chapter gives an introduction to the study.

Soils play considerable importance in the advancement of various land use systems. For this reason, one cannot use soils most adequately without understanding the factors and the processes that control their distribution for optimal land use. Being a factor in soil formation, topography mediates the interaction of soil and geomorphological processes of weathering and erosion and hydrological processes of run off and infiltration and this essentially influences the soil properties in an area (Seibert *et al*., 2007). Birkeland (1984) notes that the genetic relationship between topography and soils is a two-way development process because geomorphic processes and the landforms that result help in soil formation and distribution and in response, soil distribution influences geomorphic landscape evolution. This is because soil texture influences the efficiency of geomorphic processes especially water erosion. Soil depth influences hydro-geomorphic processes such as infiltration because when water finds an obstructing zone, infiltration is inhibited (Yoo and Jelinski, 2016).

In this study, the Mua Hills is seen in three major slope positions of the upper, middle, and the lower slopes. Depending with the location of a slope unit on the hillslope, there are certain distinguishing geomorphological processes of weathering, erosion and deposition that are prevalent. This includes processes such as vertical water infiltration on relatively flat surfaces, surface runoff on steep slope segments or deposition on lower slope sections that are relatively gentle (Gerrard, 1992). These processes in turn have the likelihood of influencing soil properties of depth and texture on the specific slope segments. In this study, these slope sections have also been referred to as geomorphic units as illustrated on figure 3.2.

1.2 Statement of the problem

Sustainable land management requires utilization of soil properties according to their spatial variability. The soil properties of depth and texture are not distributed randomly across the land. To enable precision management of the soil, the distribution of these properties should be understood (Nkonya *et al*., 2016).

The contribution of topography to the distribution of different soil properties is largely seen on a hill that has varying slope segments along the hillslope as relative slope position influences geomorphological processes of weathering and erosion that essentially influence the development of soil properties of depth and texture (Mohammadi *et al*., 2016).

Mua Hills is a hillslope which is recognized as a fundamental organizer of energy and water on a terrain and this essentially influences how soil properties are distributed. Depending on the relative positioning of a particular slope segment on the hill, dominant geomorphological processes are expected and these control soil formation and distribution to such levels that the soil reflects morphological properties of soil depth and soil texture corresponding to the dominant geomorphological processes. There are different land cover and land uses on the hill such as crop farming, lands with shrubs and grassland, bare rock surfaces and built up areas.

Topography, and in this case the aspect of relative slope position, is a fundamental natural driver of degradation of the soil through soil erosion that is caused by water (Burt *et al*., 1990). For example, slopes that are steep are more susceptible to soil erosion that is water-induced which effectively diminishes soil depth as topsoil is washed down to the lower grounds (Nkonya *et al*., 2016).

Soil depth is usually recognized as a factor that controls many surficial as well as subsurface processes such as in soil moisture storage conservation capacity (Heimsath *et al*., 1997, Catani 2010). Texture affects other aspects of the soil, such as the capacity to hold water and the vulnerability to erosion. Understanding the influence that topography has on soil depth and soil texture distribution is a key tool to regulating landscape surficial processes. This information becomes a necessary tool for area specific land management on a sloping profile.

1.3 Research Questions

1. To what extent has the relative slope position influenced soil depth in the Mua Hills?
2. How has the relative slope position influenced the development of different soil textures on the Mua Hillslope?

1.4 Research Objectives

1.4.1 Overall Objective of the Study

The overall objective of this research was to investigate the spatial link between properties of the soil and topography. The relative position of the slope is used as the explanatory variable to justify for the difference in soil properties on the hillslope of Mua hills, Machakos County.

1.4.2 Specific Objectives

In addressing the research questions in the Mua Hills, the specific objectives were:

1. To examine the influence of relative slope position on soil depth in Mua Hills
2. To establish the influence of relative position of the slope on the distribution of soil textures in Mua Hills.

1.5 Hypothesis

1. $H_{0:}$ Soil depth is not influenced by relative slope position variations in Mua Hills.
2. $H_{0:}$ Soil texture is not influenced by relative slope position variations on the different landscape units in Mua Hills.

1.6 Justification of the study

This study assessed the relationship between topography specifically the topographical aspect of relative slope positioning on the hill and the distribution of soil properties of depth and texture on a hillslope, in Mua Hills, Machakos County. A review of hillslopes (Kirkby, 1972; Birkeland, 1984) indicates that the genetic relationship between landforms and soils is a two-way development process because the geomorphic setting of form and process are important in soil formation and distribution and in response, soil properties dictate how the geomorphic landscape evolves. There are numerous studies that have researched on the horizontal and vertical variation of characteristics of the soil (Qiu *et al*., 2000; Birkeland *et al*., 2003; Seibert *et al*., 2007; Wang, *et al*., 2015) but little research has been done that explicitly links soil variations with the topographical influence of the geomorphic setting of topography. This research therefore aimed to study this interface of the fields of geomorphology and pedology. Furthermore, as an independent factor in soil formation, topography's contribution to soil formation and distribution can be considered on its own (Seibert *et al*., 2007). The expected contribution of this study to the Mua Hills included:

- Soil depth is a factor that controls several surficial as well as subsurface processes such as changes in the landscape, landslides, soil conservation sediment budgets, and storage of soil moisture (Heimsath *et al.*, 1997, Catani 2010). Texture affects other aspects of the soil, such as structural behavior and susceptibility to erosion. Understanding the influence that topography has on soil depth and soil texture distribution is a key tool to regulating landscape surficial processes.

- Knowing the various soil textures and soil depth would help in managing soil moisture within the soil for agricultural purposes. This is because moisture content levels in the soil vary with topography. During periods that are dry, soil depth and soil texture are the main factors that control water movement in the soil and these should therefore be effectively managed. In wetter periods, the form of the topographic unit i.e., steeply, gently or flatly undulating is more important and this should also be duly controlled.

- Knowledge of soil properties (depth and texture) and slope position relationship on a hillslope would help in landscape management. This is because soils act as a control in hillslope hydrology by influencing water residence times and storage mechanisms through the process of infiltration.

The contribution of this study was in the field of soil geomorphology in terms of the interactions between geomorphic landform processes and pedology, which studies soil properties. This was therefore a framework that was important for the study of soil distribution patterns on a hill.

1.7 Scope and Limitations

1.7.1 Scope

This research focused on the influence of topography and slope segment on soil development in the Mua hills. Though there were other hills in the Machakos County area, Mua Hills was chosen for this study because it was easily accessible thereby solving the issue of financial and accessibility constraints. The research focused on geomorphological processes of weathering, erosion and deposition as these processes influenced the soil properties of soil depth and texture. These two physical soil property attributes were the focus for the study because of the impact that geomorphological processes of weathering, erosion and deposition have on their distribution. The derivatives of slope were influenced by the Conacher and Darlymple (Gerrard, 1992) landscape unit concept; where the slope was divided into seven transect units based on the relative positioning of the slope segment on the hillslope surface. The Conacher and Darlymple landscape unit has been used in studies such as Selby, (1982).

1.7.2 Limitations

Certain slope positions in the Mua Hills had deeply weathered soil profiles and in such slope segments, soil depth could only be taken by digging deep soil pits. This is because effective soil depth measurements were taken at the point where soil horizon C (the point of unweathered bedrock) was differentiated from horizon B. Because of financial and human resource constraints, it was not possible to dig deep soil pits and for this reason, it was not possible to take soil depth field measurements in all of the twenty sampled points. Soil depth was therefore not taken in nine of the sample points. However, soil depth was taken on eleven sample points and these were sufficient for the study as a relationship was established between slope position and soil depth.

1.8 Operation definitions

Altitude- Height using sea level as the base

Basement Rock System-This is part of the crust of the Earth that is formed from igneous or metamorphic rocks and it lies under the cover of sedimentary rock.

Geographical information system- is a tool that is used for capturing, storing, manipulating, analyzing and managing georeferenced data to create new spatial information from various perspectives.

Geomorphology- It is the inquiry of landforms in addition to the events that are actively shaping them.

Geomorphic Unit- This is a topographic segment on the landscape that exhibit similar geomorphic processes such as erosion or deposition within itself.

Horizon C soil profile- This is the point of unweathered bedrock on the soil profile.

Slope position- The location on which a slope segment lies on the landscape.

Soil- Soil is the distinct loose unconsolidated colluvial material that lacks a relict rock structure that has been derived from bedrock.

Solum- Horizon A and B soil profile

Sub-aerial weathering- Weathering that occurs immediately on or near the Earth’s surface.

CHAPTER TWO

STUDY AREA

2.0 The Study Area

The Mua Hills (Figure.2.1) is located in Mua County Assembly Ward, Machakos Town Constituency, Machakos County and lies between latitude 1° 50' 00" South and 1º54´ South and longitudes 37° 07' 00" East and 37º21´East (Machakos County Integrated Development Plan, 2015).

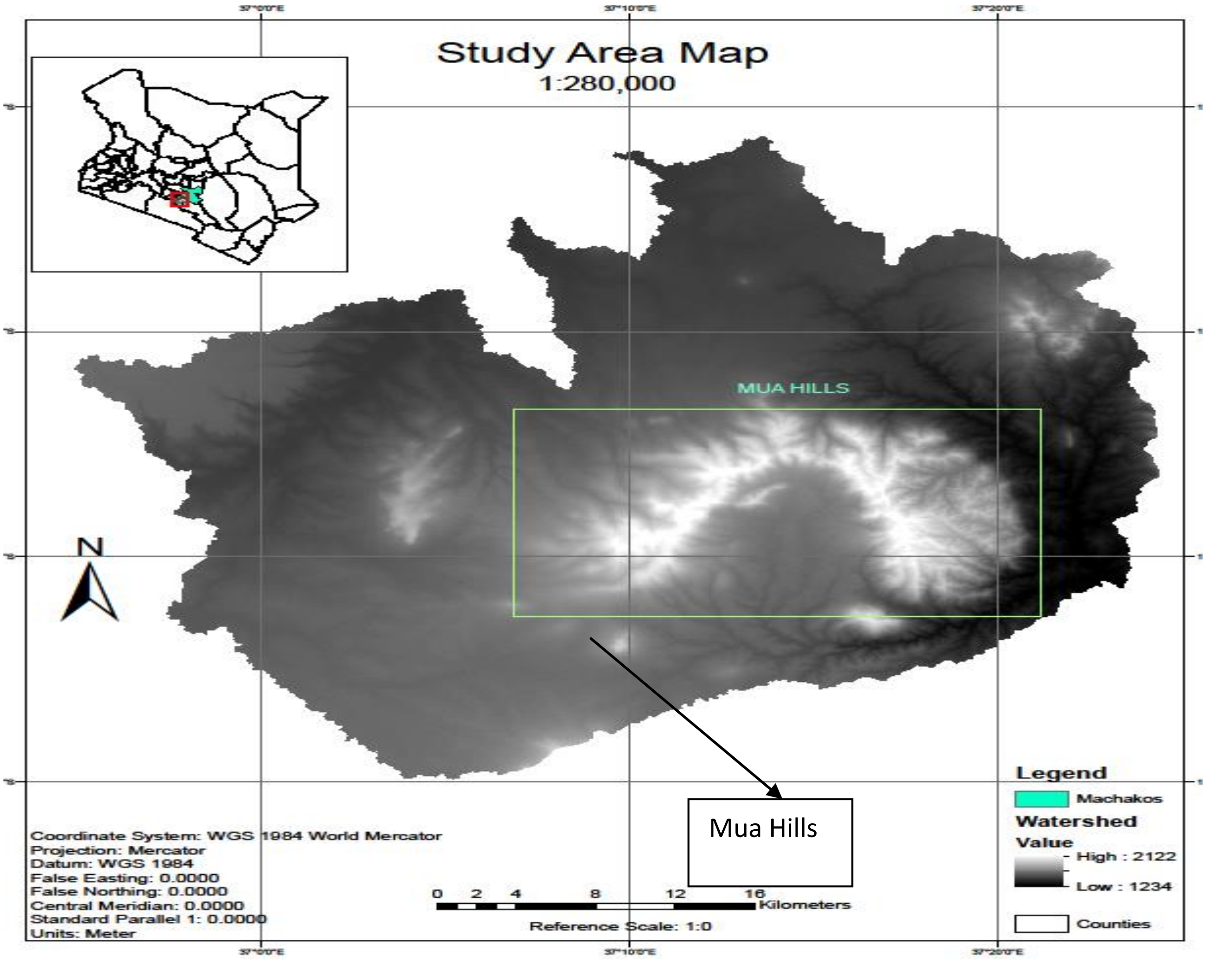

Figure 2.1: Mua Hills study area map showing topographic elevation

Source: Researcher, 2019

Mua Hill rises abruptly from the plains with an altitude of 1234 m at the bottom of the hill to 2122 m at the highest peak. It is steep sided and being actively dissected. The topographic feature of slope controls the rates of redistribution of soil across the hillslope.

2.1 Climatic characteristics

Mua Hills is in one of the highland areas of Machakos County and receives an average of 800mm of rainfall annually (Figure 2.2). There are two major rainfall periods with the prolonged rains expected from the month of March to May, with the months of October to December bringing the short rains (Machakos County Integrated Development Plan, 2015). However, there are months that do not experience rain during the year giving rise to dry spells. Water from rainfall is one of the main geomorphic agents that influence soil distribution). The average temperature is 20^{o}c (Figure 2.2).

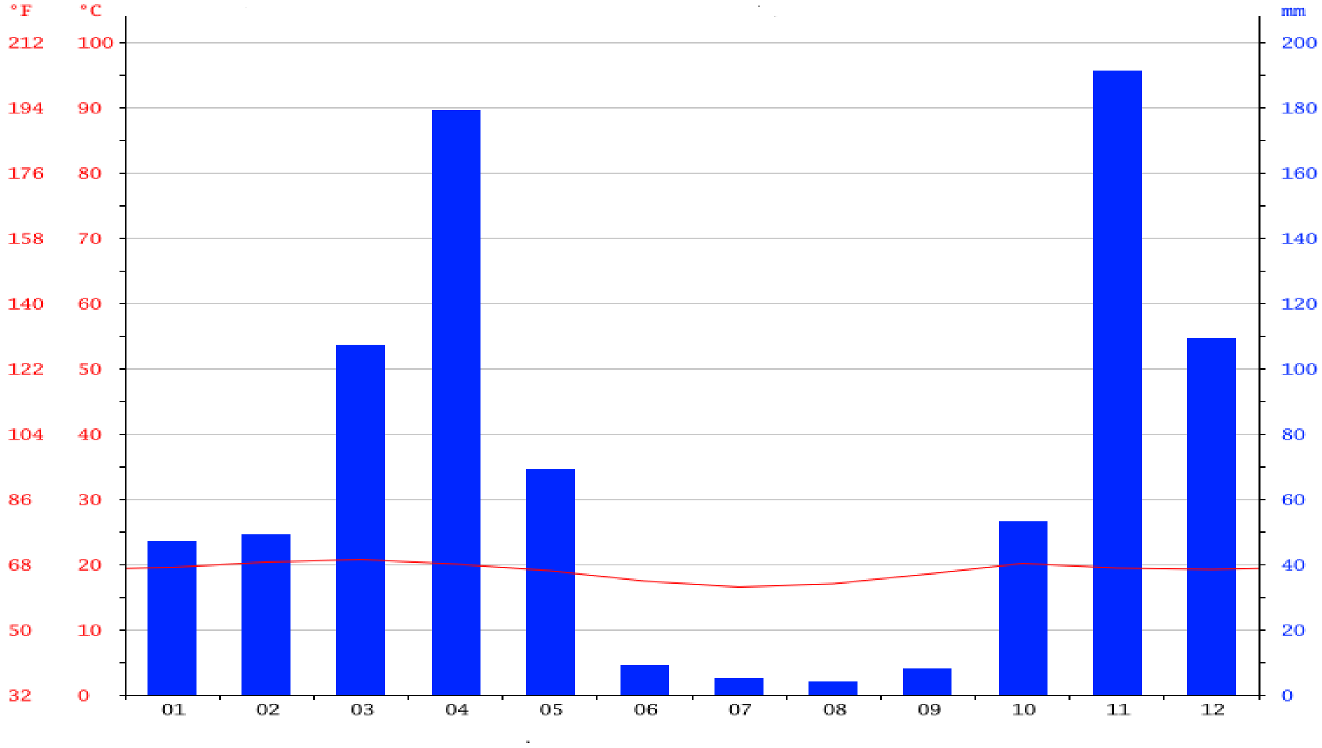

Figure 2.2: Climograph- Weather by Month Machakos

Source: climate-data.org, 2018

2.2 Geology of Mua Hills

The Mua hills are a remnant of a former peneplain bevel with deeply weathered soil profiles dated as at the end of the Cretaceous period. They are part of the Central hill masses of Machakos, steep sided, and they are being actively dissected (Scott, 1963). The hills have been eroded into a peneplain and some of the former hills is represented by the top of the Mua hills (Kanake, 1979-Kalro). The underlying geology is Basement System rocks consisting mainly of gneisses which outcrop at various places on the Mua Hills.

2.3 Hydrogeology

Mua Hills features a dendritic drainage pattern (Figure 2.4). Dendritic pattern develops on relatively uniform bedrock (Morisawa, 1963). The Mua Hills basin has five sub-basins formed from five different summits. Generally, the drainage pattern is from west to east with the Athi River being the most important river. It flows throughout the year. Most of the streams are seasonal and only flow during part of the year during heavy rainfall periods (Moore, 1979).

2.4 Topography and geomorphology

Mua hills are upland massifs in Kenya (Ojany, 1966). The topography largely influences the geomorphology of the area, and this consequently affects soil development and its distribution. Slope is the ultimate factor on how water flows on the land surface. Figure 2.3 below shows the flow direction of the Mua Hills. The amount of water increases in the down slope direction. More water means more energy to carry out geomorphic activities on the slope.

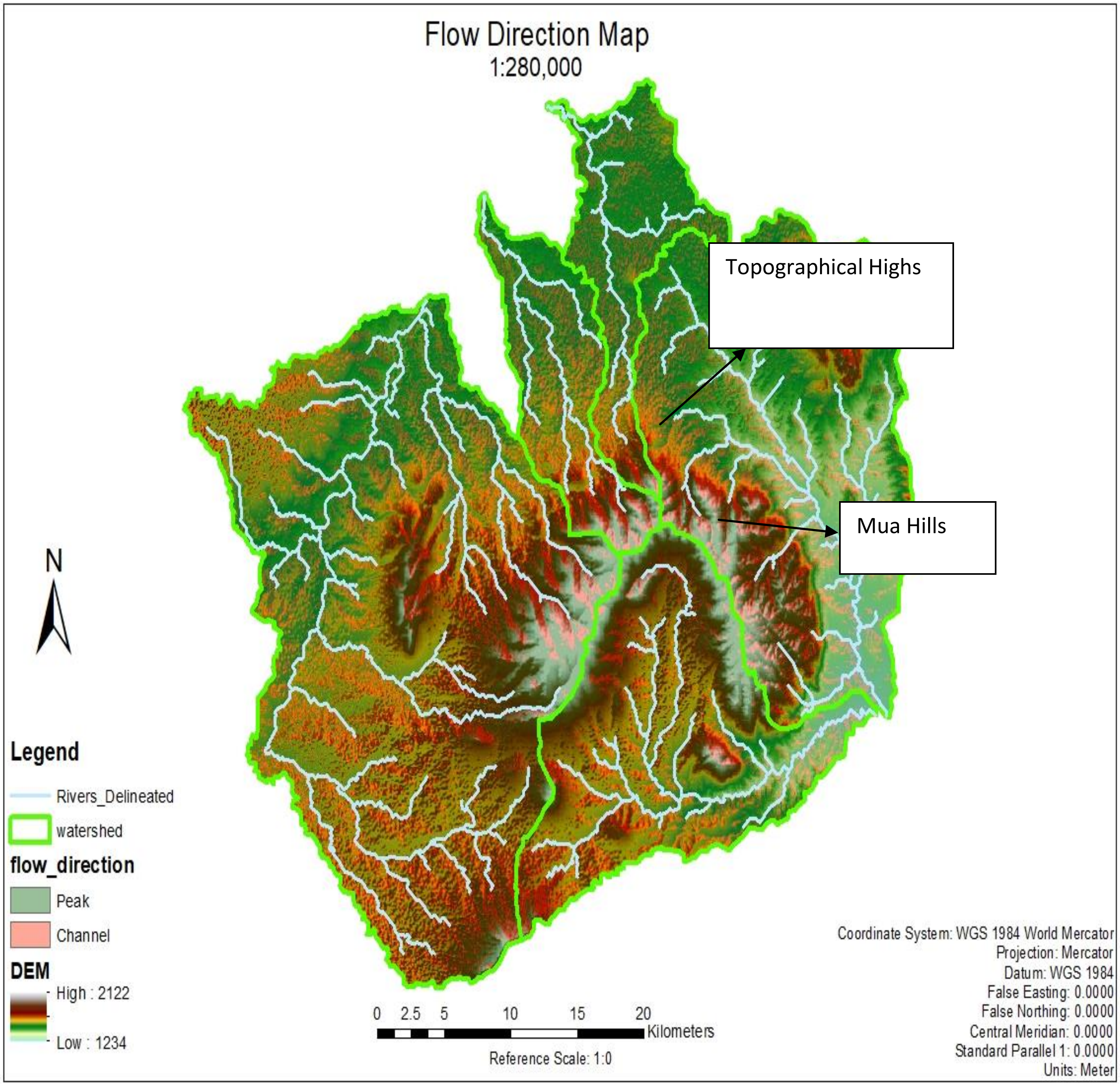

Figure 2.3: Mua flow direction map overlaid with a DEM map.

Source: Researcher, 2019

2.5 Drainage

There are five sub basins within the entire watershed of Mua Hills (Figure 2.4).

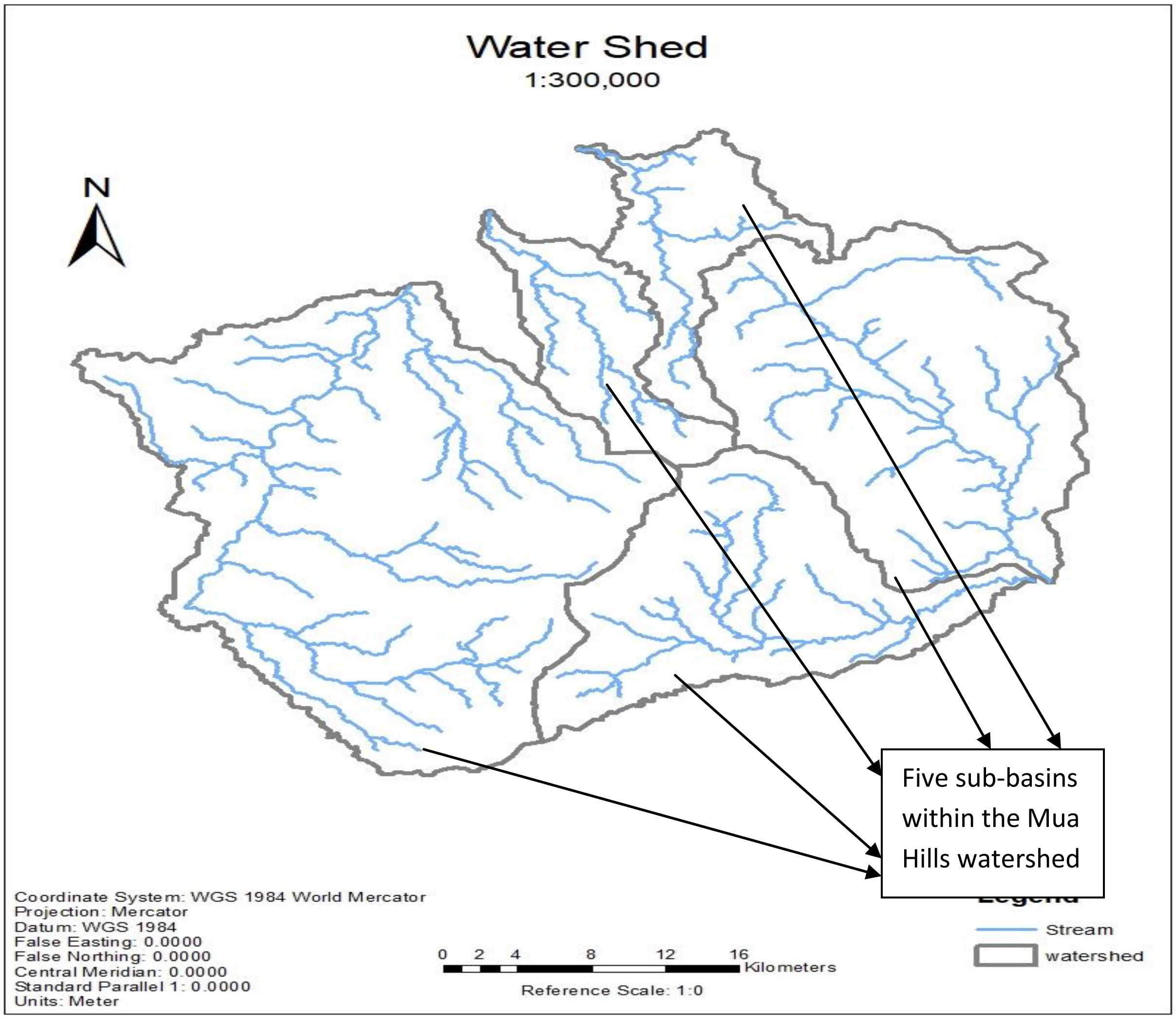

Figure 2.4: Mua Hills dendritic drainage pattern watershed

Source: Researcher, 2019

Mua hill has five summits, with five sub-basins. These basins stretch from the summit such that the entire Mua Hills is a catchment area. When water reaches the ground by falling from clouds, the water can directly hit the soil or fall into streams. Voids in the soil are filled by the water that infiltrates through it, and if the soil is impermeable or if it is saturated, the excess water flows off the soil surface as overland flow.

The Mua Hills watershed is influenced by the high altitude brought about by the hill. The high altitude substantiates the accumulation and direction of flow in the watershed. Mua region is dry as the rainfall patterns are low and therefore the streams are seasonal and only flow during the flooding season.

2.6 Soils

The soils in Mua Hills are Chromic Cambisols (FAO, 1977) soil classification (Figure 2.5). BC 14-2bc refers to Chromic Cambisols that are dominant soils at >50% and associated Lithosols soils at 20-50% composition. The Mua hill soils have a strong relationship with the geology and geomorphology of the area. They are soils classified under the soils of the Central Hill Masses. Red friable clays are found on the summits, upper, middle and lower slopes of Mua hills where the drainage is good and the infiltration capacity is high. They have a high sand content. Yellow-red sandy clay loams with laterite rock are found on the drier areas such as on the lower convex shaped western slopes of the hill. Infiltration in these soils is inhibited because of the presence of large unweathered rock resulting to shallow soils. Transport processes are quite dominant on these soils. Dark grey compacted loamy sandy soils are found on the lower slopes of the hills where the topography on the soils is flat to gently sloping. They are associated with depressions and drainage grooves. The saturated hydraulic conductivity of these soils is high and this leads to a lower infiltration capacity. This is because structure and texture of the soil have a strong influence on how the water infiltrates into the soil. Shallow stony soils with rock outcrops are found on very steep slopes of the hills. The soils are shallow owing to dominant transport processes and reduced infiltration capacity (Scott, 1963).

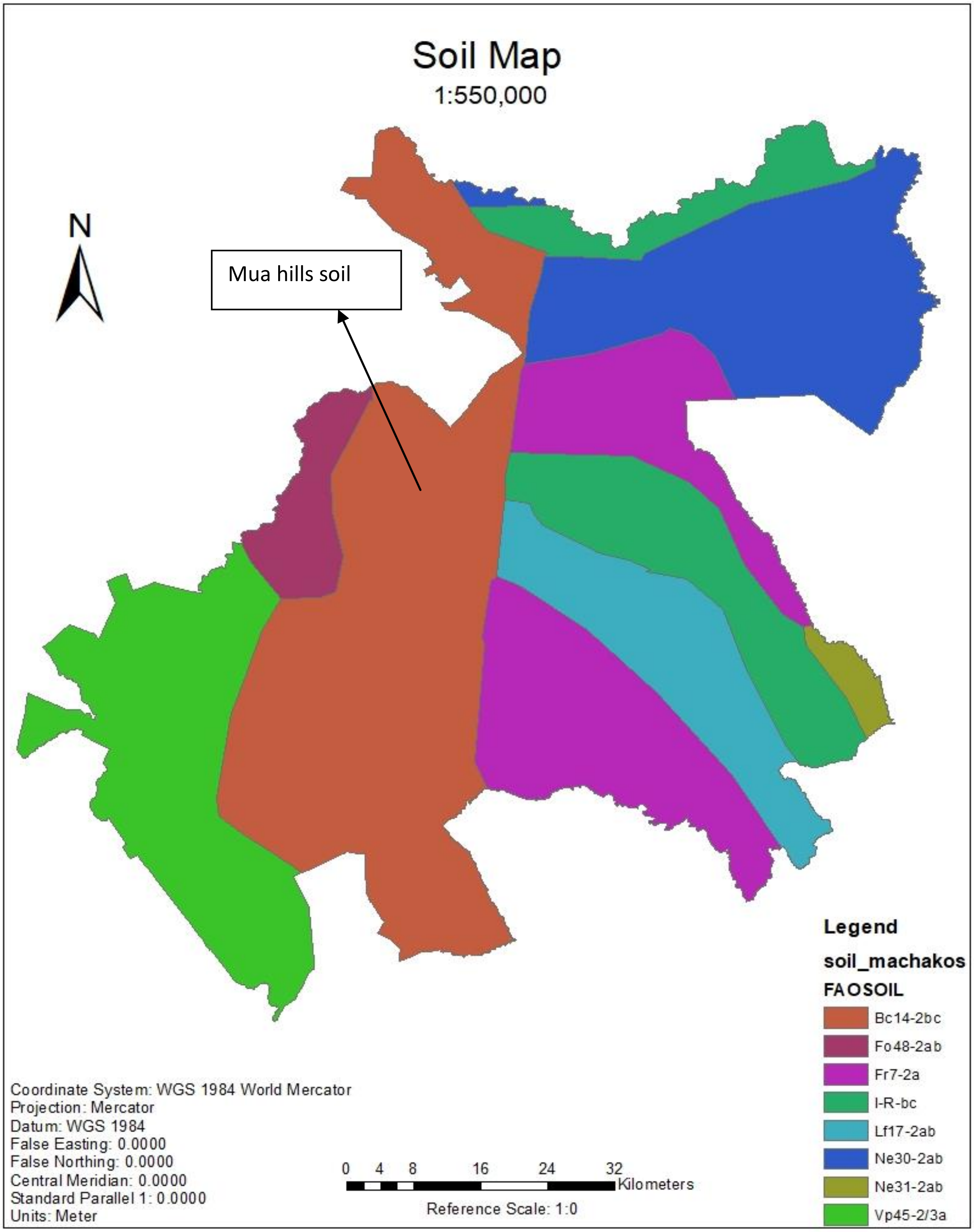

Figure 2.5: Mua Hills Soil Map

Source: Researcher, 2019

2.7 Land use

The major land uses in the Mua Hills are perennial crops such as coffee, and food crops of the likes of millet, maize and beans. On the upper slope of Mua Hills, mixed farming is practiced where crops such as maize and beans are planted and animals such as cows are kept. Terraces have been built to mitigate soil erosion. Such land conservation practices discourage carrying away of the top soil and this ensures a deep soil depth. Human activities play a huge role in landscape evolution and consequently on geomorphic processes that influence soil properties as some activities either foster soil development while some suppress soil advancement.

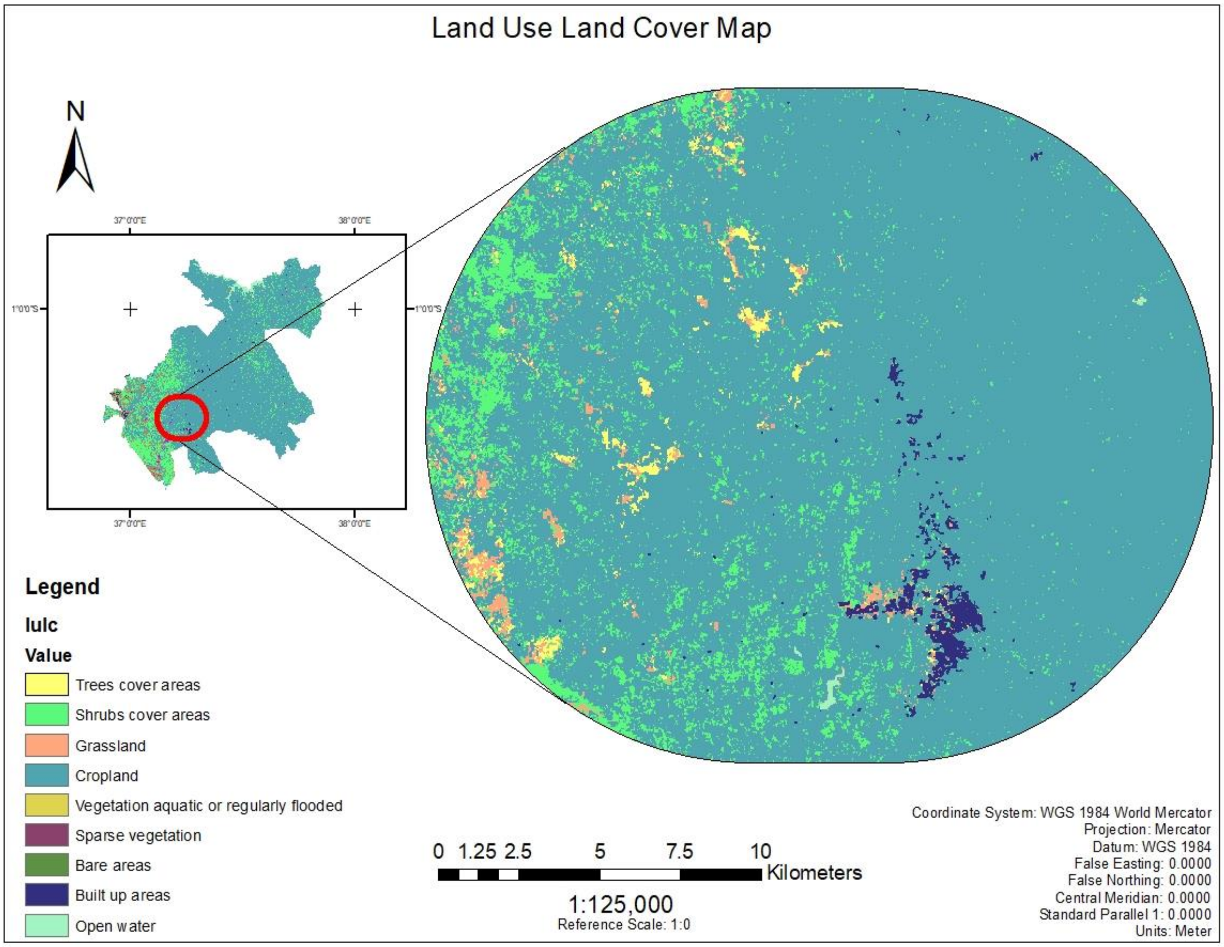

Figure 2.6: Land cover map of the Mua Hills

Source: Researcher, 2019

CHAPTER THREE

LITERATURE REVIEW

3.0 Introduction

This analysis is organized into topical issues that are based on the study problem, objectives and hypotheses. Its objective is to highlight significant studies done on relationships between topography and soil properties. This review was deemed important as it showed various relations between slope and soil, the processes involved in different soil formations and distribution along a hillslope and key elements to consider in the soil/landscape analysis, all of which were necessary in the study.

3.1 Soil Geomorphology

Soil geomorphology studies the terrain and the impact that geomorphological processes influence the evolution of the land and thereby on the formation of soil and its distribution. It aims to look at the genetic relationship between landforms and soils. The genetic relationship between landforms and soils is a development that is two-way because geomorphic processes and the landforms that result are important in the formation of soil and its distribution and consequently, the development of soil has an impact in the changes of the geomorphic landscape (Birkeland 1984; Gerrard 1992). Geomorphological processes enhance the development of hillslopes which consequently influence soil development by having an effect on the soil depth and soil texture. This is because along a hillslope transect, different geomorphological processes take place at different intensities each of which results to different soil characteristics. Soil here is defined as the distinct loose unconsolidated colluvial material that lacks a relict rock structure but has been derived from bedrock.

According to Gerrard (1992), geomorphology and pedology were once treated as separate disciplines with only a small awareness of the influence of one on the other. Geomorphology is the inquiry on landforms and the events that are molding them such as erosion, weathering and deposition. Pedology deals with soil formation processes. These pedological processes are physical, biological and chemical processes that involve four processes of addition, loss, transformation and translocation. The processes of pedology are under geomorphic control and they interact more so on hillslopes where water movement is involved (Zinck, 2013).

The study of surficial processes on the hillslope and pedology provide a framework for the study of evolution of landscape units and soil distribution. There are many studies that have put an emphasis on the horizontal and vertical differences of characteristics of the soil (Qiu et al., 2000; Birkeland *et al*., 2003; Seibert *et al*; 2007; Wang et al; 2015) but little research has been done that links soil variations with the topographical influence of landscape processes.

3.2 Soil forming factors

The distinct and unique nature of soil shows the ongoing interaction of the factors involved in formation of soil; Parent material of the rocks in the locality, the region's climate, biological processes, the duration of soil development, and the configuration of the terrain. Jenny (1994) formulated the soil forming state equation thus;

$s = f(cl, o, r, p, t \ldots .)$ ……………………………………………………………Equation (2.1)

Where;

Climate (cl), organisms (o), topography(r), parent material (p), and time completely define the soil system (Jenny, 1994). For a given combination of these variables, only one soil type will exist. The sorting out of each of these influences on soil is difficult and it is this topographical soil forming factor that geomorphology and pedology are most interconnected because of topographically controlled processes such as infiltration that occur on hillslopes (Birkeland, 1984). The soil forming factors influence geomorphological processes and in effect, the geomorphological processes influence soil distribution.

3.2.1 Parent material as a soil forming factor

Jenny, (1994) describes parent material as soil system's initial state. Parent material is a framework for developing the soil profile. It is a factor that has an influence on soil development but its influence is deemed to reduce with time because the soil might be so altered by pedogenesis that characterizing the original parent material could be a difficult task (Schaetzl and Anderson, 2006). Furthermore, the impact of relief and climate with time become more dominant over the parent material such that adjacent soils formed from different parent materials would be seen to morphologically converge. Additionally, some challenges might arise when trying to ascertain a soil's parent material. These challenges include studying soils that are highly weathered and altered. In this case, the parent material will usually be previous soil and the soil will be polygenetic. The second challenge is that there might be more than one parent material either as discrete materials or layers that are mixed intricately. The influence of parent material on soils is of particular importance on younger surfaces. Moreover, on weakly developed soil profiles, studying the parent material might be relatively easy because the solum may be thin such that digging a thin soil pit might be enough to reach the parent material (Retallack, 2008).

3.2.2 The influence of time

In this process of soil formation, the soil system state changes with time and this usually takes a long time, the changes to the soil system only being seen after several decades. Different parent materials have different rates of transformation from the consolidated rock material into the loose constituents of soil. This takes varied amounts of time (Jenny, 1994). However, certain effects of soil formation can be seen in short durations of weeks or months such as gley mottling of soils when they become very wet ((Breemen and Buurman, 2002). In the determination of the relative maturity of a soil or in the relative age estimation of a soil, the horizon differentiation of the soil is of importance (Jenny, 1994). It has been generally maintained through inferences that the greater the soil thickness and the more the soil horizons are, the more the soil maturity.

3.2.3 Climate influence in soil formation

The factor of climate is quite complex such that it necessitates to work with individual components of climate, the most important components being moisture and temperature (Jenny, 1994). As far as moisture characterization goes, rainfall patterns in an area become important with regions being characterized into arid and humid depending with the amount of precipitation that falls. Moisture content influences the mineral components in a soil. In addition, in arid regions, rainfall that infiltrates into the soil is retained by particles of the soil. Additionally, via evaporation process and through plant transpiration, the moisture moves upward again. Leaching does therefore not remove the weathering products. The reverse occurs in humid regions, showing the effect of moisture on soil formation (Shoji *et al.*, 2006).

With the temperature aspect of climate, Jenny (1994) observes that in warm and humid regions, the rocks are much weathered to greater depths as compared to cold zones. In regards to soil color, humid regions of cold and temperate zones usually exhibit soils that are greyish in color, usually modified towards the colors of brown and black. In addition, many soils from the tropic regions especially the soils originating from metamorphic and igneous rocks are typified by yellow and dark-red colors. When there is a linkage between the climate of an area and the soil color rather than the parent material or the local conditions of the area, then the soil is regarded as a climatic soil color (Jenny, 1994).

3.2.4 Organisms as a soil forming factor

There is not a definite agreement among soil scientists as to the exact place of organisms as a soil forming factor (Jenny, 1994). Some contend that without vegetation, soil would not be in existence while others argue that vegetation cannot be accorded the rank of an independent variable since it is closely regulated by climate, soil and situation. However, organisms as a soil forming factor are classified into three major associations of biota, vegetation, and man.

Within each soil reside microbial populations such as bacteria and changes in the soil is followed by a change in the constitution of the microbial constitution (Frey, 2007). Vegetation is important in the concept of plant-soil relationships. The development of vegetation units is closely related to the processes of soil formation in which there is the effect of various plant species or the vegetation type on the formation of soil ((Retallack, 2008). Moreover, man has a great influence on soil formation. He modifies the soil forming factors especially the vegetation environment. An example is through irrigation where he completely modifies the climate of the soil (Jenny, 1994). Through cultivation and fertilization of soils, man becomes an important biological soil forming factor.

3.2.5 Topography as a factor in soil formation

Topography is the structure of the land surface such as level or flat, mountainous, hilly, rolling or undulating (Jenny, 1994). Through processes of geomorphology such as weathering of rock particles, erosion and the consequential deposition of sediments, topographical features have the capability of influencing soil physical properties. Soil properties vary in characteristics such as depth and texture in relation to the topographical setting (Birkeland 1984; Reddy *et al*; 2003). Topography influences geomorphological processes through topographical attributes such as the major landform in the area explained as the morphology of the whole landscape and this is on a macro- scale, relative location of the area on a landscape seen from the micro-scale perspective and slope gradient (Baxter, 2007).

3.2.1.1 Topography as the major landform

The main topographic feature in a region influences the drainage of the area. A difference in elevation results to a change in the landscape processes of infiltration and transport. Changes in elevation result to variations in soil because differences in relief leads to alterations in the local water penetration hence different soil characteristics (Seibert *et al*; 2007).

3.2.1.2 Relative location of the site within the landscape.

The relative position that a site occupies along the slope influences the hydrological conditions of the area. Because of the location of the slope, an area can be predominantly water receiving or it can be a location of runoff. Slope location differences results to subsequent soil differences. Birkeland (1974) exemplified this through a study in southern California where he studied three soil types which though of the same geomorphic age, exemplified dissimilar characteristics. The differences could be attributed to the topographic position of their location. The three soils had an ochric A horizon, but their B horizons differed downslope; the Vista soils had only a Cambic B, The Fallbrook had an argillic B with the Bonsall having a nitric B. Soil moisture measurements taken at different times during the year showed that the soils that were downslope (Fallbrook and Bonsall) had more moisture than the Vista soil which was on the upslope. The lower slope soils also retained moisture for longer. The clay content increased downslope and this could be attributed to more weathering of the underlying rock downslope. Once the formation of clay began, the soils achieved a higher water holding capacity that resulted to an enhanced clay formation in contrast to the upslope soils that had lower clay content. More intense weathering on the downslope was most likely because of increased soil moisture that had been determined by the slope position. Soils in the lower slopes could receive more moisture than the soils on the upslope positions because of lateral movement of water at the surface or within the soil.

3.2.1.3 Slope gradient

The gradient of a slope is crucial in drainage and surface processes because it affects the rates of surface-water runoff and transportation and this consequently influences soil properties (Desmet *et al.,* 1999). Low gradient angles tend to accumulate and retain moisture for a longer time as compared to steeply inclined slopes. Soil properties in rolling terrain will differ because lower lying areas will be regions of accumulation of sediments and runoff water from the surrounding areas that are of a higher gradient. Low areas might also be influenced by a high water table, which has an effect on the soil.

An illustration as to how slope gradient affects geomorphological processes is shown by examining the soils of Manitoba as highlighted in Jenny, (1994) where he studied soils on a level topography, soils on knolls and soils in depressions. The study showed that soils with a level topography occasioned moisture conditions that were ‘normal’ for the region. This is because the process of transportation was minimal and infiltration immense. Where there were knolls, the moisture conditions were different from the norm as a result of the process of transportation which was high. For example, when the annual precipitation was 18 inches, the soils on the knolls would receive a different amount of precipitation since it would be 18 inches less the amount of precipitation that flowed as surface run-off. The amount of water penetrating and the amount of water flowing as run-off would determine the local aridity. For soils on depressions, the reverse was true. When the area received an annual precipitation of 18 inches, the depressed area would receive 18 inches of precipitation plus the amount of water that ran from the nearby area. Hence there would be more water penetrating the depressed area. These soils were ‘locally humid associates’ as they had more moisture than the soils on the flatter topography. The depressed area was also a region of deposition with sediments transported from the higher lying areas.

3.3 Soil Depth

The depth of soil is its thickness from the surface of the land to the point of un-weathered bedrock (Heimsath *et al*; 1997; Zahedi *et al*; 2017). The distribution of the depth of the soil spatially is influenced by the blending of aspects such as parent material, topography, climate, biological processes and time. Soil depth influences hydro-mechanical responses of the slopes in landscapes. It is an important factor in many surface and subsurface processes such as soil moisture storage (Heimsath *et al*., 1997, Catani 2010).

3.4 Soil Texture

The texture of a soil is the degree of the comparisons of clay, silt, sand and gravel in a soil sample. Texture has an impact on the physical aspects of the soil such as structural behavior and susceptibility to erosion. Structure is the arrangement of particles in peds, which are soil particle aggregates that are formed from the process of pedogenesis (Schaetzl and Anderson, 2006) and it influences drainage. Texture is important because it affects movement, retention and availability of water in the soil as soil texture composition influences water residence times and storage mechanisms through the process of infiltration as different soil textures allow for different rates of infiltration and permeability. Clays are not easily permeable but they allow for more water retention while sands are more permeable but retain water for less durations of time (McKenzie *et al*., 2002). Soil texture is known to influence the infiltration process of the soil through. The texture of a soil can be redistributed by topographically controlled processes such as slope-wash which might affect K_s (De Wit, 2001). To account for the relationship between soil texture and topography, various sites along the hill transect are determined to see if there is a relation between texture and topography. Below is a definition of soil particle size that constitutes soil texture as illustrated by Bakker (2012).

Table 3.1: Soil size definition

Soil name	Soil in mm
Gravel	2.0-4.00
Sand	0.05-2.0
Silt	0.002-0.05
Clay	<0.002

Source: Bakker, 2012

3.5 Soil Profiles

Soils have distinctive characteristics expressed in the nature of their profiles. There are four major layers of the soil namely the O, A, B and C horizons. The O horizon is the layer of undecomposed plant debris or human raw humus at the soil surface. Humus, organic materials and other mineral particles are mixed in the A horizon. Additionally, it is also the zone where translocation takes place whereby the process of eluviation has removed some fine particles and soluble substances both of which may be deposited at a lower level. The B horizon is the illuvial layer from which material eluviated from the A horizon gets deposited. Because of a higher clay content, it has a higher bulk density as compared to the A horizon and it is generally compact. The A and B horizon are collectively known as the solum, which is the soil generated by pedogeomorphic activities. The C horizon is composed of parent material that is unconsolidated parent material. Pedogenetic processes have little effect on the C horizon (Muller & Oberlander, 1984).

3.6 Two-dimensional soil landscape systems

In the view of Gerrard (1992), a typical two-dimension approach for analyzing the landscape is the Conacher and Dalrymple's land-surface model. It shows the association of topography, geomorphological processes and soil development. The hillslope is subdivided into distinct components where mass and energy pass from one component to the other. Each geomorphic unit is a process-response sub-system elaborated in terms of processes that are distinguishing rather than processes that are dominant such that the processes that are distinctive in one unit also occur in other units but in varying intensities and combinations.

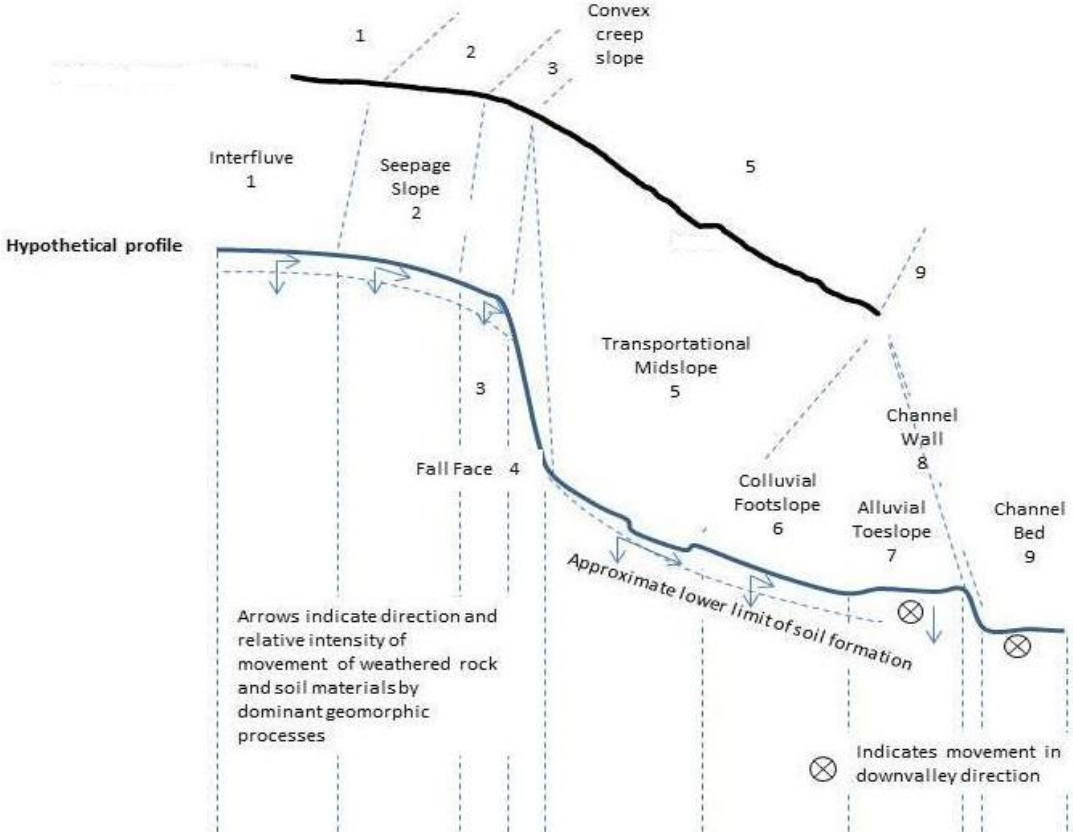

Figure 3.1: Conacher and Dalrymple hypothetical nine-unit land-surface model

Source: Adapted from Gerrard, 1992.

On units one and two (interfluve and seepage slope), pedogenetic processes that are related to vertical water processes dominate. In unit two, there is lateral and subsurface water movement that enhances mechanical and chemical eluviation. The convex creep slope on unit three is typified by both geomorphological and pedogenetic processes whereby soil creep dominates. On units four and five which is the fall face and transportational mid-slope, transportational processes of surface and subsurface water action take place. On unit six, there is re-deposition of material by slope wash. There is also transportation of material through creep and subsurface water action. On unit seven, which is the alluvial toeslope, alluvial deposition processes occur, which comes from subsurface water movement. Units eight and nine are fluvial controlled where there is corrosion, slumping and falls in the wall channel on unit eight. On unit nine, there is transportation of material down-valley by subsurface water action (Gerrard, 1992; Chesworth 2008). Because Mua Hill is a hillslope, this landscape model helps in defining the distinct units on the slope.

3.7 Hillslope Processes

When studying hillslope flow processes, Dunne (1978) demonstrated that when rain drops reached the ground surface, they encountered a filter that determined the path by which hillslope runoff would reach a stream channel. The paths that the water took determined a lot of the landscape characteristics. Landscape characteristics in turn influence soil characteristics such as depth and texture.

3.7.1 Infiltration, subsurface flow and overland flow

Water enters the surface horizon of the soil through the process of infiltration. Slope is one of the factors that control infiltration. Infiltration is also strongly influenced by the structure and texture of the soil. Soils such as gravels and sands are more permeable than clays. Land use practices and vegetation cover also modify the soil's ability to absorb water (Selby, 1982).

Local variances in elevation influence the extent of the water that penetrates into the soil in each of the different topographical units. Infiltration rate decreases with increase in slope. Moreover, no surface is absolutely level because there will always be small rises and dips such as shallow depressions which hold water after a rainfall period. These differences in topography results to a change in soil because differences in relief results to variations in the local water penetration hence a different soil climate (Gerrard, 1992).

The infiltration factors such as rainfall characteristics of duration, intensity and drop size, soil characteristics of structure and texture, vegetation and land use influence the infiltration capacity of a soil. Infiltration capacity of a soil is the speed which the soil can take in water when it is in a specified condition. If rainfall intensity supersedes the infiltration capacity, water will build up on the surface of the soil and run downslope. If the water is absorbed first by the soil, it may be stored in it or it could move toward stream channels. If the soil is of uniform permeability and deep, the subsurface water moves vertically to the zone of saturation where it then moves to the nearest stream channel. When a rock or soil has a shallow depth, percolating water meets an obstructing horizon, water flows reach the stream channel much faster. On another part of the hillslope, vertical and horizontal percolation may cause the soil to become saturated throughout its depth (Dunne, 1978; Burt *et al*., 1990).

3.7.2 Weathering, erosion and transportation

According to Gerrard 1993, the balance of the production of soil from the bedrock and soil loss through erosion controls soil mass. There are thicker soils on hillslopes where erosion is not consistent in comparison to eroding zones. Soil will be thicker on landscapes when there is stability between soil production and the subsequent soil erosion.

3.7.2.1 Weathering

The circulation of water on the bedrock influences weathering activities. Where soils are thin, water flows rapidly because the pore space is insufficient to accommodate a lot of water and the weathering rates are consequentially slow. Only a thin soil cover develops because the soil is removed as soon as it weathers loose because the water transport processes are more rapid than weathering. This movement is weathering limited. However, when the speed of weathering is more rapid than the process of transport, a thicker soil cover develops and the movement is transport limited (Kirkby, 1972).

An examination of soils in the southern Alps of New Zealand that were weathering limited and transport limited demonstrated the precision of this analysis where two soil catenas were identified; one for weathering limited slopes and two for transport limited slopes. Soils on slopes that were weathering limited were very simple when paralleled to those on slopes that were transport-limited. Bare rock slopes were a good example of weathering limited slopes (Gerrard, 1993).

3.7.2.2 Erosion and transport on slopes

After material has been loosened from the hillslope bedrock through the process of weathering, it is transported downslope by transport processes. Overland flow on the slope surface or sub-sub-surface wash within the soil may occur in erosion and transport processes. The velocity and depth of overland flow increases downslope as more water is generated from the upper slopes. It is largely governed by such factors as the slope gradient (The longer and steeper the hillslopes are, the more the intensity of erosion), vegetation, and the soil resistivity to erosion, mainly influenced by the soil texture (Price, 1997; De Wit, 2001). Water flow may move sediments in solution form where minerals are transported after being dissolved in water, or they may be carried in suspension mode where light material that is of a fine nature is transported along in the water, or in saltation where small or large grained soils are rolled along the slope (Kirkby, 1972).

3.8 Theoretical Framework

This research has examined the Conacher and Darlymple framework of approach within which soil/ slope relations analysis was done in the hillslope of the Mua Hill. The concept explains surface and sub-surface processes (mobilization, transportation and re-deposition) in profiles of the soil in the context of a seven-geomorphic land surface model. Each one of the land-surface unit is a process-response subsystem where energy and mass (soil, water and gravity) pass from one geomorphic unit into the next. Every unit is equivalent to a process-response subsystem. The seven units are described in terms of characteristic processes rather than the processes that are dominant. Thus, the definitive processes in certain units do occur in combinations and intensities that are varying in almost every other unit.

The combinations and intensities of the processes in different parts of the slope profile are reflected in pedo-geomorphic and soil morphologic properties (Conacher & Dalrymple, 1977). Pedogenesis is put within a framework of total landscape development because processes that modify landscapes affect soils, and processes that influence soil have an effect on the landscape (Birkeland, 1999).

3.9 Conceptual Framework

Mua Hills is a hillslope with the hill being a chief organizer of the geomorphologic processes of weathering, erosion and deposition. Water is a chief agent in these processes and depending with the relative position of a slope section and the slope gradient, distinguishing geomorphic processes will be occurring and these processes will largely influence the soil physical properties of depth and texture (Gerrard, 1992). Figure 3.3 below describes the conceptual framework.

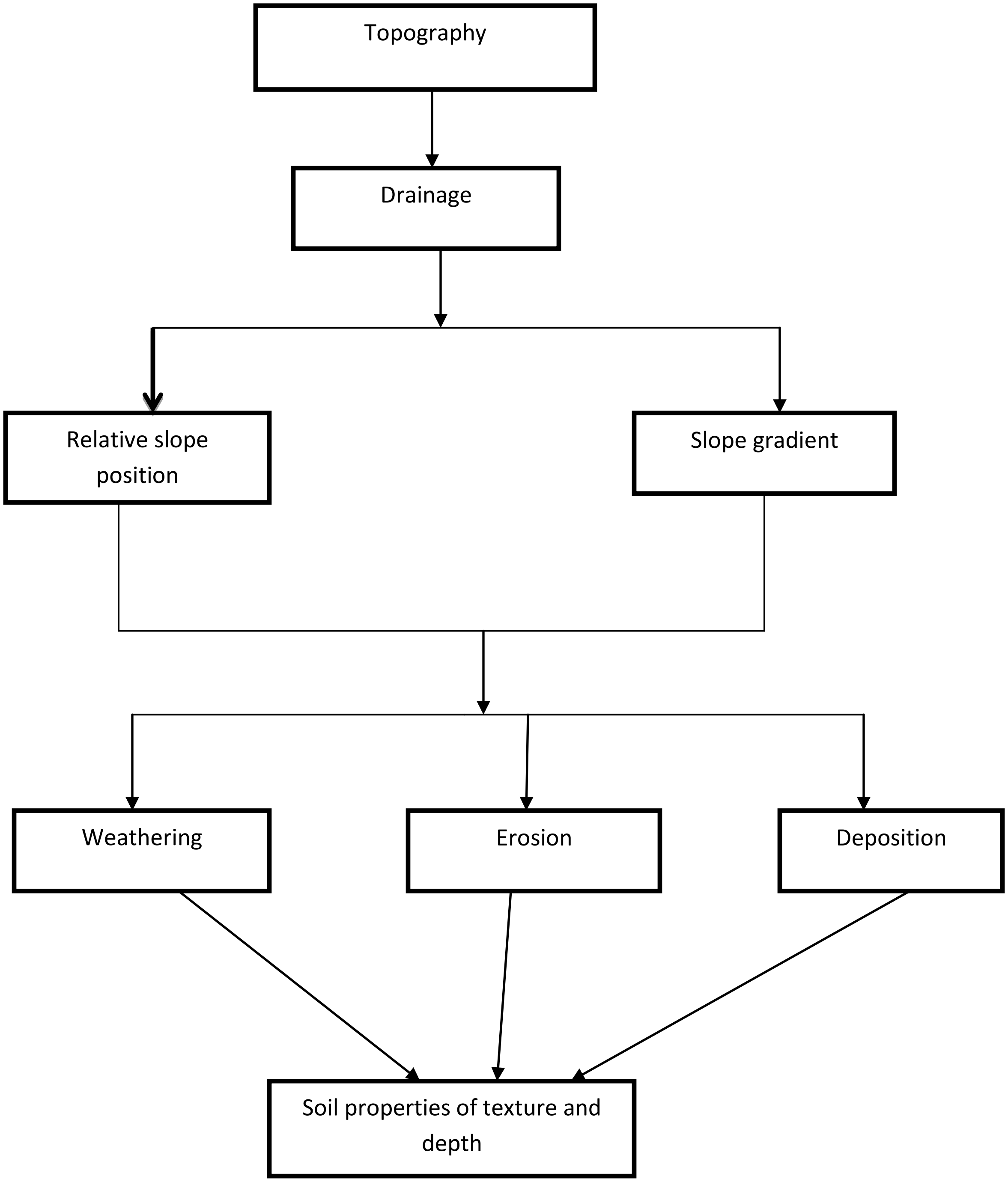

Figure 3.2: Conceptual framework

Source: Researcher, 2019

CHAPTER FOUR

STUDY METHODOLOGY

4.0 Introduction

This section deals with the methodology taken on during the study. The chapter focuses on the data sampling techniques and the methods used for collecting data and its analysis.

4.1 Data Types and sources

The study used primary data to meet the stipulated study objective of investigating the distribution of the properties of soil in relation to the relative slope positioning. The primary data on soil depth and soil textures was collected directly from the field from each of the identified geomorphic units. The relative slope position was referenced using a global positioning system (GPS), soil depth was measured using a measuring tape and the samples of soil were collected using a soil auger for soil texture analysis. GIS was used to generate the Mua Hills soil map, the maps on land use and land cover of the study area and a digital elevation model of the Mua hills. Soil maps were used to obtain data on soil type while maps on land use and land cover helped to gather information on land-use. The digital elevation model facilitated in the depiction of the topography of Mua Hills.

4.2 Data Sampling Techniques

Stratified sampling was employed for this study whereby the Mua Hills was first divided into seven geomorphic units of summit, shoulder, backslope, transportational slope, footslope, toeslope and the river channel. This sampling technique was used because each of these geomorphic units undergoes distinct geomorphic processes based on their location on the slope profile that consequently has the likelihood of influencing soil properties. Thus, the geomorphic units first needed to be identified so as to relate soil properties with the identified geomorphic segments. This method improved the representativeness of the results and helped towards achieving the objective of relating soil properties with slope position.

Purposive sampling was subsequently used to collect data on the seven geomorphic units whereby data was taken on the highest point on a geomorphic unit and also whenever a change in slope curvature or soil color was noted on a geomorphic unit.

4.3 Data Collection

Soil depth was measured using a measuring tape as shown in Plate 4.1 while soil samples to test soil texture were collected using a soil auger as indicated in Plate 4.2. The collected soil samples were put in bags as shown in plate 4.3 for ex situ soil texture laboratory analysis. Georeferencing of the relative slope positioning was done using a global positioning system (GPS).

4.3.1 Data Collection Instruments

1. Global positioning system (GPS) - This helped to geo-reference sampled points in terms of altitude and location.
2. Soil auger- This was used for the purpose of scooping soil at the sampling points.
3. Measuring tape- A tape was used to measure soil depth.
4. Sampling bags-Bags were used to pack collected soil samples for particle size analysis in an ex-situ laboratory.
5. Notebook-A notebook was used to record field events such as measured soil depth.
6. Pen- A pen was used to note down field events.

4.3.2 Sampling Frame and Sample Size

Based on the landscape dimensions of the Mua Hills, seven geomorphic units were identified because they were observed to fit in with the Conacher and Dalrymple land surface model delineation (Gerald, 1992), which was the basis for this sampling frame. These geomorphic units were summit, shoulder, backslope, transportational slope, footslope, toeslope and the river channel. Dividing of the hillslope into the seven geomorphic segments was guided by the slope breaks observed on the hill. Twenty points were then selected from the seven geomorphic units. Data was taken on the highest point on each geomorphic unit and also when a change in slope curvature or a change in soil color was noted on a geomorphic unit. Thus the total sampled units were twenty. The slope breaks in a geomorphic unit are from the fact that a land surface may have small rises and dips such as shallow depressions which hold water after a rainfall period thus affecting the soil moisture and this may consequently influence the soil properties on the particular site.

4.3.3 Sampling Procedure

The Mua Hills was divided into seven distinct geomorphic units based on slope form from field observations. The sampling procedure was guided by the concept of Conacher and Dalrymple's land-surface model for analyzing landscapes (Gerrard, 1992). The seven geomorphic units were chosen from three varying landscape locations. The varying locations were chosen so as to realize the study objectives of capturing slope positions of the summit, shoulder, backslope, transportation slope, footslope, toeslope and the channel with their varying soil distributions. The reason that led to choosing the three varying landscape locations was because Mua Hills was not a simple hill with only one straight profile from top to bottom rather it was rugged with a compound profile constituting of several slope breaks and the geomorphic units that were to be studied were in the different slope breaks as shown in Figure 4.1. Notwithstanding that the seven geomorphic units were sampled from three different locations, to note is that the underlying concept was the relatively similar geomorphic processes such as vertical water movement, lateral water movement, surface run-off and deposition that occurred on similar geomorphic units irrespective of their spatial location. The uniting factor of the three sample locations was the geomorphic processes that were happening on those segments that led the sections to be instituted into one of the seven geomorphic units.

The three landscape units that formed the basis for the sampling were:

(i) A relatively undisturbed land surface

(ii) A river bed area

(iii) A road cut area

A relatively undisturbed area was chosen as a point of orientation for the choosing of the geomorphic units from the upper slopes of the summit to the middle slope of the transportational zone on slope profile A. It was selected for the reason that it was on a relatively undisturbed and relatively flat surface area of the slope with no major breaks on the slope as shown in Figure 4.2 thus forming the basis for which geomorphic units were identified on this particular slope area.

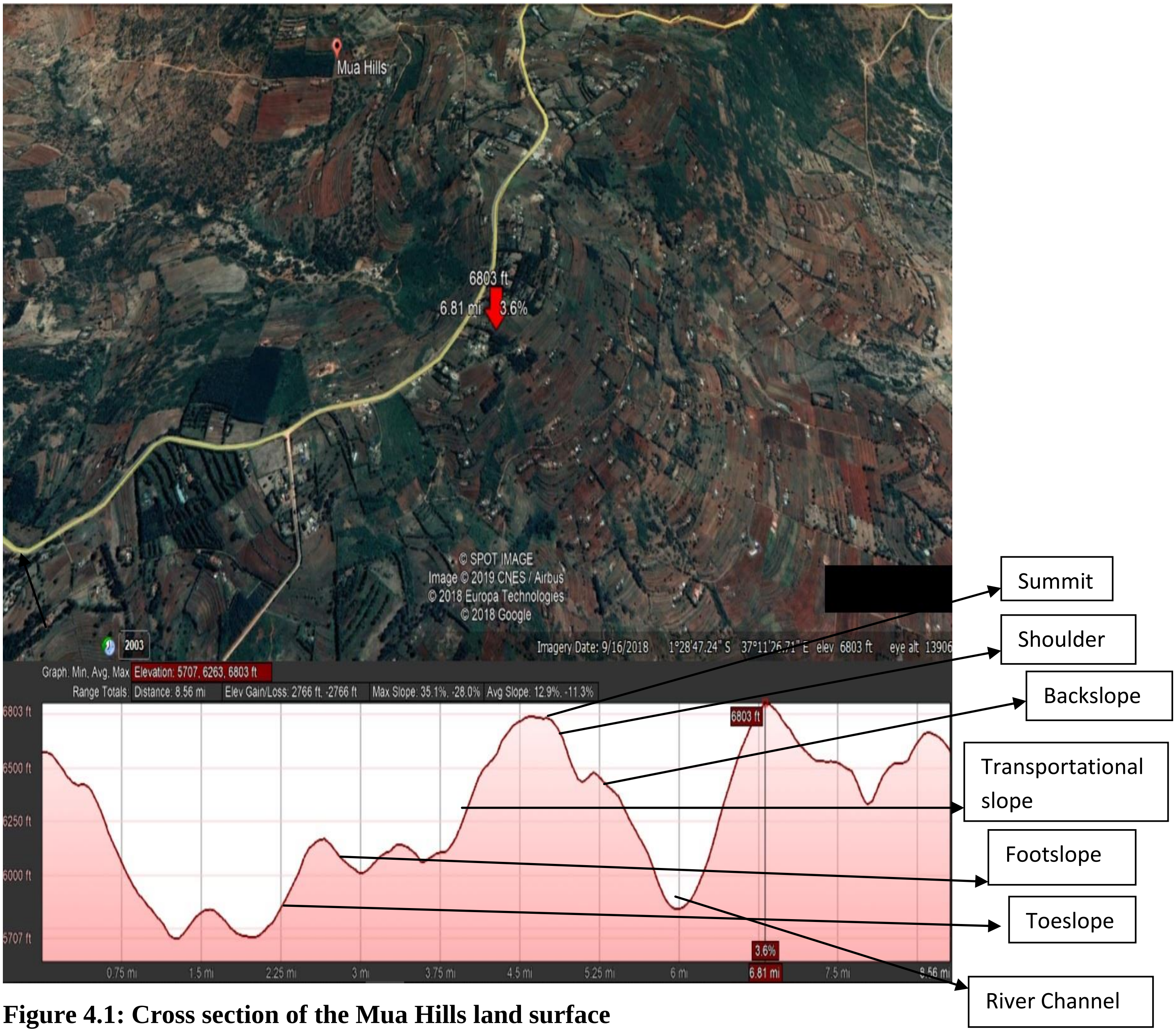

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Figure 4.1: Cross section of the Mua Hills land surface

Source: Google Maps 2018

The river bed landscape unit as indicated in Figure 4.3 was chosen so that it could represent the toe slope and river channel geomorphic units that were not present in the first profile (profile A) while the road cut area shown as Figure 4.4 was selected because it was adequate for the purposes of measuring soil depth because of the presence of a road cut that exposed Horizon C, (the point of unweathered bedrock) the point at which the effective soil depth was to be taken. It represented geomorphic units of the shoulder, backslope, transportational, footslope and toeslope slope units.

Twenty slope sampling points were then selected on the geomorphic units. The procedure of choosing the twenty points was that the highest point on a geomorphic transect was first chosen for data sampling and secondly, sampling was done whenever any change on slope curvature was observed as well as when changes in soil color were noted on a geomorphic unit. This was to ensure representativeness of all possible soil property differencies on a slope segment.

Figures 4.2, 4.3 and 4.4 show the relative slope positions from which soil data was collected. The sampling points represent the slope positions out of which soil property data was sampled.

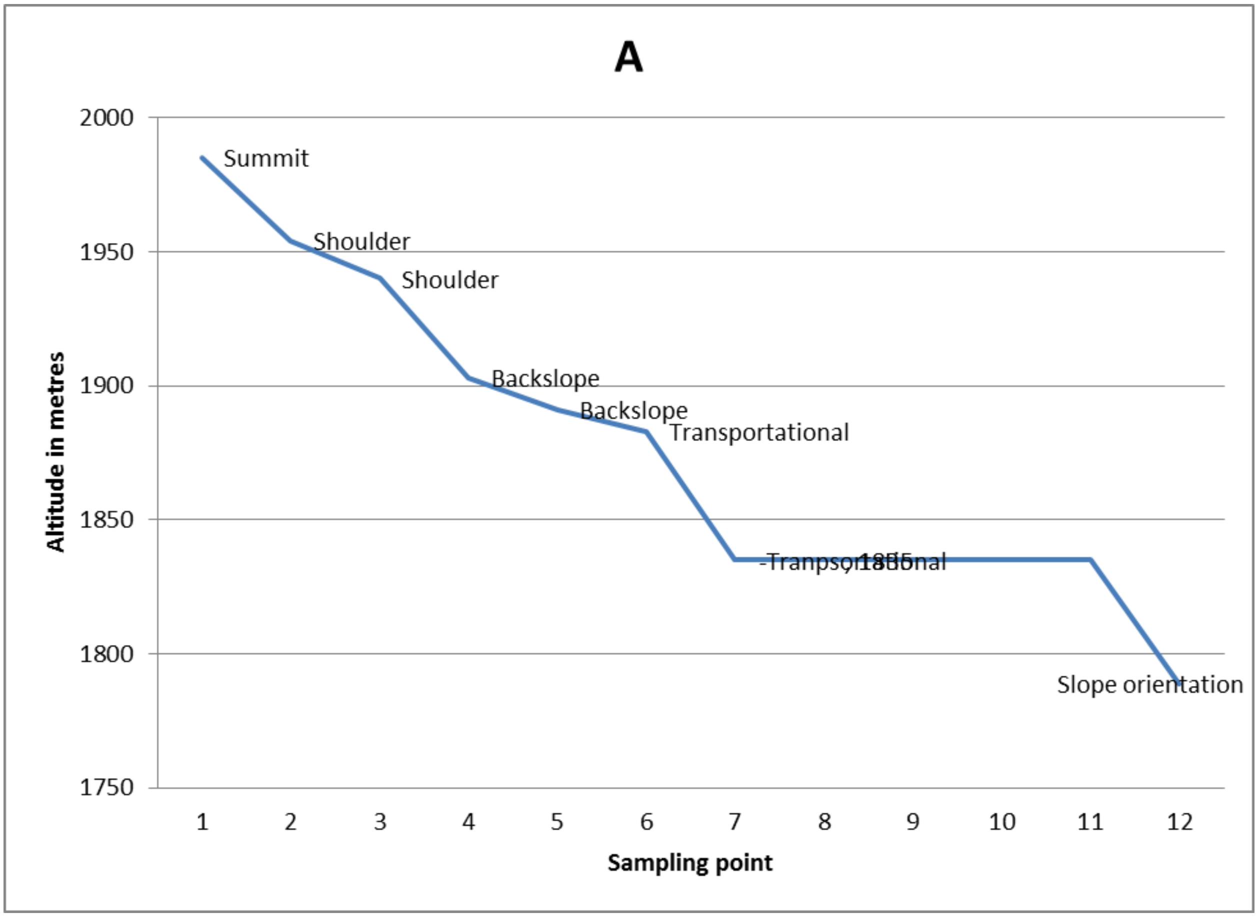


Figure 4.2: Slope positions on profile A –Relatively undisturbed landscape

Source: Researcher, 2019

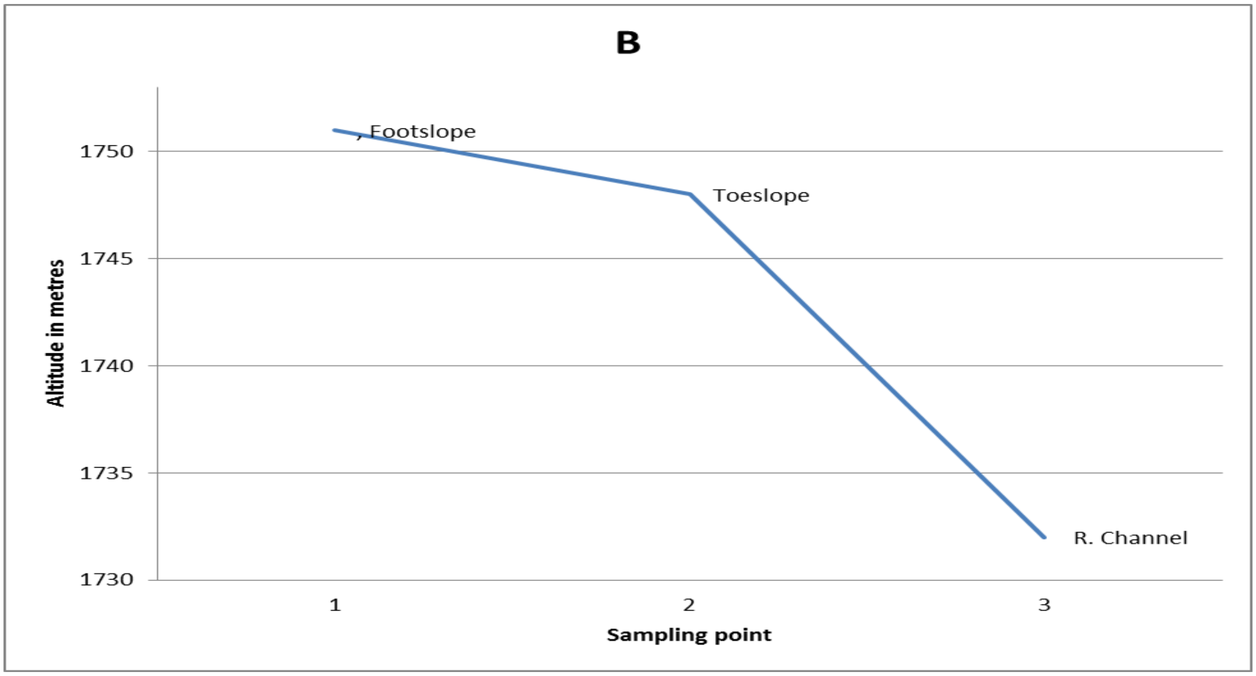


Figure 4.3: Slope positions on profile B-The River bed

Source: Researcher, 2019

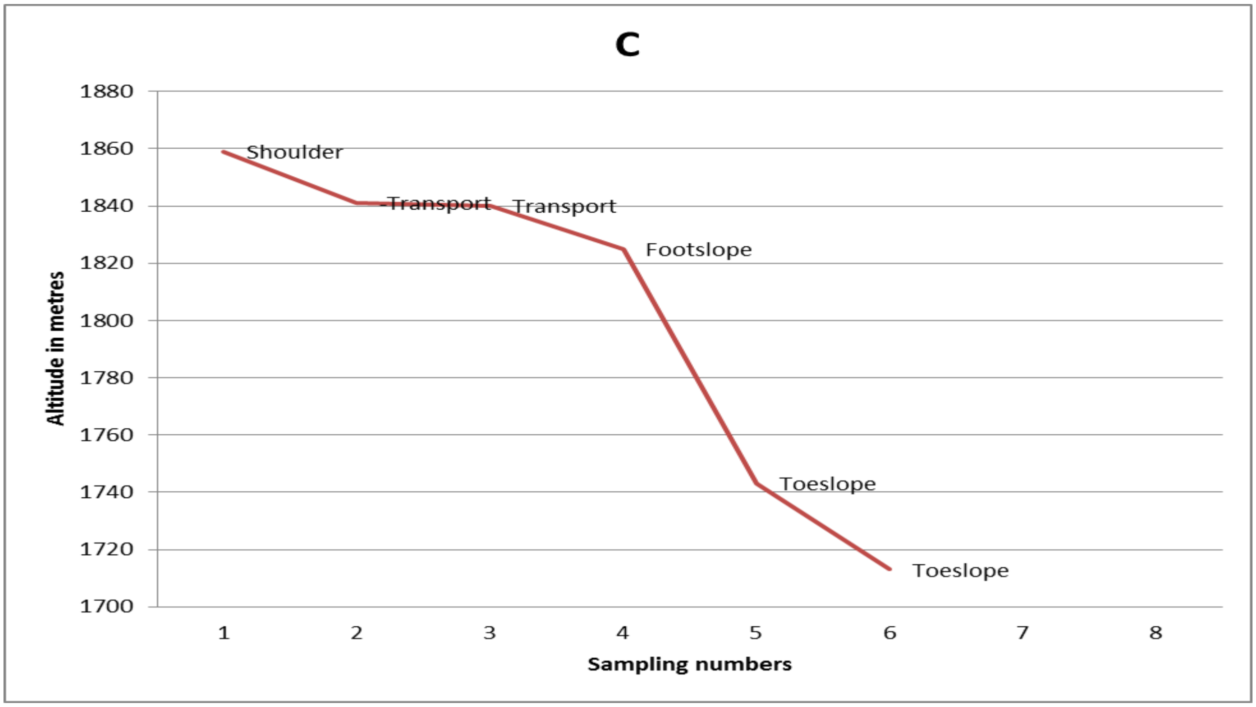


Figure 4.4: Slope positions on profile C- Road cut slope

Source: Researcher, 2019

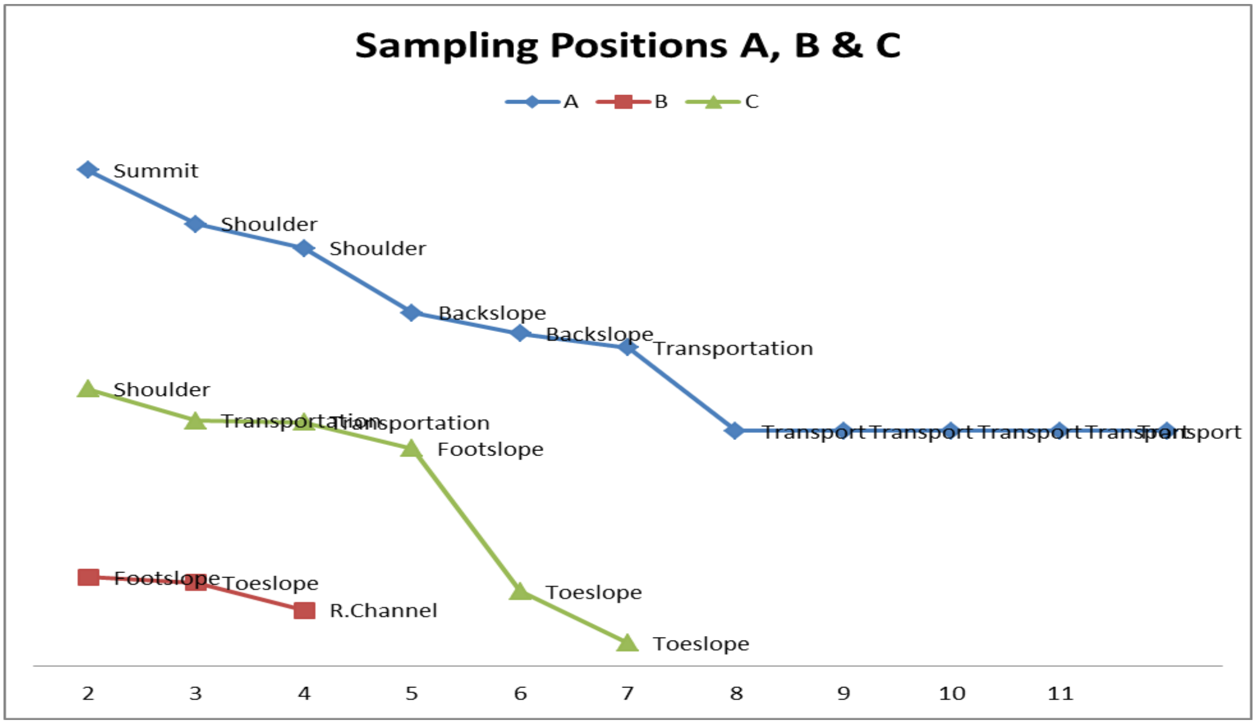


Figure 4.5: Slope profiles at each of the three sampling points

Source: Researcher, 2019

Figure 4.5 shows the overall slopes that were studied. Twenty points were sampled in total where soil depth measurements were taken and soil samples collected to test the soil texture. The sampled points on the graph characterize the seven geomorphic units as illustrated subsection 4.3.3.1.

4.3.3.1 Identifying geomorphic units

This step was aimed at identifying the geomorphic units to sample. Based on the slope breaks in the study area, seven geomorphic units were chosen based on their relative location on the hillslope.

The slope forms (referred here as geomorphic units) identified in this chapter are exemplified on figure 4.1. A schematic cross section of the slope breaks in figure 4.5 which shows the geomorphic units that were identified and studied.

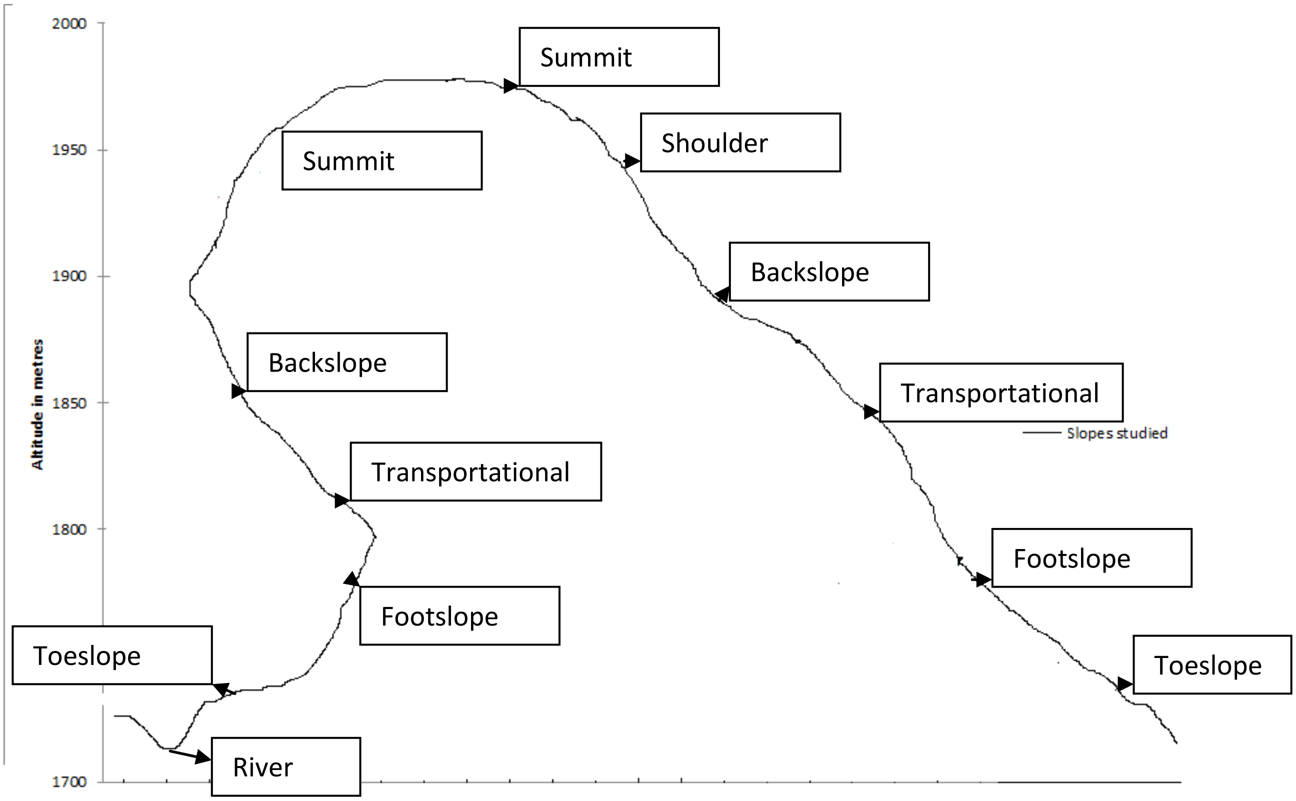


Figure 4.6: Schematic cross section of the Mua Hills study area, displaying the hillslope units and their position in the hill.

Source: Researcher, 2019

a). Summit- Summit sampling was done on altitude 1985m, which was georeferenced at easting (E) 37.17167; southing (S) 1.514444. The summit was at the highest altitude sampled and it was relatively flat. Its flat form facilitated processes related to vertical water movement on this geomorphic unit.

b). Shoulder- The shoulder was a fairly gentle slope and this slope form of slight convexity facilitated geomorphic processes of lateral and subsurface water movement. The shoulder sampling was done at three points. Two points were taken on slope profile A because of distinguishing slope breaks as a result of a change in slope curvature on that shoulder segment that necessitated sampling of both of the points to determine if the soil properties were affected by the micro change in slope. The third shoulder sampling point was taken at slope profile C. The sampled points were:

Altitude 1859m-E37.1655; S 1.52101

Altitude 1954m- E37.17786; S 1.51431

Altitude 1940m E37.17852; S 1.5151

c). Back slope- The backslope was steeply inclined and because of this slope form, processes related to rapid surface and subsurface water action dominated.

The backslope was sampled at two points. Just like the shoulder segment, this was dictated by the presence of micro slope breaks because of a change in slope curvature in the identified backslope unit. The sampled points were:
Altitude 1903m-E 37.17981; S 1.5165

Altitude 1891m E 37.1801; S 1.5169

d). Transportational Zone – The transportational zone was steeply inclined and this led to processes related to this slope form of rapid surface and subsurface action of water and movement of material by mass movement through creep and flows.

The transportational segment was sampled at eight locations. Five of the samples were taken at slope profile A on altitude 1835m. This was because distinct soil color variations were noted on this slope position despite the soils lying on the same elevation of altitude 1835m. It was therefore important to check if the color differences translated to different soil textures which necessitated having a horizontal sampling of the soils where each of the soil color variation had been noted. The other sampling point on this slope profile A was chosen because there were observed micro slope breaks on this geomorphic unit hence the need to see if the soil properties materially varied. Two sampling points were also taken into account on slope profile B because of observed micro slope breaks hence the need to investigate if the soil properties were different on those points. The sampled slopes were thus referenced;
Altitude 1883m E 37.18047; S 1.51717
Altitude 1840m E 37.1878; S 1.52201

Altitude 1841m E 37.16773; S 1.52135

Altitude 1835m E 37.18181; S 1.51911 Sampled five different soil types on the same slope but having horizontal variations.

e). Footslope- The footslope was gently sloping and this slope form facilitated geomorphic processes of re-deposition of material by surface wash and transportation of material through creep and subsurface water action.

Two sampling points were taken from slope profiles B and C.

Altitude 1825m E 37.16998; S 1.52228

Altitude 1751m E 37.17876; S 1.52249

f). Toeslope- The toeslope was flat to gently sloping which led to alluvial deposition processes on this slope unit.

The toeslope sampling was done on three points. Two of the points were taken on slope profile C. The two points were chosen because notable micro slope breaks were observed hence it was important to investigate if the soil properties also varied. The remaining sampling point was taken on slope profile B.

Altitude 1748m E 37.17906; S 1.52273

Altitude 1743m E 37.17432; S 1.53

Altitude 1713m E 37.17545; S 1.53478

g). River Channel

The river channel was on a relatively gentle landscape where periodic aggradation and corrosion was dominant.

The channel was located on Altitude 1732m E 37.17944; S 1.52343

4.3.3.2 Soil depth measuring

For soil depth analysis, actual field measurements were taken using a measuring tape as shown in Plate 4.1. Actual measurements were taken on eleven slope points where soil horizon C was visible on the surface. Horizon C (the point of unweathered bedrock) was the point at which the effective soil depth measurement was taken. Soil depth was not taken at nine sampling points because the Horizon C was not visible on the surface because these slope points had deeply weathered soils with only the solum (Horizon A and B) being visible on the surface.

4.3.3.3 Collection of soil samples

For soil texture sampling, a hole was dug to a depth of 15cm-30cm using a soil auger on each of the twenty sample points as indicated in Plate 4.2. The augered soil samples were then taken from the soil auger, put in bags and labelled for ex situ laboratory soil texture testing as shown in Plates 4.3 & 4.4.

Plate 4.1: Researcher measuring slope depth on a backslope

Source: Researcher, 2019

Plate 4.2: Researcher soil augering a soil sample

Source: Researcher, 2019

Plate 4.3: Bagged soil samples

Source: Researcher, 2019

Light colored soil at altitude 1859m on an upper slope

Dark colored soil on the lower slope at altitude 1713m

Plate 4.4: Soil samples as collected from the field

Source: Researcher, 2019

4.4 Data Processing

Soil depth data was tabulated on a table to give useful relationships of slope position and soil depth while soil samples were processed at the University of Nairobi's soil mechanics laboratory for soil texture identification.

4.4.1 Soil Depth

Soil depth measurements taken from the field were tabulated on a table format in relation to the relative slope position for all of the sampled twenty locations so that the relationship between soil depth and relative slope position could be established.

4.4.2 Soil Texture

Soil samples collected from the field were processed at the University of Nairobi's soil mechanics laboratory using the particle size evaluation process to identify different soil textures of clay, silt, sand and gravel. This particle-size evaluation laboratory process involved complete detachment of the soil material into its individual particles to determine different grain sizes contained within the soil. The dry sieving and the hydrometer methods were used for this procedure and are briefly explained in subsections 4.4.2.1 & 4.4.2.2.

4.4.2.1 Dry Sieving Method

This was a quantitative method for the establishment of the particle size distribution in the soil from the coarsest particle size of diameter 20mm down to the fine size of 0.075mm. Particle sizes less than 0.075mm in diameter were tested using the hydrometer method.

The equipments used included: Set of sieves, sieve shaker, trays, trowel, small dishes, balance, cleaning brush.

4.4.2.1.1Test Procedure

The twenty soil samples were first put in labelled trays and placed in the oven to dry for 24 hours. Oven drying removed plasticity in the soil and ensured that the soil material detached into its individual grain sizes of clay, silt, sand and gravel. After removing the soil samples from the oven, the soil from each sample tray was divided into four quarters and 200 grams from each soil sample was scooped using a trowel, weighed and put aside in a small dish for the dry sieving procedure as shown in Plate 4.5. The reason for the dividing of the soil into four quarters was to ensure that each section of the soil was represented when scooping the 200gms. The remainder of the soil was put aside for the hydrometer soil particle size procedure.

In addition, water was added to the 200gms of soil such that the soil in the small dish was soaked in readiness for the soil washing procedure as indicated in Plate 4.6. The soil was then put in a large basin and put through the process of washing. After washing, the soil solution was passed through a 0.075mm diameter size sieve such that the soil sediments that had grain sizes smaller than 0.075mm were washed down the drain and only the particles larger than the sieve size were retained. (To account for the washed down sediments, the hydrometer particle size analysis was used to measure the very fine particles that passed through the 0.075mm sieve). Clear water at the end of the washing process was the mark that all suspended sediments had passed through the 0.075mm sieve. The retained soil sediments (particles that did not pass through the sieve) were then put in a dish, labelled, and put back in the soil oven for an additional 24 hours to dry.

Plate 4.5: Researcher measuring soil samples

Source: **Researcher, 2019**

Plate 4.6: Wetting soil samples in preparation for soil washing

Source: Researcher, 2019

After drying, the sediments were passed through nine sieves of sizes 10mm in diameter to the smallest size of 0.075mm by shaking and agitating the sieves. This was done by first passing the soil grains through the sieve with the largest pore size of 10mm. Particle sizes that were retained on the sieve because they were too large to pass through the sieve were put aside and their mass weighed and recorded. The soil grains that passed through the sieve (indicating that the grains were smaller than the sieve pores) were passed through the next largest sieve. This procedure was repeated to the finest sieve of 0.075mm. This is the method of elimination among sieves to categorize the soil grains into different particle sizes of gravel, sand, silt and clay for soil texture analysis.

4.4.2.2 Hydrometer Method

This method covered the quantitative determination of the distribution of finer sized particles in the soil sample of less than 0.075mm in diameter. It was used to measure the relative density of soil solution for soil textures of clays and silts that were too small for sieve analysis.

The equipments used were: Hydrometer, sedimentation cylinder, mixer, beaker, timing device, thermometer, balance, sodium hexametaphospate, sodium carbonate.

4.4.2.2.1Test Procedure:

The remainder of the soil that had been oven dried and set aside (As per the dry sieving procedure explained earlier in this report) was put through the fine sieve of 0.075 mm. 50 grams from each soil sample that passed through the sieve was weighed, put in a small dish and labelled. Each of the soil samples was then mixed with 950ml of water to form a solution. 33g of sodium hexametaphospate and 7g of sodium carbonate were dissolved in one litre of distilled water. This solution acted as a dispersing agent that helped to improve the separation of soil particles and for the purposes of preventing settling or clumping of the soil solution.

In a cylinder, 50 ml of sodium hexametaphospate and sodium carbonate solution was mixed with 950 ml of soil solution to a uniform consistency until all the sediments were suspended in the solution. This was repeated for each of the twenty soil samples as shown in Plate 4.7. A hydrometer was then inserted into each of the solution and readings taken and recorded at ½, 1, 2, 4, 8, 15, 30, 60,120, 240 and 480 minute intervals as demonstrated in Plate 4.8.

Plate 4.7: Soil solutions ready for hydrometer particle size analysis

Source: Researcher, 2019

Plate 4.8: Researcher performing hydrometer particle size test at the soil mechanics laboratory

Source: Researcher, 2019

4.5 Data Analysis

Data analysis sought to describe the relations between the soil properties of depth and texture and the relative slope. Soil depth field measurements were plotted on a bar graph to depict relationships between soil depth and relative slope position as shown in Figure 5.3 and having performed dry sieve and hydrometer analysis for grain size differentiation, the soil texture results were plotted on a grading curve to show relationships with the relative slope position.

4.5.1 Sieve Analysis:

Sieve analysis was the technique used to evaluate the soil grain composition on sampled soil specimens for soil grains larger or equal to 0.075mm in diameter. The procedure was such that soil sediments that remained on each sieve were weighed and the mass recorded as indicated in Plates 4.9 & 4.10. The retained soil mass was converted into percentile by dividing the mass that remained on every sieve with the sample mass that was previously on the sieve. From this calculation, the percentage cumulative retained was obtained by adding each weight to the sum of the preceding weights. The percent passing was then calculated by beginning with 100 and taking away the percent that remained on every sieve in a cumulative way. A graph of grain size vs. percent passing was then made. This was used to deduce the soil texture of the sampled soils.

Plate 4.9: Set of sieves

Source: Researcher, 2019

Plate 4.10: Researcher performing dry sieve particle analysis

Source: Researcher, 2019

4.5.2 Hydrometer Analysis:

The hydrometer analysis was used to analyze the soil grains that were less than 0.075mm in diameter. The analysis is based on the law of Stokes and basing on this formula, the speed at which sediments settle after being in suspension, with other factors being constant hinges on the size, shape and weight of the sediment (Clifton *et al*., 1999).

The soil particles are assumed to be spherical and to have the same specific gravity of 2.62 and therefore in this soil water suspension analysis, the coarser particles settled more quickly than the finer ones.

In this analysis, the following was known:

a).Specific gravity G_S was 2.62- The soils under analysis were assumed to have this specific gravity.

b).Room temperature was 20^{o}c

c). HR was obtained from the hydrometer chart

d). R_w was 1.0

e). R_{h1} was the hydrometer reading

f).R_h=R_{h1}+meniscus correction

g). W_b-Weight of dry soil.

h). L= (R_h-R_w)

i). D-Diameter of soil particle in mm

j). T-Time in minutes

k). K-Settling velocity of sinking of a spherical particle (Clifton *et al.*, 1999).

After hydrometer meter readings ($R_{h1)}$ were taken at ½, 1, 2, 4, 8, 15, 30, 60,120, 240 and 480 minute intervals and recorded on a table format, the meniscus correction of 0.5 was added to the hydrometer readings to obtain R_h. R_h=R_{h1}+ meniscus correction. The reason for adding the meniscus correction was because observed hydrometer readings are always less than the true one because of the addition of the dispersing agent that increases the density of the solution, hence the inclusion of the meniscus correction. R_h was then used to obtain HR from a given hydrometer chart. HR was used to obtain the diameter in mm shown in Equation 4.2 of each sample size from which the settling velocity K shown in Equation 4.1 was obtained at each time interval. This was used to plot a graph for the finer textured grain particles of clays and silts.

$$k = \frac{Gs*(Rh-Rw)*100\%}{Gs-1*Wb} \qquad \text{……………………………………………………..Equation 4.1}$$

$$D = K\,\frac{\sqrt{L}}{t} \qquad \text{……………………………………………………Equation 4.2}$$

Source: Clifton *et al.*, 1999.

4.5.3 Geographical Information Systems

GIS is the platform where remotely sensed information of soil maps, digital elevation maps (DEMS), and land use cover maps were processed, analyzed, and the information applied to understand patterns and relationships. Land surface is represented by (DEMs). GIS allows the layering of multiple layers on a single map (Badura & Przybylski 2005).

4.6 Hypothesis Testing

The hypothesis tested in this study was to show if there was an association between soil properties and their relative slope positioning on the hill profile. It sought to test if soil depth and soil texture had differences along the slope profile and if the difference was as a result of their relative positioning on the slope.
Kruskal Wallis H test non parametric statistical method tested the soil texture premise that there was no variation in soil texture with change in relative slope position as indicated in Equation 4.3. Kruskal Wallis H test was applied for the following reasons:

1. The assumption that the data was not normally distributed since purposive sampling method was used and data at collected sample points had the possibility of being markedly different.
2. There was more than one independent group. In this case they were four independent groups.
3. The sample size n of 20 allowed for this test to be performed.

$$H = \left(\frac{12}{N(N+1)} * \Sigma\frac{{T_C}^2}{N_C}\right) - 3 * (N+1)$$ ……………………………………Equation 4.3

Where;

N= Number of samples

T_C =Total rank for each group

$N_{C=}$ Number of participants in each group

Paired t-test tested the soil depth premise that there was no variation in soil depth with change in slope as shown by Equation 4.4. This test statistic was used for the following reasons.

1. The mean for two related group of samples (soil depth and slope) was being compared.

2. The dependent variable (soil depth) was continuous.

$$t = \frac{\bar{x}_{diff} - 0}{S_{\bar{x}}}$$ ……………………………………………………………………Equation 4.4

$$s_{\bar{x}} = \frac{s_{diff}}{\sqrt{n}}$$

Where

$\bar{x}_{diff}$ =the sample mean of the differences

n =the sample size

S_{diff} = the sample standard deviation of the differences

$s_{\bar{x}}$ = Estimated standard error of the mean

Source: (MacFarland and Yates, 2016)

CHAPTER FIVE

RESULTS AND DISCUSSION

5.0 Introduction

This section is a discussion of the results in relation to the study objective of assessing changes in soil properties with change in slope. This study examined soil depth and soil texture relationship with the slope on twenty sample points along the Mua Hills. The results obtained from the field and laboratory analysis are presented in this chapter to in conformity to the stated specific objectives of the study.

5.1 Soil Depth

To meet the requirements of the first objective of the study that sought to determine the relationship between soil depth and slope, soil depth measurements were taken on 11 georeferenced sample points on different slopes using a measuring tape. The depth of the soil was based on soil formation and the point of measuring the depth was on soil horizon C, the horizon of unweathered bedrock. Soil depth was not taken on nine sample points as horizon C was not visible on the surface or sub-surface. Despite this shortcoming, a relationship was determined using the 11 measured sample points.

Table 5.1:: Soil depth field measurements

Point	Altitude in metres	Slope Position	Depth In cm
1	1985	Summit	Not taken
2	1954	Shoulder	91
3	1940	Shoulder	Not taken
4	1903	Backslope	Not taken
5	1891	Backslope	Not taken
6	1883	Transportation	Not taken
7	1859	Shoulder	40
8	1841	Transportation	30
9	1840	Transportation	15
10	1835	Transportation	213
11	1835	Transportation	213
12	1835	Transportation	213

13	1835	Transportation	213
14	1835	Transportation	213
15	1825	Footslope	86
16	1751	Footslope	Not taken
17	1748	Toeslope	Not taken
18	1743	Toeslope	244
19	1732	River Channel	Not taken
20	1713	Toeslope	Not taken

Source: Researcher, 2019

Table 5.1 shows results that indicate that thick soils were on the upper and lower grounds while soil profiles with thin soil depth were on the middle slopes. The soil thickness ranged from 15cm on the middle slope which was a transportation zone and the thickest soils were on the toeslope on the lower grounds, with a soil depth of 244cm. This conforms to the expected geomorphological processes because as per Kirkby, (1972) and Gerrard, (1993), soil depth is depicted by a balance between weathering and erosion where soil mass is governed by the balance of production of the soil from bedrock and soil loss through erosion. The soils on the middle slopes were on steep slopes that facilitated washing down of the soils and the washed down soil concentrated on the lower grounds. Additionally, the lower grounds had more soils because of in-situ soil weathering. This is consistent with a study done by Birkeland, (1974) on southern California soils that showed that lower slopes had more weathering activities taking place because of the presence of more moisture that was received from the upslope soils through lateral water movement at the surface or within the soil.

Sampling was done on five horizontal sample points on altitude 1835m, a transportational geomorphic transect. The soil depth was therefore the same on the slope points. However, the soil depth measurement recorded did not fit in with the soil depth trend of this research finding that conformed to the known geomorphic processes of middle slopes having shallow soil depths in comparison to lower slopes that had thick soil depths. This is because this geomorphic unit was in the middle slope and thus expected to have shallow soil depths. Further investigation revealed that this slope location had observed sink holes as shown in Plates 5.12 and 5.13 and this was attributed to underground water action occurring on this section. Increased water enabled moisture conditions conducive to more weathering that facilitated an increase in the soil depth. According to Tesfa *et al.*, 2009, increased infiltration and presence of moisture in soils encouraged greater soil depth.

A graphical presentation of the soil depths along the Mua Hills slope is shown on figure 5.1 below. Soil depth is moderately deep on the shoulder slope segment at 91cm, and then gradually decreases towards the transportation unit to 30cm and 15cm. As mentioned above, the soil depth on altitude 1835m (213cm), a transportational unit does not conform to the observed trend of soil depth because of underground water channels that facilitated moisture conditions facilitating deeper soil depth. From the transportation slope, soil depth gradually rises on the footslope at 86cm and the soil depth is thickest on the lower slope section of the toeslope at 244cm. The transition from soil-mantled slopes on the shoulder to thin soils on the transportational units marked a shift from the transport limited slopes characterized by a continuous mantle of soil, to hillslopes that were weathering limited with shallow soil depth.

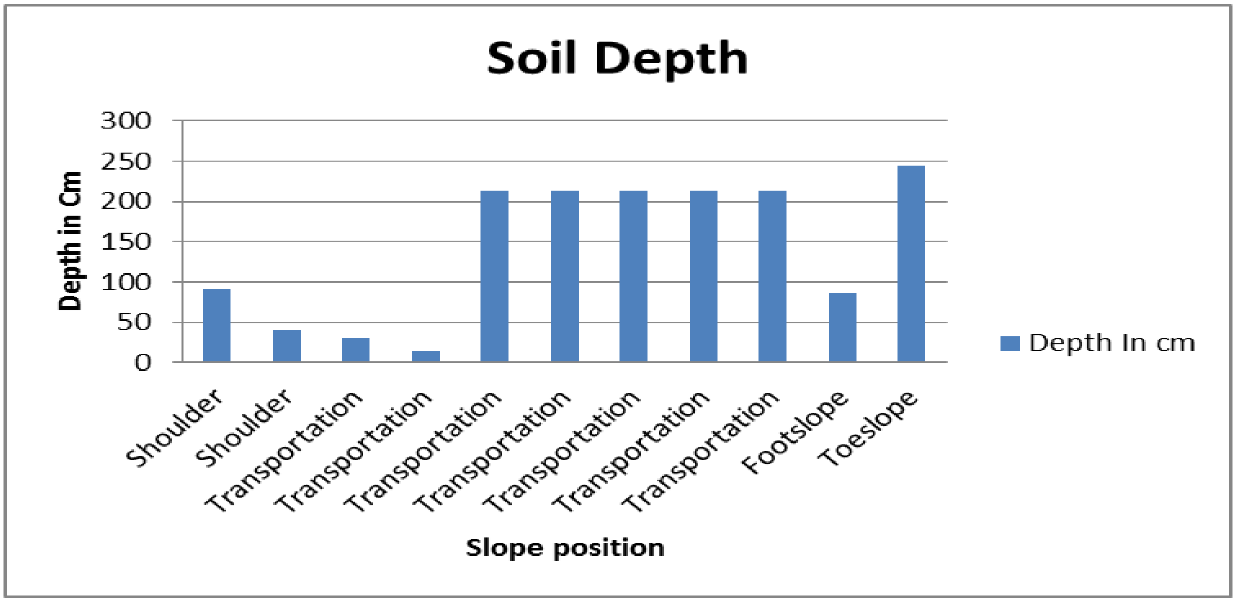


Figure 5.1: Soil Depth field measurement

Source: Researcher, 2019

5.1.1 Summit

The summit had deeply weathered horizon A and B soil profiles such that horizon C could not be viewed on the surface as the solum soils (Horizon A and B) ran deep into the subsurface. The solum soils went beyond a depth of 100cm as shown by a measuring tape placed on the surface at beyond 100cm of horizon A and B as indicated in Plate 5.1. The soil depth was thus not taken on this slope unit. The deeply weathered soil profile was connected to deep weathering because of geomorphological processes associated with vertical water movement. Gerrard, (1992) using the Conacher and Dalrymple's land surface model explained the vertical water movement on a summit was as a result of the summit being relatively flat and therefore water movements were conducted downwards. Vertical water movement ensured availability of moisture at the surface and sub-surface of the soil and moisture is one of the factors that facilitated weathering activities thus enhancing soil depth (Kirkby, 1972; Gerrard, 1992).

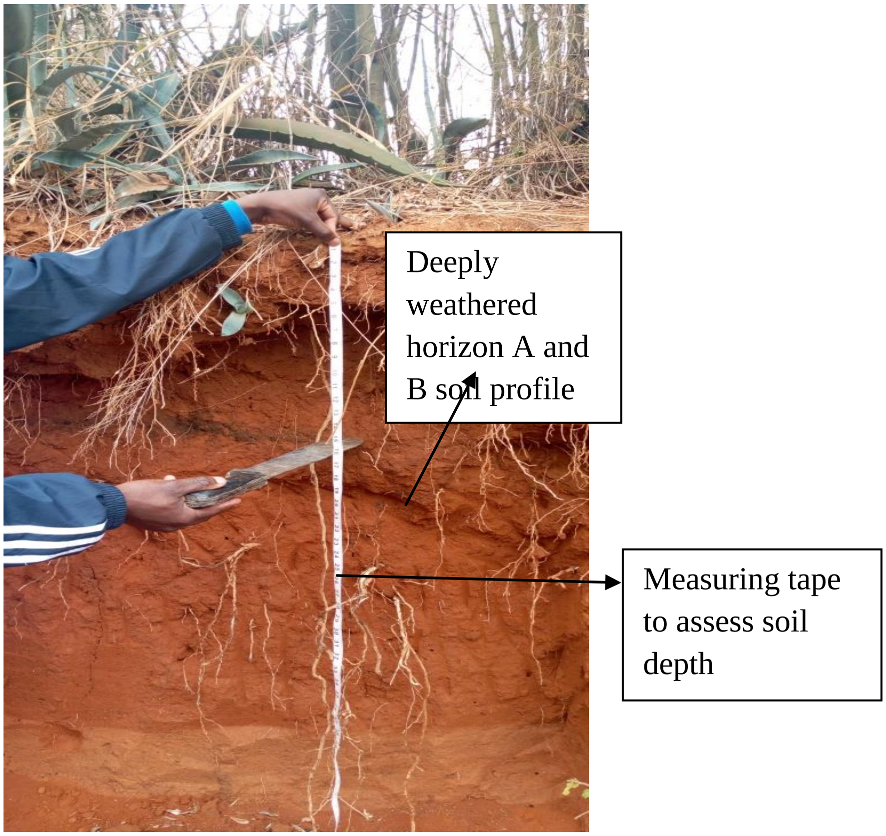


Plate 5.1:Deeply weathered soil profile at the summit

Source: Researcher, 2019

Since soil depth is a function of weathering and erosion, vegetation that mitigates soil erosion might have contributed to ensuring thick soil depth on the summit. As shown on plate 5.2, the summit was vegetated. Montgomery (2000) observed that vegetation was closely involved in actively moderating the landscape though the production and transport of soils and regulating the efficacy with which geomorphic processes eroded and transported sediment as vegetation largely offset the effects on erosion. On this vegetated summit, the topography was also modified by way of digging terraces to break the slope as shown in Plate 5.2. Breaking of the slope by terracing effectively enhanced soil depth by mitigating soil erosion that carried away soil.

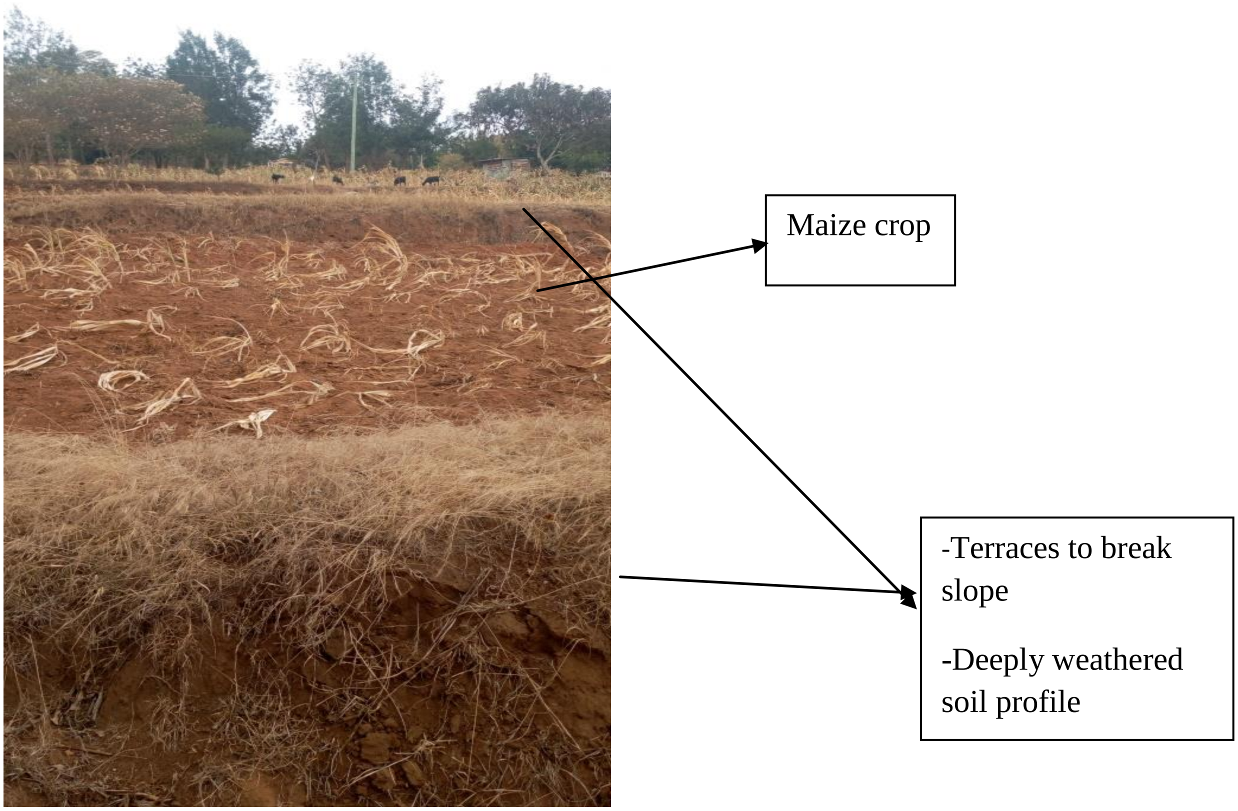


Plate 5.2: Crop farming at the Mua Hills summit with terracing to break slope

Source: Researcher, 2019

5.1.2 Shoulder

From the summit slope position, the soil depth decreased gradually at the shoulder slope unit. The shoulder on the slope was represented by three slope positions.

a). Altitude 1859m, location E37.1655; S 1.52101

b). Altitude 1954m, location E37.17786; S 1.51431

c). Altitude 1940m, location E37.17852; S 1.5151

Soil depth measurements were 40cm and 91cm taken at altitude 1859m as shown in Plate 5.3 and 1954m respectively. Horizon C was near the surface and this made it easier to take soil depth measurements. The decrease in soil depth as compared to the summit could be explained by the change in the water movements on this slope section as vertical infiltration processes that were dominant on the summit had decreased and there were more of lateral and subsurface water movements. Conacher and Dalrymple’s land surface model (Gerrard, 1992), stipulate that lateral and subsurface water movement dominate this geomorphic unit. Vegetation on this slope segment had also reduced with noticeable bare surface segments as seen in Plate 5.3. A reduction in vegetation reduces surface roughness and increases runoff which causes erosion and transportation of the top soils. This could essentially also have explained for the reduction in soil depth as soil depth is a balance between weathering and erosion.

Plate 5.3: Shoulder slope unit at altitude 1859m

Source: Researcher, 2019

5.1.3 Backslope

Points sampled on the backslope were:

Altitude 1903m, location E 37.17981; S 1.5165

Altitude 1891m, location E 37.1801; S 1.5169

Horizon C soil profile could not be observed on this slope unit and therefore, soil depth was not taken on this slope segment because of the unavailability of tools and resources to excavate a soil pit. However as per the research findings, soil depth decreased on the middle slopes where surface water action was rampant. The backslope was in the middle slopes.

5.1.4 Transportational Zone

The sampled points on this slope segment were:
Altitude 1883m, location E 37.18047; S 1.51717
Altitude 1840m, location E 37.1878; S 1.52201

Altitude 1841m, location E 37.16773; S 1.52135

Altitude 1835m, location E 37.18181; S 1.51911

Soil depth was taken on two slope points where horizon C was near the surface and near sub-surface. The depth of the soil was the thinnest on this slope unit at 15cm and 30cm. As per Conacher and Dalrymple land surface model (Gerrard, 1992), surface wash was a dominant geomorphological process on this slope. This essentially influenced the soil depth of the slope as rapid water movement washed away the soils transporting them downslope, thus explaining for the thin soil depth. This is supported by studies that indicate that velocity of overland flow increases downslope as more water is generated from the upper slopes and governed by such factors as the slope. In effect, overland flow transports sediments downslope and in so doing, depletes soil depth (Price, 1997; De Wit, 2001).

Additionally, the basement rock system was observed to be near the surface (Plate 5.4, 5.5 & 5.6) and this enhanced transport processes that carried with them soil sediments. According to Dunne, (1978); Burt *et al.*, (1990), when a rock or soil has a shallow depth, percolating water meets an obstructing horizon and water flows downslope more efficiently as shown in Plate 5.7. On this section of the transportation zone therefore, as water runoff increased because of reduced infiltration, soil sediments were transported downslope, and in this manner, soil depth was depleted. This slope section was also observed to have bare surfaces or scanty and scattered vegetation as shown in Plates 5.4 & 5.5. Mekonnen and Melesse (2011) did a study on Northwest Ethiopia highlands in relation to uses of land and the type of land cover and observed that soil erosion rate was prevalent on land surfaces that had minimal vegetation covering the soil surface. This is because land surface with no surface cover was susceptible to the action of running water, and since this transportation zone had scanty vegetation, the segment was very much exposed to the action of running water thus thinning out soils.

Plate 5.4: Thin soil depth on a transportational slope unit

Source: Researcher, 2019

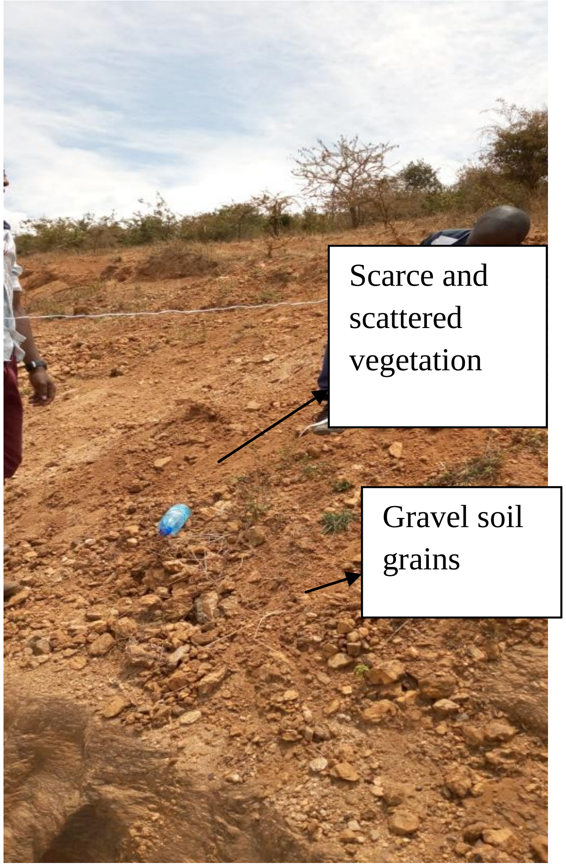


Plate 5.5: Soil on a transportational segment.

Source: Researcher, 2019

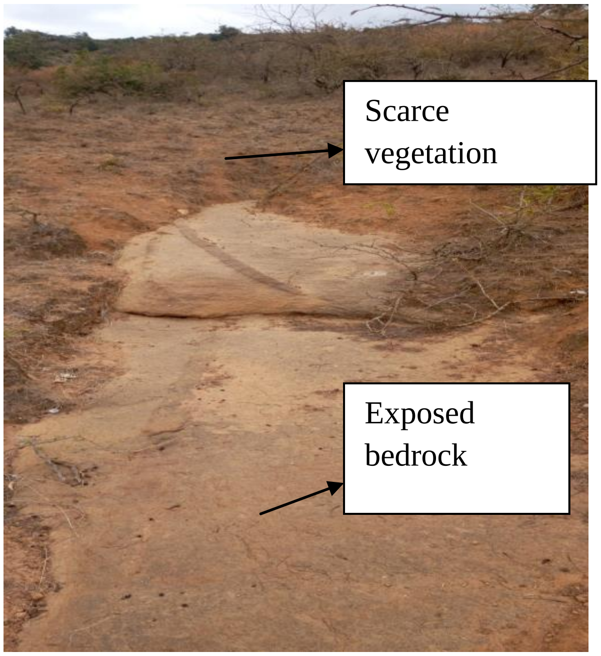


Plate 5.6: Bare rock, shrubs and acacia trees on the transportational zone of the Mua hill

Source: Researcher, 2019

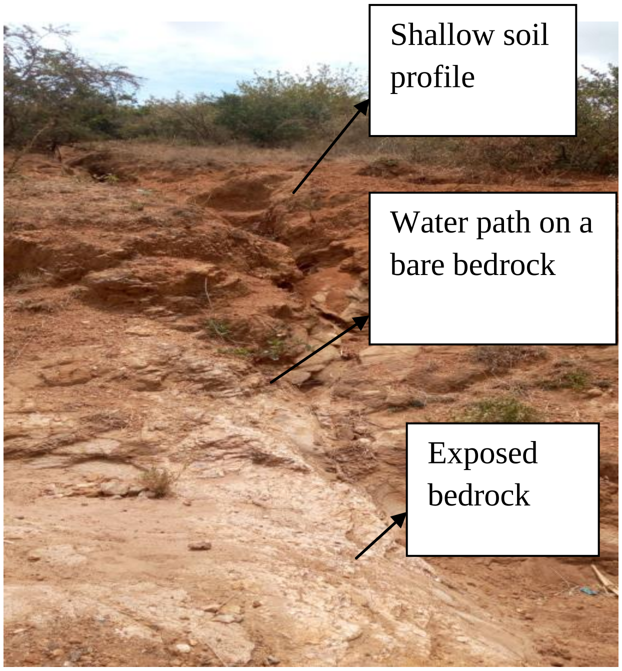


Plate 5.7: Water incision on a transportation slope

Source: Researcher, 2019

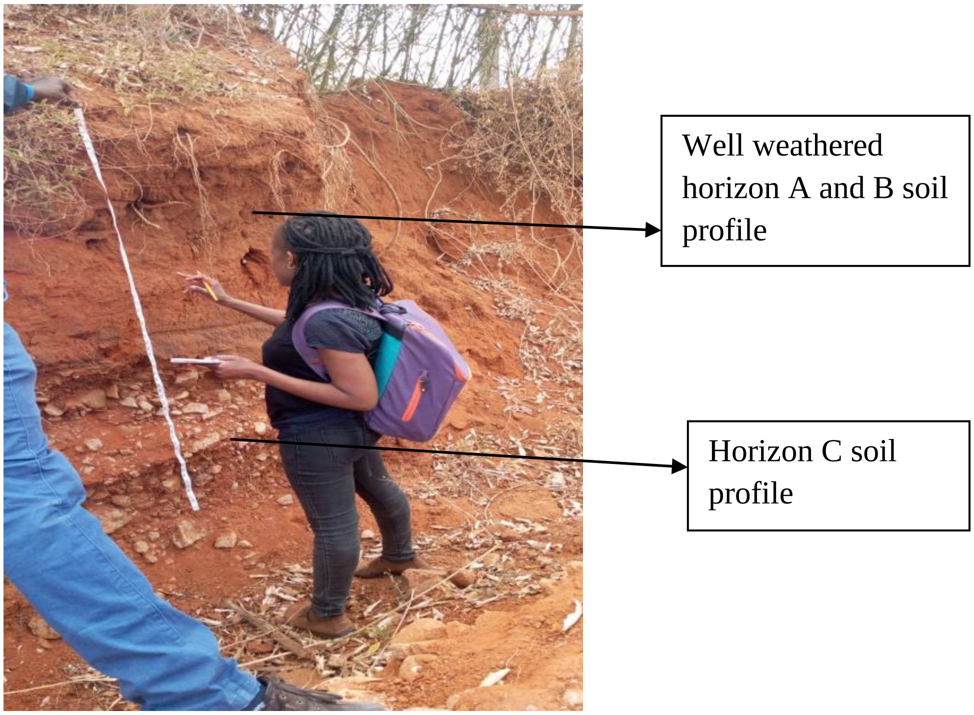
5.1.5 Footslope

Points sampled on this location were:

Altitude 1825m, location E 37.16998; S 1.52228

Altitude 1751m, location E 37.17876; S 1.52249

Soil depth measured on altitude 1825m was at 86cm. This was an increase in soil depth from the overlying geomorphic transportational unit that was measured at 15cm and 30cm. This is attributed to more deposition of soil sediments on this location as the footslope had more deposition taking place as compared to the transportation unit. According to Thornbury, (1954), geomorphic processes leave imprints that are distinctive on landforms, and a characteristic assemblage of landforms is developed by each geomorphic process. In this case, the soil profile of the footslope as shown in Plate 5.8 differed from the one above it because the lower section of the footslope had more of deposition activities by surface wash from the upper slopes than surface wash erosional activities of the overlying upper transportational slope.



Well weathered horizon A and B soil profile

Horizon C soil profile

Plate 5.8: Soil profile on the foot slope at Altitude 1825m

Source: Researcher, 2019

5.1.6 Toeslope

The main geomorphic process taking place on the lower slopes was deposition.

The sampled points were:

Altitude 1748m, location E 37.17906; S 1.52273

Altitude 1743m, location E 37.17432; S 1.53

Altitude 1713m, location E 37.17545; S 1.53478

The soils on this lower slope segment were thick with a soil depth of 244cm on altitude 1743m, taken on a freshly cut road segment. It is clear that this slope section conformed to the known geomorphologic processes of deposition on the lower slopes as studied by for example Gerrard, (1992); Chesworth (2008) who stated that alluvial deposition processes occurred on the lower slopes, enhancing soil depth. The thick soil depth was because of sediment deposition from the upper slopes. Apart from the soils being depositional sediments, there was in-situ soil development on the toeslope. This was facilitated by intense weathering because of availability of moisture in the soil. This finding was consistent with Birkeland, (1974) where he did a study of soils from southern California that showed that soils on the lower slopes had more depth and this was attributed to in-situ weathering of the bedrock that was underneath because of the presence of more moisture. Being a lower slope, the toeslope was an area of water accumulation from sub-surface water from the upper soils that could flow laterally or move down to become ground water. Higher water table has a strong influence on soil.

5.1.7 River Channel

The river channel was on altitude 1732m, location E 37.17944; S 1.52343.

Soil depth measurements were not possible to take on this slope position as the horizon C soil profile was not visible on the surface.

In this analysis of soil depth therefore, the paired t test tested the postulation that there was no variation in soil depth with change in slope. The alternative was there was significance difference in soil depth with change in slope. Significance level was at 0.05 and the computed t was 28.96 and this was compared to the critical t of 2.13 (one tailed test). The critical value was less than the computed t and so the null hypothesis was rejected. This indicated that the differences in soil depth were significant and therefore not due to chance. This finding conforms to the expected geomorphological processes where the topmost soils are washed from the high grounds and concentrated on the lower grounds varying with slope breaks, thus affecting soil depth.

5.2. Soil Texture

To meet the requirements of the second objective of the study that sought to examine the relationship between soil texture and relative slope position, soil samples were collected on 20 georeferenced sample points on different slopes and analyzed in the University of Nairobi soil mechanics laboratory. The results are as presented on table 5.2.

Table 5.2: Soil Texture Laboratory Results

Point	Height	Slope Position	Clay %	Silt %	Sand %	Gravel %
1	1985	Summit	5	38	53	4
2	1954	Shoulder	4	21	55	20
3	1940	Shoulder	5	33	60	2
4	1903	Backslope	3	30	64	3
5	1891	Backslope	3	19	77	1
6	1883	Transportation	4	24	57	15
7	1859	Shoulder	3	25	58	14
8	1841	Transportation	2	10	43	45
9	1840	Transportation	4	25	56	15
10	1835	Transportation	6	42	51	1
11	1835	Transportation	3	37	55	5
12	1835	Transportation	3	19	70	8
13	1835	Transportation	3	16	77	4
14	1835	Transportation	6	34	58	2
15	1825	Footslope	3	23	62	12
16	1751	Footslope	3	35	61	1
17	1748	Toeslope	3	38	56	3
18	1743	Toeslope	4	35	55	6
19	1732	River Channel	8	47	40	5
20	1713	Toeslope	5	39	51	5

Source: Researcher, 2019

Table 5.2 shows soil textures on the Mua hill on the different slope units. The texture of the soil is defined by the fraction of grains of gravel, sand, silt and clay. Gravel content was significantly high in the middle slopes with the highest level of gravel of 45% on the transportational slope unit while the silt content was relatively higher on the lower slopes with the largest silt composition of 47% on the river channel. Park *et al.*, 2001 notes that soil texture on slope units are typically different and this is a reflection of different processes taking place. The high level of gravel on the transportational zone was attributed to surface water processes that transported the finer textured soils of silt to the lower slopes leaving behind a high concentration of gravel. Whilst the action of water was able to transport the finer particles, the water did not have enough energy and capacity to transport the heavier soil sediments of gravel. This is in light of Holden,

(2008) who stated that the transport rate is regulated by the transport capacity of the process, which is described as the largest amount of material that can be transported. In this regard, the heavier textured particles were on the middle slopes such as the backslope and transportational slope while the lighter textured soils were on the lower slopes.

The silt content was higher on the lower slopes because of surficial water processes that transported the finer soils downslope because water has more capacity to transport lighter soil particles as these require less energy in comparison to heavier soil materials that need more energy to transport downslope.

The clay content was more or less similar along the slope profile with an average of 4%, with the highest clay content at 8% being on the river channel and the lowest at 3% on various parts of the slope. The highest clay composition on the river channel could be attributed to the action of weathering because the lower slope had the tendency to be wetter during most parts of the year hence speeding up the transformation of soil grains into clays. The sand content had the largest percent composition on all the sampled points with an average of 58% along the slope profile, the largest sand composition being 77% on the backslope and the lowest composition at 40% on the river channel. Just like gravel, the heavier textured soils such as sand were more prevalent on the middle section of the slope because of the water action. More water energy was needed to transport sandy grains downslope and this capacity might have been lacking.

The soil textures on the transportation unit on altitude 1835m did however not follow the soil texture geomorphological trends for the slope position. On further study of this section, it was established that there were sink holes that could have influenced the soil composition. In addition, this section was under intense vegetation. On the rest of the slope positions, the soil textural results conformed to known geomorphological processes where the heavier textured soil particles are deposited first when water loses its transportational capacity with a decline in slope and the fine textured and lighter soils are transported downslope as less energy is needed to transport them and as the slope gets gentler. This finding was in line with GK Gilbert in his study of the Henry Mountains where he stated that the capacity to transport sediments is a relationship that involves the type of slope, the size of debris and the discharge (Wainwright *et al.*, 2015).

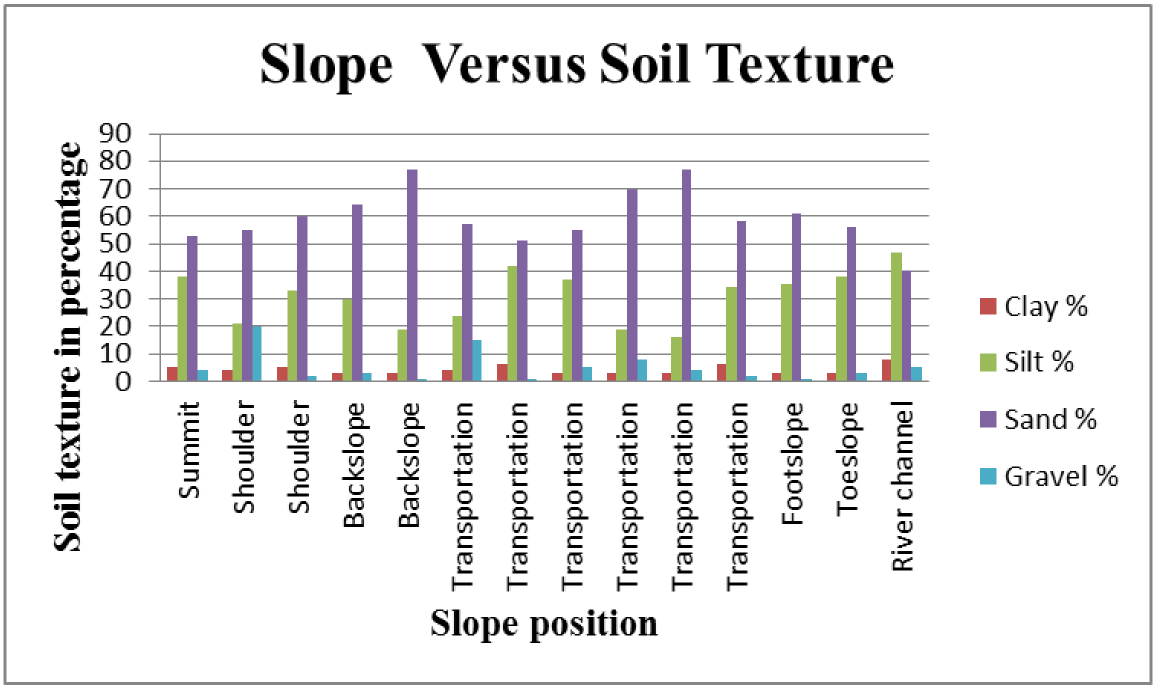


Figure 5.2: Laboratory results of soil texture vs slope position at sampling profile Aand C

Source: Researcher, 2019

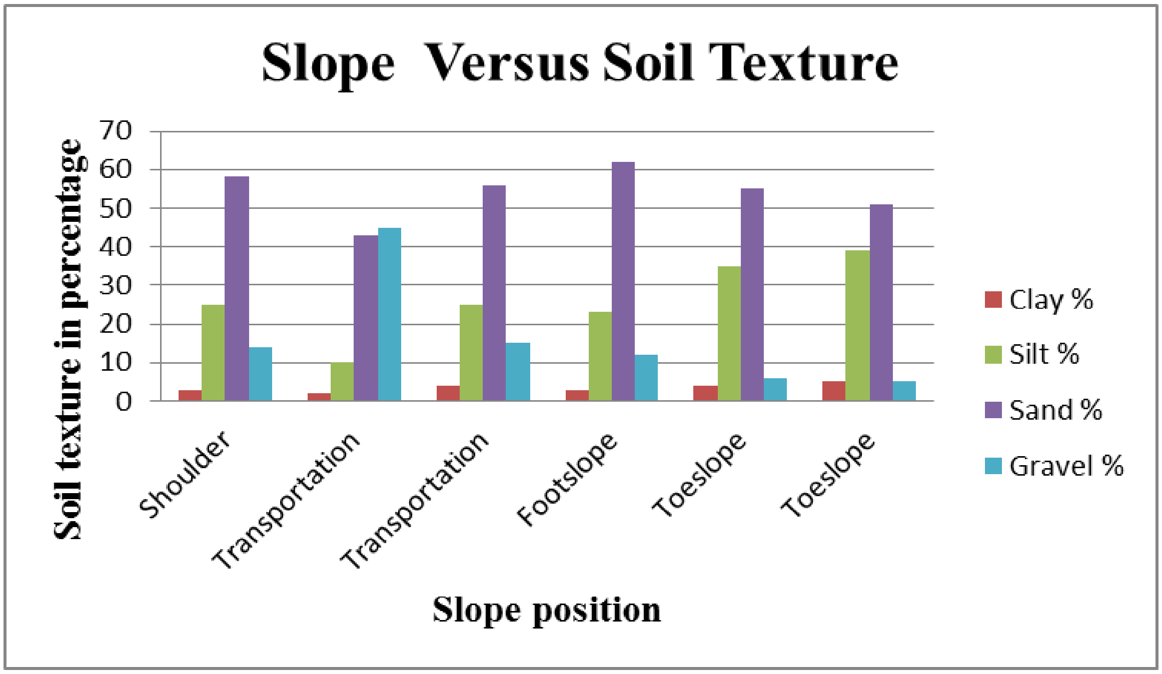


Figure 5.3: Laboratory results of soil texture vs slope position at sampling profile C

Source: Researcher, 2019

Figures 5.2 and 5.3 show the graphical laboratory results for soil texture in relation to slope position. Figure 5.2 shows soil texture versus altitude at sampling profiles A and C on a relatively undisturbed land profile and the river channel slope while figure 5.3 is for sampling done on a freshly cut road segment on Slope Profile C.

From figures 5.2 and 5.3 above, it can be seen that sand percentage rose slowly from the summit to the backslope (from 53% to 77%). Clay percentage was relatively similar in the range of 3% to 8% on all of the 20 sampled positions along the slope, while gravel, a coarse soil texture, had the least composition on the foot slopes at 1%. With an average of 30% along the slope profile, silt content was high at 38 % on the summit but decreased at the shoulder segment to 21 % and it was highest on the river channel at 47%. The heavier materials were thus deposited first and the lightest materials deposited last. A study by Kleiss (1970) on the formation of soils in northeastern Iowa showed that the heavier textured soils were on the upper slopes, and the finer textured soils were on the lower slopes.

Two soil samples taken on the horizontal transportational segment of altitude 1835m were unlike the trend on the soil/ slope position on the landscape. The silt composition was much lower at 19% and 16% on this segment (The average silt percent on this slope position was 37%). In contrast, the sand component was much higher on these two slope positions at 70% and 77% (The average sand percent on this segment was 55%). Because of these notable disparities in the soil texture trend, an investigation on the site established that these sections with varying silt and sand percentages had underground water channels as shown in Plates 5.12 & 13. This was considered to show that silt, a fine soil component, had been transported downslope through the transport mechanism of suspension, leaving the heavier textured sand component on the land surface.

Below is the results and discussion of soil textures as observed on the studied geomorphic units.

5.2.1 Summit

The highest sampled point was the summit on altitude 1985m on the GPS location of E 37.17167; S 1.51444. The soil texture composition at this point was 5 % clay, 38% silt, 53%

sand, and 4% gravel. The average clay composition along the slope was 4% and the average silt composition along the slope was 30%. Clay and silt contents were thus slightly higher than the average percentages of these soils. Fine textured soils such as these two were noted to be higher on the upper slope soil profiles. Gravel, a coarse soil texture was at a minimum on the summit. Grains of sand and gravel were at a minimum on the deeply weathered soil profiles such as observed on this summit as shown in Plate 5.1 because the larger composition of soils had been finely weathered. Kirkby, (1972) acknowledges that weathering products such as soil accumulated on gentle slopes therefore water stayed in contact with rock for longer periods of time, and thus resulted in higher weathering rates. This was also consistent with Manning *et al.*, (2001) where he noted that slope influenced soil moisture and this impacted on the profile development of the soil and thus, it was possible to relate soil properties with topography.

The summit soils were deeply weathered and this was attributed to vertical water movements which allowed for the infiltration of water into the subsurface, which encouraged fine weathering of soils.

5.2.2 The Shoulder

The shoulder on the slope was represented by three slope positions.
a). Altitude 1859m, location E37.1655; S 1.52101

b). Altitude 1954m, location E37.17786; S 1.51431

c). Altitude 1940m, location E37.17852; S 1.5151

Gravel soil composition was high at 14% and 20% on the two shoulder positions taken at slope profile C in comparison to the gravel percentage of 2% for soil sample on slope profile A. The disparity was associated to land use on the two slopes. Slope A had some minimal vegetation as shown in Plate 5.9 while slope C was on surfaces that had scanty or no vegetation at all as shown in Plate 5.3. The soils were therefore better weathered on the vegetated slope unit and thus exhibited higher percentages of finer soil textures of clay at 5% against the hillslope average of 4% and silt composition of 33% against the average on the slope of 30%. The unvegetated slope segments had lower silt percentages at 25% and 21% respectively and this was associated to downslope transport of the finer silt through suspension water transport action that was enhanced by the scanty vegetation. Montgomery, 2000; Milodowski, 2016 associated the presence of vegetation to reduced overland flows. Accordingly, Mohammadi *et al.,* (2016); Nkonya *et al.,* (2016), indicated that overland flows resulted to erosion through the particle size sorting effect whereby the finer soil particles were transported downslope through suspension water transport mechanism. Finer textured soil particles were more predisposed to erosion.

Plate 5.9: Vegetation on the shoulder slope unit

Source: Researcher, 2019

5.2.3 Backslope

Points sampled on the backslope were:

Altitude 1903m, location E 37.17981; S 1.5165

Altitude 1891m, location E 37.1801; S 1.5169

The sand composition was high on this slope segment at 64% and 77% which was above the average sand content of 58% along the slope profile while the gravel content was low at 3% and 2%. This could be attributed to efficient water runoff that washed away the heavier soil particles of gravel. The huge composition of sand at 77% though sand was a coarse soil texture was because the Mua Hills had a generally high sand content along the profile and this was the soil component that was left behind when water washed away the rest of the soil grains as rapid surface and subsurface water action was a dominant hydro-geomorphic process that occurred on this slope section as indicated in Plate 5.10. The silt component was low at 18% against the average of 30% on the slope while clay was at 3% on altitude 1903m against the average of 4%

along the slope. This contrasted with the highest percentage of sand at 77% that was found on this slope segment. The low percentage of silt was associated with suspension transport mechanism that transported the fine textured particles of clay and silt down the slope. A study by Mohammadi *et al.*, 2016, showed that slope gradient could result to preferential particle size sorting where coarser particles accumulated on steeper slopes with the finer particles being conveyed to the lower slopes. This is proven by the results of the present investigation.

Plate 5.10: Water action along the backslope

Source: Researcher, 2019

5.2.4 Transportation Zone

The sampled points on this slope segment were:

Altitude 1883m, location E 37.18047; S 1.51717
Altitude 1840m, location E 37.1878; S 1.52201

Altitude 1841m, location E 37.16773; S 1.52135

Altitude 1835m, location E 37.18181; S 1.51911 The largest concentration of gravel, a coarse soil texture along the slope profile of 45% was on this slope segment. This could be attributed to poor development of the soil because partly weathered regolith constituted a major part of the soil on this slope segment as shown in Plate 5.11. This is because on steep slopes, weathering products may be quickly washed downslope by running water and in essence, the lighter textured soil particles were more predisposed to water transport as finer particles moved in suspension to the lower slopes (Wainwright *et al.*, 2015). Additionally, suspension water transport process of the finer soil texture of silt was of importance as silt was transported downslope leaving the gravel component of the soil and thus explaining for the low percentage of silt at 24%, 25 % and 10% respectively against the average of 30% along the slope profile. According to Van den Bygaart, (2001); Mohammadi *et al.*, (2016), slope gradient could result to coarser particles preferentially accumulating on the steeper slopes and because of erosion, the upslope materials were redistributed and they were deposited on the middle slopes when the transport capacity of water diminished.

Plate 5.11: Partly weathered regolith on a transportational slope unit

Source: Researcher, 2019

On certain slope sections of this transport slope zone, the silt component of the soil was minimal at 19% and 16%, with the sand composition being high at 70% and 77%. The soil texture composition did not conform to the trend observed on other parts of the transportational zone. It was established that these slope points had underground water channels as shown in Plates 5.12 and 5.13). The minimal silt composition could thus be attributed to underground soil erosion and transportation through the suspension mechanism that carried away the fine textured silt, leaving the heavier sandy soil on the surface. According to Bernie & Poesen, (2018) soil piping impacts the landscape by changing slope hydrology.

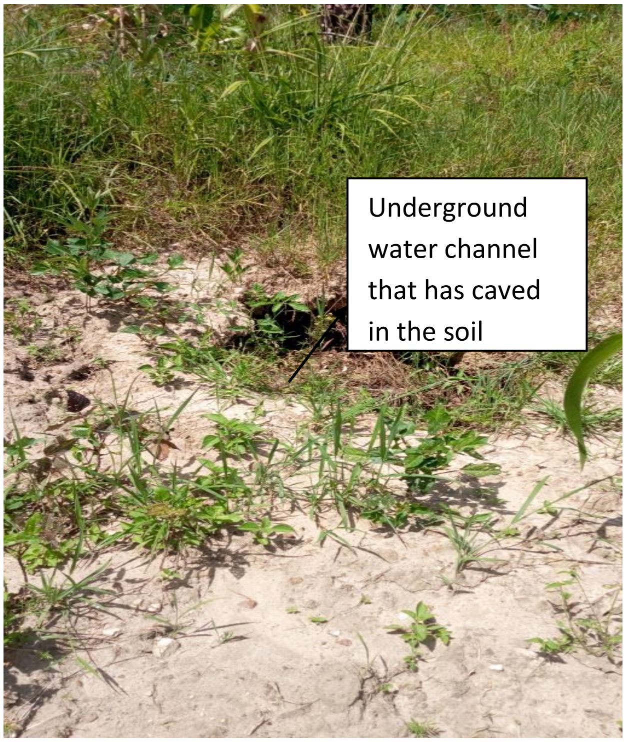


Plate 5.12: Underground water channel
Source**: Researcher, 2019**

Plate 5.13: Large sink hole showing the works of underground soil erosion

Source: Researcher, 2019

5.2.5 Footslope

Points sampled on this location were:

Altitude 1825m, location E 37.16998; S 1.52228

Altitude 1751m, location E 37.17876; S 1.52249

The dominant geomorphological process happening on this slope section was deposition of material by surface wash from the upper slopes. The gravel content differed greatly on the two sampled footslope points at 12% and 1% respectively. The silt content also varied on the two footslope points at 23% and 35% respectively. This could be attributed to water action difference on the two points because of vegetation variances. Altitude 1825m was on a freshly cut road profile with scattered vegetation, enabling more efficient transport processes. A lot of the heavier and coarser sediments of gravel and sand had thus been washed down and deposited on this lower slope because of high water velocity from the upper slopes, explaining for the large concentration of gravel. Silt, a fine and light soil component was recorded with a low percentile on this slope as it had been transported further downslope because of its fine texture.

Altitude 1751m sampling was situated on a river channel profile with a dense vegetation cover shown in Plate 5.14. Because of reduced velocity due to water interception and resistance to erosion and the presence of vegetation, transportation of sediments was minimal because of reduced erosive water action from the upper slopes explaining for the low gravel component. The silt content was also greater on this slope position at 35% and it could be attributed to deposition of fine textured soil transported from the upper slopes. Shary *et al.*, 2002 studied changes in soil types along a slope gradient and observed that soil types do change as the gradient of a slope declines. The variation in land cover could explain for the difference of the soil textures by for example Mekonnen and Melesse (2011) who observed sediment changes in relation to land use.

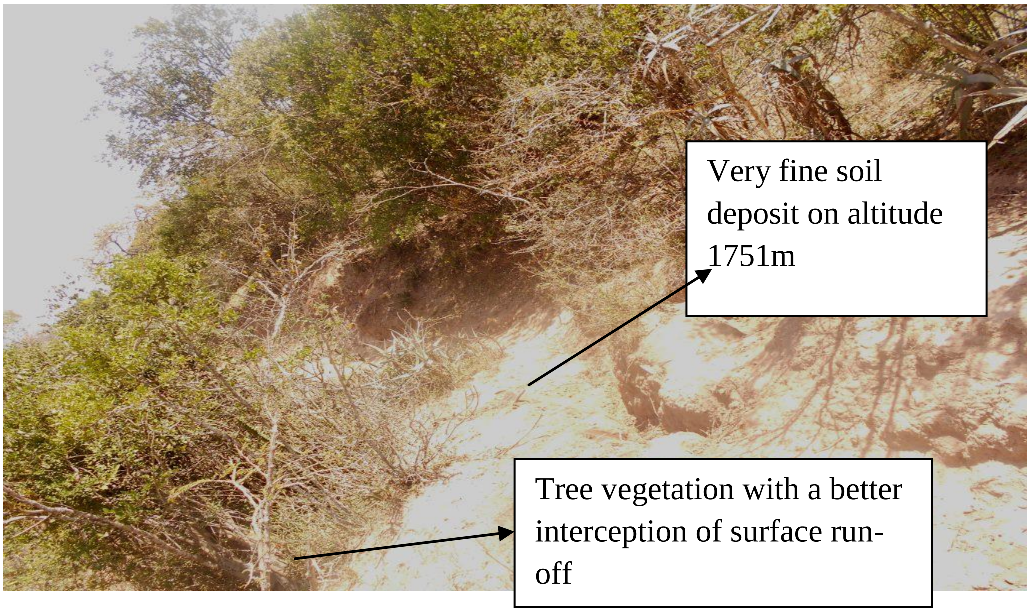


Plate 5.14: Soil deposit on the footslope on the river bed sampling point at altitude 1751m

Source**: Researcher, 2019**

5.2.6 Toeslope

Alluvial deposition processes occurred on this geomorphic unit. The sampled points were:

Altitude 1748m, location E 37.17906; S 1.52273

Altitude 1743m, location E 37.17432; S 1.53

Altitude 1713m, location E 37.17545; S 1.53478

On the sampled points at altitude 1748m, 1743m and 1713m, the gravel composition was low at 3%, 6% & 5% respectively. The silt content on all of the three sampled toe slope units was high at 38%, 35% & 39% respectively owing to the process of deposition of the finer textured soils. The main geomorphic process taking place on this toeslope was deposition. The smaller particles were preferentially transported downslope through transportation processes of sediments that had been washed down from the upper slopes, thus explaining for the low gravel composition and the high silt deposition as indicated in Plate 5.15. A study by Kleiss, (1970) on soil formation in Northeastern Iowa on a systematic investigation of a hillslope showed that variations in particle size within the soil were as a result of sedimentological sorting, where finer particles were observed to be on the lower slopes. The finer soils of silt have been found to be in the lower slopes in the Mua Hills study area.

Plate 5.15: Fine soil deposits on the toe slope

Source: Researcher, 2019

5.2.7 River Channel

The river channel was represented by the soil sample taken at altitude 1732m, location E 37.17944; S 1.52343 as shown in Plates 5.23 & 5.24. The river was dry as it was a dry season thus enabling for the taking of soil samples. Periodic aggradation and corrosion occurred on the channel. To note is that the highest composition of silt at 47% occurred on this unit and this was attributed to the deposition of sediments from the upper slopes as the fine materials were deposited last at the river channel, which is on the lower slope units. Altogether, this conforms to studies such as Kleiss, (1970) where particle size sorting has a sedimentology sorting where the finer particles are deposited the last.

Plate 5.16: Fine deposits on the riverbed soil

Source: Researcher, 2019

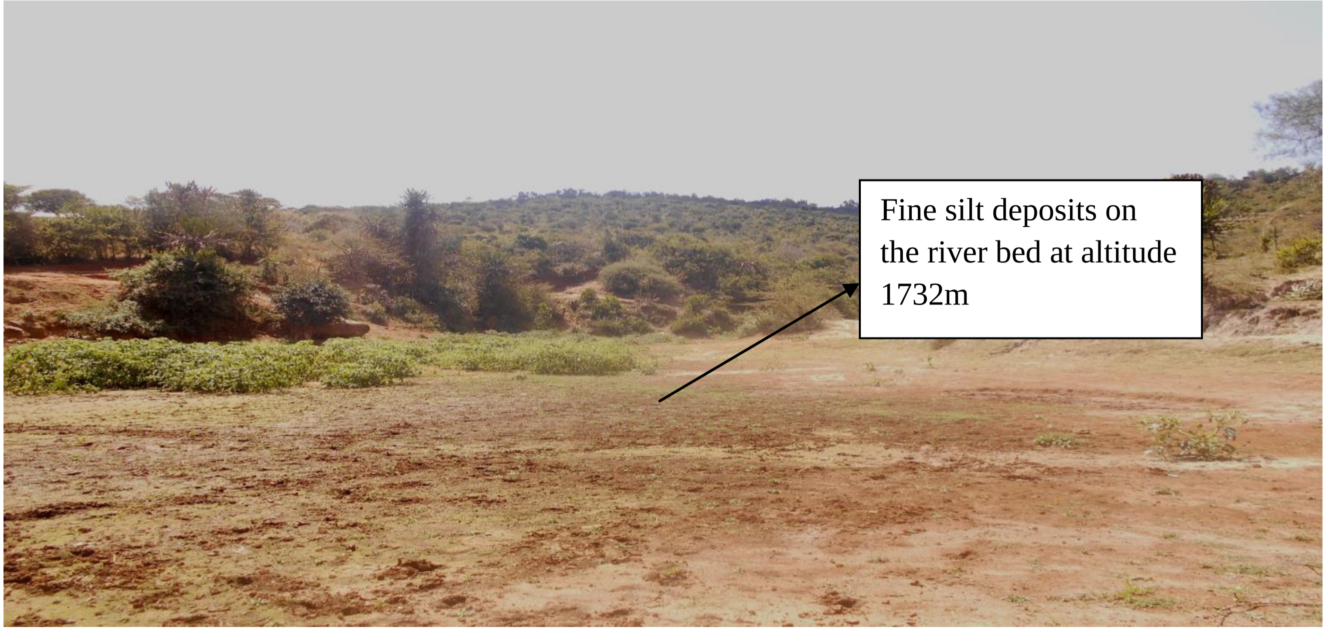


Plate 5.17: River bed soil

Source: Researcher, 2019

In light of the soil texture results from this study, the calculated Kruskal Wallis H test static at 0.05 significance level was 63.132. This was greater than the critical H of 7.81and therefore, the null hypothesis was rejected. This finding agreed with the expected geomorphological processes where fine soils were washed from the higher grounds and deposited on the lower grounds. This was because light textured soils could still be transported when the capacity of water to carry sediments diminished. The heavier textured soils were found on higher grounds because water did not have the capacity to transport heavy sediments when the water energy was reduced. The heavier textured particles were therefore the first to be deposited with a reduction in water carrying capacity.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This section is a summary of the research results, conclusions and recommendations made to enhance good management of soil properties. Avenues for more research have also been proposed.

6.1 Summary

The findings of this study indicate that soils, landscape, and geomorphic processes were found to be intimately linked as slope mediated the interactions of soil and geomorphic processes. Soil properties were not randomly distributed but they were influenced by varying geomorphological processes through the control of the slope.

As a result, the analysis of the upper, middle, and lower slopes soil properties indicates that the slope position had a substantial effect on the depth of the soil and the texture. There was a reduction of soil depth from the summit to the transportational zone, with the soil depth increasing from the middle transportational zone to the lower slope positions. The diminishing soil depth in the transportational zone, which is a middle slope segment, indicated that the middle segment of the slope was being eroded with the proximate cause being the slope. The gradient on the middle slopes was high, which had the likelihood of decreasing the speed of water infiltration, curtailing soil depth. Surface wash on the steep middle slopes also influenced soil depth as the top soils were transported to the lower slopes. The erosion and redistribution of soils from the upper slopes resulted to the buildup of soil sediments in the lower slopes which resulted to soils that were thick.

Particle size sorting was evidenced on the hillslope as heavier soil particles of sand and gravel had higher contents in the middle slopes that were location of water runoff while the finer soil texture of silt had higher percentages on the lower slopes. The lower slopes also had low gravel content. Deeply weathered soils were observed to have more of fine textured soils and this was on the upper and lower slope units while slopes with thin soils had a large composition of coarse textured soil grains of gravel. Thin soils tended to have an exposed Basement Rock near the surface. The soil properties therefore portrayed a connection with the variations to the geomorphic setting of slope form and process along the slope profile as soils are dynamic systems and they exhibit a record of current and past processes which were evidenced on the soil characteristics.

This topographic analysis showed that specific morphological features such as the geomorphic units studied in Mua Hills had a relationship with aspects of slope/soil processes that had an influence on soil properties. Additionally, by testing the hypothesis, there was found to be a significant relationship between the soil depth and slope and between soil texture and slope, which necessitated the rejection of the null hypothesis and adopting the alternative hypothesis. Vegetation was also seen as a factor that influenced soil depth and soil texture as bare rock surfaces had thin soils with gravel and sand as the predominant soil textures.

6.2 Conclusion

The findings of this research reveal that soil properties of depth and texture have been influenced by the slope position in the Mua Hills. This change was characterized by a decrease in soil depth from the summit to the middle slopes of the backslope and the transportation geomorphic unit and a subsequent increase of the soil depth from the transportation unit to the lower slopes of the footslope and toeslope. Coarse textured soil of sand and gravel had the highest percentage concentration on the middle slopes while the fine textured soil compositions occurred on the lower slopes. The transition from soil-mantled slopes on the summit to soils with thin soil depths on the backslope and transportational units marked a shift from the transport limited slopes characterized by a continuous mantle of soil, to hillslopes that were weathering limited with shallow soil depth. This represented a fundamental change in the dynamics of soil texture along the slope as slopes with shallow depths had the composition of heavier textured soil grains of gravel and sand while the deeply weathered soils on the summit and the lower slopes had more composition of the fine textured silt.

Besides slope position and soil properties being connected, this study also observed that different geomorphological processes that contributed to differing soil properties had the ability to influence land use. Geomorphic segments with thin soils had parent bedrocks lying at or near the surface. These units also constituted of large boulders, with coarse soil particles of gravel. These slope segments had minimal vegetation on the surface and they were predominant on the middle slopes and they called for a different kind of land use as compared to the upper and lower slopes that had deep soils. In effect, soil depth and soil texture are pretty much determined by their relative positioning on the slope.

6.3 Recommendations

The study makes the following recommendations.

6.3.1 Policy Recommendations

From this study on soil depth and soil texture spatial distribution on the Mua Hills, it was the position of this research that the county government ought to work hand in hand with the community to tie in specific issues related to soil properties and the landscape positions. For example, there were large areas of land that had bare rock surfaces, with very thin soils and so these called for a different kind of land use to appropriately and effectively utilize the land as per its capabilities. In addition, there were parts of the land that had underground water channels such that the erosion characteristics of these areas were different from the areas not having the underground water channels. An example is that crop failure was observed in the areas with these underground channels. This therefore called for area specific land management for maximum land utilization. Additionally, sink holes that formed from the underground water movement could pose a hazard for the community and so physical planners have a duty to ensure that land is utilized efficiently.

Moreover, through extension services, the County government has a mandate to encourage land management practices that harness the soil. This is because from the study, it emerged that some steep slopes had bare soil surfaces with minimal vegetation cover. Because of the absence of adequate vegetation, the soil resistivity to soil erosion was minimal as evidenced by thin soils on these slope segments. A proper land surface cover such as planting of suitable vegetation would help in minimizing surface run off during rainfall events that carried away loose soil sediments. Vegetation also aided in weathering processes that would ensure a greater soil depth. A thick soil depth also gives plant roots a greater ability to hold on the soil. Furthermore, the presence of vegetation was a good way of reducing the transportation of the silt soil component of the soil as vegetation gave a firm surface that roots could grow.

6.3.2 Recommendations for further research

From this research, soil depth and soil texture were observed to be linked to the relative positioning on the land surface through the influence of geomorphic processes of water erosion and deposition. For sustainable management of the land, a careful monitoring on the evolution of the soil through landscape evolution analysis would help to monitor any detrimental changes on the land and necessary measures taken up to prevent downturn of the land. This would be through such studies as predicting rates of geomorphic change and through landscape modelling. This research would be beneficial in landscape management.

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APPENDICES

APPENDIX 1: Kruskal-Wallis Test

Kruskal-Wallis Test

[Test of difference using Kruskal-Wallis H test. Compare the computed H with the critical H. When n > 5. H is a chi-square statistic.

$$H = \left(\frac{12}{N(N+1)} * \Sigma \frac{T_C{}^2}{N_C}\right) - 3 * (N+1)$$

Where;

N= Number of samples
T_C =Total rank for each group
$N_{C=}$ Number of participants in each group

Ranks

	Soil texture	N	Mean Rank
Frequency	Clay	20	18.48
	Silt	20	48.85
	Sand	20	70.25
	Gravel	20	24.43
	Total	80	

Test Statistics^{a,b}

	Frequency
Chi-Square	63.132
df	3
Asymp. Sig.	.000

Appendix 11: Paired T-test

t-Test: Paired Two Sample for Means		
The study tested the hypothesis that there was no difference in soil depth with change in slope. The alternative was there was significance difference in soil depth with change in slope. Significance level was at 0.05 and the computed t was 28.96 and this when compared to the critical t of 2.13 (one tailed test) indicated that the differences were significant and therefore were not due to chance. The critical value was less than the computed t and so the null hypothesis was rejected. This showed that there was a significance difference in soil depth with change in slope. This finding conforms to the expected geomorphological processes where the topmost soils are washed from the high grounds and concentrated on the lower grounds varying with slope breaks. This is consistent with findings by Gerrard, (1992) who indicated that water transport activities washed down soils on upper slopes reducing soil depth while deposition enhanced deeper soil depth on the lower slopes.	*Variable 1*	*Variable 2*
Mean	1821.6	93.2
Variance	2075.8	7971.7
Observations	5	5
Pearson Correlation	-0.956	
Hypothesized Mean Difference	0	
df	4	
t Stat	28.956	
P(T<=t) one-tail	4.236	
t Critical one-tail	2.132	
P(T<=t) two-tail	8.4713	
t Critical two-tail	2.776	

APPENDIX 111: Laboratory soil particle size analysis results

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

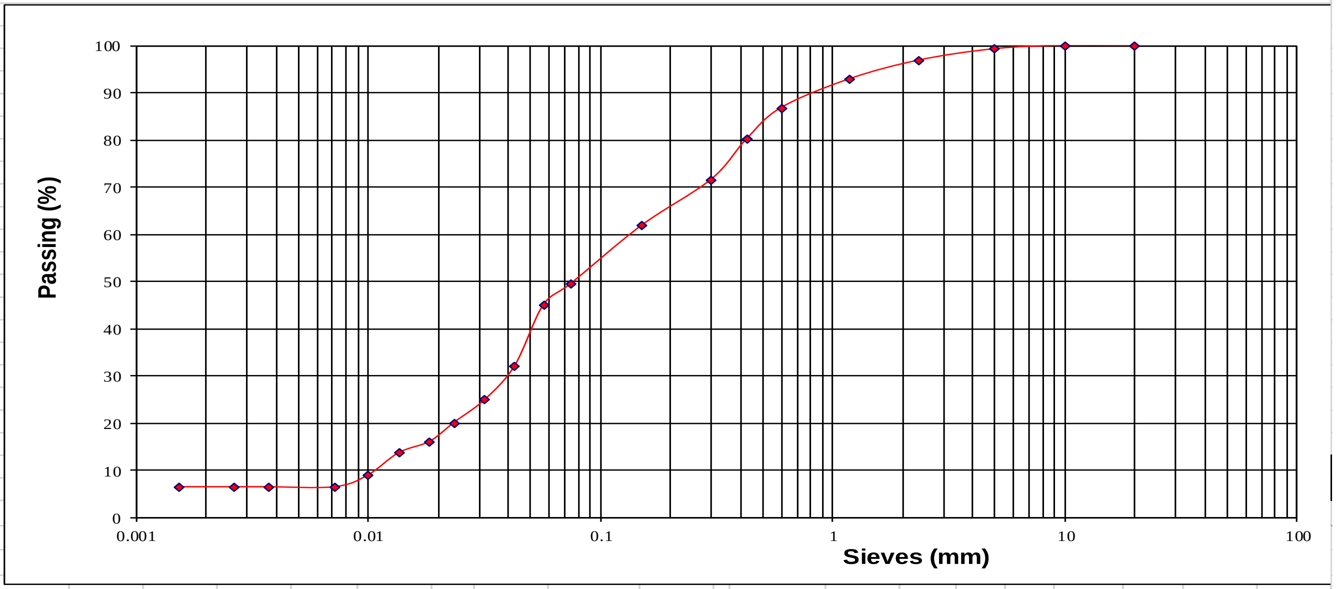
SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1713

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	49.6
Washed dry sample mass + pan	(gm)		Fine percent	49.6
Washed dry sample mass	(gm)	50.4	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377									
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**28.5**	**29**	**8.8**	**0.0568**	**91**	**45**
10	0	**0.0**	**100.0**				**25.5**					
5	0.7	**0.7**	**99.3**				**23**					
2.36	2.4	**2.4**	**96.9**		**1**	**20**	**20.5**	**21**	**10**	**0.0428**	**65**	**32**
1.18	4	**4.0**	**92.9**		**2**	**20**	**16.0**	**16.5**	**11**	**0.0318**	**50**	**25**
0.6	6.1	**6.1**	**86.8**		**4**	**20**	**13**	**13.5**	**12**	**0.0235**	**41**	**20**
0.425	6.7	**6.7**	**80.1**		**8**	**20**	**10.5**	**11**	**14.8**	**0.0184**	**32**	**16**
0.3	8.5	**8.5**	**71.6**		**15**	**20**	**9**	**9.5**	**15**	**0.0135**	**28**	**14**
0.15	9.8	**9.8**	**61.8**		**30**	**20**	**6**	**6.5**	**16.1**	**0.0099**	**18**	**9**
0.075	12.2	**12.2**	**49.6**		**60**	**20**	**4.5**	**5**	**16.7**	**0.0071**	**13**	**6**
<0.075	49.6	**49.6**			**240**	**20**	**4.5**	**5**	**17.9**	**0.0037**	**13**	**6**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.5**	**0.0027**	**13**	**6**
					1440	**20**	4.5	**5**	**18.5**	0.0015	**13**	**6**

GRADING CURVE - HYDROMETER ANALYSIS



SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1732

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	55.2
Washed dry sample mass + pan	(gm)		Fine percent	55.2
Washed dry sample mass	(gm)	44.8	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377									
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**28.0**	**28.5**	**9.0**	**0.0574**	**89**	**49**
10	0	**0.0**	**100.0**				**24**					
5	1.4	**1.4**	**98.6**				**20.5**					
2.36	1.6	**1.6**	**97.0**		**1**	**20**	**18.0**	**18.5**	**10.6**	**0.0441**	**57**	**31**
1.18	1.5	**1.5**	**95.5**		**2**	**20**	**14.5**	**15**	**12.2**	**0.0334**	**45**	**25**
0.6	4.3	**4.3**	**91.2**		**4**	**20**	**10.5**	**11**	**13**	**0.0244**	**32**	**18**
0.425	5.1	**5.1**	**86.1**		**8**	**20**	**7.5**	**8**	**14.5**	**0.0182**	**23**	**13**
0.3	6.7	**6.7**	**79.4**		**15**	**20**	**5**	**5.5**	**16.1**	**0.014**	**15**	**8**
0.15	10.5	**10.5**	**68.9**		**30**	**20**	**4.5**	**5**	**17.3**	**0.0103**	**13**	**7**
0.075	13.7	**13.7**	**55.2**		**60**	**20**	**4.5**	**5**	**18.3**	**0.0075**	**13**	**7**
<0.075	55.2	**55.2**			**240**	**20**	**4.5**	**5**	**18.5**	**0.0038**	**13**	**7**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.5**	**0.0027**	**13**	**7**
					1440	**20**	4.5	**5**	**18.5**	0.0015	**13**	**7**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1743

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	45.4
Washed dry sample mass + pan	(gm)		Fine percent	45.4
Washed dry sample mass	(gm)	54.6	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	0	**0.0**	**100.0**
5	0.8	**0.8**	**99.2**
2.36	1.5	**1.5**	**97.7**
1.18	4.3	**4.3**	**93.4**
0.6	5.2	**5.2**	**88.2**
0.425	7.7	**7.7**	**80.5**
0.3	8.7	**8.7**	**71.8**
0.15	12.9	**12.9**	**58.9**
0.075	13.5	**13.5**	**45.4**
<0.075	45.4	**45.4**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**26.5**	**27**	**9.6**	**0.0593**	**84**	**38**
	1	**20**	**21.5**	**22**	**11.7**	**0.0463**	**68**	**31**
	2	**20**	**17.0**	**17.5**	**13.4**	**0.035**	**53**	**24**
	4	**20**	**14.5**	**15**	**14.5**	**0.0258**	**45**	**21**
	8	**20**	**12**	**12.5**	**15.4**	**0.0188**	**37**	**17**
	15	**20**	**11**	**11.5**	**15.9**	**0.0139**	**34**	**15**
	30	**20**	**10**	**10.5**	**16.3**	**0.01**	**31**	**14**
	60	**20**	**9**	**9.5**	**16.7**	**0.0071**	**28**	**13**
	240	**20**	**6.5**	**7**	**17.7**	**0.0037**	**19**	**9**
	480	**20**	**5.5**	**6**	**18.1**	**0.0026**	**16**	**7**
	1440	**20**	4.5	**5**	**18.5**	0.0015	**13**	**6**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1748

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	44.5
Washed dry sample mass + pan	(gm)		Fine percent	44.5
Washed dry sample mass	(gm)	55.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	9AM	**0.5**	**20**	28.5	**29**	8.8	**0.0568**	**91**	**40**
10	0	**0.0**	**100.0**									
5	1	**1.0**	**99.0**									
2.36	1.1	**1.1**	**97.9**		**1**	**20**	22.0	**22.5**	11.4	**0.0457**	**70**	**31**
1.18	2.3	**2.3**	**95.6**		**2**	**20**	17.0	**17.5**	13.5	**0.0352**	**53**	**24**
0.6	5.2	**5.2**	**90.4**		**4**	**20**	13.5	**14**	14.9	**0.0261**	**42**	**19**
0.425	6.6	**6.6**	**83.8**		**8**	**20**	10	**10.5**	16.3	**0.0193**	**31**	**14**
0.3	9.5	**9.5**	**74.3**		**15**	**20**	7	**7.5**	17.5	**0.0146**	**21**	**9**
0.15	14.2	**14.2**	**60.1**		**30**	**20**	5	**5.5**	18.3	**0.0106**	**15**	**6**
0.075	15.6	**15.6**	**44.5**		**60**	**20**	4.5	**5**	18.5	**0.0075**	**13**	**6**
<0.075	44.5	**44.5**			240	**20**	4.5	**5**	18.5	**0.0038**	**13**	**6**
TOTAL	100				480	**20**	4.5	**5**	18.5	**0.0027**	**13**	**6**
					1440	**20**	4.5	**5**	18.5	0.0015	**13**	**6**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1751

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	46.5
Washed dry sample mass + pan	(gm)		Fine percent	46.5
Washed dry sample mass	(gm)	53.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**25.5**	**26**	**10.0**	**0.0606**	**81**	**38**
10	0	**0.0**	**100.0**									
5	0	**0.0**	**100.0**									
2.36	0.6	**0.6**	**99.4**		**1**	**20**	**20.5**	**21**	**11.9**	**0.0467**	**65**	**30**
1.18	1.7	**1.7**	**97.7**		**2**	**20**	**16.5**	**17**	**13.5**	**0.0352**	**52**	**24**
0.6	3.3	**3.3**	**94.4**		**4**	**20**	**12.5**	**13**	**15.1**	**0.0263**	**39**	**18**
0.425	7.7	**7.7**	**86.7**		**8**	**20**	**10.5**	**11**	**15.9**	**0.0191**	**32**	**15**
0.3	8.9	**8.9**	**77.8**		**15**	**20**	**8.5**	**9**	**16.7**	**0.0143**	**26**	**12**
0.15	14.5	**14.5**	**63.3**		**30**	**20**	**8**	**8.5**	**16.9**	**0.0102**	**24**	**11**
0.075	16.8	**16.8**	**46.5**		**60**	**20**	**7**	**7.5**	**17.3**	**0.0073**	**21**	**10**
<0.075	46.5	**46.5**			**240**	**20**	**4.5**	**5**	**18.3**	**0.0037**	**13**	**6**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.3**	**0.0026**	**13**	**6**
					1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**6**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

STUDENT	**ELIZABETH MUTHUI**		
SITE	**MUA HILLS**		
Depth (m)		**SITE No**	**MUA HILLS**
Test date:	28.08.2019	**Sample**	**1985m**
Specification	According to BS 1377:1990	**LOCATION**	MACHAKOS COUNTY

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	51.4
Washed dry sample mass + pan	(gm)		Fine percent	51.4
Washed dry sample mass	(gm)	48.6	Acceptance Criteria	

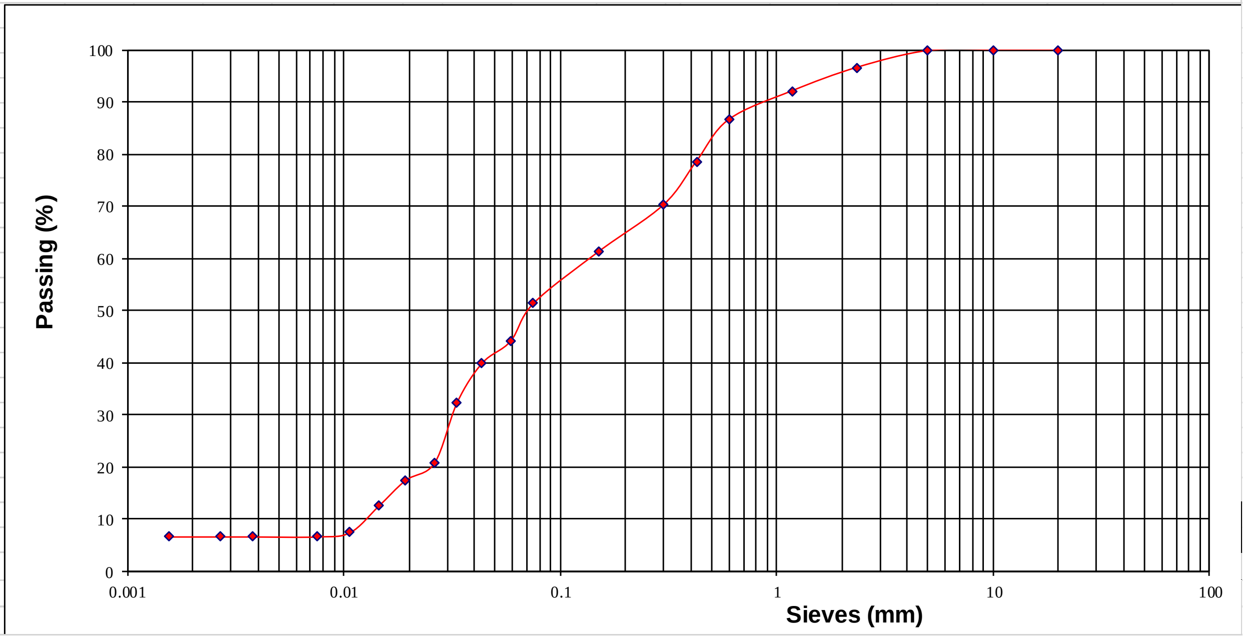
Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	0	**0.0**	**100.0**
5	0.2	**0.2**	**99.8**
2.36	3.2	**3.2**	**96.6**
1.18	4.5	**4.5**	**92.1**
0.6	5.5	**5.5**	**86.6**
0.425	8	**8.0**	**78.6**
0.3	8.3	**8.3**	**70.3**
0.15	9	**9.0**	**61.3**
0.075	9.9	**9.9**	**51.4**
<0.075	51.4	**51.4**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**27.0**	**27.5**	**9.4**	**0.0587**	**86**	**44**
	1	**20**	**24.5**	**25**	**10.3**	**0.0435**	**78**	**40**
	2	**20**	**20.0**	**20.5**	**12.1**	**0.0333**	**63**	**32**
	4	**20**	**13**	**13.5**	**14.9**	**0.0261**	**41**	**21**
	8	**20**	**11**	**11.5**	**16.1**	**0.0192**	**34**	**17**
	15	**20**	**8**	**8.5**	**16.9**	**0.0144**	**24**	**12**
	30	**20**	**5**	**5.5**	**18.5**	**0.0106**	**15**	**7**
	60	**20**	**4.5**	**5**	**18.7**	**0.0076**	**13**	**7**
	240	**20**	**4.5**	**5**	**18.7**	**0.0038**	**13**	**7**
	480	**20**	**4.5**	**5**	**18.7**	**0.0027**	**13**	**7**
	1440	**20**	4.5	**5**	**18.7**	0.0015	**13**	**7**

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

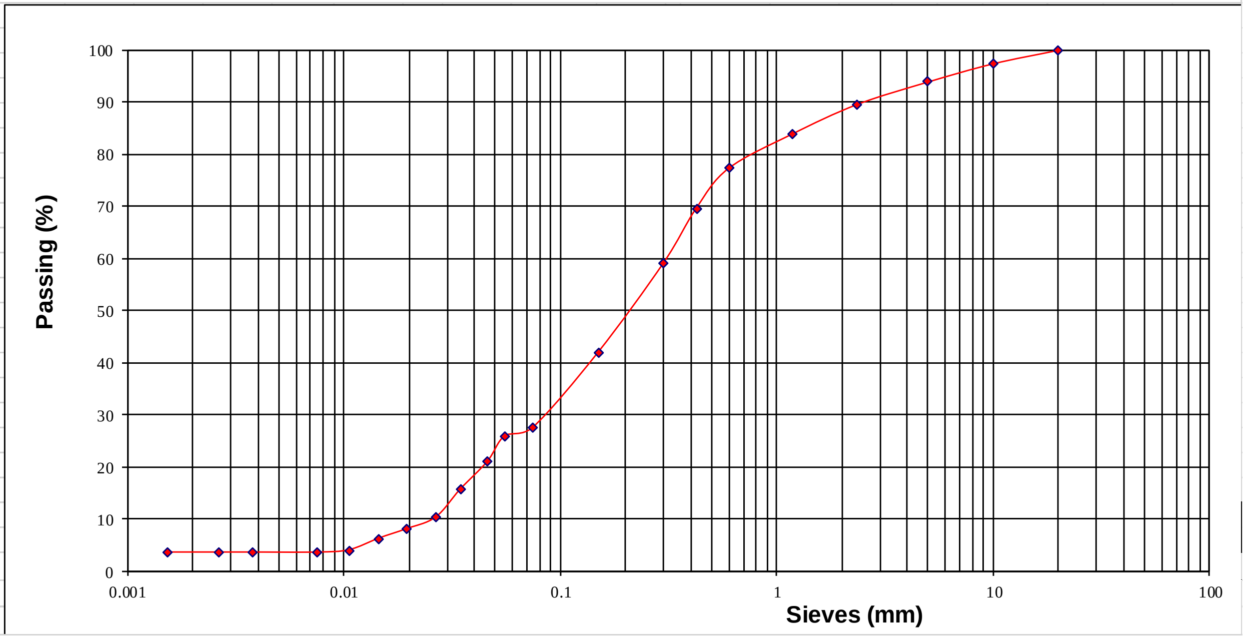
SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1825

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	27.6
Washed dry sample mass + pan	(gm)		Fine percent	27.6
Washed dry sample mass	(gm)	72.4	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	0.0	100.0	9AM	0.5	20	29.5	30	8.4	0.0555	94	26
10	2.6	2.6	97.4									
5	3.5	3.5	93.9									
2.36	4.3	4.3	89.6		1	20	24.0	24.5	11.6	0.0461	76	21
1.18	5.7	5.7	83.9		2	20	18.0	18.5	13	0.0345	57	16
0.6	6.6	6.6	77.3		4	20	12	12.5	15.4	0.0266	37	10
0.425	7.7	7.7	69.6		8	20	9.5	10	16.5	0.0194	29	8
0.3	10.5	10.5	59.1		15	20	7.5	8	17.3	0.0145	23	6
0.15	17.1	17.1	42.0		30	20	5	5.5	18.3	0.0106	15	4
0.075	14.4	14.4	27.6		60	20	4.5	5	18.5	0.0075	13	4
<0.075	27.6	27.6			240	20	4.5	5	18.5	0.0038	13	4
TOTAL	100				480	20	4.5	5	18.5	0.0027	13	4
					1440	20	4.5	5	18.5	0.0015	13	4

GRADING CURVE - HYDROMETER ANALYSIS



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(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1835 1a

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	52.5
Washed dry sample mass + pan	(gm)		Fine percent	52.5
Washed dry sample mass	(gm)	47.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	0.0	100.0	9AM	0.5	20	29.0	29.5	8.5	0.0558	92	48
10	0	0.0	100.0									
5	0.5	0.5	99.5									
2.36	0.2	0.2	99.3		1	20	26.5	27	9.6	0.042	84	44
1.18	1.3	1.3	98.0		2	20	21.5	22	11.6	0.0326	68	36
0.6	4	4.0	94.0		4	20	16	16.5	13.8	0.0251	50	26
0.425	5.9	5.9	88.1		8	20	11	11.5	15.9	0.0191	34	18
0.3	7.2	7.2	80.9		15	20	8	8.5	17.1	0.0145	24	13
0.15	13.4	13.4	67.5		30	20	5.5	6	18.1	0.0105	16	9
0.075	15	15.0	52.5		60	20	4.5	5	18.5	0.0075	13	7
<0.075	52.5	52.5			240	20	4.5	5	18.5	0.0038	13	7
TOTAL	100				480	20	4.5	5	18.5	0.0027	13	7
					1440	20	4.5	5	18.5	0.0015	13	7

GRADING CURVE - HYDROMETER ANALYSIS

SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:	18.09.2019	**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1835B

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	47.4
Washed dry sample mass + pan	(gm)		Fine percent	47.4
Washed dry sample mass	(gm)	52.6	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377									
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	0.0	100.0	9AM	0.5	20	26.5	27	9.6	0.0593	84	40
10	0.3	0.3	99.7									
5	1.5	1.5	98.2									
2.36	2.2	2.2	96.0		1	20	22.5	23	11.1	0.0451	71	34
1.18	7.5	7.5	88.5		2	20	17.0	17.5	12.3	0.0336	53	25
0.6	5.7	5.7	82.8		4	20	11	11.5	15.7	0.0268	34	16
0.425	4.6	4.6	78.2		8	20	7	7.5	17.3	0.0199	21	10
0.3	7.5	7.5	70.7		15	20	5	5.5	18.1	0.0149	15	7
0.15	8.3	8.3	62.4		30	20	4.5	5	18.3	0.0106	13	6
0.075	15	15.0	47.4		60	20	4.5	5	18.3	0.0075	13	6
<0.075	47.4	47.4			240	20	4.5	5	18.3	0.0037	13	6
TOTAL	100				480	20	4.5	5	18.3	0.0026	13	6
					1440	20	4.5	5	18.3	0.0015	13	6

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1835c

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	23.5
Washed dry sample mass + pan	(gm)		Fine percent	23.5
Washed dry sample mass	(gm)	76.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	0	**0.0**	**100.0**
5	2.5	**2.5**	**97.5**
2.36	4.4	**4.4**	**93.1**
1.18	5.3	**5.3**	**87.8**
0.6	5.7	**5.7**	**82.1**
0.425	7.2	**7.2**	**74.9**
0.3	12.1	**12.1**	**62.8**
0.15	15.9	**15.9**	**46.9**
0.075	23.4	**23.4**	**23.5**
<0.075	23.5	**23.5**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**29.5**	**30**	**8.4**	**0.0555**	**94**	**22**
	1	**20**	**25.0**	**25.5**	**10.3**	**0.0435**	**79**	**19**
	2	**20**	**17.0**	**17.5**	**13.4**	**0.035**	**53**	**13**
	4	**20**	**14**	**14.5**	**14.6**	**0.0259**	**44**	**10**
	8	**20**	**10**	**10.5**	**16.3**	**0.0193**	**31**	**7**
	15	**20**	**8.5**	**9**	**16.7**	**0.0143**	**26**	**6**
	30	**20**	**5**	**5.5**	**18.3**	**0.0106**	**15**	**3**
	60	**20**	**4.5**	**5**	**18.5**	**0.0075**	**13**	**3**
	240	**20**	**4.5**	**5**	**18.5**	**0.0038**	**13**	**3**
	480	**20**	**4.5**	**5**	**18.5**	**0.0027**	**13**	**3**
	1440	**20**	4.5	**5**	**18.5**	0.0015	**13**	**3**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

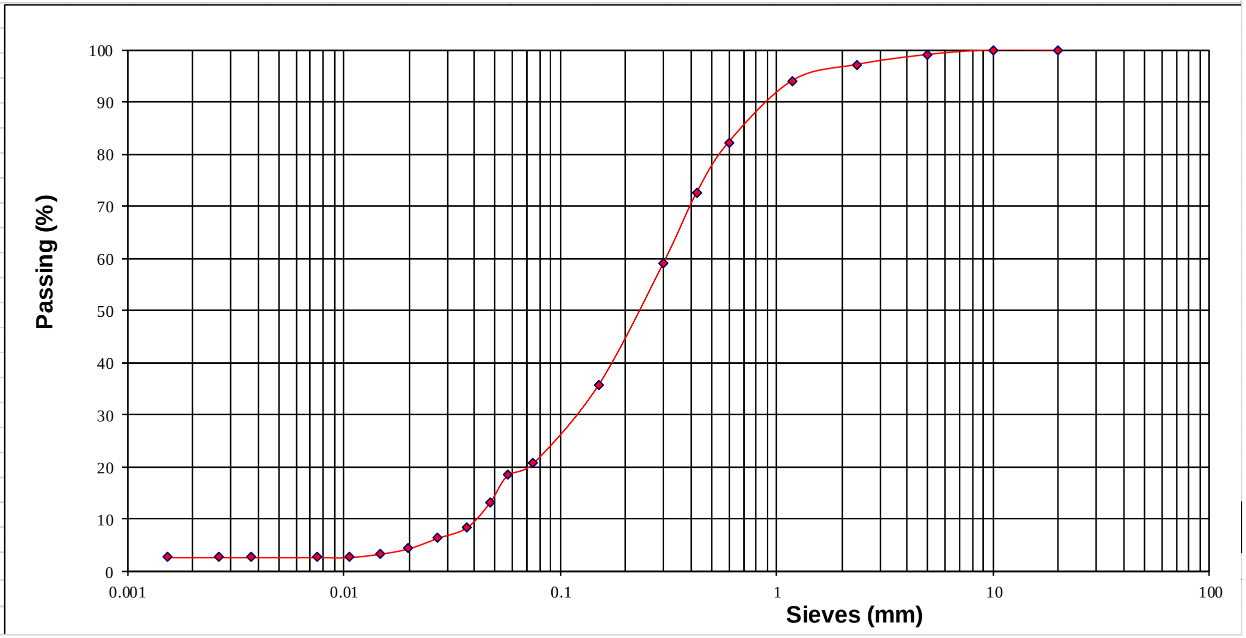
SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:	19.09.2019	**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1835D

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	20.7
Washed dry sample mass + pan	(gm)		Fine percent	20.7
Washed dry sample mass	(gm)	79.3	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	0.0	100.0	9AM	0.5	20	28.0	28.5	8.9	0.0571	89	18
10	0	0.0	100.0									
5	0.9	0.9	99.1									
2.36	1.9	1.9	97.2		1	20	20.0	20.5	12.1	0.0471	63	13
1.18	3.1	3.1	94.1		2	20	13.0	13.5	14.9	0.037	41	8
0.6	11.8	11.8	82.3		4	20	10	10.5	16.1	0.0272	31	6
0.425	9.8	9.8	72.5		8	20	7	7.5	17.3	0.0199	21	4
0.3	13.3	13.3	59.2		15	20	5.5	6	17.9	0.0148	16	3
0.15	23.5	23.5	35.7		30	20	4.5	5	18.3	0.0106	13	3
0.075	15	15.0	20.7		60	20	4.5	5	18.3	0.0075	13	3
<0.075	20.7	20.7			240	20	4.5	5	18.3	0.0037	13	3
TOTAL	100				480	20	4.5	5	18.3	0.0026	13	3
					1440	20	4.5	5	18.3	0.0015	13	3

GRADING CURVE - HYDROMETER ANALYSIS



SIEVE ANALYSIS

CLIENT			
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1835E

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	42.5
Washed dry sample mass + pan	(gm)		Fine percent	42.5
Washed dry sample mass	(gm)	57.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**29.5**	**30**	**8.4**	**0.0555**	**94**	**40**
10	0	**0.0**	**100.0**									
5	1.4	**1.4**	**98.6**									
2.36	0.7	**0.7**	**97.9**		**1**	**20**	**25.0**	**25.5**	**10.1**	**0.043**	**79**	**34**
1.18	1.6	**1.6**	**96.3**		**2**	**20**	**21.5**	**22**	**11.5**	**0.0325**	**68**	**29**
0.6	8.5	**8.5**	**87.8**		**4**	**20**	**19**	**19.5**	**12.5**	**0.0239**	**60**	**25**
0.425	7.1	**7.1**	**80.7**		**8**	**20**	**17.5**	**18**	**13.1**	**0.0173**	**55**	**23**
0.3	8.5	**8.5**	**72.2**		**15**	**20**	**15.5**	**16**	**13.9**	**0.013**	**49**	**21**
0.15	15.3	**15.3**	**56.9**		**30**	**20**	**14**	**14.5**	**14.5**	**0.0094**	**44**	**19**
0.075	14.4	**14.4**	**42.5**		**60**	**20**	**13**	**13.5**	**14.9**	**0.0067**	**41**	**17**
<0.075	42.5	**42.5**			**240**	**20**	**8.5**	**9**	**16.7**	**0.0036**	**26**	**11**
TOTAL	100				**480**	**20**	**6**	**6.5**	**17.7**	**0.0026**	**18**	**8**
					1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**6**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

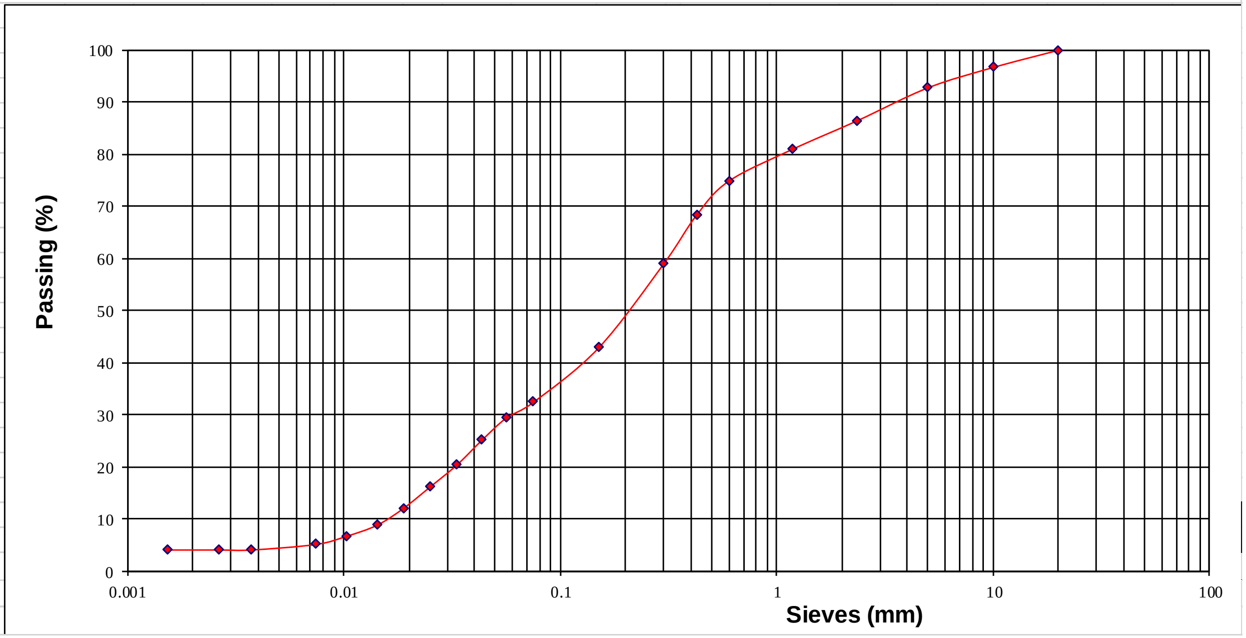
SIEVE ANALYSIS

CLIENT			
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1840

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	32.5
Washed dry sample mass + pan	(gm)		Fine percent	32.5
Washed dry sample mass	(gm)	67.5	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	0.0	100.0	9AM	0.5	20	28.5	29	8.6	0.0562	91	29
10	3.3	3.3	96.7									
5	3.9	3.9	92.8									
2.36	6.3	6.3	86.5		1	20	24.5	25	10.3	0.0435	78	25
1.18	5.5	5.5	81.0		2	20	20.0	20.5	12.1	0.0333	63	21
0.6	6.1	6.1	74.9		4	20	16	16.5	13.7	0.0251	50	16
0.425	6.6	6.6	68.3		8	20	12	12.5	15.3	0.0187	37	12
0.3	9.3	9.3	59.0		15	20	9	9.5	16.5	0.0142	28	9
0.15	16.1	16.1	42.9		30	20	7	7.5	17.3	0.0103	21	7
0.075	10.4	10.4	32.5		60	20	5.5	6	17.9	0.0074	16	5
<0.075	32.5	32.5			240	20	4.5	5	18.3	0.0037	13	4
TOTAL	100				480	20	4.5	5	18.3	0.0026	13	4
					1440	20	4.5	5	18.3	0.0015	13	4

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

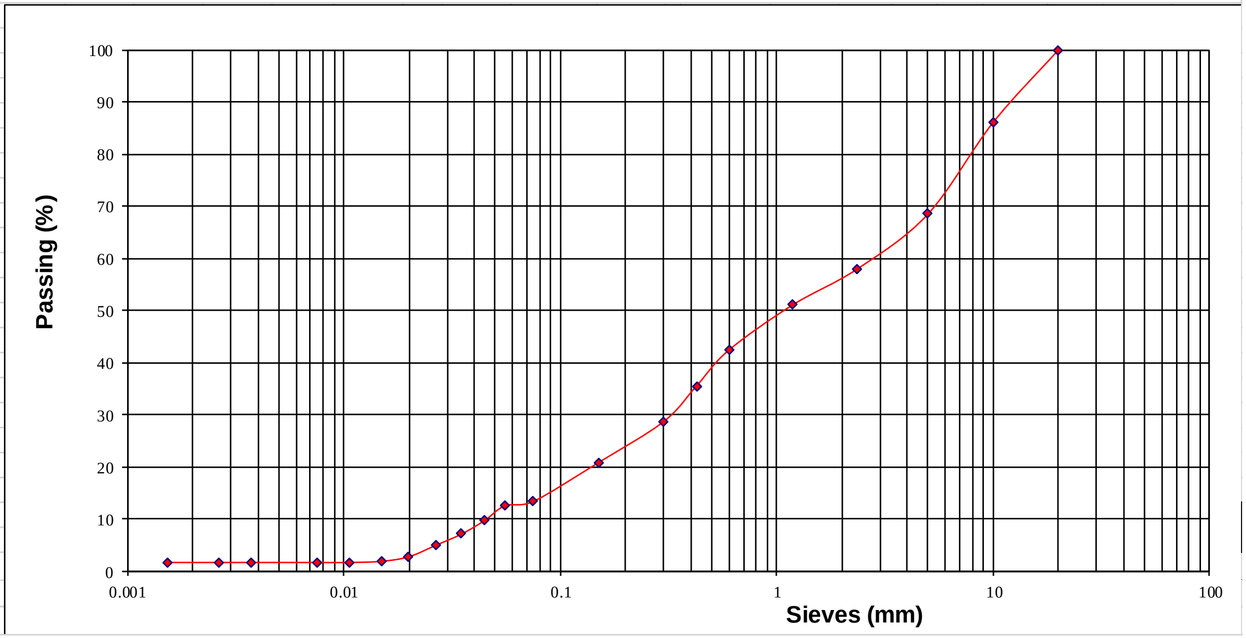
SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1841

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	13.45
Washed dry sample mass + pan	(gm)		Fine percent	13.5
Washed dry sample mass	(gm)	86.55	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	9AM	0.5	20	29.5	30	8.4	0.0555	94	13
10	13.9	**13.9**	**86.1**									
5	17.55	**17.6**	**68.6**									
2.36	10.5	**10.5**	**58.1**		1	20	23.0	23.5	10.9	0.0447	73	10
1.18	6.95	**7.0**	**51.1**		2	20	17.0	17.5	13.3	0.0349	53	7
0.6	8.65	**8.7**	**42.5**		4	20	12	12.5	15.3	0.0265	37	5
0.425	6.9	**6.9**	**35.6**		8	20	7	7.5	17.3	0.0199	21	3
0.3	6.8	**6.8**	**28.8**		15	20	5	5.5	18.1	0.0149	15	2
0.15	7.85	**7.9**	**20.9**		30	20	4.5	5	18.3	0.0106	13	2
0.075	7.45	**7.5**	**13.5**		60	20	4.5	5	18.3	0.0075	13	2
<0.075	13.5	**13.5**			240	20	4.5	5	18.3	0.0037	13	2
TOTAL	100				480	20	4.5	5	18.3	0.0026	13	2
					1440	20	4.5	5	18.3	0.0015	13	2

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

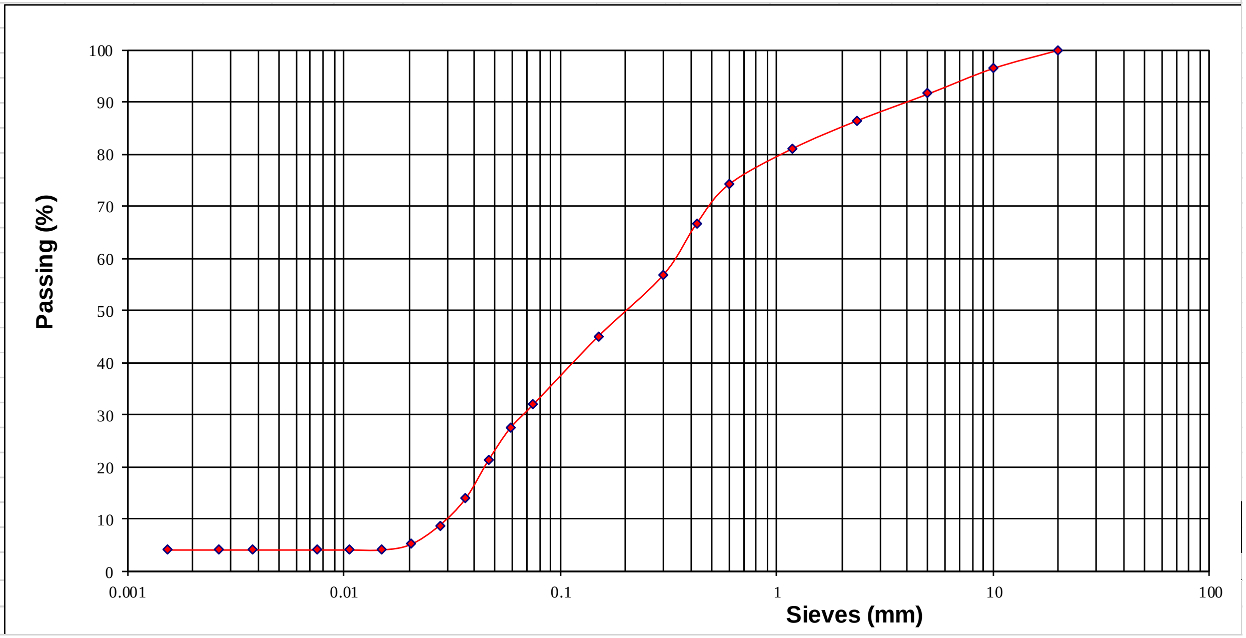
SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1859

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	32
Washed dry sample mass + pan	(gm)		Fine percent	32.0
Washed dry sample mass	(gm)	68	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**27.0**	**27.5**	**9.4**	**0.0587**	**86**	**27**
10	3.5	**3.5**	**96.5**									
5	4.9	**4.9**	**91.6**									
2.36	5.1	**5.1**	**86.5**		**1**	**20**	**21.0**	**21.5**	**11.8**	**0.0465**	**66**	**21**
1.18	5.4	**5.4**	**81.1**		**2**	**20**	**14.0**	**14.5**	**14.6**	**0.0366**	**44**	**14**
0.6	6.9	**6.9**	**74.2**		**4**	**20**	**9**	**9.5**	**16.7**	**0.0277**	**28**	**9**
0.425	7.6	**7.6**	**66.6**		**8**	**20**	**5.5**	**6**	**18.1**	**0.0204**	**16**	**5**
0.3	9.7	**9.7**	**56.9**		**15**	**20**	**4.5**	**5**	**18.5**	**0.015**	**13**	**4**
0.15	11.8	**11.8**	**45.1**		**30**	**20**	**4.5**	**5**	**18.5**	**0.0106**	**13**	**4**
0.075	13.1	**13.1**	**32.0**		**60**	**20**	**4.5**	**5**	**18.5**	**0.0075**	**13**	**4**
<0.075	32.0	**32.0**			**240**	**20**	**4.5**	**5**	**18.5**	**0.0038**	**13**	**4**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.5**	**0.0027**	**13**	**4**
					1440	**20**	4.5	**5**	18.5	0.0015	**13**	**4**

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1883

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	29.2
Washed dry sample mass + pan	(gm)		Fine percent	29.2
Washed dry sample mass	(gm)	70.8	Acceptance Criteria	

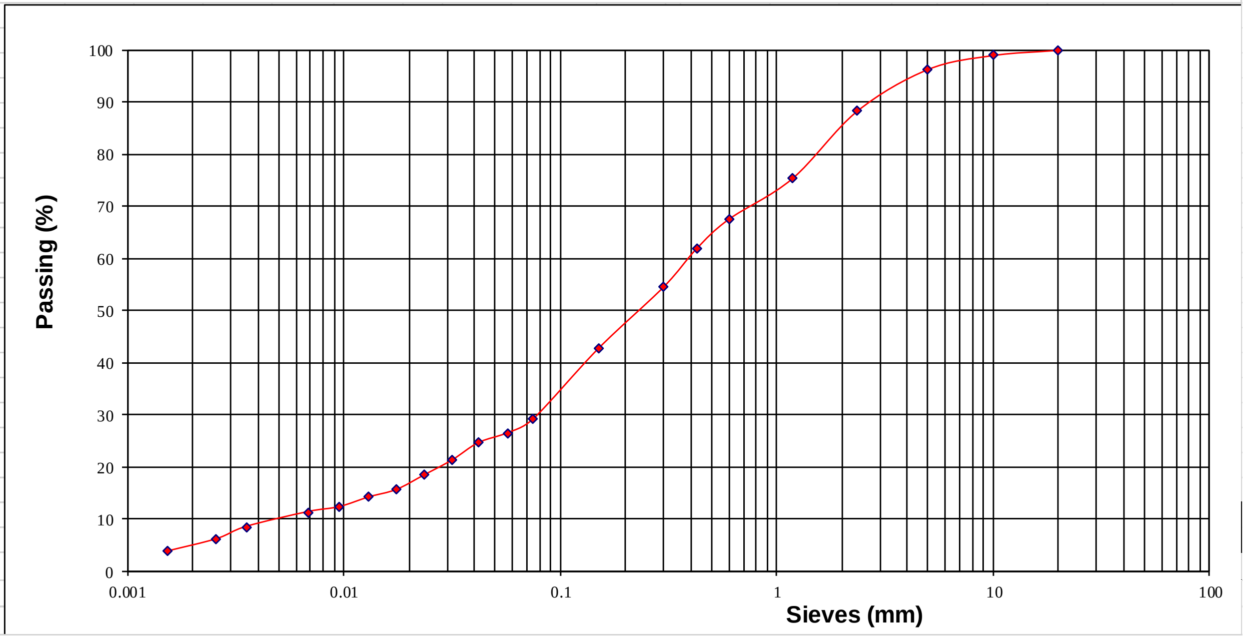
Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	1	**1.0**	**99.0**
5	2.7	**2.7**	**96.3**
2.36	8	**8.0**	**88.3**
1.18	13	**13.0**	**75.3**
0.6	7.8	**7.8**	**67.5**
0.425	5.7	**5.7**	**61.8**
0.3	7.3	**7.3**	**54.5**
0.15	11.8	**11.8**	**42.7**
0.075	13.5	**13.5**	**29.2**
<0.075	29.2	**29.2**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**28.5**	**29**	**8.8**	**0.0568**	**91**	**26**
	1	**20**	**26.5**	**27**	**9.5**	**0.0417**	**84**	**25**
	2	**20**	**23.0**	**23.5**	**10.9**	**0.0316**	**73**	**21**
	4	**20**	**20**	**20.5**	**12.1**	**0.0235**	**63**	**18**
	8	**20**	**17**	**17.5**	**13.3**	**0.0175**	**53**	**16**
	15	**20**	**15.5**	**16**	**13.9**	**0.013**	**49**	**14**
	30	**20**	**13.5**	**14**	**14.7**	**0.0095**	**42**	**12**
	60	**20**	**12.5**	**13**	**15.1**	**0.0068**	**39**	**11**
	240	**20**	**9.5**	**10**	**16.3**	**0.0035**	**29**	**9**
	480	**20**	**7**	**7.5**	**17.3**	**0.0026**	**21**	**6**
	1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**4**

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering
(Soil Mechanics Laboratory)

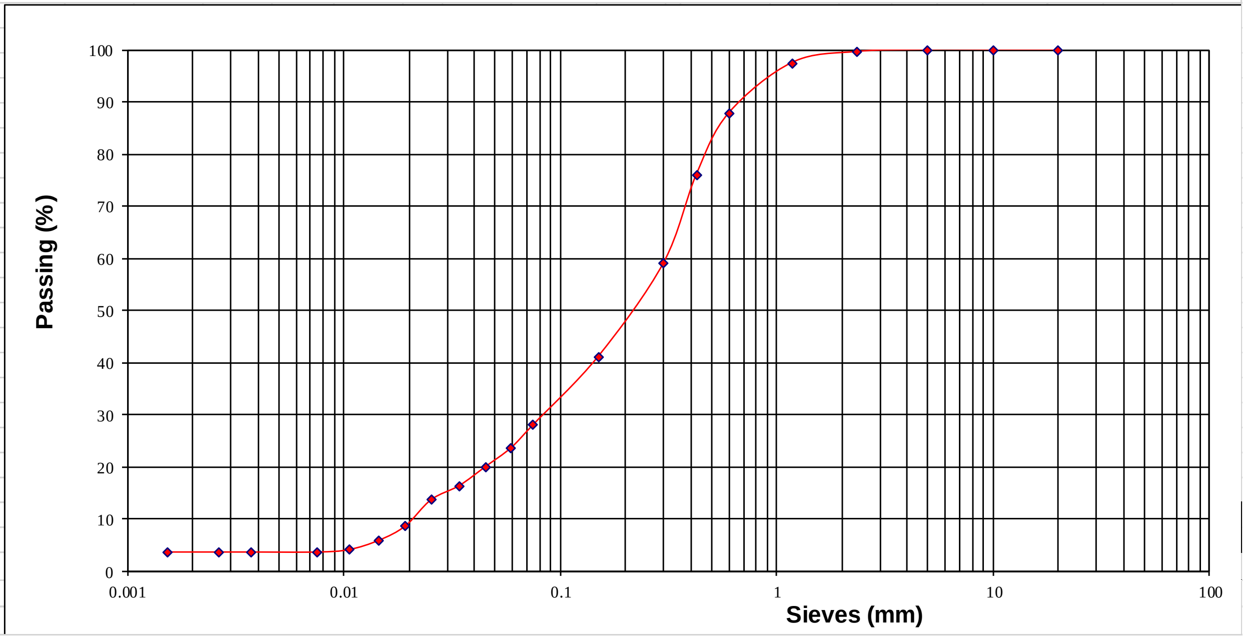
SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1891

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	28.1
Washed dry sample mass + pan	(gm)		Fine percent	28.1
Washed dry sample mass	(gm)	71.9	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377									
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**26.5**	**27**	**9.6**	**0.0593**	**84**	**24**
10	0	**0.0**	**100.0**									
5	0	**0.0**	**100.0**									
2.36	0.4	**0.4**	**99.6**		**1**	**20**	**22.5**	**23**	**11.1**	**0.0451**	**71**	**20**
1.18	2.1	**2.1**	**97.5**		**2**	**20**	**18.5**	**19**	**12.7**	**0.0341**	**58**	**16**
0.6	9.7	**9.7**	**87.8**		**4**	**20**	**15.5**	**16**	**13.9**	**0.0252**	**49**	**14**
0.425	11.8	**11.8**	**76.0**		**8**	**20**	**10**	**10.5**	**16.1**	**0.0192**	**31**	**9**
0.3	16.9	**16.9**	**59.1**		**15**	**20**	**7**	**7.5**	**17.3**	**0.0145**	**21**	**6**
0.15	17.9	**17.9**	**41.2**		**30**	**20**	**5**	**5.5**	**18.1**	**0.0105**	**15**	**4**
0.075	13.1	**13.1**	**28.1**		**60**	**20**	**4.5**	**5**	**18.3**	**0.0075**	**13**	**4**
<0.075	28.1	**28.1**			**240**	**20**	**4.5**	**5**	**18.3**	**0.0037**	**13**	**4**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.3**	**0.0026**	**13**	**4**
					1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**4**

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	Elizabeth Muthui		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1903

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	34.2
Washed dry sample mass + pan	(gm)		Fine percent	34.2
Washed dry sample mass	(gm)	65.8	Acceptance Criteria	

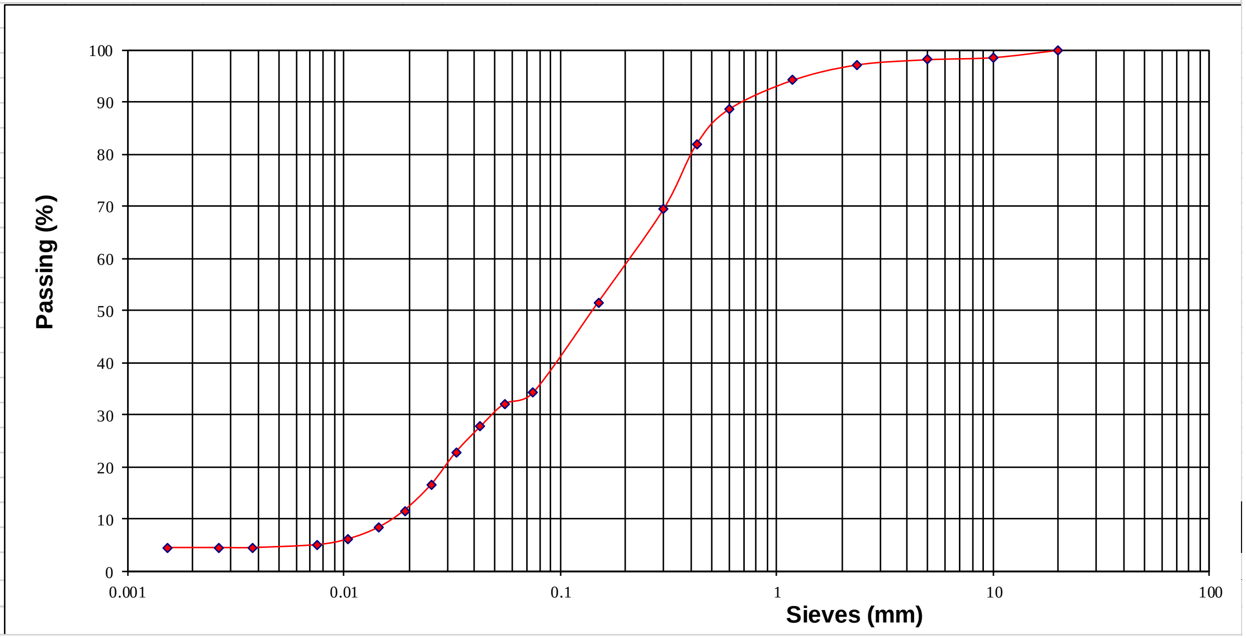
Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	1.4	**1.4**	**98.6**
5	0.4	**0.4**	**98.2**
2.36	1	**1.0**	**97.2**
1.18	3	**3.0**	**94.2**
0.6	5.6	**5.6**	**88.6**
0.425	6.8	**6.8**	**81.8**
0.3	12.4	**12.4**	**69.4**
0.15	17.8	**17.8**	**51.6**
0.075	17.4	**17.4**	**34.2**
<0.075	34.2	**34.2**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**29.5**	**30**	**8.4**	**0.0555**	**94**	**32**
	1	**20**	**25.5**	**26**	**10**	**0.0428**	**81**	**28**
	2	**20**	**21.0**	**21.5**	**11.8**	**0.0329**	**66**	**23**
	4	**20**	**15.5**	**16**	**14.1**	**0.0254**	**49**	**17**
	8	**20**	**11**	**11.5**	**15.9**	**0.0191**	**34**	**12**
	15	**20**	**8**	**8.5**	**17**	**0.0144**	**24**	**8**
	30	**20**	**6**	**6.5**	**17.9**	**0.0105**	**18**	**6**
	60	**20**	**5**	**5.5**	**18.3**	**0.0075**	**15**	**5**
	240	**20**	**4.5**	**5**	**18.5**	**0.0038**	**13**	**4**
	480	**20**	**4.5**	**5**	**18.5**	**0.0027**	**13**	**4**
	1440	**20**	4.5	**5**	**18.5**	0.0015	**13**	**4**

GRADING CURVE - HYDROMETER ANALYSIS



University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1940

Pan mass	(gm)	0		
Initial dry sample mass + pan	(gm)			
Initial dry sample mass	(gm)	100	Fine mass	39.1
Washed dry sample mass + pan	(gm)		Fine percent	39.1
Washed dry sample mass	(gm)	60.9	Acceptance Criteria	

Wet & Dry Sieve Analysis to BS 1377				Hydrometer Analysis to BS 1377								
Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)	Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
20	0	**0.0**	**100.0**	**9AM**	**0.5**	**20**	**29.5**	**30**	**8.4**	**0.0555**	**94**	**37**
10	0	**0.0**	**100.0**									
5	0.2	**0.2**	**99.8**									
2.36	1.2	**1.2**	**98.6**		**1**	**20**	**27.5**	**28**	**9.1**	**0.0408**	**87**	**34**
1.18	2.7	**2.7**	**95.9**		**2**	**20**	**24.5**	**25**	**10.3**	**0.0307**	**78**	**30**
0.6	7.9	**7.9**	**88.0**		**4**	**20**	**19**	**19.5**	**12.5**	**0.0239**	**60**	**23**
0.425	6.9	**6.9**	**81.1**		**8**	**20**	**15**	**15.5**	**14.1**	**0.018**	**47**	**18**
0.3	9	**9.0**	**72.1**		**15**	**20**	**12**	**12.5**	**15.3**	**0.0137**	**37**	**15**
0.15	17.2	**17.2**	**54.9**		**30**	**20**	**10**	**10.5**	**16.1**	**0.0099**	**31**	**12**
0.075	15.8	**15.8**	**39.1**		**60**	**20**	**8**	**8.5**	**16.9**	**0.0072**	**24**	**10**
<0.075	39.1	**39.1**			**240**	**20**	**5**	**5.5**	**18.1**	**0.0037**	**15**	**6**
TOTAL	100				**480**	**20**	**4.5**	**5**	**18.3**	**0.0026**	**13**	**5**
					1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**5**

GRADING CURVE - HYDROMETER ANALYSIS

University of Nairobi

Department of Civil & Construction Engineering

(Soil Mechanics Laboratory)

SIEVE ANALYSIS

CLIENT	**Elizabeth Muthui**		
SITE			
Depth (m)		**SITE No**	
Test date:		**Sample**	
Specification	According to BS 1377:1990	**LOCATION**	Altitude 1954

Pan mass	(gm)	0			
Initial dry sample mass + pan	(gm)				
Initial dry sample mass	(gm)	100	Fine mass		28.1
Washed dry sample mass + pan	(gm)		Fine percent		28.1
Washed dry sample mass	(gm)	71.9	Acceptance Criteria		

Wet & Dry Sieve Analysis to BS 1377

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
20	0	**0.0**	**100.0**
10	3.2	**3.2**	**96.8**
5	3.3	**3.3**	**93.5**
2.36	11.2	**11.2**	**82.3**
1.18	12.5	**12.5**	**69.8**
0.6	7.3	**7.3**	**62.5**
0.425	5.4	**5.4**	**57.1**
0.3	7.5	**7.5**	**49.6**
0.15	11.4	**11.4**	**38.2**
0.075	10.1	**10.1**	**28.1**
<0.075	28.1	**28.1**	
TOTAL	100		

Hydrometer Analysis to BS 1377

Date	Time In min	Temp ° C.	Rh1	Rh	HR	D(mm)	K(%)	K(corrected)
9AM	**0.5**	**20**	**28.5**	**29**	**8.8**	**0.0568**	**91**	**25**
	1	**20**	**25.0**	**25.5**	**10.1**	**0.043**	**79**	**22**
	2	**20**	**21.5**	**22**	**11.5**	**0.0325**	**68**	**19**
	4	**20**	**16.5**	**17**	**13.5**	**0.0249**	**52**	**15**
	8	**20**	**12**	**12.5**	**15.3**	**0.0187**	**37**	**10**
	15	**20**	**10.5**	**11**	**15.9**	**0.0139**	**32**	**9**
	30	**20**	**8.5**	**9**	**16.7**	**0.0101**	**26**	**7**
	60	**20**	**7.5**	**8**	**17.1**	**0.0072**	**23**	**6**
	240	**20**	**4.5**	**5**	**18.3**	**0.0037**	**13**	**4**
	480	**20**	**4.5**	**5**	**18.3**	**0.0026**	**13**	**4**
	1440	**20**	4.5	**5**	**18.3**	0.0015	**13**	**4**

GRADING CURVE - HYDROMETER ANALYSIS