

**EFFECT OF VEGETATION COVER ON RUNOFF AND SOIL
LOSS IN AKIRIAMET-KIMPUR CATCHMENT, WEST POKOT
COUNTY, KENYA**

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DECLARATION


This thesis is my original work and has not been presented to any other University for academic award.

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DEDICATION

I dedicate this work to my children Prince and Prudence, students of Geography and those who find interest in the dynamics of the Earth surface.

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OPERATIONAL DEFINITION OF TERMS

Rainfall	Form of precipitation falling from the atmosphere as drops of water.
Runoff	Excess water which flow on the surface during or after precipitation. It can be overland flow or channel flow
Runoff plot	A small part of the landscape designated for capturing and measuring runoff especially during rainfall event.
Semi-arid area	Region which is dry, with sparse vegetation cover and insufficient rainfall; not exceeding 650mm annually.
Soil erodibility	Capacity of the soil particles to get loosened, detached and trans-located.
Soil erosion	Detachment, removal and deposition of soil particles down slope.
Vegetation cover	Coverage over the soil surface by plant leaves and branches (canopy) expressed as a percentage cover on land.
Volume of runoff	Actual amount of water flowing on the surface in erosion plots, collected and expressed in cubic metres (m ³)

ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-Arid Lands
EuroSEM	European Soil Erosion Model
GIS	Geographic Information Systems
GoK	Government of Kenya
FAO	Food and Agricultural Organization
UNEP	United Nations Environmental Programme
KMS	Kenya Meteorological Service
KNBS	Kenya National Bureau of Statistics
NACOSTI	National Commission for Science, Technology and Innovation
RUSLE	Revised Universal Soil Loss Equation
USLE	Universal Soil Loss Equation
WMO	World Meteorological Organization

ABSTRACT

Climate and soil characteristics contribute to development of sparse vegetation cover in semi-arid areas. It is recognized that total annual rainfall experienced in such environment is low. However, it is quite infrequent and often erratic causing occurrence of massive runoff. Existing soil and vegetation characteristics favour erosion and movement of large loads of sediment in runoff leading to substantial soil loss. There is need for assessment of environmental factors which influence soil erosion in these areas in order to develop soil conservation policies for proper soil resource management and land use planning. This study aimed at establishing the effect of vegetation cover on runoff and sediment production in Akiriamet-Kimpur catchment. In particular, the study sought to determine the volume of runoff and quantity of sediment generated from runoff plots under natural vegetation cover and rainfall characteristics. Erosion plot experiment was set up based on quasi experimental research design. Two 20m long by 10m wide runoff plots were constructed on gentle slopes, 1.5–2.0% slope grade. Vegetation cover on the soil was measured using the transect line-intercept survey method. The first plot had 25–50% vegetation cover and the second plot had 50–75% vegetation cover. Each plot was replicated twice. Runoff and sediment generated from the plots were collected in cubical tanks at the base of each plot, measured and recorded for fifteen rainfall events during the long rains season. A standard rain gauge was used to measure rainfall. Data was analysed using correlation analysis and linear regression methods. The findings were presented in tables and graphs. The results show that runoff production varied from 1.03% to 1.44% of total rain water. Soil loss was 120.3–155.55 g/m². Runoff-rainfall correlation analysis showed a significant positive relationship ($r = 0.9609$). Percentage variance in runoff generation (r^2) was 92.33%, $P < 0.05$. Soil loss had significant positive relationship with runoff ($r = 0.9840$). Percentage variance in soil loss (r^2) was 96.83%, $P < 0.05$. The study established that runoff production and soil loss is slow under dense vegetation cover. Hence, the study recommends planting more trees and protection of existing natural vegetation in the study area in order to improve plant cover on the soils. It also recommends development of a soil conservation and management strategy in the study area.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Running water is a significant agent of erosion in dry areas. Sheet and channel flows on the earth surface play a key role in wearing down and building up landscape (Getis *et al.*, 2009). The Universal Soil Loss Equation (USLE) use soil erodibility factor (K), rainfall-runoff factor (R), slope length (L), slope steepness (S), cover management factor (C) and supporting practices factor (P) to compute soil loss. According to USLE, soil loss (A) is computed as $A = R \times K \times L \times S \times C \times P$ (Renard *et al.*, 1991). The most important parameters in this case are rainfall-runoff factor(R), slope values (L, S) and land cover factors(C, P). Runoff process is important in shaping landscape of dry areas (Waugh, 2003). It causes changes on the landscape by producing distinct surface landforms through erosion (Palmer and Yates, 2005). Production of runoff propels detachment of soil particles which leads to soil erosion. However, runoff production is controlled by the slope steepness, soil, vegetation cover and rainfall characteristics. These factors influence physical erosion directly or indirectly. Vegetation cover increase surface resistance to water erosion, influence infiltration and evapo-transpiration processes which determine the amount of runoff water on the land surface (Tucker *et al.*, 1999).

Fluvial activity is one of the major geomorphological processes in dry environments. Running water uses its energy to erode and transport loose soil particles down the slope and depending on the amount of runoff generated under existing topographic conditions, the process can be instrumental in fashioning landforms (Hugget, 2003; Bowen & Pallister, 2006). Runoff and soil loss have a positive relationship (Abua & Digha, 2015). Results from a study (Adediji, 2006) showed that 63.8% of the soil loss

variance from slopes of the studied basins was caused by runoff; $r^2 = 0.638$. This means that runoff is a significant parameter in establishing the quantity of soil loss.

Globally, soil erosion is a dominant agent of soil degradation accounting for 70–90% of total soil loss (Tesfahunegn *et al.*, 2013). According to Food and Agricultural Organization (FAO) and United Nations Environmental Programme (UNEP) approximations, soil erosion had already affected more than two billion hectares of land in the world by the year 2014. The typical rate of global soil degradation from these estimates was almost 9 m hectares per year. In Northern Ethiopia, India and China, high rate of soil erosion has been reported (Gelagay & Minale, 2016; Tadesse *et al.*, 2017; Kayet *et al.*, 2018 and Guo *et al.*, 2015). The depth of soil is diminished by 1mm following a loss of 15 tons of soil from a hectare piece of land in a single storm (Alam, 2014). The economic implication of this scenario is reduction in productivity of the soil. In Africa for instance, it is estimated that the yield reduction from farms due to soil erosion is 2–40%.

In Kenya, destruction of vegetation cover which exposes the soil to erosion is caused by uncontrolled human activities from their up-surgings populations (Olang & Furst, 2010). Arid and Semi-Arid Lands (ASALs) support more than 50% livestock and 35% of the human population (Obando, 2004). In a more recent study, 84% of the land area in Kenya is ASAL and is a home of 30% human population with at least 70% of the national livestock herd (GoK, 2012). The implication of this situation on such fragile environment is overgrazing and deforestation. This is a clear indication that the ASALs of Kenya are at risk of high rate of soil erosion through runoff. Based on the finding of earlier studies, it has been shown that rate of soil erosion and water loss in Kenya is high but uncertainty still exists on soil erosion in the semi-arid areas (Obando, 2004). Using the Revised Universal Soil Loss Equation (RUSLE), it was

found that the rate of soil erosion in Kathe-Kakai catchment in Machakos County, Kenya is 0–60ton/ha/yr (Wanjiku, 2015). In another study on erosion in river Perkerra catchment in Kenya, it was established that potential annual soil loss was 1.73million tonnes and the sediment yield at the catchment outlet was 1.47million tonnes (Onyando *et al.*, 2005). From the findings, the sediment delivery ratio was 83% giving impression that a higher proportion of sediment generated in the catchment was delivered to the outlet. A separate study on erosion in the upper river Mara basin found that erosion rate was high (Defersha & Melesse, 2012). According to the study, sediment yield was 29.95–162.38g/m². These studies demonstrate that runoff continues to erode large quantities of soil in Kenya's ASALs.

1.2 Statement of the problem

Soil erosion by water is most widespread and serious (Ghabbour *et al.*, 2017). It is the worst form of soil degradation with serious environmental and socio-economic implications (Phinzi & Ngetar, 2019). It is a serious problem in ASALs and affects community livelihoods and soil conservation efforts (Konana *et al.*, 2017). Rainfall, runoff, soil characteristics, terrain and vegetation cover aspects are factors that influence water erosion (Kayet *et al.*, 2018). Erratic and infrequent high intensity rainfalls common in the study area fall on highly erodible clay-sandy soils under sparse vegetation cover. This leads to occurrence of massive runoff and eventual soil erosion.

Loss of soil nutrients and organic carbon lead to decrease in productivity of the soil and its ability to sustain life (Martinez-Mena *et al.*, 2019). Poor crop and pasture development in the study area is a manifestation of degraded soils. Recurrent food shortage can be attributed to diminished soil fertility resulting from soil erosion. Thick deposits of sand in the valleys and development of gullies on slopes point at

possible loss of productive land. This can translate to huge economic losses. Hence, assessment of severity of soil loss through soil erosion study is crucial in addressing soil conservation and management efforts in the study area.

1.3 Objectives of the study

1.3.1 General objective

To establish the effects of vegetation cover on runoff and soil loss in Akiriamet-Kimpur catchment.

1.3.2 Specific objectives

- i. To determine the volume of runoff produced from runoff plots under natural vegetation cover and rainfall characteristics.
- ii. To determine the quantity of sediment generated from erosion plots under natural vegetation cover and rainfall characteristics.
- iii. To establish the rate of soil loss through runoff water in Akiriamet-Kimpur catchment.

1.4 Research questions

- i. How does runoff production on slopes respond to changes in amount of rainfall and vegetation cover?
- ii. How does sediment generation on slopes respond to changes in amount of rainfall and vegetation cover?
- iii. What is the rate of soil loss in Akiriamet-Kimpur catchment?

1.5 Hypotheses

- H_0 Runoff and sediment generation on a slope does not respond directly to changes in amount of rainfall and vegetation cover.

H₀ There is no significant relationship between the amount of rainfall and runoff produced in a catchment.

H₀ There is no significant relationship between the amount of soil loss by water and volume of runoff.

1.6 Justification and Significance of the study

It is recognized that quality of soil is the foundation of sustainable agriculture and that soil erosion is a major factor in land degradation. To mitigate the problem of soil erosion, continuous assessment and acquisition of data on severity of soil loss is necessary. This study generates information on the rate of soil loss by water in Akiriamet-Kimpur catchment. Loss of fertile soil has a definite negative impact on agriculture and community livelihoods. The findings in this study will inform policy makers on the need to develop a soil conservation strategy for proper soil resource management and land use planning in the study area.

Erosion and sedimentation are important geomorphological processes. Description of the landscape is based on identification and analysis of geomorphological processes at work. The information in this study will enrich existing knowledge in geomorphology and provide necessary information for future geomorphological studies.

1.7 Scope and Limitations of the study

The study focused on soil erosion by water using two bounded erosion plots under natural rainfall and vegetation cover characteristics in Akiriamet-Kimpur catchment. The erosion plots had precise measurements in terms of size and vegetation cover. Each plot was replicated twice for the purpose of checking validity in the resultant data. Rainfall, runoff and sediment yield were measured after each rainfall event which produced runoff in the plots during the research period. The study established a

rainfall-runoff relationship, a runoff-soil loss relationship and the rate of soil loss in the catchment using data collected.

The study assumed that the slope surfaces in the plots were even. However, surface irregularities are expected on slopes. In order to minimize the effect of surface irregularities on the results from the experiment, the range in slope grade and plot size were kept minimum. The research was conducted from March, 2017 to July, 2017.

1.8 Theoretical and Conceptual framework

1.8.1 *Theoretical framework*

Rainfall, runoff, slope and vegetation cover interact dynamically to cause soil loss. Production of runoff is controlled by amount and intensity of rainfall, soil moisture content, density of vegetation cover and slope steepness. High intensity rainfall cause occurrence of heavy runoff. However, the net amount of rain water reaching the ground surface is a function of plant canopy interception and through fall. Plant canopies intercept raindrops which reduce their direct impact on detachment of soil particles. This allows the water to drip off from the plant or to flow down the branches and stems to the soil. Infiltration of water into the soil and beginning of runoff depends on the level of antecedent moisture in the soil and the slope steepness. Steeper slopes accelerate Hortonian overland flow while higher level of antecedent moisture in the soil cause occurrence of saturation overland flow. Rate of sediment generation is then controlled by the amount and speed of runoff because the hydraulic force in runoff is influenced by its volume and speed of flow.

1.8.2 *Conceptual framework*

The study considered two independent variables: Rainfall and Vegetation. Runoff and sediment yield were dependent variables. Rainfall results to production of runoff on slopes. Through its hydraulic force, runoff generates sediment and moves it down the

slope. This depends on the amount of runoff produced, slope and vegetation attributes such as cover and rooting system. Large volume of runoff is produced under limited vegetation cover because canopy interception is least while low volume of runoff is produced under higher vegetation cover (Figure 1.1). Much sediment is carried in large volumes of runoff under reduced vegetation cover and little sediment is carried in small volumes of runoff under increased vegetation cover. The European Soil Erosion Model (EuroSEM) highlights the interactions among rainfall, vegetation, runoff and sediment generation on a flow chart (Morgan *et al.*, 1998). With modification, this study recognized the interactions and in the light of its major domains adopted it into its conceptual framework.

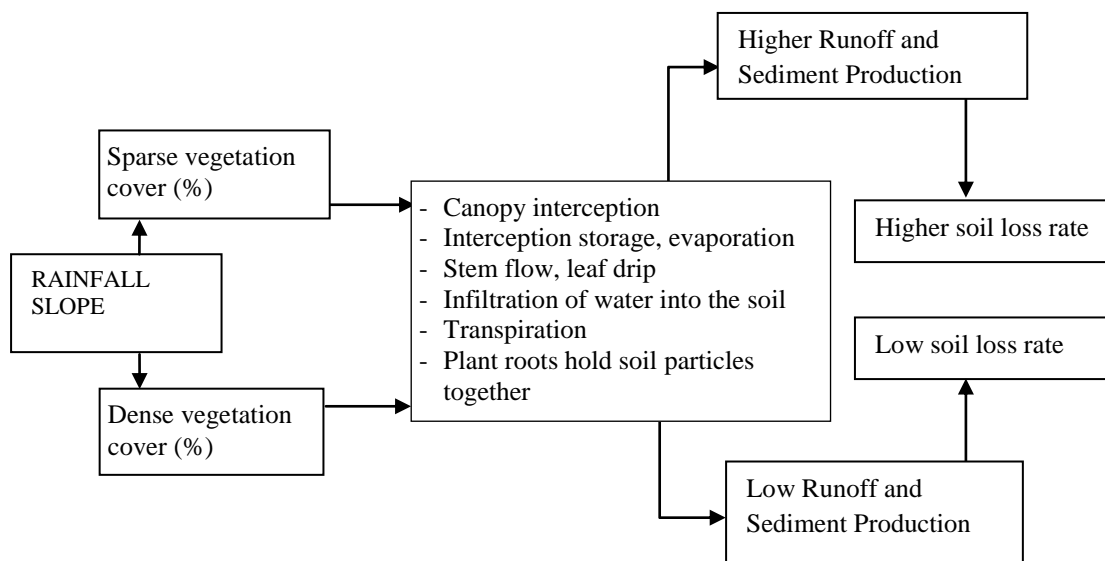


Figure 1.1: Conceptual framework of the study
Source: Adapted and modified from Morgan *et al.*, (1998)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Geomorphology is the study of landforms on the earth surface and processes that form them (Davidson-Arnott, 2010). Geomorphological studies are not only concerned with landscape description but also landscape development based on identification and interpretation of causal processes (Knapp, 1979). Processes are key elements of geomorphological studies. Erosion which defines generation and movement of sediment on slopes is one such causal process. The dynamic interactions among rainfall, vegetation and soil on slopes result in production of runoff – a key geomorphic agent on hill slopes. Runoff causes soil erosion.

It is already recognized that soil erosion is a major form of land degradation in ASALs. Soils are highly erodible in the ASALs of Kenya and therefore land degradation in the regions is rampant (GoK, 2016a). Using remote sensing platforms and GIS (Geographic Information Systems) mapping, the study shows that these regions, including West Pokot County are at high risk of soil erosion (Figure 2.1).

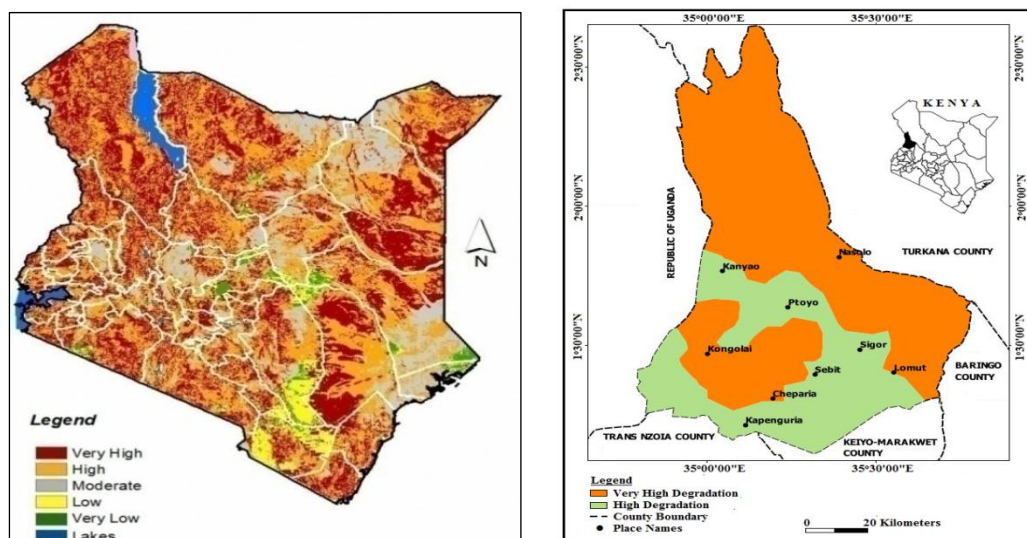


Figure 2.1: Soil erosion risk in Kenya and West Pokot County respectively
Source: GoK, (2016a)

High intensity storms cause occurrence of excessive runoff and soil erosion under limited cover of vegetation on the land surface. The current study aimed at evaluating the effect of vegetation cover on runoff and soil loss in a semi-arid catchment. This chapter gives a critical literature review of the concept of runoff and the role of vegetation cover in checking runoff production and soil loss. Field measurement of rainfall, runoff and sediment yield is also discussed in this chapter.

2.2 Overview of the runoff concept

Runoff is a process in the hydrologic cycle. It involves various mechanisms by which water is moved horizontally from the time it reaches the surface of the earth to such a time when it is discharged to storage media (Pallister, 2001). Runoff entails transfer of water to a channelized stream after reaching the ground as precipitation (Davie, 2006). It includes surface flow of water in the form of a 'thin sheet' (overland flow) and flow of water restricted within the walls of a valley (channel flow). Overland flow occur when rainfall rate is higher than the infiltration rate of the soil; a situation common in arid areas where short erratic rainfall events are experienced. The high impact of raindrops on the ground surface compact the soil particles which enable water to runoff before saturation of the soil. This is Hortonian overland flow. Shallow soils with partly weathered rocks forming closer to the surface are common in semi-arid areas. This condition does not favour infiltration of water into the soil. Occurrence of rainfall in these areas would definitely result to Hortonian overland flow. Runoff is a component of land surface water balance. It is the difference between precipitation and evapo-transpiration rate on assumption that soil water storage is roughly constant. In arid environments, vegetation and soil characteristics may be responsible for generation of as much runoff as rainfall experienced.

A study on vegetation and soil erosion within a semi-arid Mediterranean climate in Murcia, Spain established that the average rate of erosion from El Ardal experimental fields for a period of four years was 20g/m^2 (Lopez-Bermudez *et al.*, 1998). According to the study, this resulted from an average runoff rate of 1.40%. The study suggests that these results may have been affected by vegetation and soil characteristics. Although surface water travels over hillsides as sheet of laminar flow, the irregularities of the slope surface may confine the surface water into depressions leading to turbulent flow which moves down hillside gaining speed to acquire sufficient energy that detach soil particles. Turbulent flow accounts for 90% erosion during a single rainfall event in arid areas (Gregory, 2010).

2.3 The role of vegetation cover in checking runoff

Principal factors affecting runoff from studies in small watersheds and runoff plots are soil cover, basin shape and size, infiltration rate and slope values (Hassan *et al.*, 2006). A study conducted in the Opa Reservoir Basin, South Western Nigeria to examine the effect of land use and vegetation types on slope wash showed that mean total runoff and soil loss obtained from basins in built-up areas was higher than runoff and soil loss obtained from basins located in cultivated field crops, cocoa farmlands and forested basins (Adediji, 2006). It has been shown that runoff rate and vegetation cover have significant negative relationship: $r^2 = 0.58$, $P < 0.01$ (Green *et al.*, 1994). These studies demonstrate that when vegetation cover increases, runoff production decreases.

It should be borne in mind that the net amount of water reaching the soil surface is less than the actual amount of rainfall before interception by plant canopies. The rain drops fall on the leaves and branches of trees before flowing down the stems to the soil (rainfall interception). Leaves act as an umbrella and stops rain from hitting the

ground directly (Waugh & Bushell, 2001). They become covered with a film of water before dripping through and stem flow carries the water away to the ground. Their roots slow down movement of water in and on the soil. At this point, the water has ample time to infiltrate the soil if saturation has not been reached. The impact is least in dry environments where vegetation cover is sparse and therefore leads to production of large amounts of runoff.

Vegetation interacts dynamically with soil moisture regime through actual evapotranspiration and hence controls the possibility of runoff generation and production of sediment. Runoff and sediment yield generally decreases with increasing vegetation cover over a long period of time (Obando, 2005). This is interesting because insufficient vegetation cover in arid environments would mean reduced evapotranspiration and higher antecedent soil moisture content. Possibility of a higher runoff generation and sediment production in these regions on account of a rainfall event therefore exists. It is important to note that vegetation through rooting system also provides a firm grasp of the soil particles to reduce possibilities of sediment generation.

In general, vegetation controls production of runoff and eventual sediment generation in three ways. First, vegetation canopy reduces the intensity of direct raindrops on the soil through rainfall interception which decrease possibilities of Hortonian overland flow. This enables water to infiltrate into the soil to saturation point before runoff begins. Second, plant roots hold the soil particles together protecting the soil against possible erosion by runoff water. Third, vegetation canopy controls mechanical impact of direct raindrops on the soil particles which would cause loosening and splashing of the soil particles.

2.4 The role of rainfall in production of runoff

Some studies involving runoff and soil loss have used rainfall (natural or simulated) as a parameter in research (Adediji, 2006; Ouma *et al.*, 2013; Njuguna, 2014). This is because rainfall is a primary component in the determination of the amount of surface runoff to be generated in a catchment. Rainfall is a major source of water in a catchment and hence responsible for runoff generation and sediment release (Njuguna, 2014). The study found that sediment in water resulted from loose soil particles carried in runoff that was generated after rainfall events. Generation of runoff and loss of soil from a slope is therefore related to rainfall characteristics.

When infiltration capacity of the soil is exceeded perhaps due to heavy or longer periods of rainfall, excess precipitation is either stored temporarily on the soil surface or begins as direct runoff. This is saturation overland flow. In accordance with accepted hydrological hypothesis, high runoff is expected from intense rainfall events (Hassan *et al.*, 2006). Basically, the amount of runoff in this regard depends on the amount of excess precipitation with respect to soil infiltration rate. In arid areas where rainfalls are stormy, soils are thin and vegetation cover is sparse, large volumes of runoff are expected.

2.5 Field measurement of rainfall, runoff and sediment yield

2.5.1 *Measurement of rainfall*

In order to determine average rainfall in a particular catchment area, a rain gauge is fixed at some point (Rizvi, 2008). The rain gauge is installed in a place sheltered from strong winds, away from tall objects and on relatively flat ground. It is sited such that possible sources of error in measurement like ‘splash in’, ‘splash out’ and evaporation loss are controlled.

In a study on the upper Sondu-Miriu basin, runoff plots were established at Kabianga High school farm from which runoff was measured (Ouma *et al.*, 2013). Rainfall data was recorded from the Kenya Meteorological Service (KMS) station at Kericho. Rainfall data was also recorded from the nearest KMS station in a study on Nyando River basin (Olang & Furst, 2010). In both studies, spatial variations in rainfall may have influenced the findings because local physical and human factors cause differences in weather patterns over small geographical regions. Rainfall is measured in terms of volume of water that falls on the surface delineated by the rain gauge brim and expressed in (mm): the depth to which rainwater is expected to infiltrate the soil. This study obtained rainfall data using a standard rain gauge installed in the neighbourhood of the field plots.

2.5.2 Measurement of runoff and sediment yield from runoff plots

The RUSLE was used to estimate soil loss from the slopes of Kathe-Kakai catchment in Machakos County (Wanjiku, 2015). However, plot scale studies provide experimental data involving rainfall, surface runoff and soil erosion. Studies aimed at identifying and prioritizing erosion hotspots in Northern Ethiopia are based on quantitative or empirical models or runoff plots (Tsfahunegn *et al.*, 2013). It is also recognized that runoff plots have been used to calculate soil erodibility in Baringo and West Pokot, Kenya. A field plot is an elementary member of the landscape continuum created by human activity. A runoff plot is 4m by 4m (16m²) or larger (Okoth, 2003). However, small scale plots of about 100m² are commonly used for trials of cropping practices, cover effects, rotation and any other practice which can be applied on small plots (Hudson, 1993).

A study conducted in Gikuuri catchment in central highlands of Kenya to quantify soil erosion indicators, used runoff plot experiments to relate sheet and rill erosion to

quantities of soil loss during four rainfall seasons (Okoba, 2005). While Ouma *et al.*, (2013) used 2m by 2m unbounded plots and 2m by 5m bounded plots in their study, Njuguna, (2014) used 8m by 5m bounded plots. Runoff and sediment yield were measured in both cases. Plot size depends on the purpose of runoff plot research. Therefore, runoff and sediment yield can be measured from runoff plot experiments. However, research has shown that reliability of data from runoff plot experiments depend on the design of the plots, maintenance and their general operation.

2.6 Summary of research gaps identified

Although field plot research has been used to address the problem of soil erosion especially in humid areas (Okoba, 2005; Adediji, 2006; Ouma *et al.*, 2013; Njuguna, 2014), there is still need for such studies in semi-arid areas of Kenya. For instance, evidence of documented runoff plot studies on soil erosion in Alale is limited.

Based on the analysis of some selected studies, a summary of research gaps identified is provided in table 2.1.

Table 2.1: Research gaps identified in some selected studies

Author	Study	Research Gap
Adediji, (2006)	Land use, Runoff and Slope wash in the Opa reservoir basin, Southwest Nigeria	The study used unbounded runoff plots and was conducted in a humid environment. It did not focus on arid environment.
Ouma <i>et al.</i> , (2013)	Temporal variation in sedimentation and surface runoff from agricultural land uses in Sondu-Miriu basin, Kenya	Erosion plots were set up at Kabianga and rainfall data obtained from a rain gauge at KMS station in Kericho town. Location of the rain gauge did not consider the effect of local physical factors on weather patterns over small geographical areas.
Njuguna, (2014)	Analysis of runoff, infiltration rate, sediment release and nutrient drain from four vegetation types in South Kinangop forest, Nyandarua County	Research in the study was carried out in a humid environment under forest and bamboo cover. It did not focus on dry land vegetation.
Wanjiku, (2015)	Assessment of Changes in Land use, Land cover and Soil erosion Risk factors in Kathe-Kakai Catchment, Machakos County, Kenya	Estimated rate of soil loss was worked out using a mathematical model based on parameters of soil loss. The study did not measure the actual sediments in runoff water.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Study Area

3.1.1 *Geographical location*

Akiriamet-Kimpur catchment is in Alale, West Pokot County 180km North of Kapenguria town. Alale borders Kasei and Kacheliba Divisions in the South. Alale Division is 1802.23km² (KNBS, 2015). Its geographical position is 2⁰N by latitude and 35⁰E by longitude (Figure 3.1). Other Divisions in the County are Kongelai, Chepareria, Sigor, Kapenguria, Cheseгон and Lelan. West Pokot County is an ASAL area located in the North Rift region of Kenya. It borders Uganda in the West, Turkana County in the North, Trans-Nzoia County in the South, Baringo and Elgeyo Marakwet Counties in the South East.

3.1.2 *Climate*

West Pokot County is classified into two climate regions. The sub-humid highlands which rise from 1700m to 3300m above sea level include Lelan, some parts of Kapenguria, Chepareria and Cheseгон. These areas receive 1300 –1600mm of rainfall per year with mean annual temperature ranging from 09⁰C to 26⁰C. The county is 80% ASALs (GoK, 2016b). Dry semi-arid lowlands at approximately 1400m above sea level include Alale, Kasei, Sigor, Kongelai and Kacheliba. The mean monthly temperatures in these areas reach over 30⁰C. Rainfall pattern is bimodal. Long rains occur from March to July while the short rains occur from September to November. The seasons are marked with variable high intensity rainfall which causes a lot of surface runoff. Mean annual rainfall in the study area varies from 500mm to 800mm (Figure 3.2).

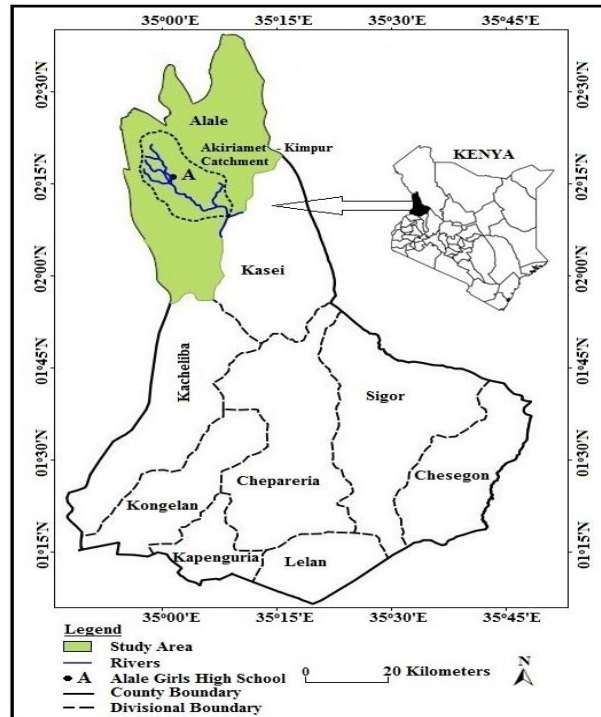


Figure 3.1: Location of Akiriamet-Kimpur catchment
 Source: Topographic Sheet for Moroto (NA-36-8) and National Atlas of Kenya.

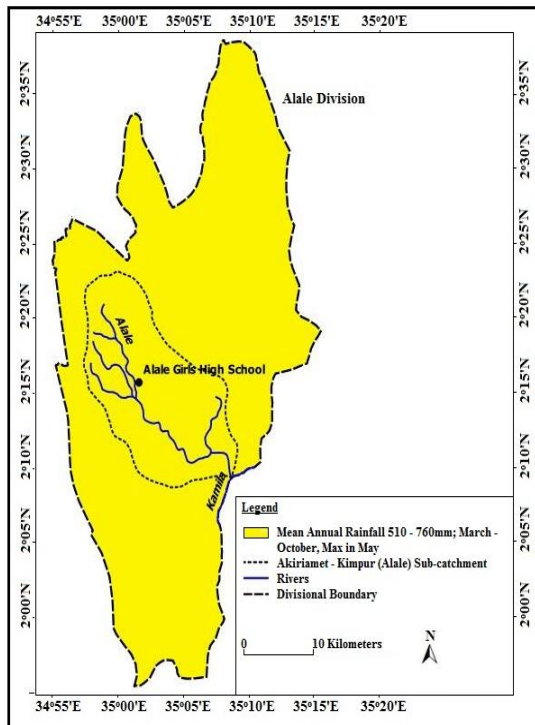


Figure 3.2: Mean annual rainfall in Alale
 Source: National Atlas of Kenya.

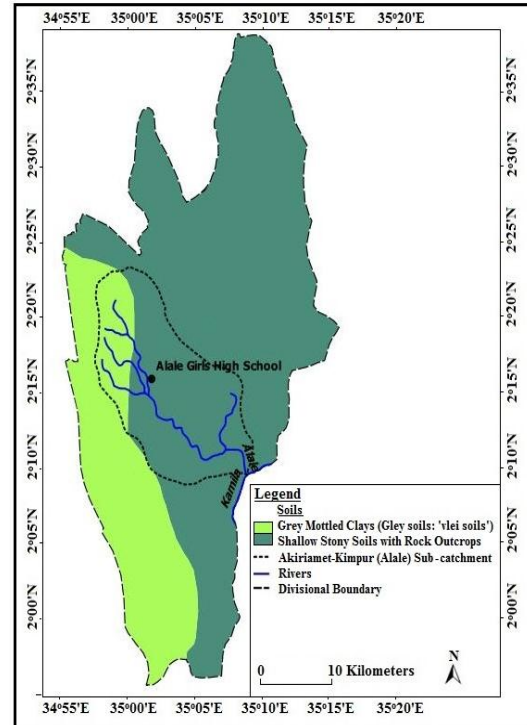


Figure 3.3: Distribution of Soils in Alale
 Source: National Atlas of Kenya.

3.1.3 Soils

The soils in arid areas are highly erodible, have high runoff generation potential, poor water holding capacity and are structurally unstable (Khresat *et al.*, 2004). This means that soil erosion risk in the ASALs is high. Clay and sandy soils occur in the study area. A large part of Alale has shallow stony soils with rock outcrops (Figure 3.3). Eastern parts from the South to the North have grey mottled clay soils. There are few areas with a mixture of clay and sand soil composition. Dominant soil type in the study catchment area is clay-sandy soil. The soil profile has a shallow depth in which partly weathered rocks form closer to the surface. Thin immature soils of azonal order occur on steep slopes. The soils are generally bare because of sparse vegetation cover.

3.1.4 Population and social economic activities

Pastoral communities who live in the ASALs keep large herds of livestock for social and cultural reasons (GoK, 2016a). According to the study, the increasing pastoralist population and subsequent increase in livestock population has led to encroachment on the semi-arid marginal lands and forest causing severe soil degradation. Alale is inhabited by the pastoralist Pokot community. A big portion of Alale is rangeland. Pastoral farmers keep large herds of livestock comprising cows, goats and camels for milk and meat production. Livestock is also used to pay dowry and as a sign of wealth among the family units. Livestock rustling is a common practice along the border with Turkana County. The pastoral farmers migrate with their livestock to Eastern Uganda in search of pasture and water during the drought periods. In the North West regions, rain-fed small scale crop farming is practiced. The 2009 population and housing census survey show that Alale is sparsely settled in with a population density of 37.00 (KNBS, 2015). There are more settlements in the North than in the South and on the Eastern slopes.

3.1.5 Topography

West Pokot County has varied topographic characteristics. The highlands consist of steep slopes especially on Cherangany and Sebit hills in the South, Sekerr hills in Central and Karasuk hills in the North. Vast plain lands occur in the lowlands. A large portion of North Pokot Sub- County is characterized by a rough terrain consisting of hills and mountains which are stony (Chebitwey, 2013). At Alale Girls secondary school, the altitude is 1606m above sea level. Karasuk hills occur in the East rising to 3200m above sea level. They form Eastern part of Akiriamet-Kimpur drainage system. The hills have steep slopes and rocky surfaces with sparse vegetation cover. The land surface has scanty natural semi-arid vegetation (Figure 3.4). Some areas in the North of Alale have dense cover of dwarf bushes of shrubs, euphorbia and grass. However, some parts have bare grounds which are dotted with few scattered trees of acacia species. In the East, the landscape is severely eroded especially along steep slopes. Large dry river valleys are common landforms across the landscape.

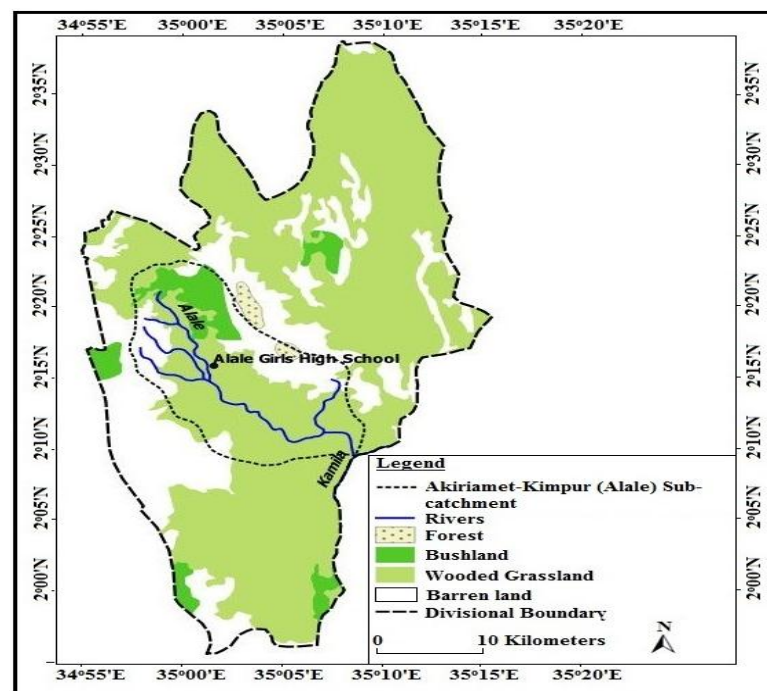


Figure 3.4: Distribution of Vegetation in Alale

Source: World Resources Institute. <<https://www.wri.org/data/kenya-gis-data#other>>

3.2 Research Design

It is recognized that the main purpose of experimental research is to establish a cause-effect relationship between two or more variables. In order to establish a rainfall-runoff and runoff-soil loss relationship, the study sought to generate primary data on the actual quantities of soil moved down the slope in runoff under natural vegetation cover and rainfall characteristics using runoff plot experiment. A natural observation, quasi experimental research design was adopted. Two runoff plots were established. The comparison plot was marked **A** while the treatment plot was marked **B**. Runoff and soil loss were observed in both plots under existing natural vegetation cover and rainfall treatments.

Each plot was replicated twice. Plot **A** and its replica plots which formed field **1** were established on a slope with 25–50% vegetation cover while plot **B** and its replica plots which formed field **2** were established on a slope with 50–75% vegetation cover. Both plots were set up on uniform slope grade. Measurements on rainfall, runoff and soil loss were taken from fifteen runoff-producing rainfall events during the study period.

3.2.1 *Sampling procedures, slope and vegetation cover measurements*

West Pokot County has two sub-climate regions: semi-arid and sub-humid regions. The semi-arid regions comprise Alale, Kasei, Kacheliba, Kongelai and Sigor. The sub-humid regions include Kapenguria, Lelan, Chepareria and Chesegon. Based on suitability to the study, the experimental plots were set up in Alale on the Northern parts of the land at Alale Girls Secondary School (2⁰15' N, 35⁰02' E). The land slopes northwest into Akiriamet-Kimpur ephemeral drainage valleys.

The slope grade was established using the formula; $\left[\frac{\text{Rise}}{\text{Run}}\right] \times 100 = \text{slope \%}$ (Barcelona Field studies Centre, 2000). The rise (change in elevation) and the run (slope length)

were measured at randomly selected points on the slope surface using a tape measure, a sisal strand, a set square and surveying rods (Figure 3.5).

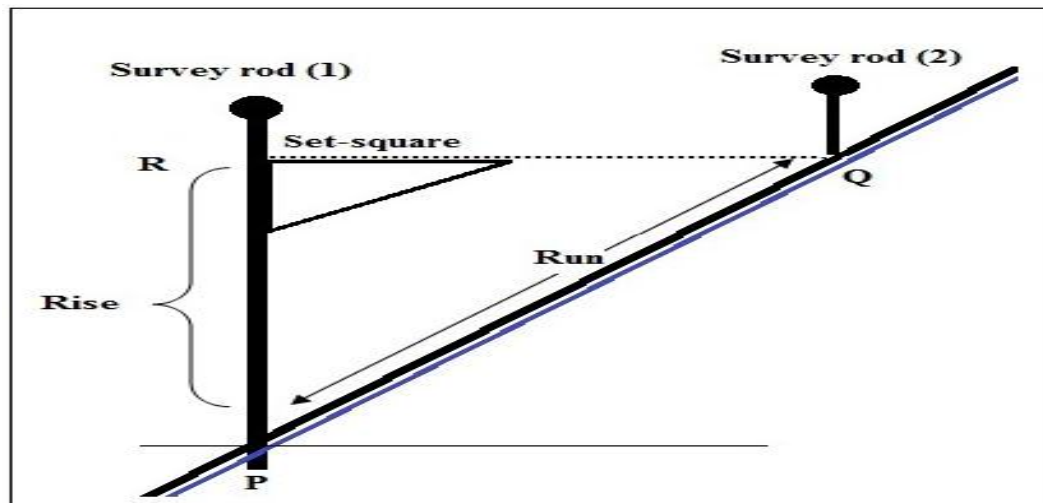


Figure 3.5: Illustration of slope measurement method used in the study

The distance PQ is an expression of the length along the slope, PR expresses the altitudinal difference between the points P and Q on the slope and QR expresses the horizontal distance between the points P and Q. The slope angle (θ°) was worked out using the trigonometric expression;

$\theta^\circ = \tan^{-1}\left(\frac{PR}{QR}\right)$, where PR is altitudinal difference between P and Q. QR is horizontal distance between P and Q

Sample units of vegetation cover were then established using transects line-intercept survey method (Coulloudon *et al.*, 1999). A base line transect was laid at random across vegetation field. Subsequent transects were laid parallel to the baseline transect at sufficiently small regular intervals (systematic sampling). Percentage vegetation cover on the soil along each transect line was computed as $\left(\frac{d_1+d_2+\dots}{l} \times 100\right)$ where (d) is the length on the transect line intercepted by tree canopies and shrubs while (l) is the total length of the transect line including bare grounds (Figure 3.6). However, this length excluded areas under grasses away from the canopies of taller plants. Grass

cover on the soil was estimated by demarcating the area into convenient regular geometrical shapes and calculated as percentage area of the field using available mathematical formulae. Percentage vegetation cover on the field was taken as the mean percentage plant canopy cover for all transects plus percentage grass cover on the soil. The runoff plots were then demarcated and constructed.

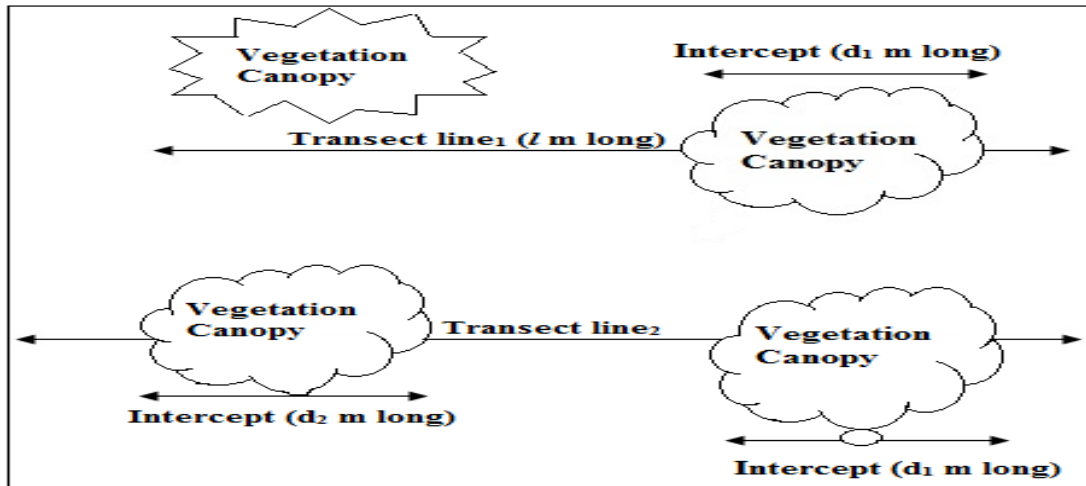


Figure 3.6: Illustration of the transect line-intercept survey technique
Source: Coulloudon *et al.*, (1999)

Vegetation cover was measured at the beginning of the experimental observations in March. The second and the third measurements were taken in May and July respectively because of expected canopy cover development on the fields during the research period (Table 3.1).

Table 3.1: Vegetation covers on each field by plant type in March, May and July

Plant types	Percentage cover on the soil in relation to the total area of the field					
	March		May		July	
	Field 1	Field 2	Field 1	Field 2	Field 1	Field 2
Euphorbia plants	5	3	6	3	6	4
Short acacia tree bushes	12	9	14	12	20	16
Grasses	8	16	15	21	23	27
Shrubs	0	22	0	26	0	28
Percentage total	25	50	35	62	49	75

Plate 3.1 and 3.2 are photographs showing how the slope and vegetation cover were measured during the study.



Plate3.1: Slope measurements



Plate 3. 2: Measuring vegetation cover

3.2.2 Design of the experimental runoff plots

The study used two sets of fields. Each set consisted of a runoff plot 20m long by 10m wide replicated twice on a uniform slope of 1.5–2.0% slope grade. The sides of each plot were bounded by concrete walls 45cm high. The foundation was at least 15cm deep to keep off unwanted runoff. A gutter was connected to the lower end of each plot in order to direct runoff and sediment from the plot to collection tanks at the base (Figure 3.7).

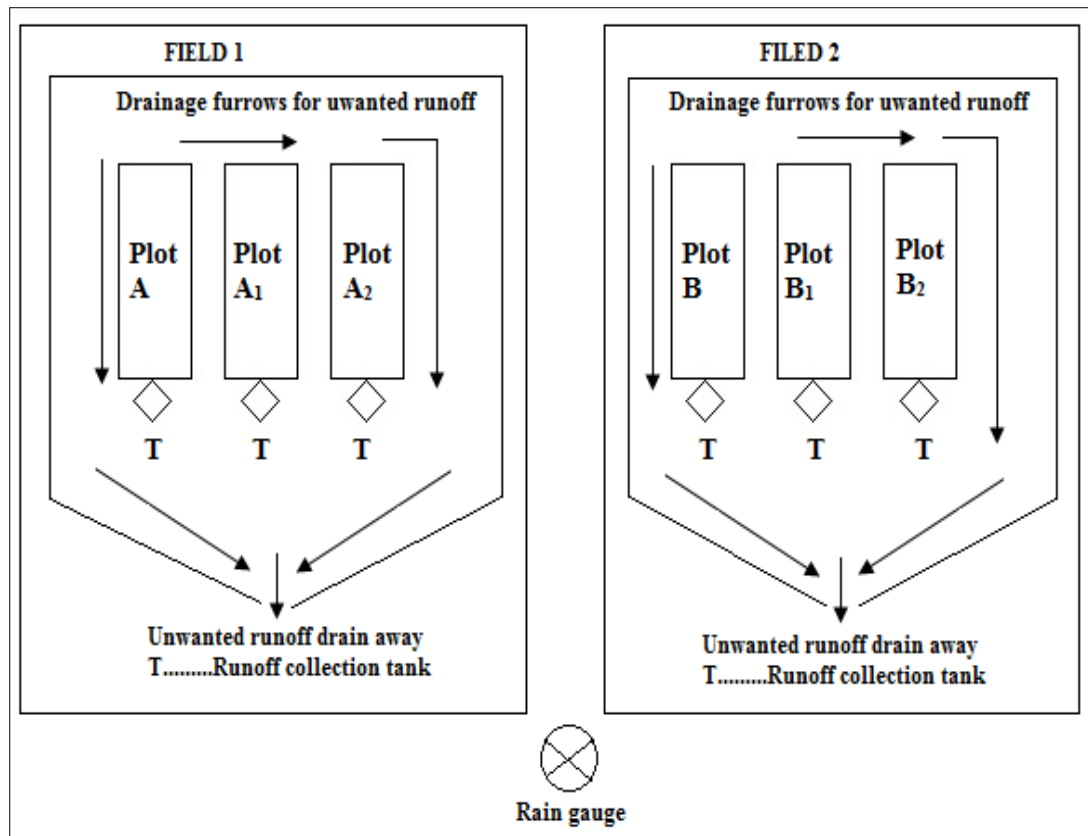


Figure 3.7: Schematic design of the runoff plots used in the study

Six cubical metallic tanks of volume 0.125m^3 each were used to collect runoff from the plots and their replicates. Each runoff collection tank with a lid was kept in a sub-surface open tank constructed at the base of each plot (Plate 3.3). The sub-surface open tanks were plastered with water-proof cement component and covered by an iron sheet to keep off direct rainfall and any water loss through infiltration and evaporation processes. They were also used to trap overflow runoff and sediment. The volume of runoff collected in the runoff collection tanks was mathematically computed. The height of runoff in the tanks was measured using a tape measure and multiplied by the base area of the tank (Plate 3.4). Sediment in the runoff was allowed to decant and then runoff poured away. The sediment was dried and measured using a weighing scale (Plate 3.5). A standard rain gauge sunk 15cm in the ground was installed in the neighbourhood of the plots on a relatively flat ground surface at least 10m by radius

away from taller plants. The funnel was kept 30cm above the surface. Water collected in the water collection jar of the rain gauge was transferred to a measuring cylinder with World Meteorological Organization (WMO) specifications for measuring rainfall in tropical regions (Plate 3.6).



Plate 3.3: Runoff plots marked A



Plate 3.4: Measurement of runoff



Plate 3.5: Measurement of sediment



Plate 3.6: Measurement of rainfall

3.3 Categories of analysis

The independent variables of the study were vegetation cover and amount of rainfall. Runoff and sediment yield were dependent variable. Vegetation cover was expressed as average percentage cover of plant canopy on the soil. Amount of rainfall was measured in millimetres (mm). Runoff collected at the base of each plot per rainfall event was measured in regular cubical tanks of known dimensions (0.5m by 0.5m by 0.5m) and expressed in cubic metres (m^3). Sediment collected in the runoff collection tanks was dried, weighed and the mass expressed in kilograms (Kg). Rate of soil erosion was computed as g/m^2 .

Table 3.2 summarizes data collection procedure against each objective. In addition, the table gives a summary of the parameters and materials used in the research.

Table 3.2: Summary of data collection procedure

Objective	Variables	Procedure followed	Material used
i) To determine the volume of runoff produced from runoff plots under natural vegetation cover and rainfall characteristics.	Runoff. Rainfall amount (mm). Vegetation cover (%)	Runoff was collected from the plots per rainfall event and its volume measured. All runoff generating rainfall events were considered.	Two sets of runoff plots Runoff collection tanks. Rain gauge.
ii) To determine the quantity of sediment generated from erosion plots under natural vegetation cover and rainfall characteristics.	Vegetation cover (%) Soil loss (kg)	Measured runoff collected from each set of field plots per rainfall event. Drained runoff from collection tanks. Dried the collected sediment and weighed.	Two sets of runoff plots fitted with runoff collection tanks. Weighing scale.
iii) To establish the rate of soil loss through runoff water in Akiriamet-Kimpur catchment	Rate of soil loss (g/m^2).	Ascertained quantity of total soil loss per plot and computed the rate of soil loss	Data generated from the experiments

3.4 Data collection, organization, analysis and presentation

3.4.1 Data collection and organization

Data on rainfall, runoff and quantity of sediment delivered at the outlet per field plot was tabulated in the format shown in table 3.3. Data was taken and entered on each date a runoff generating rainfall event occurred.

Table 3.3: Format of raw data organization

Date	Rainfall (mm)	Field 1 (25–50%) vegetation cover			Field 2 (50–75%) vegetation cover		
		1 st Set Plots (Control plot)	Runoff (m ³)	Sediment Yield (Kg)	2 nd Set Plots (Treatment Plot)	Runoff (m ³)	Sediment Yield (Kg)
		A			B		
		A₁ (1 st replica)			B₁ (1 st replica)		
		A₂ (2 nd replica)			B₂ (2 nd replica)		
		Mean			Mean		
		A			B		
		A₁ (1 st replica)			B₁ (1 st replica)		
		A₂ (2 nd replica)			B₂ (2 nd replica)		
		Mean			Mean		

3.4.2 Statistical Data Analysis

Using the data obtained, correlation analysis was done at two levels.

- i) Rainfall-Runoff correlation analysis.
- ii) Runoff-Soil loss correlation analysis.

Pearson product moment correlation coefficient was calculated in each case. All scientific research has the purpose of testing hypotheses (Mc Burney & White, 2010). In order to test for significance in the association between variables of the study, t-test at 5% significance level was applied. Linear regression analysis was also done using the data obtained. A linear relationship in each case was established. Total area of each plot was 200m². The rate of soil loss from the plots was computed as the mass of soil lost per square metre of the plot (g/m²). The results from both plots were compared and conclusion was made.

3.4.3 *Methods of data presentation*

The findings were presented in tables and graphs. Photographs were used to present the actual scenes in the process of setting up the experiments and data collection. They were also used to show the physical environment in which research was conducted.

3.5 *Logistical considerations*

Research clearance was sought from the National Commission for Science, Technology and Innovation (NACOSTI). A research permit Number NACOSTI/P/16/85476/14589 dated 6th December, 2016 was obtained. The research proposal was approved at the graduate school, Kenyatta University on September 07, 2016. Before embarking on data collection from the field, due procedure was followed by reporting to the following offices;

- i) West Pokot County Commissioner's office where a letter dated 21st December, 2016 Ref. No.: OOP.CC.ADM.15/14 VOL. 1/81 and copied to the West Pokot County Director, Ministry of Education office was issued. (Annexed as appendix 5: **A5**)
- ii) The Principal's office, Alale Girls Secondary school in Alale where the experimental runoff plots in the study were set up. A letter dated 22nd February, 2017 that gave consent to the use of the school land was obtained. (Annexed as appendix 7: **A7**)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Presentation and analysis of the results

4.1.1 Rainfall, runoff and sediment observations

Forty-two days experienced rainfall during the study period. Basic meteorological interpretation of rainfall provides that a day is rainy if rainfall depth is greater than 1mm. Twenty nine out of the forty-two days were rainy and only fifteen rainfall episodes produced runoff in the plots. Comprehensive record of daily rainfall observations is annexed on this thesis report (Appendix 2). Table 4.1 provides data on measured runoff volumes and sediment yield from rainfall episodes that produced runoff.

Table 4.1: Observed rainfall, runoff and soil loss values

Date	Rainfall (mm)	Field 1	Runoff (m ³)	Sediment yield (kg)	Field 2	Runoff (m ³)	Sediment yield (kg)
26/3/17	45.0	A	0.1550	4.22	B	0.1375	3.56
		A ₁	0.1450	3.71	B ₁	0.1250	3.43
		A ₂	0.1500	3.53	B ₂	0.1450	3.51
		Mean	0.1500	3.82	Mean	0.1358	3.50
17/4/17	28.5	A	0.1100	3.60	B	0.1025	2.88
		A ₁	0.1075	3.20	B ₁	0.0900	2.41
		A ₂	0.1000	3.10	B ₂	0.0700	2.15
		Mean	0.1058	3.30	Mean	0.0875	2.48
29/4/17	8.2	A	0.0310	0.95	B	0.0275	0.51
		A ₁	0.0290	0.58	B ₁	0.0250	0.34
		A ₂	0.0300	0.75	B ₂	0.0290	0.65
		Mean	0.0300	0.76	Mean	0.0272	0.50
30/4/17	30.1	A	0.1250	2.74	B	0.0875	2.55
		A ₁	0.1225	2.73	B ₁	0.1000	2.80
		A ₂	0.1200	2.45	B ₂	0.0725	2.15
		Mean	0.1225	2.64	Mean	0.0867	2.50
01/5/17	34.3	A	0.1325	2.51	B	0.0725	2.30
		A ₁	0.1450	2.80	B ₁	0.0700	2.57
		A ₂	0.1250	2.19	B ₂	0.0675	1.88
		Mean	0.1342	2.50	Mean	0.0700	2.25
19/5/17	69.7	A	0.2450	7.90	B	0.2250	5.82
		A ₁	0.2000	7.65	B ₁	0.2000	5.59
		A ₂	0.1735	6.95	B ₂	0.1700	5.27
		Mean	0.2062	7.50	Mean	0.1983	5.56
30/5/17	40.5	A	0.2100	5.52	B	0.1150	4.15
		A ₁	0.1875	5.27	B ₁	0.1575	4.77
		A ₂	0.1750	5.11	B ₂	0.1750	4.88
		Mean	0.1908	5.30	Mean	0.1492	4.60
31/5/17	17.8	A	0.0625	1.58	B	0.0300	0.79
		A ₁	0.0475	1.20	B ₁	0.0275	0.73
		A ₂	0.0400	0.97	B ₂	0.0150	0.22
		Mean	0.0500	1.25	Mean	0.0241	0.58
16/6/17	15.8	A	0.0700	1.12	B	0.0125	0.58
		A ₁	0.0800	1.38	B ₁	0.0375	0.80
		A ₂	0.0150	0.05	B ₂	0.0050	0.12
		Mean	0.0483	0.85	Mean	0.0183	0.50
04/7/17	12.0	A	0.0125	0.26	B	0.0050	0.32
		A ₁	0.0100	0.22	B ₁	0.0025	0.13
		A ₂	0.0125	0.24	B ₂	0.0000	0.00
		Mean	0.0117	0.24	Mean	0.0025	0.15
05/7/17	21.0	A	0.0450	1.19	B	0.0300	0.71
		A ₁	0.0500	1.33	B ₁	0.0325	0.81
		A ₂	0.0550	1.38	B ₂	0.0375	0.91
		Mean	0.0500	1.30	Mean	0.0333	0.81
21/7/17	7.2	A	0.0025	0.15	B	0.0025	0.14
		A ₁	0.0050	0.31	B ₁	0.0025	0.16
		A ₂	0.0050	0.08	B ₂	0.0000	0.00
		Mean	0.0042	0.18	Mean	0.0017	0.10
22/7/17	7.8	A	0.0100	0.20	B	0.0100	0.25
		A ₁	0.0075	0.12	B ₁	0.0050	0.07
		A ₂	0.0175	0.28	B ₂	0.0025	0.04
		Mean	0.0117	0.20	Mean	0.0058	0.12
24/7/17	16.6	A	0.0250	0.37	B	0.0100	0.18
		A ₁	0.0400	0.71	B ₁	0.0125	0.13
		A ₂	0.0575	0.87	B ₂	0.0250	0.29
		Mean	0.0408	0.65	Mean	0.0158	0.20
25/7/17	18.2	A	0.1050	0.96	B	0.0275	0.31
		A ₁	0.0575	0.52	B ₁	0.0225	0.23
		A ₂	0.0500	0.38	B ₂	0.0125	0.09
		Mean	0.0708	0.62	Mean	0.0208	0.21
Total	372.7 mm		1.2270		3 1 . 1 1	0.8770	24.06

Arising from table 4.1, monthly totals for rainfall, runoff and soil loss were summarized and presented in table 4.2.

Table 4.2: Monthly summary of observed rainfall, runoff and soil loss

Month	Rainfall (mm)	Runoff (m ³)			Soil loss (kg)		
		Plot A	Plot B	Total	Plot A	Plot B	Total
March	45.0	0.1500	0.1358	0.2858	3.82	3.50	7.32
April	66.8	0.2583	0.2014	0.4597	6.70	5.48	12.18
May	162.3	0.5812	0.4416	1.0228	16.55	12.99	29.54
June	15.8	0.0483	0.0183	0.0666	0.85	0.50	1.35
July	82.8	0.1892	0.0799	0.2691	3.19	1.59	4.78
Total	372.7	1.2270	0.8770	2.1040	31.11	24.06	55.17

The sums of runoff from both plots per rainfall event and the corresponding sediment yield were taken and summarized in table 4.3 to give impression of total runoff and soil loss from the catchment.

Rainfall event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall [$\Sigma=372.7\text{mm}$]	45.0	28.5	8.2	30.1	34.3	69.7	40.5	17.8	15.8	12.0	21.0	7.2	7.8	16.6	18.2
Total runoff [$\Sigma=2.1040\text{m}^3$]	0.286	0.193	0.057	0.209	0.204	0.404	0.340	0.074	0.066	0.014	0.083	0.006	0.018	0.057	0.092
Total soil loss [$\Sigma=55.17\text{kg}$]	7.32	5.78	1.26	5.14	4.75	13.06	9.90	1.83	1.35	0.39	2.11	0.28	0.32	0.85	0.83

Table 4.3: Summary of total runoff and soil loss from the catchment

4.1.2 Analysis of the results

A total 372.7mm of rainfall in the catchment area produced 1.2270m³ of runoff from plot **A** and 0.877m³ of runoff from plot **B** during the study period. This represents 1.44% of total rain water lost through runoff from plot **A** and 1.03% of total rain water lost through runoff from plot **B**. This is equivalent to 61,350 ltrs/ha and 43,850 ltrs/ha of runoff respectively. Similarly, 31.11kg of soil was lost from plot **A** while 24.06kg of soil was lost from plot **B**. The findings show that the rate of soil loss from plot **A** is 155.55g/m² (1.555 tons/ha) and 120.3g/m² (1.203 tons/ha) from plot **B**.

Rainfall (x) and runoff (y) values resulting from table 4.3 were treated to correlation analysis using Pearson product moment correlation function. The results show that product moment correlation coefficient (r) for rainfall and runoff is 0.9609. The percentage variance (r²) in runoff production is 92.33%, P < 0.05. The level of significance in this association was tested using a t-test formula at 5% significance level (Equation 1).

$$t = r \sqrt{\frac{n-2}{1-r^2}} \text{ (Lucey, 2002)Eqn.1}$$

$$t = 0.9609 \times \sqrt{\frac{15-2}{1-0.9609^2}}$$

$$t = 12.5122$$

The critical value of (t) for two-tailed t-test distribution at 0.05 significance level and degree of freedom (n - 2) =13 for n = 15 is 2.160 (Dougherty, 2002). The critical value of (t) is less than the derived value. In accordance with the interpretation provided by Dougherty, there exists a significant positive linear relationship between runoff and rainfall. The linear equation; y = **bx+a** connecting the runoff component to the rainfall component was worked out using the least square method of linear regression analysis. The values of constants (**b**)and (**a**)were worked out using equation (2) and equation (3) respectively.

$$\mathbf{b} = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \text{Eqn. 2}$$

$$\mathbf{b} = 0.007$$

$$\mathbf{a} = \sum y/n - b(\sum x/n) \text{Eqn. 3}$$

$$\mathbf{a} = -0.035$$

The resultant linear equation is y = 0.007x -0.035 (Figure 4.1). Ideal rainfall threshold for production of runoff in the catchment defined in this study is 5. 0mm.

However, depending on the level of antecedent moisture in the soil, some rainfalls 5.0–8.0mm did not produce runoff in the catchment.

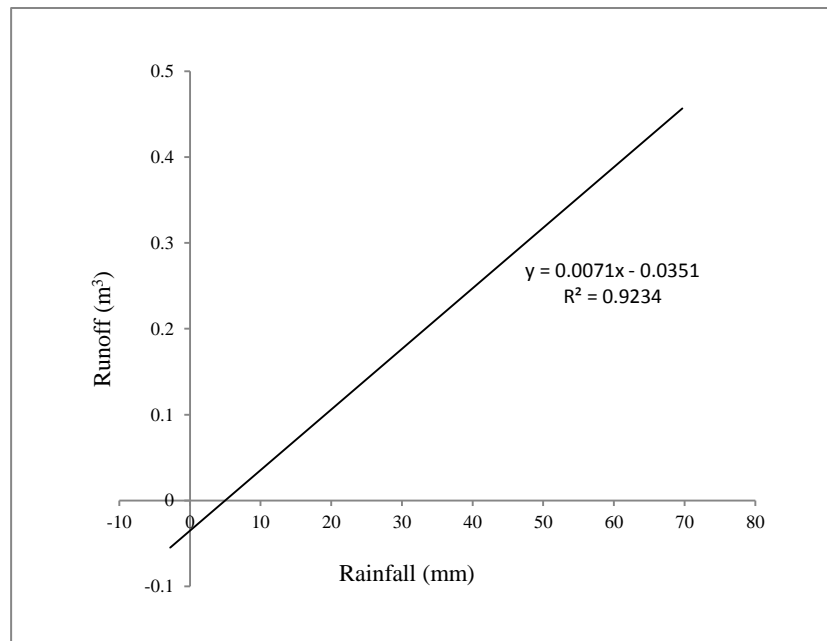


Figure 4.1: Derived runoff-rainfall linear relationship.

From table 4.3, runoff (x) and soil loss (y) values were also treated to correlation analysis using Pearson product moment correlation function. The results show that product moment correlation coefficient (r) for runoff and soil loss is 0.9840. The percentage variance (r^2) in sediment generation is 96.83%, $P < 0.05$. The level of significance in this association was tested using the t -test formula at 5% significance level.

$$t = r \sqrt{\frac{n-2}{1-r^2}} ; \quad n= 15$$

$$t = 0.9840 \times \sqrt{\frac{15-2}{1-0.9840^2}}$$

$$t = 19.8332$$

The critical value for two-tailed t -test distribution is 2.160 at 0.05 significance level.

The critical value is less than the t -value derived. Hence, there exists a significant positive linear relationship between soil loss and runoff. Linear regression analysis for

soil loss (y) and runoff (x) was performed using the least square regression method.

The resultant linear equation; $y = \mathbf{b}x + \mathbf{a}$, where **(a)** and **(b)** are constants is worked out.

The value of **(b)** and **(a)** were computed accordingly.

$$\mathbf{b} = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$$

$$\mathbf{b} = 30.67$$

$$\mathbf{a} = \sum y/n - \mathbf{b}(\sum x/n)$$

$$\mathbf{a} = -0.624$$

The resultant linear equation is $y = 30.67x - 0.624$ (Figure 4.2). Ideal threshold for

runoff to generate sediment in the catchment defined in this study is 0.02034m^3 .

However, depending on the soil characteristics, some observed runoff $0.0025 -$

0.0203m^3 generated sediment in the catchment

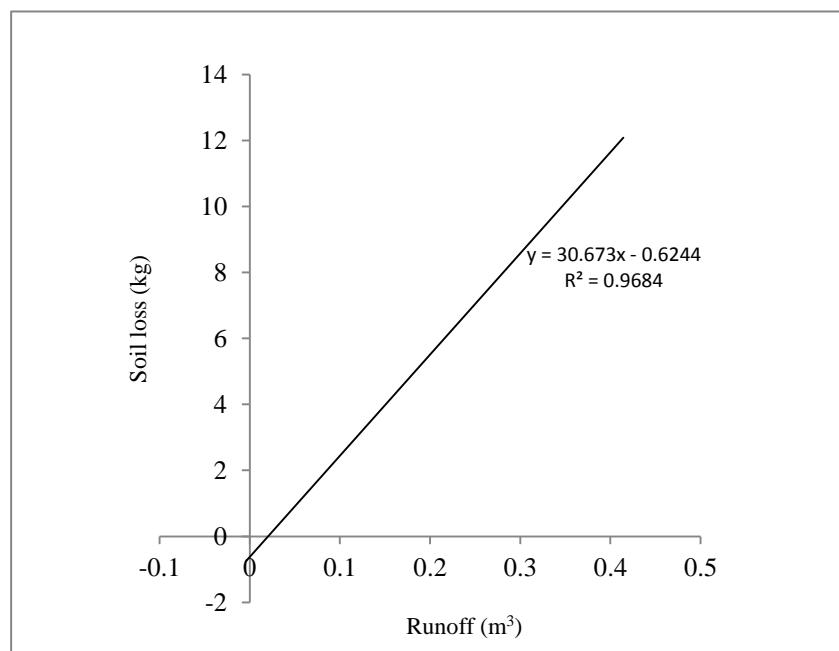


Figure 4.2: Derived soil loss-runoff linear relationship

4.2 Discussions from the findings of the study

4.2.1 Discussion on the findings from rainfall observations

Rainfall observations show that occurrence of rain in the study area is infrequent. Daily rainfall totals show an irregular trend giving impression that there was significant variation in the daily rainfall totals. Only 42 days out of 153 days experienced rainfall with a total of 426.8mm. More than 70% of the rainy days registered less than 20mm of rainfall per day. Rainfall peak occurred on 19th May when 69.7mm of rainfall was recorded (Figure 4.3).

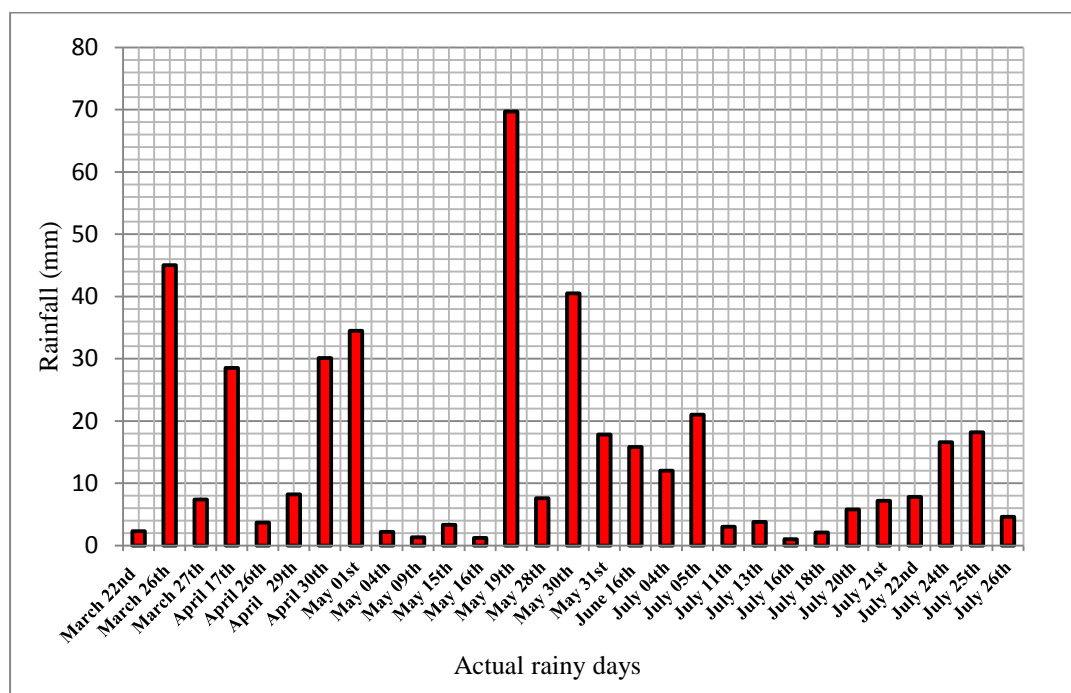


Figure 4.3: Rainfall totals from observations on rainy days (Author, 2018)

A summary of monthly rainfall totals shows that the months of May and June registered highest (180mm) and lowest (16mm) amount of rainfall respectively (Figure 4.4). This large variation in the monthly rainfall totals for the two consecutive months results from the observation that there were eight rainy days in May and only one rainy day in June.

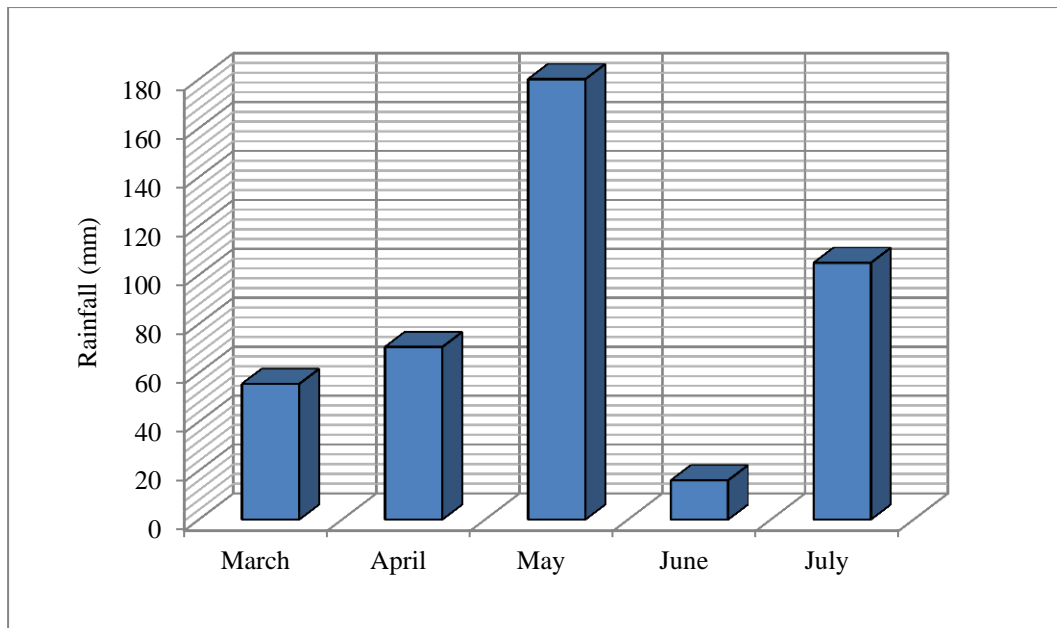


Figure 4.4: Rainfall totals per month
(Author, 2018)

The implication of rainfall on plant cover development is certain. Rain water provides moisture to the soil necessary for sprouting and regeneration of leaves on some plants. From rainfall record, fifteen rainfall events produced runoff in the catchment (Figure 4.5). Rainfall less than 8.0mm did not produce any significant runoff in the catchment. This occurrence may have been caused by one or combination of the following factors.

- i) Rain drops falling on plant leaves and branches did not contain sufficient water to drip off the leaves and branches. The water was held on the leaves by interception storage and later taken back to the atmosphere through direct evaporation.
- ii) Dry soil condition leading to absorption of all the rain water reaching the surface through direct rain drops and/or stem flow.
- iii) Low rainfall intensity. This situation favours infiltration of rain water as long as water retention capacity of the soil is not exceeded.

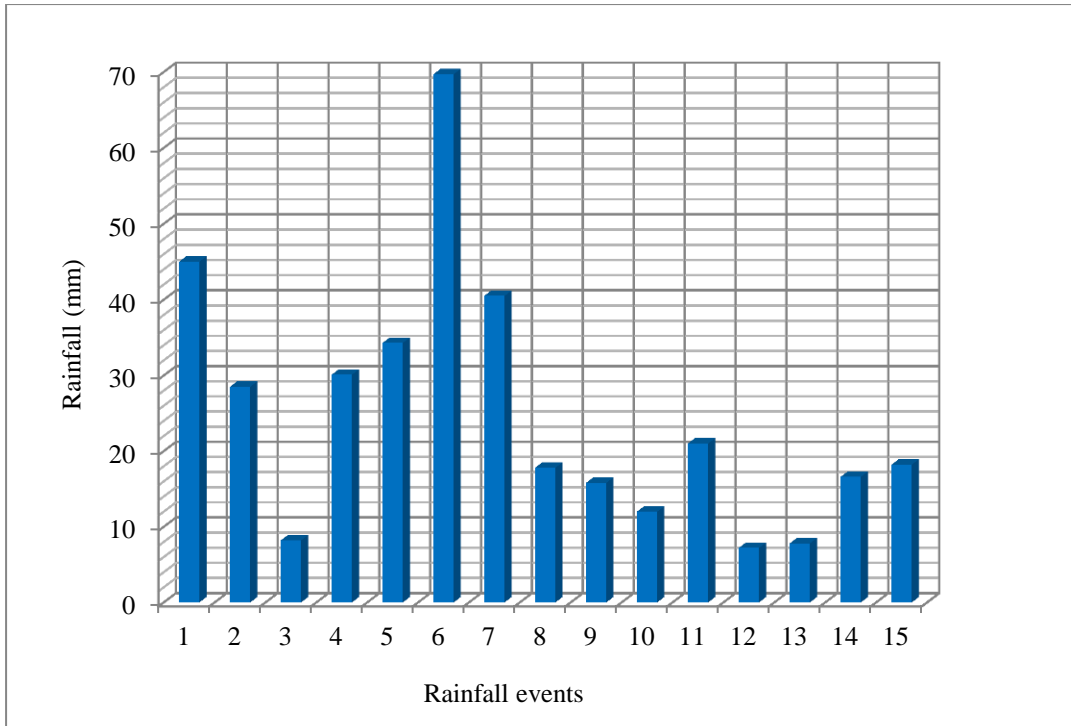


Figure 4.5: Totals of rainfall events that caused runoff in the plots (Author, 2018)

4.2.2 Discussion on the findings from runoff observations

Runoff production was higher in plot **A** than in plot **B** (Figure 4.6). The findings show that the coefficients of runoff production were 1.44% and 1.03% in plot **A** and **B** respectively. This means that runoff production dropped by 29% in plot **B**. There is a negative relationship between runoff and vegetation cover (Green *et al.*, 1994). Since the slope grade in both plots was fairly uniform under the same rainfall conditions, lower runoff generation in plot **B** is associated with denser vegetation cover on the soil.

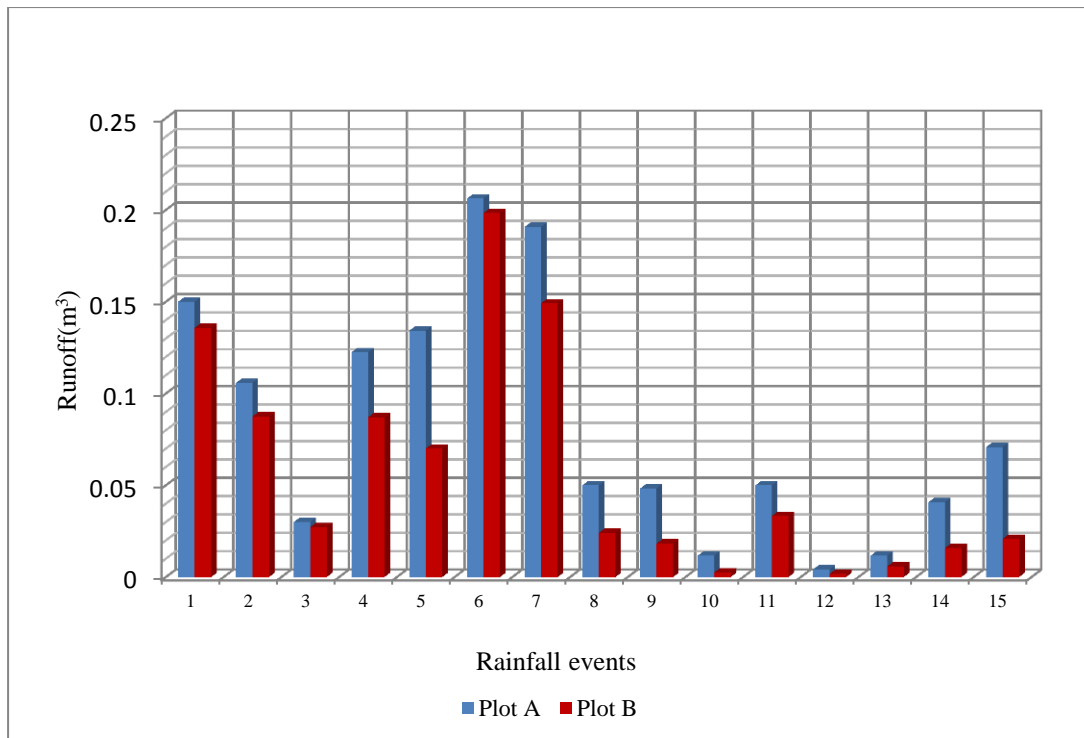


Figure 4.6: Runoff from plot A and B per rainfall event. (Author, 2018)

At the start of observations, total runoff from both plots was significantly high (1.7683 m³ in March, April and May). However, in June and July, it dropped remarkably to 0.3357m³ (Figure 4.7). This can be explained in two ways:

First, vegetation cover on the plots at the onset of rains was low perhaps due to effects of the preceding dry season where plants withered or got destroyed by livestock. Effective canopy interception of the raindrops in this case was quite low leading to production of higher runoff.

Secondly, partially weathered rock layers occur closer to the surface of the soil in the catchment. Surface crusting is widespread in ASALs and may be the primary reason for low infiltration of water in the soil (Hudson, 1987). Surface crusting may be caused by large herds of livestock. The characteristics of the ASAL soils cause decrease in infiltration rate of water in the soil causing production of higher runoff.

Generally, the amount of runoff produced on a slope depends on amount of rainfall, changing surface vegetation cover and antecedent moisture in the soil.

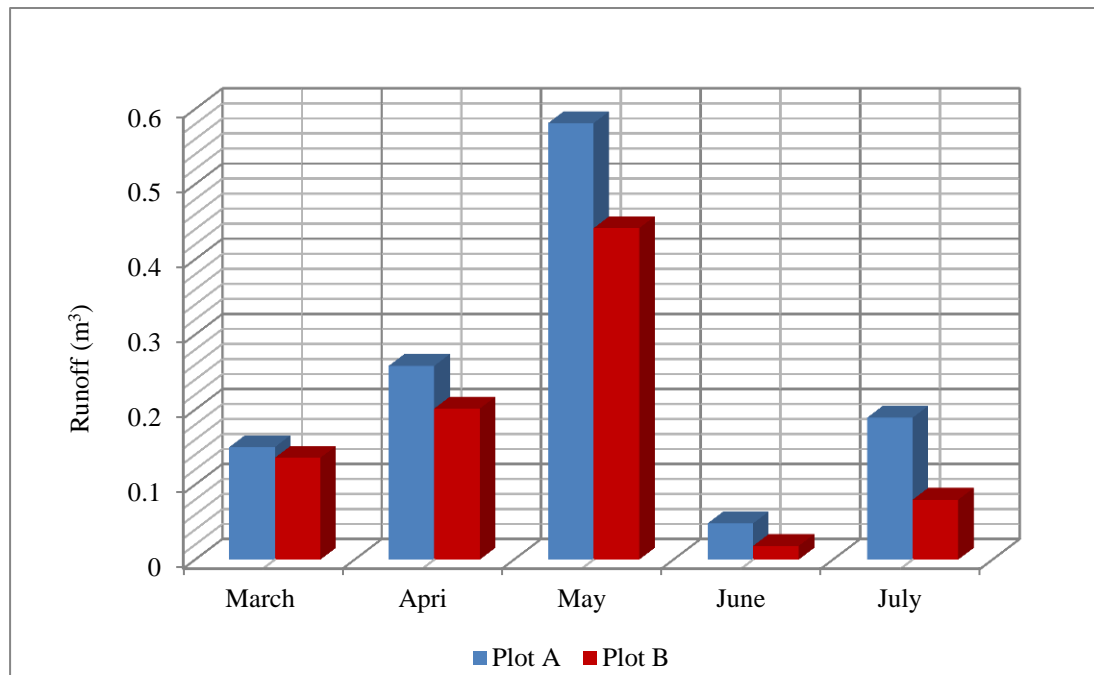


Figure 4.7: Runoff totals per month from Plot A and B (Author, 2018)

Implication of higher runoff generation from the slopes of the study area.

There is possibility of losing large volume of runoff water if there are no sufficient mechanisms of tapping and using it. The study found that over 43800litres/ha/year of total rain water is lost through runoff in the catchment. Access to adequate water is a serious problem in the ASALs. This water can be harvested and put to use. Hydrological studies on the possibilities of harvesting, using and conserving this water should be considered.

Possibility of flash floods in the lower course of Akiriamet-Kimpur ephemeral drainage system is high. This would interfere with transport services, destroy property and claim lives of people and livestock.

4.2.3 Discussion on the findings from sediment generation and soil loss

Analysis of soil loss from the plots shows that soil loss was higher in plot **A** where 56% of total soil loss occurred (Figure 4.8). However, it decreased by 23% in plot **B**.

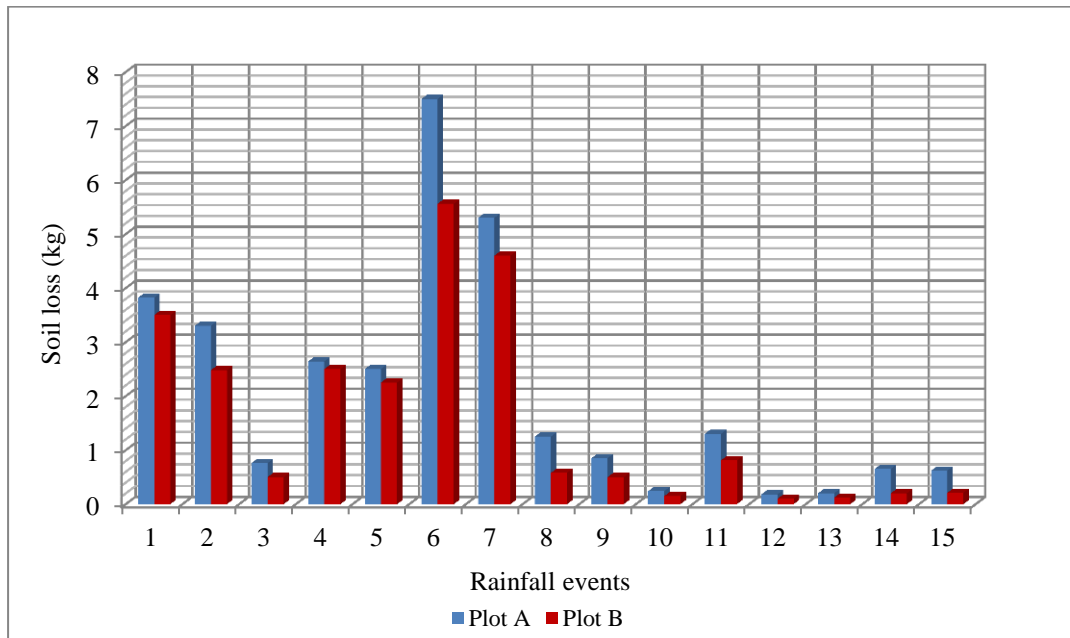


Figure 4.8: Soil loss from plot **A** and **B** per rainfall event. (Author, 2018)

Monthly soil loss summary shows a similar scenario (Figure 4.9). This observation is attributed to denser vegetation cover in plot **B**. It is already noted that denser vegetation cover slows down production of runoff. Since correlation analysis of runoff and rainfall data from this study shows a strong positive relationship, it means that dense vegetation cover is associated with reduced rate of sediment generation. In addition, vegetation through plant rooting system provides firm grasp on the soil particles to further reduce their erodibility.

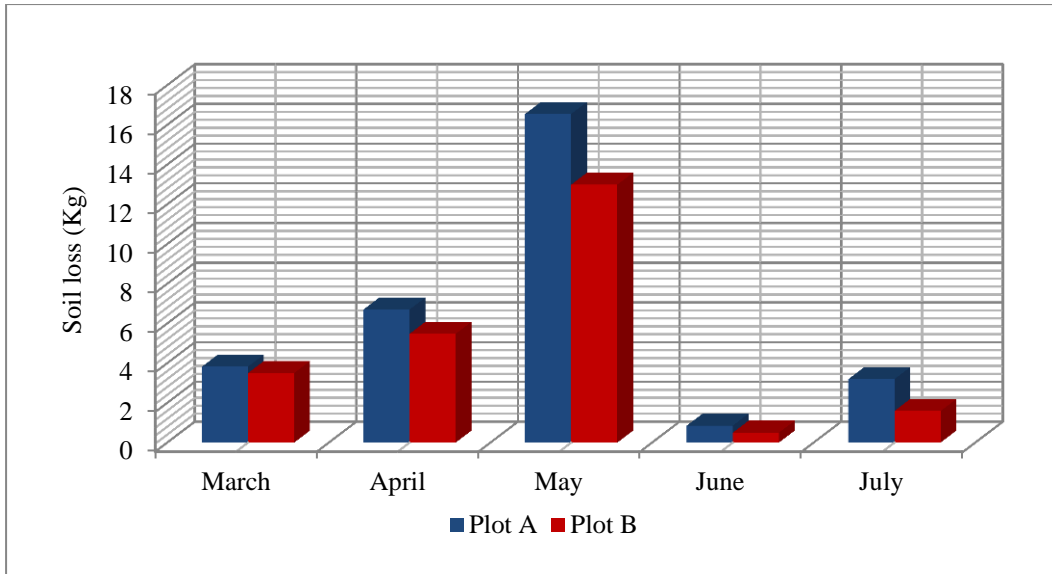


Figure 4.9: Soil loss totals per month from Plot A and B (Author, 2018)

Runoff and soil loss values in the study present a similar trend over the observed rainfall events (Figure 4.10). The study established a significant positive relationship between soil loss and runoff production ($r = 0.9840$, $P < 0.05$). This means that a larger quantity of sediment is expected in resultant runoff when higher amounts of runoff are produced from the slopes of the catchment area.

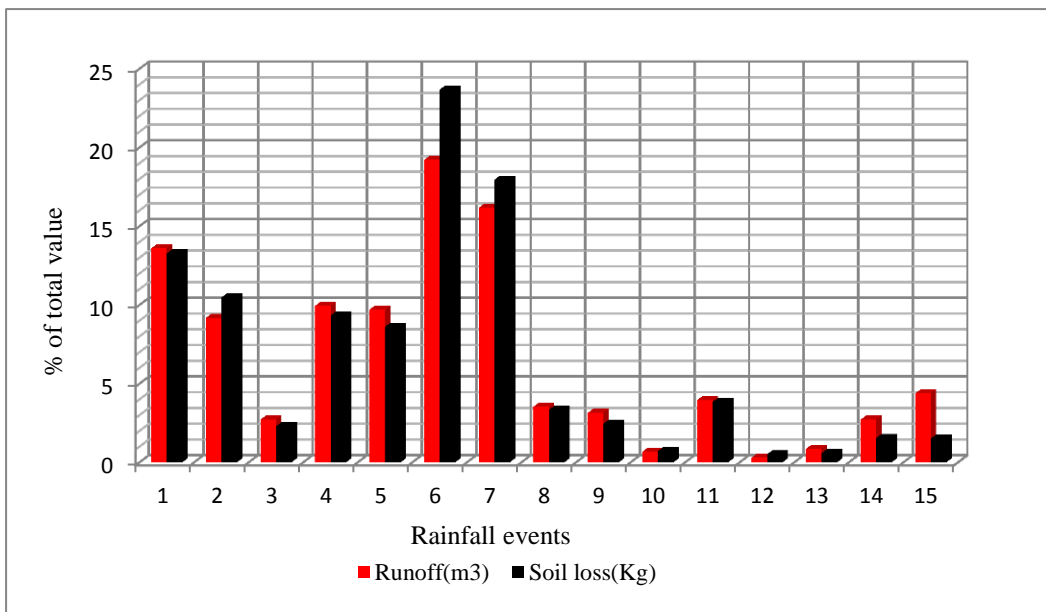


Figure 4.10: Daily runoff and soil loss values per rainfall event (Author, 2018)

High intensity rainfall is associated with high amount of runoff and higher rate of soil loss (Mohamedi & Kavian, 2015). It is important to observe that while the trend in sediment generation is similar to the trend in runoff production over the observed rainfalls, the trend in runoff production is also similar to the trend in rainfall amounts over the same rainfall events. In essence, rainfall, runoff and soil loss observations in this study show similar trends over observed rainfalls (Figure 4.11). This means that rainfall, runoff and soil loss have a positive relationship (Zenebe & Nigusse, 2011; Abua & Digha, 2015).

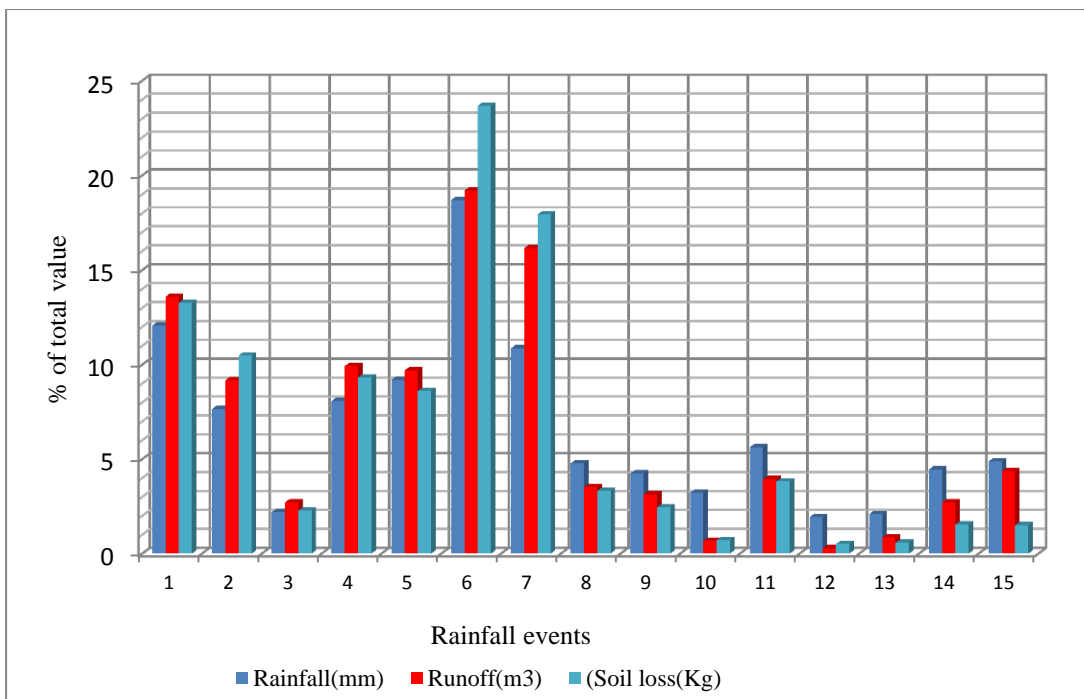


Figure 4.11: Rainfall, runoff and soil loss percentage values per rainfall event (Author, 2018)

There was notable decrease in both runoff and soil loss from the eighth to the fifteenth rainfall events. This is because canopy cover developed by dry land plants is a natural cushion against the energy impact of rainfall hence promotes infiltration of rain water and controls runoff and sediment production (Vasquez-Mendez *et al.*, 2010). The study establishes that this decrease was caused by progressive development in vegetation cover on the soil in the plots.

Implication of large sediment generation from the slopes of the study area.

Sediment production and movement from the hill slopes to valley bottoms can influence agriculture negatively. Top fertile soil is washed down the slope causing soil degradation on the slopes. Pasture development and subsistence crop production would therefore deteriorate.

Siltation in the valley bottoms especially on the ephemeral river beds can influence human activities positively. The large loads of sediments attract activities such as sand harvesting and small-scale gold pan mining. However, this situation is likely to cause floods because of reduction in the depth of river beds.

4.2.4 Discussion on the findings from soil loss and rate of soil erosion

Soil loss analysis shows that the rate of soil loss by water in the catchment is 120.3–155.5g/m². This means that a minimum of 1.203tonnes of soil is lost per hectare every year through runoff. If the results are generalized, over 0.2 million tonnes of soil are lost through runoff per year in Alale. The following conditions had significant influence on the rate of soil loss in the catchment.

- i) Bare soil surface exposed to direct sunlight and direct rain drops. Direct sunlight cause increase in evaporation of moisture from the soil which loosens the soil particles. Unconsolidated soil particles are vulnerable to erosion. Direct raindrops mechanically cause detachment of the soil particles through splash erosion.
- ii) Large herds of livestock trample on the soil as they graze. Thus, the soil particles become loose and vulnerable to erosion.
- iii) Insufficient plant rooting systems due to sparse vegetation which would provide anchorage to the soil particles. The soil particles in this case are erodible even in the event of the least hydraulic force in runoff.

iv) High rainfall intensity which caused excessive Hortonian and saturation overland flow.

Geomorphic implications of soil erosion on the environment of the study area

Development of gullies on the hill slopes is evident in the study area (Plate 4.1). This is a direct effect of detachment and movement of soil particles along the slope in runoff. Transfer of soil particles down the slope leads to siltation in the valley bottoms. This may cause development of shallow river beds, a condition which favour occurrence of floods in the study area.



Plate 4.1: Gullies, produced by water erosion near Amakuriat in Alale.

CHAPTER FIVE

5.0 SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

Runoff production in plot **A** was higher than plot **B**. The findings show that production of runoff decreased by 29 % in plot **B** compared to plot **A**. In general, over 43,800litres of rain water is lost through runoff per hectare every year in the study area. Similarly, sediment generation from plot **A** was faster than from plot **B**. From the results, 56% of total soil loss was recorded in plot **A** while only 44% was registered in plot **B**. The findings show that soil loss decreased by 23% in plot **B** compared to plot **A**. The rate of soil loss from the catchment is 1.203–1.555 tons/ha. Runoff had significant positive relationship with rainfall. Similarly, runoff had significant positive relationship with soil loss.

5.2 Conclusion

Runoff production on a slope is influenced by rainfall and vegetation cover characteristics. The amount of runoff generated from the slope corresponds to the amount of rainfall. Notwithstanding rainfall characteristics, runoff production is slow on slopes with dense vegetation cover. However, runoff production is faster on slopes with sparse vegetation cover. The amount of sediment eroded by runoff water depends on the amount of runoff produced on the slope. Consequently, slow runoff production on slopes with dense vegetation cover leads to slow rate of sediment generation. Hence, the rate of soil loss on slopes with dense vegetation cover is low. Slopes with sparse vegetation cover experience faster rate of soil erosion. In this regard, the study concludes that runoff production and sediment generation respond directly to changes in rainfall and vegetation cover characteristics. Therefore, the study rejects the null hypotheses herein and accepts the alternative hypotheses.

5.3 Recommendations

The best way to maintain healthy soil is preventing soil erosion through education, advocacy and concrete actions in the field (FAO, 2019). The recommendations in this study advocates for soil conservation through controlling the rate of runoff production in the study area.

- i) In order to control rapid production of runoff from the slopes of the study area, there is need to enhance surface vegetation cover. The study recommends enhancement of forest cover in the study area through planting trees especially on western slopes of Karasuk hills which are heavily deforested. County forestry department in conjunction with the local leadership in the study area should focus on mechanisms of rehabilitating the forest. The study recommends community participation in the exercise in order to nurture a positive relationship between people and the forest ecosystem.
- ii) There is need to enforce soil conservation and management practices in the study area. A soil conservation and management strategy is necessary. In this respect, the study recommends development and implementation of a soil conservation and management strategy in the study area. Dissemination of information to the local people on severity of soil loss from the slopes is also recommended. The County's land reclamation and Agro-forestry departments need to engage and train the local community on soil management and conservation practices.

5.4 Suggestions for further research

The study focused on runoff and soil loss under rainfall and vegetation cover parameters. Apart from runoff, there are other potential causes of soil loss in the study area such as land use practices. The study recommends further research on;

- i) The impact of land use practices on soil erosion by water in Alale.
- ii) Mapping erosion hot spots in semi-arid areas of West Pokot County to enable implementing agencies prioritize mitigation measures.
- iii) Possibility of harvesting, using and conserving the large amounts of runoff generated during rainfall events in the ASALs of West Pokot County with the view of enhancing access to adequate water.

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APPENDICES

A1: Statistical tables (*t*- distribution: Critical values of *t*)

Degrees of freedom	Two-tailed test: One-tailed test:	Significance level					
		10% 5%	5% 2.5%	2% 1%	1% 0.5%	0.2% 0.1%	0.1% 0.05%
1		6.314	12.706	31.821	63.657	318.309	636.619
2		2.920	4.303	6.965	9.925	22.327	31.599
3		2.353	3.182	4.541	5.841	10.215	12.924
4		2.132	2.776	3.747	4.604	7.173	8.610
5		2.015	2.571	3.365	4.032	5.893	6.869
6		1.943	2.447	3.143	3.707	5.208	5.959
7		1.894	2.365	2.998	3.499	4.785	5.408
8		1.860	2.306	2.896	3.355	4.501	5.041
9		1.833	2.262	2.821	3.250	4.297	4.781
10		1.812	2.228	2.764	3.169	4.144	4.587
11		1.796	2.201	2.718	3.106	4.025	4.437
12		1.782	2.179	2.681	3.055	3.930	4.318
13		1.771	2.160	2.650	3.012	3.852	4.221
14		1.761	2.145	2.624	2.977	3.787	4.140
15		1.753	2.131	2.602	2.947	3.733	4.073
16		1.746	2.120	2.583	2.921	3.686	4.015
17		1.740	2.110	2.567	2.898	3.646	3.965
18		1.734	2.101	2.552	2.878	3.610	3.922
19		1.729	2.093	2.539	2.861	3.579	3.883
20		1.725	2.086	2.528	2.845	3.552	3.850
21		1.721	2.080	2.518	2.831	3.527	3.819
22		1.717	2.074	2.508	2.819	3.505	3.792
23		1.714	2.069	2.500	2.807	3.485	3.768
24		1.711	2.064	2.492	2.797	3.467	3.745
25		1.708	2.060	2.485	2.787	3.450	3.725
26		1.706	2.056	2.479	2.779	3.435	3.707
27		1.703	2.052	2.473	2.771	3.421	3.690
28		1.701	2.048	2.467	2.763	3.408	3.674
29		1.699	2.045	2.462	2.756	3.396	3.659
30		1.697	2.042	2.457	2.750	3.385	3.646
32		1.694	2.037	2.449	2.738	3.365	3.622
34		1.691	2.032	2.441	2.728	3.348	3.601
36		1.688	2.028	2.434	2.719	3.333	3.582
38		1.686	2.024	2.429	2.712	3.319	3.566
40		1.684	2.021	2.423	2.704	3.307	3.551
42		1.682	2.018	2.418	2.698	3.296	3.538
44		1.680	2.015	2.414	2.692	3.286	3.526
46		1.679	2.013	2.410	2.687	3.277	3.515
48		1.677	2.011	2.407	2.682	3.269	3.505
50		1.676	2.009	2.403	2.678	3.261	3.496
60		1.671	2.000	2.390	2.660	3.232	3.460
70		1.667	1.994	2.381	2.648	3.211	3.435
80		1.664	1.990	2.374	2.639	3.195	3.416
90		1.662	1.987	2.368	2.632	3.183	3.402
100		1.660	1.984	2.364	2.626	3.174	3.390
120		1.658	1.980	2.358	2.617	3.160	3.373
150		1.655	1.976	2.351	2.609	3.145	3.357
200		1.653	1.972	2.345	2.601	3.131	3.340
300		1.650	1.968	2.339	2.592	3.118	3.323
400		1.649	1.966	2.336	2.588	3.111	3.315
500		1.648	1.965	2.334	2.586	3.107	3.310
600		1.647	1.964	2.333	2.584	3.104	3.307
∞		1.645	1.960	2.326	2.576	3.090	3.291

A2: Daily rainfall record for Alale from March, 2017 – July, 2017

MARCH				APRIL				MAY				JUNE				JULY			
Rainfall (mm)				Rainfall (mm)				Rainfall (mm)				Rainfall (mm)				Rainfall (mm)			
1	nil	17	nil	1	nil	17	28.5	1	34.3	17	0.3	1	0.1	17	nil	1	0.2	17	nil
2	nil	18	nil	2	nil	18	nil	2	nil	18	TR	2	nil	18	nil	2	nil	18	2.1
3	nil	19	nil	3	nil	19	nil	3	nil	19	69.7	3	nil	19	nil	3	nil	19	nil
4	nil	20	nil	4	nil	20	nil	4	2.2	20	0.7	4	nil	20	nil	4	12	20	5.8
5	nil	21	nil	5	nil	21	nil	5	0.1	21	nil	5	nil	21	nil	5	21	21	7.2
6	nil	22	2.3	6	nil	22	nil	6	nil	22	nil	6	nil	22	nil	6	nil	22	7.8
7	nil	23	nil	7	nil	23	nil	7	nil	23	nil	7	nil	23	nil	7	nil	23	0.3
8	nil	24	nil	8	nil	24	nil	8	0.9	24	nil	8	nil	24	nil	8	0.5	24	16.6
9	nil	25	nil	9	nil	25	nil	9	1.3	25	nil	9	nil	25	nil	9	nil	25	18.2
10	nil	26	45	10	nil	26	3.7	10	nil	26	nil	10	nil	26	nil	10	nil	26	4.6
11	nil	27	7.4	11	nil	27	nil	11	TR	27	0.1	11	nil	27	nil	11	3.0	27	nil
12	nil	28	0.7	12	nil	28	nil	12	nil	28	7.6	12	nil	28	nil	12	nil	28	nil
13	nil	29	nil	13	nil	29	8.2	13	nil	29	nil	13	nil	29	nil	13	3.8	29	nil
14	nil	30	nil	14	nil	30	30.1	14	nil	30	40.5	14	nil	30	0.1	14	nil	30	nil
15	nil	31	nil	15	nil	=	=	15	3.3	31	17.8	15	nil	=	=	15	0.4	31	0.4
16	nil	=	=	16	nil	=	=	16	1.2	=	=	16	15.8	=	=	16	1.0	=	=
Total =055.4				Total = 070.5				Total =180.0				Total =016.0				Total =104.9			

Key

<p>nil.....did not rain at all</p> <p>TR ...there were Traces of Rain (measured below the zero mark on the measuring cylinder of the rain gauge)</p> <p>Rainy days.....29 days. A day was considered rainy if rainfall amount was greater than 1.0mm</p>

A3: Approval of research Proposal



KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Website: www.ku.ac.ke

Internal Memo

FROM: Dean, Graduate School

DATE: 7th September, 2016

TO: Bukoma Emmanuel
C/o Geography Department.

REF: C50/CE/26130/11

SUBJECT: APPROVAL OF RESEARCH PROPOSAL
=====

We acknowledge receipt of your revised Research Proposal as per our recommendations raised by the Graduate School Board of 27th July 2016 entitled "Effect of Vegetation Cover on Runoff and Soil Loss in Semi Arid Region: A Case of West Pokot County, Kenya".

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology and Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking Forms per semester. The form has been developed to replace the Progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

Thank you.

HARRIET ISABOKE
FOR: DEAN, GRADUATE SCHOOL

CC. Chairman, Geography Department



Supervisors:

1. Dr. Shadrack K. Mirimi
C/Geography Department
Kenyatta University
2. Prof. Joy Obando
C/o Geography Department
Kenyatta University


HI/nn

A4: Copy of Research Clearance Permit from NACOSTI

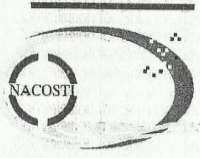
Permit No : NACOSTI/P/16/85476/14589
 Date Of Issue : 6th December,2016
 Fee Received :Ksh 1000

Director General
National Commission for Science, Technology & Innovation



REPUBLIC OF KENYA



National Commission for Science, Technology and Innovation
RESEACH CLEARANCE PERMIT

Serial No.A **12086**
CONDITIONS: see back page

THIS IS TO CERTIFY THAT:
MR. EMMANUEL BUKOMA SICHANGI
of KENYATTA UNIVERSITY, 401-30600
Kapenguria, has been permitted to
conduct research in Westpokot County
on the topic: EFFECT OF VEGETATION
COVER ON RUNOFF AND SOIL LOSS IN
SEMI ARID REGION: A CASE OF WEST
POKOT COUNTY, KENYA
for the period ending:
5th December, 2017

[Signature]
Applicant's Signature

CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officer will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one (1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

A5: Research acknowledgement at county level

OFFICE OF THE PRESIDENT



**MINISTRY OF INTERIOR AND COORDINATION
OF NATIONAL GOVERNMENT**

Office of the County Commissioner,
West Pokot County
P.O BOX 1
KAPENGURIA.

ccwestpokot@gmail.com
Email: **westpokotland@rocketmail.com**

REF: OOP.CC.ADM.15/14 VOL.I/81

21ST DECEMBER, 2016

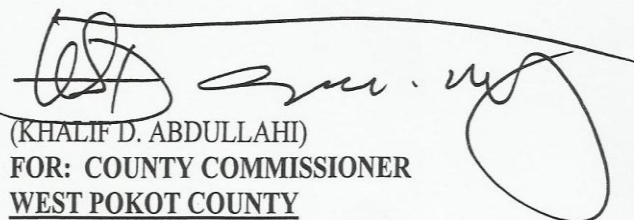
TO WHOM IT MAY CONCERN

RE: **RESEARCH AUTHORIZATION**
EMMANUEL BUKOMA SICHANGI

Reference is made to the Secretary/CEO, National Commission for Science, Technology and innovation letter NO. NACOSTI/P/16/85476/14589 dated 6th December, 2016 on the above subject.

This is to inform you that the above named who is a student at Kenyatta University College has been duly authorized to undertake a research on "*Effect of vegetation cover on runoff and soil loss in Semi Arid Region: A case of West Pokot County Kenya*" for a period ending 5th December, 2017

Kindly accord him your cooperation and necessary assistance he may require on his tour of Research study.


(KHALIF D. ABDULLAHI)
FOR: COUNTY COMMISSIONER
WEST POKOT COUNTY

c.c. The County Director of Education
WEST POKOT COUNTY.

A6: Letter seeking permission to use the school land for the purpose of the study

Emmanuel Bukoma,
P.O BOX 43844 - 00100,
Nairobi.

January 05, 2017.

The Secretary/Principal,
Board of Management,
Alale Girls Secondary School,
P.O BOX 401-30600,
Kapenguria.

Dear Sir/Madam,

RE: PERMISSION TO CONDUCT RESEARCH WORK WITHIN YOUR SCHOOL COMPOUND

Please refer to the letter of introduction and a copy of research permit attached.

Kindly grant consent to undertake academic research work on 'Effect of Vegetation Cover on Runoff and Soil Loss in Semi Arid Region: A Case of West Pokot County, Kenya' within your school compound.

Preliminary transect survey on vegetation cover and slope measurement show that the Northern parts of the school land meets the minimum physical requirements for setting up the experiments in this study. A maximum of **six 20m by 10m runoff plots** occupying approximately $\frac{1}{2}$ **an acre** of the land will be constructed and used for the purpose of the study only.

Runoff plots construction and consequent observations shall begin immediately after consent is given. The experiments will conclude in August, 2017. Your consideration upon this request will be acknowledged. Thank you.

Yours faithfully,



Emmanuel Bukoma Sichangi

A7: Letter giving consent to use the school land for the purpose of this study



**ALALE GIRLS SECONDARY SCHOOL,
P.O. BOX 401-30600,
KAPENGURIA.**

To:
Mr. Bukoma Emmanuel,
P.O. Box 43844-00100
Nairobi.



Date: 22/02/2017

*Received and
Permission granted
Allice,
Principal*

Dear Sir/Madam,

RE: PERMISSION TO CONDUCT ACADEMIC RESEARCH WITHIN THE SCHOOL COMPOUND

Your letter dated 05/01/2017 on the subject 'PERMISSION TO CONDUCT RESEARCH WORK WITHIN YOUR SCHOOL COMPOUND' refers

I am pleased to inform you that permission has been granted to this effect. You may proceed with runoff plot construction and consequent academic research work on the field you identified within our school compound.

May I take this opportunity to wish you good luck in your academic endeavour.

Yours faithfully,

B.O.M secretary/ Principal