SOIL EROSION PROCESSES AND CONTROL ON RURAL ROADS IN MT. ELGON SUB-COUNTY, TRANS NZOIA AND WEST POKOT COUNTIES, KENYA

BY

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DECLARATIONS

Declaration by student

This thesis is my original work and has not been presented for a degree award in any other University.

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Declaration by Supervisors

"We confirm that the work reported in this thesis was carried out by the candidate under our supervision as University Supervisors. This thesis has been submitted for examination with our approval as University supervisors."

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DEDICATION

I dedicate this thesis work to all the people who conserve, protect and practice the ideals of a Friendly/Good Environment for all. "A Good Environment is in the state of mind".

ABSTRACT

Roads are essential component to the counties' economy; they are key agents of economies to thrive, good and well maintained roads imply great and successful economies. Low volume rural roads are facing great challenge and highly deteriorating due to anthropogenic and climatic factors. Low volume rural roads were studied in three varied climatic zones in three counties of western Kenya. The study was carried out to assess the management and the current state of rural roads (Class D and E) in Mt. Elgon Sub County (in Bungoma County), Trans Nzoia and West Pokot counties. Soil loss and deposition on the rural roads, surface runoff rates were determined and the state of soil erosion control works were assessed. Potential areas vulnerable to soil erosion were identified. Catchment characteristics were calculated using Cooks method and the runoff rates coefficient obtained to determine the runoff rates in m^3/s. Classification of soils' drainage potential and soil types in the study areas was determined by using soil data obtained from International Livestock Research Institute. Terrain data was obtained from Shuttle Relief Topography Mission which was used to determine gradients using ARCGIS. Soil movement and deposition was analysed and it was observed that a greater change occurred in the months of November and December 2013 with a deposition change of 11.1 cm compared to 8.80cm for the month of January and February 2014. Highest rate of erosion was recorded at -10.1cm in the rainy months and -6.64 cm in dry months. Total soil volume movement in three months was 8309.75 cm^3 where Mt. Elgon Sub County exhibited the highest change of 3284 cm^3 .Terrain (gentle/flat and undulating) for West Pokot and Trans Nzoia (Sibanga) roads had a negative correlation while Mt. Elgon (hilly, mountainous and gentle) and Tans Nzoia-Sikulu (gentle/flat) roads had a positive correlation of r=0.530 and r=0.032, respectively. The runoff rates at Mt. Elgon were the highest at 3.7 m^3/s, while the mean runoff rate was $1m^3/s$ .Rainfall on the roads catchment ranged between 800-1600 mm^3 of rain annually, and this contributed to the most likelihood of roads in upper Mt. Elgon and North of Sibanga getting more eroded than roads in the south and other roads. It was found out that 54.3% of the total road network was made up of gravel and 18.6% of it had been encroached by vegetation which distorted the camber. Culverts' efficiency was rated at a mean of 40%. Areas most vulnerable to erosion were found to be in Mt. Elgon from 10 km -22 km stretch of the road and Sikulu-Kinyoro road bordering Kapsara tea factory. The research therefore draws recommendations to improve and enhance the management of roads by discouraging road reserve cultivation and creation of cut off drains on upper Mt. Elgon and Sibanga roads, the use of GIS in soil modelling is critical for engineers to avoid vulnerable and unstable areas of the roads.

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LIST OF ACRONYMS

ASAL-Arid and Semi-Arid Lands

GPS-Geographic Positioning System

ILO-International Labour Organization

ILRI-International Livestock Research Institute

KENHA-Kenya National Highway Authority

KERRA- Kenya Rural Roads Authority

KMS- Kenya Meteorological Services

KURA-Kenyan Urban Roads Authority

MEM-Micro-Erosion Meter

NEMA-National Environmental and Management Authority

SRTM-Shuttle Radar Topography Mission

TMEM-Traversing Micro-Erosion Meter

USLE-Universal Soil Loss Equation.

DEFINITION AND OPERATIONALIZATION OF TERMS

Servitude-Areas along the road reserve set aside for construction installation of road auxiliary services that include electricity, water, telephone and optical cables

Low volume roads-These are roads that handle light weight traffic less than 10 Tonnes and are considered rural roads that fall between class D, E and unclassified Roads (UCLRS)

Mt. Elgon-Refers to the Northern Section of Mt. Elgon County and it was used in this research in line with other two counties –West Pokot and Trans Nzoia

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Kenya has a road network of approximately 150,000 km out of which 63,805 km are classified, 14,000km unclassified urban roads and the rest approximately 73,000 km are unclassified rural roads including 9,000 km of roads in Game Parks and National Game Reserves. Out of the 150,000 km only 11,500 km are paved, the remaining 138,500 km are mainly unpaved low volume roads (Ministry of Roads and Public Works- Roads 2000, May 2005). The unpaved roads are much more susceptible to erosion.

Erosion is the process by which soil and rock are removed from the Earth's surface by natural processes such as wind or water flow, and then transported and deposited in other locations (Heimsath *et.al*, 2001).

While erosion is a natural process, human activities such as agriculture, road construction among others have greatly increased the rate at which erosion is occurring. Excessive erosion causes problems such as damage to infrastructural facilities, desertification, decrease in agricultural productivity, sedimentation of waterways, and ecological collapse due to loss of the nutrient rich upper soil layer. Industrialization, agriculture, deforestation, roads construction, climate change and urban sprawl are amongst the most significant human activities in regards to their effect on accelerating erosion.

Urbanization and road construction can have a number of effects on soil erosion processes-first by clearing the land of its vegetative cover, altering drainage patterns, and compacting the soil during construction; and next by covering the land with an impermeable layer of asphalt or concrete that increases the amount of surface runoff and increases surface wind speeds. Much of the sediment carried in runoff from urban areas is highly contaminated with fuel, oil, and other chemicals. This increased runoff not only erodes and degrades the land that it flows over, but also causes major disruption to surrounding watersheds by altering the volume and rate of water that flows through them, and filling them with chemically polluted sedimentation.

This environmental challenge can be solved by enhancing soil and water conservation related to road infrastructure works, this should be encouraged to start from the upper catchment area, with the objective of reducing water runoff and silt transportation towards the roads. Improved land management practices in the upper catchment such as controlled grazing and soil and water conservation on cultivated land, water harvesting from roof catchments, introduction of water pans in strategic locations, and planting of trees (reforestation) will retain water and reduce the runoff to the roads. There is also a need to divert runoff from homesteads and other built up areas through cut off drains discharging the water without creating damage to the road.

Road drainage system should be constructed along the road reserves in accordance with set road specifications and should aim at avoiding or reducing the concentration of water flowing out of the road servitude. Erosion control measures include scour checks and check dams in drains and protection of outfalls from culverts and bridges; stabilization of drains and embankments by using suitable vegetative material. In the lower catchment areas- below the road servitude, there must be a plan for safe disposal of water either to nearest natural waterway or, if there is a demand, to water harvesting and water conservation structures. In the latter case, runoff is led to infiltration ditches/pits or storage ponds for watering animals, irrigation or domestic use (Eriksson and Kidanu, 2010).

Monitoring and modelling of erosion processes can help better understand the causes, make predictions, and plan how to implement preventive and restorative strategies. However, the complexity of erosion processes and the number of areas that must be studied to understand and model them (e.g. climatology, hydrology, geology, chemistry, physics, etc.) makes accurate modelling quite challenging.

Erosion models are also non-linear, which makes them difficult to work with numerically, and makes it difficult or impossible to scale up to making predictions about large areas from data collected by sampling smaller plots. The most commonly used model for predicting soil loss from water erosion is the Universal Soil Loss Equation (USLE). USLE in the road perspective is important in estimating soil loss from catchment areas which are majorly agricultural fields. USLE estimates the average annual soil loss as:

$$A = RKLSCP$$

Where R is the rainfall erosive factor, K is the soil erodibility factor, L and S are topographic factors representing length and slope, and C and P are cropping management factors.

Erosion is measured and further understood using tools such as the micro-erosion meter (MEM) and the traversing micro-erosion meter (TMEM). The MEM has proved helpful in measuring bedrock erosion in various ecosystems around the world. It can measure both terrestrial and oceanic erosion. On the other hand, the TMEM can be used to track the expanding and contracting of volatile rock formations and can give a reading of how quickly a rock formation is deteriorating (Stephenson and Finlayson, 2009).

1.2 Statement of the problem

Poorly functioning road drainages are common on low volume rural roads. Some of them are not even due for maintenance and improvement since they were either constructed with inadequate drainage system or the system were installed inappropriately. Land use changes over time in the catchment above the road, with more intensive land utilization and deforestation that results in increased runoff which exceeds the capacity of the road drainage systems. Such roads deteriorate fast, resulting in high costs of maintenance and repairs, with extensive soil erosion damages to adjacent land often with large gullies forming. This problem perhaps, could be due to the lack of quick reporting system involving the community and other stakeholders.

Soil erosion rate and intensity is caused by a number of climate factors such as rainfall amount and intensity as well as physiographic and soil factors. The contributions of these factors to erosion on roads and adjacent land are not well understood. For effective conservation measures to be undertaken, the relationship of these factors and the soil losses needs to be studied. Soil conservation efforts have to be based on factual information about rates and extent of soil erosion. It is important to provide information about the amount of erosion on roads of different characteristics and to investigate the effectiveness of various soil conservation measures.

Recently extensive construction and maintenance of rural roads in Kenya has increased road access and efficiency, thus enhanced population mobility and consequently increase in agricultural production accompanied with improved standards of living of most rural communities. In the arid and semi-arid areas (ASALs) with little or no vegetation cover on the surface, road construction is accompanied with erosion that leads to destruction.

The current situation in most rural roads can be characterized as follows:

- Many large gullies, too much water and high flow velocity over unprotected soils near roads. As a result, many tons of fertile soil and water are being lost and land becoming unproductive;
- Siltation and erosion damages to roads and land downstream.
- Frequent conflicts with the land owners over the drainage of water over their land

The theme of this study is on soil erosion processes and control on rural roads in the regions of Mt. Elgon County (Mt. Elgon District), West Pokot and Trans Nzoia counties. Little research has been done to specifically outline the erosion problems on low volume roads, there is less research in the zones especially in comparison with the three climatic regions. There exists less knowledge on identification of high, medium and low potential erosion zones in order to design roads alignment along medium and low potential areas to minimize road deterioration and maintenance coast. It is on this background that research seeks to fill the gap.

1.3 Objectives of the study

1.3.1 General objective

To assess the amount of soil eroded, deposited and surface runoff on rural roads in Mt. Elgon Sub County, Trans Nzoia and West Pokot counties in comparison with existing soil erosion control structures.

1.3.2 Specific objectives

i. To compare soil loss and sediments for low volume rural roads in different terrains.

ii. To establish the surface runoff rates on the selected rural road segments on different terrains.

iii. To assess the state of soil erosion control works and measures in the road drainage system in the study area.

iv. To identify areas with potential high rate of soil erosion on the road segments selected for study and recommend on minimizing erosion.

1.3.3 Research questions

The study was guided by the following research questions:

i. Which factors contribute to soil erosion in the study area roads?

ii. How much sediment is eroded and deposited in the low volume roads?

iii. What are the runoff rates on road catchment zones?

iv. What is the current state of soil control drainage structures?

v. Which areas have a high potential for soil erosion?

1.4 Study area

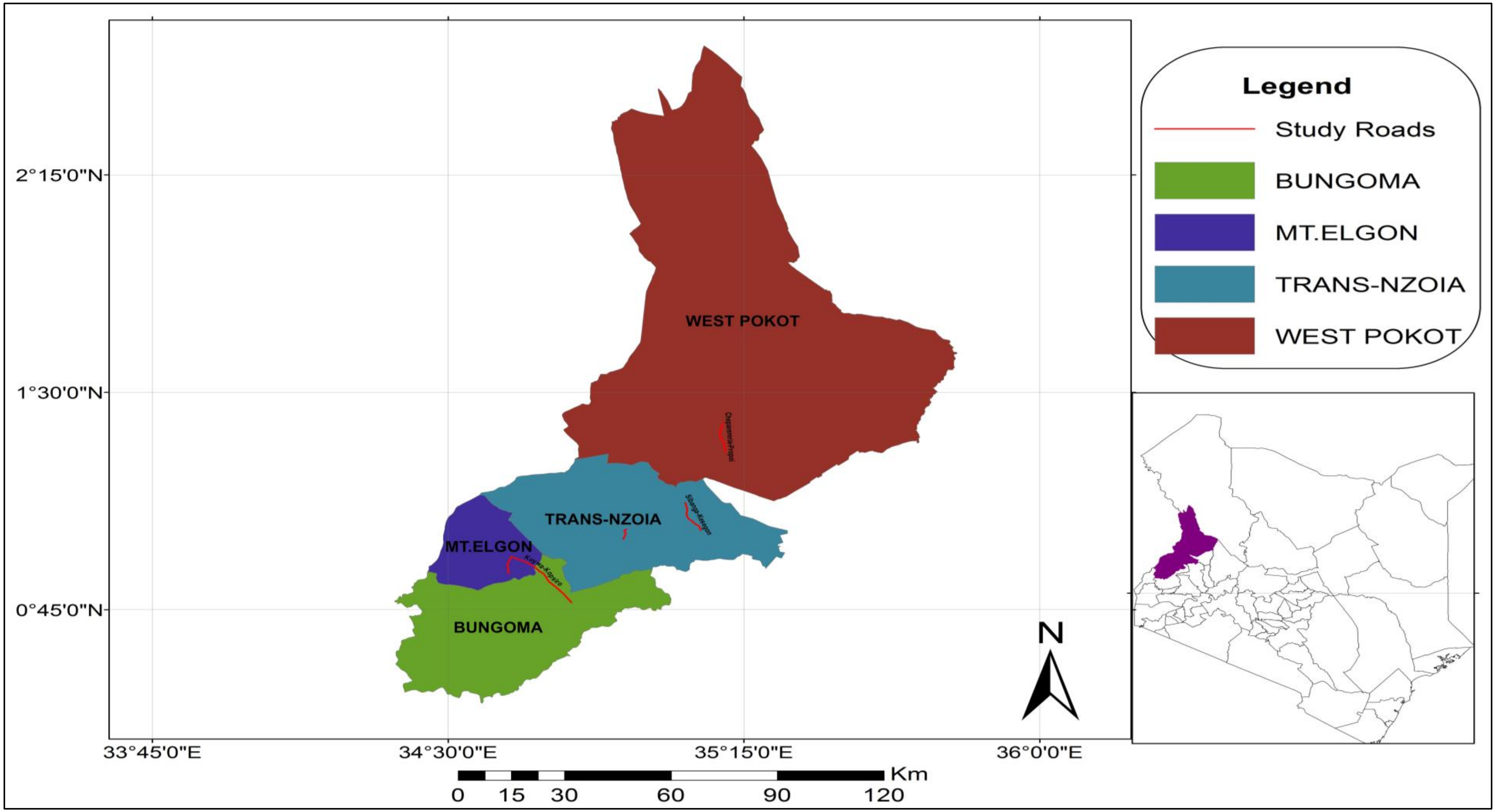


Figure 1.1: Study area location and study roads.

1.5 Scope

The study was undertaken on two classes of rural roads, class D and E roads. Chepareria-Priokwo (class D) road was selected in West Pokot County, a stretch of 8 km (Figure 1.2). The road was chosen to represent arid and semi-arid Zone. Trans Nzoia which is a mid-latitude zone was represented by two roads a class D (Sikulu-Kinyoro) 8.5 km and E (Sibanga-Kesegon) 20 km (Figure 1.3). A class D road was selected in Mt. Elgon sub-county; a 24 km class D road was picked that traverses through Kapkateny to the slopes of Mt. Elgon via Cheptonon, Kipsikirok, Chebiuk and ends at Kopsiro. The road rises from 2000 m ASL to 3000 m ASL in Kipsikirok (Figure 1.4).

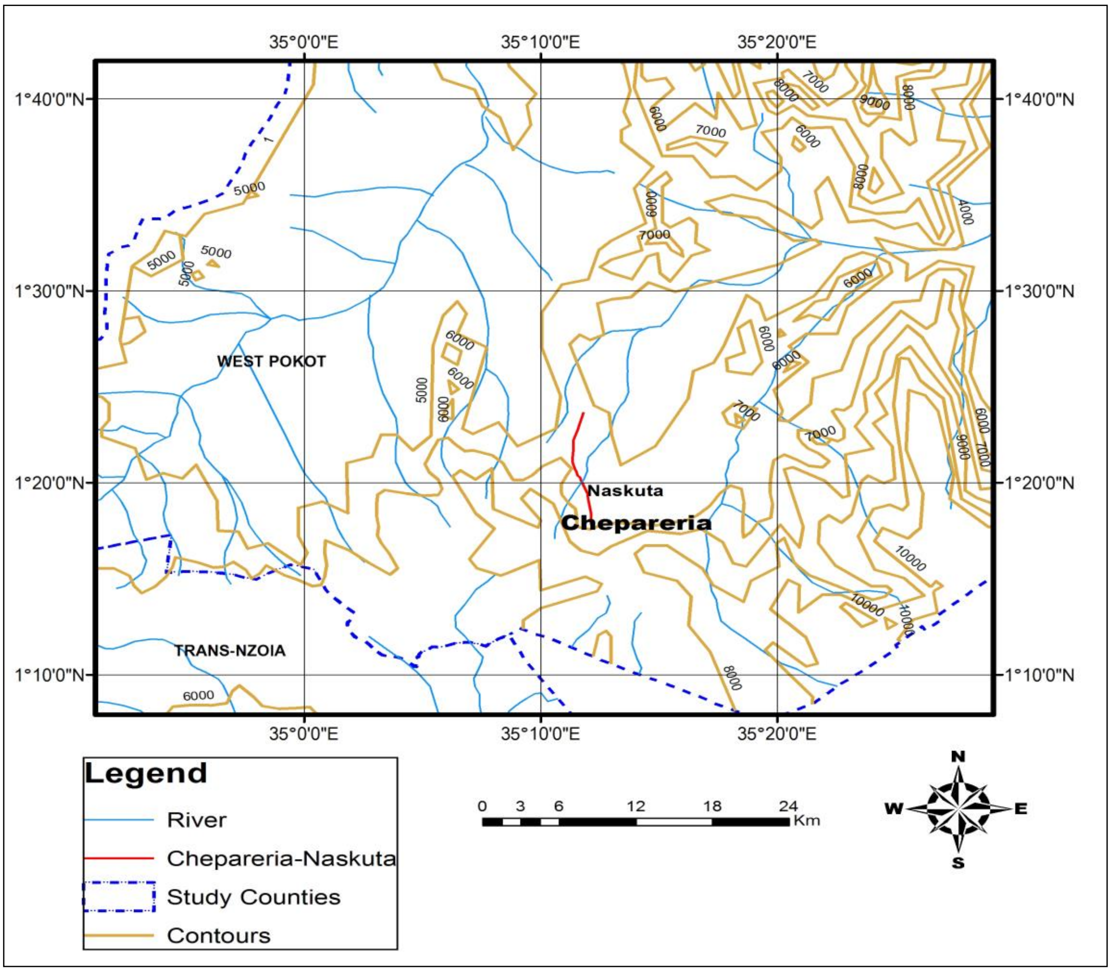


Figure 1.2: West Pokot Study Road.

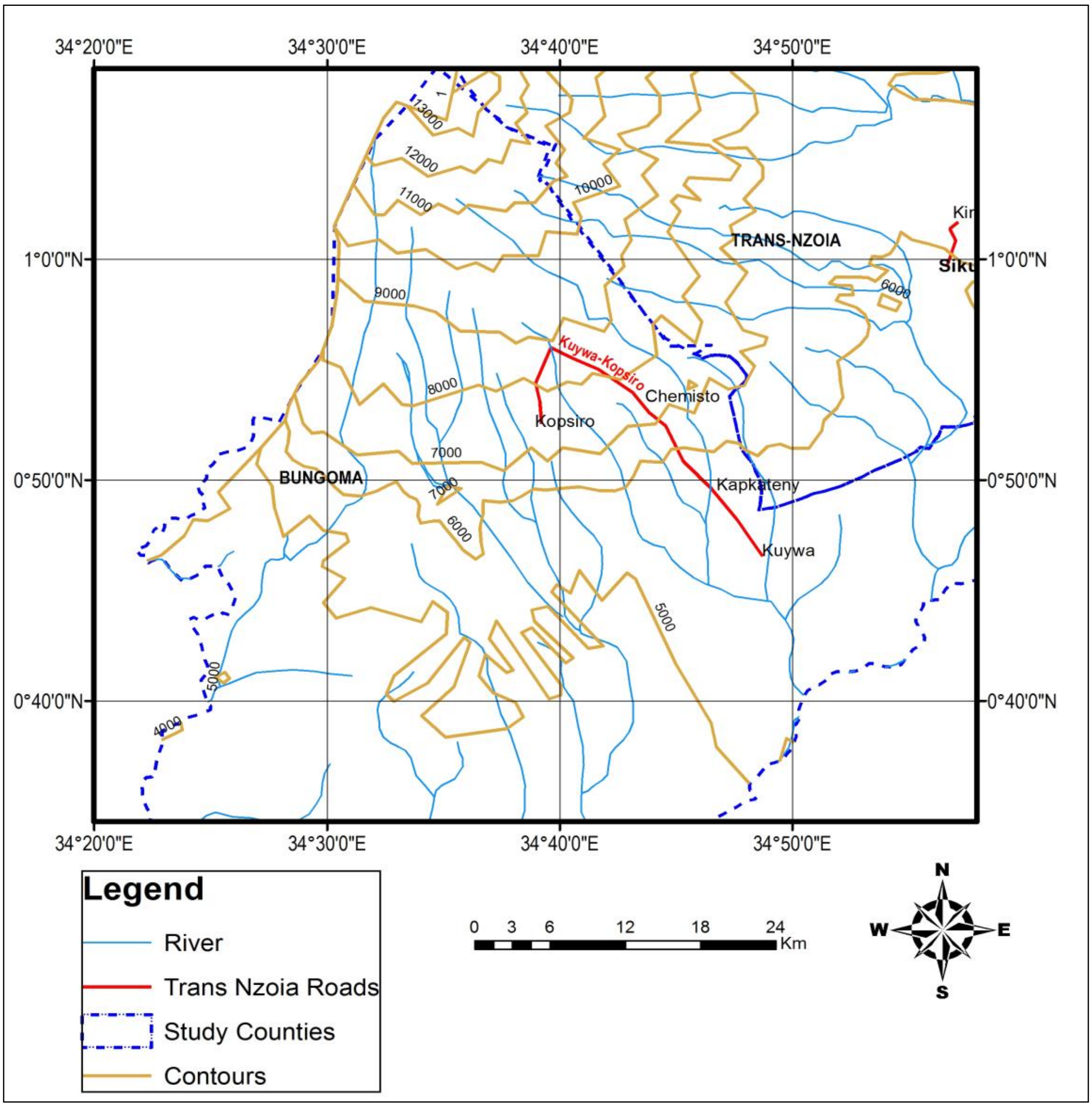


Figure 1.3: Trans Nzoia County Study Roads Class E and D.

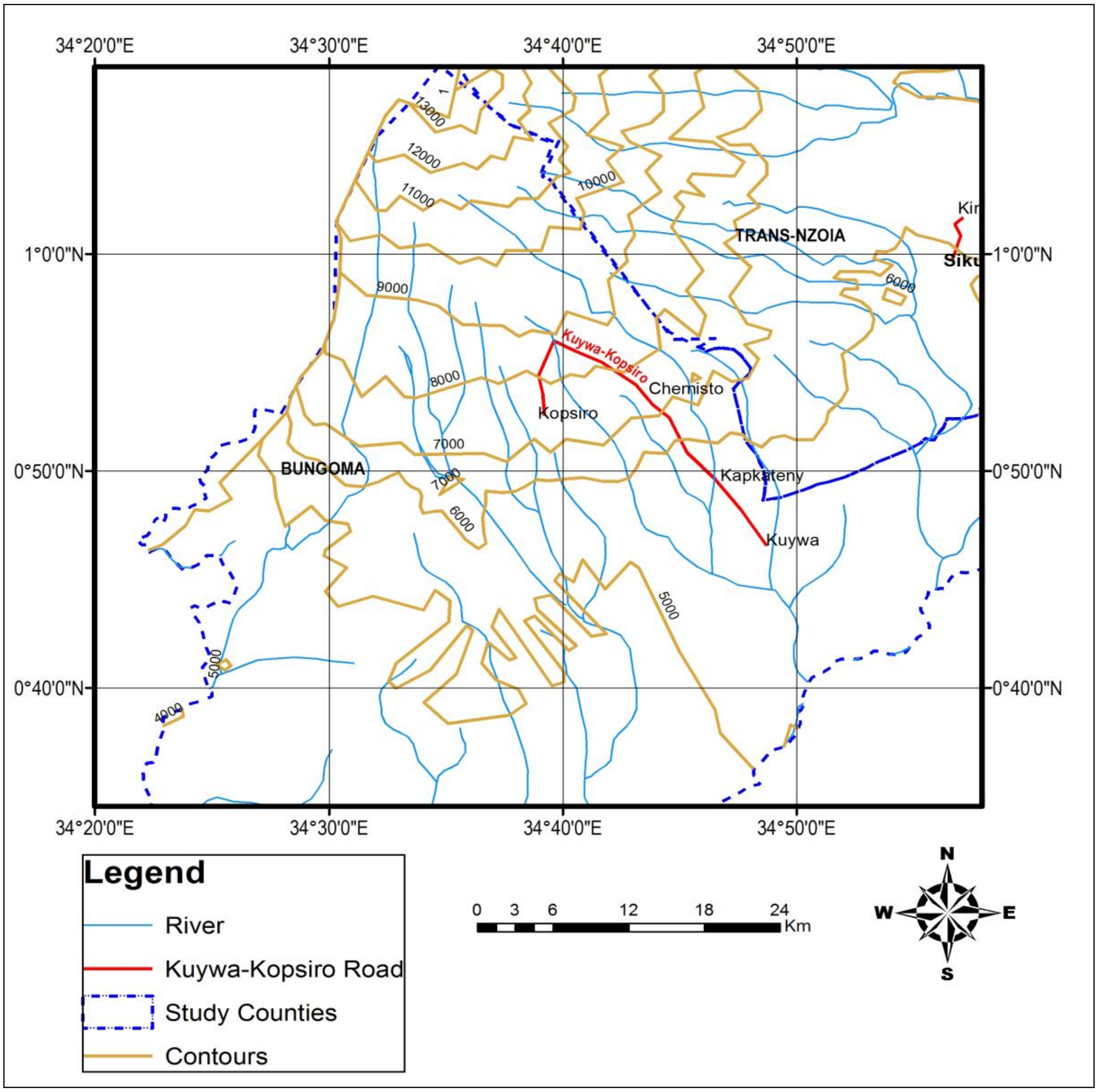


Figure 1.4: Mt. Elgon Sub county Study Road.

1.6 Justification

Roads contribute to the economic and social development of a country therefore proper maintenance and safe guarding of the infrastructure is essential. Information on soil erosion and classification system is essential to guide engineers, infrastructure managers, environmentalists and geologists in the evaluation and design of roads and bridges, in order to predict the risk of catastrophic failure during erosion events and to monitor channel erosion to maintain roads and road structures. Most of the unpaved roads (in the study area) had a substantial backlog of maintenance work. In most cases the drainage system was not functioning and the road surface was defective. The Kenya Rural Roads Authority (KeRRA) is providing leadership in sustainable rural road infrastructure planning and execution, improving rural accessibility and modernizing Rural Roads management. In realizing this undertaking, one of the critical areas KeRRA has been dealing with, is the issue of environmental damages directly related to road improvement and maintenance works as well as instituting mitigation measures to address these damages.

All road works can potentially result in environmental hazard through, for instance, interference with the natural drainage pattern resulting in soil erosion. One of the most common environmental challenges in road works is soil erosion. If not properly controlled, runoff from the road servitude and surrounding land can cause extensive damages both to the roads and adjacent property. Erosion from road catchment area on the road causes instability to the crust and loss of fertility. Soil is responsible for the turbidity of river water, where sediments interferes with the normal life of aquatic animals like fish breeding sites and in cases where the soil originates from farmlands with high rate of inorganic fertilizers this causes algae bloom on ponds, lakes and rivers.

To this end, the study illuminates on the problem of soil erosion on rural roads with a view to suggesting rationalized and sustainable soil erosion control strategies.

CHAPTER TWO

LITERATURE REVIEW

Soil erosion is one form of soil degradation along with soil compaction and loss of soil structure, poor internal drainage, sanitization, and soil acidity problems. These other forms of soil degradation, serious in themselves, usually contribute to accelerated soil erosion (Gupta, 2012). Soil erosion is a naturally occurring process on all land. Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil this can be in form of earth movement, landslides and mud flow. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks.

2.1 Soil Erosion

Soil erosion has been studied by several authors including, Pimentel.*et.al*, (1995) carried out a study in Philippines, Nigeria and Jamaica on Environmental and economic cost of soil erosion and they found out that tremendous amounts of soil are lost annually on steep slopes of Philippines and Jamaica compared to <1% gradient of yam fields in Nigeria-221 tons of soil was lost per acre per year in slopes of 12% while 3 tons of soil is lost on slopes with gradient of <1% per year. It is from this basis that there is need to determine areas with high potential of erosion and device preventive methods to curb further soil movement and increase our roads functionality timespan.

Soil web, 2014 outlines the Soils Susceptible to Erosion to include; soils with low water infiltration capability, soils with low organic matter content, soils with poor (unstable) structure and soils on steep hills (especially in regions of high rainfall), it is in this view that the research conducts an overlay of the above factors to establish zones with greater rates of erosion due to intersection of the above factors.

2.1.1 Erosion by Water

The rate and magnitude of soil erosion by water is controlled by; Rainfall intensity and runoff. Both factors must be considered in assessing water erosion problems. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles (Olugbebi, 2010).

Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration is reduced due to soil compaction, crusting/formation of hardpan or freezing (Wall *et al.,* 1987).

2.1.2 Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil type. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand and certain clay textured soil. Tillage and cropping practices which lower soil organic matter levels, cause poor soil structure, and result in compacted soil, which contributes to increases in soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by formation of a soil crust, which tends to "seal" the surface. On some sites, a soil crust might decrease the amount of soil loss from sheet or rain splash erosion, however, a corresponding increase in the amount of runoff water can contribute to greater rill erosion problems.

Past erosion has an effect on a soils' erodibility for a number of reasons. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils because of their poorer structure and lower organic matter. The lower nutrient levels often associated with subsoils contribute to lower crop yields and generally poorer crop cover, which in turn provides less crop protection for the soil.

Many factors are important for the soils ability to resist erosion. The permeability is important since it defines how the precipitation will be divided in terms of soil moisture, surface runoff and infiltrated ground water (Toy *et al.,* 2002). Also organic content is important; a higher organic content will decrease the soil erodibility (Andersson, 2010). As a high organic content increases the porosity and thereby also the permeability and the water holding capacity of the soil. Therefore, potential erosive runoff is reduced (Jankauskas *et al.,* 2007). High presence of coarse grain size particles also reduces the erosion significantly. For example in Mediterranean calcareous soils like the soils of semiarid Tunisia, a 10% presence of pebbles in the surface horizon reduces the erodibility by as much as 15%, why a high content of pebbles indicates good resistance to erosion. The grain size of approximately 1-300 microns, which is for fine and medium sand, have the highest tendency to erode. If the grain size is smaller the cohesive forces between the grains will prevent detachment, while larger grains are too heavy to transport (Anderson, 2010).

2.1.3 Slope Gradient and Length

Naturally, the steeper the slope of a field, the greater the amount of soil loss. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring and carrying capacity for sediment (Yang, 2008).

2.1.4 Vegetation and soil erosion

Vegetation is a key player in soil erosion. Potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface are the most efficient in controlling soil erosion (e.g. forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

Poorly constructed tile outlets may also contribute to stream and ditch bank erosion. Some do not function properly because they have no rigid outlet pipe, or have outlet pipes that have been damaged by erosion, machinery, inadequate or no splash pads, and bank caveins.

Soil quality, structure, stability and texture can be affected by the loss of soil. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture. Textural changes can in turn affect the water holding capacity of the soil, making it more susceptible to extreme condition such as drought.

Sediments can be deposited on down slope properties and can contribute to road damage.

Sediment which reaches streams or watercourses can clog drainage ditches, road control work like culverts, side drains, mitre drains and bridges in the agricultural and aquatic perspective silt can clog stream channels, silt in reservoirs, cover fish spawning grounds and reduce downstream water quality. Pesticides and fertilizers, frequently transported along with the eroding soil can contaminate or pollute downstream water sources and recreational areas.

2.1.5 Erosion by Wind

The rate and magnitude of soil erosion by wind is controlled by the following factors:

Erodibility of Soil -Very fine particles can be suspended by the wind and then transported great distances. Fine and medium size particles can be lifted and deposited, while coarse particles can be blown along the surface (commonly known as the saltation mechanism of transportation). The abrasion that results can reduce soil particle size and further increase the soil erodibility. Soil **Surface Roughness**-Soil surfaces that are not rough or ridged offer little resistance to the wind. However, over time, ridges can be filled in and the roughness broken down by abrasion to produce a smoother surface susceptible to the wind. Excess tillage can contribute to soil structure breakdown and increased erosion.

Climate-The speed and duration of the wind have a direct relationship to the extent of soil erosion. Soil moisture levels can be very low at the surface of excessively drained soils or during periods of drought, thus releasing the particles for transport by wind.

Unsheltered Distance-The lack of windbreaks (trees, shrubs, residue, etc.) allows the wind to put soil particles into motion for greater distances thus increasing the abrasion and soil erosion. Knolls are usually exposed and suffer the most.

Vegetative cover- The lack of permanent vegetation cover in certain locations has resulted in extensive erosion by wind. Loose, dry, bare soil is the most susceptible, however, crops that produce low levels of residue also may not provide enough resistance. As well, crops that produce a lot of residue also may not protect the soil in severe cases. The most effective vegetative cover for protection should include an adequate network of living wind breaks combined with good tillage, residue management, and crop selection.

The first scientific investigations of soil erosion were carried out by the German soil scientist Wollny between 1877 and 1895. Small plots were used to measure a great range of effects, such as vegetation and surface mulches on the interception of rainfall, and on the deterioration of soil structure and the effects of soil type and slope on run-off and erosion. Since then a vast amount of research has been done in most countries of the world to study erosion problems more especially on agricultural land.

2.2 Soil erosion in tropical Africa

Soil erosion in tropical Africa called for attention as early as 1930 when first run-off plots were built in Tanganyika by Staples in 1933, in Kenya, the intensity of soil erosion was first investigated on the basis of land use and soil conservation studies by (Kariaga, 1987).

He found that after an initial clearing of bush followed by cultivation (a change in land use) for two to three years, a further eight to twenty years were generally required to restore fertility.

There is some debate about whether long term changes in climate have affected soil degradation in the past. However, the evidence of protected temple forests in both China and Labanon suggests that even if climate has been a contributing factor, the devastation we see today is essentially a manmade phenomenon (Hudson, 1981).

According to Hudson (1981) the factor which most influences soil erosion by water is the amount and nature of rainfall. The mean annual rainfall is a good predictor of soil erosion. In regions of low annual rainfall, there is in principle little erosion by rain. However, vegetation is an important controlling factor. The most severe erosion is associated with the low range of rainfall when land is devoid of vegetation and with higher rainfall when natural vegetation is removed.

However, it is only the amount of rainfall which matters but also the intensity. The intensive downfall common in the tropics and subtropics has a much more damaging effect than the gentler rain of the temperate regions. Several other factors cause or control the erosion mechanism Meyer *et al.* (1975). These include slope length and slope angle, and the susceptibility of soil to erosion which is dependent on soil physical properties such as permeability, shear strength, clay and organic matter content.

Studies on road erosion and subsequent sedimentation in relation to logging activities in the mountains of central Idaho, U.S.A (Megahan, 1975) indicate that the combination of steep topography, high soil erodibility and high climatic stress creates extreme erosion hazards even on land on an undisturbed state. Modern techniques of data analysis have been used to correlate the results of field experiments on erosion factors (Wischmeier, 1955). As a result of this, the main features in the erosion process are identified and mathematically enumerated; e.g. by Wischmeier *et al.* (1958). This has made it possible to carry out quantitative investigations on soil erosion.

In the developed countries, erosion on roads has been recognized and siting of new roads is one of the tasks which can be done efficiently by use of aerial photography Seestrom (1966). Aerial photographs greatly simplify the siting of new roads especially through a ragged country with heavy vegetation. This is possible since the topography of the land such as the position of new roads is crucial for proper drainage of the roads because in all roads, the strength or resistance to deformation reduces greatly when the soil is wet Hudson (1981).

Recent developments in Geographical Information Systems Lillesand *et al.,* (2014) has made it possible to model high erosion potential areas by using a number of attributes such as vegetation cover, slopes and soil characteristics such as soil texture. GIS can be used, in addition to aerial photographic, to plan the siting of new roads in such a way that both erosion on the road surface and on the surrounding environment is minimized.

Studies in Baringo District, Kenya, by Bryan and Schnabel (1994) identify footpaths, paved and unpaved roads as being a major source of sediment. They used visual evidence such as soil erosion along the old Marigat-Kabarnet road which indicated major sediment contributions. As Dune (1979) observed, paths and roads are continuously disturbed by vehicles, animals and people thus pulverizing soil and exposing dense, compact sub soil which yields abundant run-off channelled directly into the drainage network. Observations of road and path erosion are abundant, but few measured data are available Dunne (1979), Reid and Dunne (1984). Reid and Dunne (1984) measured sediment yields in forested areas of Northwest of U.S.A ranging from .51 to 500 tonnes/km/annum depending largely on the level of activity on the road. Murray- Rust (1972) measured gully extension rates of 10-25/annum along stock roads converging near a reservoir near Arusha, Tanzania.

Aerial photographs have been used to determine factors influencing gully erosion from road drainage Ministry of Public Works (1992). The steepness of waterway at any point was found to be the most important. For the average erosion activity along a waterway, the average steepness of waterway was found to be the most important along the road which had culverts since 1984, while the steepness of the catchment was more important along the road without culverts. This was attributed to the fact that before culverts are installed, topographic characteristics have a bigger influence on erosion, but when culverts are installed, this influence decreases in importance. In the same study, the erosion activity in water ways crossing the road which had not been upgraded recently was found to be higher than in waterways originating from culverts along the road upgraded in 1984. This was attributed to the fact that the road without culverts was situated in a steeper terrain.

In a study on the needed soil conservation works along minor roads in Nyeri District Mati, (1992a), it was recommended that soil conservation measures even outside the road reserve should be included in the Minor Roads Programme to avoid serious soil erosion damages such as gullies. It was further suggested that the types of soil conservation measures to be used at each culvert outlet depends on slope, soil type, land use, expected run-off amounts based on catchment characteristics and availability of materials. This information should be considered for each proposed channel rehabilitation.

In the study of soil conservation structures required for safe disposal of run-off emanating from drainage in Muranga District Mati (1991b), it was found that culverts discharging into medium to steep slopes (exceeding 10%) required channel rehabilitation in the waterways. To provide stable channels for disposal of run-off from roads, conservation structures have to be planned depending on slope, expected run-off, soil stability, channel type and availability of materials. Conservation structures suggested included scour checks, stone check dams, lock and soil spill ditches to reduce run-off velocities or steep slopes and cut-off drains (Appendix 1) for diverting runoff into the waterways or retention ditches.

Problems associated with road drainage have been noted in urban areas. Krhoda (1986) has noted that roads in Nairobi, which run from the uplands and converge at the City centre, act as channels and carry a lot of discharge from the catchment. Because the drainage pattern is also parallel, the discharge to the drainage ways and the paved roads converge at the City centre nearly at the same time causing flooding along the major streets at streets at the City centre. He also recognized erosion from pavements and tarmac roads as being common in Nairobi.

The erosion of tarmac road is literally a pothole menace that results from poor drainage allowing water to stand on the road for a long time. Engineers refer to the problem as “bath tub” menace. Water is usually absorbed into the underlying bases of the tarmac road. The bases become saturated, causing expansion of clays that may form the road bed. As a heavy wheel passes over such saturated layer, the pore pressure increases and eventually bursts over into cracks on the road surface. Additional water enters through the cracks and saturates the bases further. Consequently, with the pounding of traffic, a mixture of sand, silt and water is pumped from the bases out through the cracks. The cracks also widen as the sediments are pumped through them. Finally, the tarmac fails because of lack of base and collapses. The potholes erode further by mechanical action of wheels.

Moore and Burch (1986) found that the rate of erosion increased with the length of slope (L) or the slope angle (S) of the road. Because flow channelization was rapid along the roadsides, accelerated erosion occurred at the edges of the tarmac roads without kerbs. After a short distance on the sloping terrain, rill and inter-rill erosion was initiated. The initial sediment dislodged on the surface was caused by large raindrops associated with big storms.

2.3 Soil control structures

The effectiveness of soil control on all roads highly depends on the road soil control structures. The soil control structures should be adequate depending on the road, climate and terrain. Soil control structures include those that intercept surface runoff water, drain side drains storm water to a channel and off the road.

Soil control structures are specifically built to serve certain amount of water volumes and also with specific measures distinct to the road and terrain. The specifications will include the number of culverts, mitre drains and scour checks required per gradient. There are also required standards on the alignment of the structures.

2.3.1 Culverts

A culvert is a closed conduit used to convey water from one area to another, usually from one side of a road to the opposite side along the side drain. Culvert works constitute a significant part of both rural road construction and maintenance. Road construction may obstruct the natural flow of water unless the crossroad drainage is properly designed. As a crucial part of the drainage system, the culverts are also essential for basic access along a road ILO (2013).

Culverts are of importance in leading water from one end of the road to another which is on a lower ground than the inlet side. This plan should be made prior to road construction or upgrading. The most common culvert is a 60 mm diameter culvert.

According to ILO.org (2013) the frequency and size of culverts are ideally determined by the hydrological conditions prevalent in the surrounding areas to the road. Appendix 2 for Culvert specifications. Components of culverts are discussed below:

2.3.2 Head walls and wing walls

The purpose of headwalls and wing walls is to protect the backfill and the side slope of the road embankment from water damage. Headwalls are built parallel to the centre line of the road (preferably even when the culvert is located in a skewed position) in order to take the pressure from the traffic evenly. In mountainous areas where there is little space for head walls drop inlets are constructed to gather enough water and it is covered on top to avoid debris falling onto it.

2.3.3 Scour Checks

Scour checks are installed on steep terrains that is impossible to remove water by mitre drains, they are of two types: scour check at level and raised Eriksson (2010). Their function is to slow down the water flow by reducing the natural gradient of the drain by allowing the drain to silt up behind the scour check ILO.org (2013). Scour checks are usually constructed in natural stone or from wooden or bamboo stakes.

Table 2.1: Scour check intervals

Road gradient (%)	Scour Check Interval [m]
4	Not required
5	20
6	15
7	10
8	8
9	7
10	6

2.3.4 Mitre drains

The mitre drains (or off-shoot drains) lead water away from the side ditches to lower areas. By installing mitre drains at frequent intervals, it is possible to reduce the risk of both soil erosion and silting, ILO.org (2013).

The optimal spacing between the mitre drains depends on a number of factors such as gradient, intensity of water flow, soil type, and most important, the terrain conditions. Mitre drains can only be constructed in terrain with a downward gradient.

Table 2.2: Mitre drains Interval

Road gradient (%)	Interval should not exceed (m)	When discharging the water into farmlands
12	40	20 to 50 metres wherever possible into the boundaries between farmlands
10	80	
8	120	
6	160	
4	200	
1-2	50 if excessive silting may occur	

2.3.5 Angle of Mitre Drains

The angle between the mitre drain and the side drain should never be greater than 45^o. An angle of 30^o is ideal. If it is necessary to take water off at an angle greater than 45°, it should be done in two or more bends so that each bend is less than 45°.

2.3.6 Cut off Drains

These are graded channels with supporting ridge or bank on the lower side. They are constructed across the slope and are designed to intercept surface runoff and convey it safely to an outlet such as culvert inlets and waterways. Cut-off drains are usually 0.5 m deep and 1.0-1.5 m wide and the gradient varies from 0.1-0.2 % on light sub soil to 0.4-0.5 % on heavy sub soil.

2.4 Conceptual Framework

The research concept is built from roads maintenance manual. It comprises of three sections where anthropogenic and climatic factors take centre stage in road deterioration .The key climatic or geological factors affecting the roads include rainfall, soil infiltration, the geology of the study roads, relief slope and surface runoff, this factors can be greatly accelerated by human factors which includes deforestation, land use activities and poorly maintained roads .This leads to soil deterioration .This will accelerate road camber damage, leading to shattered culverts, eroded side drains and in turn an environmental hazard owing to increased siltation and cost of maintenance.

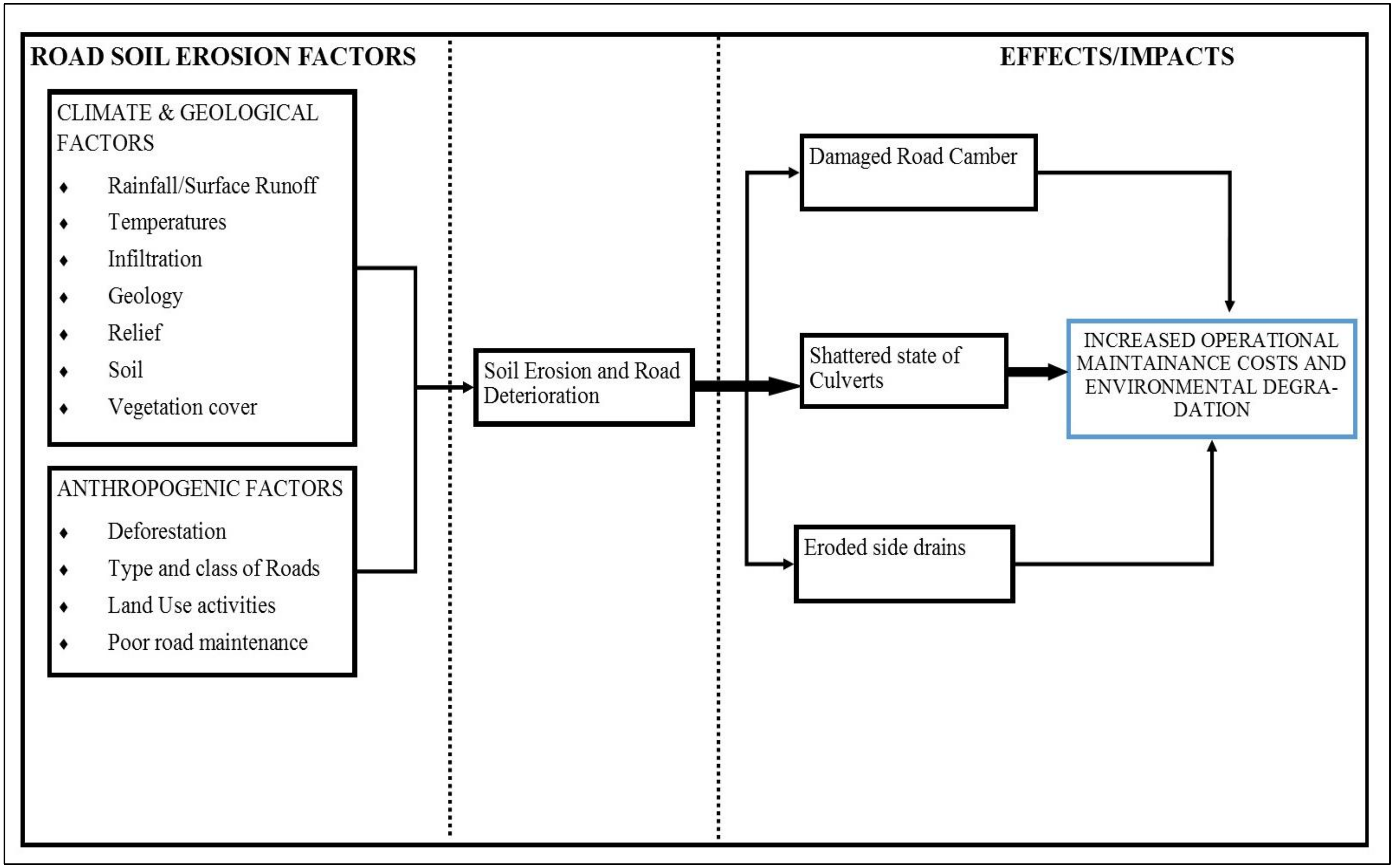


Figure 2.1: Conceptual Framework.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Reconnaissance field studies were done between the months of September and November 2013 on all the three counties. This was done to ascertain the ground location of the roads to be studied and the suitable locations for pegging. During the field visits a Garmin GPS was used to map the specific roads and identify areas where pegs for soil erosion control would be mounted, and also identify the general condition of soil control structures and sediment deposition before the actual data collection began. A clinometer was used to determine elevations of sections of roads where pegs and runoff rates were installed and calculated, respectively. Soil data and images were obtained from ILRI (International Livestock Research Institute). Elevation of the study area was determined by contour data which was obtained from Landsat 7+ SRTM images and field survey using GPS.

3.2 Sampling design

The study was carried out in four different phases. In the first phase, selection of geographic study clusters using secondary data (Maps) obtained from KeRRA Kitale were used, (Figure 3.5) which indicates total road network in the study; reconnaissance visit; establishing accessibility; identification of roads in selected geographic clusters; establishment of status in each cluster-classes of roads, types of surfacing material, type of traffic loading, topography, vegetation cover, rainfall intensity, geomorphology of the area, geological and soil formation of the study area and social-economic activities were done.

The first phase was meant to collect pre-sample the roads and check on study roads suitability. This was conducted for a period of one and half months (September and

November 2013). Various roads were identified and divided into several segments. The human activities -Farming and vegetation cover- within the road network were studied by observation and use of field study checklist (Appendix 2). Human activities along the riparian area of study zones were also assessed through observation.

The second phase of the study involved selection of study-roads and sampling of road segments for study; factors of study were serviceability levels, slope and gradient of road sites, types of soil texture, types and quantities of sediments, rainfall intensities and surface run-off, soil erodibility indices vegetation cover. Sediment sampling was done for texture analysis. Road network map was used to determine classes of roads and their serviceability levels. Various samples were collected from the road and backed up with secondary data and the soil types obtained from ILRI. This was used to determine the soil types of the particular study road. Soil deposition on road side drains, score checks and mitre drains were measured on fortnight basis for 3 months to determine the deposition and erosion extent on the selected areas of the study roads.

Third phase involved secondary data collection. This included reviewing the secondary data relevant to the study from the University of Eldoret Library, ILRI, Landsat 7 imagery, Ministry of Roads, NEMA, Regional Centre for Mapping of Resources for Development in Nairobi, International Labour Organization, Meteorological stations in Kitale, Mt. Elgon and Kapenguria. Data from published and unpublished sources were be collected and reviewed for both immediate use and data analysis.

3.3 Sample selection

According to Kenyan roads classification, rural roads are classified as classes D and E. Purposive sampling of the selected study roads was used in the three regions whereas stratified sampling was used to obtain locations for peg placement to facilitate data collection and readings. This combined various factors –terrain, gradient, type of road, soil type, altitude and general climatic conditions of the area-were considered and factored in, in order to get a good comparison sample. The comparison sample was to represent the three zones that include mountainous areas, relatively flat areas with high rainfall intensity and flat areas with low rainfall intensities and also consider the soil types in the sampled counties. Rural roads were the sampling frame which comprises of class D and E roads. Two class D roads and two class E roads were purposively chosen for the study counties and this represented a class D and E road from Trans Nzoia, E from West Pokot and D from Mt. Elgon sub-county.

3.4 Sampling Frequency

Data collection was done on a fortnightly basis for a period of three months for estimation of soil loss on all the roads. Sampling was also done for determining ground cover for the purpose of calculation of roads catchment areas.

3.5 Estimation of Soil Loss from Roads

The amount of material removed from the entire length of the road by surface runoff was estimated by calculating the amount of sediment deposited or eroded at the various sedimentation points on the road and the side drainage at 2-weeks interval for 3 Months.

The measurements were done on both sides of the road where necessary on areas marked for pegging covering 50% of the entire road network on each segment. The pegs were placed at 500 m interval on areas with a rapid change in relief and (500 m-1.2 km) on areas with no major change in relief. Pegs were placed strategically at the highest point on a road to measure erosion and at the lowest point to determine deposition of sediments.

3.5.1 Erosion/deposition marking pins

This widely-used method consisted of driving a pin into the soil so that the top of the pin gives a datum from which changes in the soil surface level can be measured. The pins are alternatively called pegs, spikes, stakes or rods. The pins can be of wood, iron or any material which could not easily rot or decay and was readily and cheaply available. Iron, steel pins or nails could not be used since they could easily be stolen. In the study area, cedar, bamboo and other wood pins/pegs were locally available and were more suitable for the function.

The pins were of standard average length of 70 cm which were driven into the soil to give a firm stable datum: 20 cm was typical, less for a shallow soil, more for a loose soil approximately 30-45 cm driven into the ground. The pins had an average diameter of 50 mm; thick pins could interfere with the surface flow and could cause scour. A total of 86 pegs were driven into the ground (Table 3.2 for peg distribution per road). Rock and tree roots painting was also done in sections of West Pokot on areas with rocky road surface and zones were pegs (Figure 3.1) could probably be plugged out or infested by pests like termites.

Figure 3.1: Erosion peg at 0+500m on Kuywa-Kopsiro Road. Author (Source 2013).

Table 3.1: Peg distribution for determining sediment deposition and erosion on study roads

Road	**Class**	**Pins**
Chepareria-Naskuta	D	21 Pins and Rock painting
Sikulu-Kinyoro	D	13
Kuywa-Chemisto-Kopsiro	E	28
Sibanga-Saiwa-Kesegon	E	24
TOTAL		86 Pegs

The first readings were done after the pins had been driven to the ground and this was taken to be the datum for consequent readings. To obtain the volume of sediments and soil deposited or eroded on the road side drain in each sedimentation point, the length and width of area covered by sediment was estimated by direct measurements. The average depth of sediments was calculated after taking five successive readings for a period of three months, during the rainy seasons of December 2013 and dry seasons of January and February 2014. The average readings were then used to calculate the volume of soil eroded or deposited by measuring the length of the back slope to the slope and multiply by the total length of the road to the next peg. The volume of sediments covering an area was calculated from the formula:

$$\text{Total soil loss volume} = \text{A} \times \text{Distance to next peg}$$

Where A (m^2) is the Area covered by the sediments calculated as:

$$\text{Area} = \frac{1}{2}(\text{a}+\text{b})\text{h}$$

Where a is the length (m) from back slope to slope (standard) b (m) is the length from current sediment deposition height to the back slope and the slope while h is the height of the sediments deposited or eroded (m^3).

3.6 Surface runoff

Cook's method was adopted to classify the catchment areas for estimation of surface runoff rates. The method assumes that runoff is a linear function of rainfall and 98% of the rainfall is left for runoff while 2% goes to recharge of underground and evaporation.

The method factors in the following catchment features;

- size (ha)
- ground cover;
- soil type and drainage properties
- ground slope

The size of the catchment area was determined by using ARCGIS software to map areas that are oriented towards the study roads and these are areas which are on a higher ground than the roads. The ground cover was investigated by conducting field surveys which were done between December 2013 and February 2014 and the data was recorded and information from topographical maps also sorted for. ARCGIS data was used to establish landform characteristics which are fundamental in computing surface runoff using cooks method.

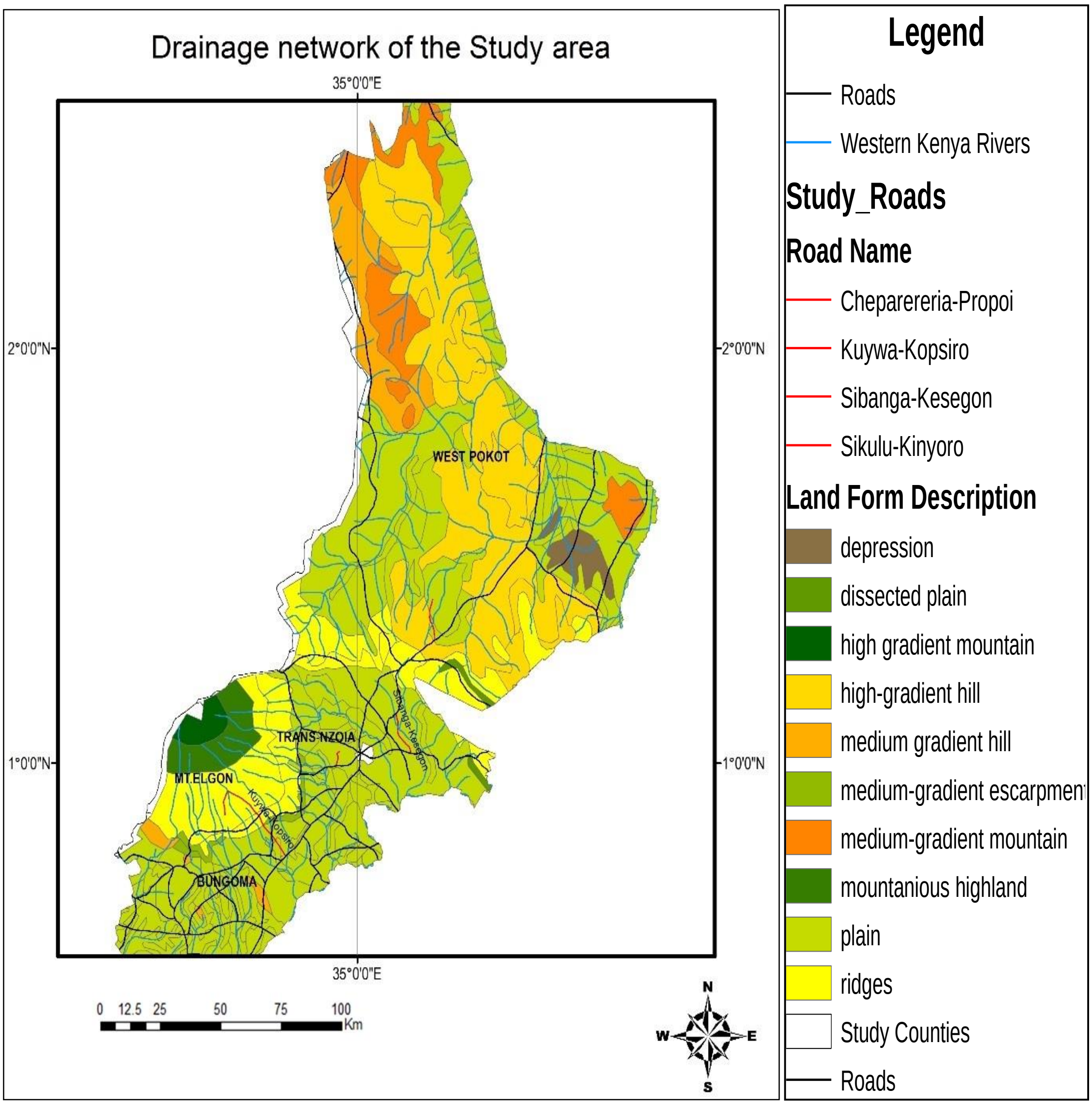


Figure 3.2: Drainage Network of the study catchment and Land Form description.

3.6.1 Land use characteristics analysis

This was performed by use of physical setting and GIS data, major economic and social activities in the catchment area. This was achieved by creating a 1.5 km buffer on both sides of the road and this was taken to represent the land characteristics along the entire catchment areas, after a comprehensive study of land use activities on all the catchment areas of the roads in the first phase of study. Topographical maps of the Cherangani hills catchment were also used to perform the analysis and calculation of areas that fall in the 1.5 km buffer zone on either side of the road.

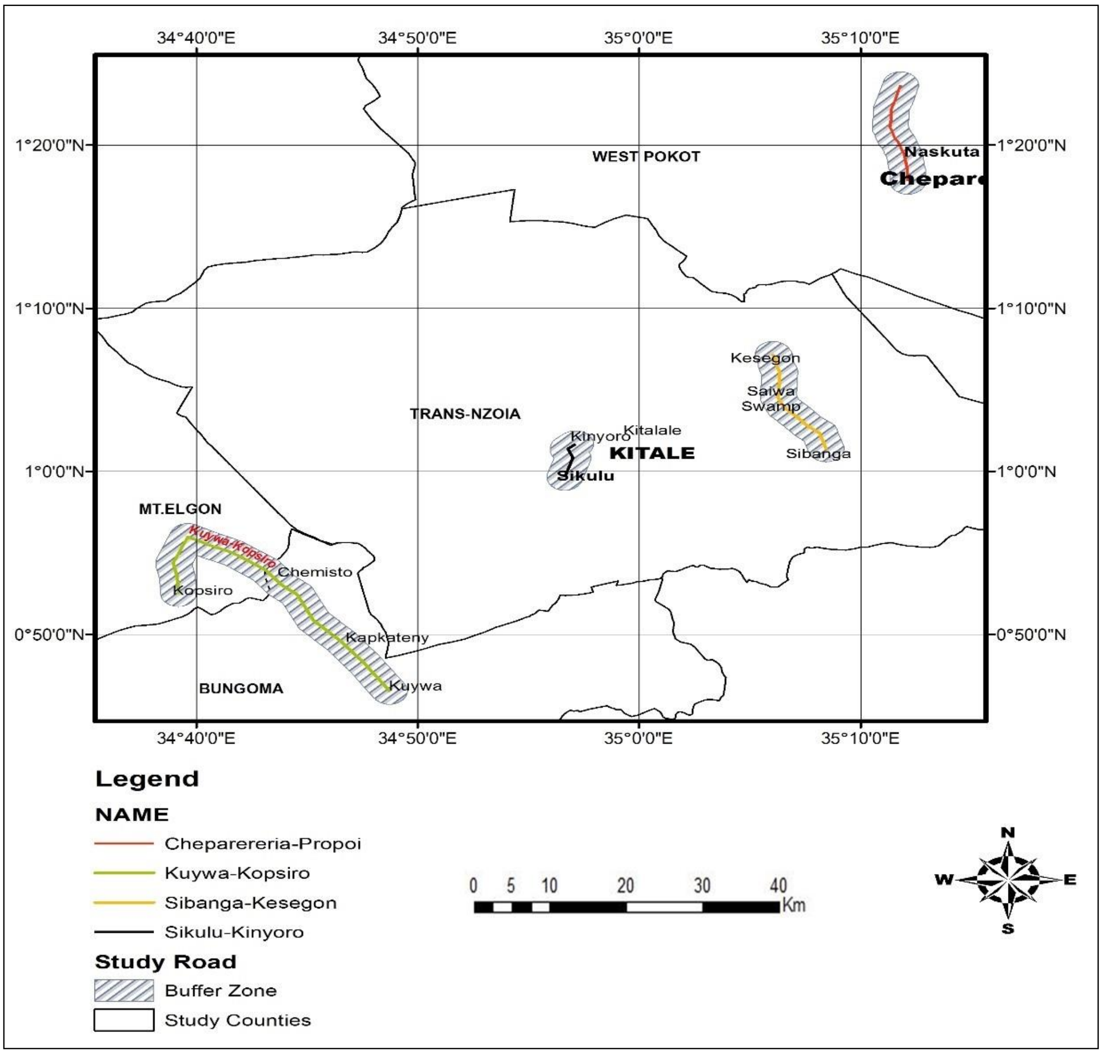


Figure 3.3: Map of 1.5 km Buffer Zone along Study Road.

3.6.2 Measurement of Slope of the Roads

The average percentage of slope was determined by using a silvaclinomaster/clinometer. This was done by averaging the slopes of short road sections of nearly uniform gradients. For each road segment the observer stood at one end of the segment and targeted research assistant. The results for all the segments were recorded together with the length of each segment. The lengths were then used to calculate the modal slope, i.e. the slope recorded by the greatest number of sections of each road segment. Slopes were determined by physical measurements on the ground by using a tape measure and a string fitted spirit level (Figure 3.3).

Figure 3.4: Measurement of slope using line and level. Author (Source 2013).

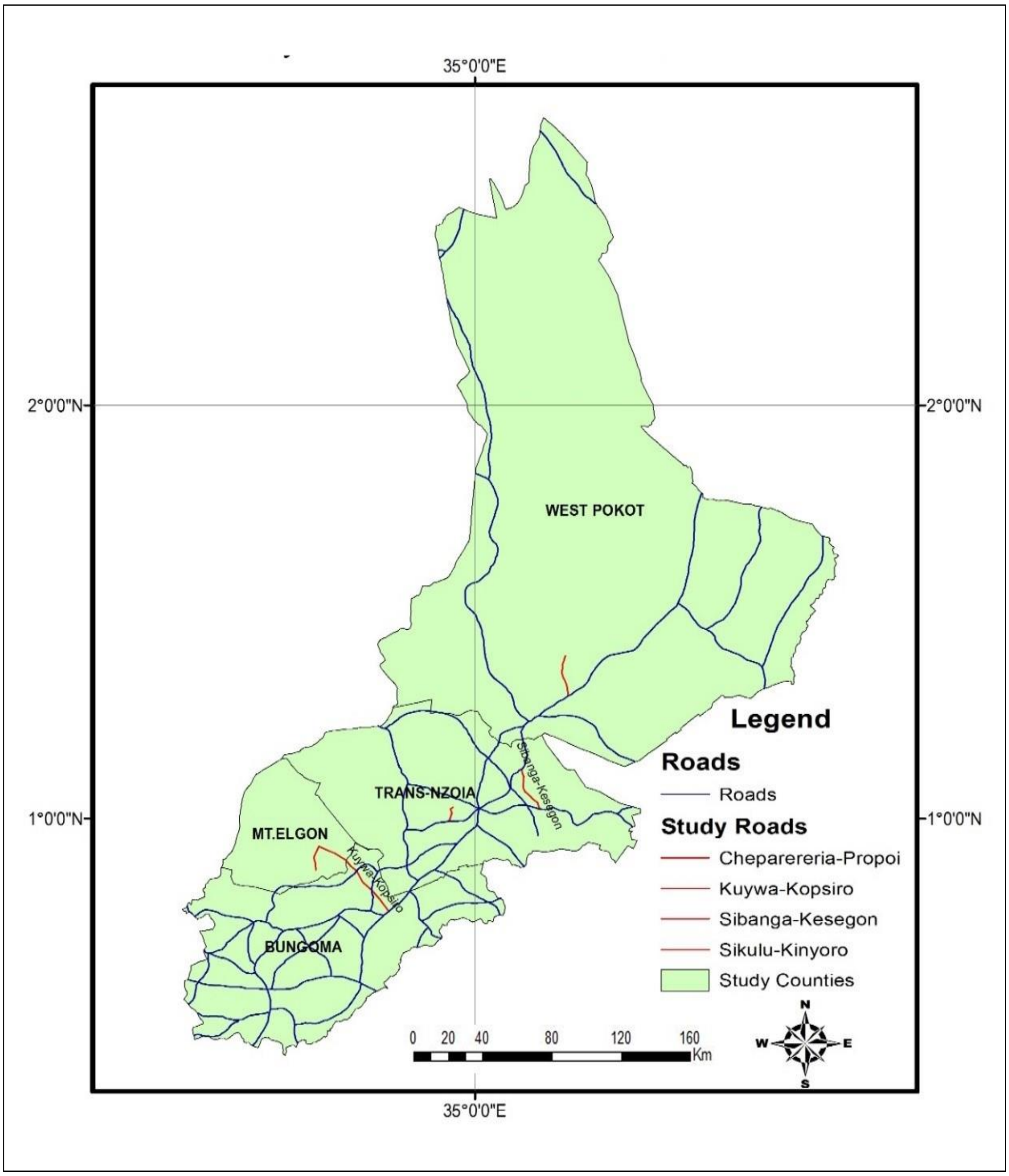


Figure 3.5: Roads networks in the study area.

Table 3.2: Cook's Catchment Characteristics table for determining ground surface runoff

Cover		Soil type and drainage		Slope	
Observed conditions	C (cover)	Observed conditions	S (Soil)	Observed Conditions	SL (Slope)
Forest or heavy grass	10	Deep, well drained Soils	10	Very flat to Gentle	5
Scrub or medium Grass	15	Deep moderately pervious soil	20	Moderate	10
Cultivated lands	20	Soils of fair permeability and depth	25	Rolling	15
Bare eroded land	25	Shallow soils with impeded drainage	30	Hilly or steep	20
		Medium heavy clays or rocky surface	40	Mountainous	25
		Impervious surfaces and waterlogged soils	50		

(Source: fao.org)

The sum of the three characteristics gives the total catchment characteristic (CC) for a more or less square catchment. For long and narrow catchments, CC equals the sum of the three characteristics multiplied by 0.8 and for broad and short catchment areas; CC equals the sum of the three characteristics multiplied by 1.25.

$$\mathrm{CC} = \mathrm{C} + \mathrm{S} + \mathrm{SL}$$

Where CC is Catchment Characteristics, C is vegetation Cover, S is Soil Condition and SL is Slope (terrain).

Level of land management was reflected in the cover (land utilization and cover) and if land is terraced it is reflected in reduced slope. Proportion of land covered by built up areas has an implication on the drainage properties.

3.7 Effectiveness of soil erosion control works

To achieve this objective a combination of measures were involved. The measures included; the structures ability to resist, control/retain sediments eroded and the rate of discharge velocity by the structure. The structures resistance to soil erosion was obtained for the project lifecycle factoring in the construction of the road and the monthly maintenance of the road.

Effectiveness was also assessed by the construction works of the facility basing on the required standards of construction of soil control structures that exists in literature; that includes the alignment of culverts, drifts, scour checks and mitre drains. The studies were undertaken from the actual field and compared with existing literature standards.

3.8 Classification of roads according to the degree of erosion and sedimentation

By walking along the road, the length of the road with signs of erosion (sediment deposits or erosion) was estimated by measuring out. These distances were used to calculate the percentage of the road, in terms of length, under erosion or sedimentation. The roads were grouped into erosion and sedimentation levels of severity of the damages caused.

3.9 Assessment of the Effectiveness of Erosion Control Measures and Associated Environmental Impacts

For each road segment, road drainage measures were documented by recording the number of culverts, mitre drains, scour checks and drifts on a field tally checklist. The existence of erosion damage of the area on the lower side of the road at the outlets of the cross drains (culverts and drifts) were assessed by comparing the depths of soil deposits and erosion on both the upstream and downstream sides of the road segments.

3.10 Prediction of area of high soil erosion potential on roads

Overlay of soil drainage versus slope gradient was conducted for the study areas. This included data obtained by geographic information on land elevation, vegetation and soil types of the area on either side of the road. This was obtained from digitized maps and by use of satellite images. The maps obtained contained information of soil types, porosity, runoff rates, amount of precipitation, vegetation cover and slope of the study areas. Overlay of features that contribute to soil erosion that includes, slope, vegetation cover and porosity of the soils was done to determine areas with the highest rate of erosion. The areas will be rated as:

i. High risk of erosion
ii. Medium risk
iii. Low risk
iv. Stable

High risk areas were achieved by doing an overlay of the factors of erosion and where there was an intersection of factors that contribute to soil erosion is where there is erosion and the more the factors intersect the higher the erosion severity.

3.11 Data analyses

Data was analysed by use of ARCGIS and a combination of Microsoft office Excel and SPSS v21.This was used to analyse qualitative data and create correlations between variables. Cooks method was also adopted to analyse surface runoff rate.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents field study results is presented with a detailed discussion of the findings. The chapter is presented in three broad topics that include; general state of the study roads, Catchment characteristics and soil loss and deposition quantification.

4.1 Soil loss and deposition

Soil movement was determined by both anthropogenic and natural factors. The rate at which erosion and deposition occurred in the regions was different due to natural factors but human factors could accelerate this in areas where erosion could be slow.

A combination of factors were considered on the research and they included, terrain, land cover, soil type, climatic conditions which comprises of surface runoff rates (Appendix 1 on Road characteristics).

4.1.1 Soil types

Soil types and infiltration rates were determined by obtaining information from images adopted from ILRI (International Livestock Research Institute). Soil texture and types were obtained by observation in the field through texture and secondary review of data. The soil descriptions of the study zones are shown in (Figure 4.9).

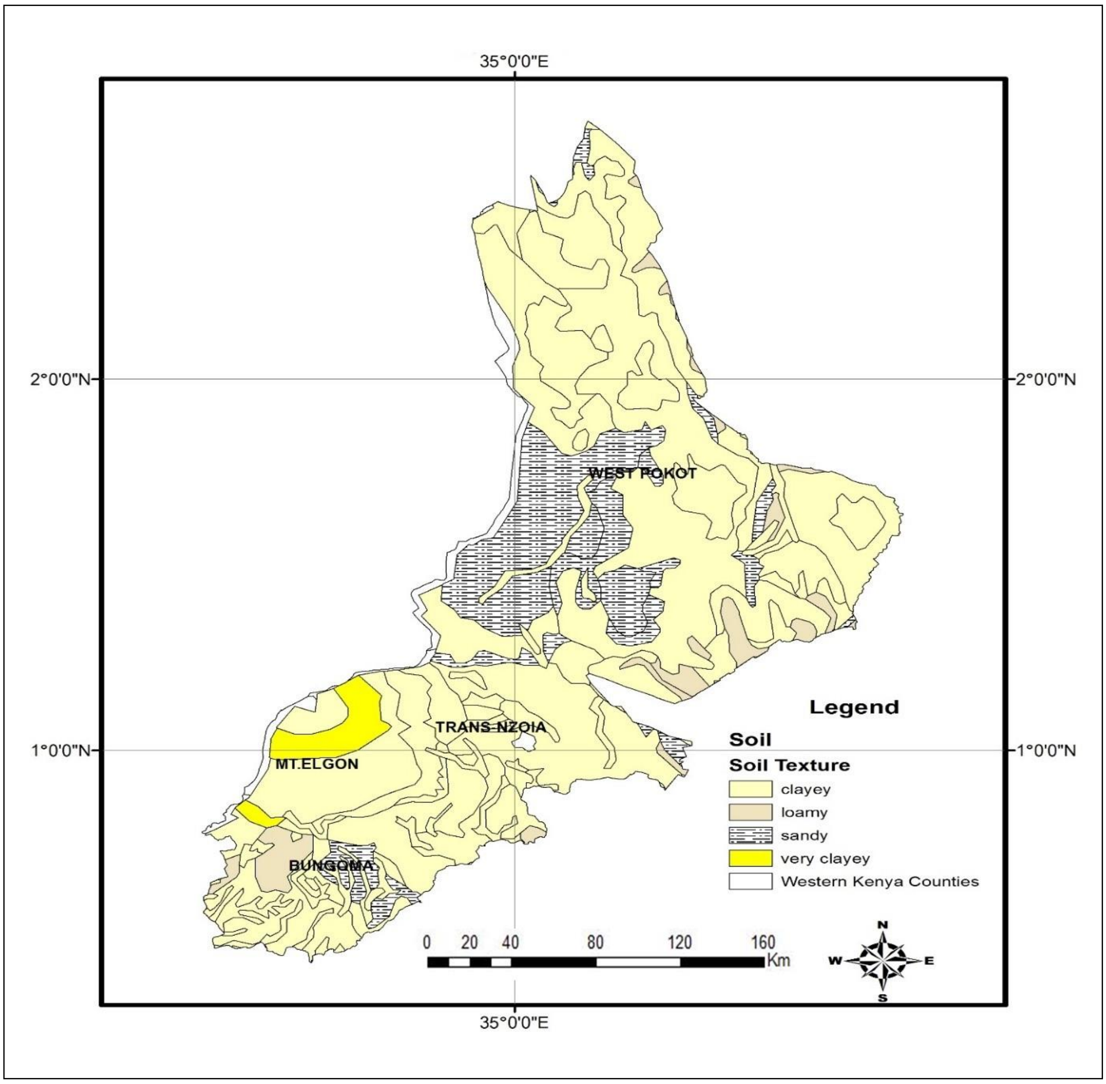


Figure 4.1: Distribution of soil types in the study area.

4.1.2 Weather conditions

Precipitation accelerates debris movement and in the process causing massive erosion down slope when combined with terrain and nature of the catchment area. The research was conducted in December 2013 which was a rainy season and two sets of data were obtained while in January through to February a set of averaged two data readings were obtained.

In the month of December it was observed that there was higher erosion compared to other months January and February, where erosion was minimal. Mt. Elgon County had the highest rate of erosion in all the months while Sibanga-Kesegon a class E road in Trans Nzoia County had the highest rate of erosion in the county and the lowest during the dry seasons. This was due to the grassy surfaces formed after the rains ceased in the months of December, by February 2014 Sibanga Kesegon road had the lowest rate of erosion. At Mt. Elgon is a stiff terrain and this could be the reason behind its high rates of erosion and deposition.

There was high rate of erosion in the months of December and this was due to the heavy rain during the months of December, the rains act as agents of erosion transporting debris which causes abrasion and scouring of surfaces which caused further erosion. The highest change in erosion –measured by peg height- was -10.1 cm and the highest deposition occurred in the month of December with a maximum value of 11.1 cm, (Figure 4.2) erosion in the month of January 2014 had a maximum value change of 8.80 cm and a minimum of -6.64 cm, this was due to minimal effect from agents of soil erosion in the months of January, it was also observed that hardpan formed in areas where grass grew and in areas where marshes existed in the month of December. The negative values indicate erosion while the positive value is indicates sediments deposition.

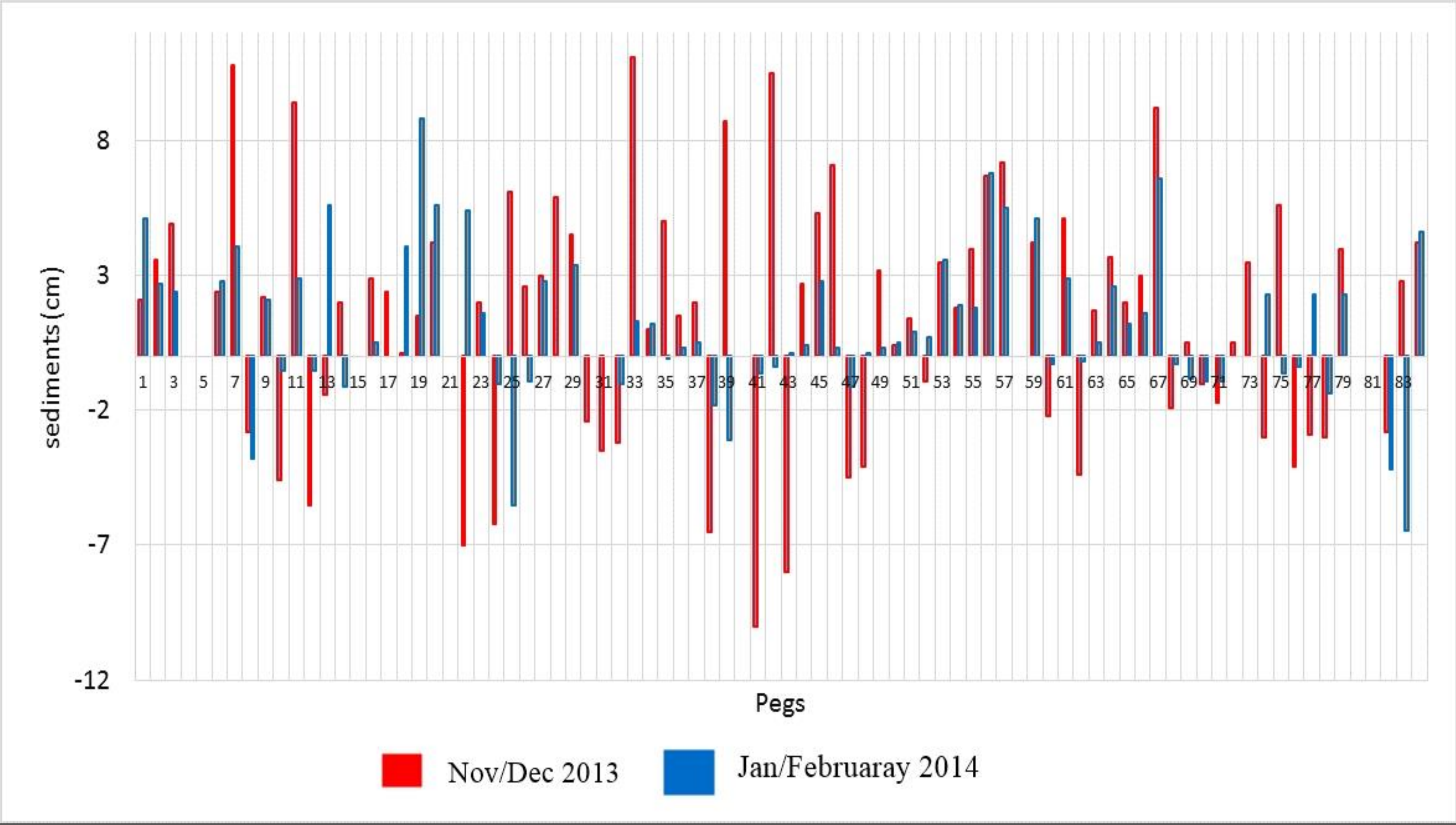


Figure 4.2: Graph indicating variations in heights for sediments deposition and erosion between November and February measured from pegs.

There was also a great disparity of readings in the month of December with a standard deviation of 4.39 and January/February had a standard deviation of 2.62. The deviation in the month of December is due to high rates of erosion and deposition caused by rains unlike in the months of January where agents of erosion were minimal. Weather is an aspect that influences soil erosion. There was a significant correlation between sediments change and weather seasons and in the month of December (r=0.472) and in January/February (rs- 0.267).

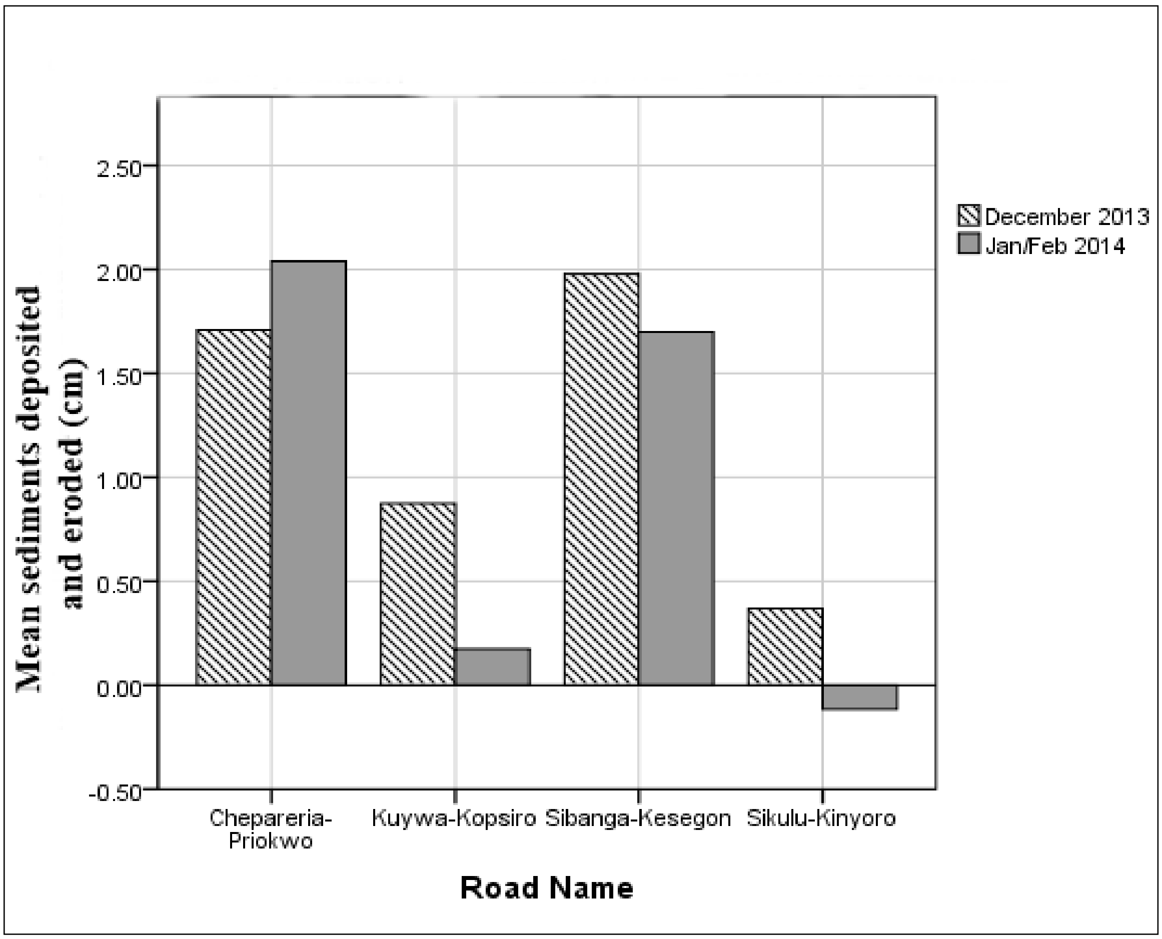


Figure 4.3: Sediments deposited and eroded in December and January.

Terrain is one of the factors that influences soil erosion, the study considered collected data for terrain of road by use of height above sea level. The correlation between height above sea level and sediments eroded or deposited was significant with an (rs=0.522). The table below (Table 4.2) shows relationship per roads between terrain and sediment eroded or deposited. In West Pokot roads and Sibanga-Kesegon there was an insignificant relationship between sediments and terrain and this might be due to the undulating terrain and most of the erosion is due to climatic factors and human factors. In Mt. Elgon sub-county there was a significant relationship between sediment deposits and terrain (rs=0.530) whereas in Kinyoro-Sikulu road there was negative significance of (rs=0.032). Chepareria-Priokwo had a negative significance of r=-0.381, while Sibanga-Kesegon had a significance of r=-0.396, this shows that when height decreases in the roads sediment volume increase which also implied that when height reduces sediments volume increase.

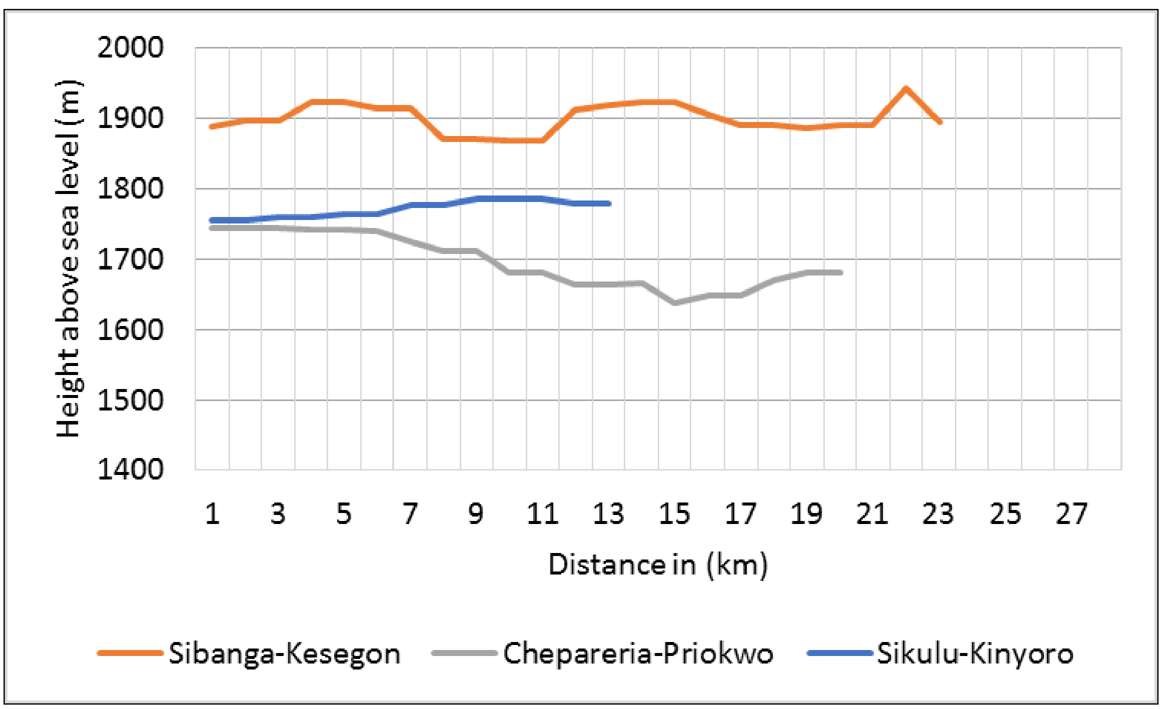


Figure 4.4: Road terrain simulation using height above sea level (m).

Table 4.1: Comparative correlation of sediments and height above sea level

Road Name			**Height ASL (m)**	**Sediments Volume cm^3**
Chepareria-Priokwo	Height ASL	Pearson Correlation	1	-.381
		Sig. (2-tailed)		.097
	Sediments Volume cm3	Pearson Correlation	-.381	1
		Sig. (2-tailed)	.097	
Kuywa-Kopsiro	Height ASL	Pearson Correlation	1	.530**
		Sig. (2-tailed)		.004
	Sediments Volume cm3	Pearson Correlation	.530**	1
		Sig. (2-tailed)	.004	
Sibanga-Kesegon	Height ASL	Pearson Correlation	1	-.396
		Sig. (2-tailed)		.061
	Sediments Volume cm3	Pearson Correlation	-.396	1
		Sig. (2-tailed)	.061	
Sikulu-Kinyoro	Height ASL	Pearson Correlation	1	.032
		Sig. (2-tailed)		.918
	Sediments Volume cm3	Pearson Correlation	.032	1
		Sig. (2-tailed)	.918	

**.Correlation is significant at the 0.01 level (2-tailed).

4.1.3 Sediments volume movement

Eroded sediments per road in all the three counties were calculated and this included sediments from both erosion and deposition. Sediments loss or gain was calculated at intervals of placed pegs. The final data was computed and Mt. Elgon County had the highest loss in sediments, 3284 cm^3 of sediments moved and deposited. West Pokot-Chepareria-Priokwoi road- had the lowest volume of sediments at 1004 cm^3. In Trans Nzoia county Sibanga had the highest number of sediments moved at 3009 cm^3. Mt. Elgon county road had the highest number of sediments this could be due to lack of soil control work in the areas.

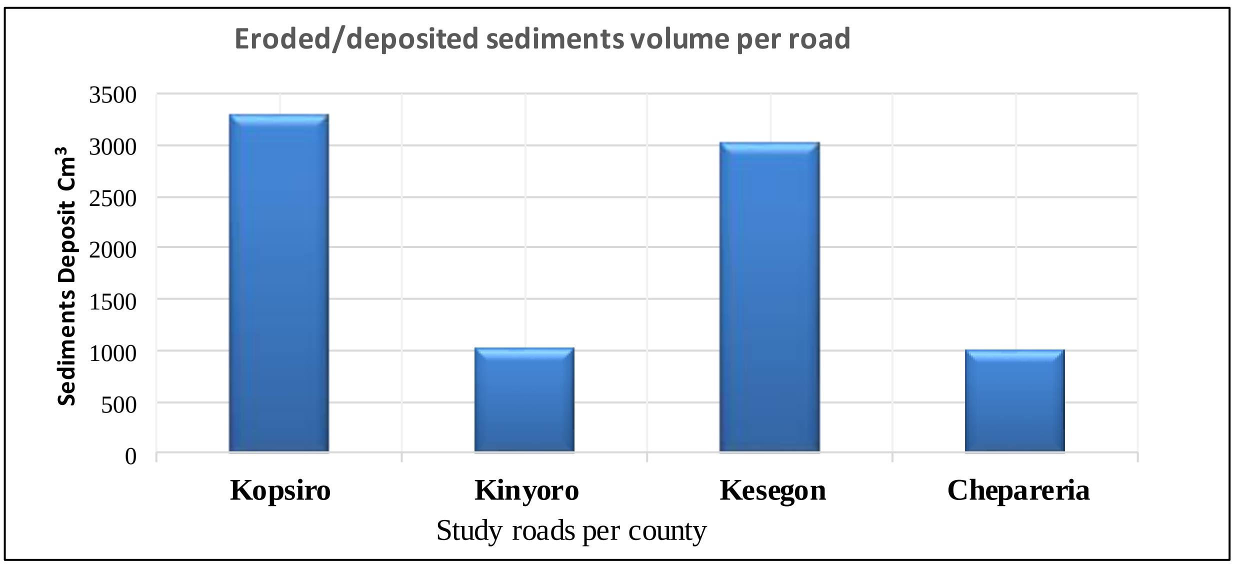


Figure 4.5: Total sediments volume (deposited and eroded) per road.

Sediments eroded and deposited were also plotted against height above sea level and grouped per road class for each study road. High sedimentation levels were recorded in Kuywa-Kopsiro area with sediments rising above 200 cm^3 after 2260 m above mean sea level. This was also experienced in parts of the lower lying road section which range between 33 cm^3– 98 cm^3 being deposited in three months period this is was as a result of a newly redone road with deep ditches and loose soil along its slopes and back slope which became source of sediments during rainy season.

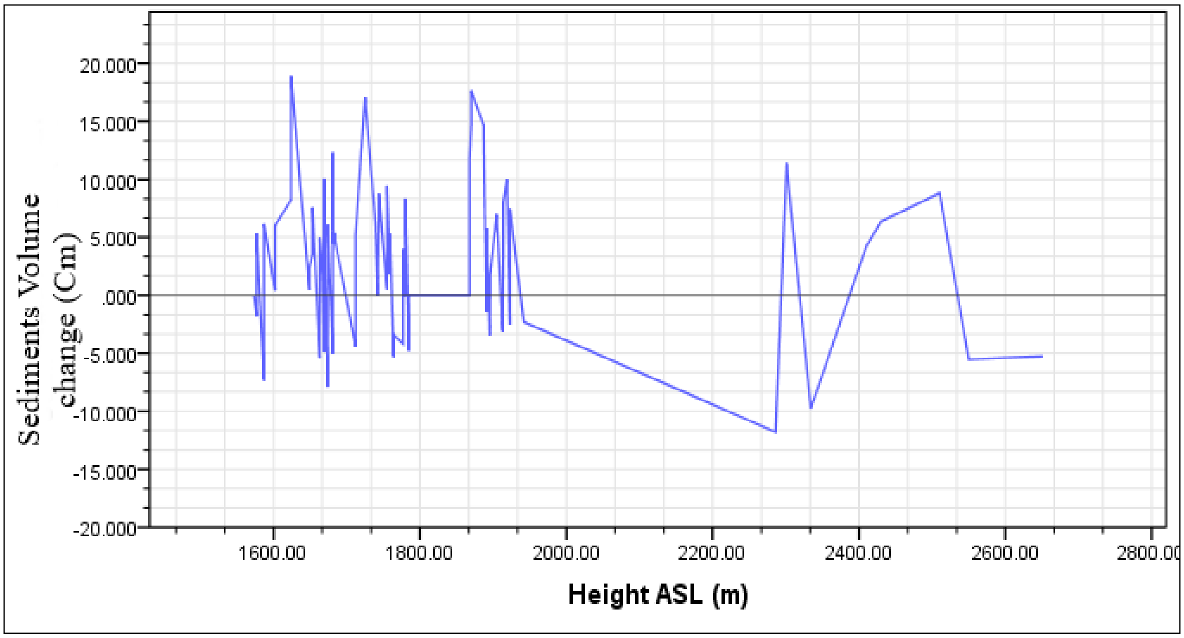


Figure 4.6: Graph of sediment loss and deposition versus Height above sea level.

4.1.4 Kuywa-Kopsiro

The road stretches 26+100 km from 1573 m - 2651 m ASL, the road traverses through steep terrain with gradients greater than 50^0. The above graph (Figure 4.7) shows variation of soil erosion and sedimentation along all the roads, the negative value signifies erosion while the positive shows deposition. It was observed that between 2300-2400 m ASL there was a drastic increase in erosion, this area signifies the slopes of Mt. Elgon which covers 2 km of the road section and it recorded -11.1 cm change in sediment movement. The area is characterized by steep slopes with no soil control structures and scanty vegetation. Between 1800 m-2200 m ASL the area was not studied in Mt. Elgon region because of the terrain and inaccessibility of the road, the inaccessible part is 2 km from Kapkateny River to Chemisto Primary school in C51 road leading to Kapsokwony, this in the figure 25 below is represented by the missing values after 1800 m to 2200 m.

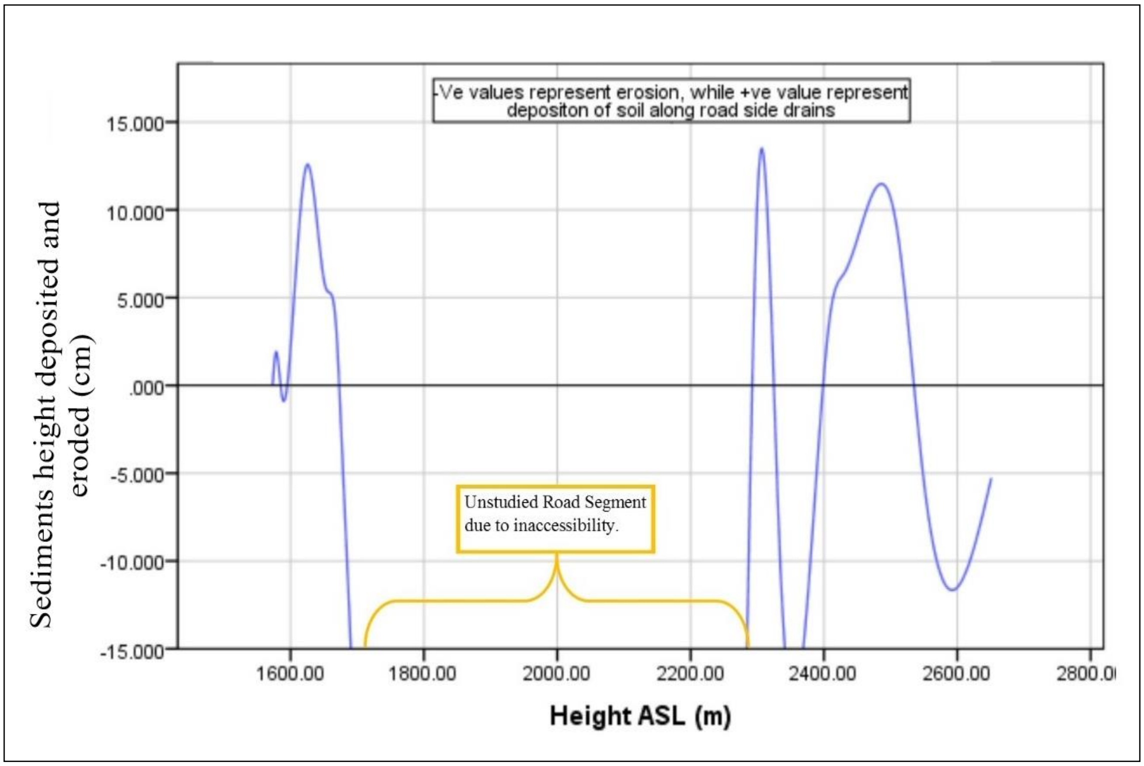


Figure 4.7: Sediments change deposited/eroded in Kuywa- Kopsiro road.

4.1.5 Chepareria-priokwo

In West Pokot County the terrain ranged from 1650 m -1725 m ASL and the highest deposition was recorded at 1725 m ASL which was at 2+800 km mark. The high rate of sand sediments was attributed to transportation by water from 0+500 km, the relief could be a factor contributing to the sedimentation, despite the availability of a mitre drain in the side drain and a cross culvert, their functionality was impaired by the massive transportation and deposition of debris.

The data was analysed using a line graph (Figure 4.8). The data collected was discrete from sampled points of the road segments. However, for projection of the representation of the entire road segments there was need to perform a projection for the entire sampled roads, to give a representation of unsampled road locations indicating their soil processes activities.

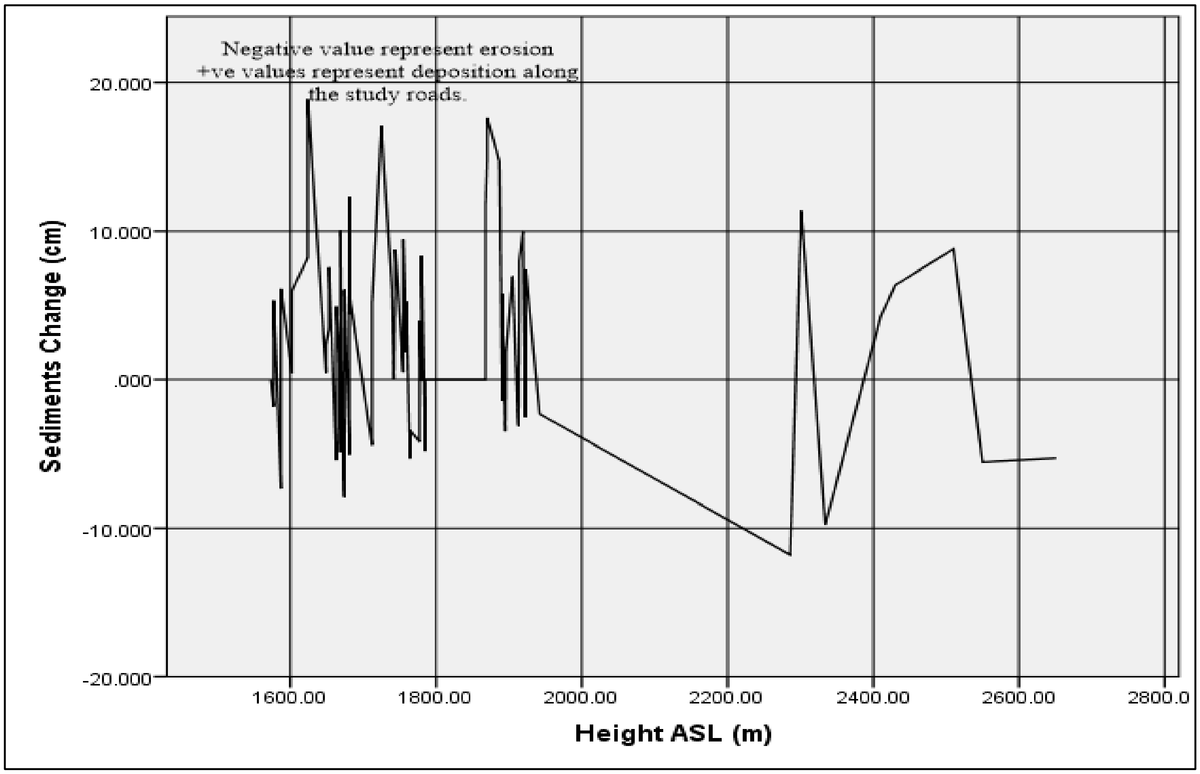


Figure 4.8: Sediments change versus Volume in Chepareria-Priokwo.

Erosion in West Pokot was not that intensive but it was a progressive and widespread across the road system, with maximum value of -5.4 cm. The erosive level was persistent in all seasons from dry to rainy seasons with a Standard deviation of (4) in rainy season and (11) in the dry months of January. The erosion in the roads occurred on side drains and in areas with descending profile leading to either a dry river valley or a river.

The average deposited sediments in west Pokot was higher than the eroded sediments from the road (Figure 4.19). The volume of eroded sediments was less at 202 cm^3 compared to deposited sediments which was 356 cm^3. The general trend of west Pokot roads was deposition, while erosion accounted for less than 40% of soil movement and deposition was higher on lower sides of the road and along dry river beds. The probable source of sediments could be from adjacent farms or transported from distant locations by water action. The sedimentation materials were deposited on the roadside damaging road soil control works and blocking culverts, shattering drifts and bridges in the area.

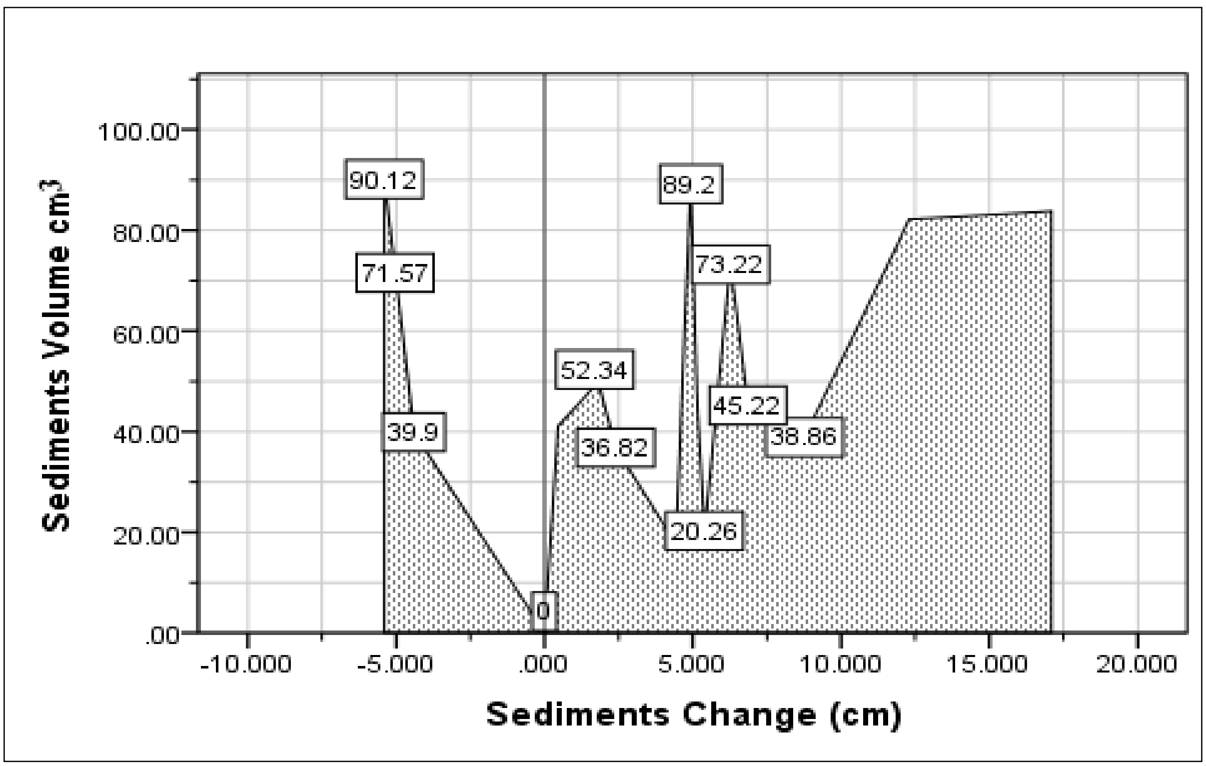


Figure 4.9: Sediment volumes in West Pokot.

4.1.6 Sibanga-Kesegon

Sibanga-Kesegon lies on the slopes of Cherangani hills along Kapkanyar Forest through Kapchorwa tea factory. The road ranges from a rolling terrain to undulating land. The road ranges from 1867-1943 m ASL and the studied road was 19+200 km with a total of 24 pegs. The general trend of the road was erosion. Erosion was higher at 3+100 km with an average high of 17 cm and low of -3 cm at 18+200 km (Figure 4.10), and this was due to anthropogenic activities in the area. The road between 2 km-5 km was being redone during the third and fourth reading of the study, the high rate of sedimentation was also attributed to the rolling terrain and newly done side drains which retain much debris. The high rate of sediments at 12 km is due to poorly placed of soil erosion control works (scour checks) from 6 km to 12 km which caused a high runoff rate causing accumulation at Saiwa swamp.

The total soil moved in Sibanga-Kesegon was 3009 cm^3, a total of 2476 cm^3 of debris were deposited along the road while 694 cm^3 was eroded. The general soil movement trend in Sibanga-Kesegon road is deposition. The deposited soil came from adjacent farms, this was evident by the inconsistency from eroded and deposited sediments.

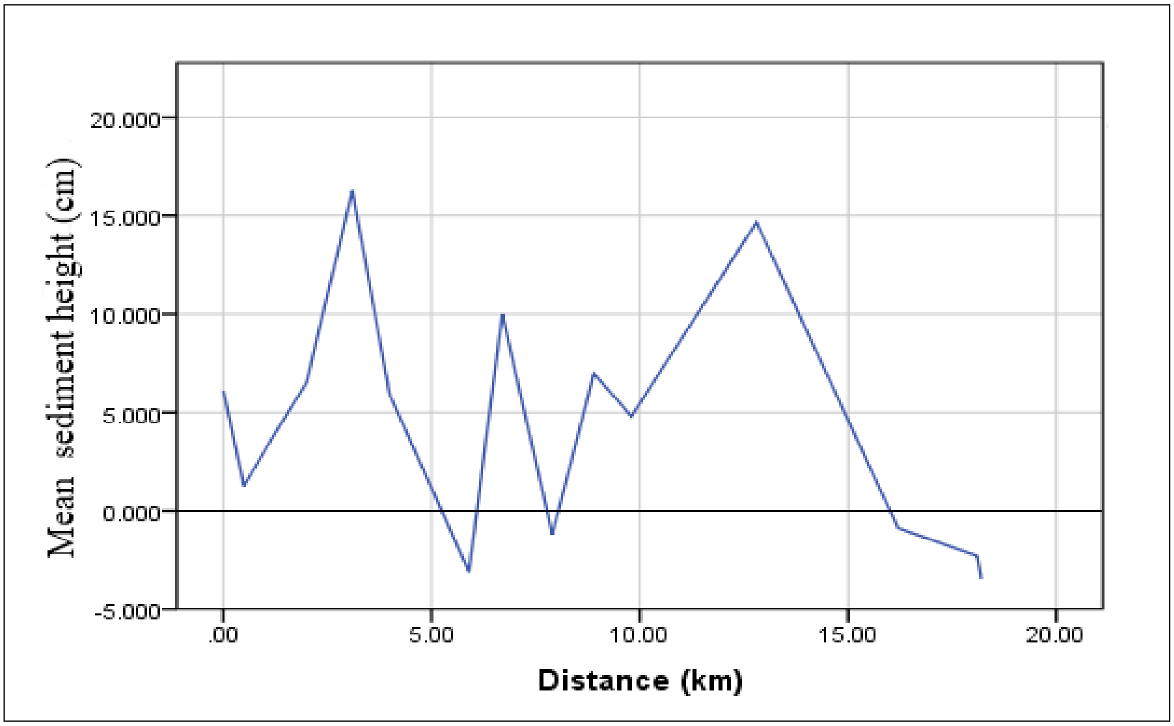


Figure 4.10: Mean sediments height versus road distance (Sibanga-Kesegon).

4.1.7 Sikulu-Kinyoro

Sikulu-Kinyoro lies on a rolling plain and it covers 8+200 km from Saboti Junction to Kitalale Junction in Kinyoro centre. The road rises from 1755-1809 m ASL at Kinyoro centre. The road is generally covered with vegetation. At 5.6 km to 6 km on height of 1768-1773 m above sea level there was no data recorded due to large existing gullies.

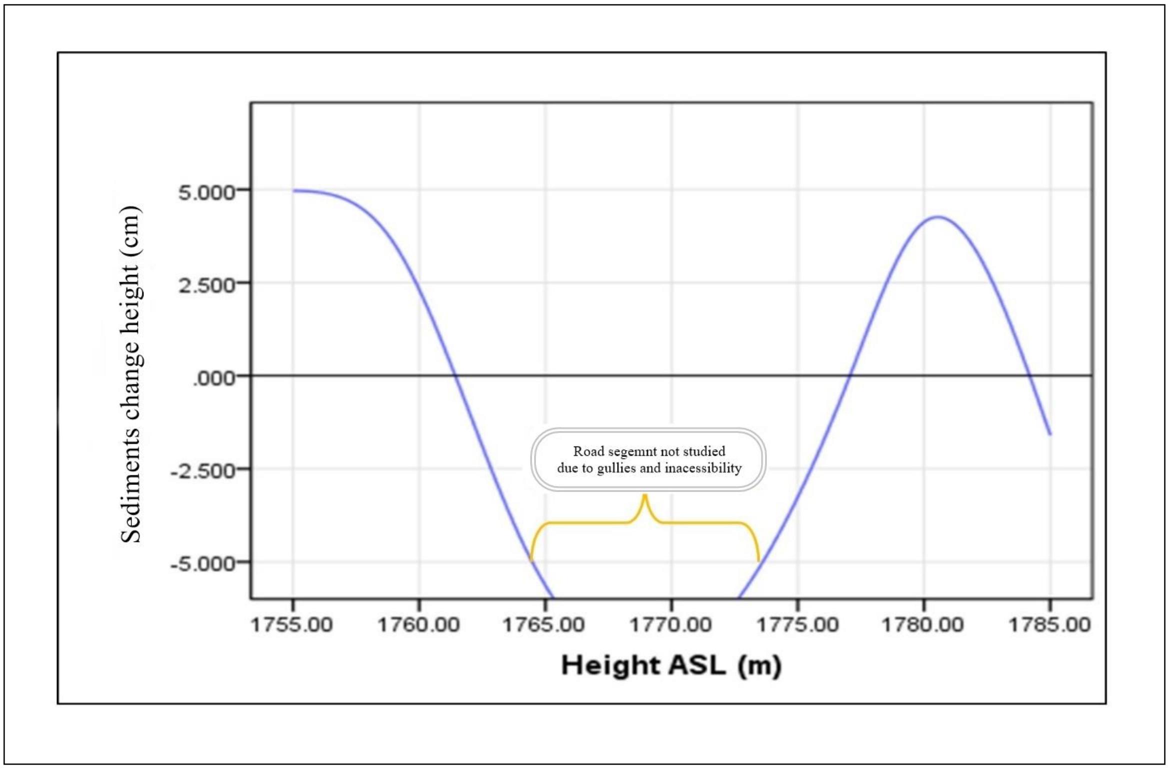


Figure 4.11: Line graph of eroded/deposited sediments change versus ASL in Sikulu-Kinyoro road.

The total sediments change in the road was 1011.47 cm^3. The total sediments deposited was 574.34 cm^3 while eroded sediments was 437.14 cm^3, the sediments eroded in the road reserve and the sediments deposited were almost equal. At 5+600 km of the road stretch from Saboti Junction there were large gullies that could have been caused by cumulative storm waters for a 2 km stretch.

4.2 Road run-off rates

Runoff rates for the road network were computed by cook's method, which factored in catchment characteristics of the catchment areas (Appendix 1for Surface Runoff rates of each road segment). A Pearson product-moment correlation coefficient was computed to assess the relationship between the sediments volume accumulated along roads and runoff rates along the study area. There was a positive correlation between the two variables, r =0.281, n = 82, p = 0.011. Generally, there was significant correlation between sediments volume and runoff rates in the study roads.

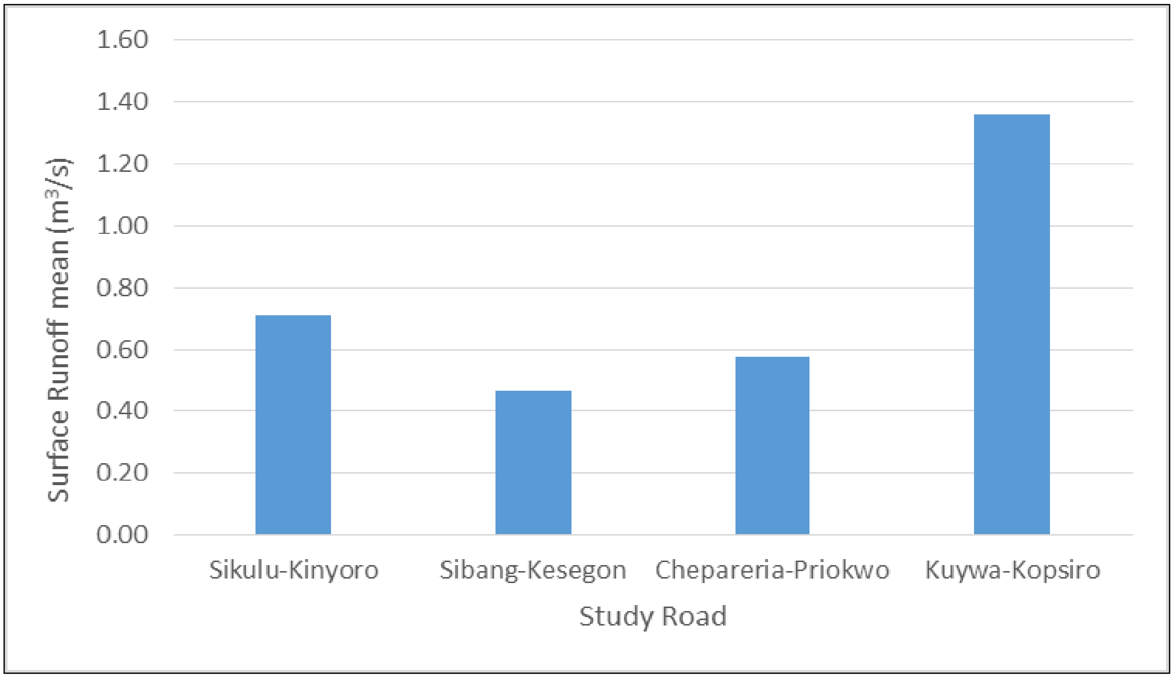


Figure 4.12: Bar graph of study roads runoff rates in (m^3/s).

Plotting the data on a scatter plot- see a scatter plot that summarizes the results in (Figure 4.13)- exhibits a general concentration rate below 1 m^3/s.

The runoff rates in all the roads concentrate on a mean of 1 m^3/s with volume sediments of less than 100 m^3. The corelation between runoff rates and sediments volume in the roads shows a positive corelation of r=+0.079.

The graph shows an equation of determining sediments volume versus runoff rates in the studied roads,the equation indicates a line of best fit at 73.39 cm^3 y axis with a coresponding any x value +33.01 (y=73.39+33.01x).

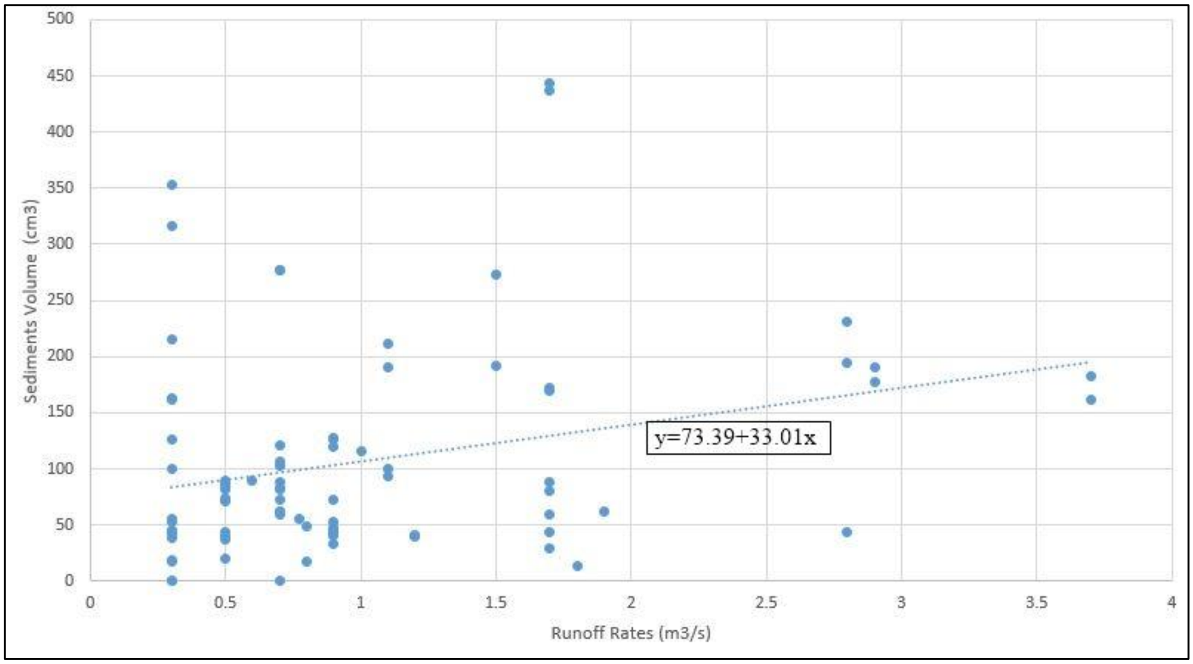


Figure 4.13: Scatter plot of sediments total volume versus runoff rates in the study area roads.

4.2.1 Chepareria-priokwo

The drainage description of Chepareria area –West Pokot County- was rated as well drained zone (ILRI, 2013), with deep and very deep soil columns. The area is on a plain land and the soils are sandy.

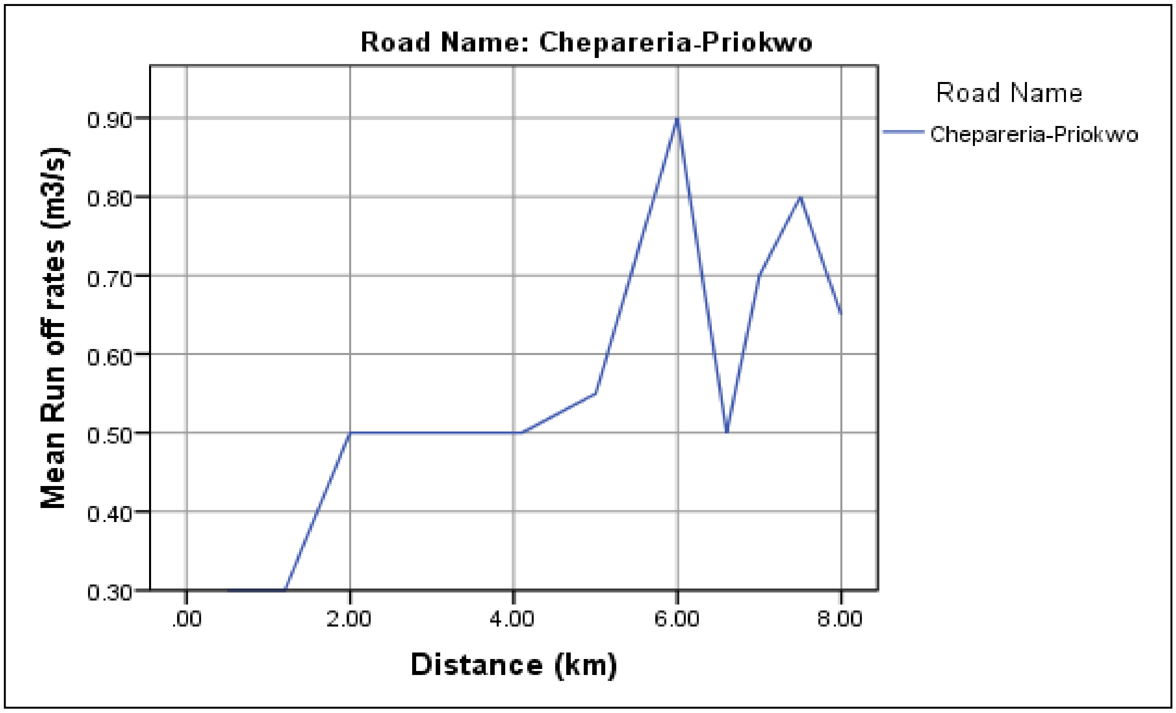


Figure 4.14: Mean runoff rate versus distance (Chepareria-Priokwo).

The runoff rate in Chepareria at the junction was 0.30 m^3/s, this was the lowest speed because of the terrain and vegetation cover at the area, the surrounding had a heavy shrub growth and this helped in reducing runoff water speeds. The rate increased and at 2km the speed of water was at 0.50m^3/s and this was maintained until at 4 km. The stretch from 1.5 km-2 km was sloping towards the west and it featured large gullies and high rate of deposition. The slope could contribute to the increased surface runoff within a 500 m stretch. A correlation of sediments volume versus runoff rates were drawn, $r=0.155$, $n=20$, $p= 0.515$, there was significant difference between runoff rates and sediments volume in the study road. From the above interpretation it is interpreted that surface runoff is not responsible for the sediment deposits or erosion in the area and so others factors contributed to it and this included anthropogenic factors- human activities upslope or on the sides of the road.

In Kuywa-kopsiro road the signifacnce between runoff rates and sediments deposition was, r=0.339, n=26, p= 0.091, there was a positive significance between the two variables with a r=0.339 the significance showed that an increase in runoff rate caused an increase in soil movement or deposition.

In Trans Nzoia County the two roads -Sibanga-Kesegon and Sikulu-Kinyoro- had a positive correlation of r=0.049 and r=0.251 respectively, this could be explained due to the ground cover on all the two roads, there was a higher percentage of grass cover. The correlation coefficient for Sibanga-Kesegon was lower than for all other roads, this could be because its sediments volume were determined more by anthropogenic activities rather than runoff rates. The Sikulu-Kinyoro road had weak positive correlation significance.

4.2.2 Relief and soil drainage

The catchment areas of roads in Trans Nzoia were in a gently undulating relief and the drainage was rapid, while in Sikulu-Kinyoro was characterized by a flat terrain with clay soil. The rainfall intensity in the study roads ranged from 800-1600 mm^3 per day per year. High rainfall intensity was experienced in Mt. Elgon areas with annual average of 1600 mm^3 and Sibanga-Kesegon traverses through 800-1600 mm^3 of rainfall zone increasing from south to North.

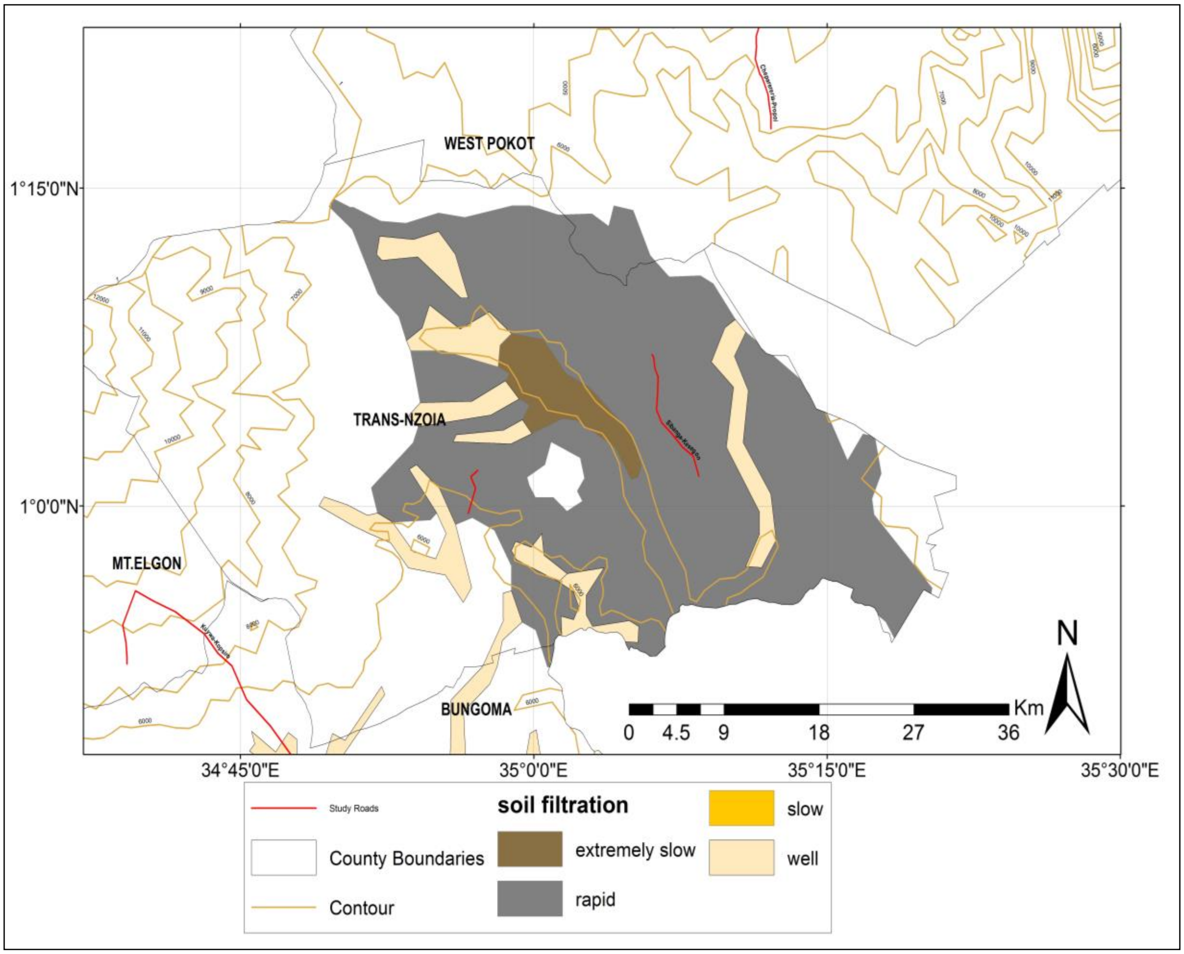


Figure 4.15: Map of Soil drainage versus relief.

Precipitation was a factor of soil erosion, and this was observed by the high sediments movement in Mt. Elgon Sub County which was attributed to high rainfall rates in the area. This factor exposes the roads in Mt. Elgon to a higher risk of erosion than any other roads. The roads in Mt. Elgon ranging from 10 km-18 km were much susceptible to erosion due to its mountainous terrain and high rate of precipitation, Sibanga-Kesegon road was also prone to erosion and 12 km stretch from Saiwa Swamp to Kipsaina bridge and at 18 km were affected due to high rate of precipitation, farming activities and terrain.

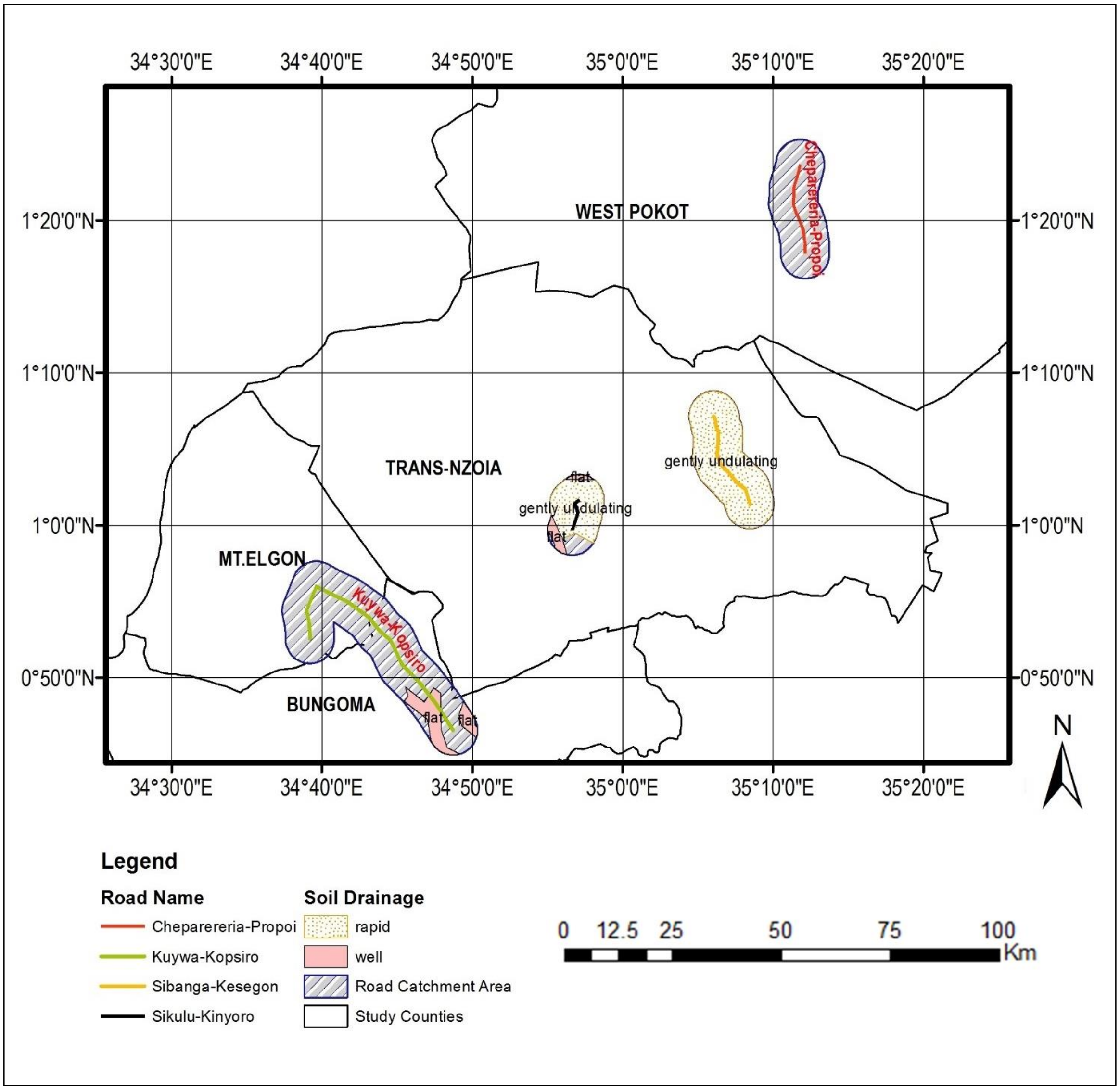


Figure 4.16: Map of Buffer zone and Soil drainage.

4.3 Results on general state of roads

The general condition of all the roads in the three zones was that 54.4% was made up of gravel while 2.9% had a rocky surface. The Rocky surface roads were found at the slopes of Mt. Elgon and parts of West Pokot.

Table 4.2: Road camber material

Type of Roads	Percentage (%)
Gravel	54.3
Earth road	21.4
Encroached by vegetation	18.6
Rocky/rock outcrop	2.9
Other characteristics	2.9

4.3.1 Soil control works

Soil control works include culverts, mitre drains, score checks, drifts and vented fords. Vented fords were the only missing soil control work in the study areas. The structures control soil erosion by acting as relief to agents of erosion and in instances where relief cannot be established off the road side drains a relief culvert was established- a relief culvert balances water levels between the left and right side drain to reduce water effect on road camber. The study roads had 245 culverts with Sibanga-Kesegon having 120 lines and Sikulu Kinyoro the least culverts.

Most of the culverts on the study roads were not fully working. Twenty eight per cent of the culverts were semi blocked with its entry and exit filled with debris half course. Only 3% a total of 7 culverts out of 245 culverts were fully functioning and in good condition.

Eighteen percent of the culverts were not functioning at all and they were shattered and completely out of order (Figure 4.17).

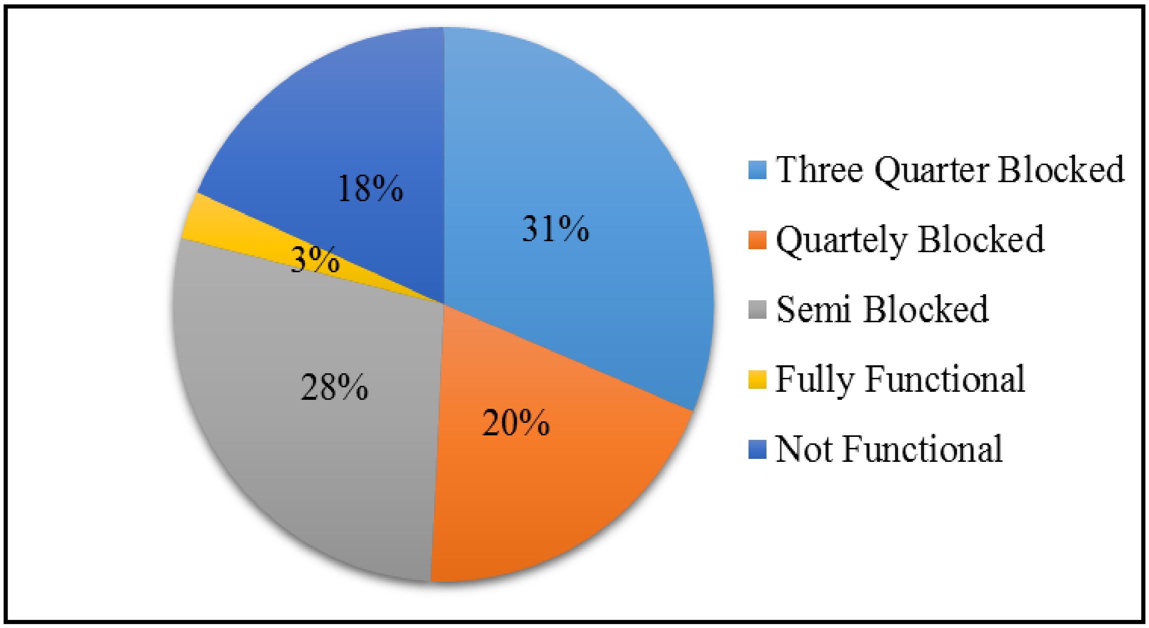


Figure 4.17: General Road culverts functioning.

The general condition of the roads' soil control works is that they were performing below the expected standards. The recommendations of any soil control works stipulated by **Ministry of Roads Handbook, 2013** requires that structures be build basing on recommended standards (Table 2.1 and 2.2).It was found out that the score checks and mitre drains were not build to recommended standards. In Sibanga-Kesegon road at 6.4 km with a gradient of 9% the score checks were placed at an interval of 12 m against the recommended 7 m. This inappropriate placement could explain the high amount of debris at Saiwa swamp at 12 km.

4.3.2 Trans Nzoia County

The roads chosen for study in the area included one Class E road which traverses through the foothills of Cherangani Hills (Kaplamai, Cherangani and Central Division) and a Class D road which lies on the Nzoia rolling plains (Saboti Division)

The class D Road to be studied was Sibanga-Kesegon road while the class E road was Sikulu-Kinyoro. In Trans Nzoia county 28.8% of them were partially in good condition 51-80% working. 52.1% of all the surface roads in the two study roads were covered with gravel while 24.7% was covered by earth road.

4.3.3 Sibanga-Kesegon (Class E)

Vegetation encroached the road and distorted the camber resulting to storm water running on the carriage way. Construction of feeder roads joining the road was the major cause of soil erosion. The side drains were covered with grass (Figure 4.18).

Figure 4.18: Sibanga-Kesegon road at 0+000 km left and right a blocked culvert at Sibanaga-Kitale Junction. Author (Source 2013).

The score checks were fully distorted on 0+500 km with blocked culverts which had side walls. At 0+800 km the culvert was fully blocked and it drained out the water to the carriage way causing erosion. At 1+300 km crossed class C48 road leading to Sibanga and Kitale road. The road camber was pronounced and there was much vegetation from adjacent lands due to farming. The major species of plant along the roadside was *lantana camara*.

Culvert at 1+900 km was cemented by debris from farm land; at 2+100 m to 3+100 km the slope steepened and oriented towards the North. There were series of score checks on the road and sand was the major deposit. The carriage way was distorted due to diversion of water from the score checks to the road.

Land ascent was experienced after 3+100 km and the slope faced south. Culvert at 3+400 km was fully blocked (entrance to Sinyeriri School).A series of 5 concrete score checks at 3+800 km had failed and thus partially functioned. The score checks were on the left side of the road oriented towards the North and were distorted with water diverting to the road. Some score checks’ aprons were fully eroded and damaged, at 3+900 m there were deep gullies caused by failed score checks on the upper side of the road. (Figure 4.19). The soil was silt quick sand which easily got washed away by water.

Figure 4.19: Gully erosion (left) and a failed scour check near Saiwa swamp (right). Author (Source 2013).

At Saiwa swamp there was a relief of fairly flat with a lot of oozing water along the road drainages and the camber was pronounced well. There was high amount of vegetation along the road and the lack and of access culverts was the major cause of soil erosion due to blockage of side drains. Access culvert at Namasi Primary School was dilapidated and in bad condition.

All the access culverts from Saiwa swamp to Kapsara were dilapidated. The road was purely earth road with no gravel. The relief changed and sloped to the North after ascending from Saiwa swamp.

Culvert at 6+800 km was functioning though there was much vegetation cover on its sides. Debris and vegetation (grass) at the inlet and the outlet drain also blocked the culvert. There was an open culvert at 7+500 m at Kapsara junction, and the road was well maintained and the camber well pronounced.

Tea was the major crop in the area. Slope was towards the North, and at 8+100 km, there were score checks on the road constructed by private adjacent land owners with a lot of siltation.

At 8+900 km a culvert was fully blocked on the inlet and 75% blocked on the outlet. The road had a good camber that sloped to the North with good vegetation composed of grass along the side drains. There were eroded side drains at 13+100 km on the south facing slopes. The side drains on most sections of the road were narrow and this was the major cause of road camber erosion by storm water as a result of incapacitation to pass water to the mitre drains or to a relief culvert (Figure 4.20).

Figure 4.20: Blocked Culvert during Rainy season at Kapchorwa tea factory Junction. Author (Source 2013).

Culverts were majorly located on road corners and masonry score checks were available too. Four culverts were distorted and not fully functional at 14+650 km. Access culvert at 14+700 km was functional on the inlet but in dilapidated state on the wing walls. At 17+300 km there were failed side drains just before the river which forced the water to enter onto the bridge, damaging it.

4.3.4 Sikulu –Kinyoro (Class D road)

The road started at GPS coordinates 0° 56' 54.099", 34° 54' 29.8902" at the junction leading to Saboti (Figure 4.21). There was no culvert on the junction since it was a flat ground. The side drains were blocked with patches of gravel on the road, grass and shrubs. At 0+100 km, an access culvert to the left was blocked hence diverting the storm waters to the main road. The road shoulders were clear with small vegetation growth. The side drains ditches at 0+500 km were fully silted with no vegetation cover.

Figure 4.21: The carriage camber at Sibanga-Saboti Junction. Author (Source 2013).

Gravellier trees were evident along the road and at 0+700 km the camber was totally distorted with high side slope erosion and a lot of sand sediments on the road ditches that drained towards the south. There were no side drains after the junction at 1+200 km and only the road camber was available. However, there was less erosion on the road sides because of the terrain in the area.

At 1+900 km there was a swamp on the left hand side of the road that caused a lot of havoc on the road. The road had a distorted camber with high siltation due to lower gradient. The camber was not graveled and the access culvert to the left at 2+500 km was functional and in good condition.

After the junction at 2+900 km the road became narrow with no gravel. The drainages were not well maintained and the slope was towards North West. At 5+ 400 km the road crossed river Kiminini which was in a dilapidated state and no defined drains that directed water into the river. The sides of the road were also worn out thus distorting the road camber from the East when ascending to the North.

Figure 4.22: Distorted road camber near Kijana Wamalwa Sec School. Author (Source 2013).

The gully at 5+500 km on both sides of the road was due to destroyed structures and steep slope with high volumes of water. The camber was in a bad state. The slope was South facing and it drained its water to river Kiminini.

4.3.5 Chepareria-Priokwo

There was short grass, well defined camber and the mitre drains were filled with sediments at 0+100 m. At 0+150 m there were deposits of sand along the road. The mitre drains were blocked by adjacent land owners making it difficult to drain water off the roads.

Figure 4.23: Silt deposits on Road camber 500m from Naskuta Primary School. Author (Source 2013).

The culvert at 0+600 km was a cross line culvert majorly built to control the hydrostatic forces along the side drains of the road and that was why it was easily blocked with silt. There were also well elaborated side drains with minimal erosion.

At 1+700 km there was a well maintained mitre drain to the right of the road. No much scouring on the road was evident because of well-functioning side drains. The score checks had specifications, the higher the disparity the higher the gradient it was. There were fifteen score checks on the left side of the road and nine on the right side of the road. From 6+000 km the slope was towards the west and the score checks had fully failed with numerous gullies.

The camber was distorted and a 15 m drift was available on the dry river bed. The culvert at 7+700 km was not working and was broken due to erosion, and the side drains had developed deep gullies that made the culvert not functional.

4.3.6 Kuywa-Kopsiro

The road started at Kuywa (0+000 km), the road side drains were silted with vegetation and the road construction was earth road with no gravel and no well-defined camber. The soil was red coffee and the major silt on roads was sand. The runoff headed towards Kuywa centre.

The first score check was at 0+500 km and the first culvert appeared at Baraka School. At 1+100 km a dilapidated culvert was present which was totally buried to the ground with diversion of storm waters on the sides. Gully erosion was majorly evident on the right hand side of the road. At 1+000 km there was a lot of siltation and this was because of the gentle slope and the vegetation cover. The vegetation cover was sparsely distributed causing much of the soil to be deposited on the road side. The major source of the silt was from an exhausted quarry (for gravel extraction).

The culvert at 1+700 km was in a fairly good condition though it was almost getting blocked. The depth of the debris on the right side was at 21 cm and this translated to almost 75% blocked culvert causing a lot of siltation on the upper end and that would eventually break the road.

The road was dominated by invasive species, lantana camara at 2 km from Kuywa market. The area was majorly characterized by sparse trees, blue gum trees and cypress. At 2+000 km there was an Armco culvert and a head wall to the left side. It was blocked, dilapidated and destroyed. At Stendi-Punda area (Kuywa).The culvert leading to Kuywa primary was in good condition though it lacked head walls.

At 2+600 km the culvert was completely blocked and access culvert made of Armco was blocked and not well protected. Its malfunctioning caused soil erosion on the road camber due to diversion of water. The road had patches of gravel. There was no culvert at the Junction to Siuna, Wetangula and Sango Primary School.

The area was densely populated and at 4+200 km the terrain changed and drainage coursed towards the north with an undulating terrain. At 4+600 km the culvert was dilapidated with no head walls and it received water from the southern and northern facing slopes, thus causing a lot of debris on the road side. At 4+600 km to 4+900 km the road was situated in flat areas. At 5+000 km the culvert was blocked with no head walls and no wing walls with debris from farm land and silt deposits.

The camber at 6+100 km was well pronounced. At the same point there was an Armco culvert with head walls that drained stream water. The side drains were overgrown with grass and weed. At 20 m from it was a junction culvert made of two culverts 600 mm diameter.

The soil at Kapkateny was black cotton and at the market centre there was no well-defined drainage. At 7+300 km there was culvert with head walls well maintained. The culvert at Chebin was 75% blocked on the inlet and 90% blocked on the outlet with debris. The culvert drained its storm waters to Kapkateny River. At 7+.900 km the side walls of a culvert was covered with mud and was half silted. There was a lot of erosion upslope 8+200 km with deep gullies present on road sides and exposed rock outcrop. Siltation and deposition was minimal while erosion was high. The vegetation was majorly made up of shrubs and rock outcrop.

The road from Kapkateny River was totally distorted. The entire road filled with rock outcrops forming a rocky zone. At Cheptonon Primary School 10+900 km and 3+000 km of the road was in a bad condition.

Kipsikirok centre is located at 11+300 km from Kuywa centre and there was a culvert which was dilapidated, scoured and eroded. The headwalls constructed with no wing walls. The road was an earth road, the side drains were eroded, with no structures to control erosion since the road was on a steep slope. There were deep gullies caused by erosion which was basically due to lack of proper drainages. There was dense vegetation on the right shoulders of the road.

The slope ended at 12+300 km with a flat terrain is experienced. At 13+000 km the road stretched to Mt. Elgon Forest. There were no drainage structures in the area. At Kipsikirok 15+000 km all the road was earth road with no much erosion. Vegetation along the road was scanty and the major economic activity was maize farming which contributes to silt formation down slope; farming was done along the road shoulders.

Masonry built culvert at Kipsikirok at 16+000 km was not efficient and most water ran off the road. At 17+000 km which was at the top of the plateau there was no much change in relief.

The road from 17+000 km - 18+500 km was generally dilapidated and unused with deep gullies and high rate of erosion due to the cumulative erosive activities and non-maintenance. At 19+800 km towards the west and to the south at 22+000 km towards Chebiuk market, the road stretching to the western end was fairly maintained with grass growing by the road side with minimal erosion.

4.3.7 Land cover

The land cover around the study roads varied from bare land to vegetated road side drains and road reserves. The road reserves in Mt. Elgon Sub-County were covered by thick grass and bushes. In Sikulu- Kinyoro road short grass and bushes characterized the road reserve. Shrubs, bare road reserve and short grass characterized the Sibanga Kesegon road; this was due to the condition of the road traversing through different zones that was a plateau and finally to foothills of Cherangani hills. A total of 72.6% of the study roads length was covered with grass, 4.9% bare road reserve while shrubs and bushes covered 23.5% and 4.9% of bare reserve were found in West Pokot study area.

4.3.8 Study road Profile

The roads ranged from 1500 m ASL in Mt. Elgon sub-county to 2680 m ASL. Mt. Elgon Sub-county road exhibited this trait while other roads stretched between 1600 m to 1900 m ASL. The change in altitude was a key factor for road maintenance, and drastic change in gradient would lead to drastic road damage when proper management is not put in place.

The general road profile of the study roads, after plotting the height above sea level, altitude against distance of the road provided the following output (Figure 4.24).

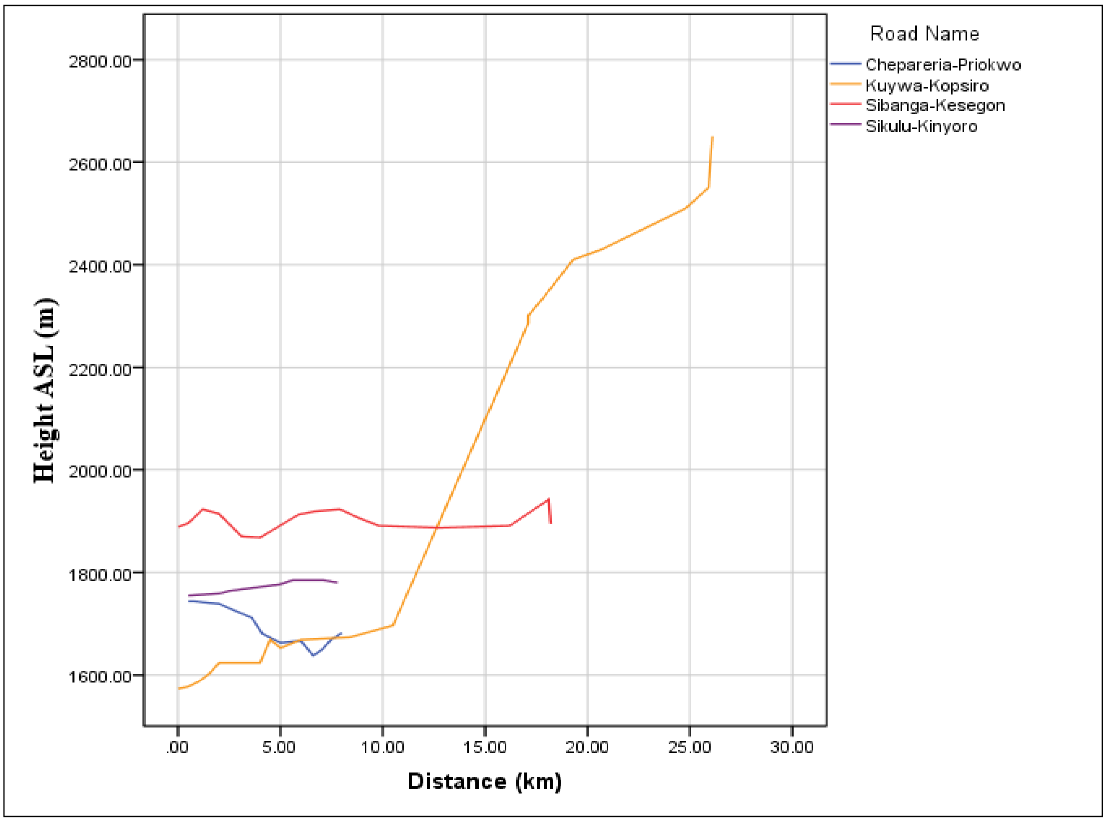


Figure 4.24: General study Roads profile.

4.4 Potential erosion zones

Soil erosion on the study roads was not generally high, but there were zones that exhibited a high potential of soil erosion than other zones.

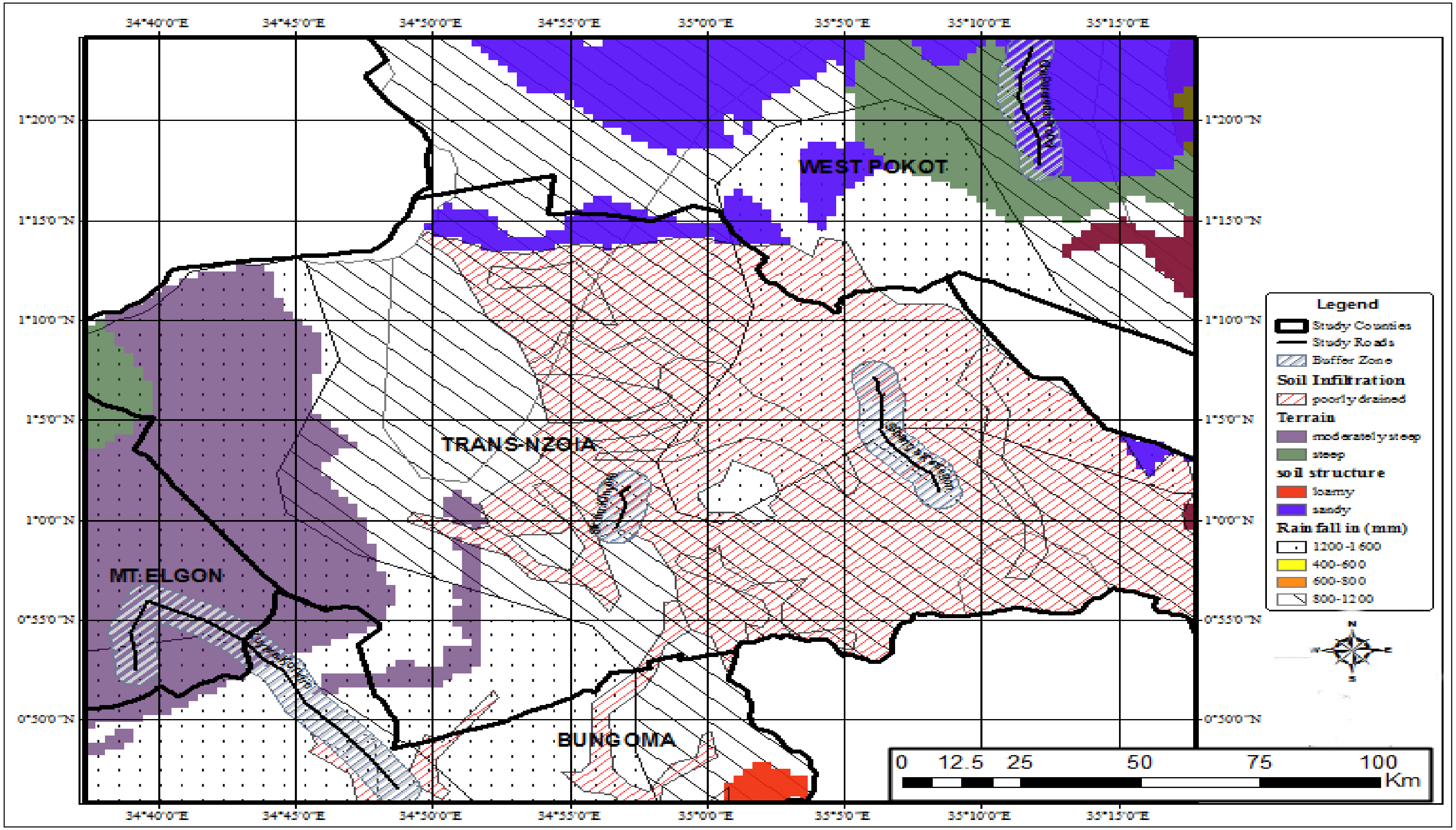


Figure 4.25: Overlay of soil erosion factors.

In west Pokot County after performing an overlay of factors that contribute to soil erosion, the south west side of the road was at a medium risk of soil erosion due to its sand soil composition, steep terrain and rainfall intensity of 800-1200 mm per year. It was also found that zones on Southern West Pokot are at a higher risk of erosion because of rainfall intensity at 35^0 50’ E and 1^0 75’ N which is a steep terrain zone and receives 1200-1600 mm of rain annually in this area upslope is probable source of sediments that causes siltation on the Chepareria- Priokwo road.

In Mt. Elgon, areas prone to soil erosion included sections of Kuywa at Sinyereri market where the soils are poorly drained and the rainfall intensity is higher at 1200-1600 mm per annum, the erosion in this zone is at a medium risk since the terrain is rolling. High rate of erosion is probable in the Mt. Elgon slopes due to moderately steep terrain. This started at Kapkateny centre on a zone that receives rainfall between 1200-1600 mm per year and with clay soil; this reduced the risk of erosion though surface runoff rates were very high at 3.7 m^3/s. The road catchment area was in a bad condition with no soil control works and this could worsen the road states in the future since the area is a high probable soil erosion zone.

Trans Nzoia County is on a poorly drained soils and this makes it be on a higher risk of soil erosion than any of the other roads. The county also receives rain between 800-1600 mm per annum with Sikulu road at the lowest while Sibanga road receiving maximum rainfall. The erosion in Trans Nzoia is moderated by the gently undulating terrain which reduces it from a high risk zone to a medium probable zone of erosion.

Table 4.3: County soil erosion potential

County	**Erosion potential**
Mt. Elgon (Mt. Elgon Sub county)	High
West Pokot	Medium
Trans Nzoia	Medium

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the recommendations made from the research for improvements and for further sustainability of our roads.

5.2 Conclusion

The research found out that there was less significance between climatic factors and soil erosion in three of the roads, this included roads of West Pokot and the Trans Nzoia roads. The road in Mt. Elgon was majorly influenced by climatic factors, it was also observed that erosion and deposition of soil was influenced by terrain and there was a relative significance in Mt. Elgon roads. In west Pokot the roads were in good conditions but the major threat to them delivering was erosion upslope. There was high rate of erosion upslope and this was evident with the road of Sibanga-Kesegon where there was immense cultivation upstream, causing high runoff rates and increased soil erosion which blocked culverts, mitre drains and cut-off or relief drains diverting the waters to the road camber and breaking it rendering the road unusable.

Runoff rates, topography and gradient had a significant soil processes impact, causing high or low depositions; and it was major impact on Mt. Elgon region. Sections which had failed drainage structures such as scour checks, culverts, drifts and vented fords showed more eroded sediments deposits and erosion along the road side drains.

GIS analysis shows that most of the roads in the three study counties had a medium erosion potential whereas those of Mt. Elgon and Sibanga had a higher rate of potentiality in erosion. The analysis of soil erosion potential areas using GIS is critical on road alignment and when constructing new roads to avert zones that have high potential rate of erosion.

5.3 Recommendations

The study makes the following recommendations; in order to reduce cost of maintenance for roads and the serviceability of roads to be elongated and serve the beneficiaries best.

- Terraces to be introduced in high grade slopes of Mt. Elgon, all farm lands upstream and cultivation should be discouraged on road reserves.
- Road reserve should be left uncultivated and the grass be kept short to enhance soil compaction and protect the back slope of the roads from erosion, this will also protect the side drains from silt/debris accumulation.
- Soil control works should be built to expected standards for effectiveness and reduce overworking of other structures. This was observed in west Pokot where the drifts were built on bends which gets the side apron damaged before next road maintenance cycle.
- Cut-off drain and relief culverts should be encouraged in zones of Mt. Elgon at distance of 10km apart and in Sibanga-Kesegon roads, these roads receive a high rate of precipitation resulting to high runoff rates and unbalanced hydrology levels breaking road camber and blocking side drains.
- GIS analysis should be used/ adopted to show areas that have higher risk of erosion due to combination of soil erosion factors and thus making it possible for easy management and for appropriate measures to be undertaken to consider management and prevention of soil erosion, before it causes immense damage to the roads. The use of GIS would be appropriate when aligning or constructing of new roads to avoid high erosion potential areas.
- All the relevant soil erosion control structures on the road should be put in the correct positions to make sure roads once constructed should remain on their

good original state for a long period of time and the general maintenance should be done on time.

- The management of the roads should be done by both the occupants who are served by a particular road and the relevant ministry in order to avert soil erosion and further damage to the roads.

- Stabilization and compaction of side slopes and shoulders of road structure should be encouraged and routine check be done by the relevant departments.
- This research recommends for further studies for development of soil erosion model for Low volume rural roads to be used in mapping out and identifying potential areas of high soil erosion and propose proper soil control measures.

REFERENCES

Abagale, F. K., Coffie, J. and Nyadzi, E. (2012). Quantification and Nutrient Levels of Eroded Soil of Farmlands in Northern Ghana.Int. J. Forest, Soil and Erosion, 2012 2 (4): 192-194.ISSN 2251-6387 [PRINT] 2251-824X [Online].

Albert, A. A, Samson, A. A., Peter, O. O. and Olufunmilayo, A.O. (2006). An Assessment of the Socio Economic Impacts of Soil Erosion in South-Eastern Nigeria.

Alfonso, C. Marco, M. Francesca, L. Andrea, P. and Simone, O. (2001). Assessment of Erosion Risk Due to Rainfall at Regional Scale. Department of Agronomy and Land Management - University of Florence (DISAT-UNIFI).

Amudu, G. (2014). A way of living, Soil Erosion Available at http://amudu-gowripalan.blogspot.com/2011/07/soil-erosion.html Accessed July 2014

Andersson, L. (2007). Soil Loss estimation Based on the USLE/GIS Approach Trough Small Catchments. A minor field study in Tunisia. Lund University. ISSN, 1101-9824.

Andersson, L. (2010). Soil Loss Estimation Based on the USLE/GIS Approach through Small Catchments-A Minor Field Study in Tunisia.

Avanzi, J. C. L. Beskow, S. Curi, N. Mello, C. R. Norton, L. D. Viola, M. R. (2009). Soil erosion prediction in the Grande River Basin, Brazil using distributed modelling, National Soil Erosion Research Laboratory, Purdue University, USA.

BBC. (2014). Surface and interior erosion. Available at http://www.bbc.co.uk/science/earth/surface_and_interior/erosion (accessed on March 12th 2014 at 7:06 am).

Bryan, R. B. and Schnabel, S. (1994). Estimation of sedimentation rates in the Chemeron Reservoir. *Advances in Geo Ecology*, *27*, 231-231.

Dangler, E. W., El-Swaify, S. A., Ahujan L. R. and Barnett, A. P. (1976). Erodibility of selected Hawaii soils by rainfall simulation, Agricultural research service, US department of agriculture, western region, 113p.

Dayton, L. (1992). "Pacific Islanders Were World's First Farmers," New Scientist, p. 14, December 12.

Doran, J. W. and Parkin, T. B. (1994). Defining and assessing soil quality. SSSA special publication, 35, 3-3.

Dunne, T. (1979). Sediment yield and land use in tropical catchments. *Journal of Hydrology*, *42*(3), 281-300.

Erdogan, H. E., Erpul, G. and Bayramin, I. (2006). Use of USLE/GIS Methodology for Predicting Soil Loss in a Semiarid Agricultural Watershed, Department of Soil Science, University of Ankara, Turkey.

Eriksson, A. and Kidanu, A. (2010). Guidelines for prevention and control of soil erosion in road works. International Labour Office, CH-1211 Geneva 22. Switzerland (2012).

G.O.K (2013). Ministry of Roads Handbook.

Haynes, R. J. and Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient Cycling in Agro-ecosystems, 51(2), 123-137.

Heimsath, A. M. Dietrich, W. E. Nishiizumi, K. and Finkel, R. C. (2001). Stochastic processes of soil production and transport: Erosion rates, topographic variation and cosmogenic nuclides in the Oregon Coast Range. *Earth Surface Processes and Landforms*, *26*(5), 531-552.

Hudson, J. A. (1981). Wave speeds and attenuation of elastic waves in material containing cracks. *Geophysical Journal International*, *64*(1), 133-150.

Jankauskas, B., Jankauskienė, G. and Fullen, M. A. (2007). Relationships between soil organic matter content and soil erosion severity in Albeluvisols of the Žemaičiai Uplands.

Kariaga, B. M. M. (1987). An analysis of soil erosion potential: the case of Sondu Basin, western Kenya.

Kleinman, P. J. A. Pimentel, D. and Bryant, R. B. (1995). The ecological Sustainability of slash-and-burn agriculture. Agric., Ecosystems and Environment. 52: 235-249.

Krhoda, G. O. (1989). Groundwater assessment in sedimentary basins of eastern Kenya, Africa. In *Proceeding of the Baltimore Symposium on Regional Characterization of Water Quality, IAHS Publ* (No. 182).

Lillesand, T. Kiefer, R. W. and Chipman, J. (2014). *Remote sensing and image interpretation*. John Wiley & Sons.

Megahan, W. F. and Molitor, D. C. (1975). Erosional effects of wildfire and logging in Idaho.

Ministry of Roads and Public Works- Roads 2000 (May 2005). Roads 2000 contract management manual, improvement works.

Moore, I. D. and Burch, G. J. (1986). Physical basis of the length-slope factor in the Universal Soil Loss Equation. *Soil Science Society of America Journal*, *50*(5), 1294-1298.

Olugbebi, I. F. (2010). Evaluation of Soil Erodibility on Three Major Soils In UNAAB.

Onyando J. O. Kisoyan, P. Chemelil, M. C. (2004). Estimation of Potential Soil Erosion for River Perkerra Catchment in Kenya, Department of Agricultural Engineering, Egerton University, Njoro Kenya.

Peeyush, G. and Swati, U. (2012). International Journal of Engineering Research and Technology.Vol.1 - Issue 10.ISSN: 2278-0181

Priest, S. D. and Hudson, J. A. (1981). Estimation of discontinuity spacing and trace length using scanline surveys. In *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts* (Vol. 18, No. 3, pp. 183-197). Pergamon.

Rapp, A., Axelsson, V., Berry, L. and Murray-Rust, D. H. (1972). Soil erosion and sediment transport in the Morogoro River catchment, Tanzania. *Geografiska Annaler. Series A. Physical Geography*, 125-155.

Reid, L. M. and Dunne, T. (1984). Sediment production from forest road surfaces. *Water Resources Research*, *20*(11), 1753-1761.

Seestrom, W. R. (1966). Highway Routes in Undeveloped Areas. Photogrammetric Engineering.

Six, J., Bossuyt, H., Degryze, S. and Denef, K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil and Tillage Research, 79 (1), 7-31.

Stephenson, W. J. and Finlayson. B. L. (2009). Measuring Erosion with the Micro-erosion Meter – Contributions to Understanding Landform Evolution and Building Stone Decay. Earth Science Reviews 95:53-62.

Stone, P. R. (2012). Universal soil loss equation Available at http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm#background

Stone, R. P. and Hilborn, D. (2000). FACTSHEET, Universal Soil Loss Equation, Ministry of Agriculture, Food and Rural Affairs, 2000, [online] accessed 2010-03-11

Toy, T. J. George, R. and Kenneth, G. (2002). Soil erosion: processes, prediction, measurement, and control. John Wiley and Sons.

Truong, P. Van, T. T. and Pinners, E. (2008): The Vetiver System for slope stabilization by, 1st Edition.

University of British Columbia (2014). Faculty of Land and Food SystemsSoilWeb200. Available at http://www.landfood.ubc.ca/soil200/soil_mgmt/soil_erosion.htm#312 (accessed on May 11th 2014 at 12:20pm).

Wall, G. Baldwin, C.S. and Shelton, I. J. (1987). "Soil Erosion – Causes and Effects." Ontario Institute of Pedology and Ridgetown College of Agricultural Technology.

Wischmeier, W. H. and Smith, D. D. (1958). Rainfall energy and its relationship to soil loss. *Eos, Transactions American Geophysical Union*, *39*(2), 285-291.

www.ilo.org/wcmsp5/groups/public/@asia/@robangkok/documents/genericdocument/wcms_101011.pdf [Accessed on 28/11/2013 19:25pm].

Yang, W., Wang, Z., Sui, G. and Ding, G. (2008). Quantitative determination of red-soil erosion by an Eu tracer method. *Soil and Tillage Research*, *101*(1), 52-56.

APPENDIX 1

Surface runoff rates for study Roads

Road Name	DISTANCE (km)	COVER	C	SOIL TYPE	S	SLOPE GRADIENT	SL	CC	Runoff Rate (m3/s)
Sikulu-Kinyoro	1	Grass medium	15	Fairly pervious	25	Rolling	15	60	0.9
Sikulu-Kinyoro	2	Cultivated land	15	Fairly pervious	25	Rolling	15	60	0.9
Sikulu-Kinyoro	3	Cultivated land	15	Water logged	50	Rolling	15	85	2.4
Sikulu-Kinyoro	4	Cultivated land	15	Well drained	10	Moderate	10	45	0.3
Sikulu-Kinyoro	5	Cultivated land	15	Well drained	10	Moderate	10	45	0.3
Sikulu-Kinyoro	6	Cultivated land	15	Well drained	10	Rolling	15	40	0.3
Sikulu-Kinyoro	7	Cultivated land	15	Well drained	10	Rolling	15	45	0.3
Sikulu-Kinyoro	8	Cultivated land	15	Well drained	10	Rolling	15	45	0.3
Sibang-Kesegon	1	Cultivated land	20	Well drained	10	Rolling	15	50	0.7
Sibang-Kesegon	2	Cultivated land	20	Well drained	10	Rolling	15	50	0.7
Sibang-Kesegon	3	Cultivated land	20	Moderatly Pervious	10	Rolling	15	50	0.7
Sibang-Kesegon	4	Cultivated land	20	Fair permeabilty	25	Steep	20	65	1.5
Sibang-Kesegon	5	Cultivated land	20	Well drained	10	Steep	20	50	0.7
Sibang-Kesegon	6	Cultivated land	20	Well drained	10	Steep	20	50	0.7
Sibang-Kesegon	7	Cultivated land	20	Well drained	10	Steep	20	50	0.7

Sibang-Kesegon	8	Cultivated land	20	Well drained	10	Steep	20	50	0.7
Sibang-Kesegon	9	Cultivated land	20	Well drained	10	Steep	20	45	0.3
Sibang-Kesegon	10	Cultivated land	20	Well drained	10	Rolling	15	45	0.3
Sibang-Kesegon	11	Cultivated land	20	Well drained	10	Steep	20	45	0.3
Sibang-Kesegon	12	Cultivated land	20	Well drained	10	Steep	20	45	0.3
Sibang-Kesegon	13	Cultivated land	20	Well drained	10	Steep	20	50	0.3
Sibang-Kesegon	14	Forest/Heavy grass	10	Well drained	10	Steep	20	30	0.2
Sibang-Kesegon	15	Forest/Heavy grass	10	Well drained	10	Steep	20	30	0.2
Sibang-Kesegon	16	Cultivated land	20	Well drained	20	Steep	20	35	0.2
Sibang-Kesegon	17	Cultivated land	20	Well drained	20	Steep	20	35	0.2
Sibang-Kesegon	18	Cultivated land	20	Well drained	20	Steep	20	30	0.2
Sibang-Kesegon	19	Cultivated land	20	Well drained	20	Steep	20	35	0.2
Sibang-Kesegon	20	Cultivated land	20	Well drained	20	Steep	20	35	0.2
Chepareria-Priokwo	1	Scrub/medium grass	15	Sand	25	Rolling	15	45	0.3
Chepareria-Priokwo	2	Scrub/medium grass	15	Sand	25	Rolling	15	50	0.5
Chepareria-Priokwo	3	Bare eroded land	25	Sand	25	Rolling	15	70	0.5
Chepareria-Priokwo	4	Scrub/medium grass	15	Sand	25	Rolling	15	65	0.5
Chepareria-Priokwo	5	Bare eroded land	25	Sand	25	Steep	20	75	0.9
Chepareria-Priokwo	6	Bare eroded land	25	Sand	25	Steep	20	75	0.9
Chepareria-Priokwo	7	Scrub/medium grass	15	Sand	25	steep	20	60	0.5
Chepareria-Priokwo	8	Scrub/medium grass	15	Sand	25	Rolling	15	60	0.5

Kuywa-Kopsiro	1	Cultivated Land	20	Well drained	10	Moderate	10	40	0.9
Kuywa-Kopsiro	2	Medium grass	15	Shallow soils	30	Rolling	15	55	1.7
Kuywa-Kopsiro	3	Cultivated Land	20	Well drained	10	Rolling	15	50	1.4
Kuywa-Kopsiro	4	Cultivated Land	20	Well drained	10	Rolling	15	45	1.7
Kuywa-Kopsiro	5	Cultivated Land	20	Well drained	10	Flat	5	45	1.7
Kuywa-Kopsiro	6	Cultivated Land	20	Fairly drained	25	Moderate	10	60	2.9
Kuywa-Kopsiro	7	Bare land	25	Rocky surface	40	Hilly/steep	20	80	3.7
Kuywa-Kopsiro	8	Bare land	25	Rocky surface	40	Mountanious	25	80	3.7
Kuywa-Kopsiro	9	Bare land	25	Rocky surface	40	Mountanious	25	80	3.7
Kuywa-Kopsiro	10	Bare land	25	Rocky surface	40	Mountanious	25	80	3.7
Kuywa-Kopsiro	11	Heavy grass	10	Moderate pervious	20	Steep	20	50	1.4
Kuywa-Kopsiro	12	Cultivated Land	20	Well drained	10	Steep	20	50	1.4
Kuywa-Kopsiro	13	Cultivated Land	20	Well drained	10	Moderate	10	50	1.4
Kuywa-Kopsiro	14	Cultivated Land	20	Well drained	10	Moderate	10	50	1.4
Kuywa-Kopsiro	15	Cultivated Land	20	Well drained	10	Steep	20	30	0.5
Kuywa-Kopsiro	16	Cultivated Land	20	Impeded drainage	30	Rolling	15	50	0.5
Kuywa-Kopsiro	17	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5
Kuywa-Kopsiro	18	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5
Kuywa-Kopsiro	19	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5
Kuywa-Kopsiro	20	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5
Kuywa-Kopsiro	21	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5

Kuywa-Kopsiro	22	Cultivated Land	20	Well drained	10	Rolling	15	30	0.5
Kuywa-Kopsiro	23	Cultivated Land	20	Well drained	10	Steep	20	30	0.5
Kuywa-Kopsiro	24	Cultivated Land	20	Well drained	10	Steep	20	30	0.5
Kuywa-Kopsiro	25	Cultivated Land	20	Well drained	10	Steep	20	30	0.5
Kuywa-Kopsiro	26	Cultivated Land	20	Well drained	10	Steep	20	30	0.5

Soil erosion potential per road

	Kuywa-Kopsiro Class E	
Name	**Distance (Km)**	**Erosion Potential**
Kuywa-Kopsiro	0.00	Stable
Kuywa-Kopsiro	0.50	Stable
Kuywa-Kopsiro	0.50	Stable
Kuywa-Kopsiro	1.00	Low
Kuywa-Kopsiro	1.00	Low
Kuywa-Kopsiro	1.50	Medium
Kuywa-Kopsiro	1.50	Medium
Kuywa-Kopsiro	2.00	Low
Kuywa-Kopsiro	2.00	Low
Kuywa-Kopsiro	4.00	Stable
Kuywa-Kopsiro	4.00	Stable
Kuywa-Kopsiro	4.50	Medium
Kuywa-Kopsiro	4.50	Medium
Kuywa-Kopsiro	5.00	Medium
Kuywa-Kopsiro	5.00	Medium
Kuywa-Kopsiro	6.00	Low
Kuywa-Kopsiro	6.00	Low
Kuywa-Kopsiro	8.40	Low
Kuywa-Kopsiro	8.40	Low
Kuywa-Kopsiro	10.50	High
Kuywa-Kopsiro	17.10	High
Kuywa-Kopsiro	17.10	High
Kuywa-Kopsiro	17.80	high

Kuywa-Kopsiro	19.30	Medium
Kuywa-Kopsiro	20.70	Low
Kuywa-Kopsiro	24.80	Medium
Kuywa-Kopsiro	25.90	Medium
Kuywa-Kopsiro	26.10	High
	SIKULU-KINYORO CLASS D	
Sikulu-Kinyoro	0.50	Low
Sikulu-Kinyoro	2.00	Low
Sikulu-Kinyoro	2.00	Low
Sikulu-Kinyoro	0.50	Medium
Sikulu-Kinyoro	2.50	Medium
Sikulu-Kinyoro	2.50	Medium
Sikulu-Kinyoro	5.00	High
Sikulu-Kinyoro	5.00	High
Sikulu-Kinyoro	5.60	Medium
Sikulu-Kinyoro	5.60	Medium
Sikulu-Kinyoro	7.10	Medium
Sikulu-Kinyoro	7.80	High
Sikulu-Kinyoro	7.80	High
Sikulu-Kinyoro	8.00	Low
	SIBANGA-KESEGON CLASS E	
Sibanga-Kesegon	0.00	Low
Sibanga-Kesegon	0.50	Low
Sibanga-Kesegon	0.50	Low
Sibanga-Kesegon	1.20	Low
Sibanga-Kesegon	1.20	Low
Sibanga-Kesegon	2.00	Medium
Sibanga-Kesegon	2.00	Medium

Sibanga-Kesegon	3.10	High
Sibanga-Kesegon	3.10	High
Sibanga-Kesegon	4.00	High
Sibanga-Kesegon	4.00	High
Sibanga-Kesegon	5.90	Medium
Sibanga-Kesegon	6.70	Medium
Sibanga-Kesegon	7.90	Medium
Sibanga-Kesegon	7.90	Medium
Sibanga-Kesegon	8.90	High
Sibanga-Kesegon	9.80	High
Sibanga-Kesegon	9.80	High
Sibanga-Kesegon	12.80	Medium
Sibanga-Kesegon	16.20	Medium
Sibanga-Kesegon	16.20	Medium
Sibanga-Kesegon	18.10	High
Sibanga-Kesegon	18.20	Medium
Kesegon	19.40	Medium
	CHEPARERIA- PRIOKWO CLASS D	
Chepareria-Priokwo	0.5	Medium
Chepareria-Priokwo	0.5	Low
Chepareria-Priokwo	0.8	Low
Chepareria-Priokwo	1.2	Low
Chepareria-Priokwo	1.2	Low
Chepareria-Priokwo	2	Low
Chepareria-Priokwo	2.8	Low
Chepareria-Priokwo	3.6	High
Chepareria-Priokwo	3.6	High
Chepareria-Priokwo	4.1	Low

Chepareria-Priokwo	4.1	Low
Chepareria-Priokwo	5	High
Chepareria-Priokwo	5	High
Chepareria-Priokwo	6	Low
Chepareria-Priokwo	7	Low
Chepareria-Priokwo	7	Low
Chepareria-Priokwo	7.5	Low
Chepareria-Priokwo	8	High
Chepareria-Priokwo	8	High
Priokwo	8.2	High

APPENDIX 2:

Road data collection checklist

County: ____________________ Road Name: Start Point________________ End: __________

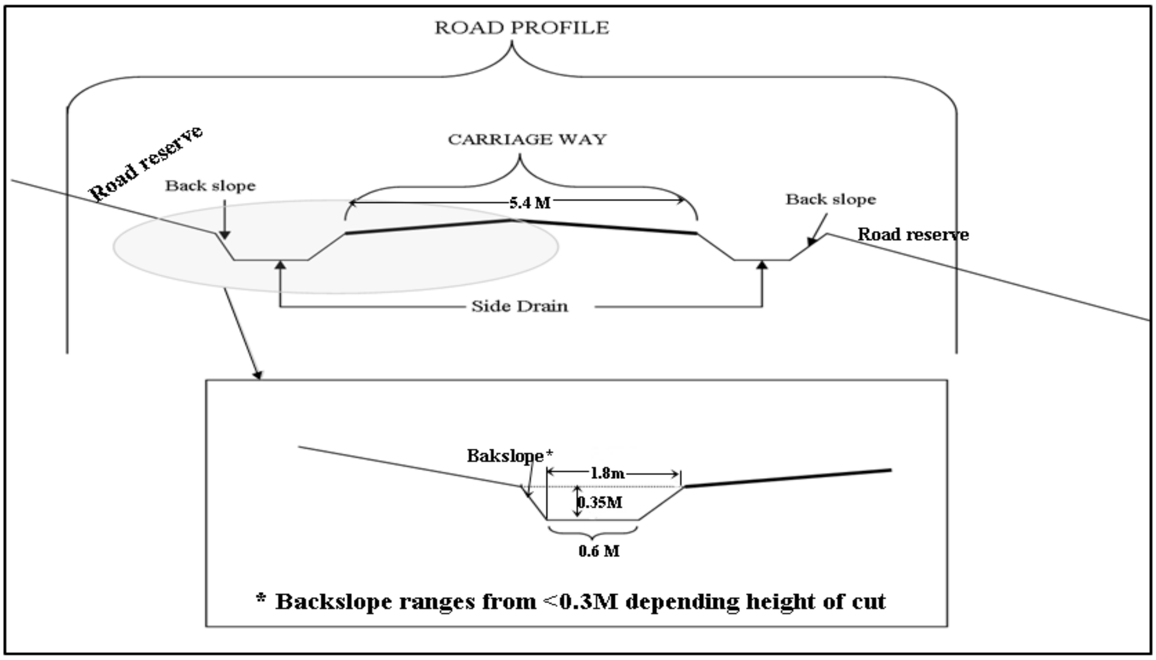
Road Class: __________

GPS Location: Start Point____________________________ End___________________________

Distance 0+00 km	General Road Condition	Culverts count	Culverts state	Vegetation cover (Description)	Camber state	Soil erosion	Slope and Relief	GPS location
Actual road Length ______________ (km)								

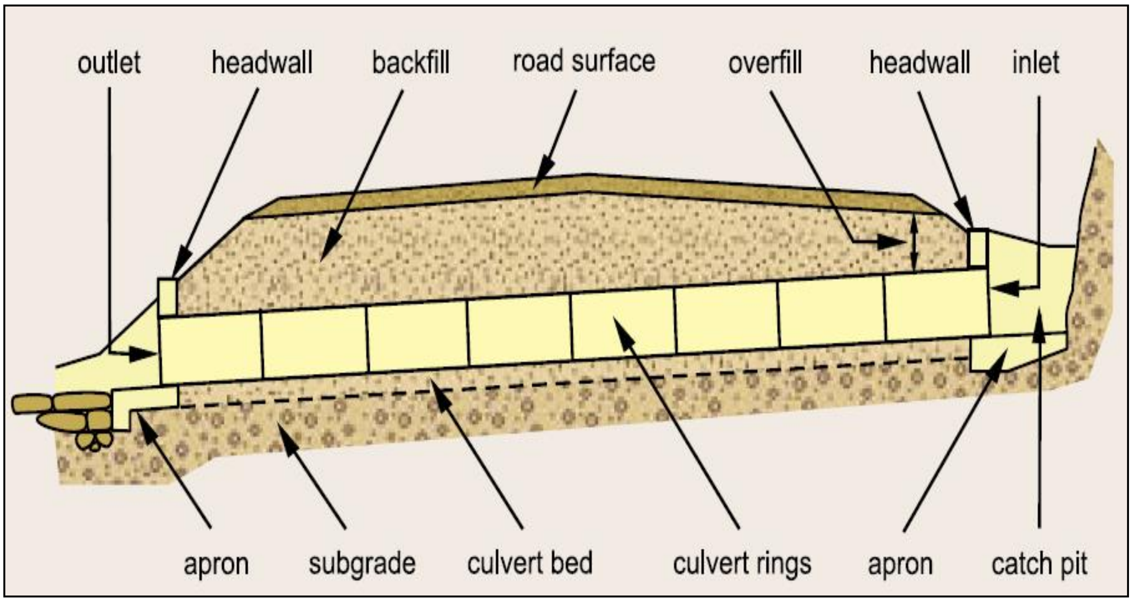
Road soil Erosion Control structures

Road profile and specifications

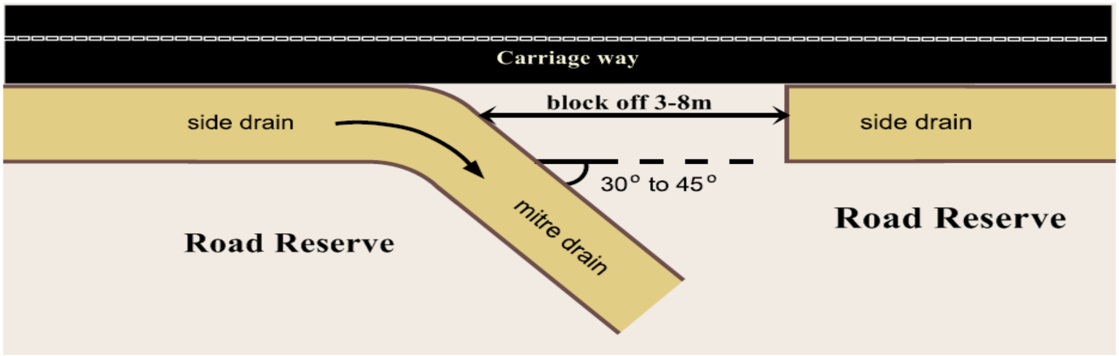


Sourcce (G.O.K Ministry of Roads technical manual)

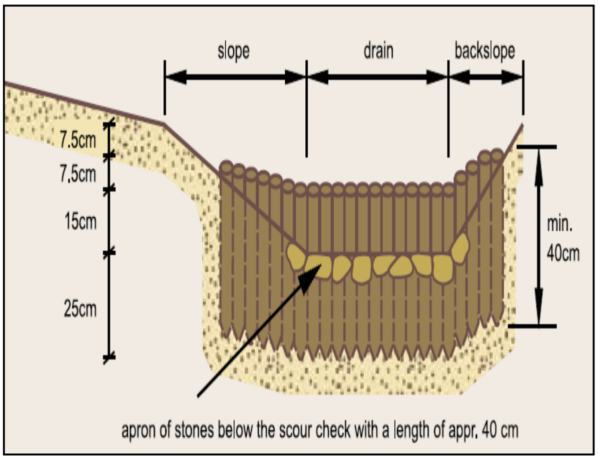
Cross section view of Culvert parts

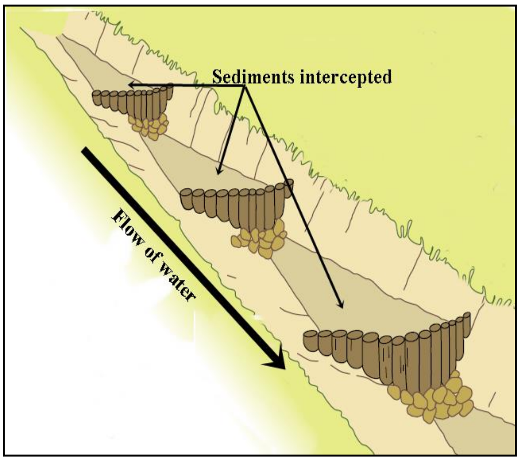


Air view of a Mitre drain and side-off drain



A cross-section and side view of Scour check installation and specification





Cross-section of catch drain location on hilly roads. Adopted from: ILO.org 2013 and Ministry of Roads Handbook.