ASSESSMENT OF CHANGES IN LAND USE AND LAND COVER AND SOIL EROSION RISK FACTORS IN KATHE-KAKAI CATCHMENT, MACHAKOS COUNTY, KENYA

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of Master of Science Degree in Land and Water Management in the Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi

DECLARATION

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

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To my family

“FOR THE GIFT OF EDUCATION”

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LIST OF ABBREVIATIONS

ASALS	Arid and Semi Arid Lands
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
EUROSEM	European Soil Erosion Model
GIS	Geographical Information Systems
GPS	Global positioning system
Ksat	Saturated hydraulic conductivity
MUSLE	Modified Universal Soil Loss Equation
NSCP	National Soil Conservation Project
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SLEMSA	Soil loss Estimation Model for Southern Africa
Tons/ha/yr	Tonnes per hectare per year
USDA	United Sates Department of Agriculture
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project

ABSTRACT

Soil erosion is still one of the most important land problem and most pronounced form of soil degradation in Kenya. Assessment of existing soil conservation measures and soil erosion rates, which would assist in the development of appropriate soil and water conservation measures, is of essence to channel available resources in erosion risk areas. Semi structured questionnaires were administrated to a randomly selected farmers in Kathe-kakai catchment to identify existing soil conservation measures and factors that affect their adoption. An assessment of soil erosion using a modified revised universal soil loss equation (RUSLE) was used to estimate soil erosion rates and in Kathe-kakai catchment in Machakos County. Analyzes on landuse and land cover changes using Landsat images for years 1988, 2002 and 2014 were also carried out. Supervised classification and change detection were done using ENVI 4.7 Software. Soil analyses were carried out to determine whether landuse changes have affected soil properties and if these changes may cause an increase in soil erosion.

The R factor (rainfall erosivity) was determined by interpolation of rainfall data from 8 stations in Machakos County. The K factor (soil erodibility) was estimated using a locally derived multiple regression equation. The LS factor (slope length and steepness) was calculated from digital elevation model. The C factor (Land cover factor) was determined using Landsat imagery for the area, P factor (conservation practices) was estimated from commonly used soil conservation measures. The R factor was estimated to be between 562 and 747 MJ mm/ha/yr while soil erodibility factor K was between 0.17 and 0.3. LS factor ranged from 0 to 413. A raster based geographic information system (GIS) was used to calculate soil loss and map hot spot areas. Estimates show erosion rates to be between 0 to 60 tons/ha/year, the highest amount recorded in areas with steep slopes and bare surfaces Approximately 54% of the area under study was within the tolerable soil erosion rate, which is taken to be 10 tons/ha/yr. Landuse and management systems were major factors associated with erosion.

Results showed that 64% farmers have adopted at least one of SWC measures with 35% not adopting any at all. Terracing (21%), mixed cropping (34%), use of grasses (16%), cutoff drains (16%) were the major measures used by farmers due to their effectiveness in controlling soil erosion. Both membership in farmers group ($p<0.01$) and Education and training on SWC ($p<0.05$) had a positive correlation with adoption of SWC measures. Farmers identified poverty, ignorance and lack of technical advice as the major constrains to taping the full potential of soil and water conservation in the area.

During 1988 and 2014 there was an increase in barelands (14.9%), cultivated lands (68%), and decreased in shrub lands (-15%), forests (-64%), and water bodies (-55%). Changes in forests and cultivated lands were significant at ($p<0.001$) over the years. Laboratory tests showed that soil properties were indeed affected by landuse. Barelands and shrub lands were characterized by high bulk density of 1.6 to 1.8 g/cm^2 and low hydraulic conductivity (0.4 – 1 cm/hr). Forests had moderate hydraulic conductivity 4cm/hr and a bulk density 1.3 g/cm^2 .These results highlight the need for proper soil and water conservation measures especially in those areas mapped as erosion hot spots.

Key words: Adoption, Soil and Water Conservation, Landuse planning, Community awareness, Change detection.

CHAPTER ONE

INTRODUCTION

1.1 Background

In Kenya arid and semiarid lands occupy approximately 80%, leaving only 20% of the country ecologically advantaged in terms of agricultural productivity. With increase in population, land has become limited forcing populations to migrate to marginal areas despite their limitations. As these marginal areas are fragile ecosystems, the exerted pressure due to increased populations and landuse and land cover changes has often resulted to severe degraded land, soil erosion and sedimentation of water bodies (Kithiia, 1997). Landuse has transformed land cover to farmlands, grazing lands, human settlement and urban centres. Maitimu *et al.* (2004) stated that concerns about changes in Landuse and land cover emerged due to realization that land surface processes impact ecosystems services. The primary concerns are the effects on soil degradation and ability of biological system to support human needs. Land lost due to degradation is compensated by farmers opening up more land (Kaihura and Stocking, 2003).

Thomas *et al.* (1997) identified soil erosion as one of the most important land problems and most pronounced form of soil degradation especially in Sub-Saharan Africa. Erosion is a natural geomorphic process occurring continually on the earth surface. However the acceleration of this process due to anthropogenic activities such as considerable immigration of people into marginal dry areas and the growing population has had severe impacts on soil and environmental quality (Pimentel, 2000). Lal, (1998) stated that in many regions, unchecked soil erosion and associated land degradation have made vast areas economically unproductive. It is estimated that worldwide about 80% of the current degradation on agricultural is caused by soil erosion (Angima *et al.,* 2003). In response to the devastating impacts of soil erosion, government and other non government organization have promoted practices to help farmers control soil erosion they include terracing, use of contours, trenches, agroforestry practices and planting of Napier grass. Adoption remains low despite the efforts hence the need to spatial show areas which are at risk of soil erosion and concentrate the scarce resources there.

Soil erosion is a complex process that is related to soil properties, topography, land cover, and human activities. In order to estimate soil erosion and optimize soil conservation management, many soil erosion models have been developed. Lal, (2001) ; Merritt *et al.* (2003) summarized major soil erosion models such as the Universal Soil Loss Equation (USLE) and the Watershed Erosion Prediction Project (WEPP), Revised USLE (RUSLE) and Modified USLE (MUSLE), as the most widely used empirical models because of their minimal data and computation requirements. USLE and RUSLE models estimate average annual gross erosion as a function of rainfall energy while in MUSLE, the rainfall energy factor is replaced with a runoff factor. Soil erosion is a hydrologic driven process and it depends on sediment being discharged with runoff (Kinnell, 2005), hence including runoff as an independent factor in modeling erosion, MUSLE has an improved accuracy of soil erosion prediction over USLE and RUSLE. Soil erosion and related degradation of land resources are spatio-temporal phenomenon in many countries (Fistikoglu and Harmancioglu, 2002; Hoyos, 2005; Pandey *et al.,* 2009). Often, a quantitative assessment is needed to infer the extent and magnitude of soil erosion problems so that effective management strategies can be used to solve the soil erosion problems. Complexity of the variables used in assessment of soil erosion makes precise estimation or prediction of erosion difficult.

Latest advances in spatial information technology have augmented the existing methods and has provided efficient methods of monitoring, analysis and management of earth resources. Jain *et al.*(2001); Srinivas *et al.* (2002); Kouli *et al.* (2009) have successfully used soil data, Digital elevation model (DEM) along with remote sensing data collected by Landsat images and GIS to enable rapid as well as detailed assessment of erosion risk.

This study focuses on soil erosion in kathe-kakai catchment, causes and consequences of landuse and land cover change in the area. Soil erosion is the most visible form of land degradation in the area. Sheet and rill erosion are evident throughout the catchment, and gulley erosion is widespread along river systems and water channels. Soil erosion is a threat to lands used for grazing and agriculture, water resources and road networks. Kathe-kakai catchment is located at the lower parts of Mua hills extending up the hills. These steep slopes are also contributing to erosion. A survey was also conducted to determine factors affecting soil and water conservation in the area.

1.2 Research problem

Soil erosion is still one of the most important land problems and it is linked to landuse and land cover changes. Soil erosion has negative effects on land resource, soil productivity and available agricultural land and water resources due to sedimentation. As population expands toward these marginal arid and semiarid lands there are a lot of landuse land cover changes. There is massive settling of people into kathe-kakai area due to its proximity to Nairobi and its accessibility due to good road networks, resulting to massive clearing of land for settlement and more demand for agricultural land. This has resulted to increased soil erosion which is evident throughout the catchment. Efforts by farmers and other organization bodies to control it are futile, but if the key erosion hotspots are identified and conserved the erosion levels will reduce. Most of the population depends on their small farms for sustenance and soil erosion is a threat to cultivatable land both where they are used for agriculture and grazing. There is need to address ways to prevent soil erosion in the area.

1.3 Justification

Land is a critical resource and the basis for survival for many rural populations. Over the years land is being degraded due to high population growth rate and overexploitation of natural resources. Land degradation, in the form of soil erosion is important as it threatens agronomic productivity, the environment, food security, quality and the well-being of many small scale farmers. Farmers in Kathe-kakai catchment continue to experience soil erosion despite effort to conserve soil. The damage to land has prompted the need for better understanding of the soil erosion process and to develop effective approaches to assess soil erosion and pinpoint key soil erosion risk areas for prioritization and effective soil and water conservation planning purposes to avoid blank recommendation. Remote sensing and GIS technology has proven to be of assistance in monitoring change in land resources and assessment of soil erosion at local scale. In developing countries assessment of erosion focuses mainly toward onsite effects of erosion. This affects crop yields, undermines the long term sustainability of farming systems and presents a threat to rural communities, whose livelihoods depend on farming. In developed countries concern is more on offsite effects which affects more people. Whether concern of soil and water conservation planning is toward prevention of on-site or off-site effects of erosion, there is a growing need for tools that enable definition of spatial distribution of soil erosion within a catchment and to locate sources of soil sediments and identify where to invest more SWC efforts, is more important than quantification of soil losses. The study will immensely help the land use planners and policy makers to identify and execute site specific best management practices to bring soil erosion rates within the permissible limits at national and local environment.

1.4 Research gap and challenges

Water related soil erosion is often related to important current issues like food security, decline in fertility, sedimentation of water sources and environmental management and sustainability. Seriousness of soil erosion has triggered several studies (Tiffen et al., 1994; Kithiia, 1997; Wambua and Kithiia, 2014). All of these studies point out ongoing soil erosion, increase in sediment load and show that increase in soil erosion will increase in the future if certain conservation measures are not carried out. These studies have associated increase in erosion with landuse and land cover change, inappropriate farming methods, overgrazing and other unsustainable systems. However prediction of soil loss and its distribution spatially remains a difficult research challenge. Models used to predict soil loss were developed to be used in the United States of America and other temperate countries i.e. RUSLE and USLE. Data used in these models are a major limitation in developing countries for statistical modeling of soil erosion risk. For instance long term rainfall data to estimate rainfall erosivity was a challenge. Stations around the study area have only recent records and those with long records there were many gaps. For soil erodability most of the patchy soil units were not captured as survey is done at a very small scale. In order to bridge this gap this study aims at integrating remote sensing and GIS in modified RUSLE model. The model will be fit to local condition to try and predict soil erosion losses spatially for conservation recommendation.

1.5 Overall objective

- Application of remote sensing and GIS in assessment of soil erosion as basis for resource management in Machakos County, Kenya.

1.6 Specific objective

- Document soil conservation measures currently used by farmers and factors that influence soil and water conservation adoption in Kathe-kakai, Machakos County.
- Determine changes Landuse and land cover and their effect on soil properties using remote sensing and GIS in Kathe-kakai, Machakos County.
- Estimate the average amount of soil loss rates within the area and identify soil erosion hotspots that require urgent remediation in Kathe-kakai, Machakos County.

1.7 Research questions

- Are there any observable indicators that erosion is taking place?

- What are the existing SWC measures? Do farmers have preferences for certain SWC types?
- What Landuse and cover changes have occurred between the years 1988 to 2014?
- What are the soil loss rates in the area?
- Are there erosion hotspots in the area? And if so, are they confined to certain soil type or land use types

1.8 Organization of the thesis

The presentation of this thesis is divided into six chapters. The first chapter presents the general background to the study concerning soil erosion and assessment of soil erosion. In this chapter, landuse and land cover changes are defined and its effect on soil. It also presents the research problem under investigation, objective and hypothesis. Chapter two gives the literature behind this study. Chapter three, four and five presents the abstracts, introductions, methodologies and results of analyses and interpretations of data for each of the individual objective. Chapter six gives the summary of the study finding and gives general conclusions, recommendation and further research need on the major findings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the main focus will be on landuse land cover change, soil erosion, soil erosion assessment using remote sensing and GIS and conservation practices in Machakos. Soil and water conservation is not new concept farmers have been using different practices to control erosion i.e. agronomic, cultural and structural (Tiffen *et al.*, 1994), despite efforts put in place, erosion continues in this area. There is need to determine the soil erosion rates in the area and pinpoint erosion key spots for conservation prioritization and delineation of these areas.

2.2 Soil erosion in ASALS

Accelerated soil erosion has been a serious environmental and economic problem, as it results to loss of millions of productive acres of land. Three-quarters of Kenya's land area is Arid and Semi Arid. Sun *et al*. (2005) reported that with increase in population and development, the expansion is toward these ASALS. Significant changes in land use and cover change has occurred placing a lot of pressure on these fragile environments. In order to feed the exploding population across the country there has been increase in areas under agriculture and decrease in natural vegetation such as forests, bush land grassland and wetlands. Githui *et al*. (2009) identified ASALS are fragile ecosystems and more vulnerable to erosion than other regions. Soil erosion in Kenya dates back to 1930s when it was realized that many areas were experiencing high rates of soil erosion, resulting to loss of potentially productive lands. Main factors contributing to this problem are poor methods of cultivation, livestock husbandry and lack of conservation (Tiffen *et al*., 1994). Erosion causes loss of productive topsoil, organic matter, nutrients and water storage capacity. Nandwa, (2001) documented that ASALs are characterized by relatively shallow soils and erratic rainfall making soil erosion and nutrient depletion the most pronounced processes causing soil degradation. The two processes can appear separately but often aggravate each other. Mwasi, (2001) found that about 50% of annual rainfall is usually lost from eroded slopes due to decreased infiltration and high surface runoff from the bare surfaces.

Machakos County is one of the most affected areas in Kenya by soil erosion. It is a fragile ecosystem, characterized by unfavorable climate, poor soils, hilly topography and a history of land degradation. Baaru, (2011) found that, due to its proximity to the capital city of Kenya, Nairobi, population has increased over the years resulting to massive land clearing to create more land for settlement and farming. These newly opened lands are on the hilly parts which are vulnerable to erosion due to topography. Livestock have also been squeezed to smaller and smaller land resulting to overgrazing resulting to barelands making these areas more prone to erosion (Gathaara *et al.,* 2010). Kithiia, (1997) observed an increase in sediment load and projected that soil erosion will further increase due to landuse changes.

2.3 Soil and water conservation

Soil conservation generally aims at minimizing the negative effects on soil presented by soil erosion. Gachene *et al*. (2004); Khisa *et al*. (2002) stated that soil erosion in Kenya was recognized as an environmental problem way back in the 1890s. This is when the first soil and water conservation techniques were introduced into the country (Tiffen *et al*., 1994). However, although some of the techniques developed during this period were effective, the fact that the practices were based on forced communal work, soil conservation practices were bitterly resented by the people. Little happened immediately after independence (1963) until in 1970, when the Kenya government initiated the National Soil and Water Conservation Campaigns under the National Soil Conservation Project (NSCP).

After independence the government with the support of Swedish government established National Soil Programmes (1974) in the ministry of agriculture to deal with the problem of soil erosion which included terracing, trenching, grass planting and construction of gabions. Machakos County was selected as the pilot, it was an appropriate choice since erosion was a serious problem in the area and farmers were concerned about the problem. Also suitable soil and water practice were already established in most parts. Machakos had strong and active self help groups, who were ready and willing to participate in conservation projects. In 1997, the Government of Kenya established Soil and Water Conservation Branch in the ministry of agriculture to strengthen its efforts in soil and water conservation. A new approach was initiated to concentrate resources and conservation efforts on a defined catchment area (Tiffen *et al*., 1994).

The catchment approach meant interactive extensionist participation coupled with intensified publicity, training, farm demonstration and tours. Since erosion has had the most damaging effect on cropped fields, focus on soil and water conservation has been on improving arable land. The main technique used was fanya juu terraces whereby soil is thrown up slope from a ditch to for a bund and with time the field develop step like form referred to as bench terraces. The objective of this practice was insitu rainfall conservation and keep soils in the field. In instances where farmers had surplus rainfall runoff a cutoff drain was cut to hold it. Farmers used the embankment to plant fodder grasses while the ditch was used to plant banana and trees among other plants that need more water. Terracing was not the only practice used. On sloping lands, terracing is used to reduce overland flow rates thereby contributing to water and nutrient conservation. Some of the common terracing technologies used by farmers were *fanya juu* and bench terraces.

Bench terraces are commonly made on steep slopes and they are labor intensive. For this reason, bench terraces are rarely excavated directly but instead they are developed over time from *fanya juu* terraces (Thomas, 1997). *Fanya juu* terraces are made by digging a drainage channel and throwing the soil upslope to make a ridge. Just like in the case of contours, grass and multipurpose trees can be planted on the ridges to help stabilize the ridges, prevent erosion and provide fodder and tree products (Thomas and Biamah, 1991). At a smaller scale farmers also use grass strips, contour ploughing, simple gulley control, tree planting, grazing control and protection of riverbanks. In recent years due to population pressure and unsustainable farming systems there has been intensive cultivation on steep slopes, production of annual production and reduction in vegetation cover. These activities have exposed fragile soil surface resulting to increased soil erosion. Farmers are reluctant from soil and water conservation as they consider them expensive and laborious. For those who have adopted the practices are poorly laid out or maintained (Gathaara *et al*., 2010).

Adoption of soil conservation technologies is affected by various factors. These factors are categorized as farm specific characteristics, technology specific attributes and farmers' socioeconomics characteristics. Olwande *et al*. (2009) identified following factors influencing conservation practice adoption farm size, farmer's age, education social networks (e.g. membership of association), dependency ratio, gender, access to agricultural advice and information, land tenure security, soil fertility, soil type, income, input availability, access to markets, technology awareness, farming experience adequacy of farm tools, technical and economic feasibility of using the technology, access to credit and presence of enabling policies Some of these factors increase adoption while others reduce adoption. Yrga, (2006) and Nakhumwa, (2004) showed that farmers in developing countries oppose to taking risks and they therefore tend to avoid some technologies especially if there is uncertainty in relation to cost.

2.4 Soil erosion assessment

Assessment of soil erosion is a complex process driven by both natural and anthropogenic forces. Soil erosion varies temporally and spatially, making its quantification a great challenge. Generally, soil erosion assessment is divided into three approaches. The first approach is field research, it is suitable for small-area studies only, while modeling has been used both in small and large-area studies. Surveying has normally been used in medium-scale projects using aerial photographs often in combination with the two other approaches (Stroosnijder, 2005). Assessment carried out using field research are highly time consuming and site specific, they are of three types rainfall simulator, sediment collection approach and erosion plots which is known as a standard method for on-site erosion research (Hudson, 1993). Despite the method shortcoming, field research is yet the only way to validate results from erosion surveys and erosion modeling.

Soil erosion surveying was the earliest attempts to assess erosion. It was carried out using aerial photographs to map the location and extent of gullies and rills (Nachtergaele and Poesen, 1999). To monitor the change in erosion patterns and the intensity of erosion, new aerial photographs were acquired at regular intervals and mapping of the rills and gullies repeated (Herweg,1996) It was then easy to identify and examine the changes in gully densities in relation to increasing population pressure and the changing farming patterns and techniques. This process is static and does not understand erosion process it only shows the manifestation of it. The factors, their interaction and relationship which result to these features are ignored hence it has no predictive power. Need for a dynamic method which addresses these shortcomings was needed (Lal, 2001). Williams and Morgan (1976) devised ways of depicting information on the distribution and type of erosion using erosivity, runoff, slope length, slope angle, slope curvature in plan and profile, relief, soil type and land use on a map introducing the use of model. Researchers are now able to these factors to modeling of erosion by isolating significant variables to derive models used to calculate soil losses.

2.5 Soil erosion modeling

Modeling soil erosion is a process of mathematically describing soil particle detachment, transport and deposition on land surface. Models simplify the processes and interaction with the aim of extracting, evaluating and simulating the relevant processes (Renschler *et al*., 1999). Environmental models deal with problems arising from the complexity of nature and limitations in measurements, understanding the processes and computation power (Beven, 2001). Many natural phenomenon acts at different spatial and temporal scale in different media and with complex interactions. Models are classified as empirical, mechanistic, static or dynamic.

Erosion modeling approach can evaluate soil erosion and sediment yield related to many conditions. Physically-based models require large data bases and still have limitations in predicting basin sediment yields (Renschler & Harbor, 2002). However, empirical models such as the Universal Soil Loss Equation present a simple structure, an easy application, and require relatively small data sets (Bartsch *et al*., 2002). It reasonably estimates soil erosion and sediment yield worldwide caused by interrill and rill erosion. Empirical models are efficient and effective for predicting the amount of erosion under alternative management strategies. It based on experimental data or observations, since it is designed to fit observed facts and lead to the prediction of events under certain prescribed circumstances. If the circumstances under which the data was gathered are known, the events under similar circumstances in the future can be predicted. With a large enough database, the model will serve reasonably well, under different conditions in different locations, provided appropriate precautions are taken.

These models have variables each represented by a quantified factor and are combined using a simple operator for example additive or multiplicative combination. Countries have predictive models which suit their local conditions and available database for example SLEMSA (Soil Loss Estimation Model for Southern Africa) cater for region around Zimbabwe and (EUROSEM) European Soil Erosion Model for European Community Regions (Elwell, 1978) and USLE for United States of America.

Soil erosion modeling was introduced using empirical universal soil loss equation (USLE) model. USLE was developed at the US Department of Agriculture (USDA) in 1965 then updated and republished in agriculture handbook No. 537 (Wischmeier and Smith, 1978). This model was developed to meet an increasing awareness of soil loss in the United States. RUSLE model particularly used in this study is an upgrade of USLE designed to predict average rates of soil erosion in an areas under different scenarios in term of management technique, cropping systems and erosion control measures.

2.6 Revised universal soil loss equation (RUSLE)

RUSLE is an erosion model, designed to predict longtime average annual soil loss carried by runoff from specific field slopes in specified cropping and management systems as well as from rangeland. RUSLE is an empirical based model, founded on USLE (Wischmeier and Smith, 1978) but is more diverse and includes database not available when USLE was developed (Renard *et al*., 1997). These improvements include new and revised is erodent maps, time varying approach to reflect freeze-thaw conditions and consolidation caused by extraction of moisture by growing crops for erodibility factor (K). A sub factor approach to evaluate cover management factor (C) for cropland, rangelands and disturbed areas. A new equation to reflect slope length and steepness (LS), the new terms also reflect the ratio for both cropland and interrill erosion. New conservation practice values (P) for both cropland and rangeland practices. These additions have improved USLE as they were integrated into RUSLE factors. The input data is divided into five different factors; rainfall erosivity, soil erodability, topography, crop management and conservation practice.

2.6.1 Rainfall erosivity factor (R)

Soil erosion by rainstorm is seen as one of the main problem especially in areas receiving variation in rainfall spatially and temporally (Arshad and Martin, 2002). The contribution of the erosive agent water is represented by intensity and the energy of the rainfall events. Soil erosivity is a term used to describe the potential for soil to be washed off by rainfall. This factor is the most important parameter especially for risk assessment of for soil erosion. RUSLE methodology requires long term data for proper estimation of rainfall erosivity which is a very onerous procedure as historical methods of collecting rainfall data resulted to lots of gaps. More readily available types of data on precipitation, such as mean monthly or annual rainfall also have been utilized. Mati *et al*. (2000) estimated rainfall erosivity using a regression analysis of annual rainfall spread in and around the Upper Ewaso Ngiro basin. The data was separated into two groups as per the agro-climatic zone location of each station, in order to get better correlation coefficients. Lo *et al*. (1985) found a correlation between mean annual precipitation and the long-term average of annual rainfall erosivity (R).

2.6.2 Soil erodibility factor (K)

The soil erodibility factor can be described as the soils tendency to erode. It is dependent on physical and chemical soil properties and can be determined in various ways methods like sample analysis of the soil, from a soil map or pedological survey of the site or through a combination of these (Jebari, 2009; Fistikoglu and Harmancioglu, 2002). Soil erodability is related to physical and chemical properties of a specific soil type. Two energy sources are considered to erode soils, the surface impact of the rain droplets and the shearing stress of the horizontal runoff (FAO, 1996). Wischmeier and Smith (1978) found that the main attributes of the soil determining the K-values were organic matter content, texture, surface horizon structure and the permeability. Gachene (1982) found that the relative erodibility of 14 Kenyan soils under artificial rainfall conditions were influenced by dispersion ratio, per cent clay, per cent organic matter and bulk density.

2.6.3 Topographical factor (LS)

Soil erosion vary with landforms for instance sheet and rain splash occur on uncultivated slopes, sheet and rill are common in cultivated and undulating and rolling plains while mass movement and gully erosion are severe on overgrazed slopes. The *LS*-factor accounts for the effect of slope length and slope gradient on erosion Angima *et al*., (2003). Lal, (1985) observed that soil loss increases more rapidly with slope steepness than it does with slope length making slope steepness more important than slope length. Slope steepness and length are combined into a single factor in RUSLE. These two factors affect the total sediment yield from a site. This factor can be determined in different ways; different empirical relations are used to determine it. The combined LS factor can be computed using DEM. The computation requires factors such as flow accumulation and direction using arc hydro extensions (Wischmeier and smith, 1978; Jebari, 2009; Onyando *et al*., 2004)

2.6.4 Crop management C and Conservation Practice P Factors

The C factor describes the relationship between erosion on bare soil and erosion on cropped conditions. Values of C can vary from near zero for well-protected soils to 1.5 for finely tilled, ridged surfaces that are highly susceptible to rill erosion. RUSLE software provides extensive crop database values, including some tropical crops, which are used to evaluate the C-factor, especially when plant growth characteristics are known, or the user may develop a more appropriate database from experimental data (Renard *et al*., 1997). The P-factor is the ratio of soil loss with specific support practice to the corresponding loss with up and down-slope tillage. These practices proportionally affect erosion by modifying the flow pattern, gradient, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983). Values for P-factor range from about 0.2 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices (Wischmeier and Smith, 1978). On croplands, support practices include contouring, tillage and planting on or near the contour, strip cropping, terracing, and subsurface drainage and their values can be calculated in conjunction with the R, K, and LS-factors to reflect their effect on reducing runoff (Renard *et al*., 1997).

2.7 Geographic information systems and soil erosion modeling

In many regions soil erosion has rendered vast areas economically unproductive hence termed as waste lands. Quantitative assessment is often needed to get the extent and magnitude of soil erosion problems. The complexity of variables used to estimate erosion makes this difficult. Kouli *et al*. (2009) stated that the latest advance made in spatial information technology has improved existing methods, making them effective in detecting, assessing, mapping, and monitoring the land. Spatial information technology have large area coverage with varying temporal, spatial and spectral resolutions making it possible to monitor temporal and spatial land degradation patterns (Vrieling, 2007). Since the launch of ERTS-1 (Landsat 1) in 1972, digital remote sensing has been used with some success to monitor natural resources and provide input to better manage the Earth.

Chafer, (2008); Geerken and Ilawi, (2004); Mathieu *et al*. (2007) have carried out studies using different methods of remote sensing and geographic information system (GIS) to determine land degradation risk at various levels including modeling of soil loss. GIS when combined with RUSLE provides a relatively fast analysis of sheet and rill erosion potential. It allows large scale simulation studies using large amount of data within a short time and with minimal cost (Sanchez *et al*., 2009). This is because GIS acquires spatial function that performs geo-referencing and spatial overlays (Blaszezynski, 2001). GIS also simulate scenarios under different landuse and management as it allows assessment of different management systems and their effects on soil erosion (Biro *et al*., 2013). Remote Sensing can facilitate studying of factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics.

Spanner *et al*. (1982) first demonstrated the potential of GIS and Remote Sensing (RS) in geospatial data analysis for erosional soil loss assessment using USLE. Bartsch *et al*. (2002) used GIS techniques in getting RUSLE factors for determination of soil erosion risk at Camp Williams. Considering the limitations of previous studies Wilson and Lorang, (2000) studied the GIS applications for soil erosion estimation and proved that GIS provides the extraordinary ability to improve soil erosion estimation. Wang *et al*. (2003) have attempted using the geocentric data, Landsat images (TM) and DEM for soil erosion prediction by geo statistical methods. These researchers showed that these methods give significantly better results than traditional methods. Arekhi and Niazi (2010) used the RUSLE model, RS techniques and GIS for soil erosion estimation and sediment yield of Ilam dam. The output is a single layer showing the average annual soil loss per hectare. The extent and geographical distribution of eroded lands can be used as an input for future planning of reclamation conservation programs. Mandal *et al.* (2006) argued that the criterion for judging whether a given soil has potential risk of erosion or not is essentially required for adopting appropriate erosion control measures on agricultural and other landuse systems.

2.8 Land use land cover change and effect on soil

Ellis (2007) stated that landuse and land cover change (LULCC) is a general term for the human modification of earth's terrestrial surface. Land-use refers to the social and economic purposes for which land (or water) is managed, such as grazing, timber extraction, conservation, irrigation, and farming while land cover refers to the biophysical state of the earth’s surface and immediate subsurface for example biota, surface water, ground water, soil, topography, and human structures (Prakasam, 2010).

In studies done in different parts of the world, soil erosion has been linked to landuse and land cover changes due to human activities. Wijitkosum (2012) carried out a study in Thailand where he observed that soil erosion increased when forests were converted to agriculture land and erosion reduced when cropland was converted to forest. This results show that land use has the potential to reduce soil erosion through cover which reduce impact of raindrop and slow the speed increasing infiltration. LULCC in Kenya has been associated with increased demand for land resource for development and agricultural activities, infrastructure improvement, population increase and land subdivision. Syombua (2013) found that there has been an increase in rainfed and irrigated agriculture and decrease in natural vegetation. Baaru (2011) carried out a study in kathe-kakai, Machakos County between the year 1988 to 2009 landuse and land cover changes were found to be influenced by human population increase, infrastructure and proximity to Nairobi city and Machakos town.

Inappropriate land use practices such as deforestation, overgrazing, intensive cropping, mining and constructions projects aggravate the soil loss (Liang *et al*., 2003). Soil erosion is a process influenced by soil type, topography, climate and landuse. Zhou *et al*. (2008) associated soil erosion risk areas with areas having minimal vegetation cover (Lal, 1990). Teh (2011) carried out a study in Malaysia whereby he found that, rate of soil erosion increased from 0.24t/ha/yr to 4.9t/ha/yr when landuse changed from natural forest to manure coffee. Then to 7.32 t/ha/yr in area used for cultivated vegetation crops. High soil erosion rates tend to occur more when soil is exposed. Zhou *et al*. (2008) stated that increasing cover especially vegetation greatly reduces erosion by water. Biro *et al*. (2013) found that various soil properties change with changes in landuse and land cover. The change occurs in both physical and chemical properties of the soil attributed to the changes in the LULC. These changes deteriorate soils and subsequent increase soil degradation.

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CHAPTER THREE

SOIL EROSION AND ANALYSIS OF FARMERS CHARACTERISTICS IN RELATION TO SOIL AND WATER CONSERVATION IN KATHE-KAKAI CATCHMENT, MACHAKOS COUNTY, KENYA.

3.1 Abstract

Water related soil erosion is one of the major causes of land degradation in Kenya. Many SWC technologies have been promoted and disseminated to drive sustainable use of resources by small scale farmers, however land degradation continues intensely. The study set out to identify existing soil conservation measures, factors that affect the adoption of SWC measures, assess the constraints to implementation and maintenance of these conservation practices and identify challenges and opportunities in soil and water conservation in the study area. To also identify household characteristics that affects the adoption of soil and water conservation. The study was conducted in three sub locations Kimua, Makyao and Kathe-kakai. A hundred farmers were randomly selected. Results showed that education level, land tenure, size of farm did not influence use of SWC measures. Membership in farmers group was significant at ($p<0.01$) and had a positive correlation with soil and water conservation measures. Education and training on soil and water conservation were significant ($p<0.05$) and did positively influence the use of SWC measures. Farmer's formal education was negatively correlated with being a member in farmers groups ($p<0.01$). Formal education was reduces links, shared values and understandings in society that enable individuals and groups to trust each other and so work together. The research found that SWC structures commonly used by farmers include terracing (30%), contour ploughing (20%) and use of cutoff drains. Agronomic practices commonly used are Agroforestry, crop rotations and use of grasses strips. Farmers identified poverty, ignorance and lack of technical advice as the major constrains to taping the full potential of soil and water conservation in the area. Poorly laid out soil conservation structures were also accelerating soil erosion. The findings show that there is need for farmers to form groups to benefit from training and credit facilities.

Key Words: Soil erosion, Soil and Water Conservation.

3.2 Introduction

About 40% of the world's agricultural land is seriously degraded, where 80% of this degradation is caused by soil erosion particularly in developing countries (Nanpham *et al*., 2001). Soil erosion is second only to population growth as the biggest environmental problem the world is facing. Pimentel, (2006) documented that around 60% of eroded soil ends up in rivers, streams and lakes, making waterways more prone to flooding and to contamination from fertilizers and pesticides. Erosion also reduces the ability of the soil to store water and support plant growth, thereby reducing its ability to support biodiversity (Jaetzold *et al*., 2007).

Machakos County is known as a fragile ecosystem with high rates of soil erosion which are reducing land productivity (Tiffen *et al*., 1997). In response small scale farmers seek to increase area under production through expansion of cultivated lands to areas previously covered with vegetation (Nkonya, 2002). This expansion has led farmers to cultivate steep slopes and riverbanks. The study area is characterized by steep slopes, bare grounds, overgrazing, low adoption of SWC measures with are further exacerbating soil erosion problem. Moreover these areas are planted with annual crops that require clean tillage practices and with no fallow periods, these soils are further exposing them to erosion and nutrient mining and loss.

Increase in tree cutting for fuel and timber has also contributed in land cover change in the area. Moreover unsustainable sand harvesting carried out along watercourses where sand is extracted along water courses has also resulted to increase in land degradation. As demand for sand grew especially in areas around Nairobi, there has been increased sand mining in these areas resulting to massive land destruction (Mwaura, 2013). The impacts are quite vivid on the extraction sites where river banks have been altered. These unreclaimed excavated areas are major sources of siltation of watercourses and they become prone to erosion. In response many soil conservation technologies have been promoted and disseminated in the area to spur agricultural productivity and the sustainable use of land resources by small scale farmers. Despite availability of various technologies, adoption rates have remained low and land degradation continues unchecked (Wauters *et al.*, 2010). Government with assistance from donors promoted measures like terraces and cutoff drains among small scale farmers to reduce soil erosion but these soil conservation structures have been neglected and are causing more soil erosion (Gachene, 1999).

With this history in mind land degradation has really affected the area resulting to loss of large acreage of land and poor yields. This paper discusses the findings of a baseline study in

Kathe-kakai catchment area in Machakos County. It discusses farmer's characteristics and how they influence use of soil and water conservation, types of soil and water conservation measures that have been put in place by farmers in attempt to curb the situation, constrains and challenges they face and incentives to be put in place to encourage use of SWC practices.

3.3 Materials and methods

3.3.1 Study area

The study was carried out in Kathe-kakai catchment, Machakos County, Kenya as shown in Figure 3.1.

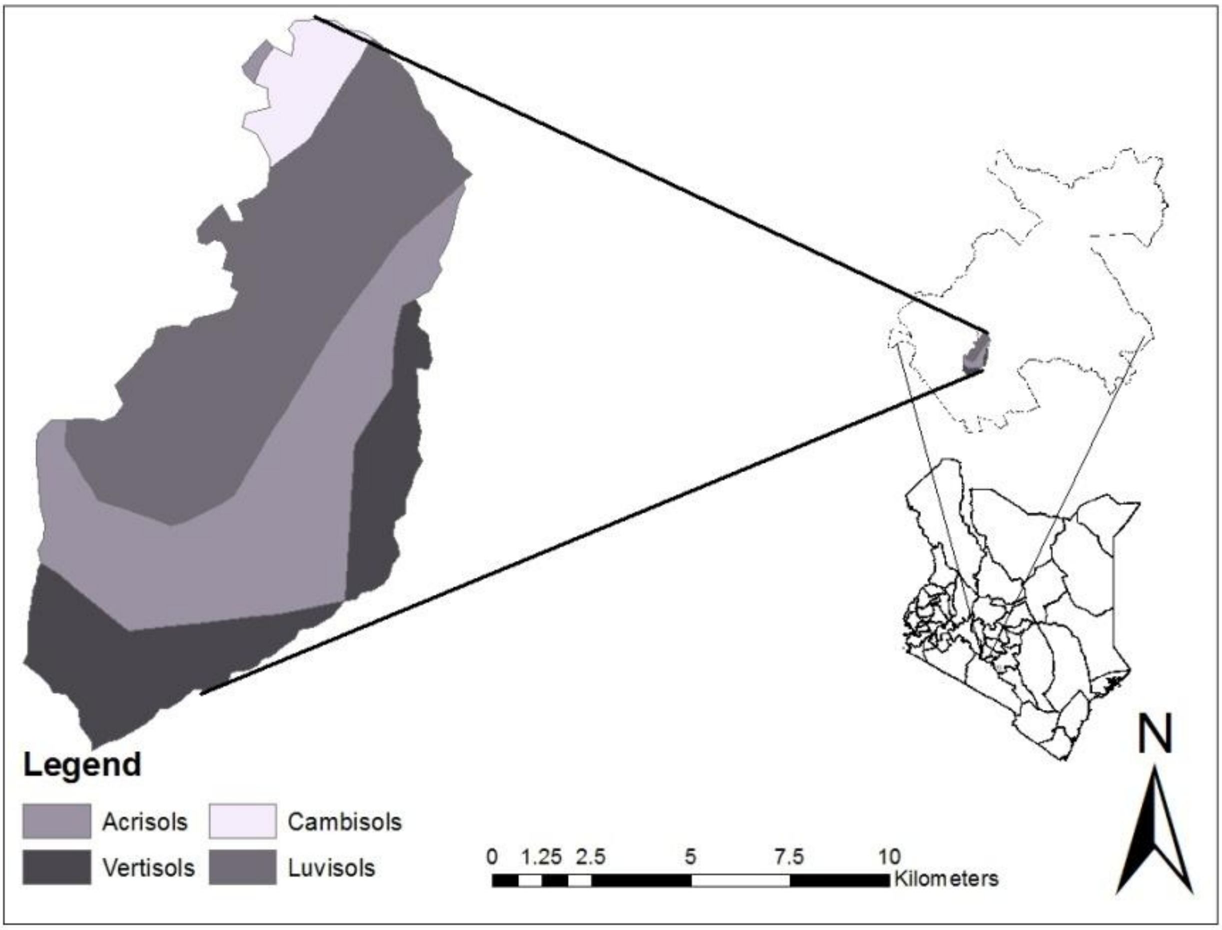

Figure 3.1 Kenya map showing the study area

The study area covers approximately 8800hectares. It lies between 1^0 30'S and 37^0 15'E and maximum and minimum elevation are 1500 and 2100m above sea level. The area lies at the end of agro-climatic zone V and VI (semi-arid to arid) in Kenya (Kassam *et al*., 1991). The area experiences irregular bimodal (short rains from April and long rains occurring from November) type of rainfall with an annual mean of about 700 mm. The area is naturally hilly;

the predominant soils are Luvisols with patches of Vertisols, Acrisols and Cambisol. Agriculture is the main occupation with majority of the population. Some parts still have natural forest though the area is being opened up for agriculture and settlement. From field observation bare and cultivated lands are the vulnerable to soil erosion. With expansion of agricultural area and the invasion of forest soil erosion is becoming more pronounced.

The topography of the area is sloppy and during the periods of too much rainfall, the floods carry away most of the soils to the valley bottoms, leaving the sloppy areas bare resulting in severe inter-rill, rill and gully erosion (Mutuoki *et al*., 2008).

3.3.2 Research methodology

Two locations were selected as sample areas for this study, namely Mutituni and Mumbuni location in Machakos Central. A random sampling procedure was used to select a target sample of 100 farmers from a compiled village sampling frame. Both primary and secondary data were collected for this study. Primary data was collected using a pre tested semi-structured questionnaires to gather information on household demographic characteristics, soil and water conservation. Institutional questionnaire was administered to extension officers in the area to get in-depth information regarding SWC technologies. The extension officer from the Ministry of Agriculture assisted in site selection and provision of secondary information and guidance during the site visits.

Prior to the field study a transect walk was carried out to understand the area in terms of topography, population size and composition and farming systems, landuse, soils and vegetation. Reconnaissance surveys focused on characterization of the sites by collecting biophysical and social data relevant for the assessment of soil erosion patterns in the study area and data collected recorded. Transect walks were held in each sub location, guided by the respective key informants, who were asked to give their opinions regarding soil erosion issues and land-management diversity in the area. The checklists of issues that guided the discussions were causes and factors contributing to soil erosion, SWC measures in the area by types and stabilizing materials. A literature search was undertaken from both published and unpublished materials on the study area, SWC technologies and adoption studies in general. Data entry and cleaning was done in MS Excel. Correlation and descriptive statistics such as averages, minimum, maximum, standard deviations, frequencies and percentages was analyzed using Statistical Package for Social Sciences (SPSS Ver. 20).

3.4 Results and discussions

3.4.1 Soil erosion in the area

Results showed that sixty five percent (65%) of respondent farmers experience erosion, of this thirty five percent (35%) experience serious erosion while the rest consider erosion as moderate. Common indicators of erosion are surface water flow and rock outcrops on the surface especially uphill and sedimentation on the lower farms. Most of the farmers reported that they observe erosion damage during the first rains when the land is bare. Kinyua *et al*. (2010) found that bare surfaces cause heavy runoff due to smooth sealed surface crust which hinder infiltration during rain storm and cause shallow lateral flow. Beukes and cowling, (2003) also in their work observed that once the ground becomes bare there is compaction restricting water infiltration.

Rill erosion (40%) is the most common form of soil erosion along farm boundaries and waterways used to get rid of excess water, followed by gulley and sheet erosion. riverbank erosion and splash erosion were not common among the farmers (Table 3.1). According to farmers, surface water runoff on bare surfaces forming rills with time they widen and deepen to form gullies.

Table 3.1 Types of soil erosion in the study area

Types of soil erosion	%
Rill erosion	49
Gulley erosion	26
Sheet erosion	14
River bank erosion	4
Splash erosion	3
Others	4

Farmers identified several causes of soil erosion in the area, heavy erratic rains on bare grounds, steep slopes, poor and lack of soil and water conservation measures were ranked highest (Table 3.2). Reduction in forest cover and expansion of farming upslope in previously forested area were identified as the landuses resulting to increase in erosion (Chapter 5)

Gathaara, (2010) observed that cultivated land were prone to sheet and rill erosion due to poor or land of conservation measures.

Table 3.2 Causes of soil erosion

Causes of soil erosion	**%**
Steep slope	30
Lack of cover	22
Poor constructed structures	20
Lack of SWC measures	20
Heavy rains	8

Farmer's observation is in agreement with farmers in central Kenya who associated soil erosion problem on their land with high rainfall, steep erosion and lack of vegetation (Okoba and De Graaff, 2005). Mushir and Kedru, (2012) reported the same finding whereby highest soil loss of 114.59 tons/ha/yr was recorded on steep slopes. Gullies developing from conversion of hillside areas into farmland were identified as the most destructive form of soil erosion. It has displaced huge masses of soil becoming a potent hazard to cropland and habitats.

Table 3.3 Indicators of soil erosion in farms

Indicators of erosion	**%**
Surface water flow	31
Sedimentation	16
roots outcrops	16
Surface crusting	15
Siltation	13
Rocky outcrops	9

Moreover gullies have also developed due unsustainable sand mining especially along water drainage courses further causing soil erosion of river banks and destroying infrastructure. According to farmers interviewed, gullies started developing after the area was subdivided to farmers in the 1990s. The process was aggravated by the heavy rain "El nino" rains which occurred in 1998. Gabions were put in place to reduce sediment transport, decrease water velocity so far these gabions have been destroyed, filled up with sediments. Infrastructure i.e. rural road are further accelerating gulley formation. Defectively designed road culverts and pavement gutters were observed to cause massive erosion in nearby lands as runoff water from these roads are being diverted to nearby lands (Salleh and Mousazadeh, 2011). Other areas identified as erosion hotspots in the area are coffee plantation owned by farmers Sacco which are no longer functional. These areas have been termed as common lands used as public grazing fields resulting to over grazing. These areas are devoid of vegetation especially during the dry seasons, when the erratic rains occur these areas are vulnerable to soil erosion as these soils are very compact from continuous animal tramping. Analysis of these soils showed low saturated hydraulic conductivity (Chapter four) resulting to formation of big and active gullies due to high runoff during the rainy season (Tarekegn, 2012). The restricted water movement probably was due to the high bulk density impeding water infiltration. The low Ksat values could also be influenced by the soil particle size as observed the soils had high levels of clay (40%) (Chapter 4) this are fine grains hence restricted water movement (Karuku *et al*., 2012).

3.4.2 Knowledge and use of soil conservation measures

The results showed that at least sixty five percent of farmers interviewed have adopted at least one of SWC measures with thirty five percent not adopting any at all. Figure 3.2 shows the common soil and water conservation measures among farmers in the study area. Fanya juu terraces ranked the highest with twenty one percent, especially among farmers farming on the upper sides of the catchment. Agronomic practices i.e. Agroforestry (16%), mixed cropping (18%), use of grasses (16%) were also common among farmers. Finally cutoff drains sixteen percent were the main measures used by farmers due to their effectiveness in conserving water in farms and controlling soil erosion.

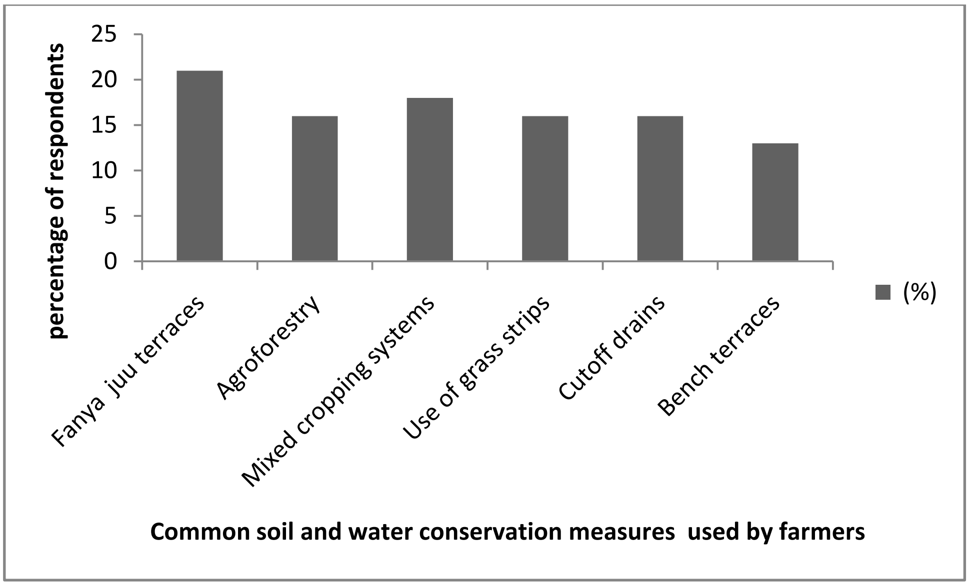

Figure 3.2 Common SWC measures in Kathe-kakai

Common soil and water conservation structures were fanya juu terraces and cutoff drains especially on the sloppy farms as they not only reduce the speed of runoff down the slope but also retain moisture. The ditch hold water and allow it to infiltrate slowly into the ground reducing runoff and with time the structure will form permanent bench- like terrace (Dorren and Rey, 2004). Also farmers utilize the embankment by planting cover crops which not only provide food and pasture but also hold the soil reducing the maintenance cost and also land is not lost. Commonly terrace ditch is utilized by planting fruits trees as there is plenty of water. Terrace embankment is usually covered with either grass used as pasture and cover crops (Botha *et al.*, 2005;Posthumus and De Graaf, 2005; Alemayehu et al., 2011).

Agroforestry is slowly being adopted by farmers. Farmers have integrated trees in their farms as their deep roots hold the soil firmly and also act as wind breakers. Leguminous trees also replenish nutrient as these trees are major sources of nutrients for instance *Leuceana leucocephala, Tamarindus indica* and *Sienna* species were very common among farmers. In work done in the area by Nthenge, (2011), farmers have realized the benefit of trees in their farming systems, which included increase fertility and also protection of soils against soil erosion.

Farmers have also employed certain efforts to control gulley erosion they are planting grasses and sisal plant along gully channels to trap most of the incoming sediment from upstream. Though the process is slow there has been success in certain cases. Extension officers have tried to encourage farmers to use crop residues and other farm materials as mulch or as manure. There have been setbacks due to the completing uses of farm residues, farmers prefer using the material as feed for their animals. These organic materials improve both the physical and chemical properties of the soil. Tilahun, (1996) observed these materials not only do they provide organic matter to the material but also conserve the soil when bare and vulnerable to erosion.

3.4.3 Factors influencing the adoption of soil and water conservation

Table 3.4 shows that the average age of household head is between twenty and forty years followed by age forty to sixty. This indicates that majority of the household heads are in the economically active age group. In this study age was positively correlated to use of soil and water conservation though not significant.

Table 3.4 Age of farmers

Age of farmers	%
20-40	42
40-60	32
60-80	19
above 80	6

Older farmers are likely to engage in soil and water conservation since they have more farming experience than younger farmers. (Table 3.5) shows that fifty two percent of the respondents had farming experience of less than twenty years while thirty five percent had experience of more than twenty years. Alufah *et al.* (2012) study agree with this finding as they found that increasing the age of farmers increases the odd of adopting SWC measure by about 1.36 times.

Table 3.5 Years of farming

Years of farming	**% of respondents**
0 – 10	25
10-20	32
20-30	22
30-40	12
40-50	7
50-60	3
60-70	1

Formal education is an essential indicator for literacy levels, Results show that (Table 3.6), sixty five percent of the respondents have attended primary education while twenty seven percent having attended secondary education hence most of the farmers are able to read and write. Doss and Morris, (2001); Sidibe, (2005) argue that farmers who have education and can read and understand are able to comprehend information about available technology and make choices than those who have no education. This was not the case in this specific study as education did not have any significance in relation to SWC use (Table 3.12).

Table 3.6 Formal education level of farmers

Education level	% of respondents
Primary	65
Secondary	27
Tertiary	5
Non	3

The probable reason being that awareness and use of some measures i.e. fanya juu terraces is since 1960s. As shown in Table 3.12, there was a negative correlation between level of formal education and membership in farmer groups. Educated farmers find joining groups unattractive since they are mostly busy with other non-farming activities and they may be financial stable so they do not require assistance in terms of credit.

Most of the farmers in the area are small scale farmers. Table 3.7 showed that more than eighty percent of the farmer's farm sizes are between one to five hectares. From the results farm size did not influence use of SWC measures (Table 3.12). Donkoh and Awuni, (2011); Mbaga-Semgalawe and Folmer, (2000) results differ; they argued that adoption of SWC technologies increased with increase in acreage of land. Their results showed that farmers with larger farm size were likely to use SWC than small scale farmers. This is because such measures are associated with using up more land. In this case farmers utilize the areas used up by the structures to grow crops.

Table 3.7 Farmers farm size

Farm size(Hectares)	% of respondents
1 – 5	83
5 – 10	8
10 – 15	5
15 – 20	4

Field observation showed that farmers utilize ditches where potholing, terraces and cutoff drains have been laid out to grow cereals and fruit trees which not only provide food and income but also control wind and water erosion. Terrace embankments are used to grow cover crops like pumpkins, bean, peas and grasses. These plants hold the soil together and are also used as food and as pasture. Farmers being able to utilize these areas taken up by these structures may be the reason for small scale farmers adopting SWC (Mwakubo *et al*., 2006). About eighty percent of the farmers did not have title deeds (Table 3.8). Sixty eight percent of farmers have inherited their farms while twenty one percent bought land in the area and remaining ten percent are on community lands. Most of the land is held by owners under customary land rights. Some acquired their lands through inheritance, allocation by government or purchase from those with customary land rights.

Table 3. 8 Tenure security of farmers

Title deed	% of respondents
No	80
Yes	20

Table 3.9 Form of land acquisition

Form of land acquisition	% of respondents
Family land/inheritance	68
Private land/brought	21
Community lands	10
Others	1

The study found that land tenure did not have an influence on use of SWC practices (Table 3.12). Farmers are secure under current tenure system; this is contrary to most studies as they regard tenure insecurity as a constraint in SWC adoption (AgREN, 2000). Studies in the Philippines and in the Ethiopian Highlands have shown that security of ownership was not always a necessary condition for the adoption of SWC measures—factors like inheritance, rental contracts were enough to encourage investment in soil conservation (Kidanu, 2004). As expected there was a positive correlation between being in groups and SWC use by farmers ($p<0.01$). Farmers consider most of the soil conservation structures as laborious and time consuming. Farmers who are in groups tend to work together to construct these structures for both soil conservation and water harvesting purposes reducing time spend and also saving on cost (Alufah *et al*., 2012). Farmers also share information with each in this groups hence have access to free and important information. Financial assistant in terms of credit to peasant farmers is of great emphasis. Results indicate that fifty six percent of farmers acquire credit to access assistance to pay labor and acquire materials needed in SWC from these groups and with this credits farmers have access to inputs and tools (Abdul-Hanan *et al*., 2014).

The study showed that 33% of farmers had received some form of extension training in soil and water conservation while 67% have not received any extension training or education (Table 3.10). Sources of information were from fellow farmers in local farmer groups (60%), ministry of agriculture (15%) and other sources including media, organizations and researchers (25%) as shown on Table 3.11.

Table 3.10 Extension training and education on SWC

Extension training and education on SWC measures	% of respondents
Yes	33
No	67

Education and training influenced use of SWC positively as it assists in creating awareness among farmers in soil and water conservation among other areas. Farmers may be aware of available techniques but there are other areas where education and extension services are needed to enhance their practical skills.

Table 3.11 Sources of extension training and education on SWC measures

Sources of extension training and education	% of respondents
Fellow farmers	60
Ministry of agriculture	15
Other sources	25

Having education and training on SWC was found to correlate with association in farmer groups. Farmers in groups are aware of erosion and how to control it, as lack of awareness was identified as a major caused the low rates of SWC measures use in this area there is urgent need to improve extension services and motivate farmers to interact more. Association in farmers groups is a key factor to farmers using SWC measures. Being members to these groups enable farmers to get relevant information regarding proper agronomic practices, access to credit, attend seminars and workshops and also receive inputs. Self help groups and women group are very important in the area if we are to achieve social capital and ensure dissemination and adoption of innovative technologies (Coleman, 1998).

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Table 3.12 Correlation matrix of variables

Variables	Age	Years of farming	Education	Association	Farm size	Land tenure	SWC use	Extension training on SWC
Age	1							
Years of farming	.769**	1						
Education	-0.19	-.244*	1					
Association	0.073	0.149	-.284**	1				
Farm size	.382**	.300**	0.021	0.09	1			
Land tenure	-0.05	-0.078	0.144	0.114	-0.08	1		
SWC use	0.036	0.226	0.012	0.570*	0.05	0.013	1	
Extension training on SWC	-0.05	0.026	-0.044	.273*	0.03	0.114	0.643*	1

**. Correlation is significant at the 0.01 level (2-tailed). N= 100
*. Correlation is significant at the 0.05 level (2-tailed).

3.4.4 Insitu rainwater harvesting

Table 3.13 below indicated that 64% of respondent farmers are carrying out rainwater harvesting and the rest 35% did not use any water harvesting techniques.

Table 3.13 Rainwater harvesting

Rainwater harvesting	%
Yes	64
No	35

80% of farmers harvesting rain water use insitu water harvesting using soil and water conservation measures.

Table 3.14 Insitu rainwater harvesting

Insitu rainwater harvesting	%
Yes	80
No	20

The most common combination of SWC measures used by farmers is use of grasses, Agroforestry and fanya juu terraces and conservation tillage by fifty two percentages (52%). The least used techniques are semicircular bunds, trash lines and stone terraces. Extension officers when interviewed stated that among the most soil and water conservation techniques, rainwater harvesting is massively promoted by NGOs, national agricultural extension services and government agencies in the area. Water supply and its availability in this area are dependent on season with big variations between wet and dry season. Severe drought incidences are usually reported in these dry seasons as very few farmers have piped water, meaning water availability at homestead level is rare. Stroosnijder, (2003); Pandey et al. (2003) have documented the support that rainwater harvesting have received in Africa and India and since most rural areas population depend on rainfed agriculture, 65 % as documented by (World Bank, 2000) and due to the effects of climate change in African drylands, rainfall tends to vary. Rainwater harvesting offer an opportunity in these semiarid regions to make them more productive and resilient toward these changes in climate (Lal, 2001). In kathe-kakai there are seasonal rivers and a hilly terrain resulting to massive runoff flowing from uphill to farms downstream. This water flow at a very high speed due to bare ground especially before planting season and poor farming practices like cultivating on steep slopes without contour ploughing, deforestation of steep slopes and lack or poor soil and water conservation measures. Few farmers (20%) have tanks or other structures to water harvesting. Farmers use these structures to store water for drinking and other domestic uses but the adoption rate is slow as farmers lack capital to procure them. Woyessa et al. 2005 and Aberra, (2004) found the same challenge whereby there is low rates of adoption or failed adoption as farmers as farmers do not participate. Farmers use a variety of traditional and innovative insitu RWH practices such as conservation tillage, 90% of farmers interviewed use animal drawn implement to work their farm. This practice conserve moisture as there is minimal turning of soil. Contour ridges, fanya juu terraces and cut off drains were common among farmers in the area as water collect behind the structure increasing moisture content. Farmers observed that crops did better in terraced farms than in non terraced ones. Since farmers are faced with unreliable rainfall distribution, lack of soil moisture and declining soil fertility resulting to reduced yields and persistent crop failure (Miriti, 2011 and Gitao, 2004). Insitu rainwater harvesting techniques provide a solution to this situation as they have been found very effective in increasing infiltration and moisture retention in the soil (Fox and Rockstrom, 2003). Gicheru, (1990) monitored the effects of conventional tillage, tied ridging and crop residue mulching on moisture conservation in Laikipia under rainfall conditions. The results showed that mulching did conserve moisture and improved crop performance. The major challenge is coarse textured sandy soil had rapid water movement due a high hydraulic conductivity of 10cm/hr. Water is loss from dams and ponds through seepage and evaporation. Relevant agencies in these areas should provide support to farmers by providing materials like lining tanks with plastic papers and cementing, as these extra costs do discourage farmers from adopting these technologies.

3.5 Conclusions and recommendations

This study shows that farmers are aware of soils erosion and the negative effects caused due to factors they cannot effectively control. Kathe-kakai catchment experiences severe rates of soil degradation inform of soil erosion. Contours, fanya juu terracing and strips cropping are the most commonly used conservation practices while Agroforestry and mixed cropping are slowing being adopted by farmers. Intensity of SWC measures adoption is reasonably low; farmers using the soil and water conservation measures are on small scales. Of the factors analyzed extension training on soil and water conservation and membership of farmers in organization or groups had significant effects on adoption of soil and water conservation. These two factors had a positive influence (significant at $P<0.01$) on adoption on SWC practices. Education and training in SWC and membership in farm groups is one way to achieve adoption of soil and water conservation effectively. Extension officers are in charge of disseminating information and training on soil and water conservation practices available for adoption and they work with farmer groups. Farmers in groups benefit not only from training and education but also they get financial assistance. Constrains to adoption of soil and water conservation measures were lack of capital and insufficient labor force, lack of technical knowledge, poverty and ignorance.

These finding show that in order to achieve proper soil and water conservation institutional and economic factors has to be given special attention. It is important to strengthen this link between the farmers and extension officers to facilitate education and training of farmers. Different methods of disseminating information for instance on-farm training should supplement farmer meets and baraza for illustration on how to construct structures. Providing subsidies will encourage use of soil and water conservation measures and rainwater harvesting among farmers.

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CHAPTER FOUR

LAND USE AND LAND COVER CHANGE AND ITS IMPACT ON SOME SOIL PROPERTIES IN KATHEKAKAI CATCHMENT, MACHAKOS COUNTY, KENYA USING REMOTE SENSING AND GIS

4.1 Abstract

Landuse and land cover change is a significant factor in environmental conservation and it is being used by planners for sustainable development. This Study focused on landuse landcover changes in Kathe-kakai catchment, Machakos. The study covered about 8800 hectares. Landsat images (1988, 2002 and 2014) were acquired and analyzed, classification and change detection using ENVI. Using supervised classification system, five different landuse and landcover categories were classified as forests, cultivated lands, shrub land, barelands and waterbodies. Soil properties were also analyzed to determine whether they were affected by changes in landuse. From the year 1988 to 2014 there was an increase in barelands (14.9%), cultivated lands(68%), and a decrease in shrub land (-15%), forests(-64%), and water bodies (-55%). Chi-square statistic values were significant at ($p<0.001$) for changes in forests and cultivated land between 1988 and 2014. All soils had low organic carbon (<3%) except forests. Barelands and shrub lands were characterized by high bulk density (1.6g/cm^3) and low hydraulic conductivity (0.1-0.4 cm/hr). High bulk density and low Ksat were the probable cause of high overland flow resulting to high soil erosion rates and gully erosion as the soils were compact restricting water infiltration. Cultivated lands had moderate hydraulic conductivity this could be due to repeated ploughing. Deforestation was associated with opening up of lands for settlement and agricultural expansion due to population increase. Steep slopes previously covered by natural vegetation have been exposed and are under unsustainable farming system. These changes could be the probable cause of massive runoff from the Mua hills causing development of gullies along water channels and sheet and rill erosion throughout the catchment. Proper planning in landuse and community awareness is necessary to avoid negative effects of land use and land cover changes.

Key words: Land Use and Land Cover Change, Supervised classification, Land management, Sustainable development

4.2 Introduction

Globally there are immense changes in landuse and cover patterns which may be positive or negative depending on how they occur. LULCC information is becoming very important in supporting decision at various levels. Changes in landuse are due to natural and socio-economic factors as evidenced by persistent expansion in cultivated lands, decrease in natural woodlands and grassland in the world (Matsa and Kudakwashe, 2010). Kithiia, (1997) suggested that major causes of land use/cover change are population growth, agricultural expansion and clearing of land for settlement among other forces that cause changes which lead to severe environment problems. Lambin *et al*. (2003) associated changes in landuse and land cover with increase in soil erosion, increased surface runoff and flooding, increased carbon dioxide concentration and climate change. Gachene *et al*. (2004) also suggested that these changes have exposed the land to soil erosion resulting to loss of fertile topsoil.

LULCC are used together with remote sensing change detection studies to detect the changes over the years (Seto *et al*., 2002). Many researchers have used remote sensing together with GIS to monitor and detect landuse landcover changes (Kaswanto *et al*., 2010; Mubea *et al*., 2012; Syombua, 2013)**.** Change detection involves use of multispectral data sets to discriminate areas of land use land cover change between dates. Kathumo (2011) applied remote sensing and GIS to assess land use and land cover changes and their impact on hydrological regime in river Gucha catchment, he observed that increase in anthropogenic activities have caused continuous change in land cover and a lot of pressure on natural resources, making it essential to monitor changes that have occurred and are yet to occur. . Haruna *et al*. (2014) did a study across river Nanyuki catchment in Kenya using CLASlite and ENVI from 1984 to 2010 and concluded that agricultural lands and water bodies expanded significantly over the period while forest and uncultivated land experienced depletion..

Biro *et al*. (2013) working on LULCC using multitemporal Landsat data from year 1979 - 2009 and the impact of these change on selected soil properties found that LULC changes do affect soil chemical and physical properties. Zhou *et al*. (2008) found out that ground cover is a protection against soil erosion hence activities reducing cover tend to increase erosion. Accurate and timely information about landuse and landcover and its changes is crucial for decision making and ecosystem monitoring in land management.

4.3 Materials and methods

4.3.1 Study area

Figure 1 shows the study, located at Kathe-kakai catchment, Machakos County, Kenya which lies between 1^0 30'S and 37^0 15'E and 1700m above sea level. The study area covers approximately 8800hectares. The topography of the area is naturally hilly, the predominant soils are Luvisols with patches of Vertisols and Cambisol. The main occupation in the area is agriculture. Some parts still have natural forest though the area is being opened up for agriculture and settlement.

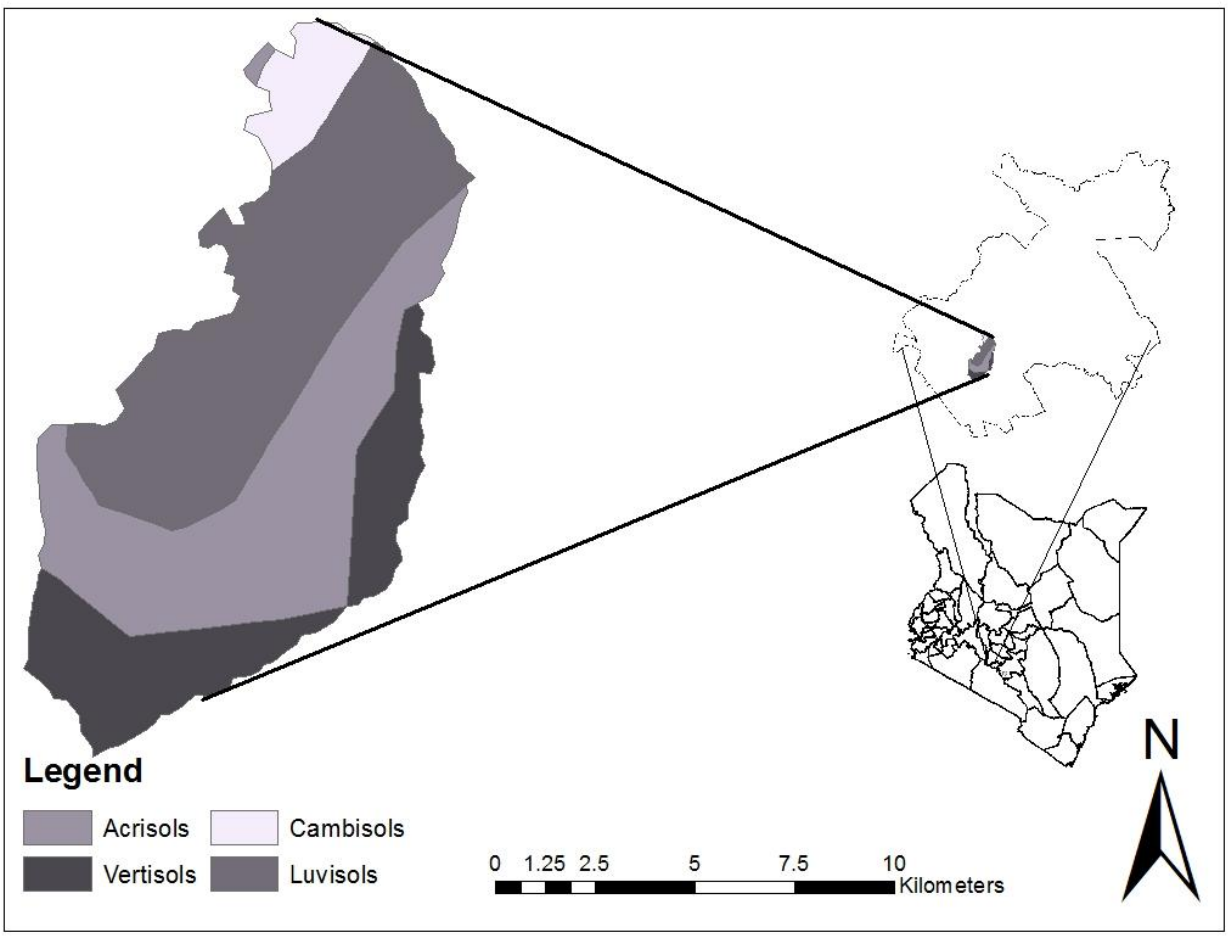

Figure 4.1 Kenya map showing the study area

4.3.2 Data acquisition

Selection of appropriate satellite imagery was the first task used image data processing. Table 4.1 shows the three set of satellite images to be analyzed.

Table 4.1 Description of data used in imagery analysis

Satellite	Acquisition date	Spectral band	Ground resolution(m)
Landsat 8 OLI - TIRS	03/02/2014	1 - 11	30
Landsat 7 ETM + SLC	10/02/2002	1 - 8	15
Landsat 4 - 5 TM	17/02/1988	1 - 7	30

OLS-TIRS, operational land imager and thematic infrared sensor, TM, thematic mapper; ETM+, enhanced thematic mapper plus.

Three images were analyzed for years 1988, 2002 and 2014 and were acquired from Regional Centre for Mapping of Resources for Development (RCMRD). The 2002 image was from Landsat 7, 2014 image from Landsat 8 finally 1988 image from Landsat 4-5. The images covered the path/row of 168/061. All satellite images were geometrically corrected to the universal Transverse Mercator coordinate system (zone 37S). Satellite scenes were acquired during the same season in order to minimize the influence of seasonal variations on LULCC analysis. Ancillary data consisting of different LULC features and their location points were recorded using a Global Positioning System (GPS) instrument.

4.3.3 Image classification

Landuse and landcover maps were developed using satellite images by defining spectral classes. Multi-temporal Landsat data processing was done using ENVI 4.7 Software (ESRI, 2009). Regions of interest (ROI) were defined to extract statistics for classification. Supervised classification was used to cluster pixels into classes used selected regions of interest (ROI). Minimum distance classification methods were used to classify the images (ESRI, 2009). Five landuse and land cover types were classified as forests, grasslands, cultivated, barelands and waterbodies.

4.3.4 Change detection and analysis

Thematic changes were computed for classified LULCC types using ENVI EX software. Two images from different time periods were compared at a time (1988 and 2002 images, 2002 and 2014 images). Different landuses and cover area of lands were used to calculate percentage change in LULCC using Excel. The overall change in landuse from 1988 to 2014 was calculated and chi-square goodness of fit was used to determine if there was significant change using SPSS.

4.3.5 Soil sampling and analysis

Soil samples were collected from the identified types of landuse and land cover namely, cultivated, forests, shrub lands and barelands. The soil was sampled at a depth of 0-30cm from eight sampling plots in each of the LULC type. A soil auger was used to collect disturbed samples while samples dry bulk density determination undisturbed cylindrical core rings were used. The disturbed samples were air dried and passed through a 2mm sieve.

Soil particle size fractions were determined by the hydrometer method after dispersion with sodium hexa-metaphosphate solution (Day, 1956). Dry bulk density was calculated by dividing the oven drymass at 105°C by the volume of the core (Richards, 1954). Organic matter (OM) was determined using the Walkley and Black method (Black, 1965). Hydraulic conductivity was determined using the constant head method as described by Klute and Dirksen (1982).

The area of land under different land uses and cover was used to calculate percentage changes in land use and land cover using Excel software. Overall land use and cover changes were calculated from the 1988 and 2014 statistics. Chi-square goodness of fit was used to determine if there were significant changes in land use and land cover (Zar, 1996).

4.4 Results and discussions

4.4.1. Landuse and land cover change analysis

In the study area, LULC classes have changed significantly. Changes are normally quantified per pixel counts, areas and percentages. Different classes were represented with different colors in each image, making it easy to identify not only where changes have taken place but also the class into which the pixels have changed. The change detection statistics for twenty six years in the study area are presented in tables and graphs.

In figure 4.2 the decreasing trend in forest cover is shown from the year 1988 to 2014. In 1988 forests occupied approximately 44% of the area while in the year 2002 the area reduced to 39%

and finally in the year 2014 forests occupied 19%. Between years 1988 and 2014 more than 60% of forest land was lost. Area under forest had reduced drastically from the year 1988 to 2014. Figure 4.7 shows that loss in Forest area has been compensated by gains in cultivated lands.

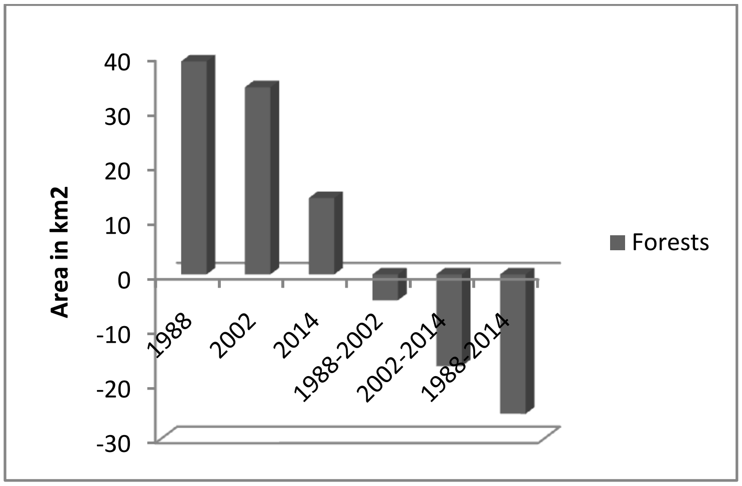

Figure 4.2 Forest coverage from the year 1988 to 2014

Figure 4.2 shows the increasing trend in cultivated lands from the year 1988 to 2014. In the year 1988 cultivated lands were occupying approximately 4.1km^2 (4%), during 1988-2002, cultivated land increased by 5% between 1988 and 2002. Between 2002 and 2014 cultivated land increased immensely by (210.5%). This can be seen in Figure 4.7 where the green color for cultivated land has increase over the years the possibly cause of these expansion is due to people settling into the region and practicing farming.

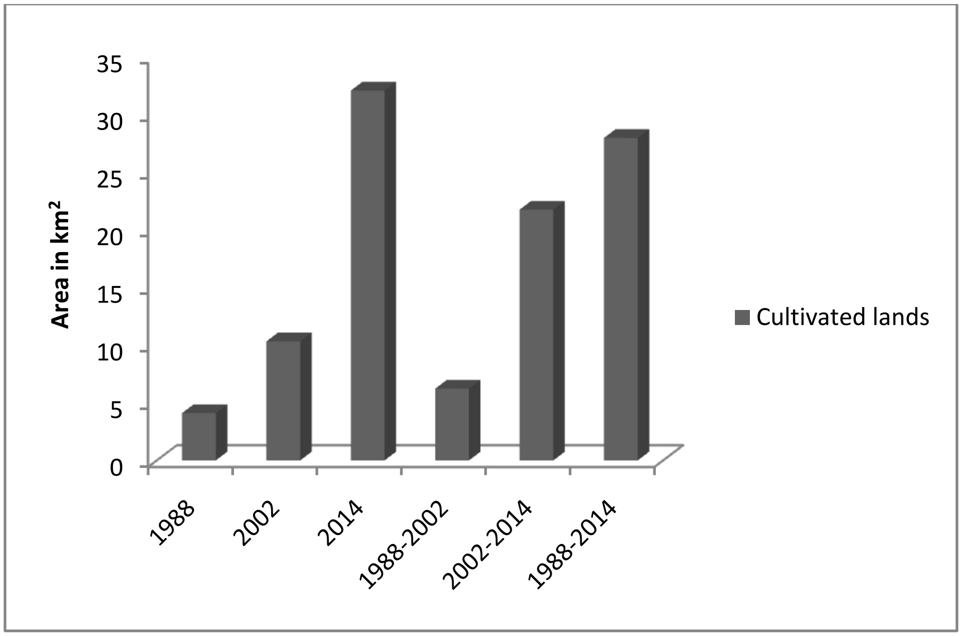

Figure 4.3 Cultivated lands from the year 1988 to 2014

Figure 4.7 shows that deforestation has occurred on lower section up the hill expanding upward. Mua hill forest has been undergoing deforestation due to human encroachment to create land for settlement, to practice agriculture and tree logging activities. Similar results were observed in Budongo forest where forests were being converted to agriculture (Mwavu and Wirkowski, 2008). Suleiman, (2008) results agree that agricultural expansion has been identified as one of the key drivers of landuse change.

Haruna *et al*. (2014); Singh and Khanduri, (2011) observed that changes in landuse and land cover has occurred where natural vegetation is converted to cropland and open lands with increase in population. Baaru, (2011) made similar observation were changes in landuse and land cover were influenced by human increase, infrastructure and proximity of the area of study to Nairobi city and Machakos town. In the 1980s, kathe-kakai was sparsely increasing population forced slow sedentarization and this marked the beginning of rapid changes in land cover. Expansion in area under cultivation was observed from the year 2000 upslope. Farmers consider cultivation a better livelihood strategy due to available markets from increasing populations. Syombua, (2013) suggested that agriculture is expanding in this marginal area due to good road networks and markets. Similar results have been observed in Africa, Asia and Latin America whereby expansion in agriculture is resulting in deforestation

Table 4.2, show that in the year 1988 shrubs occupied 39km^2 which is approximately 45% of the study area but in the year 2002 the area reduced to 32km^2 which is approximately 37% finally in the year 2014 the area increased to 33km^2 around 38%. Between the year 1988 and 2002 the shrub land decreased by 17% while between the year 2002 and 2014 the area increased by 2.7%. Overall shrub land decreased with 15% though the change was not significant. In the year 1988 shrub land was the second most landuse/land cover after forests with acreage of 39.8km^2 by the year 2002 the area under shrubs reduced to 37.5km^2(5.7%). Overall there was a decrease in shrub lands though the change was not significant when chi-square analysis were carried out.

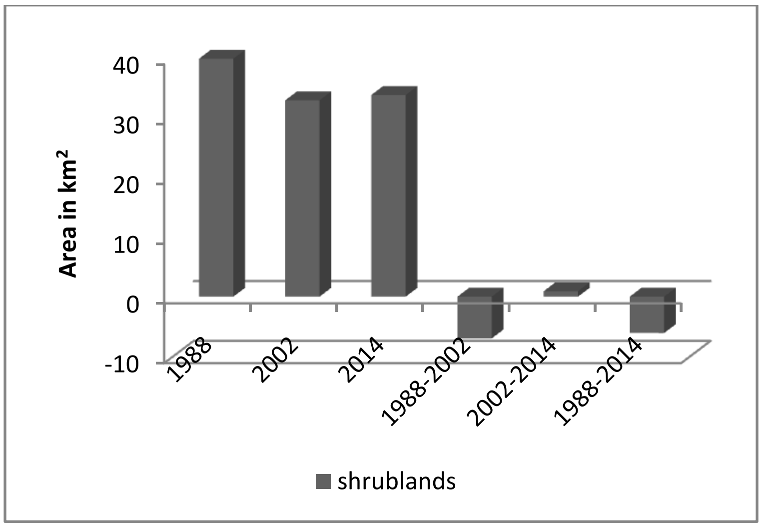

Figure 4.4 Shrub lands from the year 1988 to 2014

Baaru, (2011) found that between the years 1995 and 2000, majority of the land cover was shrubs when a participatory resource mapping was done. Movement of people into the catchment has resulted in an increased in shrub land explaining why in the 1988 image most of the cover was shrubs but in 2002 the resource reduced. Overgrazing in the lower parts of the catchment is resulting to bare lands. These areas have no vegetation and regeneration rates are slow due to harsh climatic conditions. Angassa and Oba, (2008); Oba *et al*. (2000) argued that with time areas abandoned by farmers due to their unsuitable nature for grazing and farming are now dominated by shrubs and few grasses. Reducing barelands and increasing area under shrubs as observed in 2014 image.

Figure 4.5 shows that in the year 1988 barelands occupied approximately 4.7 % of the area by the year 2002 the area increased to 12% then reduced to 5.4% in the year 2014.

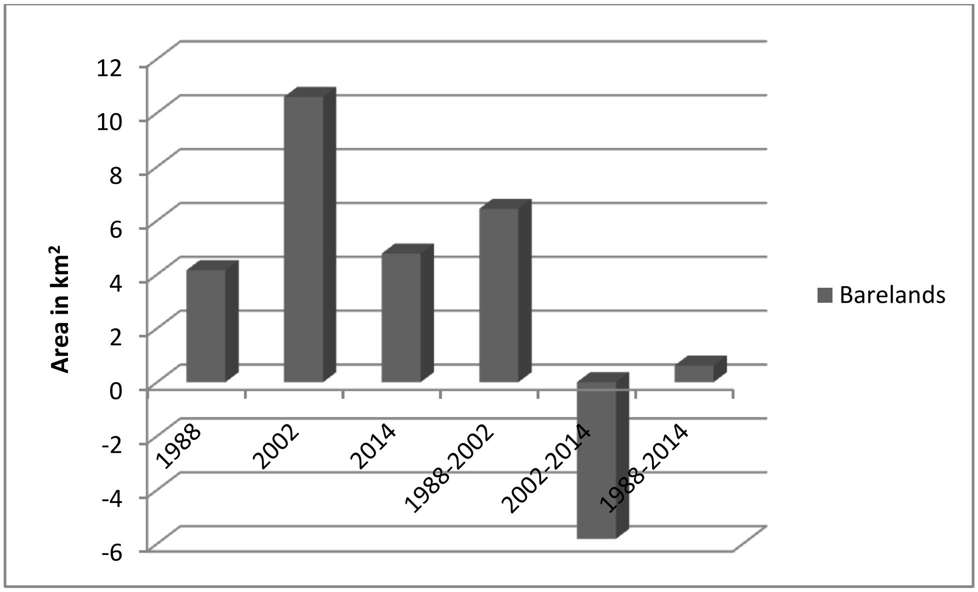

Figure 4.5 Barelands in the area from 1988 to 2014

Table 4.2 shows that during the period of 1988 to 2002 barelands increased by (154.8%). Then between the year 2002 and 2014 the area reduced by 5.8km^2 probably because barelands were converted into shrub land. Figure 4.5 shows that overall there was an increase in barelands from the years 1988 to 2014 though the increase was not significant (Table 4.3).

Removal of natural vegetation, intensive cultivation on these fragile lands and overgrazing without effective conservation measures are the probable cause of increase in barelands between the year 1988 to 2002. Gathaara, (2010); Tsegaye *et al*. (2010) observed that farmers abandoning degraded land when they were no longer productive.

Water is a scarce resource in Kathe-kakai, with increase in population and agricultural activities, this resource will continue to dwindle. Table 4.2 shows that this resource occupied 0.2% of the area in year 1988, water bodies reduced to 0.1% in year 2002 to 2014. Some of the dams constructed to store water have been lost due to siltation and poor management. Overall between the year 1988 to 2014 there was reduction in waterbodies area reduced from 0.082km^2 which is -55.3% though as shown in Table 4.3 the decrease was not significance.

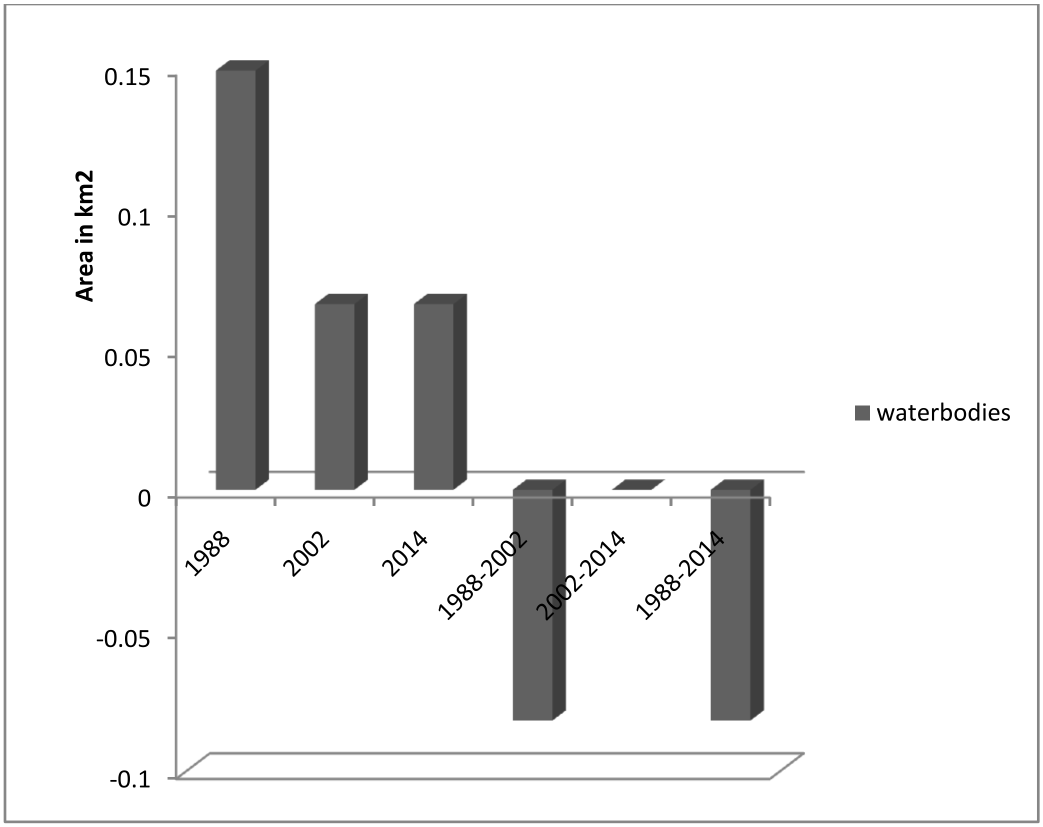

Figure 4.6 Waterbodies from the year 1988 to 2014

Mua hills are a source of a few permanent springs and streams which are used both for domestic uses and by agricultural purposes. There were seasonal rivers and man-made structures such as earth dams, water storage tanks, wind-vanes for pumping water from the dams to the storage tanks and watering troughs when under a ranch. When the rancher left and land was subdivided to squatters in the area these structures were destroyed due poor management as observed during field survey, this explains the decrease in water resource from the year 2002 (NEMA, 2013). Sand harvesting along the river channels is affecting surface water flow as water channels have been destroyed due to excessive mining (Mwaura, 2013). Kithiia, (1997) also observed an increase in sediment load been deposited into water reservoir and other water storage structures due to increase soil erosion. Gathaara ,(2010) documented that farmers have attempted to conserve water using conservation measures such as Agroforestry, construction of subsurface dams along river valleys and construction of dams and pans. However most of these conservation measures have been neglected and are no longer functional.

Overall shrub land, forests and waterbodies decreased over the years while cultivated land and barelands increased over the years. Changes in shrub land, barelands and waterbodies were not significant (Table 4.3) while changes in cultivated lands and forests were significant at ($p < 0.001$).

Table 4.2 Landuse Land Cover Change (km^2) in Kathe-kakai between 1988 and 2014

Land use/ Land cover	1988		2002		2014		Change (1988-2002)		Change (2002-2014)		Overall change (1988-2014)	
	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%	Km^2)	%
Shrub lands	39.821	45.6	32.844	37.3	33.738	39.3	-6.976	-17.5	0.893	2.7	-6.083	-15.3
Forests	39.016	44.7	34.279	39	13.974	16.8	-4.737	-12.1	-16.805	-58.8	-25.542	-64.2
Cultivated lands	4.102	4.7	10.320	11.7	32.048	37.4	6.217	151.6	21.728	210.5	27.945	681
Waterbodies	0.149	0.2	0.066	0.1	0.066	0.1	-0.082	-55.3	0	0	-0.082	-55.3
Barelands	4.156	4.7	10.593	12	4.776	6.4	6.436	154.8	-5.817	-54.9	0.6191	14.9

Table 4.3 Chi-Square goodness of fit test for various Land use/Land Cover Changes in Kathe-kakai catchment between 1988-2014.

Landuse/Land cover	1988(Km^2)	2002(Km^2)	2014(Km^2)	Change 1988- 2014 (Km^2)	X^2 goodness of fit test
Shrub lands	39.821	32.844	33.738	-6.083	X^2= 0.804, df=2, p=0.669
Forests	39.016	34.279	13.974	-25.542	X^2= 13.447, df= 2, p= 0.001
Cultivated lands	4.102	10.32	32.048	27.945	X^2= 28.348, df= 2, p= 0.001
Waterbodies	0.149	0.066	0.066	-0.082	X^2= 0.000, df= 2, p= 1.000
Barelands	4.156	10.593	4.776	0.6191	X^2= 3.263, df= 2, p= 0.196

4.4.2 Impacts of landuse and land cover change on soil properties

Table 4.4 shows soil properties of different landuse in the area. Bareland textures were dominated by clay, followed by sand and finally silt on lower part of the area and silt dominated on the upper part. Bareland Ksat was 0.3cm/hr resulting to slow water movement. Bulk density was 1.4g/cm^3.Organic carbon was 2.72% classified as low. Shrub lands texture was sandy clay dominated by sand followed by clay and finally silt. Saturated hydraulic conductivity was 0.97cm/hr which means water movement was slow too. Bulk density was 1.64g/cm^3 which were the highest for all the landuses. Finally organic carbon was 1.97% which was still low.

Table 4.4 Soil properties for different Landuse in the study area

Soil properties	Cultivated lands	Shrub lands	Barelands	Forests
Hydraulic conductivity (cm/hr)	3.6	0.97	0.3	4
Bulk density(g/cm^3)	1.25	1.64	1.413	1.3
Organic carbon (%)	1.3	1.97	2.72	3.4
% Sand	54	50	25	60
% Clay	36	40	55	37
% Silt	10	10	20	3
Textural class	Clay Loam	Sandy clay	Clay	Sandy Clay

Cultivated lands texture was clay loam, Ksat was 3.6cm$^/$hr, which is moderate water transmission and Bulk density was 1.25g /cm3 while organic carbon was 1.3. Forests texture was sandy clay; hydraulic conductivity was 4cm/hr which is moderate water movement. Bulk density was 1.25g/cm^3 while organic carbon was 4% which is moderate.

The differences in soil properties of forests from other landuse could have been due to the presence of trees that increase organic matter, due to litter deposition. Soil organic matter binds soil particles which increase porosity and reduces bulk density (Batjes and Sombroek, 1997). Humus found near trees is highly porous encouraging water retention in the soil reducing runoff.

Soils in this area have inherently low organic matter due to low plant density and rapid microbial activity, with continuous cultivation and lack of replenishment as farmers rarely leave residue in their farm. Organic matter continues to decline as farmers also do not use fertilizers. Areas under cultivation had moderate saturated hydraulic conductivity. Biro *et al*. (2013) suggested that repeated ploughing loosens the soil hence the moderate hydraulic conductivity. The high bulk density as compared to forests is attributed to low organic matter and compaction due to tillage operations at constant depth. In return farmers are experiencing rill and sheet erosion on their farmers. Karuma *et al*. (2014) found that soils having high bulk densities are compact and less porous affecting soil water transmission properties hence high surface runoff.

The study showed that the conversion of forests to cultivated land has affected the selected soil properties. A general decline of the physical and chemical properties was observed. The significant increase of bulk density and the decline in the soil OM content are likely to be one of the main causes of soil erosion in the study area. Thomas *et al*. (2000) point out that change for the better is possible as with time the trend can be reversed that is with proper landuse practices and management these degraded land can be converted to be productive.

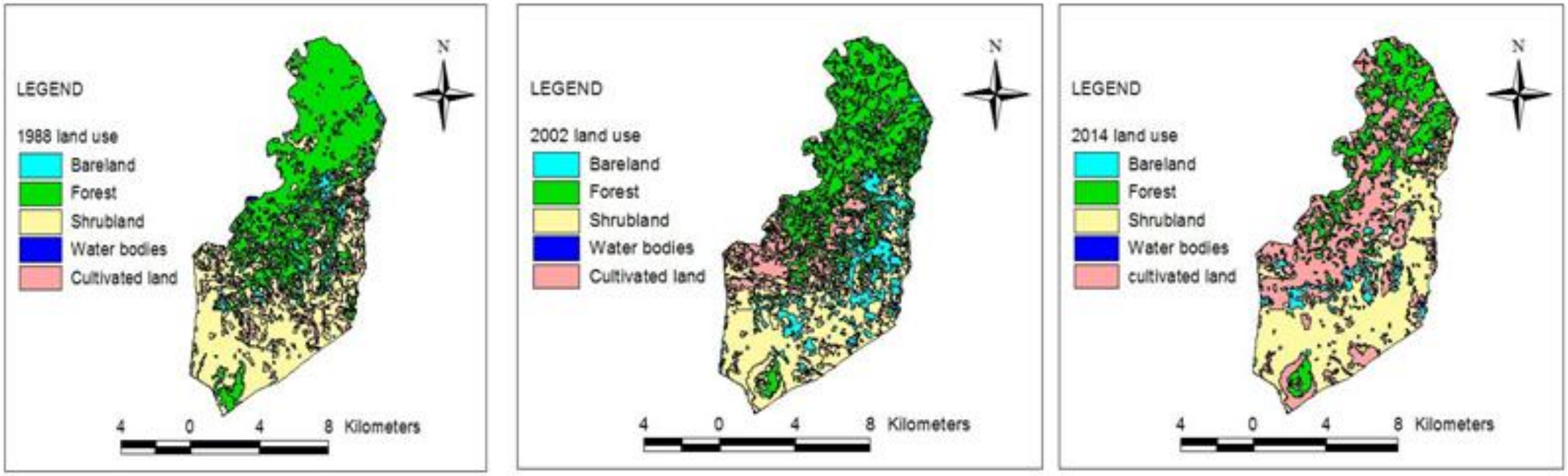

Figure 4.7 Land use Land cover change from the year 1988 to 2014

4.5 Conclusions and recommendations

Based on the LULC analysis of Kathe-kakai catchment for the years 1988, 2002 and 2014, using remote sense imagery to monitor changes over a twenty-six year period, showed that changes varied significantly during the periods. Large areas previously covered with natural vegetation (64%) have been converted to cultivated lands and open lands over the past 20 years due to anthropogenic activities. Expansion of rainfed agriculture with increase in deforestation was the driving force of landuse changes. Shrub lands and barelands were characterized by low saturated hydraulic conductivity and high bulk density compared to cultivated lands and forests. Decline in natural vegetation and poor farming systems are the probable cause of land and soil degradation. Increase in bare land is the probable cause of increase in overland flow making these areas prune to rill and gulley erosion. This trend of vegetal cover loss within the catchment has caused more harm than benefit hence need for proper planning. Mapping and monitoring of these undesirable changes becomes a vital tool in management decisions. Lack of defined land ownership systems in areas termed as commons lands and unregulated human activities like overgrazing, tree logging and sand mining are aggravating the problem. Giving land rights especially on this fragile ecosystem will encourage sustainable activities and encourage soil and water conservation. Regulation of activities like mining of sand and logging of trees should be enforced by the County government. Intensification of public awareness to encourage prudent use of resource should be encouraged, as those who still do not realize the need for environmental protection can destroy or frustrate the effort of the majority to safeguard the environment. Farmers should also be convinced to stop cultivating in sloppy areas without proper soil and water conservation measures.

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CHAPTER FIVE

5. AN ASSESSMENT OF SOIL EROSION RATES IN KATHE-KAKAI CATCHMENT, MACHAKOS COUNTY IN KENYA.

5.1 Abstract

Soil erosion is a global problem. In sub-Saharan Africa about 5 tons/ha of top soil is lost annually due to soil erosion. Assessment of soil erosion rates, which would assist in the development of appropriate soil and water conservation measures especially in developing countries is a challenge due to lack of relevant data. A modified revised universal soil loss equation (RUSLE) was used to estimate soil erosion rates in Kathe-kakai catchment in Machakos County. The R factor (rainfall erosivity) was calculated from annual precipitation data from eight stations in Machakos County. The K factor (soil erodibility) was estimated using a locally derived regression equation for soil mapping units identified in the study area. The LS factor (slope length and steepness) was derived from a digital elevation model. The C factor (Land cover factor) was determined using Landsat imagery for the year 2014. Finally P factor (conservation practices) was estimated from commonly used soil conservation measures. The R factor was estimated to be between 562 and 747 MJ mm/ha/yr. Relative soil erodibility factor K was from 0.17 to 0.3, which the predominant soil having the highest erodibility factor. LS factor varied from 0 to 413, with the steep slopes having the highest LS values and reducing toward the lower parts. A raster based geographic information system (GIS) was used to calculate soil loss and map hot spot areas Estimates show that the study area experiences soil erosion rates between 0 to 60 tons/ha/year, the highest amount being recorded in areas with steep slopes and bare surfaces Approximately 54% of the area under study was within the tolerable soil erosion rate, which is taken to be 10 tons/ha/yr. 16% of the catchment had moderate soil erosion while 24% had high erosion rate, while the remaining 6% were classified as having very high to severe soil erosion rates. Using RUSLE the final output was able to show site specific erosion hazard areas under different landuse, land cover and management practices. Planning efforts should focus toward effective measures against soil erosion especially in areas mapped as erosion hot spots. However there is need to develop long term data management systems to validate the model to suit the local conditions.

Key words: soil erosion, GIS, RUSLE

5.2 Introduction

Soil erosion is one of the most serious environmental problems affecting tropical and sub tropical regions. Removal of topsoil cause deleterious effects on the productive capacity of soils as well as on the ecological wellbeing (Sullivan, 2004). Kithiia (1997) observed that about fifty percent of rainfall can be lost on eroded lands due to decreased infiltration and high surface runoff, as soil erosion reduce soil water storage capacity. He also reported that sediment load in basins has been on the rise affecting both water and environmental quality.

Tiffen *et al*. (1994) estimated soil erosion rates of Machakos County to be 12 t/ha/yr and the rates are projected to increase due to further changes in landuse and land cover (Amore *et al*.,2004). Kathe-kakai catchment has undergone significant changes in terms of land cover and land use (Chapter four). Increase in population coupled with the proximity of the area to Nairobi, the capital city of Kenya has resulted to increase in settlement and decrease in natural vegetation (Baaru, 2011). Steep slopes have undergo deforestation or cleared for cultivation and are under poor farming practices making them highly eroded and probably a major source of overland flow.

Soil erosion factors are complex in nature, making it difficult to make precise estimate of soil erosion extent. However several models have been developed to calculate soil erosion rates of a given area even though it is hard to find a model that considers all forms of soil erosion. They include Universal Soil Loss Equation (Wischmeier and Smith, 1978), Revised Universal Soil Loss Equation (Renard *et al*., 1997), Water Erosion Prediction Model (Flanagan and Nearing, 1995), Soil and Water Assessment Tool (Arnold *et al*., 1998) among others. USLE model is mostly used as it is simple and has a limited data requirement, for estimation of potential soil erosion (Kinel, 2000).

RUSLE model is an upgrade of USLE designed to predict average rates of soil erosion in an areas under different scenarios in term of management technique, cropping systems and erosion control measures. The results are compared with estimated soil loss tolerance values and gauge whether soil erosion is above the maximum allowable rates (Renard *et al*., 1997). RUSLE model was developed for use in temperate United States of America regions. Use of these factors in tropical regions may lead to misinterpretation of soil loss. Difference in the two conditions is observed in terms of soils, crops, management, for instance grasslands and croplands where soil erosion control is higher in humid tropics than suggested by RUSLE. This observation is due to the more rapid development of dense vegetation protecting the soil than in the temperate. Data collected for the tropical regions should be used to avoid misestimating RUSLE values.

RUSLE computes average erosion rates by multiplying factors of soil erodability, rainfall erosivity, topography and, land use and management aspect of the land (Renard *et al*., 1991). Rainfall erosivity factor is an index based on kinetic energy of the rain, the impact of raindrop and rainfall intensity as a result of rainfall amount (Morgan, 1994). Soil erodibility factor reflect the ease with which soil is detached by rainfall or runoff.

For tropical soils, unstable soil aggregates, modified silt, sand, and the corresponding base saturation are used to determine soil erodibility (El-Swaify and Dangler, 1976). This factor in RUSLE accounts for the influence of soil properties on soil loss during storm events. Tiffen *et al*. (1994) characterized Machakos soils as being low in organic matter due to less plant cover and high microbial activities. These soils have an added disadvantage of being of high erodability due to poor soil structure together with low vegetation cover at the beginning of the rainy season. Topography in RUSLE is accounted for by slope length and slope gradient on erosion by assigning LS on uniform slopes. The C- factor measures the effect of land cover and management. Renard *et al*. (1997) assigned values of C to vary from near zero to 1, where a high value denotes scarce vegetation hence susceptible to erosion while a lower value shows well protected soils. P factor is also a key value that governs soil erosion rates. The value ranges from 0- 1 depending on soil management activities employed in an area. This factor highly depends on slope of the area where the slopes are modified to influence flow rate and direction of runoff (Renard and Foster, 1983).

The latest advances in spatial information have made it possible to make precise estimation of soil erosion rates saving on time and resources. Digital elevation models (DEM), digital soil map, Landsat imagery along with remote sensing data and GIS have been used successfully in many researches. Boggs *et al*. (2001) estimated the soil erosion risk based on the revised RUSLE model, DEM data and land units map. Bartsch *et al.* (2002) used the GIS techniques to calculate the required factors of RUSLE for determination of soil erosion risk at Camp Williams. Fathizad *et al.* (2014) used RUSLE model, remote sensing and GIS to estimate soil loss and sediment yield in Doviraj watershed, Iran, their results showed that the annual soil loss was estimated at 273.6 tons/ha/year while the measured rate was 253.42 tons/ha/yr. The very near tally of results shows ability of RUSLE, RS and GIS to estimate soil loss rates.

This study was carried out to assess annual soil loss estimates for Kathe-kakai catchment and generate a map showing soil erosion intensity in the area using modified RUSLE model, RS and GIS techniques. The final output can aid in identifying critical areas were limited soil conservation measures funding can be targeted.

5.3 Materials and methods

5.3.1 Study area

The study was carried out in Kathe-kakai catchment, Machakos County, Kenya (Figure 5.1). The study area covers approximately 8800 hectares. It lies between 1^0 30'S and 37^0 15'E and altitude ranges from 1500 and 2100 m above sea level. The area lies in agro-climatic zones IV and V (semi-humid to semiarid).

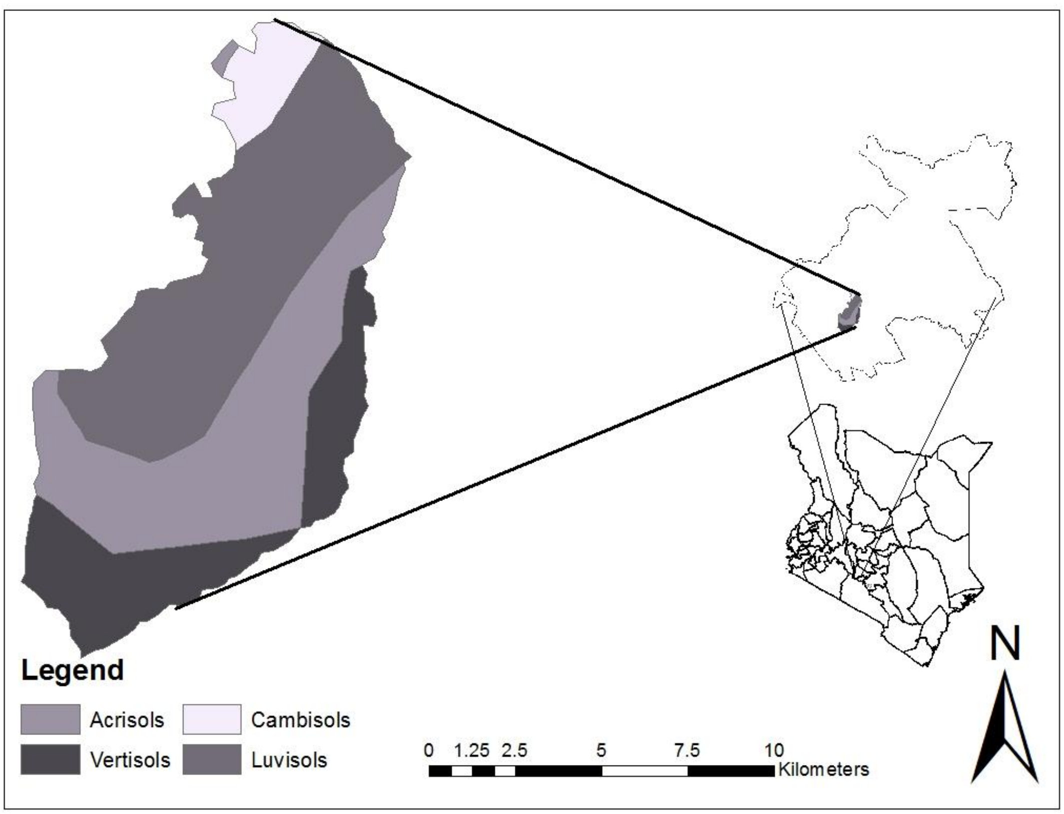

Figure 5.1 Kenya map showing study area

The area experiences irregular bimodal (short rains from April to June long rains occurring from November to December) type of rainfall with an annual mean of about 700 mm. The area is naturally hilly; the predominant soils are Luvisols with patches of Vertisols, Acrisols and Cambisols (Sombroek *et al*., 1982). Agriculture is the main occupation for majority of the population. Some parts still have natural forest though the area is being opened up for agriculture and settlement. From field observations bare and cultivated lands are very vulnerable to soil erosion. With expansion of agricultural area and the invasion of forest land soil erosion has become more pronounced.

5.3.2 Estimation of soil loss

The average soil loss (A) per hectare per year was quantified using modified RUSLE model. The model used knowledge of the catchment for instance major soil unit in the area were sampled and analyzed for both physical and chemical properties which influence soil erodibility according to a local regression equation developed for local soils according to Gachene, (1982).

RUSLE developed by Renard *et al*., (1997) uses the Equation 1

$$\mathrm{A(t/ha)} = \mathrm{R} \times \mathrm{K} \times \mathrm{L}S \times \mathrm{C} \times \mathrm{P} \qquad (1)$$

Where A is the mean annual soil loss in ton/hectare/year, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the land use factor and P is the erosion control practice or land management factor. The study included the use of exploratory soil map of Kenya to acquire soil units in the study area (Sombroek *et al*., 1982), followed by field auguring to confirm the soil types. A total of 36 samples were collected in representative points of the study area based on elevation using a clinometers, soil and landuse. The study also involved use of rainfall data from weather stations located in Machakos County, Landsat imagery 8 OLI-TIRS path /row: 168/61 was acquired and used to analysis land cover in the area using ENVI.

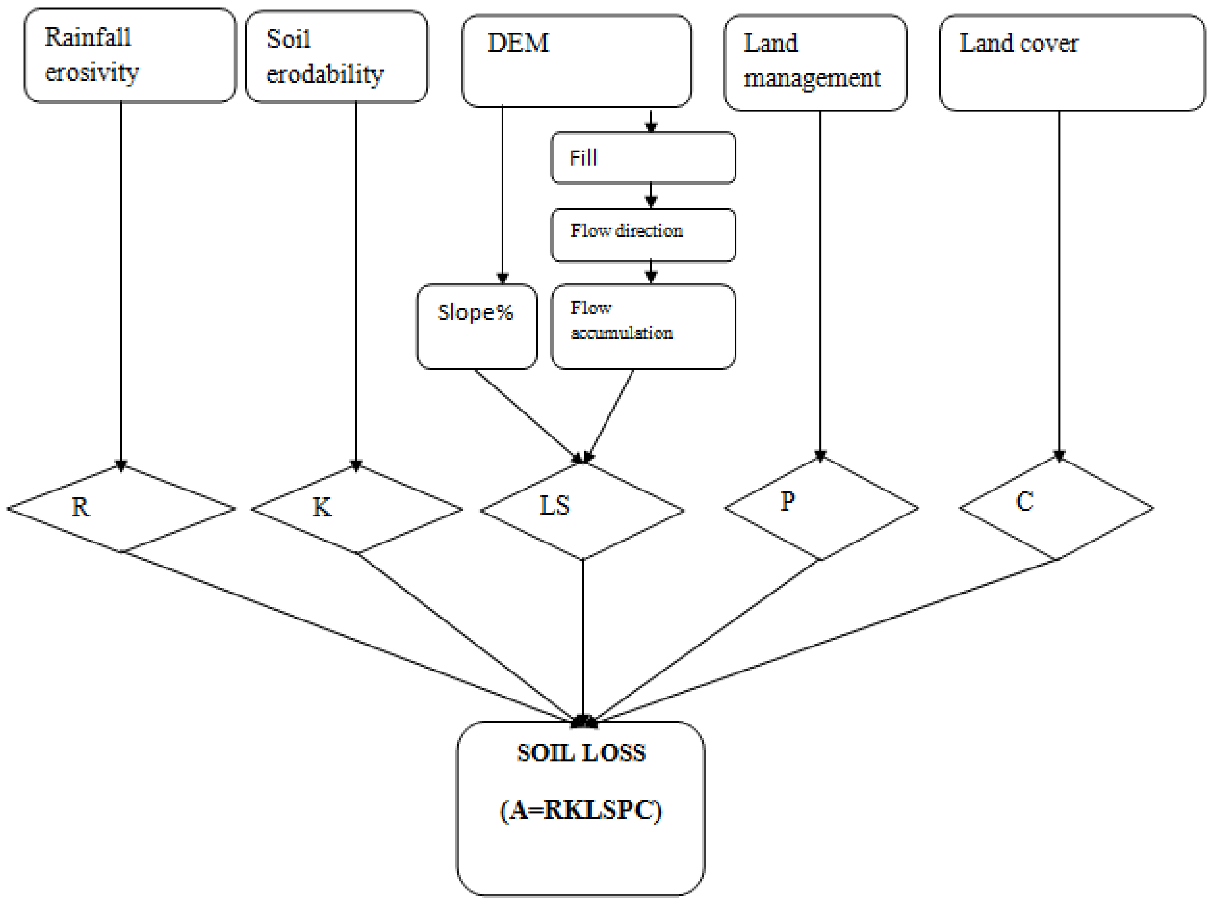

Figure 5.2 Flow chart showing analysis of soil loss based on GIS application.

5.3.3 Determination of Rainfall erosivity factor

The R factor was calculated using average rainfall data for 15 years from stations located in Machakos County. Mean annual erosivity was determined using the regression equation 2, using KE (kinetic energy) of rain falling at intensities greater than 25mm/hr for 15 minutes periods (Moore, 1979) as shown in Equation 2 and .

$R = 0.029KE - 26.0$ r = 0.95, n = 11 (2)

$KE = 3.96P + 3122$ r = 0.55, n = 35 (3)

Where, KE = Rainfall kinetic energy in MJ

P = Mean annual rainfall in mm/hr

Table 5.1 Rainfall data used to calculate erosivity

Rainfall stations	Longitudes	Latitudes	Annual Rainfall (mm)	Erosivity (R)
Machakos Potha estate	37.16667	-1.56667	532	460.18
Machakos Matiliku	37.5319	-1.96504	395	341.675
Machakos dam	37.4468	-1.4866	582	503.43
Ngelani Station Agric. Quarters	37.224	-1.4335	765	661.725
Machakos Makabete	37.3	-1.5	590	510.35
Katumani EXP. Res. Station	37.2533	-1.58	582	503.43
Kilome District office	37.333	-1.8	960	830.4
Machakos District office	37.26716	-1.51602	767	663.455

5.3.4 Determination of Soil erodibility factor

Soil erodibility factor is termed as the average long term soil response to the erosive power of rainfall. There have been several attempts to develop regressions relating soil erodibility to soil physical and chemical properties which would enable predictions (Wischmeier *et al*., 1978). Important soil parameters which affect the erodibility of soils are related by multiple regression equations to soil losses measured either in the field or under laboratory conditions. Of these the most widely referred to is soil nomograph Wischmeier for soil in United States of America (Wischmeier and Smith, 1978). The *K*-factor derived from the USLE nomograph is applicable to tropical soils that have kaolinite as the dominant clay mineral, but less applicable where Vertisols dominate (Roose, 1977). Locally Angima *et al.* (2003) used Elwaify and Dangler, (1976) procedure for tropical soil. The equation uses percent modified silt and sand, base saturation, percent unstable aggregates and percent fine sand to estimate soil erodibility. In this study soil erodibility factor was determined using a locally derived equation developed for Kenyan soil, following the Gachene, (1982) regression equation. The relative erodability (k) of 14 Kenyan soil types with different physical and chemical properties and parent materials were determined under simulated rainfall conditions. Factors found to influence the relative erodibility most strongly were dispersion ratio (DR), percent clay (C), percent organic matter

(OM) and bulk density (BD. The values for the analyzed soil properties were used to calculate K using the regression equation proposed by Gachene, (1982) as shown in equation 4.

$$Y = 0.297 + 0.069\ DR - 0.001\ C - 0.011\ SOM - 0.148\ BD \qquad (4)$$

$$r = 0.95, n = 14$$

Where Y is the predicted relative soil erodibility factor (K), DR is the dispersion ratio determined using the ratio between non-dispersed and dispersed % silt and % clay, particle size fractions were determined by hydrometer method after dispersion with sodium hexa-metaphosphate solution(Day, 1956). Bulk was determined using undisturbed core samples from sampling point. Soil cores were then oven-dried at 105^0Cto a constant mass and then weighed. Bulk density was then calculated as the mass of the dry soil divided by the core ring volume expressed in g/cm^3(Richards, 1954) finally soil organic matter (SOM) content was determined using Walkley and method (Black, 1965).

Table 5.2 Soil erodability factor, (K)

Soil units	K_value
Eutric Cambisol	0.28
Luvisols	0.3
Chromic Acrisols	0.17
Vertisols	0.25

Soil properties data were calculated to give the soil erodibility factor for the four mapped soil units as shown in Table 5.2. The K – factors were added to the attribute database to create the soil erodibility layer. The results of the soil erodibility map were converted into grid format for further analysis.

5.3.5 Determination of slope length and steepness factor

The LS factors in RUSLE model present the topography effect on soil erosion. The increase in slope length and steepness increases the flow of surface water thereby increasing soil erosion. The slope length is the distance between the high point of start downhill to the lowest point. The topography effect is estimated by LS factor. Slope length and slope steepness (LS) were calculated as a single index, which expresses the ratio of soil loss as defined by Weischmeir and Smith, (1978) in equation 5.

$$LS = \left(\frac{X}{22.1}\right)^{m} \ (0.065 \ + \ 0.045S \ + \ 0.0065S^{2}) \qquad (5)$$

Where X = slope length (m) and S = slope gradient (%)

The values of X and S were derived from DEM. To calculate the X value, Flow Accumulation was derived from the DEM after conducting FILL and Flow Direction processes in ArcGIS.

$$X \ = \ (\text{Flow accumulation} \ \times \ \text{Cell value})$$

By substituting X value, LS equation:

$$LS = (\text{Flow accumulation} \ \times \ \text{Cell value}/22.1)^{m}(0.065 \ + \ 0.045S \ + \ 0.0065S^{2}). \qquad (6)$$

Slope (%) was also directly derived from the DEM using GIS. The value of m varies from 0.2 – 0.5 depending on the slope. For preparation of the LS map, first the raster map of flow accumulation was prepared by Arc Hydro Extension, DEM map and the ArcGIS 10.1 software was used to prepare the output LS factor map (Figure 5.5).

5.3.6 Determination of land cover management factor(C)

The cover management factor represents the impact of ground and vegetation cover on soil erosion, which is related to vegetation type and density (Weischmeir and Smith, 1978; Renard et al., 1997). The study used recent Landsat image to assign C values, landuse/cover classification was thus used to assign C value (Reusing *et al.* 2000). Classification was done using ENVI 4.7 Software (ESRI, 2009) which was used to prepare land use land cove map of the study area. Supervised classification using minimum distance classification was used to classify the images (ESRI, 2009).

Table 5.3 Landuse classes and C-value assigned.

Land-use/cover classes	C Factor
Open forests	0.02
Savannah/Grassland	0.11
Agriculture	0.16
Waterbodies	0
Barelands	0.99

Five classes of land use were identified namely agricultural lands, barelands, grazing lands, forests and water bodies. The result of the classification was used to derive C – factor for each land cover identified (Table 5.3).

5.3.7 Determination of conservation practice factor (P)

The conservation practice factor is the soil loss ratio with a specific conservation practice (Renard *et al.*, 1997). In the present study P factor map was derived from soil conservation measures practiced in the area. Absence of conservation measures assumes unity value while the other conservation measure assumes a value of between 0 and 1 according to Renard and Freimund, (1994). In this study protective operations included terracing, strip cropping and contour farming which were carried out in cultivated lands. Terracing P values were used since this practice was consistent throughout the slopes.

5. 4 Results and discussions

Rainfall erosivity of the catchment ranges between 830.4 MJ mm/yr in the upper parts and 341.67 MJ mm/yr in lower parts of Mutituni. The erosivity is highest in the upper part of the study area, as the area receives more rainfall 960 mm/yr than the lower regions 395 mm/yr as shown in Table 5.1.

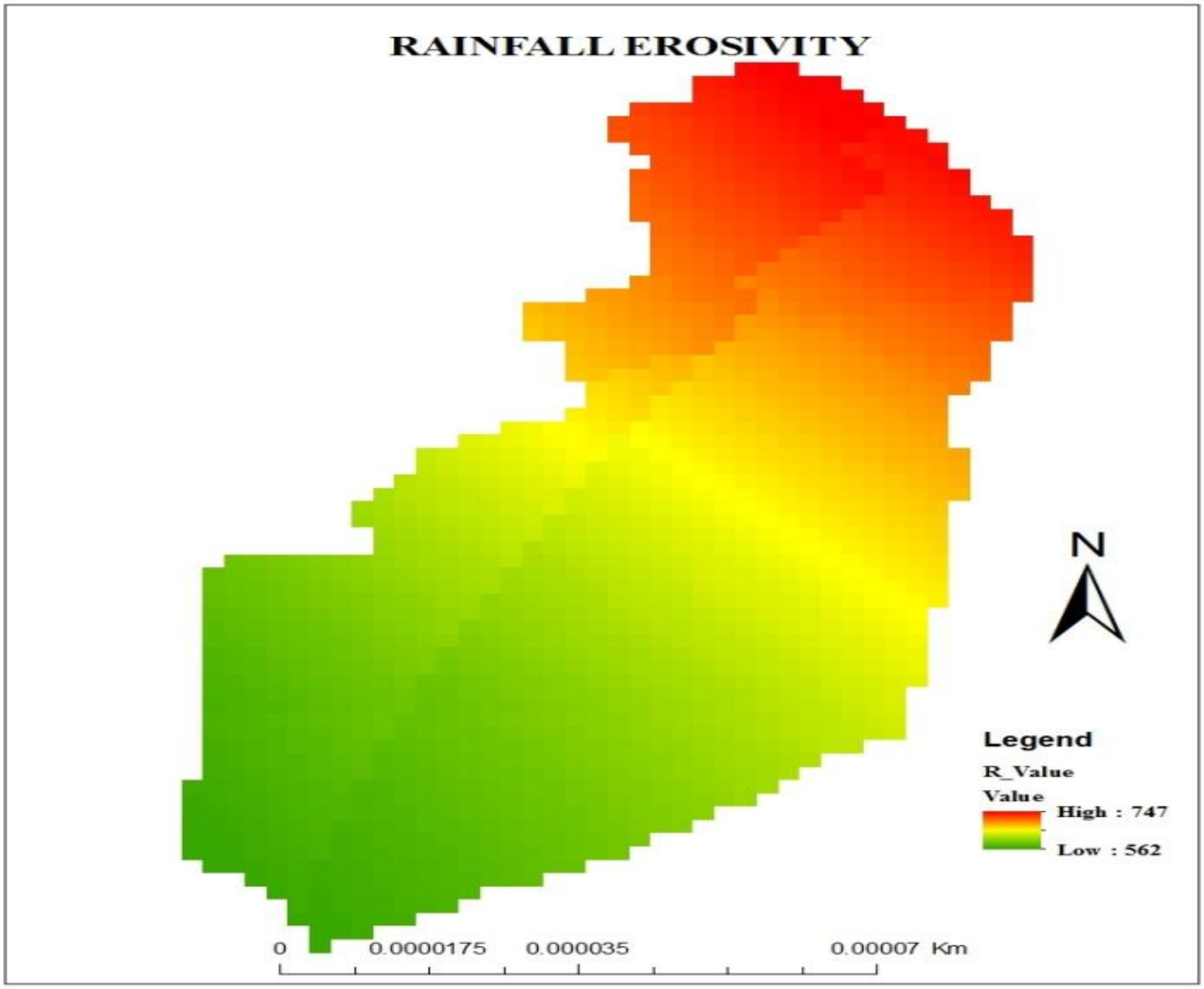

Figure 5.3 Rainfall erosivity factor (R)

As the topography changes from the hilly Mua areas to the flat Katelembo areas, erosivity decreases. Kouli *et al.* (2009) observed that erosivity was highest on the mountainous areas and decreased towards the coastal areas from 2352 to 348MJ mm/ha/year. Rainfall intensity and raindrop's impact are more important in the lower parts where moderate rainfall and poor vegetation cover is experienced than associated runoff. Rainfall erosivity was identified to be of high importance as precipitation is the driving force of erosion and has a direct impact on the detachment of soil particles, the breakdown of aggregates and the transport of eroded particles via runoff especially on the upper parts of Mua hills.

The catchment has 4 major soil units as shown in Table 5.3. Soil erodibility factor (K) was between 0.17 and 0.3 which is within the erodibility range of Kenya soils (Figure 5.4). These soil units are Acrisols, Luvisols, Vertisols and Cambisol whose erodibility factor were within the range as suggested by Barber *et al.* (1979), whereby erodibility of some soil of Kenya to range from 0.03 to 0.49.

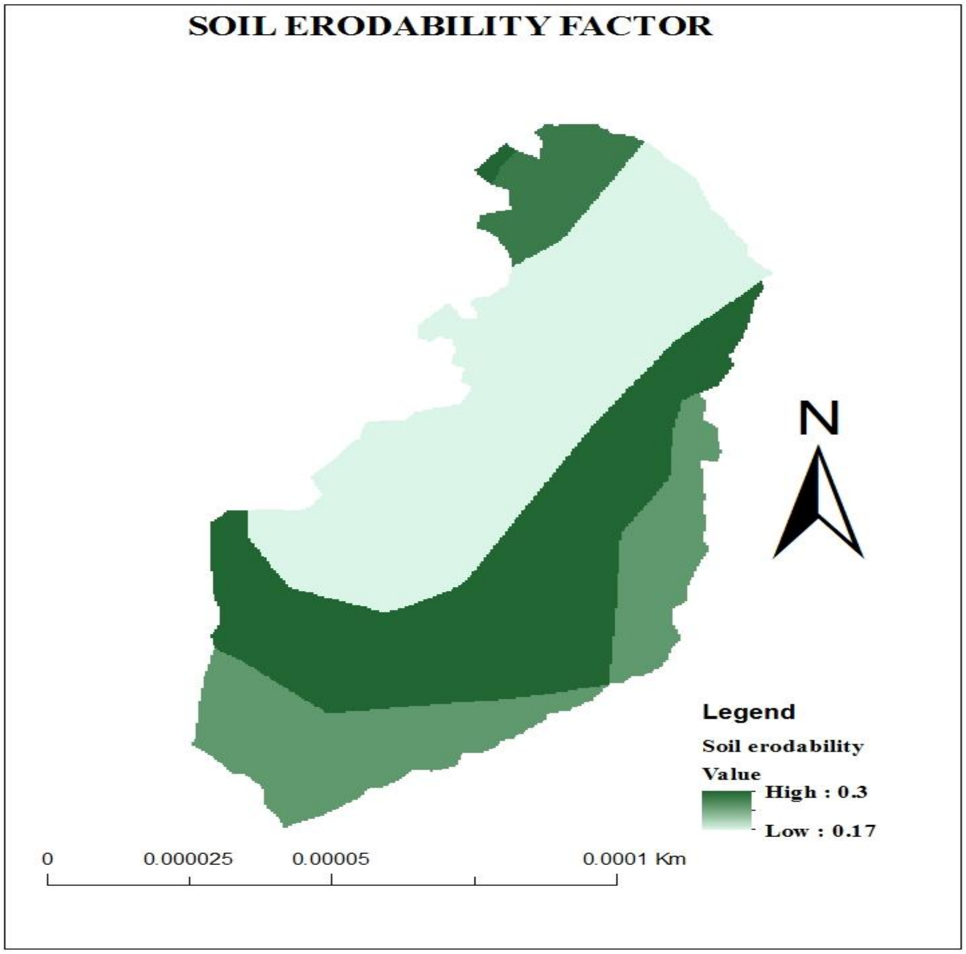

Figure 5.4 Soil erodability factor

Generally these soils had low organic matter content ranging from 1.3 to 2% except for forested areas which had high organic matter of more than 3% (Chapter 4). Vertisols which were found on the lower parts of the area had a K factor of 0.25 which is moderately susceptible to erosion. These soils contain predominantly low activity clay and are susceptible to erosion due to their heavy texture and low permeability especially when wet due to swelling nature of the clays. Work done by Gachene, (1982) also showed that vertisols had the highest K values (0.21) compared to the other soils that were investigated. Vertisols had high clay content of 55% and due to their swelling nature when wet, infiltration rate is reduced. Vertisols were compact when dry as shown by their high bulk density of 1.413 g/cm^3 during analysis. Duiker *et al.* (2001) observed that soil loss of vertisols doubles between the dry and wet season and infiltration rate is reduced suggesting that vertisols erodibility increases when they are wet. Luvisols which was the predominant soil unit in the area had a K value of 0.3. Despite this soil having moderate hydraulic conductivity of 3.6 cm/hr and moderate bulk density of 1.3 g/cm^3 compared to the other units, presence of high silt (30%) content of the surface layer, they are sensitive to crusting and sealing hence more vulnerable to soil erosion. Middleton, 1930 carried out dispersion ratio test on a Luvisols, this soil had a dispersion ratio of 73% which is above 15% mark for erodible soils. Luvisols is the predominant soil in the study area. Furthermore Kilewe, (1984) found similar results for the Katumani Luvisols, whose dispersion ratio ranged from 59.4 to 78.8. Luvisols was a soil erosion risk factor in the area due to it susceptibility and the fact that it was the most common soil unit in the area.

Acrisols had a low K value of 0.17. During survey observation showed that these soils are also were susceptible to slaking forming hard crusts which could have been the probable cause of low hydraulic conductivity of 0.97cm/hr restricting water movement resulting to erosion, especially where the soil was bare. Cambisol found on the upper part of Kathe-kakai catchment had a moderate K value of 0.28, this soil unit had high sand content of 60% and low organic carbon content of 1.97% could be the probable cause of high erosivity. Duiker *et al.* (2001) results disagree with this finding whereby he found erodibility of Cambisol to be low due to high infiltration rate and high organic matter content. These conditions were different in Kathe-kakai explaining why erodibility was high. As this soil had generally low organic carbon below 3% and the presence of sand could make the soil unstable and easily transported by rill erosion.

Figure 5.5 shows that LS factor the LS factor value is fluctuating between 0 and 413, flat regions had the lowest altitude (1564 feets) while the upper parts of the area, Mua hills had the highest altitude (2094feets).

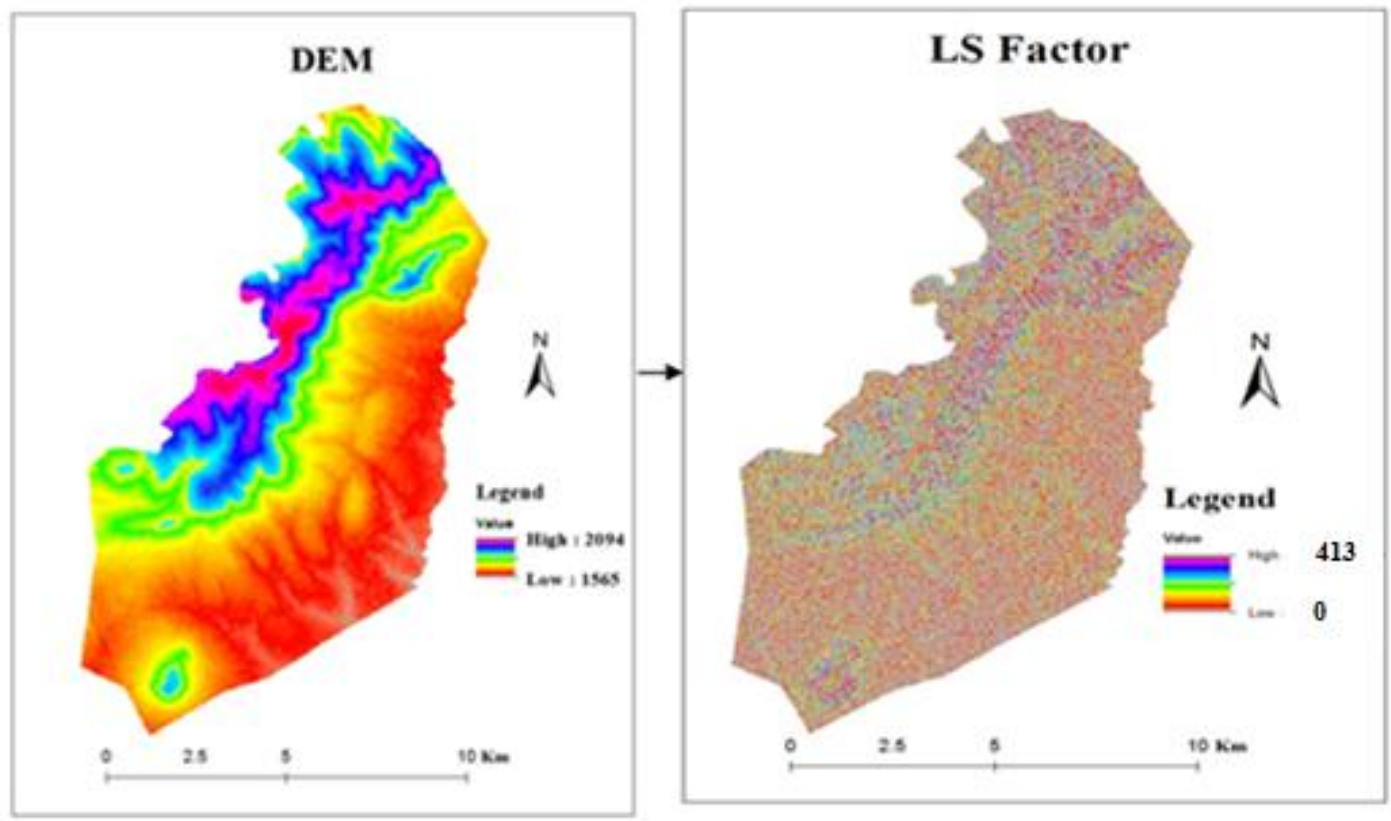

Figure 5.5 Slope length and slope angle factors (LS)

Such steep areas are vulnerable to soil erosion by water (Angima *et al*., 2003), as observed in the erosion map these steep area are likely to have high overland flow. The results showed that erodibility factor is related to slope length. Manyiwa and Dikinya, (2013) observed similar results where K value almost doubled in areas where slopes were 3^0 and above.

Figure 5.6 shows that C value ranges from 0.008 to 1, C value was high where vegetation was scarce and minimal where vegetation was dense. During the baseline survey in the area (see chapter three) results showed that there has been continued loss in natural vegetation.

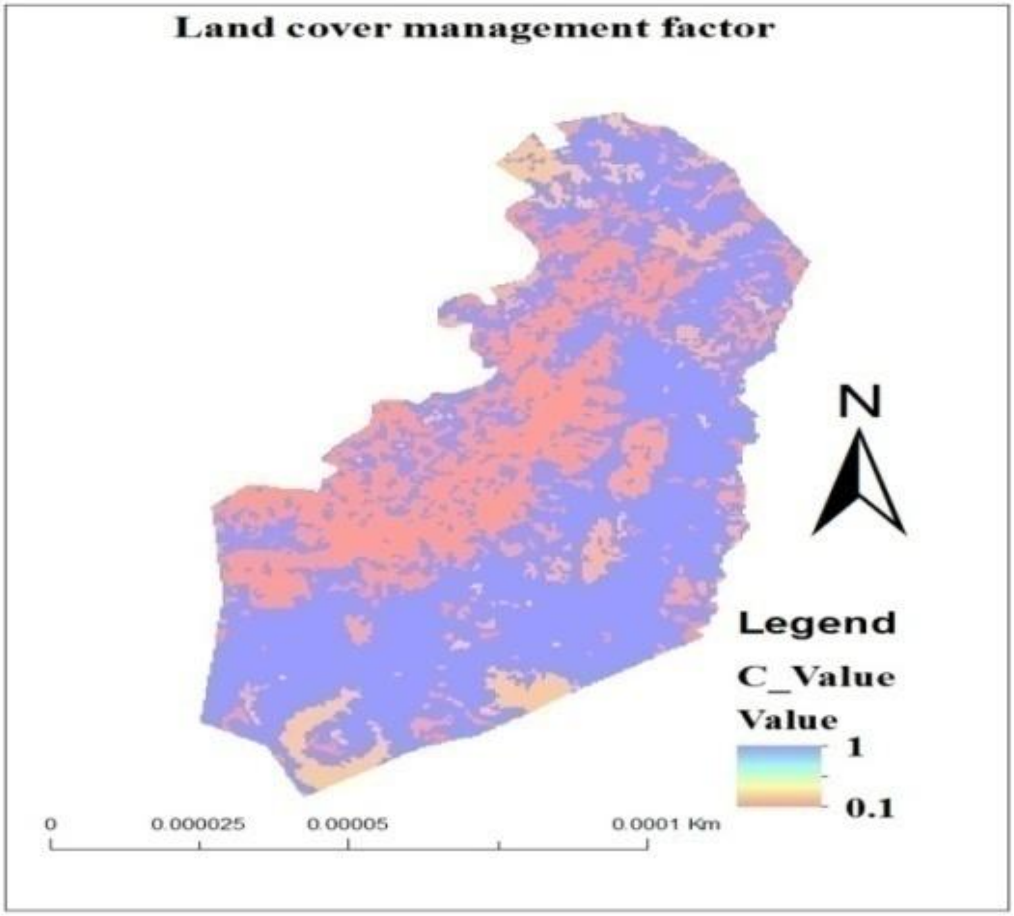

Figure 5.6 Land cover management factor

Mua hill forest has been declining over the years as also observed from Landsat images of the area. In the last 12 years forest has reduced from 38% to 20% from the year 2002 to 2014. Removal of this natural vegetation on steep slopes has resulted in increased soil erosion and gully formation. Rainfall and gradient influence flow of runoff down slope resulting to development of huge and deep gullies, making these regions erosion hotspots. Similar effects of deforestation have been reported from studies in Africa. Zheng, (2006) detected that when human activities encroached into forested areas erosion increased and erosion rates in these deforested lands reached 797 to 1682 times greater than the forested land prior to deforestation. These results showed that accelerated erosion caused by vegetation destruction played a key role in soil degradation and eco-environmental deterioration in deforested regions. Farming in kathe-kakai has increased in the last 10 years from 11% to 36% (see chapter four). Continuous and intensive cultivation has replaced the traditional fallow farming. High erosion rates were observed at the onset of seasons when fields are bare(see chapter three). During field survey in the area farmers who maintained a continuous cover by developing cropping systems observed minimal soil loss in their farms than farmers carrying out mono cropping. De santisteban *et al.* (2006) recorded high erosion rates when there was low percentage of surface covered by vegetation. Gullies and rill were also common in abandoned fields as they experienced very high erosion rates suggesting that the abandonment of marginal lands without implementing any erosion control can lead to severe erosion rates.

The P factor was analyzed using slope together with value assigned for different conservation practices as show in Table 5.4. Conservation practice (P) value ranges were from 0.18 to 1. Where conservation measures were absent, P value assumes unity while areas with conservation practices were assigned values according to Table 5.4.

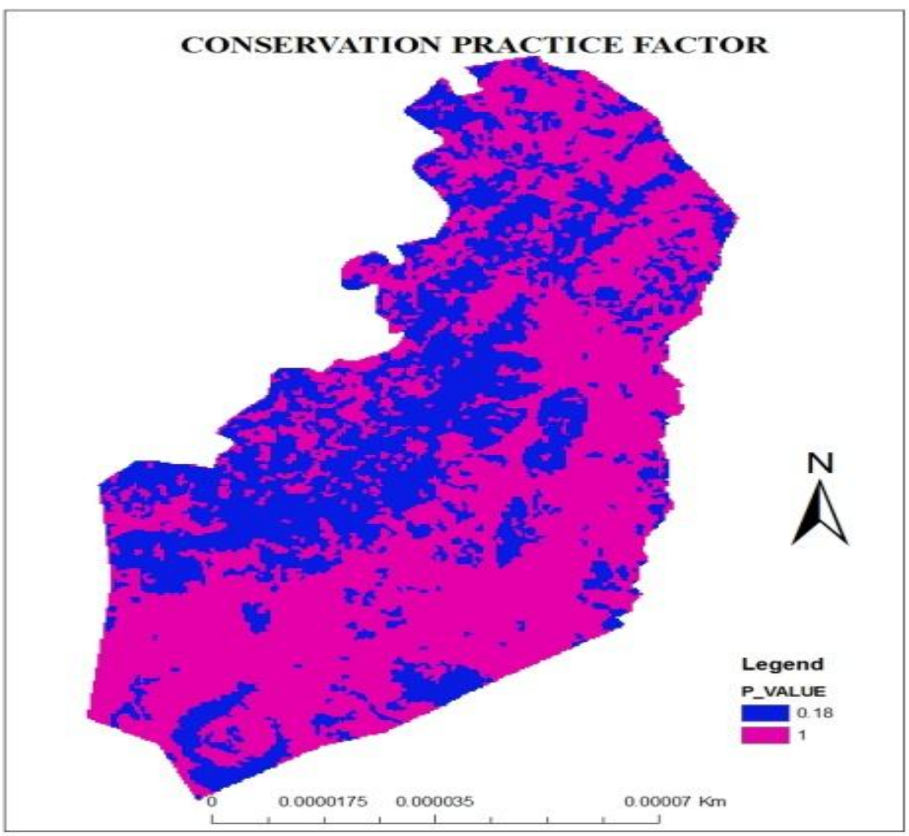

Figure 5.7 Conservation practice factor

Farmers in the area are using both agronomic and structure measure to control erosion. Common agronomic practices observed during intensive survey done in the area are mixed farming, use of grasses and agroforestry while common structural measures used are terracing contouring and use of cutoff drains.

5.4.1 General evaluation of soil erosion

Figure 5.8 shows that soil erosion rates in the area were between 0-60 t/ha/yr. The lower parts of Kathe-kakai and Katelembo are experiencing low to moderate erosion rates while the upper sides of Mua hills are experiencing high to very high erosion rates with patches of erosion hotspots experiencing severe soil erosion. The upper sides are experience soil erosion rate which are very high due to a combination of steep slopes as shown by LS factor of 4.13, inappropriate farming activities as observed during the base line survey (see chapter three) and high rainfall erosivity. Survey showed that these steep slopes are undergoing deforestation and are now under inappropriate systems which are probably accelerating rates of soil erosion beyond the tolerable limits. Angima *et al.* (2003) observed that despite soils in central Kenya not being prone to rill and interrill erosion due to their high clay content, steep slopes greater than 8% caused rill and interrill erosion.

Prasannakumar *et al.* (2012) found that there is a high spatial correlation between annual average soil losses with LS factor. Observation showed that topography had a role to play in controlling soil movement by water. High rates of soil erosion on the upper parts can also be explained by the high rainfall erosivity, soil erodibility of 0.28 to 0.3 which are the highest among the four units and the steep slopes as shown by high LS factor of 4.13. Srinivas *et al.* (2002) observed that soil erosion classes were associated with rainfall erosivity, soil erodibility and sloping lands. Very high soil erosion rates were ascertained where it was hilly, soils erodibility (0.25) were high and rainfall erosivity above 350.

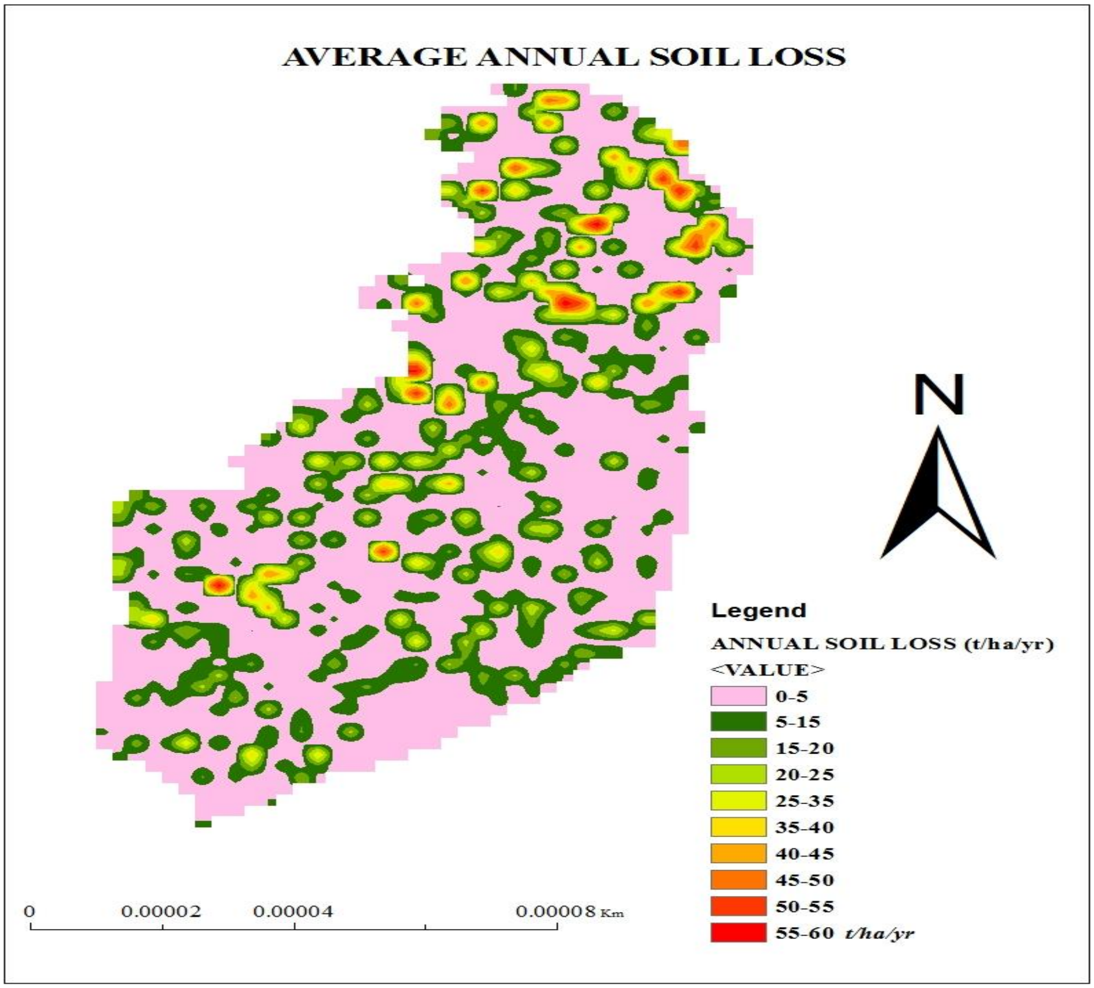

Figure 5.8 Soil losses in tons/ha/yr for Kathe-kakai catchment

Dong-Sheng *et al.* (2006) documented that Cambisols are sandy and shallow, have high infiltration rates and poor structure which is easily detached and limited water holding capacity. Luvisols have a sealing problem impeding infiltration hence they have high runoff rates and thus more susceptible to erosion.

The lower part of the catchment is experiencing high rates of soil erosion due to bare grounds. These bare surfaces are either mining sites for sand or overgrazed areas. These areas have undefined ownership hence termed as common lands (Chapter three). Gomez *et al.* (2004) reported highest soil loss in bare lands than other areas with vegetation cover. More erosion was observed when bare surfaces were on slopes that were steeper than (20%). Gachene, (1997) in his study on the effects of soil erosion on soil properties found that bare grounds experienced more soil loss and runoff than vegetated areas. He found that erosion rates in bare grounds were between 16.7 to 247tons/ha/yr. Vertisols were found on the lower part of the study area. As shown in Table 5.2 vertisols had an erodibility factor of 0.25 which is moderately high. This could explain why the areas under Vertisols are experiencing high soil erosion rate of 40tons/ha/yr and above especially were the lands were bare. Lal (1985) suggested that the heavy texture, type of clay mineralogy and low permeability of Vertisols make them particularly susceptible to sheet and gulley erosion. As observed during the survey, erosion on cultivated area has resulted into abandoned field which are no longer productive. During field survey it was identified that farmers leave their farm fallow when they become unproductive (See chapter three). De santisteban *et al.* (2006) observed that abandonment of bare lands in these marginal lands without considering any soil conservation measure was causing increase in soil erosion rates beyond tolerable rates. Moreover land encroachment and agricultural expansion on to the forest areas have further aggravated the problem as observed during field work. Sharma, (2004) observed that agricultural activities on steep slopes without conservation measures accelerated soil erosion.

Table 5.5 shows the % distribution of mean annual soil loss and area under each risk class. Soil erosion hazard classes determined by Bergsma *et al*., (1996), were taken into consideration to classify erosion hazard in this study. Approximately 54% of the study area is experiencing soil erosion within the tolerable limit hence classified as low erosion hazard areas. This classification is associated with a combination of the erosion factors that result in no appreciable erosion damage occurring during or after the development of the particular land use under consideration. Soil conservation management should however include simple practices, such as conservation tillage where appropriate. 16% of the areas are experiencing moderate soil erosion. Moderate erosion hazard was classified from 12 to 25 tons/ha/yr. Implying that significant erosion may occur during development of the particular land use, but provided appropriate soil conservation measures are adopted during development, both short term and long term erosion problems may be avoided. 24% of the catchment is experiencing high rates of soil erosion. High erosion hazard was taken between 25 to 60tons/ha/yr. This class implies that significant erosion will occur during development of the particular land use and that appropriate erosion control measures are needed in order to minimize long term erosion problems. Control of short term erosion could be provided by simple soil conservation measures but long term erosion control would involve intensive measures.

Table 5.4 Percent distribution of mean annual soil loss and erosion risk classes in (tons/ha/yr)

Numeric range tons/ha/yr	Area (%)	Erosion hazard class
0-10	54	Low
10-25	16	Moderate
25-60	27	High
>60	3	Very high

Bergsma *et al*., 1996

The remaining parts about 3% are experiencing very high soil erosion rates. Very high erosion hazard above 60tons/ha/yr implies that significant erosion will occur during development and after the landuse has been established, even with intensive soil conservation measures. Such an erosion hazard infers that planning will need to carefully consider the balance between the probability of long term erosion damage and the maintenance or repair needed to ensure the viability of the land use. In soil erosion hazard areas as shown in the spatial pattern of annual average soil erosion map there is a high spatial correlation with LS-factor map, management of soil s and landuse. Therefore areas with high LS-factor degraded grassland, bare land and degraded cultivated areas need immediate attention in term of soil conservation.

5.5 Conclusions and recommendations

A GIS based RUSLE equation was used to make a quantitative assessment of average annual soil loss in kathe-kakai catchment. Rainfall, soil, landuse topography and conservation practices datasets were used. All factors used in the model were calculated for the catchment using locally available data for the study area. The estimated soil loss rate for the area was classified from 0 to 60tons/ha/yr. areas with natural forest, proper management practices were observed to experience soil erosion rates within the tolerable rates. High to very high soil erosion rates were observed in areas with degraded shrubs, open forests and very steep lands located on the upper parts of the study area. High soil erosion rates in the lower part are associated with bare lands and Vertisols due to their high erodibility factor of 0.25 which were especially vulnerable to rill and gully soil erosion. Areas with high LS factor were likely to be associated with overland flow due to poor management and partly due to topography.

Since landuse pattern was one of the risk factor in erosion prune areas as areas with natural vegetation for instance forests and grasslands experienced minimum rates of soil erosion. Areas which have undergone human disturbances especially along areas with high LS factor, abandoned and degraded farms experienced high rates of soil erosion. Management efforts like terrain alterations, management practices like contour farming, strip cropping in cultivated areas and planting of trees will reduce erosion. Terrain alteration for instance terracing, reduces the LS factor hence reducing soil erosion rates to tolerable levels as observed. Agroforestry and reforestation are practices being adopted by farming slowly into their farming system. Trees like *Grevillea robusta* and *Calliandra calothyrus* were observed in farming system as they not only reduced soil erosion but also improve soil quality. Farmers are also use trees especially fruit ones to stabilize soil and water conservation structures.

This study shows that GIS environment using RUSLE can be applied to estimate soil loss quantitatively and spatially and also predict erosion hazard in the catchment by pinpointing site specific soil erosion hotspots.

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CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Results from this study are evidence to the reports that land degradation is on the rise in Kenya semiarid areas. The social survey analysis and LULCC study showed a positive relation between human intervention in terms of landuse and land cover change and increase in soil erosion.

Analyzing on LULC change in Kathe-kakai catchment from the year 1988 to 2002 and 2002 to 2014 were carried out to produce map, demonstrating the use of remote sensed imagery to monitor changes for twenty six years. These maps showed a close link between losses in natural vegetation with rising human settlement in the area. Forests declined with 64% while the cultivated areas increased with 68%. Large areas previously covered by natural vegetation have been converted to cultivated lands and open lands over the years due to anthropogenic activities. The nearness of the catchment to Machakos town and Nairobi capital city of Kenya has increased demand for lands for both residential purposes and other activities like sand mining, tree logging and farming. There was also an increase in degraded grasslands and farms, hence an increase in barelands (14%). Physical properties of degraded lands have deteriorated probably causing an increasing in soil erosion. Degraded lands were characterized by low hydraulic conductivity of 0.1 – 0.4 ml/hr and high bulk density of $1.6 g/cm^3$ and low organic carbon of less than 3%, probably causing of increase in overland flow due to reduced infiltration. Forests and well managed lands gave the lowest erosion hazard rates < 5 tons/ha/yr.

GIS environment using RUSLE model was used to estimate soil loss quantitatively and spatially and also predict erosion hazard in the catchment. Results showed that Kathe-kakai catchment is experiencing severe rates of soil degradation inform of soil erosion. Soil erosion rates varied from 0 to 60tons/ha/yr. High to very high erosion were observed in association with shrubs, open forests and very steep lands in the upper parts of the study area. High soil erosion rates in the lower part were associated with bare lands and vertisols which are vulnerable to soil erosion especially rill and gully type due to their expanding clays.

Areas pinpointed during erosion assessment can benefit from urgent conservation efforts. Agronomic measures such as strip cropping, contour farming, use of residue cover, mixed cropping are appropriate for area with high to very high erosion rates. Degraded areas need to be reclaimed i.e. areas with gullies require reclamation to fill them and avert the problem. Structural measures such as bench terracing, rock filling structures, drainage channel diversion and gulley control structures are suitable for extremely severely eroded areas that are considered as hotspots due to their shallow soils and very steep slopes would also reclaim them and make them productive. Conservation efforts in some parts of the catchment have shown success especially where farmers are using trees with grasses and sisal plant. These materials reinforce structures and also hold soil together reducing soil erosion in addition to having other benefits.

Though farmers are using conservation practices like contours, fanya juu terracing and strips cropping, adoption is reasonably low and quite localized. Poverty and ignorance and weakening ties among farmers are the major constrains to adoption of conservation practices. Extension education and training in SWC and membership in farm groups was identified as an important component toward achieving adoption of soil and water conservation effectively. Farmers tend to work as groups in laying out structures and also assist in financial terms. As noted from discussion with farmers these ties are weakening. Farmers prefer to work individually as they find it cumbersome to work as groups. This has become a serious challenge in soil and water conservation as extension officers' work with groups. It is of utmost important to strengthen this link between the farmers and extension officers so as to not only educate farmers but also undertake on farm training. These training will assist farmers in laying soil conservation structures and improve their technical efficiency. Providing subsidies will encourage use of soil and water conservation measures and rainwater harvesting among farmers. Intensification of public awareness to encourage prudent use of resource should be encouraged, as those who still do not realize the need for environmental protection can destroy or frustrate the effort of the majority to safeguard the environment.

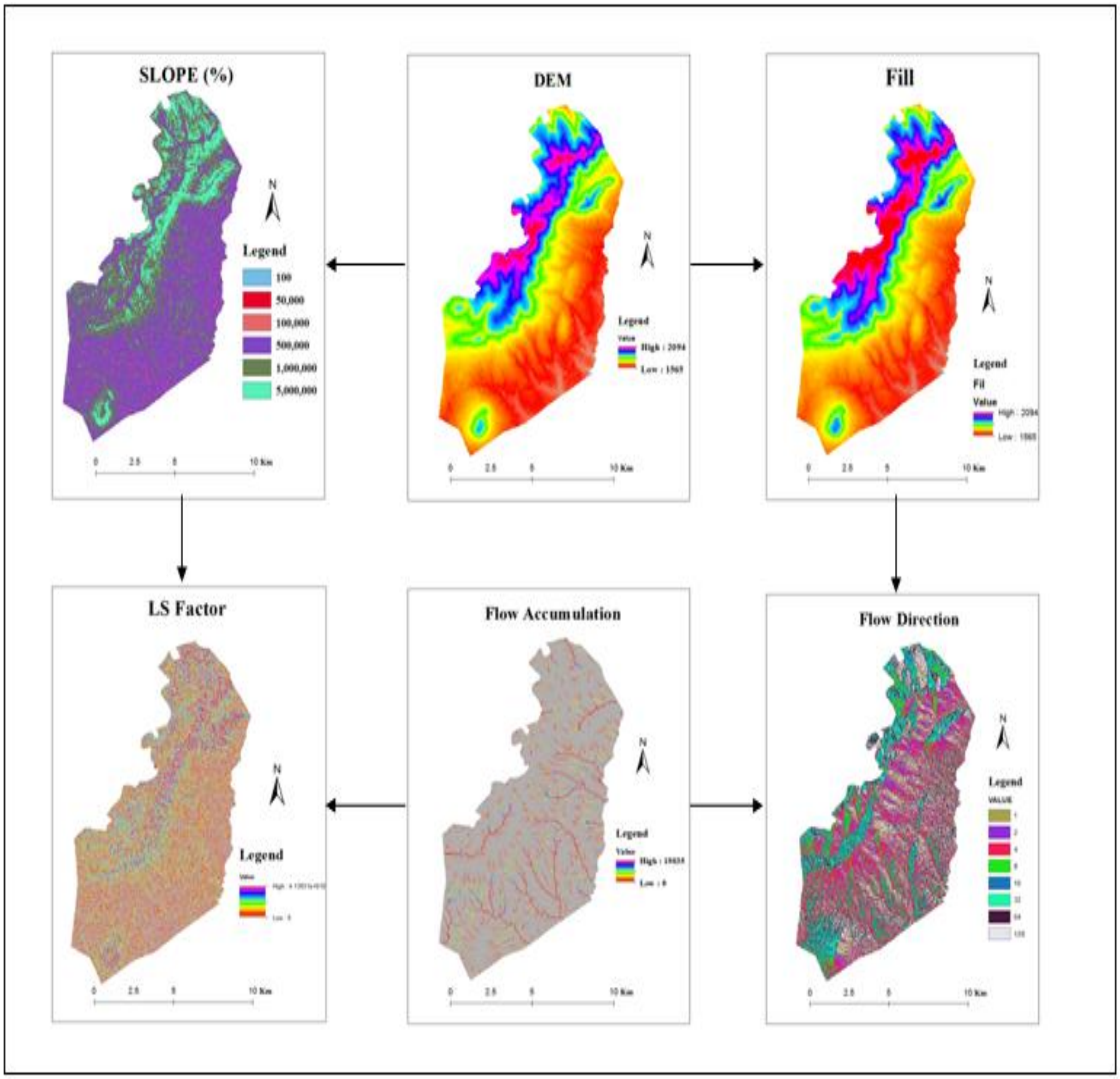
6.2 Recommendations

Following the survey conducted, landuse land cover analysis and soil erosion assessment done in the study area a number of interventions can be recommended.

- Extension officers involvement in promotion of SWC technologies through education and training and providing credit facilities and tools is necessary is important to improve adoption of SWC practices.
- Lack of defined land ownership systems in areas termed as commons lands and unregulated human activities like tree logging and sand mining are aggravating the problem. Giving land rights especially on fragile ecosystem will sustainable activities and encourage soil and water conservation.
- Regulation of activities like mining of sand and logging of trees should be enforced by the County government.
- Farmers should also be convinced to stop cultivating in sloppy areas without soil and water conservation measures.
- Provide subsidies to encourage use of soil and water conservation measures, rainwater harvesting. Long term solutions can be achieved if there is local participation with researchers and commitment of policy makers.

APPENDICES

Appendix 1: Derivation of slope length and slope angle factors (LS)



Appendix 2: Questionnaire on soil erosion and soil and water conservation in Kathe-kakai catchment, Machakos County

Enumerator's name: ____

Date ___/___/___ Start time__ h ___ End time ___h___

Approved YES/NO

Date entered___/___/____ Entered by: _________________________

General information

Name of the respondent__________________________________

Sex of the respondent a) Male b) Female

County ___________________ Division ____________

Location ___________________ Sub location _________________

Village____________________

GPS of the Homestead____________________ Elevation_________________

Agroecological Zone_________________________

Period which the respondent has operated the farm_____________

First name	Last name	Sex	Age	Sources of income	Estimated income	Parenthood	level of Education	Years of farming experience

B Household profile

a)Do you belong in any social group?

1)Yes 2)No

b)If yes which one?

- Self help group
- Women group
- Others (specify)

c)Which activities does the group facilitate?

- Farming
- Welfare

- Community
- Financial investment/saving

C Land ownership/ land tenure

a)What is your total farmer size?

____

b)Do you have a title deed?

1)Yes 2) No

c)What is your form of land acquisition?

- Community lands
- Rental contracts land
- Family land (inheritance)
- Private land (brought)
- Others (specify)

D. Natural resource status

a) What was the area like when you first settled here?

1)Forested 2. Grassland 3. Agricultural land 4. Bareland

b) Rocky water 6. Catchment area

What changes have you noticed since then?

____

____

____

c) What change have you made on your farm?

____

____

____

d)Have this changes had any impact on the land 1. Yes 2. No

e)If yes are these impacts positive or negative? List them

Positive	Negative

f) Have you planted any trees /leguminous crops in your farm? Yes =1   No=2

g) If yes list them

h) Why did you plant the trees/leguminous crops in your farm?

i) Do you graze animals in your farm?   1= Yes   2=No

j) If yes how do you do it?

- Use paddocks
- Animals graze all over the farm

k) In the area are there communal grazing lands 1=Yes   2=No

E Soil erosion status

a) How do you perceive the fertility status of your soils?

1. Very fertile   2. Moderate   3. Very poor   4. Poor

b) Have you experienced soil erosion in your farm?

Yes   No

c) If yes how serious is it

1. Very serious   2. Not serious

d) What observable erosion indicators are there in your farm? Tick where appropriate

- Rills
- Gullies
- Stoniness
- Sedimentation
- Siltation of water bodies
- Rocky outcrops
- Tree roots exposure

e. What types of erosion occur in your farm?

Soil and water conservation technologies.	**If yes, what is the area technology was used on (acres)**	**Number of years farmer used the technology**	**Cost of the technologies**	**How efficient is the technology**
Agronomic practices				
Structural measures				

G Education and training in SWC measures

a) Where did you get information regarding soil and water conservation?

Sources of information	Tick where appropriate(✓)
Public extension service providers	
Private extension service provider	
Fellow farmers	
Public researcher	
Consultant	
Radio	
Television	
Print media: newspapers, pamphlets	
Others(NGOs, barazas, international organizations)	

b) Have you experienced any benefits from the measures you have used?

1= Yes 2. No

c) If yes what are the benefits

d) What difficulties you encounter in laying the structures

e) How is the terrace embankment utilized?

- Crops grown
- Grasses
- Left bare

f) How is the terrace ditch utilized?

- Crops grown
- Grasses
- Left bare

g) Which structure stabilizing material do the farmer use e.g. grasses

h) What are the advantages and disadvantages of stabilizing materials

Advantages	Disadvantages

i) How do you utilize your crop residues?

a) Mulch

b) Sold

c) Forage

i) How would you rate the adoption of SWC measures by farmers?

- Good
- Fair
- Poor

i) What are the constrains to adoption of SWC measures? Tick where appropriate

- Lack of capital
- Lack of labor
- Lack of tools benefits not known
- Women headed households
- Land tenure insecurity
- Small farm size
- Others(specify)

H Water harvesting

a) Do you have any insitu water harvesting structures within your farm

1)Yes 2)No

b) If yes list them

Appendix 3: Questionnaire for erosion hazard areas

1. **Erosion hotspots**
   a. Are you aware this is an erosion hotspot?

      1)Yes 2)No

   b. If Yes, what features would you associate with this situation?
   c. What would you say are the root causes?
   d. What factors make this area vulnerable to erosion?
2. **Management aspect**
   e. Are there any management strategies in place to reduce erosion?

      1)Yes 2)No

   f. If Yes, can you state them
   g. Who are rehabilitating these areas?
3. **Questionnaire for Soil and water conservation officer in the area**
   h. Are you aware about these hotspots in the area?

      1)Yes 2)No

   i. What were the areas like before they became a erosion hotspots?
   j. Why are they there?
   k. Are these hotspots being addressed?

      1)Yes 2)No

   l. If Yes, how?
   m. Are you training the farmers on soil and water conservation?

      1)Yes 2)No

   n. If Yes, what are the challenges?

Appendix 4: Questionnaire for focused group discussions on soil erosion and soil and water conservation

A) Engagement questions:

1) What makes this area vulnerable to erosion?

2) What are the root causes of erosion hotspots in the area?

3) How would you rate the adoption rate of SWC? Why?

1=good, 2=fair, 3=poor

B) Exploration Questions:

1) Which are the common SWC measures used in the area by type?

Agronomic	Structural

2) Why do farms have a preference toward these SWC measures?

3) Why are farmers not carrying out water harvesting technique? Incentives?

4) What factors do you consider to be a hindrance of SWC adoption in the area?

5) Which incentives would make farmers adopt SWC?

C) Exit question:

1) Is there anything else you would like to say about soil and water conservation?