EFFECTIVENESS OF RIPARIAN BUFFER STRIPS IN MITIGATING CHANGES IN SOIL PROPERTIES RELATED TO LAND USE ACTIVITIES IN THE RIVER NJORO WATERSHED, KENYA

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A thesis submitted to the Graduate School in partial fulfilment for the requirements of the degree of Master of Science in Environmental Science of Egerton University

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DEDICATION

I dedicate this thesis to the Enanga family, relatives and friends who have continuously supported me in my studies and my life in general.

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ABSTRACT

Riparian buffer strip guidelines are under scrutiny in the River Njoro Watershed in Kenya. The riparian buffer strip in River Njoro watershed varies from zero to more than 30 m. There is no scientific justification for a 30 m riparian buffer strip or any other width yet the Water Act of 2002 sets a maximum of 30 m width. The purpose of this research was to investigate the effects of different land use areas, such as gazetted forest, small scale agriculture in recent settlements, peri-urban settlements, and large scale commercial agriculture, on the physical (bulk density) and chemical [carbon content (%), nitrogen content (%), phosphorus concentration (mg/kg)] properties of soils in different land use areas and their adjacent riparian buffer strips and to compare these properties to the reference condition provided by the gazetted forest. Land use influence on stream bank stability and riparian buffer strip width were investigated too. The research was conducted in a stratified random sampling design with the different land use areas as different strata. The research revealed that the government regulated 30 m riparian buffer strip was effective in mitigating changes in soil properties in recent settlement land use areas in upper River Njoro watershed. However, the 30 m riparian buffer strip was not effective in mitigating changes in phosphorus concentration in peri-urban areas, or bulk density, carbon content, nitrogen content, or phosphorus concentration in commercial agriculture land use areas. Land use activities were not a factor in determining the stability of stream banks; rather the water access points were equally disturbed in each of the land use areas. Land use activities influenced width of the riparian buffer strip with gazetted forest (30.00 m) having the widest width followed by recent settlement (20.05 m), peri-urban (17.95 m) and commercial agriculture (15.98 m) had narrowest. Based on the research, it can be concluded that a 30 m riparian buffer strip is effective in mitigating changes in soil properties in recently settled areas but not peri urban and commercial agriculture areas. Land use does not affect stream bank stability but local land use has an influence. It is recommended that policies governing riparian buffer strips be: modified, with the current "maximum" of 30 m considered a minimum; adaptive, with 30 m used in small scale agricultural areas, but wider riparian buffer strips used in medium and large scale agricultural areas; and water access points be relocated away from the banks edge to outside the riparian buffer strip area. The research provides scientific support for the use of riparian buffer strips to mitigate changes in soil properties related to land use activities within River Njoro watershed.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BD	Bulk Density
BSI	Bank Stability Index
C	Carbon
CA	Commercial Agriculture
CRF	Catchment Research Facility
GF	Gazetted Forest
GL-CRSP	Global Livestock-Collaborative Research Support Program
WAS	World Agroforestry Centre
N	Nitrogen
NIR	Near Infra Red
P	Phosphorus
PRA	Participatory Rural Appraisal
PU	Peri-Urban Settlements
RNW	River Njoro Watershed
RS	Recent Settlements
SUMAWA	Sustainable Management of Watersheds

DEFINITION OF TERMS

Aquatic- relating to water, living in or near water or taking place in water.

Bank Stability Index- a scale for showing the stability of a stream bank based on vegetation cover, substrate type, depth of stream bank and angle of the stream bank.

Commercial agriculture-agriculture that is practiced on a large scale, it is highly mechanized and synthetic fertilizer use is intensive.

Ecosystem- a biological community that occurs in a location and the physical and chemical components that makes up its non-living environment.

Gazetted forest- government owned forest that has not been opened up for settlement to the public.

Peri urban areas- areas that fall both within urban set ups and agricultural setting

Recent settlements- areas that have recently been degazetted for settlement with small scale mixed agriculture as the main land use activity.

Riparian buffer strip- strips of vegetation next to water resources that protect water resources from non-point source pollution and provide bank stabilization and aquatic and wildlife habitat.

Riverine- located on or inhabiting the banks of a river.

Stream bank- the raised edge of land after a stream that is the highest water point that confines water into the channel.

Watershed- the area of land where all of the water, which is under it or drains from the land goes into the same place.

CHAPTER ONE

INTRODUCTION

1.1 Background

Riparian buffer strips have become an integral part of watershed management in many landscapes. However, in most of Africa, riparian buffer strips are not used. For example, current policy in Kenya requires a maximum of 30 m riparian buffer strip width to exist between land used for various human activities and streams (Government of Kenya, 2002). This policy is being debated, as some stakeholders feel the width is too wide, while others express a need for a wider riparian buffer strip. There is no scientific basis to support a 30 m or any other width of the riparian buffer strip. Land use activities adjacent to riparian buffer strips may lead to changes in soil properties within these areas and thereby reduce water quality in the adjacent stream. To facilitate proper management of aquatic resources, we must advance our understanding of the effectiveness of riparian buffer strips in mitigating changes in soil physical and chemical properties caused by adjacent land use activities. This study provides scientific support for the use of riparian buffer strips to mitigate changes in soil properties caused by adjacent land use activities within African landscapes.

In traditional African culture, there is no demarcation or separation of people from nature since nature and people are viewed to be one and the same (Lelo *et al.*, 2005). With regard to riparian buffer strips, people in communal Africa have sustained their livelihoods for many years by practising riverine and/or stream bank cultivation without posing a significant threat to the environment (Derman, 1998). Therefore, visits to watercourses and the activities of humans and domestic animals in the humid and wet zones of streams occur on a daily basis in tropical countries (Mathooko, 2001).

Early in the 20th century, many countries in eastern, western and southern Africa became British colonies. British colonial governments enforced forestry policies against the felling of riparian areas by establishing large zones that were to be left intact, extending in each direction from the stream's edge. Stream bank regulations that were enacted during the colonial period and continued in post-independence Africa stipulated that no cultivation should be done in the riparian area. The regulations were developed out of awareness that riparian vegetation provides useful ecological services including regulation of stream water

quality and sediment flows (Carroll, 1947). Unfortunately, the British colonial systems protected the forests and riparian buffer strips through coercion through forest guards and chiefs who were given authority to punish those who encroached into the forests and riparian areas (Lelo *et al.,* 2005).

After the end of the Second World War most of the countries under British rule became independent states and inherited the British conservation regulations which were and continue to be perceived as oppressive by most people (Lelo *et al.,* 2005).

In recent years, there has been a shift from no significant impact to significant impacts on riparian buffer strips as human activities within watersheds have escalated. In many African countries, the expansion of riverine and wetland gardens have caused increased pressure on existing water resources (Derman and Ferguson, 2003). Furthermore, increasing human population with consequent increase in use of synthetic fertilizers and intensive grazing are being experienced causing increase in pressure on existing water resources (Zehdner *et al.,* 2003). Local communities in African countries are posing a significant threat to the environment; they can no longer leave in harmony with nature. This suggests that the traditional communal use of riparian resources when human populations were small and agricultural practices and grazing were in balance with natural ecological processes cannot continue.

Challenges to effective riparian buffer strip management seem to affect all parts of Kenya. For example population increase has resulted in a corresponding increase in demand for food while the level of technology to increase food production has not kept pace (Ministry of Planning and National Development, 2003). Similarly, demand for energy and water has increased while the forests are declining and water supply systems are failing. Consequently, the natural resource base upon which rural populations depend almost entirely is under pressure due to these growing demands (Lelo *et al.*, 2005). Furthermore, humans and livestock spend a large portion of the day seeking shelter from equatorial sunlight and heat in the shade of riparian trees (Wyant and Ellis, 1990). Unfortunately, regulatory mechanisms that enforce sustainable management of communal property resources have failed and each community is applying their own cultural values and experiences to the use of riparian resources (Lelo *et al.*, 2005).

In Kenya, River Njoro drains a major watershed covering an area of approximately 280 km^2 (SUMAWA, 2004). The headwaters occur on the eastern Mau escarpment and descend in a northeast direction cutting across several land use areas and communities with diverse cultural orientations before terminating at Lake Nakuru on the floor of the Rift Valley at about 1759 m above mean sea level. The River Njoro watershed contributes about 65% of the freshwater supply to Lake Nakuru (Gichuki *et al.*, 1971; Lelo *et al.*, 2005, Shivoga *et al.*, 2007) a saline-alkaline lake enclosed within Lake Nakuru National Park. The park is Kenya's second most internationally visited wildlife park, due in part to Lake Nakuru's large population of flamingos. In addition to the birds, other wild animals abound and their presence is dependent on the continued flow of the River Njoro (Lelo *et al.*, 2005).

During the last 20 years the River Njoro watershed has undergone rapid population growth and land use change with associated negative impacts to water resources, human public health, the local economy and livelihood systems (Lelo *et al.*, 2005). The watershed is being converted from forest to agriculture, ranging from small-scale agricultural practices with people settling in the area to large-scale commercial agricultural enterprises (Krupnik, 2004). The effect of these developments has been a conspicuous reduction in riparian area over a wide area (Mathooko, 2001). This has resulted in increased pressure on riparian buffer strips in terms of their role as filters for stream bound sediments and nutrients and maintenance of stream bank stability in River Njoro watershed.

Rivers in Kenya are public resources and are accessible to any one at any time (Lelo *et al.*, 2005). The Land Act (Cap 307, section 13 and 3) states that; the riparian zone, including the vegetation which grows along the river, is government property (Jackson, 1988). The official size of the strip of government owned riparian land is marred in confusion. It is not standard and varies according to the width of the river. The two pieces of land on both sides of the river are to be left intact.

The Water Act 2002 describes riparian zones as land lying within 2 meters of a watercourse, or, in case of a watercourse more than 2 meters wide, a distance equal to the width of that watercourse to a maximum of 30 meters (Government of Kenya, 2002). However, in most cases due to the vastness of the task of definition and enforcement, management of the riparian zone is left to interpretation of the individual owning land adjacent to the river (Lelo *et al.*, 2005). In practice, this leads to many landowners clearing the vegetation and using the land right up to the edge of the river. Indeed, River Njoro riparian

vegetation is disturbed through grazing and browsing by wildlife and domestic stock, cultivation and other human uses (Mathooko and Kariuki, 2000). As a consequence, there is increased erosion, nutrient and sediment loadings and human and animal pollution, along with damage to the ecological integrity of the riparian corridor with resultant changes in the hydrologic regime of River Njoro (Lelo *et al.*, 2005; Shivoga, 2001).

Studies reveal that River Njoro has only a narrow strip of native riparian vegetation of about 20 m covering either side of the river channel (Magana and Bretshko, 2003) and some sections of the riparian vegetation have been completely cleared for access to stream water for domestic use and watering animals amongst other uses (Mathooko, 2001). It is believed that the conflict over the use of riparian resources in River Njoro provides an example of the land management crisis facing Kenya: a case of the existence of laws that are not supported by local people and their institutions (Lelo *et al.*, 2005).

The Kenyan government recognizes a need for change on how water resources are managed and has set up regional water management boards with the mandate to manage all water and its associated resources like riparian buffer strips. Advocacy for a properly functioning riparian buffer strip is strong because River Njoro is stressed by nutrients from activities within its catchment (Mokaya *et al.*, 2004, Shivoga *et al.*, 2007) with consequent impacts on water quality and quantity. The Kenyan government through the Ministry of Water and Irrigation and the local Water Resources Management Authority (WRMA), along with private and public partners, are seeking ways to reduce the country's degradation of water resources.

One of these scientific partnerships included the Sustainable Management of Rural Watersheds: Biophysical, Livestock and Human Interactions (SUMAWA) a Global Livestock Collaborative Research Support Program (GL-CRSP) project.

Intact riparian buffer strips act as filters for sediments, pollutants, contaminants and confer stream bank stability. The underlying assumption of riparian buffer strip management is that the optimal width of the riparian buffer strips should function to reset soil properties and stabilize stream banks to those of natural landscapes. However, there may be a limit to the effectiveness of riparian buffer strips, when land use activities result in sediment and nutrient loads to riparian buffer strips that exceed their buffering capacity.

This study focuses on land use activities and their effects on the soil physical and chemical properties and bank stability in the riparian buffer strips themselves.

The goal of this study was to determine if Kenya's policy of a maximum of 30 m width riparian buffer strip is effective in mitigating changes in the physical and chemical properties of soils within riparian buffer strips and stream bank stability related to land use activities in the River Njoro watershed.

1.2 Statement of the Problem

Watershed management practices may use riparian buffer strips (i.e., strips of vegetated areas adjacent to streams, ponds and other waterways) to protect water resources from pollution; prevent erosion of the banks of these water resources; provide wildlife food and cover; shade the adjacent water; and moderating temperatures for aquatic species. The riparian buffer strip is an important and significant part of the River Njoro watershed in Kenya and ranges from zero to greater than 30 m in width in the different land use areas. Current policy in Kenya requires a maximum of 30 m riparian buffer strip width between streams and adjacent land use areas. This policy is being debated, as some land owners feel it is too wide, while others feel it is too narrow. However, there is no scientific basis to support a riparian buffer strip width of between 2 m and 30 m or any other width of the riparian buffer strip. The aim of this study was to investigate the effects of different land use activities on soil physical and chemical properties within a 30 m width band on both sides of the stream; stream bank stability and riparian buffer strip widths in River Njoro Watershed and make appropriate recommendations.

1.3 Objectives

1.3.1 Broad Objective

To investigate the effects of different land use activities on riparian buffer strip width, stream bank stability and the physical and chemical properties of soils in different land use areas and their adjacent riparian buffer strips and to compare these properties to the reference condition provided by the gazetted forest.

1.3.2 Specific Objectives

1. To determine the riparian buffer strip width in different land use areas in River Njoro Watershed.

2. To determine the soil physical and chemical properties in riparian buffer strips in different land use areas in River Njoro Watershed.

3. To determine stream bank stability and the soil physical and chemical properties in riparian buffer strips adjacent to different land use areas in River Njoro Watershed.

4. To determine if a 30 m riparian buffer strip is too wide or too narrow in mitigating changes in soil physical and chemical properties in different land use areas in River Njoro Watershed.

1.4 Hypotheses

The null hypothesis is:

> Land use (gazetted forest, recent settlement, peri-urban settlement, and commercial agriculture) does not affect the width of the riparian buffer strip, physical (bulk density) and chemical properties (% total carbon, % total nitrogen, extractable inorganic phosphorus) of soils in riparian areas or the stability of stream banks.

To assess whether land use activities are important in determining riparian buffer strip widths, soil physical and chemical properties, and stream bank stability, the following null hypotheses were tested:

1. There are no significant differences in riparian buffer strip widths in different land use areas in River Njoro watershed.

2. There are no significant differences in soil physical (bulk density) and chemical properties (% total carbon, % total nitrogen, phosphorus concentration) in different land use areas in River Njoro watershed.

3. There are no significant differences in soil physical (bulk density) and chemical properties (% total carbon, % total nitrogen, phosphorus

concentration) and stream bank stability in riparian buffer strips adjacent to different land use areas in River Njoro watershed.

4. There are no significant differences in soil physical and chemical properties in different land use areas, where riparian buffer strip widths are ≥30 m, <30 m and the reference condition (gazetted forest) in River Njoro watershed.

1.5 Justification

Riparian areas are the interfaces between terrestrial and aquatic ecosystems that border water bodies. As interfaces, they encompass sharp gradients of environmental drivers (moisture, temperature, and redox), ecological processes, and plant and animal communities (Gregory *et al.,* 1991). Riparian buffer strips represent an important filter of sediments, nutrients and contaminants in water flowing from contributing hill slopes to the stream (Bilby, 1988). Riparian buffer strips are composed of unique vegetation that helps stabilize stream banks and soil properties that vary in space, land use area and width of riparian buffer strip. Natural riparian buffer strips in the River Njoro watershed are composed of grasses and/or trees, or both types of vegetation and if they are appropriately managed or protected, they can exist under most land use areas (e.g. natural, agricultural, forested, suburban, and urban).

The riparian buffer strip in the River Njoro watershed is a unique region that buffers the river against effects of upland land use activities. It ranges from 0 m in width to > 30 m in some areas of the watershed which is heavily dependent on the adjacent land use activity. This is a source of concern since without the riparian buffer strip there is a danger of the River Njoro being overloaded with sediment, nutrients and contaminants and weakening of stream banks with the potential of the effects being felt by downstream communities, that depend on the river, and Lake Nakuru; a Ramsar site and the terminus of River Njoro.

Most researches in River Njoro watershed have concentrated on riparian vegetation species composition and water quality and generalized functions of the riparian buffer strips but none have quantitatively determined changes in soil physical and chemical properties and stream bank stability. This research attempted to address this concern by investigating soil physical and chemical properties since the carbon, nitrogen and phosphorus ratio in soils adjacent to different land use activities may reflect the ratio in the adjacent stream water with the resultant repercussions being felt by downstream communities that include Lake Nakuru. The research may provide scientific justification for a maximum of 30 m

riparian buffer strip width as provided in the Water Act of 2002 or help guide on the optimal riparian buffer strip widths to be maintained in different land use areas in order to protect River Njoro against the effects of different land use activities in its watershed.

The ultimate goal of this study was to determine if the 30 m riparian buffer strip is effective in buffering the stream against catchment land use activities while at the same time ensuring that downstream communities continue to benefit from the ecological services provided by the riparian buffer strip and River Njoro in general.

1.6 Limitations

Despite all the findings that have come out of this research, the current experimental design had limitations.

1. Each land use area did not have its own reference condition, within the same land use, to be used to compare effects of the land use on the soil physical and chemical properties and stream bank stability. Having gazetted forest as the sole reference condition may have overstretched its influence.

2. What was delineated as different land use areas were not as homogenous as would have been expected, for example the land use gazetted forest had pockets of grasslands for grazing.

3. The boundary between peri-urban settlements and large scale commercial agriculture was not distinct, peri-urban areas had large influences of large scale commercial agriculture. Egerton University (Turkana flats) site is a hybrid between large scale commercial agriculture with its large farm and peri-urban land use within its environment yet it was classified exclusively as peri-urban.

1.7 Significance of the Study

This research has contributed to the enhancement of knowledge regarding the effectiveness of riparian buffer strips in mitigating changes in soil properties related to different land use activities in River Njoro watershed. Scientifically, it has provided confirmation of the role of riparian buffer strips in mitigating changes in soil properties related to land use activities. Research in other areas that have experienced changes in riparian buffer strip soil properties have highlighted the variable nature of land use controls

on soil properties (e.g., Lowrance *et al.*, 1984a; 1984b). Although confirming the work of others, this thesis extended the understanding of the nature of riparian buffer strips equal to or greater than 30 m and less than 30 m within different land use areas in River Njoro watershed by showing that buffers of 30 m or less responded differently, and that differences were largely attributable to land use activities.

It is hoped that the research findings will contribute significantly in positively influencing decisions regarding riparian buffer strip widths and management in the ongoing stakeholder workshops in the River Njoro watershed (Lelo *et al.*, 2005) on the importance and proper management of riparian buffer strips.

1.8 Assumptions of the Study

The following assumptions were made when conducting this research:

1. Gazetted forest land use riparian buffer strip soil physical and chemical properties provided a reliable reference against which soil properties of riparian buffer strips adjacent to all other land use areas could be assessed.

2. Natural features like parent rock material had minimal effect on riparian buffer strip soil physical and chemical properties and differences were mainly due to different land use effects.

3. Land use activities within each stratum were homogenous and heterogeneous between strata.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes reviews related to influence of catchment land use activities on riparian buffer strip widths, soil physical and chemical properties and stream bank stability. The chapter also summarizes the ecological roles of riparian buffer strips and best management practices that can be implemented. The role of land use (gazetted forest, human settlement and agricultural activities) in affecting riparian buffer strip widths, soil properties and stream bank stability is not to be neglected as indicated in the literature. This is because in the past, the general strategies of identifying effects of land use on riparian buffer strip have mainly aimed at describing the nature of riparian vegetation species composition (Mathooko and Kariuki, 2000) in different land use areas and water quality and quantity (Shivoga *et al.,* 2007). However, these strategies have not been successful in quantifying the effects of land use activities on riparian buffer strip widths, soil properties and stream bank stability in the River Njoro watershed since this has not been previously researched on.

It is hoped that this review will provide an assessment and be able to site the broad implications of catchment land use activities and the condition of the riparian buffer strip will have for watershed management policy and institutional coordination with a view to improving the riparian buffer strip along the River Njoro. It will also bring out issues related to soil physical and chemical properties that have not been previously assessed.

2.2 Ecological Services Provided by Riparian Areas

Riparian areas provide key services for all ecosystems. Such services include dissipation of stream energy, trapping of sediments, filtration of pollutants and contaminants from surface runoff, provision of wildlife habitat and corridors and regulation of both seasonal and perennial flows of water (Price and Lovett, 2002). The ecological services that riparian areas provide are especially important in dry regions, where they provide the main source of moisture for plants and wildlife, and the main source of water for downstream plant, animal and human communities (Armour *et al.*, 1994). Mathooko (2001) observed that increased human population and associated livestock population along the stream has led to an

increase in the disturbance of the vegetation in riparian areas. Therefore, this thesis focuses on sediment control, pollutants and/or contaminants control, and stream bank stabilization roles of riparian buffer strips in the River Njoro watershed. These issues have not been seriously addressed before, yet the soil physical and chemical properties in riparian buffer strips are likely to reflect the water quality in the River Njoro since rivers are ecosystem dependent resources (Baldyga, 2005). This will in turn influence the water quality in Lake Nakuru, the terminus of River Njoro.

2.2.1 Sediment Control

Sediment refers to soil particles that enter streams, lakes, and other bodies of water from eroding land, including ploughed fields, construction and logging sites, urban areas, and eroding stream banks. Studies indicate that both forest and grass riparian buffer strips can effectively trap sediment (Klapproth and Johnson, 2000). For example in North Carolina, adjoining hardwood deciduous riparian areas trap 84 percent to 90 percent of the sediment from agricultural fields (Cooper and Gilliam, 1987). However, riparian buffer strips may be most effective at removing larger particles such as sand, but less effective at removing smaller particles such as clay and silt (Klapproth and Johnson, 2000). Due to change in land use from forest to agriculture in River Njoro watershed, rates of erosion are likely to increase with increased silt and clay transportation into the streams which may affect the soil physical (bulk density) properties.

2.2.2 Pollutant/Contaminant Control

The riparian area is one of the landscape elements which can have a moderate to strong mediating effect on nutrient export to stream ecosystems (Meynendonckx *et al.*, 2006). Riparian zones are uniquely situated within the watersheds to intercept soils solution as it passes through the riparian rooting zone before entering the stream (Gregory *et al.*, 1991). The degree to which the riparian buffer strip protects water quality is a function of the area's hydrology, soils, and vegetation (Klapproth and Johnson, 2000). Riparian areas slow the movement of pollutants (excess nitrogen or phosphorus) and contaminants (pathogens and toxins) to surface waters and/or increase the opportunity for the contaminants to become buried in the sediments, adsorbed into clays or organic matter, or transformed by microbial and chemical processes (Johnston *et al.*, 1984). Solutes may be transformed from soluble to gaseous form (e.g., ammonium and/or nitrate denitrified to gaseous forms), stored via

biological uptake and storage as biological tissue (e.g. amino acids, protein and phosphorus as a structural component), removed via adsorption onto soil particles (e.g. ammonium ion and all metallic cations) (Klapproth and Johnson, 2000). Many of the water quality functions of the riparian buffer strip are as a result of the activity of soil micro organisms. Like plants, micro organisms take up and convert nutrients to forms which are less biologically available and more readily stored in the soil (Klapproth and Johnson, 2000). Pesticides and heavy metals may also be deposited in riparian zones hence protecting the aquatic ecosystems from their toxic effects.

Solute control is achieved through the interaction of solutes with the unique hydrology, soils and vegetation of riparian buffer strips. Consequently, protecting riparian buffer strips where they are and restoring them where they once existed should be viewed as a long term investment in "infrastructure" that reduces the direct costs of water treatment and the indirect cost associated with water-quality degradation (Sweeney and Blaine, 2007). However, studies have indicated that riparian buffer strips should not be regarded as inexhaustible sinks for high nutrient inputs and that there is a need to match nutrient inputs to sustainable rates of nutrients removal if long-term water quality benefits are to occur (Cooper *et al.*, 1995).

Riparian soils vary considerably through a distance as little as 30 feet (≈10 m) (Gold and Groffman, 1995) and are more heterogeneous in mineral character than their upland counterparts. Surface soils are situated in the zone that interacts directly with surface runoff and consequently riparian land use is expected to have the greatest impact on surface soil properties (Cooper *et al.*, 1995). Nutrients can enter surface waters in subsurface or surface flows (as a dissolved form (solute) or attached to soil particles) (Gilliam *et al.*, 1997). For example N is most commonly transported as dissolved N through subsurface flows. In contrast, P mostly enters the stream adsorbed onto soil particles and organic materials in surface runoff after storm events (Pionke *et al.*, 1996). A study by Cooper *et al.* (1995) comparing riparian soils under different land use areas revealed large differences in several key physical, chemical, and microbial properties that have consequences for the zone's role as a buffer of material transfer across the land-water interface.

Amounts and types of vegetation present affect nutrient cycling in riparian buffer strips. Elements like phosphorus and nitrogen tend to be taken up rapidly and conserved by riparian vegetation, while others, like calcium, chlorides, and magnesium, show limited uptake by these plants (5-40% of total available) and are generally found in high concentrations in

streams (Bilby, 1988). Some nutrients, like nitrate, uptake by plants may be limited to the growing season exhibited by seasonal fluctuations in concentrations in streams (Mikkelsen and Vesho, 2000). A previous study focusing on the relationship between the upstream proportion of land-use types and riparian buffer strips to nutrient concentrations and supply to downstream reaches of River Njoro concluded that land use near the stream accounts for the variability in water quality more than land use in the entire River Njoro watershed (Shivoga *et al.*, 2007). Establishing the soil physical and chemical properties and riparian buffer strip widths in different land use areas in River Njoro will help understand more the linkages between land use and water quality and quantity.

2.2.3 Stream Bank Stability

Riparian buffer strip vegetation confers stability to stream banks. Roots reinforce the soil in the same way that steel rods reinforce concrete with fine root size being more important in this process than coarse root size. Reinforcement by roots of riparian vegetation is usually the most important safeguard against bank collapse (Price and Lovett, 2002). Riparian vegetation has also been shown to reduce scour of stream banks by slowing the speed of water adjacent to the bank and therefore dissipating stream energy. Vegetation will also "ride down" with a collapsed bank and protect its toe from further scour. Channel morphology is thereby strongly influenced by stream bank stabilization by riparian vegetation and large woody debris (Keller and Swanson, 1979). Therefore there is need to establish what effects the varying riparian buffer strip widths in the River Njoro watershed have on stream bank stability.

2.3 Ecological Services at Risk when Faced with Human Related Activities in the Watershed

The rapidly expanding investigation of streams in the context of their catchments and landscape clearly indicates that stream ecosystems are strongly affected by human actions across different/many spatial scales (Allan, 2004). An increase in human related activities within the watershed is accompanied by a corresponding increase in both point and non point pollution sources. The result is an increase in the load of non point source pollutants that riparian buffer strips, in their capacities as filters, have to deal with and River Njoro watershed is not an exception. Agricultural activities generate sediments through ploughing and nutrients that are employed as fertilizers for crop production and livestock waste.

Urbanization creates more impervious layers in the watershed resulting to changes in the flow regime and routing more runoff to streams and less into the ground water. The result is an increase in stream power with concomitant increase in bank erosion.

Change in land use activities may have potential effects on the ecological services provided by riparian areas. The transition from natural to human-modified landscapes worldwide has impacted ecosystems and quantification of land use/land cover is a valuable indicator of the state of ecosystems. Agriculture, urbanization, and other human modifications of the landscape have been shown to alter and degrade stream ecosystems (Fitzpatrick *et al.*, 2001). Therefore, it is imperative to look at their influence on riparian buffer strips which are the first line of defence against impacts on the stream ecosystem. Studies conducted by Allan *et al.* (1997) suggest that the influence of land use on stream integrity is scale-dependent. In streams, organic matter inputs and stream habitats are determined primarily by local conditions such as vegetation cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to the stream sites (Allan *et al.,* 1997).

Attempts to identify the spatial scale at which human modification of land use most affects stream habitat and biota indicate that catchment-wide land use is of greater importance than local or riparian land use, and that the study design as reflected in the distribution of study sites can greatly influence results of land use influence on stream integrity (Allan *et al.,* 1997). Some major changes associated with increased urban land area include increases in the amount and variety of pollutants in runoff, more erratic hydrology owing to increased impervious surface area and runoff conveyance, increased water temperatures owing to loss of riparian vegetation and warming of surface runoff on exposed surfaces. Reduction in channel and habitat structure owing to sediment inputs, bank destabilization, channelization, and restricted interactions between the river and its land margin is also experienced (Paul and Meyer, 2001).

Anthropogenic disturbances tend to increase surface runoff in riparian systems, remove protective riparian vegetation, and alter the flow of water through aquatic systems (Manci, 1989). Intensive human activities in riparian areas interrupt natural drainage as riparian soils become compacted, sedimentation rates increase, solar radiation increases, and stream channels are altered. Similarly, streams can also be degraded by activities in the

surrounding watershed (Klapproth and Johnson, 2000). Wherever agriculture or other anthropogenic activity extends to the stream margin and natural riparian forest is removed, streams are usually warmer during summer and receive fewer energy inputs as leaf litter, and primary production usually increases (Quinn *et al.*, 2000).

Nutrient and sediment measures often show that land use overrides natural features like parent rock material, particularly in agricultural lands (Johnson *et al.*, 1997). Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indexes and bank stability (Wang *et al.*, 1997), as well as greater deposition of sediments on and within the streambed. However, streams in agricultural catchments usually remain in good condition until the extent of agriculture exceeds a threshold of more than 30%-50% (Allan, 2004).

Natural factors like underlying bedrock composition may be of primary importance when human influence is minor, or when human influence is widespread and fairly uniform across the study region (Allan, 2004) which is not the case in the River Njoro watershed since it has different land use areas and is under intense human activity.

2.4 Management Practices for Protection of Riparian Areas

Riparian buffer strips have become best management practice (BMP) in most American (Sweeney and Blaine, 2007) and European (Decker, 2003) landscapes and hopefully this will be the practice worldwide. An ecosystem perspective of riparian buffer strips provides a rigorous ecological basis for identifying riparian management objectives, evaluating current land-use practices, and developing future resource alternatives (Gregory *et al.*, 1991). Crafting good riparian policies and practices requires not just sound scientific research but also an understanding of the people's values, beliefs, and perceptions. Planners should be able to show that individual acts to protect or restore riparian forests will have long-term economic benefits for the entire watershed (Sweeney and Blaine, 2007). This is particularly important in developing countries where communities want to witness tangible benefits from their efforts, and River Njoro is not an exception to this rule.

The current knowledge on riparian areas should encourage preservation of riparian buffer strips. Studies have recommended that riparian forests be preserved and where they do not exist, they be restored based on the magnitude of the in-stream benefits provided by

streamside trees (Sweeney *et al.*, 2004). The result will be savings in terms of the cost and energy that go into restoration of degraded riparian buffer strips.

The optimal size of the riparian buffer strip continues to generate debate with no fixed width being agreed upon universally. Generally, recommendations for riparian buffer strip widths are of the order of 10 to 100m on each side of the stream, and are based on a sound intuitive grasp of the processes that should be protected (Allan *et al.*, 1997). Riparian buffer strip widths may vary with stream size, stream order and ecosystem type. These recommendations are sensible but the scientific information for or against a specified riparian buffer strip width is limited (Osborne and Kovacic, 1993). Some scientists have noted that the size of riparian buffer strip required for maintenance of status quo in rivers and streams of different geographic zones is not yet known (Magana and Bretschko, 2003). This is confounded by observations that little is known about how the width, extent and continuity of forested vegetation along stream networks affect stream ecosystems (Johnson *et al.*, 2007). Cooper *et al.* (1995) sums it all by noting that riparian set-aside widths should be established on the basis that the sustainable net nutrient removal capacity of the zone needs to be matched to the nutrient influx from upslope. Therefore focus should shift more on nutrient flux into the riparian area in order to come up with the optimal width. However looking at different sizes of widths under the same loading zone and against a suitable reference condition would provide a suitable guide on which width is suitable for a given land use. This is the underlying assumption in this research in River Njoro watershed.

The restoration of native, forested riparian habitats is a widely accepted method for improving degraded streams (Johnson *et al.*, 2007). While grass and trees may work equally well as barriers to certain nutrients (Mayer *et al.*, 2006), it is now well documented that riparian forests more effectively sustain stream-bank stability, moderate light and temperature levels, increase benthic habitat and supply a more diverse food base for aquatic life (Allan, 1995). In sum they provide a more natural, stable, and effective stream ecosystem than do their grass counterparts (Sweeney and Blaine, 2007). It is believed that riparian deforestation might make streams less healthy and therefore less able to deliver high levels of ecosystem services. Retentive characteristics of stream channels are also closely linked to the structure and composition of adjacent riparian zones (Gregory *et al.*, 1991). Studies by Sweeney (1993) demonstrated that riparian areas in which trees had been removed and replaced with grass exhibited significant and permanent channel narrowing

(bank instability) which affect structure and function of the stream and delivery of stream ecosystem functions. Other studies have demonstrated that stream narrowing resulted in as much as a 50% loss of total benthic habitat-and therefore of stream biodiversity- from the watershed (Vondracek *et al.*, 2005).

2.5 Summary

The literature reveals more emphasis has been directed towards influences of land use activities on water quality and quantity, but issues of land use activities on riparian buffer strip soil physical and chemical properties and stream bank stabilization have not been addressed adequately. Riparian buffer strips serve as interfaces between the terrestrial and aquatic ecosystems, therefore knowledge of the influence of land use on their soil physical and chemical properties and bank stability is important. It may reveal the effects of different use areas on soil properties and consequently water quality which would assist in identifying hot spots that need rehabilitation, however, riparian buffer strips should not be regarded as inexhaustible sinks for high nutrient inputs, but nutrient input should be matched to sustainable rates of nutrients removal if long-term water quality benefits are to occur.

Most studies have generalized functions of the riparian buffer strips but none have quantitatively determined changes in soil physical and chemical properties and stream bank stability. This is the gap the literature reviewed exposed and this research aims to fill.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted in the River Njoro watershed (Figure 1).

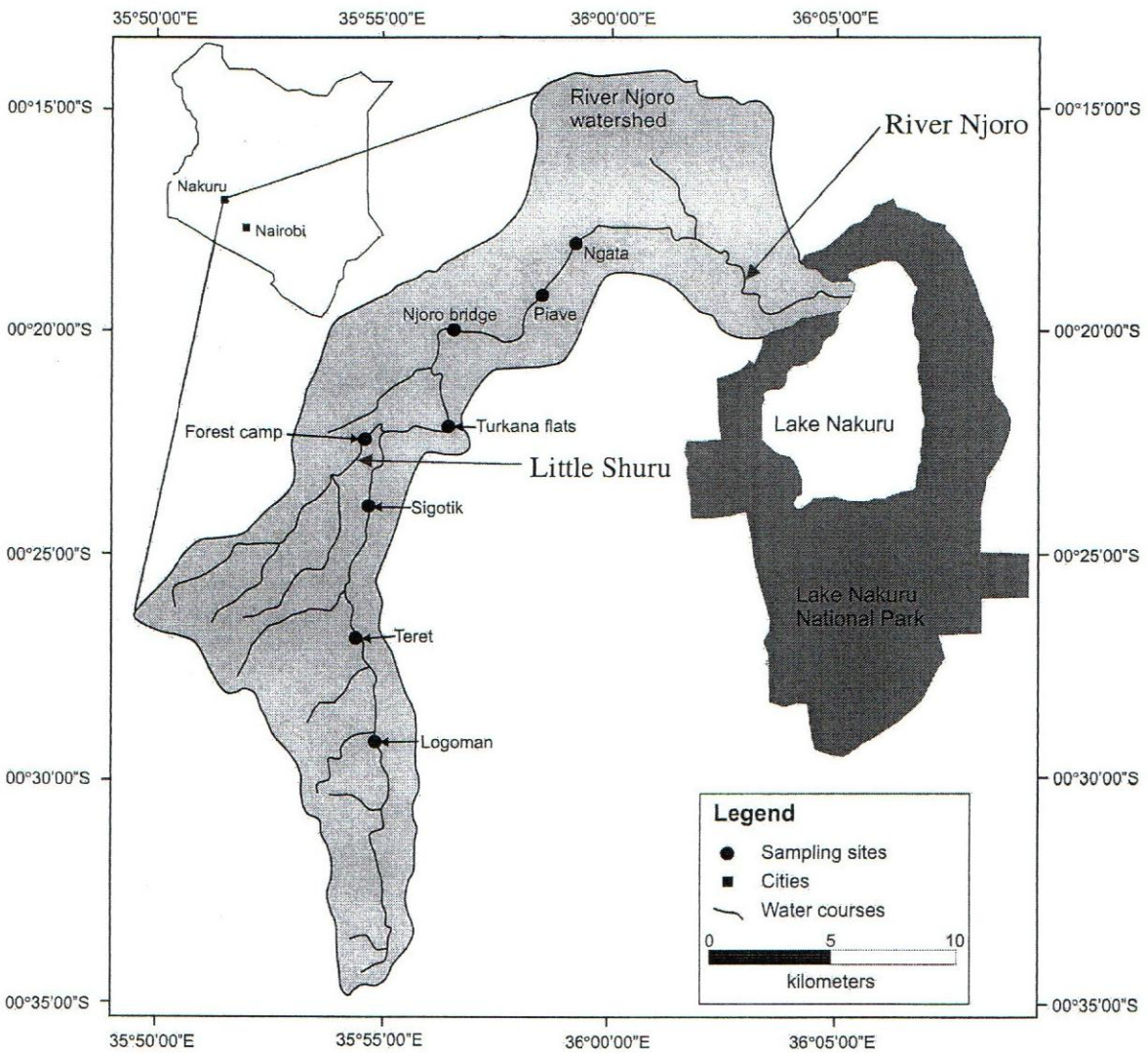


Figure 1: Map showing location of sampling sites in River Njoro watershed.

Source: Gabor (CRF laboratory, University of Western Ontario)

River Njoro lies on Latitude 0°15'S, 0°35'S; longitude 35°50'E, 36°05'E. It covers an area approximately 280 km^2 (SUMAWA, 2004). Originating at an elevation of 2700-3000 m above sea level (a.s.l.) in the Eastern Mau Escarpment and latitude of one degree south of the equator, the River Njoro descends in a northeast direction through several ecological zones before terminating at Lake Nakuru on the floor of the Rift Valley at about 1759 m a.s.l.

Climate is characterised by a trimodal precipitation pattern, with long, intense rains occurring from April to May, short, intense rains occurring in August, and shorter, less intense rains from November to December. Based on data from a meteorological recording station at Egerton University which is located in the middle section of the watershed, the total annual precipitation is 956 mm and the mean annual temperature is 16.5°C, ranging from a minimum of 9°C (July) to a maximum of 24°C (January).

Geology is influenced by volcanic activities and is characterised by porous pumiceous formations (McCall, 1967). Historic volcanic activity and topography in the area influence soil formation. Soils in this region range from Humic Acrisols (Ultisols), Phaeozems (Mollisols), Andosols, Planosols (Aqualfs), Plinthosols, and Fluvisols (Fluvents) (Mainuri, 2006). Soil textures range from clay loams in the lower watershed to sandy clay in the plantations and indigenous forest areas at higher altitude.

Vegetation can be characterized into one of two main forest types: montane and sub-montane (Mathooko and Kariuki, 2000). Montane forests are common in the upper reaches of the River Njoro watershed. In these forests, heavily grazed moorlands are found bordering a dense closed canopy of indigenous montane forest consisting of cedar mixed with bamboo which in turn borders tracts of forest plantations consisting of cypress and pine species. Sub-montane forests are common in the middle and lower portions of the River Njoro watershed which, because of management activities, are now restricted to the riparian areas (Mathooko and Kariuki, 2000).

Activities include subsistence farming [crops include legumes, maize, sorghum, pyrethrum, wheat, barley, tomatoes, cabbages, yams and potatoes (Baldyga, 2005)], commercial farming (wheat, barley), and animal husbandry [grazing animals are sheep, cattle, goats and donkeys (Lelo *et al.*, 2005)]. The diversity of vegetation found in the watershed serves a wide range of purposes including timber, agriculture, medicine, human

food, livestock fodder, building material and fuel wood. Most settlers in this upland region practice a mixture of animal husbandry and subsistence farming.

Based on the 1999 census survey of the watershed, the population is over 300,000 people and includes the urban centres of Njoro Town (approximately 30,000 people), and much of Nakuru municipality (approximately 240,000 people) (Lelo *et al.*, 2005).

The river cuts across several land use areas and communities with diverse cultural orientations. At least four land use areas are significant: (1) predominantly protected government forests (i.e., gazetted forests GF) (Plate 1); (2) small-scale agriculture associated with new settlements on recently felled plantation forests characterised by temporary structures (i.e., recent settlements, RS) (Plate 2); (3) medium-scale agriculture associated with older settlements surrounding urban areas (i.e., peri-urban settlements, PU) (Plate 3); and (4) large-scale agriculture with permanent structures (i.e., commercial agriculture, CA) (Plate 4) (Lelo *et al.*, 2005). Vegetation cover ranges from 90% in upland indigenous forests that are difficult to reach due to extreme topographic relief (Figure 2) on the eastern rift escarpment to 0% in areas affected by anthropogenic practices such as agriculture and livestock husbandry (Baldyga, 2005).

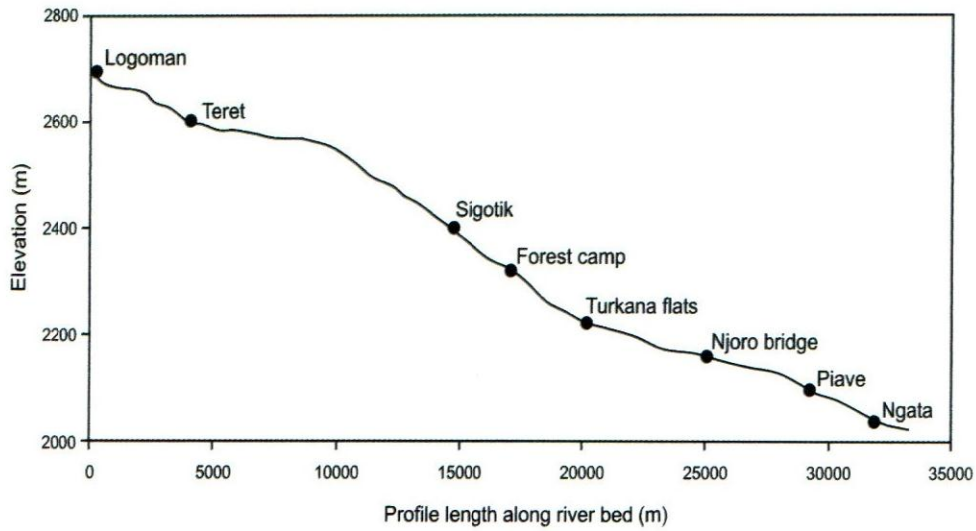


Figure 2: Location of the eight watering points (to create two replicates for each of the four blocks) along an elevation gradient in relation to the altitude above mean sea level.

Source: Gabor (CRF, University of Western Ontario)

River Njoro provides 65% of the total stream inflow into Lake Nakuru (Gichuki *et al.*, 1971), a large shallow saline lake, designated a Ramsar wetland site of international importance. Lake Nakuru, which is the terminus for the River Njoro, recharge is not exclusively by way of surface water runoff. Rather, the lake recharge is primarily through a combination of direct rainfall and groundwater accrued from stream losses through the highly porous landscape (McCall, 1967).

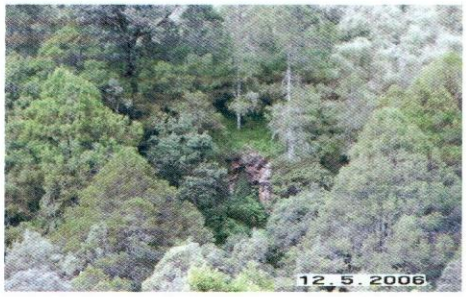


Plate 1: Gazetted forest (GF)



Plate 2: Recent settlements (RS)

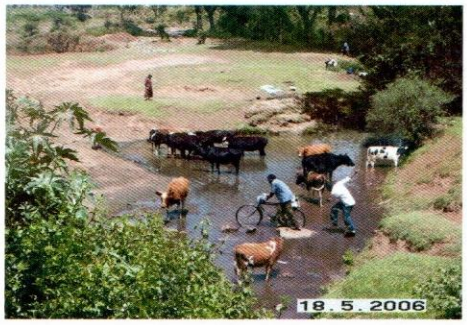


Plate 3: Peri-urban settlements (PA)

Source: Eric Enanga



Plate 4: Commercial agriculture (CA)

3.2 Methods

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3.2.1 Experimental Design

The study was conducted in a stratified random sampling design. The different land use areas in the upper reaches of the River Njoro watershed were divided into four discrete blocks (strata), each with two replicates: (1) Gazetted forest (Logoman and Teret) (Plate 1); (2) Recent settlements (Sigotik and Forest camp) (Plate 2); (3) Peri-urban (Turkana flats and Njoro bridge) (Plate 3); and (4) Commercial agriculture (Piave and Ngata) (Plate 4).

The strata (different land use areas) were defined to minimize the within-unit variance and maximize the between-unit variance of the soil properties; stream bank stability and riparian buffer strip widths. Two sampling sites were randomly selected from each stratum. Each sampling site consisted of a cluster of five 30 m length transects to the left and right hand side of the stream at 50 m intervals running perpendicular to the stream and centred on a watering point where people and livestock access the river. The River Njoro width was on average 10 m in width (ranged from about 1 m to 15 m). The first transect was located at the watering point, two more transects were located at the 50 m mark both upstream and downstream of the watering point, and two more transects were located 100 m upstream and downstream of the watering point (Figure 3). Soil properties, including bulk density (g/cm^3), % carbon content (C), % nitrogen content (N), and phosphorus concentration (P) (mg/kg) were examined at the surface (0-20 cm) and the subsurface (20-50 cm) at 10 m intervals (10 m, 20 m and 30 m) along each of the five 30 m transects within each of the four strata (no samples were collected at sites where there was extensive underlying rock).

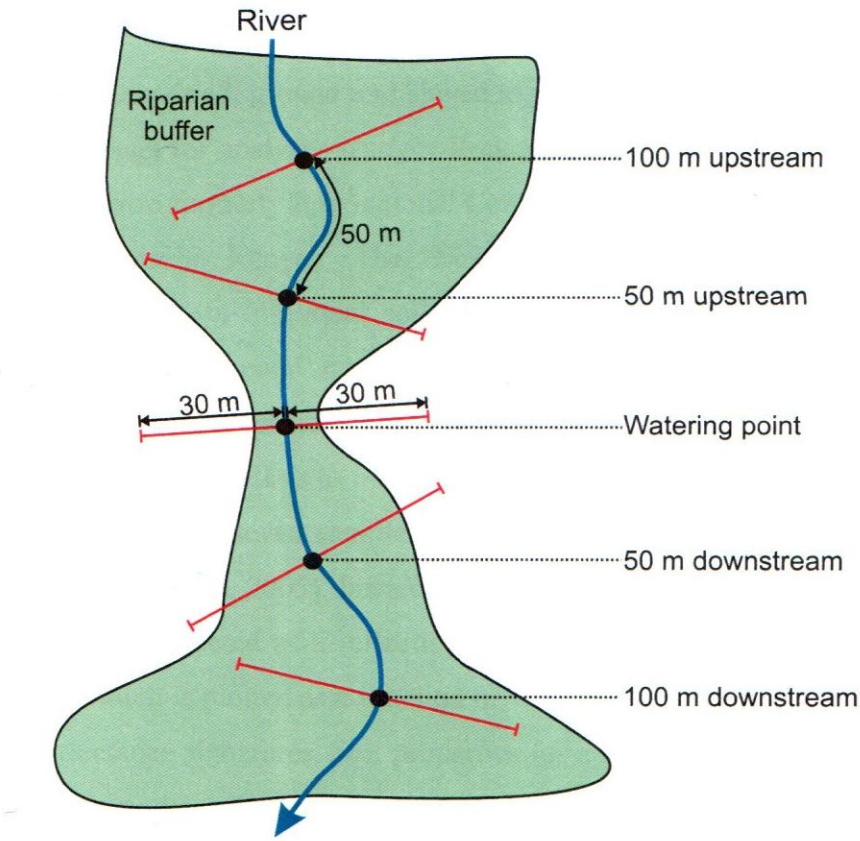


Figure 3: Experimental design at each of the sampling clusters.

The total numbers of plant species present on both the left and right hand sides of the stream and on each transect were identified.

3.2.2 Soil Properties

Soil samples for determination of bulk density in surface soils (0-20 cm) were extracted using cylindrical core rings (50 mm height × 50 mm inner diameter) and stored in plastic bags. Coarse fragments (> 2 mm in diameter) were removed manually from the soil samples prior to estimation of bulk density. Samples were oven dried at 105°C, cooled in desiccators, and then weighed. Bulk density was calculated as the ratio of dry weight of soil sample (g) to volume of the sampling ring (cm^3).

Soil samples for determination of % carbon content, % nitrogen content, phosphorus concentration (mg/kg) were collected using a soil auger, stored in plastic bags, and transported to the laboratory for analysis. Litter and roots were manually removed from the soil samples prior to spectral analysis (Cohen *et al.*, 2005).

Samples were air-dried, ground and sieved to pass through a 2 mm diameter sieve, then stored in paper bags for analyses using a Bruker MPA spectrometer located at the World Agro forestry Centre formerly International Centre for Research in Agro Forestry (ICRAF) laboratories in Nairobi, Kenya. The Bruker MPA spectrometer uses technology that integrates information on important soil properties into one measurement, providing an ideal index for environmental monitoring of soil quality, and is highly reproducible (repeatability of 0.99) (Shepherd, 2005). The choice of air-dried samples is basically for handling convenience as well as to minimize variation due to soil moisture (Ben-Dor *et al.*, 1999). The air-dried and sieved samples were placed on a petri dish and positioned on an optical window (Shepherd, 2005). Infrared light was then broadcast onto the sample and the reflected light was collected as a reflection spectrum on a computer. The intensity of the reflected light, which is plotted as a function of wavelength gave distinctive patterns known as spectral reflectance signatures. Soil properties for a sample were predicted within 30 sec using calibration models. The calibration models for C, N, and inorganic P were developed by taking a sub sample of a subset (n=30) of the samples on which both traditional methods of analyses and spectral analyses were conducted (see Appendix A). After every 100 samples analyzed, the instrument was checked for consistency using a standard soil sample from the Mua Hills in Kenya.

3.2.3 Vegetation assessment

All line transects that were sampled along the river were visually observed on whether the site was impacted/disturbed or not-disturbed, land use, vegetation cover (%), species composition (Appendix D; Appendix E) and canopy cover (%) were visually assessed and recorded. Canopy cover (%) at the middle of the stream was also assessed and recorded. The width of the riparian buffer strip was measured if it was less than 30 m but if more, it was noted as greater than 30m (>30m).

3.2.4 Slope measurements

Slope measurements were done from the 30 m mark to the stream bank edge using a surveyor's level and rod at 1 m intervals up to the centre of the stream (Plate 5).



Plate 5: Elevation measurements used to calculate slope.
Source: Steve Huckett

The slope of the line transect on each side of the stream was calculated by getting the difference in elevation at the 30 m mark and the stream bank edge. If the difference in elevation was x m and the horizontal distance was 30 m, then the perpendicular distance to the height, y m was calculated using Pythagoras theorem ($30^2 = x^2+y^2$ or $y = (30^2-x^2)^{1/2}$. The

angle of elevation θ was then calculated using the formula: Sine θ= y/30. The angle θ in degrees was then derived from the inverse sine ($sine^{-1}\theta$).

3.2.5 Stream Bank Stability Assessment

Stream banks at each transect were photographed and described. The presence or absence of bank erosion (potential for sediment in the bank to fall into the stream) was recorded at each site. The four categories of bank slope, bank height, substrate (i.e., bedrock or soil, and if soil then soil texture) and % cover by vegetation were recorded and used to calculate a Bank Stability Index (BSI) (Simon and Hupp, 1992 as adapted by Fitzpatrick, 2001) (Table 1).

Table 1: Explanation of the bank stability index (BSI).

Bank characteristics	Measurement	Score
Slope (degrees)	0-30	1
	31-60	2
	>60	3
Height (meters)	0-1.1	1
	1.1-2	2
	2.1-3	3
	3.1-4	4
	>4	5
Substrate (category)	Bedrock	1
	Boulder, cobble	3
	Silt	5
	Sand	8
	Gravel/Sand	10
Vegetative cover (%)	>80	1
	50-80	2
	20<50	3
	<20	4

Source: Simon and Hupp, (1992)

The BSI ranges from 4 (very stable) to 22 (very unstable), with index values calculated by adding scores from each of the four categories. In general, banks with a BSI of 4 to 7 were

considered stable, 8-10 were considered at risk, 11 to 15 were considered unstable, and 16 to 22 were considered very unstable (Fitzpatrick *et al.*, 2001). The BSI is estimated by the total of the scores from each category. A BSI of: 4 to 7 is stable; 8 to 10 is at risk; 11to 15 is unstable; and 16+ is very unstable.

3.2.6 Statistical Analysis

Data were tested to determine if parametric or non-parametric tests should be performed using the statistical package Sigma Stat 2.03. One-way ANOVAs were used to determine if there were significant differences in ratio and parametric data, while Kruskal Wallis ANOVA on ranks were used to determine if there were significant differences where ratio data failed the normality or equal variance tests for parametric data (McBride and Booth, 2005). Appropriate multiple pair wise tests were performed where ANOVAs yielded significant differences. Significance was assessed at α=0.05 level.

CHAPTER FOUR

RESULTS

Generally, dominant vegetation in riparian buffer strips varied with different land use areas. Gazetted forest had *Juniperus procera* as the most frequently observed vegetation; recently settled areas had *Olea Africana;* peri-urban areas had *Achyranthes aspera* while commercial agriculture areas had *Acacia abyssinica* as the most frequently observed vegetation along transects and within the 30 m strip in each land use area (Appendix E).

The slope (degrees) of the land between the 30 m point and the edge of the stream bank also varied with the different land use areas with gazetted forest areas having the lowest median slope followed by peri-urban areas, commercial agriculture and recently settled areas had the highest median slope (Appendix C). This research did not reveal any relationship between slope and soil physical and chemical properties within the 30 m riparian buffer strip in different land use areas. Recent settlements with the highest median slope, a 30 m riparian buffer strip was adequate to mitigate changes in soil properties in the different land use areas while peri-urban with a lower median slope it was not adequate. However, the transect with the highest slope (36 degrees) was observed in peri-urban areas while the one with the lowest (2 degrees) was observed in gazetted forest (Appendix D).

There were no significant differences in median bank vegetation cover (%) in the different land use areas (Appendix C) although commercial agriculture had the least median bank vegetation cover.

Commercial agriculture had the least median canopy cover (%) that was significantly different from other land use areas while the other land use areas (recent settlement, gazetted forest and peri-urban) were not significantly different from each other (Appendix C).

Riparian buffer strip surface and subsurface soils exhibited variations in physical and chemical properties due to change in the land use activity and location of the soil sample relative to the land use activity (whether soil sample was inside or outside the riparian buffer strip).

4.1 Soil Properties in Different Land Use Areas

Physical and chemical properties (bulk density, carbon, nitrogen and phosphorus) of surface soils (0-20 cm) showed significant differences across a gradient of land use activity, that ranged from gazetted forest (which served as a reference condition), to low effect in the recent settlements, and higher effects in peri-urban and commercial agriculture (Table 2).

Table 2: Soil properties in different land use areas in River Njoro watershed.

Land use	Bulk Density (g/cm^3)	Carbon (%)	Nitrogen (%)	Phosphorus concentration (mg/kg)
Surface (0–20 cm)				
Gazetted forest	0.87^{b} (25^{th} 0.76, 75^{th} 0.95)	5.06^{a} (1.18)	0.45^{a} (0.11)	3.47^{b} (25^{th} 2.92, 75^{th} 3.83)
Recent settlements	0.84^{b} (25^{th} 0.74, 75^{th} 1.07)	4.24^{b} (1.09)	0.42^{a} (0.11)	4.19^{a} (25^{th} 3.97, 75^{th} 4.60)
Peri–urban settlements	1.00^{a} (25^{th} 0.92, 75^{th} 1.13)	2.69^{c} (1.08)	0.24^{b} (0.11)	3.88^{a} (25^{th} 3.64, 75^{th} 5.16)
Commercial agriculture	1.14^{a} (25^{th} 0.84, 75^{th} 1.24)	3.14^{c} (1.06)	0.30^{b} (0.092)	4.15^{a} (25^{th} 3.70, 75^{th} 4.80)
Subsurface (20–50 cm)				
Gazetted forest	Not available	3.57^{a} (1.23)	0.31^{a} (0.11)	2.85^{b} (25^{th} 2.58, 75^{th} 3.25)
Recent settlements	Not available	2.74^{b} (1.00)	0.28^{ab} (0.09)	3.61^{a} (25^{th} 3.29, 75^{th} 4.27)
Peri-urban settlements	Not available	2.30^{b} (0.78)	0.19^{c} (0.08)	3.55^{a} (25^{th} 2.79, 75^{th} 4.50)
Commercial agriculture	Not available	2.28^{b} (1.03)	0.22^{bc} (0.10)	3.73^{a} (25^{th} 2.78, 75^{th} 4.13)

Means or medians with the same letter are not significantly different from each other (based on $p<0.05$). Mean with standard deviation in parenthesis for carbon content (%) and nitrogen content (%) and median with 25^{th} and 75^{th} percentiles in parenthesis for bulk density (g/cm^3) and concentration of phosphorus (mg/kg).

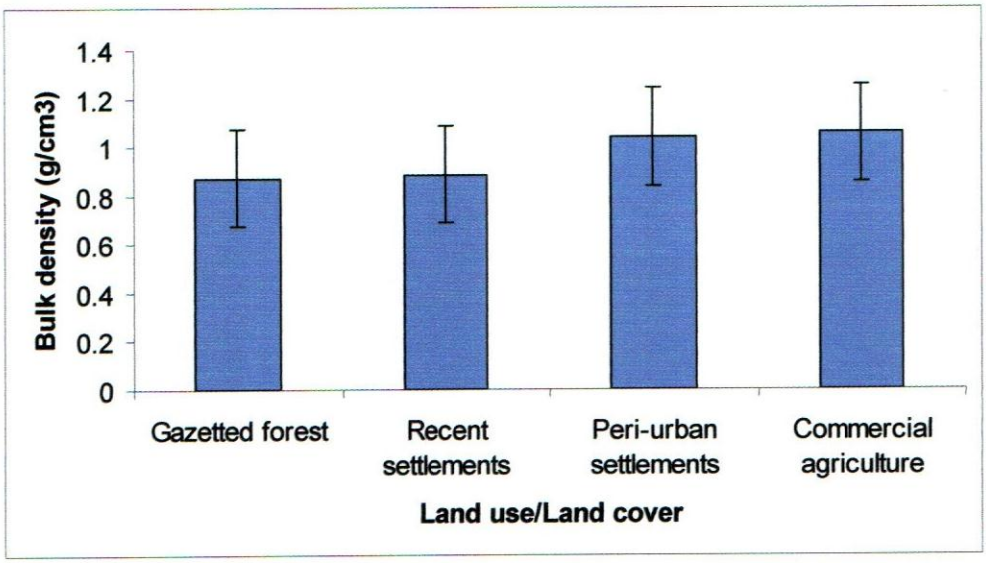


Figure 4: Mean soil bulk density (compaction) variation among different land use areas in River Njoro watershed.

Figure 4 shows that soil bulk density varied in accordance with land use practiced at the site of soil sampling. Mean soil bulk density increased from 0.87 g/cm^3 in gazetted natural forest through 0.89 g/cm^3 in recently settled areas to 1.04 g/cm^3 and 1.06 g/cm^3 in peri-urban and commercial agriculture land use areas respectively. This implies that as one moves from the gazetted forested headwaters of River Njoro downstream, soil compaction increases probably due to increased human activities including road construction, trampling by livestock, tillage and use of heavy machinery in agricultural fields. One way ANOVA displayed significant differences in soil bulk density among the different land use areas ($F_{(3,129)} = 7.042$, $p<0.001$). Pair wise multiple comparison Tukey test established significant differences in bulk density between commercial agriculture and gazetted forest ($p<0.001$), commercial agriculture and recent settlement ($p=0.041$) and peri-urban and gazetted forest ($p=0.008$). However, commercial agriculture and peri-urban means were not significantly different, recent settlements and commercial agriculture areas were not significantly different from each other.

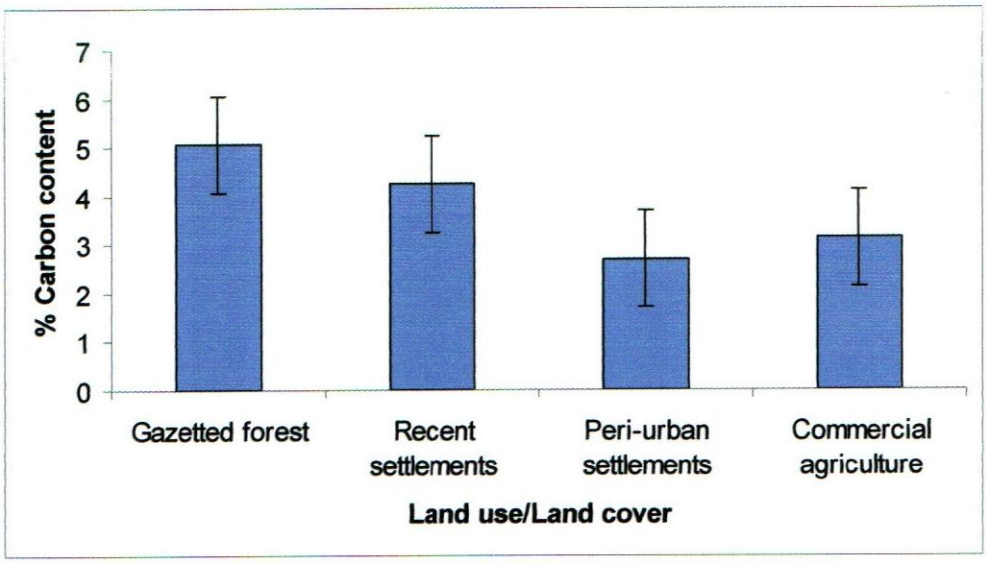


Figure 5: Mean soil carbon content variation among different land use areas in River Njoro watershed.

Mean percent carbon content in surface soils varied among the different land use areas, with the highest mean carbon content observed in gazetted forest, followed by recent settlements, and then by commercial agriculture and peri-urban (Figure 5). The soil carbon content decreased from 5.06% in gazetted natural forests through 4.24% in recently settled areas to 2.69% and 3.14% in peri-urban and commercial agriculture, respectively. This indicates that as one moves from the gazetted forested headwaters of River Njoro downstream, carbon content decreases probably due to increased removal of vegetation cover/bare ground and reduced litter input to surface soil.

One way ANOVA revealed significant differences in soil carbon content among all the different land use areas ($F_{(3,129)} = 34.231$, $p<0.001$). Tukey test revealed significant differences in mean carbon content between gazetted forest and recent settlements ($p=0.038$), gazetted forest and peri-urban ($p<0.001$), gazetted forest and commercial agriculture ($p<0.001$), recent settlements and peri-urban ($p<0.001$), and recent settlements and commercial agriculture (0.007), However, there was no significant difference observed between peri-urban and commercial agriculture land use areas ($p=0.472$).

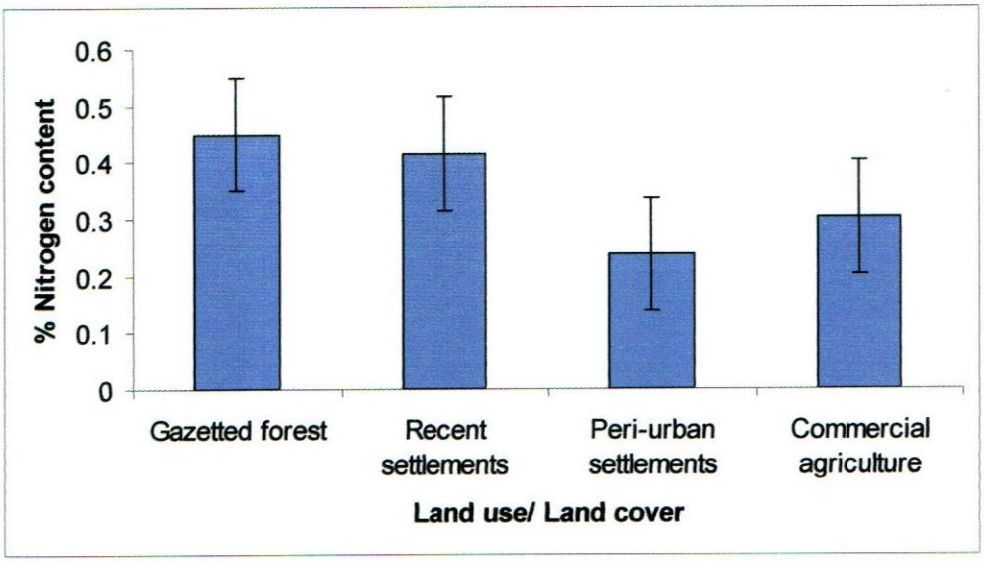


Figure 6: Mean soil nitrogen content variation among different land use areas in River Njoro watershed.

Figure 6 illustrates a similar pattern was observed for the mean nitrogen content in surface soils. The gazetted forest had the highest mean nitrogen content (0.45%), followed by recent settlements (0.42%) and then commercial agriculture (0.30%) and by peri-urban (0.24%). One way ANOVA confirmed significant differences in soil nitrogen content among all the different land use areas ($F_{(3,129)} = 28.875$, $p<0.001$). Tukey test revealed significant differences in mean nitrogen content between gazetted forest and peri-urban ($p<0.001$) and gazetted forest and commercial agriculture ($p<0.001$), recent settlements and peri-urban ($p<0.001$) and recent settlements and commercial agriculture ($p=0.002$), but no significant differences were observed between gazetted forest and recent settlements ($p=0.628$) or peri-urban and commercial agriculture ($p=0.107$) land use areas.

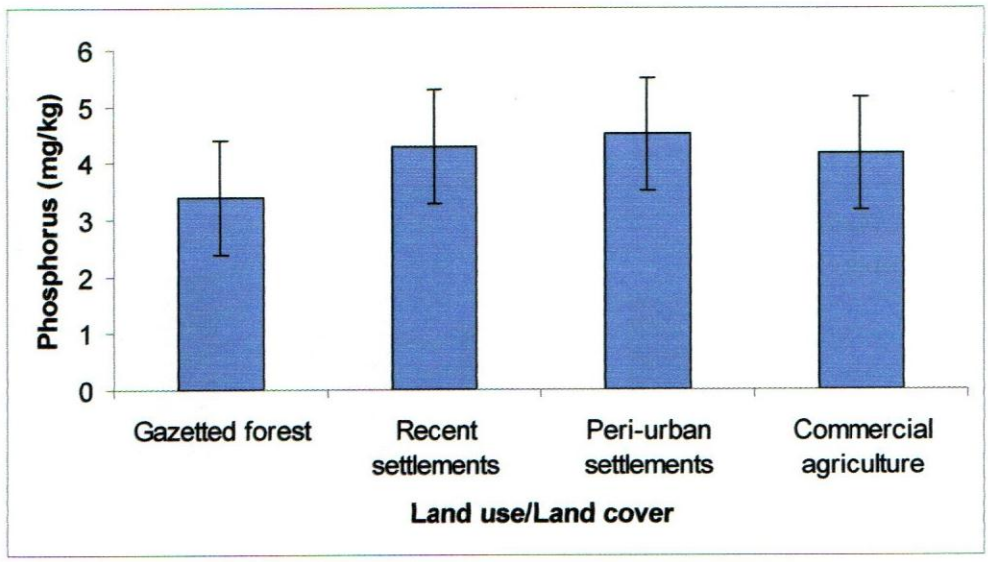


Figure 7: Mean soil phosphorus concentration variation among different land use areas in River Njoro watershed.

Figure 7 revealed gazetted forest had the lowest mean phosphorus concentration (3.39 mg/kg) followed by commercial agriculture (4.17 mg/kg), recent settlement (4.29 mg/kg) and peri-urban had the highest (4.51 mg/kg). One way ANOVA confirmed significant difference in soil phosphorus concentration among all the different land uses ($F_{(3,129)} = 7.171$, $p<0.001$). Tukey test showed mean phosphorus concentration in surface soils was significantly lower in gazetted forest land use compared to recent settlements ($p=0.025$), gazetted forest compared to peri-urban ($p<0.001$) and gazetted forest compared to commercial agriculture ($p=0.013$) land use areas. There were no significant differences in phosphorus concentration observed among the recent settlements, peri-urban and commercial agriculture land use area pairs.

Properties of subsurface soils (20-50 cm) were similar to surface soils, but the magnitude of change in soil properties among the different land use areas was muted (Table 2). Carbon content of surface soil was higher than the corresponding subsurface soil in the different land use areas (Figure 8).

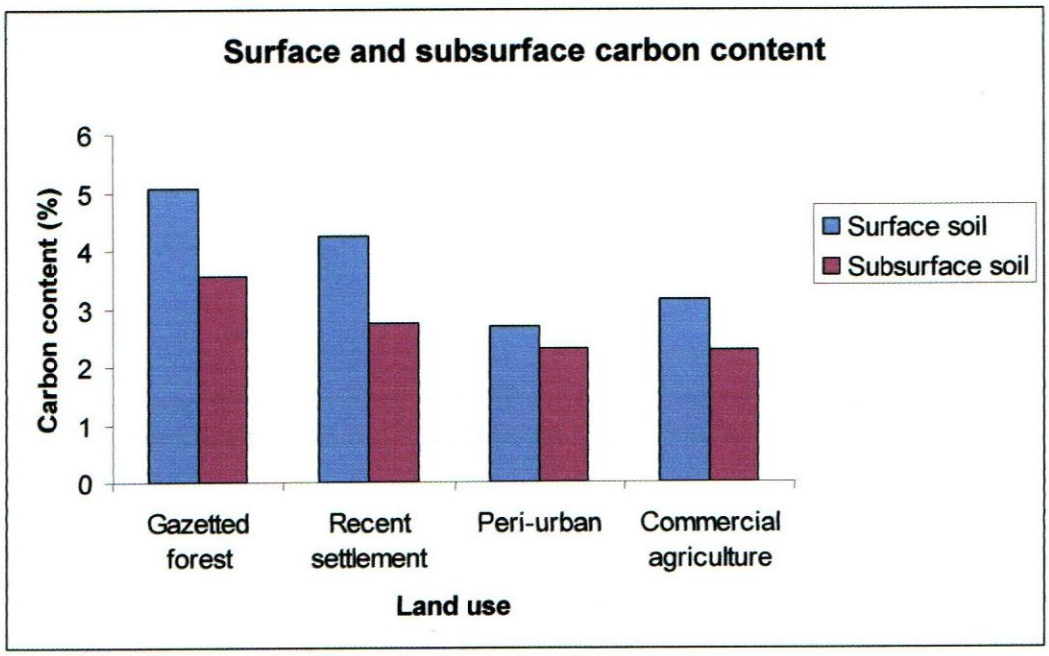


Figure 8: Comparison between carbon content of surface and subsurface soils in different land use areas in River Njoro watershed.

Nitrogen content of surface soils was similarly higher than in subsurface soils (Figure 9). However, the trend was similar to that observed in surface soils with a general decrease in nitrogen content as one moved from gazetted forest to commercial agriculture.

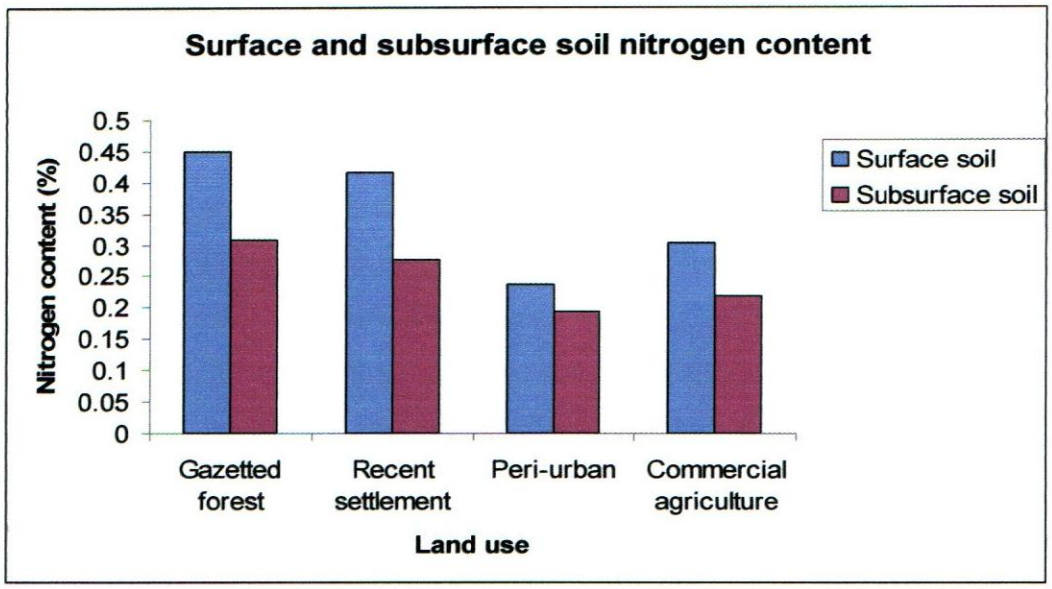


Figure 9: Comparison of surface and subsurface soil nitrogen content in different land use areas in River Njoro watershed.

Concentration of phosphorus was higher in surface soil than subsurface soil in all land use areas (Figure 10). The trend in subsurface soils phosphorus concentration was similar to that observed in surface soils with areas with higher human/livestock influence (recent settlement, peri-urban and commercial agriculture) registering higher inorganic phosphorus concentrations than gazetted forest.

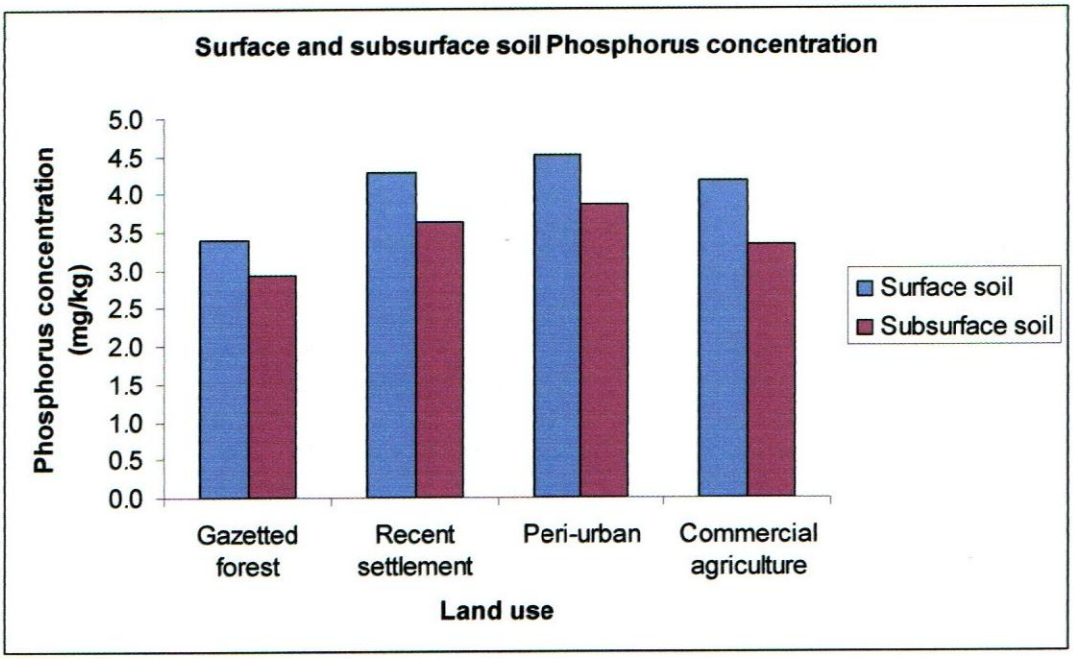


Figure 10: Comparison of surface and subsurface soil phosphorus concentration in different land use areas in River Njoro watershed.

Generally all soil properties had lower values in subsurface soils compared to the corresponding surface soils in the different land use areas. Bulk density data for subsurface soils were not collected. Gazetted forest mean carbon (3.57%) and nitrogen (0.31%) content were significantly higher than in recent settlement (2.74% C and 0.28% N), peri-urban (2.30% C and 0.19% N) and commercial agriculture (2.28% C and 0.22% N), however, phosphorus concentration (2.85 mg/kg) was significantly lower in gazetted forest land use area compared to recent settlements (3.60 mg/kg), peri-urban (3.55 mg/kg) and commercial agriculture (3.73 mg/kg) land use areas subsurface soils (Table 2).

4.2 Soil Properties in Riparian Buffer Strips Adjacent to Different Land Use Areas

Properties of surface soils in the riparian buffer strips adjacent to different land use areas showed significant differences across a gradient of land use activities (Table 3). Recent settlement land use area had the lowest median bulk density (0.77 g/cm^3) followed by gazetted forest (0.87 g/cm^3), peri-urban (0.96 g/cm^3) and commercial agriculture had the highest (1.11 g/cm^3). Carbon content reduced as intensity of land use increased. Gazetted forest had the highest mean value (5.06 %) followed by recent settlement (4.80 %), peri-urban (3.73 %) and commercial agriculture (3.36 %) had the lowest.

Table 3: Soil properties in riparian buffer strips adjacent to different land use areas in River Njoro watershed.

Land use	Bulk Density (g/cm^3)	Carbon (%)	Nitrogen (%)	Phosphorus concentration (mg/kg)
Surface (0–20 cm)				
Gazetted forest	0.87^{ab} (25^{th} 0.76, 75^{th} 0.95)	5.06^{a} (1.178)	0.45^{a} (0.107)	3.47^{b} (25^{th} 2.92, 75^{th} 3.83)
Recent settlements	0.77^{b} (25^{th} 0.67, 75^{th} 0.96)	4.80^{ab} (1.77)	0.47^{a} (0.16)	3.34^{b} (25^{th} 2.84, 75^{th} 4.70)
Peri-urban settlements	0.96^{a} (25^{th} 0.81, 75^{th} 1.10)	3.73^{bc} (1.45)	0.33^{b} (0.15)	4.02^{ab} (25^{th} 3.70, 75^{th} 4.98)
Commercial agriculture	1.11^{a} (25^{th} 0.89, 75^{th} 1.17)	3.36^{c} (1.43)	0.33^{b} (0.14)	6.59^{a} (25^{th} 4.32, 75^{th} 7.05)
Subsurface (20–50 cm)				
Gazetted forest	Not available	3.57^{a} (1.23)	0.31^{a} (0.11)	2.85^{b} (25^{th} 2.58, 75^{th} 3.25)
Recent settlements	Not available	3.19^{ab} (1.56)	0.32^{a} (0.14)	3.51^{a} (25^{th} 2.71, 75^{th} 5.06)
Peri-urban settlements	Not available	2.77^{ab} (1.03)	0.24^{a} (0.10)	3.98^{a} (25^{th} 3.28, 75^{th} 4.37)
Commercial agriculture	Not available	2.51^{b} (1.18)	0.24^{a} (0.11)	3.88^{ab} (25^{th} 2.38, 75^{th} 6.83)

Means or medians with the same letter are not significantly different from each other (based on $p<0.05$). Mean with standard deviation in parenthesis for carbon and nitrogen content and median with 25^{th} and 75^{th} percentiles in parenthesis for bulk density (g/cm^3) and concentration of phosphorus (mg/kg).

For nitrogen content, gazetted forest had the highest mean value (0.45 %) followed by recent settlement (0.47 %), commercial agriculture (0.33 %) and peri-urban had the lowest

mg/kg) followed by peri-urban (4.02 mg/kg), gazetted forest (3.47 mg/kg) and recent settlement had the lowest (3.34 mg/kg) value.

There is a general increase in soil bulk density in riparian buffer strips as one descends from the headwaters (gazetted forest) downstream to commercial agriculture land use areas (Figure 11)

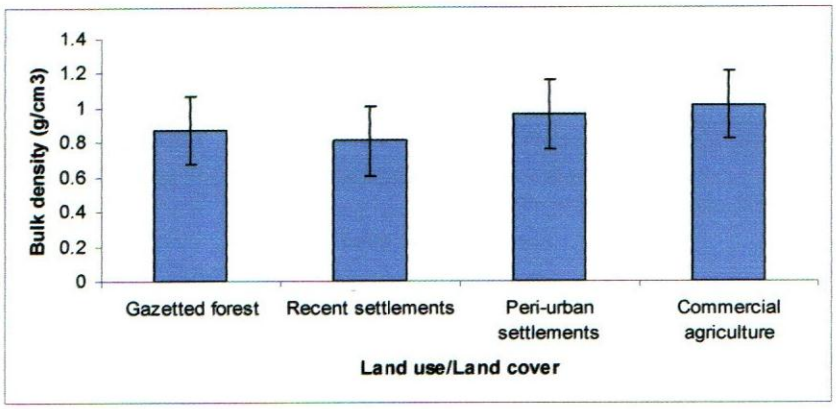


Figure 11: Mean bulk density variation in riparian buffer strips adjacent to different land use areas.

There is a general decrease in soil carbon content in riparian buffer strips adjacent to different land use areas as one descends from gazetted forest through recent settlement, peri-urban areas and the lowest is in commercial agriculture land use areas (Figure 12).

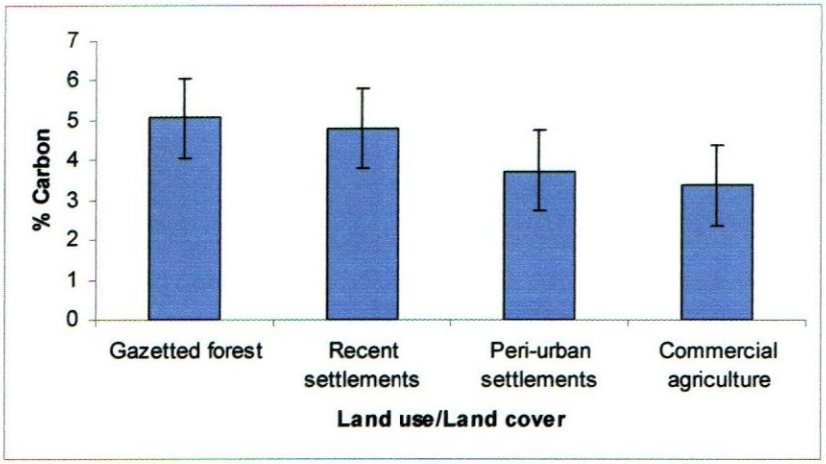


Figure 12: Mean carbon content in soils of riparian buffer strips adjacent to different land use areas.

There is a general decrease in nitrogen content in riparian buffer strips adjacent to different land use areas as one descends from gazetted forest downstream to commercial agriculture land use areas (Figure 13).

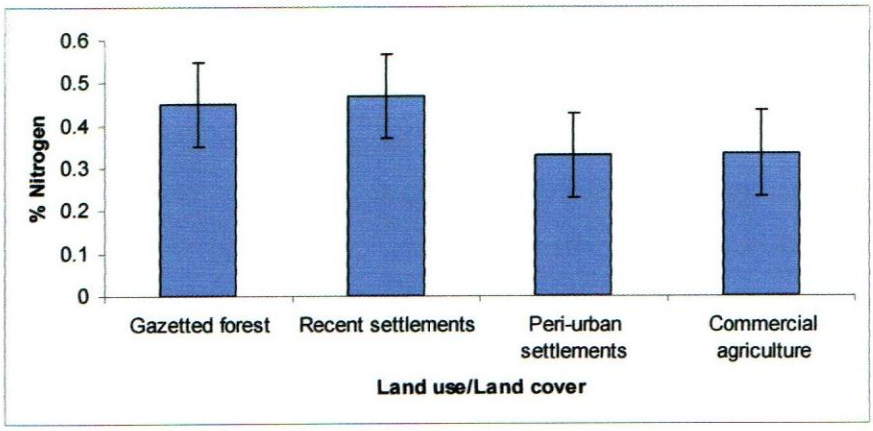


Figure 13: Mean nitrogen content in soils of riparian buffer strips adjacent to different land use areas.

There is a general steady increase in inorganic phosphorus concentration as one descends from less human influenced gazetted forest areas to more intensely influenced areas in peri-urban and commercial agriculture areas (Figure 14).

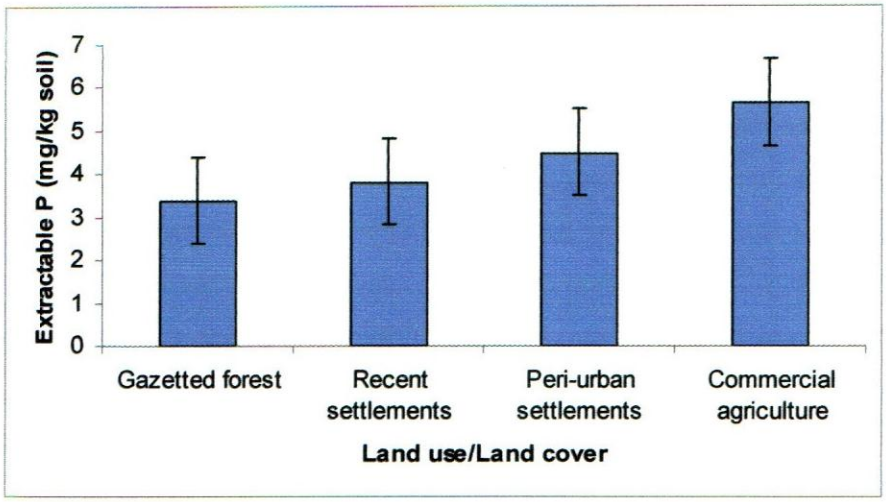


Figure 14: Mean extractable inorganic phosphorus in soils of riparian buffer strips adjacent to different land use areas.

Significant changes in bulk density of surface soils were observed in riparian buffer strips as land use shifted from gazetted forest to higher intensity land use activities (recent settlement, peri-urban and commercial agriculture). Recent settlement bulk density significantly differed from peri-urban and commercial agriculture land use areas ($p<0.05$). But no significant differences were observed between recent settlement and gazetted forest and gazetted forest and peri-urban or commercial agriculture. One way ANOVA on carbon content revealed significant differences between the different land use areas ($F_{(7,236)} =14.062$, $p<0.001$). No significant changes in carbon content ($p=0.990$) and nitrogen ($p=0.998$) content or inorganic phosphorus concentration were observed between gazetted forest and recent settlements. However, significant differences were observed in surface soil carbon content between gazetted forest and peri-urban ($p=0.005$) and between gazetted forest and commercial agriculture ($p<0.001$). The highest mean carbon and nitrogen content and lowest concentration of phosphorus was observed in the gazetted forest and significantly lower mean carbon and nitrogen content was observed in peri-urban and commercial agriculture and higher concentration of inorganic phosphorus was observed in commercial agriculture (Table 3).

Trends in properties of subsurface soils in the riparian buffer strips adjacent to different land use areas were similar to surface soils, but once again the magnitude of the values of subsurface soil properties was lower than the corresponding surface soils (Table 3). Carbon and nitrogen content and concentration of inorganic phosphorus were lower in subsurface soils compared to surface soils in the riparian buffer strips adjacent to the different land use areas. Bulk density data for subsurface soils were not collected. Mean carbon content tended to decrease from gazetted forest (3.57 %) to recent settlements (3.19 %), peri-urban (2.77 %) and commercial agriculture (2.51%). Mean nitrogen content varied from gazetted forest (0.31 %) to recent settlements (0.32 %), peri-urban (0.24 %) and commercial agriculture (0.24 %) and concentration of phosphorus tended to increase from gazetted forest (2.85 mg/kg) to recent settlements (3.51 mg/kg), peri-urban (3.98 mg/kg) and commercial agriculture (3.88 mg/kg) (Table 3).

4.3 Soil Properties in Different Land Use Areas; Adjacent Riparian Buffer Strips and the Reference Condition

The soil properties of the gazetted forest were treated as a reference condition against which the effects of land use activities on soil properties of different land use areas and their adjacent 30 m riparian buffer strips could be assessed (Appendix B).

Agricultural activities in recent settlements had no effect on bulk density, carbon and nitrogen content, but resulted in an increase in the concentration of phosphorus in soils of different land use areas. The 30 m riparian buffer strip served to reset the concentration of phosphorus in surface soils to the concentration found in the reference condition, but did not serve to reset the concentration of phosphorus in subsurface soils of the riparian buffer strip (Appendix B).

Soil bulk density in riparian buffer strips adjacent to recent settlement land use area was lower than gazetted forest while outside the riparian buffer strip, and in the same land use area (recent settlements), it was the highest (Figure 15).

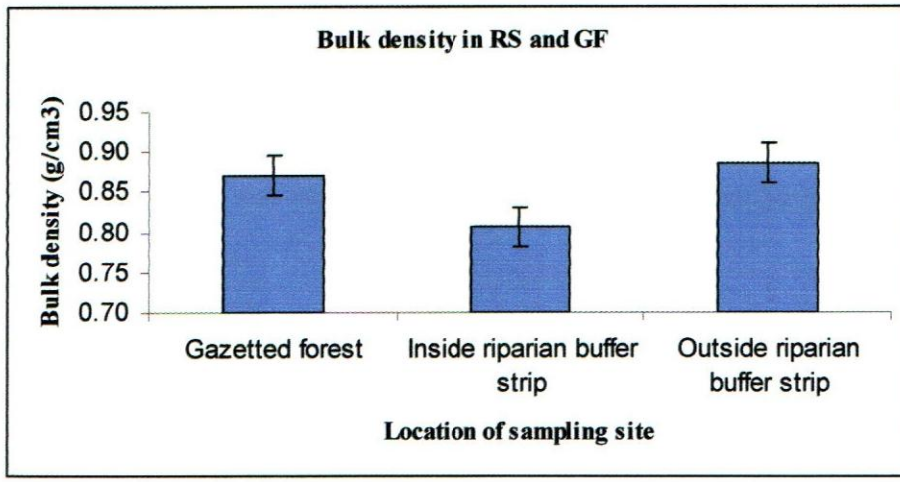


Figure 15: Bulk density inside and outside riparian buffer strips in RS and GF.

Carbon and nitrogen mean content was higher inside (4.80% C and 0.47% N) riparian buffer strips than outside (4.24% C and 0.42% N) riparian buffer strips within recent settlement land use area while bulk density was higher outside the riparian buffer strip (0.84 g/cm^3) than inside the riparian buffer strip (0.77 g/cm^3) (Appendix B). For peri-urban land use area, similar observations were made with higher bulk density outside (1.00 g/cm^3) than inside (0.96 g/cm^3) the riparian buffer strip. Carbon content was higher inside (3.73 %) than

outside (2.69 %) riparian buffer strips and mean nitrogen content was higher inside (0.33 %) than outside (0.24 %) riparian buffer strips. For commercial agriculture bulk density was higher outside (1.14 g/cm^3) than inside (1.11 g/cm^3) while mean carbon content was higher inside (3.36 %) than outside (3.14 %) same to nitrogen content 0.33 % inside and 0.30 % outside riparian buffer strips.

Soil total carbon (%) was higher and closer to the reference condition inside the riparian buffer strip than outside in recent settlement land use areas (Figure 16).

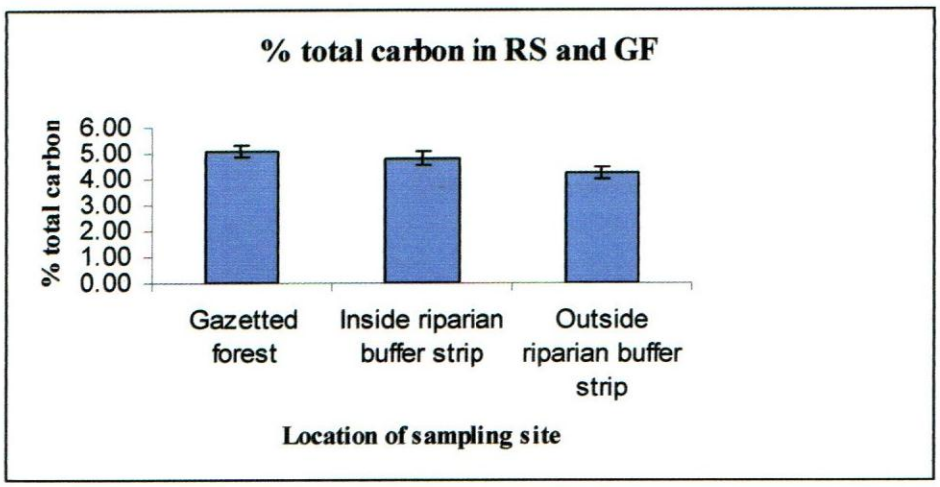


Figure 16: Total carbon (%) inside and outside riparian buffer strips in RS and GF.

Mean total nitrogen (%) was lowest outside the riparian buffer strip in recent settlement land use areas (Figure 17).

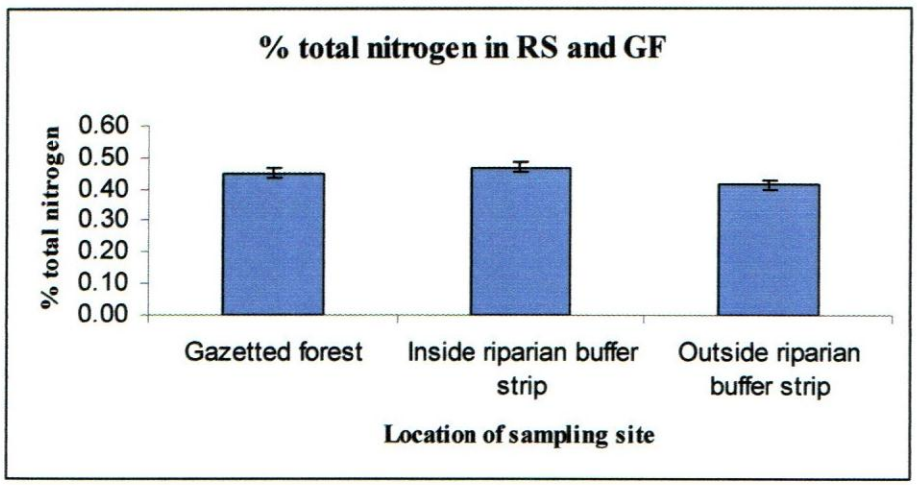


Figure 17: Total nitrogen (%) inside and outside riparian buffer strips in RS and GF.

The lowest extractable inorganic phosphorus concentrations were observed in the reference condition (gazetted forest) while the highest were observed outside than inside the riparian buffer strip adjacent to recent settlement land use areas (Figure 18)

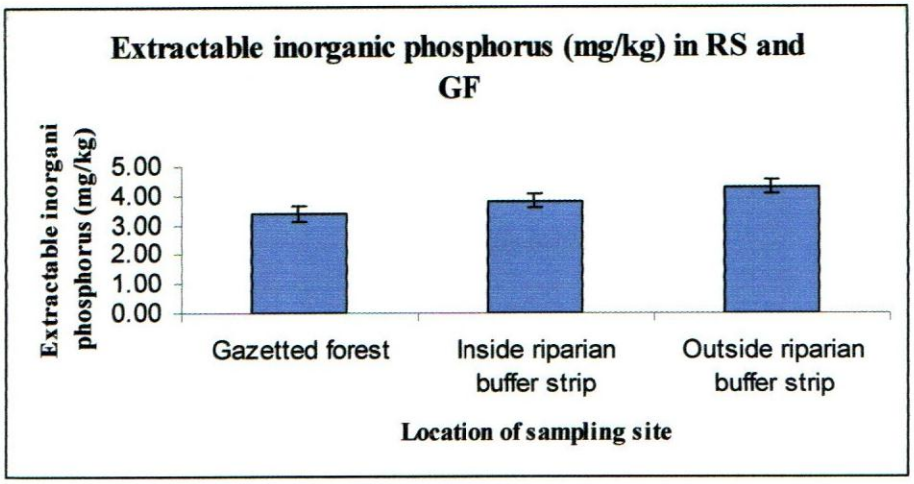


Figure 18: Extractable inorganic phosphorus inside and outside riparian buffer strips in RS and GF.

Agricultural activities in established peri-urban settlements resulted in an increase in bulk density in soils, no effect on carbon and nitrogen content of surface soils but an increase in carbon and nitrogen content of subsurface soils, and an increase in concentration of phosphorus in surface and subsurface soils in different land use areas. The 30 m riparian buffer strip served to reset the bulk density, but not the carbon and nitrogen content of subsurface soils and the concentration of phosphorus in surface and subsurface soils to the concentration found in the reference condition (Appendix B).

The highest mean bulk density values were observed outside than inside the riparian buffer strips adjacent to peri-urban land use areas while the reference condition (gazetted forest) had the lowest (Figure 19)

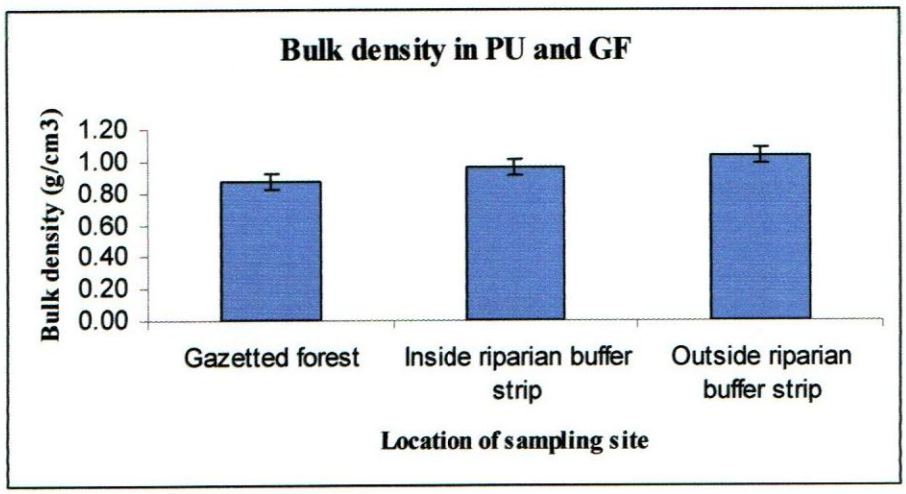


Figure 19: Bulk density inside and outside riparian buffer strips in PU and GF.

The lowest total percent carbon was observed outside than inside the riparian buffer strip adjacent to peri-urban land use areas while the highest percentage was observed in the reference condition (gazetted forest) (Figure 20).

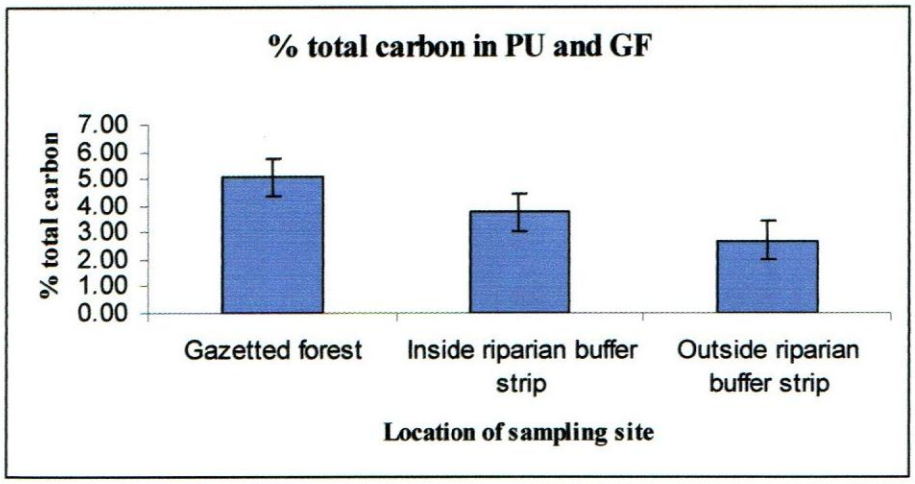


Figure 20: Total carbon (%) inside and outside riparian buffer strips in PU and GF.

The mean total percent nitrogen followed a similar trend to carbon with the lowest mean observed outside the riparian buffer strip adjacent to peri-urban land use area while the highest was in gazetted forest land use area (Figure 21).

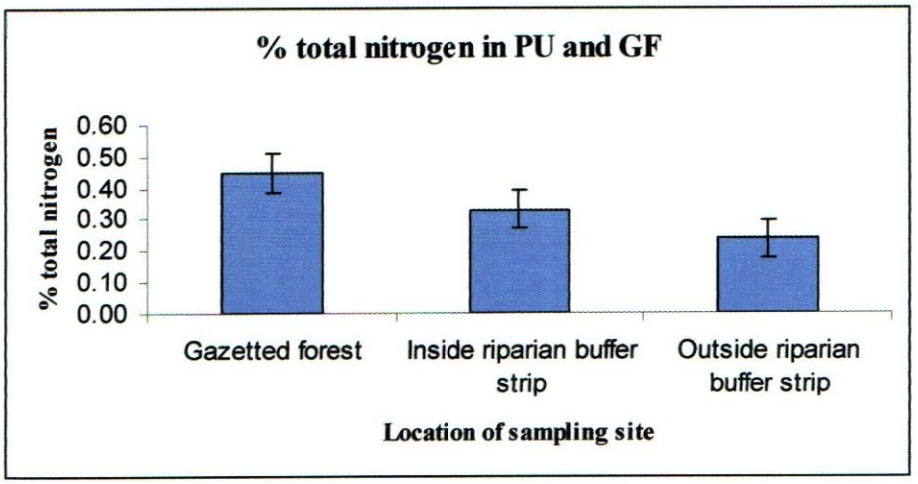


Figure 21: Total nitrogen (%) inside and outside riparian buffer strips in PU and GF.

For extractable inorganic phosphorus, the highest mean values were observed outside the riparian buffer strip adjacent to peri-urban land use areas while the lowest were observed in gazetted forest land use areas (Figure 22).

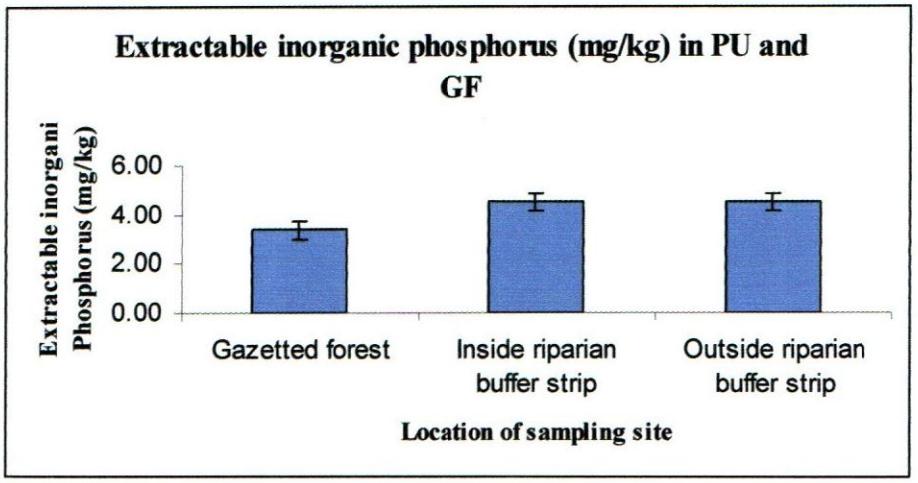


Figure 22: Extractable inorganic phosphorus inside and outside riparian buffer strips in PU and GF.

Activities in peri-urban areas resulted in an increase in bulk density and concentration of phosphorus and a decrease in carbon and nitrogen content, of surface soils. The 30 m riparian buffer strip did not serve to reset these soil properties to those found in the reference condition. These peri-urban activities also resulted in a decrease in carbon and

nitrogen but surprisingly not concentration of phosphorus of subsurface soils. The 30 m riparian buffer strip did not serve to reset the carbon and nitrogen content of subsurface soils to concentrations found in the reference condition (Appendix B).

For riparian buffer strips adjacent to commercial agriculture land use areas, higher values for soil bulk density were observed outside the riparian buffer strip while the lowest values were observed in the reference condition (gazetted forest) (Figure 23).

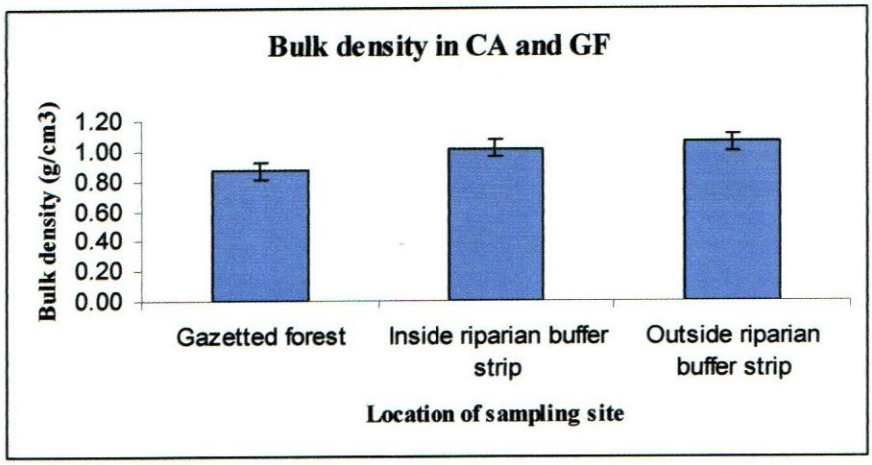


Figure 23: Bulk density inside and outside riparian buffer strips in CA and GF.

For mean total % carbon, there was a general decrease with gazetted forest land use area having the highest values while outside the riparian buffer strip adjacent to commercial agriculture land use areas had the lowest values (Figure 24).

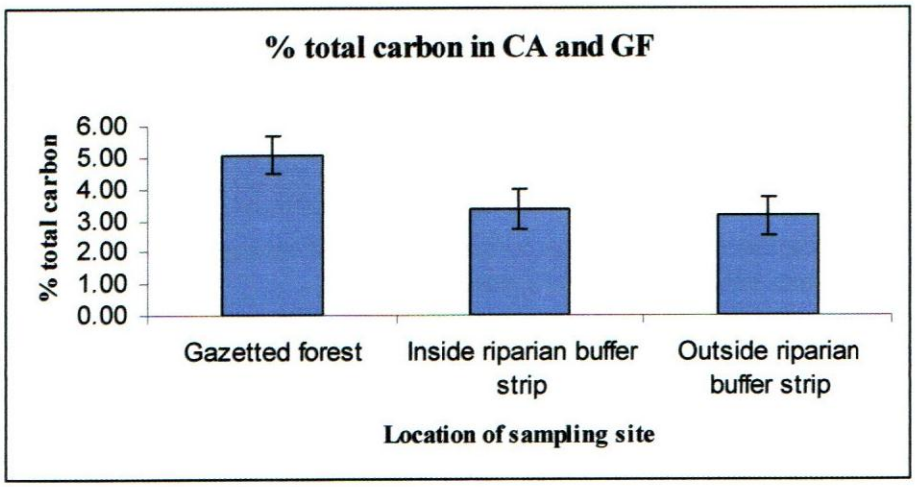


Figure 24: Total carbon (%) inside and outside riparian buffer strips in CA and GF.

A similar trend as was observed for carbon was also observed for mean total % nitrogen with gazetted forest with highest percentages while outside riparian buffer strips adjacent to commercial agriculture land use area had the lowest (Figure 25).

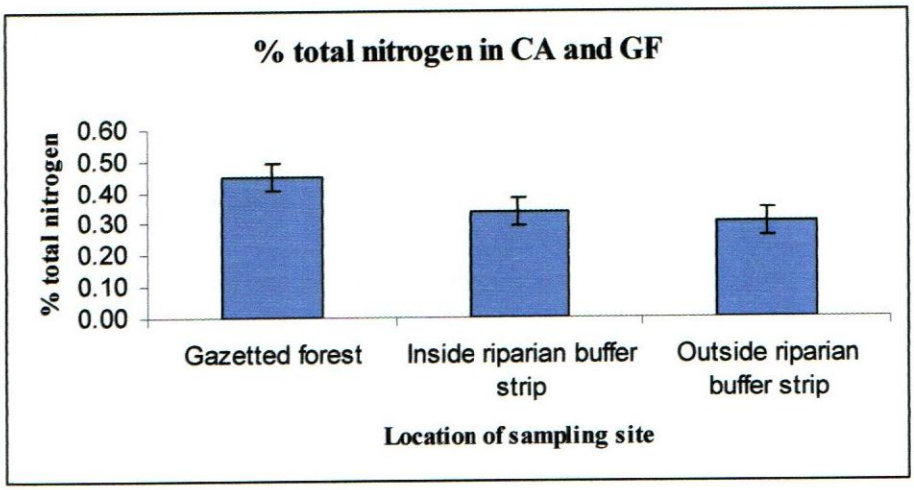


Figure 25: Total nitrogen (%) inside and outside riparian buffer strips in CA and GF.

For extractable inorganic phosphorus, gazetted forest had the lowest concentrations while outside the riparian buffer strip adjacent to commercial agriculture had a lower concentration compared to inside the riparian buffer strip but higher than observed in gazetted forest land use area (Figure 26).

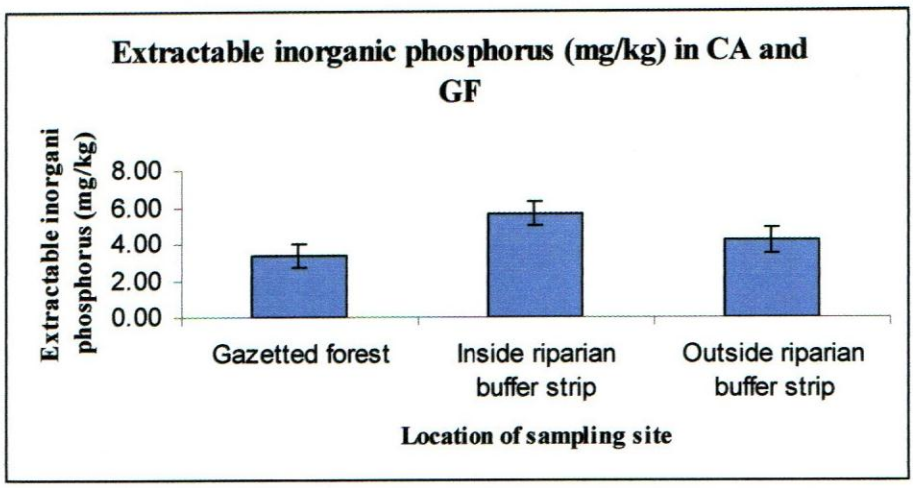


Figure 26: Extractable inorganic phosphorus inside and outside riparian buffer strips in CA and GF.

4.4 Soil Properties in Riparian Buffer Strips that are ≥ 30 m, < 30 m and the Reference Condition

The soil properties of the gazetted forest were treated as a reference condition against which the effects of a riparian buffer strip that was ≥ 30 m versus one that was less than 30 m in surface soils of different land use areas could be assessed. The width of the riparian buffer strip had no effect on bulk density – no significant differences were observed between riparian buffer strips ≥ 30 m or < 30 m in any of the different land use areas and the reference condition (Table 4).

Recent settlement land use areas, bulk density was higher where the riparian buffer strip was less than 30 m (1.07 g/cm^3) than where it was at least 30 m (0.77 g/cm^3) and the differences were significant. Mean carbon content was higher where the riparian buffer strip was ≥ 30 m (4.80 %) than where it was less than 30 m (3.67 %). Similarly, mean nitrogen content was higher where the riparian buffer strip was at least 30 m (0.47 %) than where it was less than 30 m (0.37 %). This indicates that where the riparian buffer strip is less than 30 m, the soils are degraded i.e. compacted with low carbon and nitrogen content. The width of the riparian buffer strip did have an effect on carbon content in recent settlement, with riparian buffer strips < 30 m having significantly smaller carbon than the reference condition but riparian buffer strips ≥ 30 m having no significant difference in carbon compared to the reference condition. Similarly, the width of the riparian buffer strip did have an effect on concentration of phosphorus in recent settlement, with riparian buffer strips < 30 m having significantly larger phosphorus concentrations than the reference condition but riparian buffer strips ≥ 30 m having no significant difference in phosphorus concentrations compared to the reference condition (Table 4). The width of the riparian buffer strip had no effect on nitrogen content in recent settlement.

Table 4: Comparison of soil properties at the surface (0-20 cm), where the riparian buffer strip width is equal to or more than 30 m versus where it is less than 30 m in different land use areas.

Riparian buffer width	Bulk Density (g/cm^3)	Carbon (%)	Nitrogen (%)	Phosphorus (mg/kg)
Reference condition (n=60)	0.87^{ab} (25^{th} 0.76, 75^{th} 0.95)	5.06^{a} (1.18)	0.45^{a} (0.11)	3.47^{b} (25^{th} 2.92, 75^{th} 3.83)
Recent settlements				
Inside 30 m (n=27)	0.77^{b} (25^{th} 0.67, 75^{th} 0.96)	4.80^{ab} (1.77)	0.47^{a} (0.16)	3.34^{ab} (25^{th} 2.48, 75^{th} 4.70)
Inside < 30 m (n=12)	1.07^{a} (25^{th} 0.76, 75^{th} 1.12)	3.67^{b} (1.72)	0.37^{a} (0.14)	4.98^{a} (25^{th} 3.46, 75^{th} 5.93)
Peri–urban settlements				
Inside 30 m (n=18)	0.96^{b} (25^{th} 0.81, 75^{th} 1.10)	3.73^{b} (1.45)	0.33^{b} (0.15)	4.02^{a} (25^{th} 3.70, 75^{th} 4.98)
Inside < 30 m (n=16)	0.96^{b} (25^{th} 0.78, 75^{th} 1.06)	3.72^{b} (2.00)	0.33^{b} (0.20)	3.53^{ab} (25^{th} 3.07, 75^{th} 3.73)
Commercial agriculture				
Inside 30 m (n=15)	1.11^{a} (25^{th} 0.89, 75^{th} 1.17)	3.36^{b} (1.43)	0.33^{b} (0.14)	6.59^{a} (25^{th} 4.32, 75^{th} 7.05)
Inside < 30 m (n=14)	1.11^{a} (25^{th} 0.85, 75^{th} 1.19)	2.97^{b} (0.85)	0.29^{b} (0.10)	4.01^{a} (25^{th} 3.69, 75^{th} 6.01)

Means or medians with the same letter are not significantly different from each other (based on $p<0.05$). Mean with standard deviation in parenthesis for carbon (%) and nitrogen (%) and median with 25^{th} and 75^{th} percentiles in parenthesis for bulk density (g/cm^3) and concentration of phosphorus (mg/kg).

Peri-urban land use areas exhibited differences in soil properties where riparian buffer strips were ≥ 30 m and where they were less than 30 m. Bulk density was higher where riparian buffer strip was ≥ 30 m (0.96 g/cm^3) than where it was less than 30 m (0.96 g/cm^3), differences were not significant. Mean carbon content was higher where riparian buffer strip was ≥ 30 m (3.73 %) than where it was less than 30 m (3.72 %) although differences were not significant. Mean nitrogen content was the same both where riparian buffer strips were less than or ≥ 30 m (0.33). Commercial agriculture land use showed variations in soil properties where riparian buffer strip widths were less and ≥ 30 m. Bulk density was higher where riparian buffer strips were less than 30 m (1.11 g/cm^3) than where it was less (1.11 g/cm^3) but differences were not significant. Mean carbon content was higher where riparian

buffer strips were ≥ 30 m (3.36 %) than where it was less than 30 m (2.97 %) but not significantly different. Mean nitrogen content was higher where riparian buffer strips were ≥ 30 m (0.33 %) than where it was less than 30 m (0.29 %) but not significantly different.

The width of the riparian buffer strip had an effect on carbon and nitrogen content, or concentration of phosphorus in riparian buffer strips ≥ 30 m or < 30 m in peri-urban or commercial agriculture. The 30 m width was insufficient to reset the concentrations of these nutrients back to the reference condition (Table 4). One exception to this rule was that of the concentration of phosphorus in riparian buffer strips < 30 m in peri-urban which was marginally not significantly different from the reference condition, but phosphorus concentrations in riparian buffer strips ≥ 30 m were significantly larger than the reference condition (Table 4).

4.5 Stream Bank Stability

The stability of stream banks was not affected by the different land use areas. The average bank stability index of both ≥ 30 m and < 30 m riparian buffer strips adjacent to recent settlement, peri-urban and commercial agriculture did not increase (i.e., become unstable) compared to the reference condition. Gazetted forest had the highest bank stability index score (10.00) denoting least stability followed by peri-urban (9.00), recent settlement (8.00) and commercial agriculture (7.00) with the lowest median value hence more stable where the riparian buffer strip was at least 30 m. At sites where the riparian buffer strip was less than 30 m, peri-urban (11.50) had the highest bank stability index value (11.00) followed by recent settlement, gazetted forest (10.00) while commercial agriculture (9.50) had the lowest value hence most stable (Table 5).

Table 5: Comparison of the bank stability index in different land use areas for banks where riparian buffer strip width is equal to or more than 30 m versus where it is less than 30 m.

Riparian buffer width	Bank Stability Index
Reference condition (30 m) (n=60)	10.00^{a} (25^{th} 9.00, 75^{th} 11.50)
Recent settlements	
Inside 30 m (n=27)	8.00^{b} (25^{th} 7.00, 75^{th} 8.00)
Inside < 30 m (n=12)	11.00^{a} (25^{th} 7.00, 75^{th} 13.00)
Peri-urban settlements	
Inside 30 m (n=18)	9.00^{a} (25^{th} 7.00, 75^{th} 11.00)
Inside < 30 m (n=16)	10.50^{a} (25^{th} 5.50, 75^{th} 11.00)
Commercial agriculture	
Inside 30 m (n=15)	7.00^{a} (25^{th} 7.00, 75^{th} 11.00)
Inside < 30 m (n=14)	9.50^{a} (25^{th} 8.00, 75^{th} 10.00)

Medians with the same letter are not significantly different from each other (based on $p<0.05$). Data provided are medians with 25^{th} and 75^{th} percentiles in parenthesis.

In contrast, the stability of the stream banks was affected by the water access points (Table 6). The median bank stability index score (12.50) of stream banks at the water access (livestock watering) points was higher (less stable). However, this bank stability index score was not always significant when compared to points 50 m or 100 m upstream and downstream of the watering points.

Table 6: Comparison of the bank stability index for banks located at the watering point, at 50 m and 100 m upstream from the watering point, and at 50 m and 100 m downstream from the watering point in each of the different land use areas.

Transect	Median bank stability index ≥30 m buffer
100 m upstream	10.00^{ab} (25^{th} 8.00, 75^{th} 11.00)
50 m upstream	7.00^{b} (25^{th} 7.00, 75^{th} 10.00)
Initial site (watering point)	12.50^{a} (25^{th} 10.50, 75^{th} 14.50)
50 m downstream	10.00^{ab} (25^{th} 8.00, 75^{th} 12.00)
100 m downstream	8.50^{b} (25^{th} 7.00, 75^{th} 11.50)

Medians with the same letter are not significantly different from each other (based on $p<0.05$). Data provided are medians with 25^{th} and 75^{th} percentiles in parenthesis.

4.6 Riparian Buffer Strip Widths in Different Land Use Areas

The width of the riparian buffer strip differed with change in land use. Gazetted forest had the widest mean riparian buffer width (30.00 m), followed by recent settlement (20.05 m), Peri-urban (17.95 m) and commercial agriculture land use had the lowest (15.98 m) (Table 7). This indicates that the size of riparian buffer strip decreases downstream in River Njoro watershed.

One way ANOVA revealed significant differences in mean riparian buffer strip widths in different land use areas ($F_{(3, 79)} = 9.07$, $p<0.001$). Pair wise mean comparison (Tukey test) showed significant differences between gazetted forest and commercial agriculture ($p<0.001$), gazetted forest and per-urban ($p<0.001$) and gazetted forest and recent settlement ($p=0.006$) land uses. Differences in mean riparian buffer strip widths between recent settlement and commercial agriculture ($p=0.508$), recent settlement and peri-urban ($p=0.890$) and peri-urban and commercial agriculture ($p=0.906$) were not significant. Different land use activities result in significantly narrower riparian buffer strips compared to reference condition (gazetted forest)

Table 7: Mean riparian buffer strip widths and standard deviation in parenthesis in different land use areas in river Njoro watershed.

Land use activity	**Riparian buffer strip width (m)**
Gazetted forest	30.00 (0.00)
Recent settlement	20.05 (10.51)
Peri-urban	17.95 (10.20)
Commercial agriculture	15.98 (11.31)

CHAPTER FIVE

DISCUSSION

The ability to determine, with reasonable accuracy, the effectiveness of riparian buffer strips in mitigating changes in soil properties and stream bank stability in different land use areas is essential for establishing and reviewing riparian resource management and policies. One of the challenges of determining effectiveness of riparian buffer strips in mitigating changes in adjacent land use activities is the identification of a reliable reference condition (Bailey *et al.,* 2004) of soil properties and stream bank stability. Given the comparatively intact and undisturbed riparian buffer strip within the gazetted forest managed lands, it was assumed, in this study, to provide a suitable reference condition for soil properties and stream bank stability in the River Njoro watershed. The stream bank stability and physical and chemical properties of soils in recent settlements, peri-urban settlements (peri-urban) and commercial agriculture land use areas and their adjacent riparian buffer strips were compared to the reference condition. The effects of different land use activities on soils and stream bank stability and the effectiveness of the 30 m riparian buffer strip in mitigating these effects could be assessed.

5.1 Soil Bulk Density

There is a general increase in bulk density (a measure of compaction of soil) with increasing intensity of land use activity in the different land use areas (Table 2) and their adjacent riparian buffer strips (Table 3) in River Njoro watershed. Cooper *et al.,* (1987) observed that up to 90% of sediments that enter streams, lakes and other bodies of water from eroding contributing areas (including ploughed fields, construction and/or logging sites), eroding riparian areas and stream banks could effectively be trapped by both forest and grass riparian buffer strips. Furthermore, previous studies have shown that human activities in riparian areas interrupt natural drainage as riparian soils become compacted, sedimentation rates are increased, and stream channels are altered (Klapproth and Johnson, 2000). Finally, there can be periodic sediment deposition to riparian areas by streams during floods (Mikkelsen and Vesho, 2000). Each of these factors could contribute to the observed patterns in bulk density particularly in the riparian buffer strips in River Njoro watershed.

The 30 m riparian buffer strip may not be effective in mitigating changes in bulk density caused by peri-urban or commercial agriculture land use activities (Table 4). For recent settlement, there was no significant difference between bulk densities in different land use areas or their adjacent riparian buffer strips versus the reference condition. For peri-urban land use areas, there was no significant difference between the land use activity and their adjacent riparian buffer strips. There was no significant difference between riparian buffer strips versus the reference condition, but there was a significant difference between peri-urban lands versus the reference condition. For commercial agriculture, there was a significant difference between the land use area and their adjacent riparian buffer strips versus the reference condition. Based on these observations, a 30 m riparian buffer strip is effective in mitigating changes in bulk density caused by peri-urban land use activities (i.e., the riparian buffer strip is serving to reduce the bulk density towards the reference condition). However, the 30 m riparian buffer strip is not effective in mitigating changes in bulk density caused by commercial agriculture land use activities. The maximum of 30 m riparian buffer strip is not effective in reducing bulk density within the riparian buffer strip adjacent to land use characterized by medium- to large-scale agricultural activities.

5.2 Soil Carbon Content

There is a general decrease in carbon content moving from gazetted forest to recent settlement and then to commercial agriculture and peri-urban in surface and subsurface soils (Table 2). A decrease in carbon content with increase in scale of land use intensity is likely caused by less organic matter deposition due to low leaf litter. There is an abundance of natural sources of organic matter present in the gazetted forest in the form of leaf litter and dead wood. Recently settled lands (small-scale agriculture) may show slightly lower carbon content because these areas have been only recently converted from gazetted forest to recent settlement and the soils may still contain residues of organic matter left over from the original state (gazetted forest). The legacy of original land cover may still be influencing the soil carbon properties of recent settlement land use area. In addition, recent settlement land use activities restrict harvest to the crop itself, leaving the plant residues to be incorporated into the soils, thereby maintaining the carbon content of the soil. In contrast, carbon content in peri-urban areas reveals that the soils receive little organic matter. This is characteristic of lands dominated by large areas of bare land that are prone to erosion that

would wash away any remaining organic matter down slope into the riparian buffer strip and/or stream. Furthermore, periodic deposition of sediments to riparian buffers by streams during floods may be accompanied by the flushing of particulate and dissolved organic matter from the riparian buffer strips to surface waters (Mikkelsen and Vesho, 2000) with resultant decrease in carbon content.

The trend of decrease in carbon content with greater intensity of human activity is reflected in the riparian buffer strips adjacent to the different land use areas but the carbon content is higher (Table 3). The increase in carbon content in riparian buffer strips could be due to the addition of organic matter from riparian vegetation and/or mobilization of organic matter from the different land use areas to the adjacent riparian buffer strips. Indeed, a study by Ritchie and McCarty (2003) showed that soil carbon is significantly higher in riparian soils than upland soils suggesting both a capture of soil carbon moving in the runoff and increased primary productivity possibly related to an increase in nutrients moving into the riparian soils by surface and ground water flow pathways.

The 30 m riparian buffer may not be effective in mitigating changes in soil carbon content caused by peri-urban or commercial agriculture land use activities (Appendix B). There was no significant difference between carbon content in the riparian buffer strip or land use in recent settlements and the reference condition. However, if the riparian buffer strip was reduced in width to < 30 m there was a significant difference in carbon content in the riparian buffer strip in recent settlement and the reference condition (Table 4). Therefore a maximum of 30 m riparian buffer strip may be required to avoid a reduction in soil carbon content within the riparian buffer strip adjacent to different land use areas characterized by small-scale agricultural activities.

There was no significant difference in carbon content in the riparian buffer strips adjacent to different land use areas or different land use in the surface soils in peri-urban and the reference condition (Table 4). An apparent inconsistency was revealed when evaluating the effects if the riparian buffer strip was reduced in width to < 30 m. While no significant difference in carbon content in the riparian buffer strip in surface soils and the reference condition, was revealed when the one-way ANOVA included reference condition, inside 30 m buffer, different land use areas (Appendix B), a significant difference in the riparian buffer strip in surface soils and the reference condition was revealed when the one-way ANOVA included reference condition, inside 30 m riparian buffer and inside < 30 m

riparian buffer (Table 4). There was a significant difference in carbon content in the riparian buffer strip in different land use areas in the subsurface soils in peri-urban and the reference condition. There was no difference in carbon content within riparian buffer strips that were 30 m or < 30 m; the maximum of 30 m riparian buffer strip is inadequate in mitigating changes in carbon content within the riparian buffer strip in different land use areas characterized by medium-scale agricultural activities (Table 4).

There was a significant difference in carbon content in both the riparian buffer strip and different land use areas in surface and subsurface soils in commercial agriculture and the reference condition (Appendix B). There was no significant difference in carbon content of surface soils within riparian buffer strips that were 30 m or < 30 m; the maximum of 30 m riparian buffer strip is inadequate in mitigating reductions in carbon content of surface soils within the riparian buffer strip in different land use areas characterized by medium-scale agricultural activities (Table 4). There was no significant difference in carbon content of subsurface soils within riparian buffer strips that were 30 m or < 30 m and the reference condition (data not shown).

5.3 Soil Nitrogen Content

Similar to carbon content, there is a general decrease in nitrogen content moving from soils in gazetted forest and recent settlement to peri-urban and commercial agriculture in surface and subsurface soils (Table 2). The similarity between carbon and nitrogen content could be explained by the fact that over 90% of the nitrogen in soils is associated with organic matter in the soils (Oldham, 2003a). Nitrogen occurs in relatively simple organic compounds such as amino acids as well as relatively complex organic compounds that may occur in decomposing organic matter (Oldham, 2003a). Decreasing levels of nitrogen when changing from gazetted forest to recent settlement and then peri-urban and commercial agriculture may be caused by the same factors causing decreasing levels of carbon content (i.e., reduced sources of organic matter). Furthermore, only a small proportion of the nitrogen passing through a riparian buffer strip may be taken up and stored in woody plant tissues, as most of it may be transformed from particulate to dissolved forms that are readily mobilized into surface waters (Oldham, 2003a) especially in areas with less vegetation as is the case in areas with high human intensity activities.

The trend of decrease in nitrogen content with greater intensity of land use activity is reflected in the different land use areas but nitrogen is higher in the adjacent riparian buffer strips (Table 3). While not significantly different, nitrogen content in recent settlement was higher than gazetted forest. This trend could be attributed to the fact that communities inhabiting recently settled land use areas use riparian areas as grazing grounds (Lelo *et al.*, 2005) so both human and animal wastes that are rich in nitrogenous compounds could contribute to the higher nitrogen content in recently settled land use areas.

For peri-urban and commercial agriculture, nitrogen content is similarly lower. In addition to particulate losses of nitrogen (as described for carbon), riparian buffer strips in peri-urban and commercial agriculture may experience more surface flows during rain events due to the presence of more bare ground in the uplands. Nitrogen in the form of dissolved nitrate nitrogen is mobile and therefore may be flushed out of the riparian buffer strip to the stream (Bretschko and Moser, 1993; Creed and Band, 1998) if it is not denitrified. Some studies have shown that not all areas of the riparian buffer strip function equally in removing nitrogen. For example, nitrogen levels are reduced in portions of a riparian buffer strip that are frequently flooded, but remain elevated in portions that remain dry (Johnston *et al.*, 1984; Gold and Groffman, 1995).

The 30 m riparian buffer strip may not be effective in mitigating changes in nitrogen content caused by peri-urban or commercial agriculture land use activities (Table 4). There was no significant difference between nitrogen content in the riparian buffer strip or the land use recent settlement and the reference condition of the 30 m riparian buffer strip (Appendix B) or the < 30 m riparian buffer strip (while there was a reduction in %N in riparian buffer strips < 30 m, this reduction was not statistically significant) (Table 4). The maximum of 30 m riparian buffer strip may be needed to avoid a reduction in nitrogen content within the riparian buffer strip in different land use areas characterized by small-scale agricultural activities.

There was no significant difference in nitrogen content in the riparian buffer strip or different land use areas in the surface soils in peri-urban and the reference condition (Appendix B). However, there was a significant difference in nitrogen content in the riparian buffer strip or different land use areas in the subsurface soils in peri-urban and the reference condition. Riparian buffer strips that were 30 m or < 30 m showed no significant difference in nitrogen content within surface soils (Table 4); the maximum of 30 m riparian

buffer strip is inadequate in mitigating reductions in %N within the riparian buffer strip in different land use areas characterized by medium-scale agricultural activities.

There was a significant difference in %N in both the riparian buffer strip and different land use areas in surface and subsurface soils in commercial agriculture and the reference condition (Appendix B). There was no significant difference in %N of surface soils within riparian buffer strips that were 30 m or < 30 m; the maximum of 30 m riparian buffer strip is inadequate in mitigating reductions in nitrogen content of surface soils within the riparian buffer strip in different land use areas characterized by medium and large-scale agricultural activities (Table 4).

Shivoga *et al.* (2007) observed that there was no net contribution of nitrate into surface waters from sites near recent settlement, but that there was a significant contribution of nitrate into surface waters near lands with higher intensity human land use activity. This suggests that nitrogen in the peri-urban and commercial agriculture riparian buffer strips is being flushed to surface waters.

5.4 Soil Phosphorus Concentration

Unlike soil carbon and nitrogen content, there is a general increase in extractable phosphorus concentration with increase in scale of land use activity. Gazetted forest had the lowest concentration of phosphorus in soils. In contrast, recent settlement, peri-urban and commercial agriculture had higher phosphorus concentrations that were not significantly different. This trend was observed in both surface and subsurface soils, with surface soils having higher inorganic P than subsurface soils (Table 2). The trend was also observed in the riparian buffer strips adjacent to the different land use areas (Table 3).

Phosphorus adsorbs to soil particles and therefore it provides a "memory" of human activities more so than nitrogen. Probable sources of inorganic P in peri-urban areas include detergents from washing of clothes in the riparian area and human and animal waste from animals used to ferry water for commercial purposes. Sources in commercial agriculture land use areas include di-ammonium phosphate (DAP) which is the main fertilizer used in the commercial agricultural farms (Mokaya *et al.*, 2004). Studies reveal that, the movement of phosphorus within landscapes is intimately associated with the mobilization of soils (Oldham, 2003b; Sharpley *et al.*, 1993). Ritchie and McCarty (2003) have observed that the riparian system acts as a filter removing eroded soil materials from the overland flow before

it reaches the stream. Other studies show soils of riparian wetlands are highly effective at phosphorus adsorption and there are suggestions that because clays tend to accumulate in riparian soils, riparian soils play an important role in the removal of dissolved phosphorus (Walbridge and Struthers, 1993). These factors may explain the large levels of extractable inorganic phosphorus in soils in riparian buffer strips adjacent to peri-urban and commercial agriculture land use areas, since they may be receiving phosphorus-rich material from the adjacent land use activity. Furthermore, riparian ecosystems, because of their flatter slopes and high surface roughness, effectively reduce suspended soil particulates and, in doing so, often reduce phosphate concentrations in streams while accumulating them in riparian buffer strip soils with resultant changes in their soil physical and chemical properties (Amador *et al.*, 1997; Lowrance *et al.*, 1984a).

The 30 m riparian buffer strip may be effective in mitigating changes in soil phosphorus concentrations related to different land use activities in recent settlement areas but not in peri urban or commercial agriculture land use areas (Appendix B).

5.5 Stream Bank Stability

For recent settlement areas stream bank stability values are significantly different from one another where riparian buffer strip widths are equal to or greater than 30 m and less than 30 m (Table 6). Where riparian buffer strip widths are less than 30 m stream banks are unstable while at risk where riparian buffer strips are equal to or more than 30 m. The significant differences imply that 30 m riparian buffer strips may be sufficient in maintaining stream bank stability in recent settlement but may not be sufficient for peri-urban and commercial agriculture land use areas. This could be because there were no significant differences in bank stability index scores in this land use areas. This suggests that riparian buffer strips with widths greater than 30 m may be required to realize significant differences in bank stability index scores in the different land use areas. Since the variable land use/cover did not show significant differences in bank stability index values, the next source of variation in the whole study was the transect location. Further exploration revealed significant differences when Kruskal Wallis ANOVA on ranks was performed on stream bank stability index scores on different transects. Pairwise multiple comparison procedures (Tukey test) revealed that the watering point was the least stable which is consistent with results from other studies whose findings show that banks that are

constantly disturbed with less riparian vegetation are the least stable (Belsky, *et al.*, 1999; Mathooko, 2001; Allan, 2004).

5.6 Riparian Buffer Strip Width

Results revealed that intact government gazetted forests had the widest riparian buffer strip widths (Table 7) which were significantly different from the other land use areas (recent settlements, peri-urban and commercial agriculture). However, riparian buffer strip widths in the different land use areas were not significantly different from one another (mean riparian buffer strip widths between recent settlement, peri-urban and commercial agriculture were not significantly different from each other). Therefore, land use activities result in reduction of riparian buffer strip widths.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The aim of this study was to assess the effectiveness of the Kenyan policy of a maximum 30 m riparian buffer strip for management of the River Njoro watershed by comparing the physical and chemical properties of soils and stream bank stability in recent settlement, agricultural and peri-urban land use areas and their adjacent riparian buffer strips to a reference condition provided by gazetted forest. Based on the findings of this study the following conclusions can be made:

1. The nature of land use controls on riparian buffer strip soil properties is dependent, on the width of the riparian buffer strip. The presence of a 30 m riparian buffer strip may be appropriate for small scale human activities (e.g., recent settlements) where settlers coexist with indigenous peoples, respecting one another's way of life and therefore the riparian buffer strip has been left intact in most sites. However, the presence of a 30 m riparian buffer strip may not be appropriate for larger scale human activities in peri-urban areas and commercial agricultural areas.

2. Changes in the width of riparian buffer strips significantly, but differentially, affect soil properties in riparian buffer strips. Changes to the soil properties of riparian buffer strips could have far reaching effects because if the C: N: P ratio of the soil properties reflect the C: N: P ratio of the water that is discharged from the riparian buffer strip, these changes may have fundamental consequences not only for the riparian vegetation but also for the adjacent aquatic ecosystem.

3. Phosphorus appeared to be the most sensitive indicator of impacts of human activity, as elevated concentrations were found at all scales of high intensity human land use activities (peri-urban and commercial agriculture). In contrast, carbon and nitrogen contents were high in low intensity human land use activities (recent settlement and gazetted forest areas) and low in high intensity human activity areas.

4. Changes in land use activities influence significantly riparian buffer strip widths in River Njoro watershed. Increasing intensity of land use may result in narrower

widths of the riparian buffer strip. With the exception of gazetted forest, other land use activities result in narrowing of riparian buffer strip widths.

5. Catchment land use does not influence stream bank stability in the River Njoro watershed but local land use (watering points) has a significant influence on stream bank stability with high intensity use (watering points) resulting in unstable stream banks.

Most of the differences in soil physical and chemical properties within riparian buffer strips in the River Njoro watershed are probably explained by whether the riparian buffer strip width was equal to or greater than 30 m or less than 30 m and also systematic changes in land use.

6.2 Recommendations

Based on the results from this research, the following recommendations were made:

1. This thesis has policy implications regarding the optimal width of the riparian buffer strip in the River Njoro watershed and other watersheds in Kenya. It has revealed that a 30 m riparian buffer strip width may not be optimal for all different land use areas and that a "one size fits all" (Strayer *et al.*, 2003) riparian buffer strip width may not be appropriate in different land use areas in River Njoro watershed and other watersheds. Therefore, it is recommended that the current 30 m maximum riparian buffer strip width should be treated as a minimum in most land use areas, adaptive, with 30 m used in recent settlements in River Njoro watershed and wider strips used in areas with higher intensity human activity.

2. The slope and vegetation cover are important factors to be considered when recommending the optimal size of riparian buffer strips in each land use area. Despite the results of this research showing little influence of slope and vegetation cover, further research on the influence of slope and vegetation cover in mitigating changes in soil properties and stream bank stability related to land use activities is recommended.

3. Modification of the work contained in this thesis is recommended in order to be able to generalize in all areas of the River Njoro watershed and other watersheds in Kenya.

Possible inclusion of soil characteristics outside the 30 m riparian buffer strip but adjacent to the study site may increase the regional applicability of the conclusions. Further verification of the influence of soil properties on water quality adjacent to the riparian buffer strip is also recommended since it would better assist in developing links between water quality in relation to adjacent land use and corresponding riparian buffer strip widths. This would provide the missing link in the complex issue of linking land use, healthy riparian buffer strips and water quality and quantity.

4. Sediment tracking in the river bed is recommended since it could help link land use activities to sediment load in the river bed and hence better assess the effectiveness of different widths of riparian buffer strips in mitigating adjacent land use effects on water quality and quantity.

5. Due to watering points resulting in least stable stream banks, it is recommended that livestock watering points (in the form of troughs) should be located away from the stream and outside the riparian area.

6. Future studies on land use influence on soil properties should concentrate on surface soils since this study revealed that subsurface soils had suppressed land use effects.

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APPENDICES

APPENDIX A: Soil Analyses Methods

Calibration for the Near Infra Red Soil Physical and Chemical Characteristics

Wet chemical analyses were performed on a fraction of the total samples (30 samples) to generate calibrations that were later used to predict parameters on the remaining 427 samples. All 457 soil samples were subjected to scanning using Infra red technology.

Determination of % carbon and % nitrogen.

Determination of % carbon and % nitrogen was done using a CNS2000 analyzer. Soil samples for analysis were oven dried at 105^0C for 2 hours. Soil samples were weighed directly into the ceramic crucible and weight recorded, then I g of combustible catalyst, 502-321 COM-CAT was added on top of the sample and mixed. The crucible was placed into the autoloader rack and analysis began. The % carbon and % nitrogen were read directly from the machine after 4 minutes.

Extractable inorganic phosphorus

Laboratory determination of extractable inorganic phosphorus was performed using a modified Olsen extractant. Soil extracting solution (0.5 M $NaHCO_3$ + 0.01 M EDTA, pH 8.5) was prepared by dissolving 74.4 g disodium EDTA then adding 200 mL of Superfloc solution then made up to 20 L with deionized water. Then 90 ml of 20% NaOH solution was added to adjust pH of the extractant to 8.5.

Phosphorus colour reagent was prepared by slowly adding 1 g antimony potassium tartarate to 400 ml deionised water in a 1000 ml volumetric flask with mixing. 165 ml concentrated H_2SO_4 acid was added with mixing and then allowed to cool. In a separate container, 7.5 g ammonium molybdate was dissolved in 300 ml deionized water, then added to the cool acid antimony solution in the 1000 ml volumetric flask and made to mark with deionized water. A working phosphorus colour reagent was freshly prepared by adding 150 ml of concentrated P colour reagent to 100 ml volumetric flask and made to volume with deionized water; 1 g of ascorbic acid was added and dissolved.

Phosphorus stock solution (500 mg P/L) was prepared by dissolving 1.0986 g of dry KH_2PO_4 in deionized water and made up to 500 ml in a volumetric flask Intermediate stock

phosphate solution (50 mg P/L) was prepared by pipetting 25 ml of 500 mg P/L solution into a 250 ml volumetric flask and made to volume with deionized water. Working standards in $NaHCO_3$ extracting solution (0, 1, 2, 4 and 5 mg P/L were made by pipetting 0, 1, 2, 3, 4, and 5 ml of the 50 mg P/L solution into labelled 50 ml volumetric flasks and made to volume with $NaHCO_3$ extracting solution and mixed well.

Phosphorus extraction from soil samples was done by weighing a 2.5 ml spoon with holder, scooping 2.5 ml of soil and weighing spoon with soil and holder, then recording the weight. Soil was added into 60 ml bottle and 25 ml of extracting solution added then stirred for 10 minutes. Filtration was done by gravity using Whatman No. 5 filter paper into clean 60 ml bottles.

Colorimetric determination of P was done using a spectrophotometer. 2 ml of standard solution or filtered extract was dispensed and 8 ml of deionised water and 10 ml of working P colour reagent into a clean 60 ml bottle and left for 1 hour for colour to develop fully. After full colour development, the standard and sample absorbance/concentration was read at 880 nm. Absorbance values for the standards were determined to check linearity of the standard curve. Blanks and samples were read in concentration mode. Phosphorus concentration in soil (mg/kg) using the following equation:

$$\text{P concentration in soil (mg P/kg soil)} = \frac{(\text{EXPCONC} - \text{EXPBLNK})\,(\text{EXPVOL})}{\text{EXKSOLWT}}$$

Where EXPCONC = Phosphorus concentration for sample (mg P/L)

EXPBLNK = Phosphorus concentration for blank (mg P/L)

EXPVOL = Volume of extracting solution (mL)

EXKSOLWT = Weight of dry soil extracted (g)

The R^2 values obtained for the different parameters are as follows

Parameter	**Calibration**	
	R sq.	*RMSEC*
Nitrogen	96.14	0.033
Carbon	95.46	0.38
Phosphorus	84.95	0.26

APPENDIX B: Soil Properties Inside Riparian Buffer Strip, Outside the Riparian Buffer Strip and the Reference Condition (GF)

	Bulk Density (g/cm^3)	Carbon (%)	Nitrogen (%)	Phosphorus concentration (mg/kg)
Surface (0-20cm)				
Reference Condition	0.87^{b} (25^{th} 0.76, 75^{th} 0.95)	5.06^{a} (1.18)	0.45^{a} (0.11)	3.47^{b} (25^{th} 2.92, 75^{th} 3.83)
Recent settlements				
In Buffer	0.77^{b} (25^{th} 0.67, 75^{th} 0.96)	4.80^{a} (1.77)	0.47^{a} (0.16)	3.34^{ab} (25^{th} 2.84, 75^{th} 4.70)
Out Buffer	0.84^{b} (25^{th} 0.74, 75^{th} 1.07)	4.24^{a} (1.09)	0.42^{a} (0.11)	4.19^{a} (25^{th} 3.97, 75^{th} 4.60)
Peri–urban settlements				
In Buffer	0.96^{ab} (25^{th} 0.81, 75^{th} 1.10)	3.73^{a} (1.45)	0.33^{a} (0.15)	4.02^{a} (25^{th} 3.70, 75^{th} 4.98)
Out Buffer	1.00^{a} (25^{th} 0.92, 75^{th} 1.13)	2.69^{a} (1.08)	0.24^{a} (0.11)	3.88^{a} (25^{th} 3.64, 75^{th} 5.16)
Commercial agriculture				
In Buffer	1.11^{a} (25^{th} 0.89, 75^{th} 1.17)	3.36^{b} (1.43)	0.33^{b} (0.14)	6.59^{a} (25^{th} 4.32,75^{th} 7.05)
Out Buffer	1.14^{a} (25^{th} 0.84, 75^{th} 1.24)	3.14^{b} (1.06)	0.30^{b} (0.09)	4.15^{a} (25^{th} 3.70,75^{th} 4.80)
Subsurface (20-50cm)				
Reference Condition		3.57^{a} (1.23)	0.31^{a} (0.11)	2.85^{a} (25^{th} 2.58, 75^{th} 3.25)
Recent settlements				
In Buffer		3.19^{a} (1.56)	0.32^{a} (0.14)	3.51^{b} (25^{th} 2.71, 75^{th} 5.06)
Out Buffer		2.74^{a} (1.00)	0.28^{a} (0.09)	3.61^{b} (25^{th} 3.29, 75^{th} 4.27)
Peri-urban settlements				
In Buffer		2.77^{b} (1.03)	0.24^{ab} (0.10)	3.98^{b} (25^{th} 3.28, 75^{th} 4.37)
Out Buffer		2.30^{b} (0.78)	0.19^{b} (0.08)	3.55^{b} (25^{th} 2.79, 75^{th} 4.50)
Commercial agriculture				
In Buffer		2.51^{b} (1.18)	0.24^{ab} (0.11)	3.88^{a} (25^{th} 2.38, 75^{th} 6.83)
Out Buffer		2.28^{b} (1.03)	0.22^{b} (0.10)	3.73^{a} (25^{th} 2.78, 75^{th} 4.13)

Means or medians with the same letter are not significantly different from each other (based on $p<0.05$).

Mean with standard deviation in parenthesis for carbon and nitrogen content and median with 25^{th} and 75^{th} percentiles in parenthesis for bulk density (g/cm^3) and concentration of inorganic phosphorus (mg/kg).

APPENDIX C: Slope, Bank Vegetation Canopy Cover in each Land Use Area.

Land use	Slope (degrees)	Bank vegetation cover (%)	Canopy cover (%)
Gazetted forest	6.00^{b} (25^{th} 5.00, 75^{th} 9.00)	100.00^{a} (25^{th} 92.5, 75^{th} 100.00)	89.50^{a} (25^{th} 73.00, 75^{th} 100.00)
Recent settlements	12.50^{a} (25^{th} 9.00, 75^{th} 16.00)	75.00^{a} (25^{th} 0.00, 75^{th} 100.00)	95.00^{ab} (25^{th} 0.00, 75^{th} 100.00)
Peri-urban settlements	7.50^{b} (25^{th} 4.00, 75^{th} 10.00)	100.00^{a} (25^{th} 35.00, 75^{th} 100.00)	91.00^{ab} (25^{th} 35.00, 75^{th} 97.50)
Commercial agriculture	12.00^{a} (25^{th} 9.50, 75^{th} 14.50)	65.00^{a} (25^{th} 0.00, 75^{th} 100.00)	0.00^{b} (25^{th} 0.00, 75^{th} 100.00)

Medians with the same letter are not significantly different from each other (based on $p<0.05$).

Median values with 25^{th} and 75^{th} percentiles in parenthesis.

APPENDIX D: Slope on each Transect and Vegetation Percent Cover

Land use/land cover	Site name	Transect location (m)	Slope of 30 m riparian buffer (degrees)	Side of stream	% riparian canopy closure	% bank vegetation cover
Gazetted forest	Logoman	100 m downstream	2	Right	60	100
Gazetted forest	Logoman	100 m downstream	4	Left	60	100
Gazetted forest	Logoman	100 m upstream	13	Right	79	100
Gazetted forest	Logoman	100 m upstream	6	Left	79	100
Gazetted forest	Logoman	50 m downstream	19	Right	74	90
Gazetted forest	Logoman	50 m downstream	4	Left	74	95
Gazetted forest	Logoman	50 m upstream	8	Right	100	100
Gazetted forest	Logoman	50 m upstream	3	Left	100	100
Gazetted forest	Logoman	initial (impacted) site	12	Right	100	100
Gazetted forest	Logoman	initial (impacted) site	5	Left	100	100
Gazetted forest	Teret	100 m downstream	9	Right	100	100
Gazetted forest	Teret	100 m downstream	9	Left	100	100
Gazetted forest	Teret	100 m upstream	6	Right	100	100
Gazetted forest	Teret	100 m upstream	6	Left	100	100
Gazetted forest	Teret	50 m downstream	8	Right	73	90
Gazetted forest	Teret	50 m downstream	6	Left	73	90
Gazetted forest	Teret	50 m upstream	11	Right	100	100
Gazetted forest	Teret	50 m upstream	5	Left	100	100
Gazetted forest	Teret	initial (impacted) site	9	Right	0	0
Gazetted forest	Teret	initial (impacted)	6	Left	0	0

		site				
Commercial agriculture	Ngata crossing	100 m downstream	18	Right	0	90
Commercial agriculture	Ngata crossing	100 m downstream	14	Left	0	80
Commercial agriculture	Ngata crossing	100 m upsream	13	Right	0	100
Commercial agriculture	Ngata crossing	100 m upsream	15	Left	0	100
Commercial agriculture	Ngata crossing	50 m downstream	11	Right	0	50
Commercial agriculture	Ngata crossing	50 m downstream	21	Left	0	20
Commercial agriculture	Ngata crossing	50 m upstream	3	Right	0	100
Commercial agriculture	Ngata crossing	50 m upstream	8	Left	0	100
Commercial agriculture	Ngata crossing	initial (impacted) site	12	Right	0	0
Commercial agriculture	Ngata crossing	initial (impacted) site	12	Left	0	0
Commercial agriculture	Piave bridge	100 m downstream	29	Right	100	0
Commercial agriculture	Piave bridge	100 m downstream	31	Left	100	0
Commercial agriculture	Piave bridge	100 m upstream	10	Right	0	100
Commercial agriculture	Piave bridge	100 m upstream	14	Left	0	100
Commercial agriculture	Piave bridge	50 m downstream	7	Right	100	0
Commercial agriculture	Piave bridge	50 m downstream	11	Left	100	0
Commercial agriculture	Piave bridge	50 m upstream	12	Right	100	100
Commercial agriculture	Piave bridge	50 m upstream	10	Left	100	100
Commercial agriculture	Piave bridge	initial (impacted) site	8	Right	0	10
Commercial agriculture	Piave bridge	initial (impacted) site	9	Left	0	0
Peri-urban	Njoro bridge	100 m downstream	3	Right	70	100
Peri-urban	Njoro bridge	100 m downstream	4	Left	70	100

Peri-urban	Njoro bridge	100 m upstream	8	Right	100	100
Peri-urban	Njoro bridge	100 m upstream	8	Left	100	100
Peri-urban	Njoro bridge	50 m downstream	2	Right	100	100
Peri-urban	Njoro bridge	50 m downstream	5	Left	100	100
Peri-urban	Njoro bridge	50 m upstream	6	Right	100	100
Peri-urban	Njoro bridge	50 m upstream	9	Left	0	0
Peri-urban	Njoro bridge	initial (impacted) site	4	Right	0	0
Peri-urban	Njoro bridge	initial (impacted) site	12	Left	0	50
Peri-urban	Turkana flats crossing	100 m downstream	9	Right	95	100
Peri-urban	Turkana flats crossing	100 m downstream	7	Left	95	70
Peri-urban	Turkana flats crossing	100 m upstream	11	Right	71	20
Peri-urban	Turkana flats crossing	100 m upstream	36	Left	71	100
Peri-urban	Turkana flats crossing	50 m downstream	12	Right	91	100
Peri-urban	Turkana flats crossing	50 m downstream	3	Left	91	100
Peri-urban	Turkana flats crossing	50 m upstream	4	Right	95	100
Peri-urban	Turkana flats crossing	50 m upstream	30	Left	95	100
Peri-urban	Turkana flats crossing	initial (impacted) site	5	Right	0	20
Peri-urban	Turkana flats crossing	initial (impacted) site	8	Left	0	0
Recently settled	Forest camp	100 m downstream	4	Right	95	75
Recently settled	Forest camp	100 m downstream	10	Left	95	0
Recently settled	Forest camp	100 m upsream	12	Right	95	75
Recently settled	Forest camp	100 m upstream	18	Left	95	80
Recently settled	Forest camp	50 m	9	Right	94	50

		downstream				
Recently settled	Forest camp	50 m downstream	9	Left	94	50
Recently settled	Forest camp	50 m upstream	15	Right	100	100
Recently settled	Forest camp	50 m upstream	12	Left	100	100
Recently settled	Forest camp	initial (impacted) site	8	Right	20	10
Recently settled	Forest camp	initial (impacted) site	9	Left	20	0
Recently settled	Sigotik bridge	100 m downstream	13	Right	100	100
Recently settled	Sigotik bridge	100 m downstream	17	Left	100	100
Recently settled	Sigotik bridge	100 m upstream	16	Right	100	0
Recently settled	Sigotik bridge	100 m upstream	19	Left	100	0
Recently settled	Sigotik bridge	50 m downstream	13	Right	56	100
Recently settled	Sigotik bridge	50 m downstream	8	Left	56	100
Recently settled	Sigotik bridge	50 m upstream	15	Right	100	100
Recently settled	Sigotik bridge	50 m upstream	18	Left	100	100
Recently settled	Sigotik bridge	initial (impacted) site	8	Right	0	0
Recently settled	Sigotik bridge	initial (impacted) site	16	Left	0	0

APPENDIX E: Riparian Vegetation at each Sampled Transect along River Njoro

Logoman	
Left	Right
(100m upstream) *Rhamnus staddo, Olea africana, Impatiens sp., Fibristilis sp., Asparagus racemosus, Ranunclus aquarticum*	*Juniperus procera, Rhamnus prinoides, Carduus sp., Citronella asiatica, Clutia abyssinica, Maytenus senegalensis.*
(50m upstream) *Prunus africana, Eleusine jaegeri, Rapanea melanophloes, Citronella asiatica*	*Jasminum flanbunch, Olea africana, Rhapanea melanophloes, Pennisetem clandestinum.*
(0m) *Rubus steudneri, Olea africana, Juniperus procera, Senecio montuosum*	*Jasminin floribindin, Juniperus procera, Rhamnus prinoides, Oxalis corniculata*
(50m downstream) *Clutia abyssinica, Podocarpus latifolius, Olea africana, Eleusine jaegeri, Juniperus procea, Solanum nakurense*	*Juniperus procera, Rhamnus prinoides, Oxalis corniculata.*
(100m downstream) *Triumfetta macrophylla, Rhamnus staddo, Dombeya goetzanii, Maytenus ovatus, Asparagus racemasus, Plectrenthus sp.*	*Polygonum sp., Rhamnus staddo, Juniperus procera, Clutia abyssinica, Openanthe palustris, Utica massaica, Citronella asaitica.*
Teret	
(100 upstream) *Kalanchoe sp., Cyperus rotundus, Balsam sp., Solanum nakurense, Clutia abyssinica, Rubus steudneri, Garlinsoga parviflora.*	*Maytenus senegalensis, Kalanchoe densiflora, Satureja biflora, Clutia abyssinica*
(50m upstream) *Fibristilis asp., Oenanthe palustris, Portulacca sp. Hypoestis sp., fern*	*Oxalis sp., Eleusine jaegeri, Cupressus lusitanica*
(0m) *Citronella asiatica, Maytenus senegalensis, Oenathe palustris, Rhus natalensis, Asparagus racemosus.*	*Clutia abyssinica, Maytenus senegalensis, Conyza newii*
(50m downstream) *Trifolium repens, Rhannus prinoides, Fibristilis sp., Oenanthe palustris, Olea africana, Rhus natalensis.*	*Rhamnus staddo, Clutia abyssinica, Eleusine jaegeri, Cyperus rotundus*
(100 m downstream) *Oxalis corniculata, Carduus kikuyorum, Pennisetum kikuyorum, Asparagus racemasus, Rhamnus staddo, Citronella asiatica, Juniperus procera, Asparagus racemosus, Hypoestis sp., Rhapanea melanophloes, Rhamnus staddo*	*Trifolium repens, Citronella asiatica, Juniperus procera, Clutia abyssinica, Prunus Africana, Jasminum floribundum, Maytenus senegalensis, Clerodendrum sp., Rhus natalensis, Rhamnus prinoides.*
Sigotik Bridge	

(100m upstream) *Clutia abyssinica, Senecio petitianus, Pentas lanceolata, Hypoestis sp., Kalanchoe densiflora, Cussonia spicata, Toddalia asiatica, Solanum nakurense, Solanum sissilestrum,*	*Olea africana, Trachladus, Teclea nobilis, Cyphostema sp.*
(50m upstream) *Olea africana, Cyathula cylindrical, Phytolacca octandra, Leonotis nepetifolia, Senecio petitianus, Rhus natalensis.*	*Trachladus, Olea africana, Rhus natalensis, Phytolaca octandra.*
(0 m) *Pennisetum, Clandestinum, Cynodon dactylon*	*Rubus steudneri*
(50 m downstream) *Cyathula polycephala, senecio montuosum, Oenanthe palustris*	*Achyranthes aspera, Satuneja biflora, Solanum Sissisletin, Oenanthe palustris.*
(100 m downstream) *Cyathula polycephala, Polygonum sp., Senecio sp., Oenanthe palustris, Ustica massaica, Jasminum floribundu, Teclea simplicifolia, Rubus steudneri, Traclyladus.*	*Pennisetum clandestrin, Achyranthes spera. Toddalis asiatica, Trachladus, Olea africana, Hypoestis sp.*
Forest Camp	
(100m upstream) *Cyathula cylindrica, Piltosporum abyssinica, Senecio montuosum, Jasminum floribundum*	*Hypoestis spp, Cyathula cylindrica, Olea africana, Maytenus ovatus, Pittosporum abyssinica, Cuscuta sp.*
(50 m upstream) *Asparagus abyssinica, Hypoestis sp., Cynodon dactylon, Rhus natalensis*	*Cuppressus lusitanica (plantation), Coleus barbatus, Phytolacca octandra, Tagetes minuta, Acacia abyssinica, Urtica massaica, Olea africana, Rorripa nasturtum-aquaticum.*
(0 m) *Rorripa nasturtum-aquaticum, Phytolacca octandra, Olea africana, Hypoestis sp.*	*Pennisetum Kikuyorum, Coleus barbatus, Polygonum usambarenses, Urtica massaica, Olea africana, Bidens pilosa, Rorripa nasturtum-aquarticum.*
(50 m downstream) *Cassia didymobotrya*	*Achyranthes aspera, Senecio petitianus, Vangueri acutiloba, Galium simense*
(100 m upstream) *Rorripa nasturtum-aquarticum, Polygonum spp., Vangueri spicata, Rhus natalenses, Dovyalis abyssinica, Grewia forbesii, Asparagus racemosus, Pennisetum kikuyorum, Grewia forbesii, Cyphostema bambuseti, Iteteromorpha trifoliata, Cyathula cylindrica*	*Acacia abyssinica, Senecio petitianus, Vangueri acutiloba, Galium spurium, Pennisetum kikuyorum, Rorripa nasturtum-aquaticum, Vangueri acutiloba, Trifolium repens, Hypoestis sp., Plectranthus spp., Cuppressus lusitinica.*
Turkana Flats	

(100 m upstream) *Lysine sp., Hypoestis, Pennisetum clandestinum, Syzyguin cordatum*	*Teclea nobilis, Acacia abyssinica, Basella alba, Alternanthera pungens, Achyranthes aspera, Schinus molle, Pennisetum clandestinum, Cyathula cylindrica*
(50 m upstream) *Rhus natalensis, Basella alba, Bidens pilosa, Garlinsoga paviflora, Pennisetum clandestinum*	*Pennisetum clandestinum, Acacia abyssinica, Solanum incanum, Datura stramonium, Vernonia lasiopus.*
(0m) *Garlinsoga perviflora, Amaranthus hybrida, Opuntia vulgare, Momordica foetida, Ricinus communis, Urtica massaica, Achyranthes aspesa, Pennisetum clandestinum.*	*Ekerbergia abyssinica, Rhus natalensis, Jasminus floribundum, Dombeya goetzeni, Hypoestis sp., Plectranthus sp., Achyranthes aspera.*
(50 m downstream) *Solanum incanum, Basella alba, Pennisetum clandestinum, Hypoestis verstillaris, Maytenus senegalensis, Nuxia congesta, Buddleja polystachya*	*Basella alba, Plectranthus,Sonchus oleracea, Sida cuneifolia, Solanum aculeastrum, Vernonia galamensis, Penniosetum clandestinum, Cyperus rotundus, Hypoestis sp.*
(100 m downstream) *Kalanchoe densiflora, Sida cuneifolia, Ocimum grattisimum, Vangueri acutiloba, Pennisetum clandestinum, Polygonum pulchrum*	*Achyranthes aspera, Momordica foetida, Ocimum grattissimum, Hypoestis sp., Acacia abyssinica, Dombeya goetzenii, Albizia gummifera.*
Njoro Bridge	
(100 m upstream) *Syzygium cordatum, Acacia abyssinica, Vernonia lasiopus, Tagetes minuta, Hypoestis verticillatis, Urtica massaica*	*Bidens pilosa, Tagetes minuta, Dombeya dawei, Polygonum pulchrum, Achyranthes aspera, Datura stramonium, Ipomoea wightii, Hypoestis Vesticillaris.*
(50 m upstream) *Bidens pilosa, Tagetes minuta, Solanum nigrum, Ipomoea cairica, Parvonia urens, Urtica massaica, Ricinus communis*	*Datura stramonium, Tagetes minuta, Bidens pilosa, Garlinsoga parviflora, Cynodon dactylon, Vernonia lasiopus, Amaranthus hybridus, Malva verticillata, Leonotis nepetifolia, Achyranthes aspera, Hypoestis verticillata*
(0 m) *Achyranthes aspera, Pavonia urens, Basella alba, Phytolaca dodecandra, Ricimus communis, Tagetes minuta, Senna didymobotrya, Pennisetum clandestinum, Datura stramonium, Urtica massaica, Rorripa nasturtium-aquatica*	*Dovyalis caffra (hedge), Kalanchoe densiflora, Cyperus rotundus, Rorripa nasturtium-aquarticum*
(50 m downstream) *Rorripa nasturtium-aquarticum, Achyranthes aspera, Momordica foetida, Phytolacca dodecandra, Ricinus communis,*	*Urtica massaica, Triumfetta rhoboidea, Vernonia lasiopus, Basella alba, Vernonia galamensis, Grevillea robusta, Eucalyptus*

Solanum incanum, Senna didymobotra	*globulous, Cynodon dactylon, Plactrenthus spp., Tagetes minuta,*
(100 m downstream) *Achyranthes aspera, Plectrenthus spp., Vernonia lasiopus, Urtica massaica, Phytolacca dodecandra*	*Achyranthes aspera, Bidens pilosa, Hyperncum revolutum, Vernonia lasiopus, Eucalyptus globulous, Solanum incanum, Acacia Xanthophloea, Cynodon dactylon*
Piave	
(100 m upstream) *Acacia abyssinica, Digitaria scalurum, Commelina spp., Echiloroa spp., Vangueria spicata*	*Aspilia mossambicensis, Acacia abyssinica, Syzygium cordatum, Dombeya goetzenii, Carisa edulis, Vangueria spicata.*
(50 m upstream) *Ipomoea wightii, Commelina spp., Hyparthenia rufa, Acacia abyssinica, Digitaria scalurum, Achyranthes aspera, Vernonia lasiopus, Ipomoea cairica*	*Tagetes minuta, Bidens pilosa, Acacia abyssinica, Vanguena spicata*
(0 m) *Lippia javanica, Ocimum grattissimum, Acacia abyssinica, Kalanchoe densiflora, Opuntia vulgare, Maytenus senegalensis, Aloe graminicola, Portulaca oleracea*	*Cynodon dactylon, Pennisetum clandestimum*
(50 m downstream) *Hypericum revolutum, Heteromopha trifoliata, Syzygium cordatum, Acacia abyssinica, Aloe graminicola, Rumex usambarensis*	*Tagetes minuta, Rumex usambarensis, Opuntia vulgare, Fuerstia abyssinica, Acacia abyssinica, Themeda triandra, Eragrotis spp., Cynodon dactylon, Sedum sp.*
(100 m downstream) *Syzygium cordatum, Maytems senegalensis, Rhus natalensis, Lippia javanica, Themeda triandra, Chloris gayana, Hypoestis sp.*	*Cussonia holstii, Syzygium cordatum, Euphorbia candelabrum, Aloe volkensii, Coleus barbatus, Fuerstia abyssinica, Periploca linearifolia, Hypoestis sp., Aristida sp., Hibiscus fuscus.*
Ngata	
100m upstream *Themeda triandra, Indigofera arecta, Ocimum grattissimum, Hypoestis sp., Acacia abyssinica, Aristida sp., Tarchonanthus camphoratus*	*Leonotis nepetitolia, Vangueria spicata, Tarchonanthus camphoratus, Hibiscus diversifolia, Acacia abyssinica, Fuerstia abyssinica.*
50m upstream *Maytems senegalensis, Acacia abyssinica, Lippia javanica, Aloe graminicola, Fuerstia abyssinica, Sida cueinifolia, Polygonum pulchium, Sonchus oleracea, Carrisa edulis, Momordica foetida, Aspillia mossambecensis*	*Cynodon dactylon, Senecio petitianus, Maytenus senegalensis, Sesbania sesban, Polygonum pulchrum.*
(0 m) *Cussonia holstii, Rumex usambarensis, Acacia abyssinica, Coleus barbatus, Ipomoea wightii, Hypoestis spp., Cynodon*	*Coleus barbatus, Ageratum conyzoides, Tagetes minuta, Solanum incanum, Ocimum grattissimum, Cynodon dactylon, Pennisetum*

dactylon.	*clandestimum.*
(50 m downstream) *Rorripa nasturtium-aquarticum, Solanum incanum, Coleus barbatus, Hyperricum revolutum, Tagetes minuta, Vangueria spicata, Leonotis nepetifolia*	*Vernonia galamensis, Tagetes minuta, Ocimum kilimandicharum, Aspillia mossambicensis, Ricimus communis, Fuerstia abyssinica*
(100 m downstream) *Portulaca oleracea, Polygonum pulchrum, Pennisetum clandestimum, Phytolacca dodecandra, Solanum incanum, Tagetes minuta, Chenopodium ambrosoides, Leonotis nepetifolia, Acacia abyssinica*	*Polygonum pulchrum, Verbena bonariensis, Cussonia holstii, Rumex usambarensis, Vernonia lasopius, Vangueria acutiloba, Acacia abyssinica, Solanum incanum*