LAND USE, VEGETATION COMPOSITION, WATER QUALITY AND BENTHIC MACROINVERTEBRATES ASSEMBLAGES IN THE NJORO AND KAMWETI RIVERS, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree

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DEDICATION

This work is dedicated to my husband and our children, Victoria and Trevor. Also to my parents for the unconditional support, constant prayers and encouragements throughout my studies.

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ABSTRACT

Land use transformation patterns in watershed impacts riparian vegetation, stream water quality and macroinvertebrate assemblages. The understanding of this relationship is important for the management of water resources. This research established the link between land use, vegetation, water quality and benthic macroinvertebrate in the Njoro and Kamweti Rivers. Five sampling sites which represented the major land use categories were selected in each river to for data collection. Sampling was carried out from August 2018 to August 2019. For vegetation data collection, three 70-m quadrants were established and three plots established. Trees were sampled in 10×10 m plots, 5×2 m plots for shrubs and 2×0.5 m for the grasses and herbs. *In situ*, readings of temperature, pH, Electrical Conductivity (EC) and Dissolved Oxygen (DO) were determined using a Hanna HI 9829 Multi-parameter meter. Nutrient analysis were determined in the laboratory following APHA procedures. Samples of benthic macroinvertebrates were collected using a kick net and identified to the family level. Remote sensing datasets, utilized from 1988 to 2019, 10 years epoch. The results indicated that in 2019, the LULC in the Njoro River Catchment were Forest, 29.31 %, Farm Land 50.34%, Built Up Areas 5.24%, and in Kamweti River Catchment the Forest, 62.34%, Farm Land 3.29%, Built Up Areas 3.06%. In Njoro River recording 124 plant species from 40 families and Kamweti River recording 128 species from 44 families. In the forest areas, water sample recorded high levels of DO, lower temperatures, EC and nutrient concentrations as compared to the sites downstream. Benthic macroinvertebrates data displayed a similar pattern along the land use gradient. Ephemeroptera and Diptera orders dominated the Njoro River with Ephemeroptera mostly present in forest areas with high abundance. Kamweti River, forest site was dominated by order EPT with decreased densities downstream. One way Analysis of Similarity (ANOSIM), revealed that the sites were similar in Njoro River (R= -0.27, p=0.92) whereas Kamweti River, the sites were not similar (R= 0.65, p= 0.01) in benthic macroinvertebrates assemblages. This results indicates that vegetation abundance and diversities, water quality and benthic macroinvertebrates structure is influenced by the adjacent land uses. From the findings of the study the enforcement of water pollution prevention techniques such as increasing forest and land conservation, improving and protecting the riverine areas and reducing sediment and nutrient runoff to the stream are encouraged.

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LIST OF ABBREVIATIONS AND ACCRONYMS

APHA	American Public Health Association
BWRC	Basin Water Resource Committee
CBO	Community Based Organizations
CPOM	Coarse Particulate Organic Matter
ETM+	Enhanced Thematic Mapper Plus
FPOM	Fine Particulate Organic Matter
G.P.S	Geographical Positioning System
IDH	Intermediate Disturbance Hypothesis
LULC	Land use/Land Cover
MHS	Multi-Habitat Sampling
NEMA	National Environmental Management Authority
NH4-N	Ammonium-Nitrogen
NIR	Near Infra-Red
NO2-N	Nitrite-Nitrogen
NO3-N	Nitrate - Nitrogen
R.O.K	Republic of Kenya
RCC	River Continum Concept
SRP	Soluble Reactive Phosphates
SWIR	Short Wave Infra- Red
TDS	Total Dissolved Solids
TM	Thematic Mapper (TM)
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United states Geological Survey
WHO	World Health Organisation
WRMA	Water Resource Management Authority

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Life is nourished by water, which is a vital, ever-changing renewable natural resource (Fekadu, 2021). Supply of sufficient amounts of high-quality water is essential to aid the human existence together with terrestrial and aquatic organisms (Mwangi, 2014). Lotic systems are regarded as essential natural water supplies for human progress, however they are contaminated by unrestricted wastewater disposal, by – products from industries and a range of anthropogenic disturbances altering the water's physicochemical and biological characteristics (Gichana *et al.,* 2015). Its importance to humans cannot be overstated. A human may go without food for longer periods of time, but not without water, which is required to cook, clean, for cleaning, drinking, crop cultivation, and operating factories (Fekadu, 2021). Therefore, monitoring and analyzing water quality in the rivers while also protecting them from various types of pollution is vital.

International concerns about land utilisation transformations patterns have evolved as a result of the realisation that the earth's surface dynamics are impacted by changes in environmental circumstances and especially the changes in climatic patterns. The modifications in such mechanisms have an impact on ecological products and services (Lambin *et al.*, 2003), causing humans to reclaim and till extra land to suit their demands (Campbell *et al.*, 2003). Land cover shifts will have an impact on global stormwater, sediment deposition processes, soil conditions, variety and variabilibity of life, water circulation and the biological cycles of elements such as carban, nitrogen and phosphorus. The repercussions of such land utilization patterns have resulted to international attention (Turner, 2003).

Africa has seen massive improvements linked to development advancement, including improved health outcomes, educational, and income development, particularly in urban regions in the recent past. Africa is undoubtedly integrated into the world's economy and society. It is expected that the current energy consumption patterns, commercial sectors, and trade relations have an impact on the surroundings and economic growth of other countries. Global environmental change is quickly becoming a top topic on the global scientific and diplomatic agenda. Global environmental changes are those that affect the earth's natural resources such as air and water. Being transboundary they are felt globally, as opposed to those which occur in isolated locations (Lambin *et al.*, 2003).

Anthropogenic use of land has had significicant impacts in recent centuries, altering landforms and ultimately impacting the planet's biodiversity, nutrient and hydrological cycles, as well as climate (Legesse *et al.*, 2003). The causes and consequences of human-caused environmental change are not evenly dispersed across the globe; rather, they converge in some locations where their effects may jeopardise the sustainability of the link between man and the environmnet. Understanding their dynamics, how they effect human civilization is necessary for planning.

Changes in land use patterns have been reported to impact locally on the stream-flow in a watershed (Gichana *et al.*, 2015). Both field measurements and model simulations have been utilized to investigate surface hydrology as impacted by land use changes. The most significant land-use change processes are deforestation and forest degradation. These processes pose significant risks to the highly valued biodiversity and hydrology (Chiwa, 2012). Despite various logging-reduction regulations, recent commercial deforestation, illicit logging, settlement growth, and agricultural expansion pose a significant danger to surviving wooded and water-catchment regions. Large areas in emerging countries have gradually been transformed to agricultural land as a result of continued migration and internal population increase, as well as growing of crop when the environmental conditions are suitable (Gituanja, 2020). Population growth has resulted in plot subdivisions and competition for agricultural land. Because of the rivalry for land, other land-uses within the sub-catchment, such as forests, have come into competing directly with agriculture. Competition over supplies is an aspect of the region's resource consumers' extremely high levels of competition (Chiwa, 2012).

Physico-chemical parameters of water are important and dynamic in freshwater courses (Ryan, 1991). They differ in space and time as influenced largely by climate, soil and biota (Mwangi, 2014). Freshwater ecosystems play important roles to man and the environment. Some of the functions include provision of water for domestic and industrial use, irrigation, electricity production and provides habitat (Dudgeon *et al.*, 2006). Due to their ability to maintain and nourish both macro and micro ecosystems, rivers and streams are regarded as biodiversity hotspots (Dudgeon *et al.*, 2006).

Riparian vegetation influences stream biodiversity in many ways. It is a source of organic matter, nutrients, provides shade, and regulates the amount of silt and sunlight into the river, and by extension affects various ecosystem processes including both primary and secondary productivity, breakdown of organic matter and the biogeochemical cycles (Naeem, & Wright, 2003). In undisturbed environments, riparian buffer strips are characterized by increased variety and variability of life and is vital in ecosystem functioning. Wanton deforestation is primarily one main way in which humans alter the energy flows in stream ecosystems. Riparian forest removal boosts periphyton growth and decreases allochthonous litter intake. Inputs from allochthonous sources offer a substitute energy source to temporally erratic autochthonous output, enabling the preservation of higher population carrying capacities. However, if allochthonous inputs are very high, the community may become dependent on them and sensitive to their removal, which would diminish community resilience. Additionally, altering the balance of various energy sources might affect the benthic macroinvertebrate assemblages in streams and their tropical stability (Canning *et al.,* 2019).

Human activities have impacted freshwater systems globally, leading to pollution and a scarcity of water resources. Various physical, chemical, and biological pressures have had an effect on these systems. Catchment land management practices are influenced by the human disturbance that occurs there (Carpenter *et al.,* 2011). Agriculture and urbanisation are the major land uses globally, and disturbances from both types of land use can put different stresses on receiving streams. Agricultural land use affects streams by increasing non-point pollutant inputs, degradation of riparian zones and modifications of the stream channel habitats and alterations of flows (Masaba, 2020). As agricultural land use increases more fertilisers, sediments, and pesticides in streams. According to Calijuri *et al.* (2015) streams in predominantly agricultural landscapes typically have low habitat quality, which is demonstrated by declining habitat indices, unstable banks, and increased silt deposition on and within the stream bed. In many lotic systems, cattle trampling and sediments in runoff from cultivated land are regarded as important degraders of water quality. Some of the key changes associated with a growth in urban land area are an increase in the type and quantity of contaminants in surface runoff, more erratic stream flow due to an increase in impermeable land area, and storm-water transportation. Due to urban development, riverine buffer strip vegetation loss and surface storm water warming on open surfaces leads to higher water temperatures (Wang & Kanehl, 2003).

The "disturbance-response" mechanism of an aquatic system typically happens on a regional scale, although their influence on the water quality parameters on lotic system is dependent on the global and regional level of the disturbance. Watershed, sub-catchment, riparian zone, and local areas are four spatial scales that could be applied to the stream system (Song *et al.*, 2020). The physico-chemical and biological characteristics of water in a first-order streams are generally thought to be influenced mostly by land utilization patterns located in the upper reaches, whereas the downstream water quality in streams are predominantly governed by the adjacent land utilization pattern (Song *et al.*, 2020).

Several multi-scale research focused on the following areas, such as multi-scale watershed buffer zone versus total watershed comparisons and comparisons at varying riparian zone (Song *et al.*, 2020). Various buffer scales are frequently utilized to explore interaction between land use and water quality in regions with a plain stream network or metropolitan areas with complex underlying surfaces. However, the appropriate spatial scale (in terms of correlation) between the two variables differs from case to case. With the nature of stream basins, the severity of human interference, and the accuracy of data all have varied degrees of influence on multi-scale analysis (Song *et al.*, 2020).

To strengthen the information obtained from the physico-chemical parameters of water, it is important to include biological factors because of their responsiveness to modifications in the physical habitat allowing for a more comprehensive environmental impact assessment (Rodriguez-Badillo *et al.*, 2016). Biological indicators have had the feature of not being restricted to the period of sampling; hence, they allow analysing long-term changes because live organisms have evolved responses to such ecological parameters and have tolerance limits to various adjustments (Alvarez, 2007). According to Rodriguez-Badillo *et al.* (2016) macroinvertebrates comprise one of the best categories used in evaluating the quality of fresh water environments due to their capacity for detecting changes, widespread use as a source of functional nutrition, and some species' resistance to hypoxia.

Analyzing the impacts of anthropogenic activities on fresh water ecosystems allows researchers not only to analyze the consequences, but also in making sustainable development decision (Dudgeon, 2011). It is recognized in this study that ecosystems are adversely affected by anthropogenic activities which includes, the alteration of flows, habitat destruction, exploitation, the presence of pollutants and the introduction of exotic species have a negative impact on ecosystems, leading to major variation to acquatic bodies and the diversity of life in that area (Hauer & Lamberti, 2011). However, there is a dearth of knowledge regarding the linkage between land use on riverine plant structure and their composition, the quality of surface water, and benthic macroinvertebrate assemblages in tropical streams. In light of this context, the Njoro and Kamweti Rivers in the African Tropics were the subject of this study.

An ongoing case study conducted of the ecological decline of the riverine zone can be found in the Njoro River Watershed. This watershed is currently going through an era of fast land usage transformation, sustained major growth in populations (both rural and urban areas) and related economic activity. Significant environmental harm is being done, especially to the amount and quality of the river's water. The main inflow into Lake Nakuru, a RAMSAR site, comes from the Njoro River. Increased sediment and nutrient loadings from the river's watershed have all had an effect on the quality and quantity of the river's water. The industrial wastes discharged to the river contains heavy metals and molasses which float on the water surface and block sunlight penetration that is essential for photosynthesis to take place in aquatic plants. The modifications in the status of water quality in the Lake Nakuru has been reported to have several impacts on wildlife species (Kiprutto *et al.*, 2012).

The Njoro River flows across wide areas with a variety of human activity, including farming and settlements in the lower reaches and the wanton deforestation in the upper segments. People living within the catchment rely on the river for their livelihood. However, significant land transformations in the upper segments has altered biophysical and hydrological processes, leading to water quality degradation and flooding (Mainuri & Owino, 2013) and the changes in climatic conditions being experienced currently will almost certainly exacerbate the effects as explained by (Gichana *et al*., 2015).

Due to its degradation, rehabilitation works have been ongoing alongside awareness creation, Egerton University was mandated to rehabilitate the Mau Escarpment and specifically Njoro River that supplies fresh water to Lake Nakuru. This study aimed to determine whether water quality had changed from earlier investigations of the same topic. The results obtained were compared to those of Kamweti River which is situated in an area with fewer human actions. The study also provides useful insights about the consequences of land transformations on water resources and what efforts must be made for their sustainable use.

1.2 Statement of the Problem

The lesser and greater flamingos (*Phoeniconaias minor* and *Phoenicopterus roseus*), as well as a variety of other wild animals and plants, find home at Lake Nakuru, a RAMSAR site. The Njoro River is the lake's main feeder. The ecology and human health are adversely affected by activities inside this river's basin, which also have an adverse effect on the lake. Along the banks of this river, there have been more unpermitted communities and factories built during the past 20 years. Settlements and industrial setups have been identified as the major sources solid and liquid waste. Several illegal dumpsites also occur along this river. Several flower farms along this river are also thought to be a source of pesticides and nutrients to this river and the lake whose effects on aquatic biota is largely unknown. The end result of these activities on aquatic biota has not been exhaustively researched and documented. Since 1994, there has been an increased demand of agricultural land in the watershed thus ongoing reduction in the areas under forest affects the integrity of the riparian ecosystem. It might be worthwhile to conduct study on the effects of changing the forest to allow different land use practises in the Njoro River. Since 2012, numerous institutions and community-based organisations (CBOs) have worked to raise the river's overall water quality. The extent of these activities' success is not well-documented or established. The aim of this study was to establish the connection between land utilization practises, riparian vegetation structure and composition water quality, and benthic macroinvertebrate complexities. The Kamweti River served as a benchmark for determining the efficacy of future efforts to restore the Njoro River and other aquatic systems.

1.3 Objectives

1.3.1 Broad Objective

To contribute to the understanding of the linkage between land use, vegetation, water quality and benthic macroinveretbrates in tropical rivers.

1.3.2 Specific Objectives

i). To evaluate the spatio-temporal variations in land use and land cover in the Njoro and Kamweti River catchments

ii). To determine how changes in land use influence the riparian vegetation composition abundance and diversities in the two catchments.

iii). To assess spatio-temporal variations in the physico-chemical parameters of water in both catchments.

iv). To determine the influence of land use type on benthic macroinvertebrate abundance and diversities in both catchments.

1.4 Hypotheses

i). H_1: Changes in land use and land cover in the Njoro and Kamweti River catchments is comparable in time and space.

ii). H_2: There was no significant spatial differences in riparian plant composition abundance and diversities amongst the land use types in both catchments.

iii). H_3: There are no significant spatiotemporal variations in physico-chemical parameters of water across the land use types.

iv). H_4: There was no significant spatial differences in benthic macroinvertebrate abundance and diversities amongst the land use types in both catchments.

1.5 Justification and significance of the study

The Njoro and Kamweti Rivers, two highland tropical streams with similar geology, altitude, and vegetation but different amounts of anthropogenic disturbance, (M'Erimba & Mbaka, 2021) served as the sites for the research. Njoro River catchment was selected because of its well documented anthropogenic disturbance (Mbaka *et al.,* 2018; M'Erimba & Mbaka, 2021) and its importance as the main feeder to Lake Nakuru, an internationally recognized RAMSAR site. The catchment has over the years experienced rapid population increase and corresponding land cover changes that are thought to impact negatively on water supplies, public health, livelihoods, and the regional economy (Shivoga *et al.,* 2005). The river is vital to the residents of its catchment area providing and riparian vegetation products (such as fuel wood, herbs, and medicines), and it also has significant economic value due to tourism and biodiversity preservation (Mathooko & Kariuki, 2000; Ngari, 2010). Due to the excessive reliance on the water body, both the quantity and quality of the water have decreased. The river is contaminated by pollutants that come from diverse sources, including tourism, agriculture, residential pollution, and industrial pollution. Exacerbating the problem are the uncontrolled solid and liquid disposal methods and rising population within the immediate urban area (Mokaya *et al.,* 2004; Shivoga *et al.,* 2005).

The research will be contributing to the achievement of Sustainable Development Goals (SDGs) and specifically: SDG 4 by promoting high-quality learning and research; SDG 13 by organising climate action-reduction in greenhouse gases. This study will make a contribution to achieving SDGs 3 and 6, which aim for universal access to clean water and sanitation, as well as good health and well-being. SDG 15 will be met by encouraging the conservation, recovery, and appropriate use of terrestrial ecosystems, sustainable forest management, averting desertification, reversal of land degradation, and preventing biodiversity loss (United Nations, 2015). Quantitative data obtained will important to policy makers in decision making, researchers, environmental managers and scholars as it will contribute to new knowledge. It will also contribute to Kenya's vision 2030 aiming to transform Kenya into “a newly-industrializing, middle income country providing a high quality of life to all its citizens in a clean and secure environment" (R.O.K, 2007). The goals being to increase forest cover from less than 3% to 4%, to lessen by half all environmental related diseases with specific strategies to promote environmental conservation and support the economic pillar flagship projects and for the purposes of achieving the SDG.

From the study, information on impacts of conservation to guide on the mechanisms that are being employed in the process of conserving the watersheds will be obtained. The information will be important in guiding conservation strategies to ensure ecological sustainability with useful insights to the riparian residents. The information obtained will also be used by relevant institutions in the management and conservation of such water bodies.

1.6 Scope and limitations of the study

The focus was on Njoro and Kamweti Rivers from upstream to downstream, with a geographical scope that included the Njoro River Catchment and the Kamweti River Catchments as determined by the watershed limits as guided by the Digital Elevation Models (DEM). The three major land use categories of forests, agriculture, and built-up areas were represented by the sampling sites chosen upstream, midstream, and downstream from the two rivers.

Vegetation analysis was carried out to analyze the riparian vegetation species structure and composition. This study was structured on benthic macroinvertebrates and water quality parameters for the assessment of the water's quality. Some of the chosen physico-chemical parameters included; Temperature, pH, D.O, E.C and Nutrients (Nitrates and Phosphates). Benthic macroinvertebrate samples were collected. Utilizing remote sensing methods, the identification of changes in LULC was limited to spatio-temporal analysis using 1988-2019, satellite images, 10-year epoch.

Some of the limitations of the study included:

a) Acquisition of cloud free images.

b) Benthic macroinvertebrate identification was limited to family level owing to lack of taxonomic keys.

c) Failure to disaggregate impacts of land use from those of climate variability.

1.7 Assumptions

i. Removal of vegetation cover altered the physicochemical parameters of water which in turn affected the benthic macroinvertebrates.

ii. Physicochemical characteristics of water and macroinvertebrates assemblages in each river were linked to the adjacent land use activities in those zones.

iii. The sampling equipment used did not attract or repel targeted organisms.

1.8 Definition of Terms

Benthic macroinvetebrates: refers to species that spend at least some of the time in freshwater habitats' bottom layers and can be retaineded by mesh sizes of between 200 to 500 µm (Dahl, 2004).

Biological indicator: a live entity or a living thing's portion that provides data on the condition of the surroundings (Gituanja, 2020).

Biological monitoring- is the regular utilisation of biological reactions to assess environmental dynamics to utilize information for quality assurance (Gituanja, 2020).

Biotope: A biotope in an aquatic ecosystem is the environment of a group of related species that is determined by the characteristics of the river flow (Simonson, 1994).

Canopy cover: Horizontal surface that has plant foliage projected vertically onto it (Stenberg, 2006).

Disturbance: It is an effect that causes aspects of a community or ecosystem, including species diversity, nutrient production, or the height or width of structures, to rise or fall outside of their normal (homeostatic) range of variation (Lake, 2000).

Land use- involves transforming the natural world or wilderness into constructed environments like towns and villages as well as semi-natural habitats like arable farms, grasslands, and protected forests (Razmavar & Savari, 2022).

Substrate - is the substance that makes up a river's bed; examples include clay, sand, bed rock, and tree logs (Simonson, 1994).

Water quality: state of having the necessary physical, chemical, and biological components to make water appropriate for use by humans, aquatic life, or both. (Chapman, 1996).

CHAPTER TWO

LITERATURE REVIEW

2.1 Driving forces of land use change

Land-use and land-cover alterations are expected to be one of the difficulties that the Earth will encounter in the near future. Land use and land-cover trends, as well as their maintenance, are generated by complex interactions between the environment, societal, and biophysical phenomena at the regional and international scales (Aspinall & Hill 2008). Some of the repercussions of changes in the environmental life support systems are widely debated in the context of global and regional ramifications, there is a growing realisation that many of the fundamental causes come from interactions between sociocultural and biophysical processes at the local level (Lambin *et al.,* 2003; Lambin *et al.,* 2008). The driving forces behind land use and land cover change are complicated, varying in relative significance over time, and their effect alters as the regional situation develops. The involvement of both economic and political power as represented in land use and ownership regulations is crucial to developing a clearer understanding of the relationships between driving forces and outcomes as expressed in land use and land cover modification patterns.

The interaction between land use and land cover change, as well as contributing factors, have become complex and shifting. Changes in land cover and use are primarily influenced by both natural and sociocultural forces. Economic, institutional, technological, cultural, and demographic change are the five key driving forces behind land use change, as reported by Lambin *et al.* (2003). The causes are divided into two categories: proximate (direct) and underlying (indirect drivers of land use change.) Proximate causes comprises of the activities that results due to the unplanned use of land which eventually affects the present land cover for instance forest clearing, whereas underlying forces are extraneous forces that underpin the proximate cause e.g. regulations which are enforce concerning the use of land.

The increased commercialization and the realized expansion of the market for timber products together with the failures that have been observed in the market structures have resulted as the main force behing the clearance of forests by communities. Various Institutional factors such as the regulations on the use of land and factors such as the growth of the economies, infrastructure and land based practices that require national subsidies, nonefficient structures of the government, land ownership issues have been reported to be some of the factors that have motivated the population to engage in land transformation . Changes in technology in the forestry sector, power saws, and wood processing, as well as modification of farming systems through intensification, all have a key impact in cover change. Attitudes and perceptions such as detachment for forests due to low morale and frontier mentalities and disregard for "nature," profit-oriented actors, traditional or inherited modes of cultivation or land-exploitation, and a commonly expressed sentiment that clearing the land is required to establish an exclusive claim are all cultural factors.

Natural growth, for example, is a demographic component. Another motivator is immigration. The majority of its explanatory value is derived from interactions with other underlying forces, particularly in the full interplay of the five key drivers. Migration is a significant demographic factor influencing land-use change. Changes in geography and demographics have a significant impact on agricultural land. LUC suffers from population pressure (Shiferaw, 2011). According to Lambin *et al*. (2003) the growing population associated with government policies on agricultural and forestland management may result in land use change. Knowledge of land cover change, where and when it occurs, and the rates at which it occurs is required.

2.2 Riparian vegetation and their functions

The transition zone between aquatic and terrestrial ecosystems is the riparian zone (Liu *et al.*, 2018). They are impacted by fluvial processes including flooding and the deposition of alluvial soil, and they often support a particular flora that is different from the nearby terrestrial vegetation in terms of structure and function (Naiman *et al.*, 1993). As a result, the riparian zone is characterised by significant spatial and temporal variability, which is primarily driven by bioclimatic, geomorphological, and land-use variables, all of which change over time due to natural and human impacts (Riis *et al.*, 2020). Regarding aquatic settings, riparian vegetation provides a variety of crucial ecological purposes, including enhancing water quality, offering optimal home for several animal species, and playing crucial roles for humans (Richardson *et al.*, 2007). The riparian zone typically has a high diversity, and it is crucial to the river's health (Mwangi, 2014). By giving organic matter to primary producers and limiting the amount of light and thermal energy available to them, it likewise alters the energy input into streams and rivers. By removing excessive sedimentation, surface runoff pollutants, and toxins from the nearby landscape, they enhance water quality (Enanga *et al.*, 2011).

The riverine vegetation provides various ecological services. The concept of ecosystem services has evolved into a key model for connecting ecosystem functioning to humanity, regarded as important in a variety of problem solving scenarios (Riis *et al.,* 2020). These services are generally those advantages that humans receive from environment. The paradigm, which established a new framework for studying social-ecological systems, has been promoted as a useful tool that allows a comprehensive and objective evaluation of consequences for human well-being, enabling decision-making to take the value of ecosystem services into consideration (Riis *et al.,* 2020). Summary of the functions of riparian zones as documented by Quinn *et al.* (1993) are presented in Table 2-1.

Table 2- 1: A summary of the riparian zone's ability to buffer environmental conditions and water input streams from the effects of various land use influences.

Riparian zone function	**Potential in-stream effects**
- Prevents erosion of the banks	-Reduces fine sediment levels
- Channels are protected from local changes in morphology.	-Maintains water quality
- Cushions energy inputs	-Reduce contaminant loads
- Buffers overland flow input of nutrients, soil, microorganisms, and pesticides	-Encourages the development of thin periphyton coatings and bryophytes
- Provides habitat and in-stream food sources.	-Sustains lower maximum temperatures
-Buffers flood-flows	- Increased terrestrial carbon inputs and in-stream habitat characteristics
-Keeps microclimate stable	-stabilizes food cycles
-Maintains dispersal corridors	-lessens the effects of flood flows
-Denitrifies groundwater	-supports vast array of life

According to Vannote *et al.* (1980) riparian vegetation frequently influences numerous headwater streams, reducing autotrophic output by shadowing and providing significant inputs of allochthonous debris. The authors further asserted that a decrease in the terrestrial organic inputs was brought on by an increase in stream size. Depending on the size of the stream, the influence of canopy cover on macroinvertebrate population may vary.

Because smaller streams are more likely to be completely shaded, medium-sized streams with less riparian cover can achieve higher primary production than their smaller counterparts (Ryan & Kelly-Quinn, 2016). Turbidity and depth increase with stream size and hence limiting light penetration. Therefore, large rivers according to Vannote *et al.* (1980) are expected to be heterotrophic in nature. Furthermore, because of their greater surface area, larger streams are most likely to have a lower abundance of terrestrial macroinvertebrates in the aquatic environment than small rivers (Ryan & Kelly-Quinn, 2016). The Njoro and Kamweti Rivers being a second-order streams are heavily dependent on the riparian vegetation and thus their ecology including the aquatic ecosystem are heavily influenced by the riparian vegetation including their composition.

2.2.1 Impacts of Loss of Riparian Vegetation on Streams

Riverine ecosystems are impacted by a wide variety of human-caused disturbances, which can occur both locally and globally. The immediate hydrological changes brought about by dams and the control of flows change the shape of river channels as well as the kind and extent of riparian habitat (Dudgeon, 2011). According to Paul and Meyer (2001) urbanization-related riparian deforestation decreases food availability, alters stream temperature, and obstructs the uptake of sediment, nutrients, and toxins from surface runoff. According to Lorion and Kennedy (2009) agricultural clearing of forests has a negative impact on stream biodiversity by changing the taxonomic makeup of benthic macroinvertebrate communities, reducing the diversity of these organisms, and eradicating the most vulnerable taxa from the Ephemeroptera, Plecoptera, and Trichoptera groups. Riparian zones are additionally impacted by grazing, trampling, water abstraction, and recreation (Mathooko & Kariuki, 2000).

The majority of global advancements have been concentrated on freshwater ecosystems because of its critical importance for environmental, economic, societal, and cultural activities. Freshwater ecosystems are critical to human survival because they supply safe drinking water, food, livelihoods, and other ecosystem services worth more than $4 trillion per year (Fekadu, 2021). These freshwater habitats are currently in danger across the globe due to an increase in pollution from residential runoff water, changes in land use, and industrial sources. Human activities like cattle rearing, linen washing, timber harvesting, forestry, and farming contaminate fresh water ecosystems resulting to habitat destruction, deterioration of water quality status and the ecological services received are reduced (Fekadu, 2021).

Lotic systems are severely harmed by a various anthropogenic actions that resulting in contamination (Fekadu, 2021). Non-point pollutants are mainly from agricultural practises that favour nutrient enrichment and pesticide contamination in surface waters, as well as urbanisation (Nowak & Schneider, 2017). Because of changes in flow patterns, sediment delivery, biodiversity loss, deteriorating water quality, and habitat degradation, anthropogenic actions that release contaminants are exerting pressure on water bodies, which affects both human health and aquatic ecosystems (Morrissey *et al.,* 2013; Wang *et al.,* 2012). According to Ekpo *et al.* (2012) there are various deleterious consequences of human actions on the water bodies, including eutrophication, a deterioration in or loss of ecological integrity, aquatic biota assemblage alteration, and reduced water quality among others. Surveys and other direct approaches must be used to monitor, measure, and evaluate the condition of streams and rivers (Fekadu, 2021).

Riparian vegetation is frequently destroyed along water bodies for farming purposes such as livestock grazing, livestock watering, and crop production. Previous research by Alemu *et al.* (2017) highlighted on the negative effects of rivarine vegetation clearance globally, including the influence on aquatic life, such as by silting up the spawning grounds, raising the river water temperatures and output, and depleting the amount of oxygen that is available for aquatic organisms. Agricultural practises, in particular, can lead to nutrient accumulation in aquatic settings, resulting in seasonal algal blooms that limit dissolved oxygen levels (Alemu *et al.,* 2017).

2.3 Impacts of deforestation on the quality of water

Streams represent the most readily available water resources for both residential and commercial use. Water quality has declined as a result of physical habitat degradation, increased rates of sedimentation, hydrological changes brought on by human pressure through removal of natural vegetation, and modification of land use for farmland, notably in riparian zones (Gichana, 2013).

The unplanned clearing of native woodland as well as their transformation to land to agricultural usage are becoming increasingly prevalent. The majority of land clearance in East Africa is due to subsistence agriculture and the gathering of fuelwood; only around 28% of the ancient rain forests are still standing there (Kasangaki *et al.,* 2008). Key water catchment zones in Kenya have lost forest cover over time (Fekadu, 2021) and according to a 2007 World Bank report, with the closed canopy forest cover currently just covering a meagre 2.0% of the total area. These activities, together with high levels of habitat degradation, freshwater streams, and surface water quality degradation, are the biggest risks to the world's tropical forests. The quantity and quality of water sources in developing countries, notably in Africa, pose significant risks to socioeconomic growth, particularly in dry and semi-arid regions. In nations with limited water resources, like Kenya, catchment areas must be adequately maintained in order to maintain their capacity to supply high-quality water all year long (Fekadu, 2021).

Impacts of deforestation for various purposes has resulted to changes in water quality which alters and subsequently degrades ecosystems processes and functions (Camara *et al.*, 2019). Agricultural operations cause non-point pollution due increased nitrate and phosphate leaching into rivers as a result of fertiliser inputs (Tasdighi *et al.*, 2017). Fekadu (2021) highlighted that forested watersheds have lower nitrogen concentrations than agricultural areas when comparing the two types of land use. Recognizing the potential consequences of shifts in land use / land cover patterns is thus required for successful water resource management.

2.4 Effects agriculture on stream characteristics

Human population increase and expansion around the world have made agriculture a prominent and expanding form of land management, occupying 40% globally (Cornejo *et al.*, 2020). Agriculture's encroachment into natural forests is of concern especially within the tropics as rainforests areas are being transformed to farmlands at alarming rates, threatening biodiversity and ecosystems. Lotic systems are of particular concern in this context for two reasons: first, they are significantly impacted by agricultural production through inputs of nutrients, sediments, and contaminants, as well as the regeneration or removal of riparian vegetation; second, they experience the greatest species diversity reductions and are some of the threatened ecosystems on the planet (Cornejo *et al.,* 2020).

Agricultural operations are well documented to have a deleterious impact on tropical stream ecosystems and invertebrate assemblages. In principle, water quality is diminished, physical habitat is altered, and communities are simplified, with sensitive taxa being replaced by tolerant taxa and biodiversity lost. However, there is limited information on the possible repercussions of agricultural production on the running of lotic systems which is critical for determining the state and ecological sustainability of these ecosystems (Cornejo *et al.*, 2020).

Agricultural production is known to impair the quality of stream water, environment and ecosystem condition relative to unaltered natural landscapes (Allan, 2004). While some studies focus on the overall links between stream characteristics and agricultural land use, others aim to shed light on the specific land use practises that cause these types of deterioration. Megan *et al.* (2007) for example, established a strong relationship between the amount of agricultural land cover and the quantities of fertilisers and pesticides. High quantities of bacteria are caused by livestock operations, near-stream grazing, and run-off from areas where pesticides are used, and concentrations of these substances in streams (Muriithi & Yu, 2015). Manure and fertiliser applications that are made in excess have been associated with higher nitrogen levels and lower dissolved oxygen concentrations (Nurmi, 2010). On a landscape scale, tillage causes soil erosion, which results in sedimentation, increased turbidity, and burial of the coarse substrate in streams (Baldyga *et al.*, 2005; Herringshaw, 2009). Along with the removal of riparian vegetation, these sediment sources result in decreased habitat variability, an abundance of plant debris and allochthonous organic material, as well as the presence of rough substrates (Allan, 2004).

2.5 Linkage between the urban land use and stream characteristics

At local and global scales, anthropogenic activities have had a substantial impact on the physicochemical aspects of water quality as well as the overall health of water bodies (Fekadu, 2021). Fast growing urbanized areas are where anthropogenic activities are most intense, land use is changing dramatically, and, therefore, are the most common places for water quality degradation. The global degree of urbanization hit 50% in 2008 and is anticipated to reach 60% by 2030, with projected urban population growth primarily occurring in developing countries (Song *et al.*, 2020). Expanding built-up regions, along with the gathering population and industry, have tremendous influence on the indigenous natural flora, soil environment, and aquatic ecosystem during the urbanization process. Increased impermeable surfaces and land use transitions, for example, may have a direct impact on pollutant concentrations in urban streams (Song *et al.*, 2020).

Stream ecology literature frequently discusses connections between urban land use and different types of stream deterioration. One of the most frequently researched aspects of urban terrain is impervious surfaces, which include roads, parking lots, walkways, rooftops, and other impermeable places. As a result, there are fewer surfaces that can contribute to the production of clean storm-water (Herringshaw, 2009). Impervious cover inhibits infiltration, which elevates storm water runoff and raises the amounts and speed of storm water reaching the river channel, ultimately contributing to stream deterioration (Herringshaw, 2009). These hydrologic changes increase the likelihood of flash floods and hydrological disturbance while also causing channel erosion. Meanwhile, because less water is soaking into the ground, water tables can drop and streams and wells fed by groundwater begin to dry up.

Furthermore, even light rain events swiftly carry contaminants to streams due impermeable cover's effective mechanism. Urban runoff and treated wastewater, which are the main sources of water for many urban streams, frequently include high concentrations of fertilisers, pesticides, organic compounds, and heavy metals. Alterations in aquatic biota have been connected to these physical habitat changes and changes in water quality (Dahl, 2004; Wang *et al.*, 2006). Regular vegetation control techniques further exacerbate issues in urban waterways. For instance, increased peak discharges in streams are also correlated with the degree of conversion to suburban vegetation (i.e., mowed lawns) in low-density settlements (Allan, 2004). Similar to agricultural regions, cutting riparian vegetation raises temperatures because less shade is provided by the stream and more allochthonous organic matter is available for habitat and sustenance. Invertebrate and fish diversity and productivity losses brought on by these physical and chemical changes reorganise ecological ecosystems. In a watershed, even very tiny quantities of urban land use can significantly affect aquatic biota (Wang *et al.*, 2001).

The spatial heterogeneity in land usage reflects on the human actions and thei magnitude. This is an important factor impacting stream quality of the water in metropolitan regions. In general, rivers that flow near industrial activities, mines and farmlards are regarded to contain more pollutants than othe land use classes (Song *et al.*, 2020). On the other hand, forested areas are repositories of dangerous contaminants that could end up in water bodies as the fluvial vegetation buffer zone has a filtering and barrier effect on pollutants (Song *et al.*, 2020). The major changes in geographic land transformations caused by urbanisation have been regarded as a critical factor in the growth of impermeable surfaces including building structures, tarmac or concrete road networks (Song *et al.*, 2020).

Different types of impervious surfaces, as well as pervious surfaces, generate different spatial patterns of land use in metropolitan settings. This land use pattern's negative hydrological effects are mostly indicated by decreased soil permeability and higher surface discharge, as well as increased sediment and pollution sources. Regional urbanisation is usually accompanied by deterioration of surface water quality and aquatic ecosystems over time. Common contaminants such as nitrogen, phosphorus, and heavy metals have been proven to grow dramatically in streams with increasing urbanisation, while stream river water quality and aquatic ecosystems may be affected if the proportion of impermeable surfaces in watersheds reaches 10%-15% (Song *et al.,* 2020).

2.6 Water quality status in rivers

Many both natural and man-made factors may have an impact on river water quality. Human impact on surface waters may result in dynamics in water flow regimes and the quality of surface water due to pollutant discharges at specific areas or via surface/subsurface flows. Indirect factors such as atmospheric deposition, land management, and climate change may also have a negative impact. The interest in the field in assessing the ecological state of water bodies has grown dramatically in recent decades. It has progressed from assessing water quality metrics to more comprehensive methodologies that allow for a more in-depth information on the health of the water body and the link between its natural response and anthropogenic effect (Yotova *et al.*, 2021).

Nowadays, environmental authorities analyse a river catchment's surface water quality by tracking the regional and temporal variations of a variety of standardized indicators of surface water quality (Yotova *et al.*, 2021). These monitoring of water quality techniques create massive amounts of complex multivariate data. As a result, multidimensional statistical methods are used in many water standard evaluation studies to: and (i) show dataset commonalities, (ii) identify natural and human sources influencing water quality; and (iii) recognise spatial-temporal changes in water quality metrics (Yotova *et al.*, 2021). Although commonly used multivariate approaches such as Cluster analysis, Principal component analysis, Self-organizing maps (SOM), Discriminant analysis (Yotova *et al.*, 2021) and others provide extensive and credible information about water quality, incorporating them into environmental management operations is not easy.

The determination of physical, chemical, biological, hydromorphological, including the aesthetic qualities of water is known as "water quality" (Giri & Qiu, 2016). The factors that affect the variations in water parameters include weather conditions at the time of sampling, height, locations sources of contaminants, and the time of sample collection (Giri & Qiu, 2016). There are many uses for high-quality water, including drinking, agriculture, industry, recreation, and the preservation of water bodies (Fekadu, 2021). Despite this, one of the major problems that people are dealing with is the rapidly diminishing quality of water in many locations. The primary reasons for degradation are both the human induced and natural factors. Human causative factors include unsustainable water resource usage in metropolitan populations, commercial sectors, and agricultural enterprises) and natural causes (for example, variations in precipitation and erosion) (Selemani *et al.,* 2018). As a result, this research study examined selected physical and chemical characteristics and benthic macroinvertebrates in relation to surface water quality offering information about water quality in the catchments of the Njoro and Kamweti Rivers.

Distributional patterns and species composition of an aquatic habitat's inhabitants are directly impacted by the state of the environmental parameters (Koffi *et al.,* 2014). The physical characteristics of surface water, for instance the solution of elements, the amount of solar radiation that can penetrate, water temperatures and its density, are some of the environmental elements that affect aquatic environments. Chemical characteristics such as pH, hardness, and nutrients such as phosphates and nitrates all have a large impact consumers that rely on them for survival (Lashari *et al.,* 2009). Dynamics of the elements frequently result in an unfavourable environment for organisms, restricting their growth and interfering with physiological functions. The aforementioned criteria change based on the water levels as well as the width and length of the water body. Numerous physical elements, such as wind and solar radiation, contributes to the regional changes of the quality of surface water metrics (Mazumdar *et al.,* 2007).

Typically, environmental authorities use procedures that give a broad evaluation of surface waters and give categories based on the conditions of surface water. The techniques combine data from comparing water quality indicators and threshold values into a single integral indication - the water quality index (WQI) (Yotova *et al.,* 2021). The most commonly used integrated index is the aggregate WQI developed by the Canadian Council of Ministers of the Environment (CCME). It may use several types of indicators for water quality and is easily adapted to evolving regulatory standards (Yotova *et al.,* 2021).

2.6.1. Water quality parameters

The first stage in determining the quality of the water is to choose the variables in which the measurements will be taken. This is because there aren't enough resources to monitor all the variables affecting water quality, thus only the vital ones should be taken into account. The sort of chemical and physical analysis carried out on each sample was determined by the research's objectives and the available resources. Temperature, oxygen concentration, conductivity, and pH were measured *in situ* and used to depict point estimates of the quality of the water variables in time and location. The selected sic nutrient concentrations were analysed in the laboratory. They included: nitrates, nitrites, Ammonium Nitrogen, Total Nitrogen, Total Phosphorus and Soluble Reactive PPhosphates. The above stated parameters were selected for this research since they primarily affect the quality of aquatic ecosystems.

Temperature

Physical, chemical, and biological processes in aquatic environments and are influenced by temperature. Most surface waterways' temperature regimes are significantly influenced by a number of important characteristics, including latitude, height, sample period, air airflow, canopy overhead, river discharge characteristics and depth (Fekadu, 2021). A temperature increase that may be caused by elements like climatic changes an increase in some elements such as clarity, electrical conductivity, shallow surface waters, as well as anthropogenic actions like the discharge of contaminants, storm water runoff and clearance of vegetation (Fekadu, 2021).

Water extraction, hot industrial effluent from manufacturing activities, changes in land-use, destruction of riverine plant communities, high amounts of stormwater flows, and other anthropogenic activities can cause rivers to warm up (Mwangi, 2014). This changes a variety of water's physical and chemical properties, such as the amounts of dissolved oxygen present, biological action as well as the rate and severity of chemical reactions. The natural surroundings of freshwater changes as water temperature rises in aspects of density, pH, and dissolved oxygen adsorption, resulting in an elevation of BOD from promoting microbial breakdown of organic molecules (Chapman, 2021).

Changes in a river's temperature regime have a substantial impact on aquatic biota because many species accustomed to cold circumstances may drift from warmer waters and be replaced by heat tolerant species that multiply and replace the native organisms in that water body (Abel, 2002). Due to the fact that water temperatures falls in correspondents with height, the dynamics in river nacroinvertebrate community assemblages may also be linked to lower water temperatures at higher altitudes (Hepp & Santos, 2009). Many stream macroinvertebrates, however, have evolved so that seasonal temperature changes function as indicators for schedule of movement, hatching or emerging, cystic development or even to changing feeding, produce flowers, or set seed.

pH

The Hydrogen ion concentration is an important parameter. Natural freshwaters have pH values ranging from 3.0 to 11.0, and often higher. Aquatic animals are generally kept alive at the range from 5.0 to 9.0. Human activities have an impact on the pH levels of aquatic ecosystems via a range of point-source industrial effluent that can be highly acidic or alkaline (Chapman, 1996). Heavy metal contaminants such as copper, cadmium and lead, non-metallic elements such as ammonium ions and metallic elements (such as Selenium) could be released in low pH streams, impacting water quality (Ogendi *et al.,* 2008). High biological activity generated by specific companies' alkaline wastewater elevates pH levels in waterways in eutrophic conditions (Gichana *et al.,* 2015). Elevated pH levels, as well as too low pH values, have an impact on aquatic biota. Several studies have found acid environments as a result of low pH levels, can affect structure of macroinvertebrate assemblages as well as species diversity (Calijuri *et al.,* 2015), and the Ephemeroptera being vulnerable order affected by acidic environments (Anyona *et al.,* 2014; Connolly *et al.,* 2004; Ogendi *et al.,* 2008).

Dissolved oxygen

Oxygen availability is influenced most the chemical and biological activities in aquatic envionments. It denotes the amount of biological matter contamination, the breakdown of organic materials, and rate of water self-purification. Dissolved oxygen in natural freshwaters ranges mg L-1 at 0° C to 8 mg L-1 at 25° C (Mwangi, 2014). In unpolluted water, dissolved oxygen concentrations are typically close to, but less than, 10 mg L-1. Dissolved oxygen levels below 5 mg L-1 may have a negative impact on biological community functioning and survival, whereas levels below 2 mg L-1 may be hazardous to aquatic animals (Mwangi, 2014). Oxygen flows into the water by direct absorption from the air, photosynthetic activity by algae and other aquatic plants and is expelled via respiration and organic matter breakdown (Mwangi, 2014).

The three main elements that induce fluctuations in DO levels in stream water are height above sea level, water temperature, and photosynthetic action by fresh water organisms (Mwangi, 2014). Water turbulence, depth of the stream, and the amount of substrate exposed on streams all have an impact on water re-aeration. The fast-flowing rivers are aerated as the water flows over boulders and drop over water falls. Because bacteria towards the bottom digest organic matter, oxygen penetrates to the outer layer only of the slow, stagnant water, while deeper water has a lower DO levels due to breakdown of organic matter (Mwangi, 2014). Rainfall reacts with oxygen in the atmosphere as it drops, therefore oxygen levels rise during the wet seasons and with the dry season, the water levls in the river reduces and thus the flow rate slows. Because water moves slowly, it combines with less oxygen, causing the DO concentration to fall (Mason, 2002). Organic pollutants such as sewage treatment plant effluent, industrial effluent, urban storm-water and agricultural runoff can induce a decrease in dissolved oxygen avalability due to increased microbial metabolism during organic matter breakdown (Mwangi, 2014).

If DO levels in a lotic system are generally stable, it is regarded as a functioning habitat that can accommodate a diverse range of aquatic species (Mwangi, 2014). The shortage of oxygen (hypoxia), on the other hand, may be a condition of severe pollution, with serious effects for such river biodiversity. A reduction in DO level in aquatic ecosystems may have negative consequences for many aquatic creatures that rely on oxygen to function properly (Mwangi, 2014; Ogendi *et al.,* 2008).

The importance of DO reduction on aquatic organisms is influenced by its occurrence, duration, and degree. The oxygen requirements of benthic macroinvertebrates vary according to taxa (warm or cold species), developmental stage (eggs, larvae, nymphs, adults), and numerous life mechanisms (feeding, maturity, mating), as well as size (Mwangi, 2014). The impact could result in acute, physiological, and behavioural repercussions, as well as the ability to drift away from the oxygen-depleted areas (Mwangi, 2014). Aerobic organisms are killed by extremely low dissolved oxygen concentrations, while somewhat lower levels can lead to dynanics in behaviour, structural deformities, developmental rates, as well as food consumption (Van der Geest, 2007).

Mwangi (2014) also highlighted that oxygen reduction impacts on spread and behavior of macroinvertebrates, as well as species-specific mortality caused by hypoxia in their research of the reaction of benthic macroinvertebrates to low levels of oxygen. Through oxygen depletion, susceptible benthic macroinvertebrates (Ephemeroptera, Trichoptera, and Plecoptera) that respire with gills or by direct cuticular exchanges diminish and may be completely destroyed (Abel, 2002; Dallas & Day, 2004; Ogendi *et al.,* 2008). While

Tubificidae, Hirudinae and Chironomidae are often adaptable to lower levels of dissolved oxygen and muddy substrate, other benthic macroinvertebrates are more severely affected as explained by Mwangi (2014).

The shift mechanism is an important behavioural response used by macroinvertebrates to evade unfavourable environmental conditions caused by oxygen deficiency (Mwangi, 2014). Masese *et al.* (2009) reported that high migratory taxa such as Ephemeroptera (Heptageniidae) that cannot tolerate hypoxic conditions react to diminishing oxygen levels by drifting upstream which could result in the reduction the population and variety of vulnerable benthic macroinvertebrates. *Turbidity*

The presence of suspended particles in water, such as clay, silts, finely divided organic and inorganic matter, plankton, and other microscopic organisms, causes turbidity. Silt has the advantage of limiting light penetration in specific areas of the lake, notably inlets (Ryan, 1991). Increased turbidity levels in water bodies intended for domestic use can potentially pose issues with water purification operations such as flocculation and filtration, potentially raising treatment costs (Enanga *et al.,* 2011). Increased surface runoff and erosion caused by rain falls could explain elevated turbidity readings during the raining season. High sedimentation rates cause an increase in turbidity, which can damage water quality. Turbidity is caused by biological and inorganic particles dispersing light in water (Mason, 2002). Wind motion causes sediments to re-suspend, resulting in reduced transparency in the water system. This physical element is important in these ecosystems because it affects both both biotic and abiotic variables. Light cannot penetrate a body of water due to a lack of transparency. This diminishes primary output, which has a knock-on effect up the food chain and eventually has an impact on fish stocks (Omondi *et al.,* 2014).

Nutrients

Nutrient enrichment is the most common cause of water quality degradation caused by eutrophication. Nitrogen, phosphorus, and silica are all elements found in aquatic environments in either dissolved inorganic or organic forms (Omondi *et al.,* 2014). Land uses are typically related with nutrient enrichment, and the majority of external sources of nutrients flow straight into rivers from streams or shorelines. Organic elements like human excreta, animal manure, and vegetation waste are decomposed by aquatic microorganisms and create additional nutrients for plant growth.

a) Nitrates

Human activities create nitrate levels elevated in surface waterways which vary based on land use. Many river systems may have high nitrate concentrations due to dispersed inputs including urban and agricultural discharge, in addition to point release from wastewater treatment facilities. Nitrogen can be added to surface waterways through atmospheric deposition, which includes agricultural gases and fossil fuel combustion (Carpenter *et al.*, 1998). Nitrate levels may also rise due to decreased vegetative cover caused by both natural and human caused disturbances.

Temperature, dissolved oxygen, and pH are among physicochemical characteristics that influence nitrification rates (Mwangi, 2014). Most nitrifying bacteria strains thrive at pH levels ranging from 7.5 to 8.0, in water temperatures ranging from 25 to 30°C, in darkness (Mwangi, 2014). Temperature, dissolved oxygen levels, and nitrate and organic material availability all have an impact on denitrification rates. High nitrate quantities are associated with eutrophication, algal growth blooms, and oxygen depletion. Although nitrates are significantly less harmful to aquatic life, some detrimental consequences observed in aquatic animals include death, growth decline, lowered feed intake rates, lowered reproductive potential, and decreased spawning success, lack of energy, strain behavioural changes, tilted spines, and other genetic defects. (Mwangi, 2014). Water with a high nitrate levels above 100 mg L^{-1} poses a risk to humans because it is poisonous and has been connected to methemoglobinemia in babies (Chapman, 1996).

b) *Phosphates*

Phosphorus is present in water resources and effluents in both particulate and dissolved forms, constituting about 70% of total phosphorus accessible in freshwater flows. It is most commonly found in the form of dissolved orthophosphates and polyphosphates (Mwangi, 2014) although it can also be found organically as the phosphate ion (Chapman, 1996). Tillage and ploughing on agricultural fields expose the soil to rain and wind, which erode the soil and transport nutrients and debris to surface waters in runoff. Lawn fertilisers strong in P may run off into streams in metropolitan areas. Furthermore, synthetic fertilisers used in urban and agricultural regions are leached off the fields or through groundwater and can subsequently be transferred to surface waterways via groundwater transport (Hayashi & Rosenberry, 2001). The nutrient's concentrations in natural freshwater range from 0.005 to 0.020 mg L-1, with some pristine waters having values as low as 0.001 mg L-1(Chapman, 1996).

Human activities, intensive livestock production, home wastewaters, detergents, industrial effluents, and fertilisers all contribute to high phosphate concentrations in surface waterways. High phosphate and nitrate concentrations increase productivity and are mostly responsible for eutrophic environments. Low phosphorus levels frequently inhibit plant productivity in freshwater. Total phosphorus (TP) values in fresh and estuary waters that above 0.100 mg/ L-1 is considered hazardous. Phosphorus availability in water is not regarded immediately as harmful to humans or animals. It's toxicity in freshwaters, on the other hand, may have an indirect effect. Excess supply can result in harmful algal blooms, hypoxic conditions, and a loss of biological diversity (Mwangi, 2014).

2.7 Aquatic macroinvertebrates as an ecosystem health indicator

Analyzing how aquatic community's response to diverse perturbation intensities, both the natural such as climatic changes and those induced by anthropogenic activities such as land-use change, is critical for the conservation of species diversity and effective management of water resources. Stream macroinvertebrates are indeed strongest predictors of stream and river water quality, habitats, and overall health of the aquatic ecosystems. By assimilating allochthonous organic compounds and making it available to other aquatic consumers, stream macroinvertebrates make a significant contribution to the food chain that links the organisms in the upper trophic levels to base resources in aquatic environments (Gichana, 2013).

Due to their diversity, wide range of environmental adaptations and reliance on a variety of energy sources, macroinvertebrates are vulnerable to different types and degrees of anthropogenic pertubations in lotic systems. As a result, land use transformations within the watershed and stream size that affect the environment and primary food supplies may affect the structural makeup and functional organisation of macroinvertebrate assemblages. With this knowledge, it has led to the use of stream macroinvertebrate structural and functional compositions in aquatic habitats to assess the ecological condition and processes at the ecosystem level (Barbour *et al.*, 1999).

Physico-chemical parameters determined gives a snapshots of the acquatic ecosystem condition at a particular point in time. These might not provide a comprehensive assessment of the river's overall health and may, at times, fail to detect degraded waters (Anyona *et al.*, 2014; Dulo, 2008). Therefore, in the recent past, focus on monitoring programmes has shifted from the sole use of physico-chemical metrics to the combined use of both biological and physico-chemical metrics. The most popular biological approach for assessing streams and rivers is the use of benthic macroinveterbrates as indicators of the health of an ecosystem (Dahl, 2004; Rodriguez-Badillo *et al.*, 2016).

Disturbances in river basins damage the environmental qualities of streams. This causes structural and functional changes in freshwater ecosystems, prompting the analysis of river water quality. Different type of stream macroinvertebrates that have been categorized being susceptible to environmental and habitat changes have thus recognized as the best bio - indicators (Mwangi, 2014). These species indicate the degree of human pressure and react to all environmental parameters encountered during their life cycle.

Benthic macroinvertebrates are aquatic organisms that spend at least part of their lives on the bottom substrates of freshwater ecosystems and are maintained by mesh sizes ranging from 200 to 500 m. (Dahl, 2004). Their functional and structural makeup fluctuates in response to environmental conditions, both geographically and temporally. Discharge, substrate composition, dissolved compounds, the clarity of water, riverine vegetation, land use, temperature, altitude, and latitude (Gichana, 2013) are among these influences. Human activities, on the other hand, alter the consequences of these factors, which in turn affect the composition and distribution of macroinvertebrates (Masaba, 2020).

The presence of macroinvertebrate communities in an aquatic ecosystem is ecologically important since they are a source of food for fish, can have significant influence in nutrient cycle, primary productivity, decomposition, and translocation of materials and also act as indicators of stream degradation (Wallace & Webster, 1996). This is particularly due to the characteristics of macroinvertebrates as a community of high diversity and abundant which are initially sensitive to environmental changes. Although the tropics, particularly Africa, are still lagging behind other parts of the world in the creation of biomonitoring indices and programmes for streams and rivers (Fekadu, 2021), significant progress has been made in understanding how aquatic ecosystems react to various stresses in streams and rivers.

The occurrence and complete lack of these aquatic insects reflect the extent of pollution, although physico-chemical procedures can identify the precise causative physicochemical contaminant. Macroinvertebrates are particularly important in the operation of freshwater systems for a number of reasons, and can thus be seen as intermediaries for ecosystem stability (Sharma & Rawat, 2009).

Due to this expanding body of knowledge, biotic indices for various countries biomonitoring of streams and rivers are continuously being produced. Assessing the variety, organizational structure, and species distribution of a data set of macroinvertebrates in a particular stream will aid in determining the general richness and abundance of the macroinvertebrate fauna in that water-body (Sharma, & Rawat, 2009) and this will indicate the general health of the river. The current study looked at the physico-chemical qualities of water as well as the diversity of macroinvertebrates found in the Njoro and Kamweti rivers. The study aimed to monitor macroinvertebrate diversity as a bio - indicators for assessing the condition of these freshwater environments of the Njoro and Kamweti rivers, which are key conservation sites within the Mau and Mt. Kenya water towers.

2.7.1 Effect of Land-Use Activities on Benthic Macroinvertebrates

To develop better cost-effective management plan, a detailed understanding as to how ecosystem categories within the same watershed reach work as distinct entities, and how these environmental factors vary amongst river type with land utilisation choices, is required. A variety of biotic and abiotic elements interact at many geographical and temporal dimensions to shape river communities (Deborde *et al.,* 2016). Large-scale landscape characteristics interplay with small-scale features to form regionally stratified hierarchy of sections, reach, macro- and microhabitats. Several studied have been conducted to investigate the significance of scale-related relationships between catchment land use, riparian changes, and in-stream physicochemical degradation on the composition of aquatic assemblages. However, land use-stream connections are expected to differ depending on habitat type (e.g., pools, riffles) and season (Deborde *et al.,* 2016).

Deborde *et al.* (2016) highlighted that habitats (pools and riffles) within the channel vary in several aspects such as depth, discharge and bottom substrate. Therefore, benthic macroinvertebrate assemblages (structure and composition) in pool and riffle habitats were predicted to differ; yet, results on the nature of these changes are contradictory. Riffle habitats have greater invertebrate densities than pool habitats, although some studies show that pools have higher densities and diversity than riffles, or that there are no differences in densities or diversity. The majority of studies comparing pool and riffle ecosystems have almost entirely focused on minimally disturbed upland/mountain streams, with few addressing anthropogenic consequences such as watershed land use.

Deforestation in riparian zones and the reduction of forest cover (Hailu *et al.,* 2020) in these catchments are the main causes of most of these effects (Cooper *et al.,* 2013; Woodward *et al.,* 2012). Riparian forests have a substantial impact on stream ecosystems because they are the interface between terrestrial and aquatic systems. They protect streams by increasing infiltration rates, retaining sediment, increasing shade, and supplying allochthonous supplies of food and shelter (Tanaka & Dos Santos, 2017).

Human impact on rivers can be of reach or catchment factors, and they can be of variable magnitudes since different stressors have distinct effects on stream ecosystem functioning at different scales. Predicting biological responses to these stressors is challenging, though, because organisms and their assemblages might respond linearly or nonlinearly to gradients of anthropogenic disturbance (Tanaka & Dos Santos, 2017). In the multi-metric technique, responses to anthropogenic pressures from a variety of assemblage components, such as richness, composition, trophic guilds, diversity, and dominance, are combined (Ferreira *et al.,* 2012). The technique also takes into account how different anthropogenic stresses respond at catchment and reach scales. The technique has advantages over simple physical and chemical water monitoring in that it is simple to comprehend, quick to produce, and more affordable (Allan, 2004).

Anthropogenic disturbances in streams vary widely and become damaging to the related waterways whenever it surpass the macroinvertebrate community's threshold (M'Erimba *et al.,* 2014). These have had an impact on the makeup of individual taxa, which has an impact on the functioning of stream ecosystems. Mechanical disruptions of bottom sediments, such as coring, kicking, and shuffling, result in a reduction in overall density, variety, and taxon richness of benthic species immediately following the disturbance (M'Erimba *et al.,* 2014).

Different land use activities in catchment areas lead to the introduction of suspended sediments on rivers, impaction on the fauna therein in different ways (Ryan, 1991). Silt deposition on stone surfaces can reduce the available food supply while also decreasing attachment points for creatures that require to attach itself to the substrate, such as larval simuliids (blackflies). Furthermore, reduced interstitial space within the stream bed means less habitat and less exchange of oxygen and metabolites for benthos species. Except for a few species adapted to surviving in deoxygenated silt, entire stream sections can be rendered practically devoid of all macroinvertebrates in "worst-case" scenarios (Ryan 1991).

Research by Hepp *et al.* (2010) evaluated impacts of different land uses on local benthic communities. The streams in conserved areas were compared with streams in urbanized and pasture areas. Significant differences in organism density and taxonomic richness were found: in both urban sites and pastures, macroinvertebrate density was higher and species richness was significantly lower than in conserved areas. These findings were found to be in agreement to those reported by Mori and Brancelj (2006) that the absence of riverine vegetation and the input of organic material in lotic systems significantly lowered the species richness.

Urban land usage closer to the stream was noted to adversely have an impact on the macroinvertebrate structure and composition and especially the sensitive taxa (Mwangi, 2014). The author highlighted that urbanisation reduced macroinvertebrate abundance and diversity considerably, resulting to a population dominated by species tolerant to pollution such as the diptera order, oligochaeta and some gastropods. The Ephemeroptera, Plecoptera and Trichoptera orders were noted to reduce in their richness, abundance and diversities.

2.8 Research gaps

Some of the research gaps identified included the lack of documentation of studies in the study areas with the goal that links the changes that have occurred in time and space in land use and land cover in the catchments to riparian vegetation structure and composition, water quality, and macroinvertebrate assemblages. Another gap was on the need to shift to the utilization of cost-effective macroinvertebrates in the study areas that present an integrative freshwater ecosystem status to complement the physico-chemical parameters. There is insufficient data to give a reference point if restoration efforts are undertaken. As a result, this research will help to fill information gaps in tropical streams.

2.9 Theoretical Framework

The River Continuum Concept (RCC), Figure 2.1- reproduced from Vannote *et al.* (1980) is based on the size of the river and the gradual dynamics in biological indicators that occurs within a lotic system. Mwangi (2014) highlighted that the stream ecology is separated into three primary types such, headwater (low order stream), medium-sized stream, and large rivers based on stream orders. With the River Continuum Concept, low order streams (headwaters) are distinguished by forest canopies, which reduce autotrophic production by shadowing and adding considerable amounts of detritus in the form of coarse particle organic matter (CPOM). Shredders and collectors typically dominate macroinvertebrates in this section of the stream. (Mwangi, 2014). Further to the lower reaches, the width of the stream increases and the impact of the forest canopy reduces, enabling sunshine to penetrate and favouring considerable periphyton and macrophyte formation. As the forest canopy shrinks, the CPOM contribution decreases, FPOM occurs, ecosystems become much more autotrophic, and water temperature reach its maximum due to increased solar radiations.

As the width of the stream increase, the overhead canopy reduces together with numerous main hydrologic phenomena may occur. The productivity of the channel is frequently reduced by the slope and clarity, which causes discharge to diminish and the substrate composition to reduce in size consisting of mainly silt and clay and also become increasingly uniform. Due to plentiful FPOM from upstream, the river channel reverts to heterotrophy as a result of increased sedimentation causing the water to be turbid thus restricting solar radiation from penetrating. Also the river bed stability is reduce due to sand accumulation. Water temperature measured in high order streams is frequently substantially reduced due to the buffering effect of the enormous volume of water in the channel (Mwangi, 2014). Collectors (e.g., Tricorythodes, Baetis, and Ephemerella) and shredders dominate macroinvertebrate communities (Mwangi, 2014) as the stream size increases. The Njoro and the Kamweti Rivers are being second order streams they are heavily impacted by the riverine vegetation and coupled with anthropogenic activities, leads to the changes in benthic macroinvertebrate composition and structure.

Statzner and Higler (1985) highlighted on the limitations of the RCC when assessing macroinvertebrate community structures along longitudinal stream gradients. These included: the river is in an undisturbed state; the overall entropy at the length of the rivers can vary in rivers located in high altitude areas and with the different amounts and types of the loads from the streams and it is noted that spatial effects from the water bodies are of different natures.

The lotic system structure is elaborated as being a longitudinally linked system and that the ecological activities in the upper reaches are tied to that which occur in the lower reaches, however there are certain outliers due to the unexpected nature of human influences. Human effects including riparian destruction, forestry, dam construction and dumping of wastes that interfere with the natural states in the river continuum resulting to increased sediment and nutrient loads and eventually the degradation and loss of water based environment and the damage ecological and biodiversity functions (Mwangi, 2014). The intermediate disturbance hypothesis helps explain the consequences of these disturbances on river health (IDH).

Connell (1978) in the IDH theory points out that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent. All species are at risks of extinction when the levels of disturbance are high. The IDH theory, explains that, at intermediate levels of disturbance, diversity is thus maximized because species that thrive at both early and late successional stages can coexist. IDH considers the following, (1) within an area, ecological disturbances have major effects on species richness. (2) interspecific competition results from one species driving a competitor to extinction and becoming dominant in the ecosystem and (3) moderate ecological scale disturbances prevent interspecific competition. The Njoro and Kamweti Rivers faces disturbances either natural of human induced at different levels from upstream to downstream which impacts on species composition, abundance and diversities.

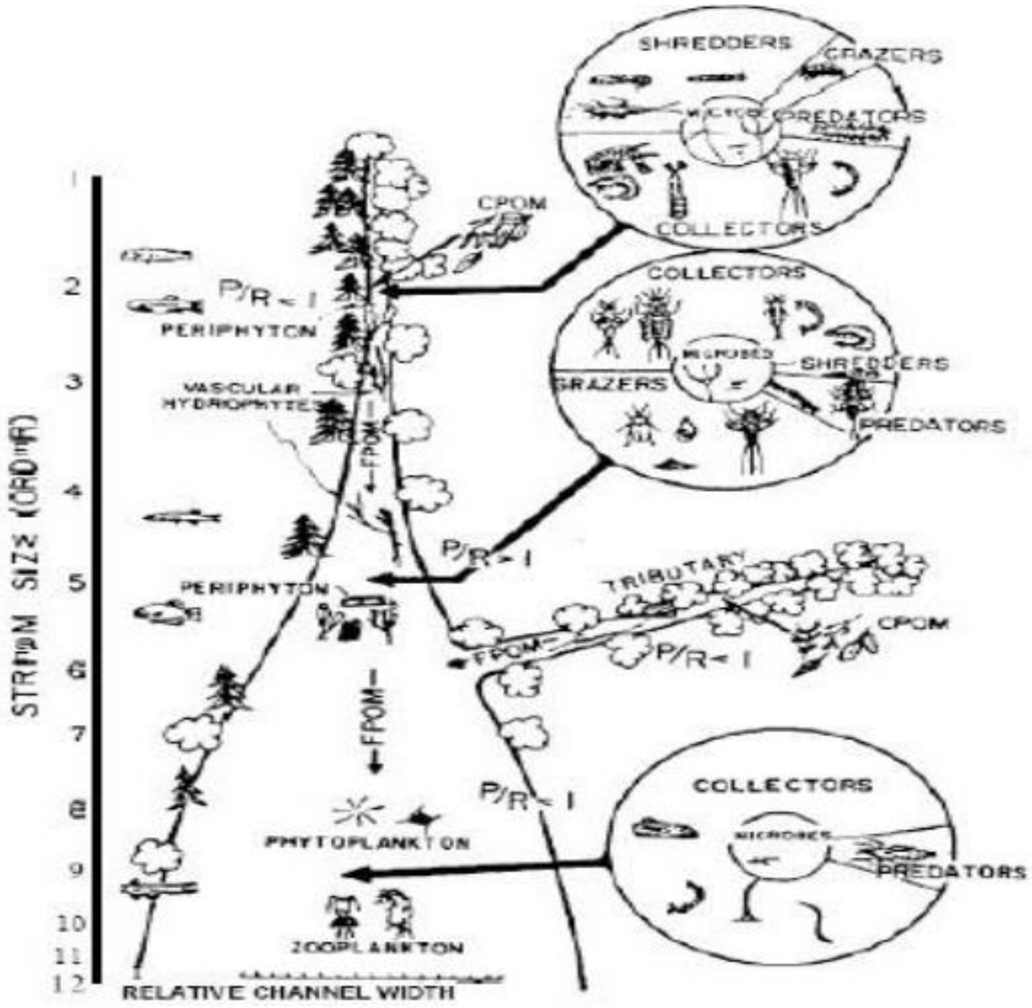


Figure 2- 1: The River Continuum Concept.

2.10 Conceptual Framework

Interaction of the different processes within river systems are interrupted by humans through their activities which have the potential to stress the systems by different ways. The conceptual framework (Figure 2-2) links the variables in the study. Changes in land use activities such as logging may impact negatively on the riparian corridors of streams as well as exert influence on in-stream processes through canopy cover removal. Effects on humid zones of a river as a result of canopy cover removal could include less organic matter on banks, increased soil erosion, and unstable banks. This may lead to reduced energy inputs into a stream through reduction in benthic coarse particulate organic matter, increase or reduction in autochthonous production due to increase in light and suspended sediments respectively, and reduced habitat complexity due to reduced woody debris input.

These modifications have an impact on the physicochemical properties of water. This decline in stream health may eventually lead to a drop in benthic macroinvertebrate diversity, abundance, and biomass. Reduced macroinvertebrate diversity, biomass, and abundance may have an impact on stream functionalities such as organic material decomposition and the cycling of nutrients. Macroinvertebrates that are unable to adjust to the new conditions will drift or perish, causing changes associated with the community structure. Changes in surface water quality are typically interfered with the by natural phenomena processes such as ecological succession as well as human interventions such as research, water quality monitoring, and law enforcement. These intervention measures aid in mitigating the effects of stress factors on streams.

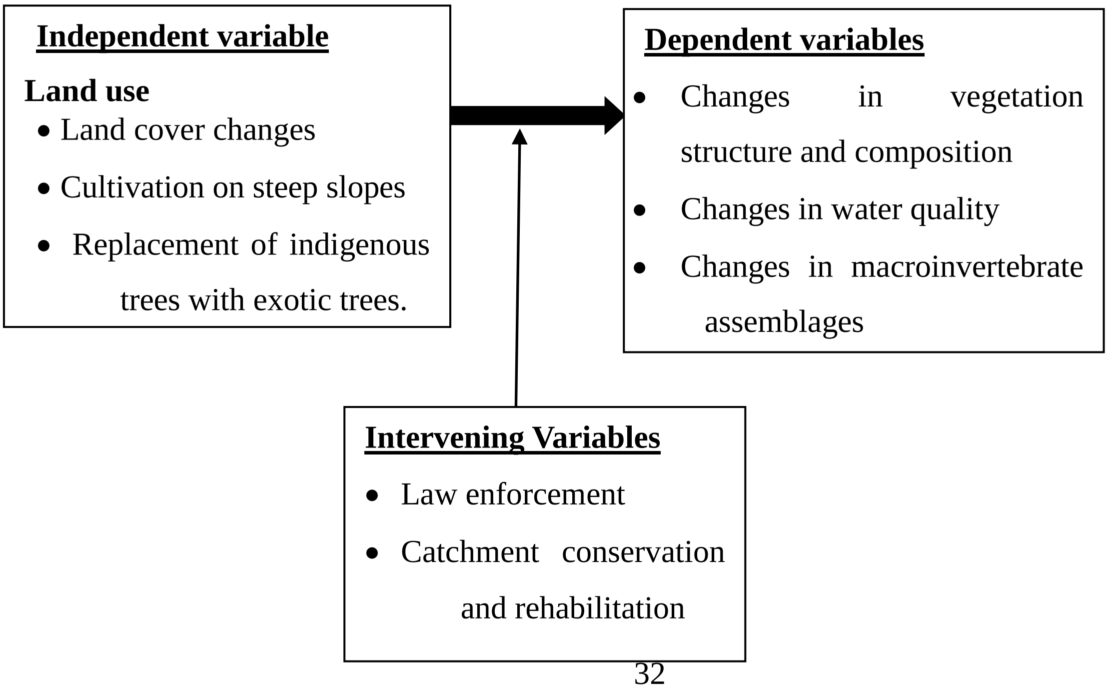


Figure 2- 2: Conceptual frame indicating the variables of the study.

CHAPTER THREE

SPATIAL AND TEMPORAL VARIATIONS IN LAND USE AND LAND COVER CHANGES IN THE NJORO AND KAMWETI RIVER CATCHMENTS, KENYA

Abstract

The Njoro and Kamweti River Catchments in Kenya are productive catchments that have and continue to experience major land use changes with consequences on land cover and the associated environmental resources. It is therefore crucial to understand the type of changes occurring, spatial patterns and the rates at which these changes are occurring. The study quantified the variations in land utilization patterns that occurred between 1988 and 2019 identifying areas of change and the average annual rate of change. Thematic Mappers (TM), Enhanced Thematic Mappers Plus (ETM +) and Sentinel Images were obtained from 1988 to 2019, a period of 31 years, 10 years epoch, in which LULC change can be monitored. Ground truthing was carried out to verify the accuracy of the remotely sensed data using in-situ observations to refine the classification output. The results obtained indicated that both catchments have experienced land use changes but at different levels. The Njoro River Catchment displayed greater changes as compared to the Kamweti River Catchment in terms of forest cover and farmlands. The changes in LULC were attributed to increased demand for agricultural land, firewood, charcoal, timbers and housing materials and thus continued degradation of the two river catchments and more so for the Njoro River Catchment. Increase in human population and the associated anthropogenic activities resulted to the observed changes in LULC observed in both catchments. Providing different energy sources, farm inputs and promotion of the non-agricultural economies will contribute greatly towards conservation of natural resources including water catchment areas in the study area. Continued analysis of the trends and rates of land cover conversions is recommended for successful integrated watershed management.

3.1 Introduction

Changes in land use reflect the history and perhaps, the future of mankind. Land use/land cover change has become a major global challenge, it’s an important variable that impacts many aspects of the natural environment similar to the effects of climate change (Berihun *et al.*, 2019). Many land use system patterns and dynamics are not uniform in all parts of the world driven by various social causes including; human activities, Population pressure and development. Land use change has significant impacts on climate, biodiversity, hydrological cycles, biogeochemical processes and human society (Were, 2013). The process of deforestation as a cause of land use change, is one of the largest anthropogenic contributors to carbon dioxide emissions and it’s the primary driver of global warming hence climate change (Le Quéré *et al*, 2009).

Land use change is considered a local environmental issue, but in the recent past, it is turning to be a force of global importance. Global changes to forests, farming areas, water, and air are being driven by the need to provide food, shelter and water to more than six billion world population. Rapid expansion in the recent years of world plantations, croplands, pastures, and urban areas have intensified the decline in resources such as water and energy which in turn results in losses of biodiversity (Foley *et al.*, 2005). There has been significant historical global changes in land cover and land use,) between 1700 and 1990 when cropland area expanded to approximately 16.5 million km^2 from 3.5 million km^2 (Ayuyo & Sweta, 2014).

Most important land use changes is anticipated to occur in Europe in the decades to come because of socio-economic, technological, and political advancements as well as global environmental change. Collectivization “kolkhozes” in Eastern Europe after World War II was associated with higher yields but also with unfavorable changes in land use and cropping patterns causing acidification, soil erosion, and salinization and chemical pollution (Bouma *et al.*, 1998). Africa though endowed with a highly diverse and fragile environment, is experiencing rapid change at many levels including climatic, natural resources, agricultural, demographic, political, and socioeconomic associated with land use changes. For centuries, humans beings have had insignificant force in the environmental equation; As Africa enters the 21st century environmental changes are projected to hasten, with possibly unknown severe repercussions for both its people and the environment (Tappan & Cushing 2004).

In Ethiopia LULC changes are also a major environmental challenge (Gashaw *et al.*, 2017), where agricultural activity functions as the pillar of the economy. Research Studies show LULC changes in many parts of the country through both deforestation and reforestation activities since the late 21st century. In Ethiopian highlands a study has revealed that the extend of cultivated land expanded as the natural forest reduced (Betru *et al.,* 2019). Many parts of East Africa are experiencing dramatic changes in land-cover/use at a variety of spatial and temporal scales, due to both climatic variability and human activities (Maitima *et al*., 2009).

Whilst change in land use to industrial agriculture has increased crop yields, it has also severely impacted the environment, receiving a lot of attention due to its contribution to changes in the environment. Forest conversion to other uses is one of the most concerning land-use shifts. Land-use changes for crop production and wood harvesting have led to a worldwide net loss of 8-13 million km^2 of rainforest over the last 300 years. Between 1980 and 2000, over 55% of added farmland in the tropics originated from native vegetation, whereas the remaining 28% came from disturbed forests. Despite several measures to halt forest loss, the world continues to lose approximately 15 million hectares of forest each year. In the 1980s and 1990s, deforestation in Asia reached 8.2% of total forest area, 6.1% in Latin America, and 4.8% in Africa. The most significant changes on the earth's surface include increased land degradation, siltation of water bodies, deforestation, and extinction of key terrestrial and aquatic species, with the majority of these changes being linked with unsustainable exploitation of resources, widespread land deterioration, agricultural land expansion, and a rise in human and farm animals communities (Masayi *et al.,* 2021).

Land scarcity in East Africa's highlands has resulted in the conversion of wooded regions to agriculture, lowering forest cover. Land under cultivation in East Africa has more than doubled in the last few decades where natural forests in Tanzania fell by roughly 12.7% between 1980 and 1990. Kenya compared to Tanzania and Uganda, it has the most diversified yet extremely fragmented woodlands. Natural and manmade forces both contribute to the increase of fragmentation. Road building, timber harvesting, conversion to agriculture, and wildfire are examples of anthropogenic disturbances. Kenya's indigenous forest canopy covers around 6.9% of the country (3,467,000 ha) however, this figure is lower in comparison to Tanzania's forest cover of 55%, Mozambique's forest cover of 43%, and Uganda's forest cover of 12.4% and the current coverage is less than the internationally required ten percent (10%) (Masayi *et al.,* 2021). For the last 20 years, Kenya has been losing forest cover at a pace of about 1900 acres per year. Between 1990 and 2000, the country's forests dropped by 0.34% (12,050 hectares) per year, with a 6.5% (241,000 ha) loss between

1990 and 2010. Forest deterioration has been attributed to a variety of issues, including illicit logging, encroachment on forest area for farming, and charcoal-burning. The existing land use patterns in Kenya's mountainous forest ecosystems demonstrate that land uses are changing quickly, which may have a severe impact on the environment both locally and worldwide (Masayi *et al.,* 2021).

Kenya’s watersheds are exception of such activities. Reduction in forest cover has contributed to diminishing livelihoods of many the populations caused by reduced land productivity, famine and drought. Kenya’s forests have been the destroyed mostly by degradation as one of the factors, for instance, the Maasai Mau block in Mau forest complex has had the most effects and in turn receded significantly over time (Jebiwot *et al.,* 2021). Irregular forestland allocation and encroachment has exacerbated the already serious situation. Persistent obliteration of the forests will cause serious water predicament including, perennial rivers are turning to seasonal, downstream flooding in some areas.

Many environmental planning and management activities rely on knowledge and available data on LULC changes to contribute in making decisions. In order to achieve better and more efficient use of land resources, it is essential to have effective, precise, continuous, previous, as well as up-to-date specific data on LULC changes (Muriithi, 2016). Because of its repeating nature, satellite remote sensing data have shown to be highly valuable in mapping land use/land cover patterns and changes over time (Garcia, 2019). Different modeling approaches have been utilized to enable the prediction of the behavior of natural and human systems in order to study and understand where LULC changes are occurring and their driving forces (Meyer *et al.,* 1994; Mwaura *et al.,* 2016).

Remote sensing (RS) and geographic information systems (GIS) have proven to be effective methods for quantifying, mapping, and detecting LULC spatiotemporal dynamics. Remote Sensing has evolved as a very powerful technology capable of giving accurate spatial information and LULC distribution over time. Satellite data enables rigorous, efficient and cost-effective ways for mapping the distribution of biomass on the earth's surface, allowing for faster and more consistent studies of terrestrial surfaces and changes over time. Geospatial approaches have been widely employed to generate valuable information on land cover, vegetation type and detection of land-use change (Muriithi, 2016).

Landsat imagery has been utilized globally for change detection. Recently, Wang *et al.* (2018) assessed spatial patterns of LULC changes in the Xitiaoxi River Basin from 1985 to 2008 and reported that during the periods of 1985 to 2008, the key trend of land-use conversion was between forest-grass land and agricultural land, and the shrinking amount of forest-grass land and agricultural land led to the increase of urban land. Birhanu *et al.* (2019) noticed a similar trend between 1986 and 2015 in the Gumara watershed, Ethiopia, where the area under forest and grass land was at 11% and 18%, respectively, in 1986, and 5% and 10%, respectively, in 2015. It was also observed that farmed land expanded from 70 % in 1986 to 82 % in 2015.

In Kenya, spatio-temporal changes in land cover states have been researched using landsat imagery. For example, Kirui *et al.* (2013) analyzed the mangrove forest on the Kenyan coast using Landsat images between 1985 and 2010, and the results showed a drop in the percentage cover of the mangroves. Olang *et al.* (2011) analyzed the Nyando Basin and found that between 1973 and 2000, the area covered by forests decreased by 20 % while agricultural fields rose by 16 %. Langat *et al.* (2019) noted that agricultural land and built-up area increases by 32.57 % and 26.35 % respectively, while bare land, water bodies, and vegetation decreased by 35.9 %, 3.13 %, and 8.29 %, respectively, between 1987 and 2015. Ayuyo and Sweta (2014) used geospatial technology to map and detect changes in the Mau complex and reported a decrease in forest cover. Similarly, Jebiwot *et al.* (2021) reported a 25.2 % reduction in area under forest cover within the Mau Forest complex over a fourty-years where the Njoro River watershed is located.

The Njoro and Kamweti rivers catchments are located in the Kenya’s water towers of Mau and Mt. Kenya respectively. They are sources of important rivers that drain into various aquatic ecosystems. For example, the Mau Forest Complex serves as the primary water source for twelve rivers that flow into Lakes Natron, Victoria, and Turkana, while rivers that originate from Mount Kenya are tributaries of two major Kenyan rivers: the Tana and the Ewaso Ng'iro, the latter flowing all the way and discharging its waters into the Indian Ocean.

The Njoro River Catchment was characterized by low population, woodland, and large scale conservation agriculture in the 1940s. Later, following independence, in the 1960s, there was an upsurge in the human settlements following Kenya’s post-independence era. As large scale farms (formerly Kenya’s White Highlands and occupied by the White Settlers) were turned into small scale farms resulting in land subdivision, intense agriculture, and urbanization, and gradually loss of significant portions of the adjacent forests including the Mau Forest (Mainuri & Owino, 2013). In 1970, natural vegetation covered 47% of the land, but by 2003, approximately 35 % were destroyed, and farming in small -scale increased (Baldyga *et al.*, 2008). Jebiwot *et al.* (2021) also highlighted that the watershed has sustained disturbances from anthropogenic activities in the Mau and recognized deforestation and land transformation for other purposes being the major challenges.

Climatic factors, on the other hand, determine the top tree limit of the Kamweti River Catchment. Land clearing, on the other hand, has substantially extended the catchment's lower limit of forest, and most of the catchment's lower areas, as well as places that historically supported forest, are now either under agriculture or have recently been replaced with mostly exotic fast-growing softwoods (Tattersfield *et al.,* 2001). A segment of the Kamweti River Basin is located in the Mount Kenya Forest Reserve, whereas the lower side of the watershed is agriculturally productive. Unauthorized livestock herding, unchecked logging, and "shamba" cultivation, which entails localised clearance and intermittent farming inside the rainforest, have all put a burden on the Forest Reserve. Indigenous forests have also been destroyed in some locations and replaced with fast growing softwood plantations.

The objective investigated the dynamics of LULC changes in two catchments, Njoro and Kamweti River Catchments. The catchments are distinguished by varying degrees of anthropogenic disturbance, landscape characteristics and ecology. They also support livelihoods for many people, making them vulnerable to environmental degradation caused by anthropogenic activities.

3.2 Materials and Methods

3.2.1 Description of the study areas

3.2.1.1 Njoro River Catchment

The study region, Njoro River Catchment, Figure 3-1 A, covers an area of 284.39 Km^2. It is found in the south western part of the Rift Valley at 0° 30’ South 35° 20’ East (Baker *et al.,* 2010). Within this catchment is the Njoro River with an approximate length of 55 Km discharging into Lake Nakuru (at 1,750 m ASL), a RAMSAR site. (Figure 3.1 A). The river traverses forest, agricultural fields, settlements and urban areas before it discharges into the shallow soda lake (Lelo *et al.,* 2005). Some sections of the river, has its riverine vegetation removed and the canopy cover over this hydro-system ranges from 0 % to about 80 %. Topographic variation and historical volcanic activity in the area are known to contribute to soil formation (Baldyga *et al.,* 2008).

Recently, notable dynamics in land use and rise in human population have been experienced within this watershed. This has had negative impacts on the available natural resources, the health of the population and their wellbeing, the local economy and types of livelihood systems (Enanga *et al.,* 2011). The upland regions of the watershed have conditions favorable for crop production which contributed to the conversion of the available forests and other natural vegetation to small-scale agriculture. The majority of farmers in the watershed produce crops and animals, which have become their primary sources of household income in the watershed. Other socioeconomic activities include gathering and selling firewood, burning and selling coal, quarrying, and sand harvesting.

3.2.1.2 Kamweti River Catchment

Kamweti area, Figure 3.1 B, is located on Mount Kenya's southern slopes, an area dissected through by many rivers and streams. Kamweti River is a tributary of the Thiba river. It is the main source water for the population of the catchment.

The climate in Kamweti is cool and moist. The average temperature ranges from 16.6°C in the coldest month to 20.1°C in the warmest month. The rainfall is bimodal, where the long rain are experienced in from March to May and sthe sort rains from October to December (Kaberia, 2007). Kamweti area consists of a rain forest and the upstream consist of mainlt native vegetation species of trees and shrubs such as *Rhus vulgaris* and *Vernonia auriculifera* (Kaberia, 2007). *Tithonia diversifolia* was also a widespread understory herb that grows naturally in the forest (Oduma, 2016). The lower reaches of the river has some farming activities. The Nyayo Tea Zone (Kenya tea zone and forest protection) separates the forest zone from the farmers' fields. The farmed area is an undulating high plateau that gradually rises northwards towards Mount Kenya, which reaches 5,199 metres above sea level at its highest point. *Urtica diversifolia* is the most common weed species in coffee and tea plantations, growing to a height of 30-150 cm (Kaberia, 2007).

The Njoro and Kamweti River Catchments are both quite productive however they differ in terms of ecology, landscape characteristics and human characteristics. The pressure for arable land especially through agriculture and settlements has been on the rise within the Njoro Catchment since 1994 which contributed to the recession of area under forest cover and affected the forest ecosystem integrity. The anthropogenic pressure and forests land transformation to other land utilization types in both catchments at different rates makes them important case studies. Efforts have been made by various institutions and community organizations to rehabilitate sections of Njoro Catchment since the year 2012. The extent of success of these efforts is not well established or documented. Kamweti area, which is considered to be in a “semi-pristine” state and forms a yardstick for evaluating the extent of degradation of the Njoro River Catchment which presents a fragile ecosystem whose natural resource require better management. This information obtained will be used by land managers and planners for sustainable utilization and conservation of the resources.

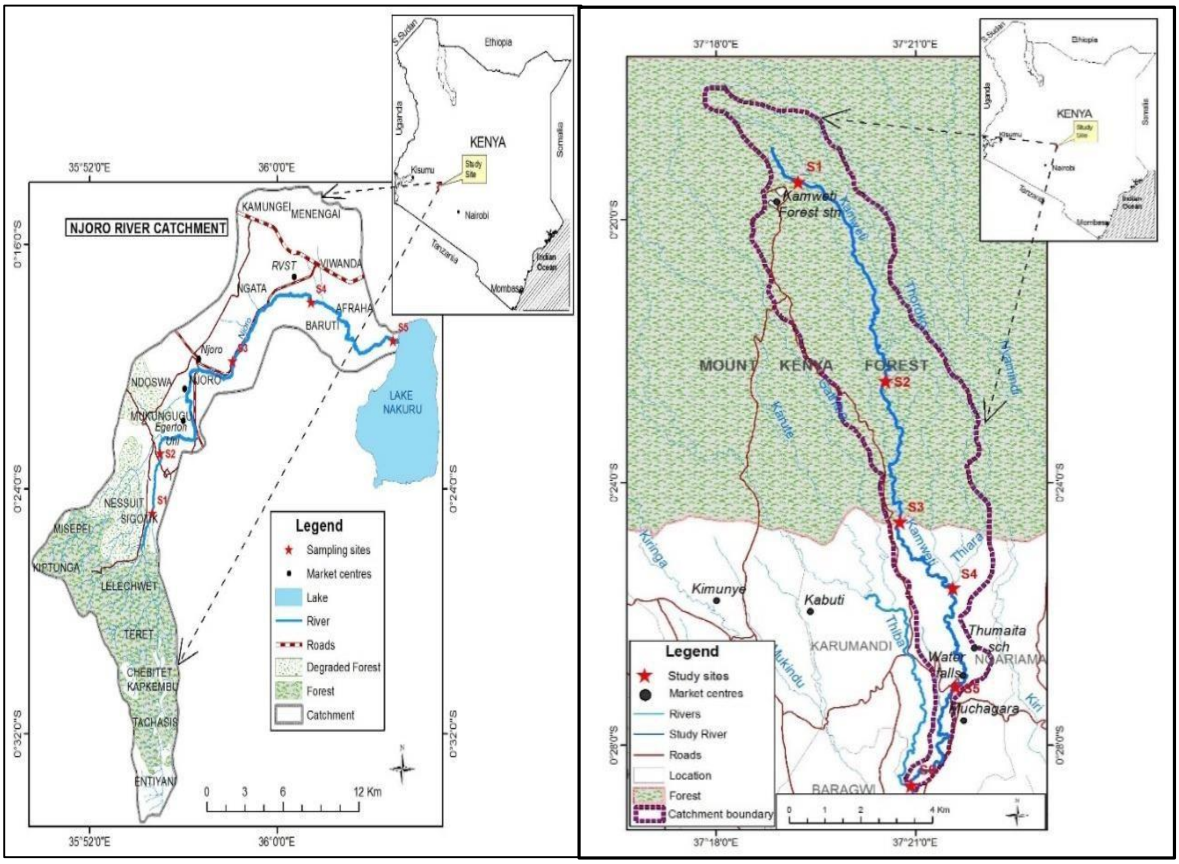


Figure 3- 1: Maps showing the study areas A: Njoro River Catchment. B: Map of the Kamweti River Catchment (Map of Kenya inset). (Source: World Resource Institute GIS data)

3.2.2 Methods used for land use and land cover change detection

3.2.2.1 Data Collection

Changes in Land Use and Land Cover in Njoro and Kamweti River Catchments from 1988 and 2019 were detected using Landsat imagery. Thematic Mappers (TM), Enhanced Thematic Mappers Plus (ETM +) and Sentinel images were obtained from 1988 to 2019, a period of 31 years, 10 years epoch, an ample period of time in which LULC changes can be monitored and cloud free image scenes were acquired for this purpose. The images were obtained when cloud cover was minimal, which were obtained from USGS Global Visualization Viewer (http://glovis.usgs.gov). The images used were already geo-referenced to correct alignment, and also they were co-registered to the Universal Transverse Mercator

(UTM) projection system (zone: 37N, datum: WGS-84). The purpose was to avoid the need for geo-rectification which would have required the use of ground control points. The details of satellite data are presented in Table 3-1. The process applied the use of Remote Sensing and Geographic Information System to evaluate the LULC changes, trends, magnitudes and the emerging environmental consequences in the area for the study period.

Table 3- 1: Remotely sensed data used in the analysis of land use/cover change in the two catchments.

Catchment	Satellite sensor	Acquisition date	Path/ Row
Njoro River	ETM	30.01.1988	168/60
	TM	03.04.2001 ; 30.01.2010	168/60
	Sentinel-2A	12.01.2019	T36MZE
Kamweti River	TM	17.10.1988	168/60
	ETM	21.02.2000 ; 17.07.2010	168/60
	Sentinel-2A	28.02.2019	T37MCV

TM = Thematic Mapper sensor; ETM+ = Enhanced Thematic Mapper plus sensor and Sentinel.

3.2.2.2 Data analysis

Land cover classification

Areas of interest on the earth’s surface have been for decades studied and classified into different land covers using multi-temporal remote sensing data (Butt *et al.*, 2015). Satellite data comprised of multi-temporal satellite imageries (Landsat imageries from 1988 to 2019) which were classified across four epochs. Image processing done using IDRISI imaging for layer stacking, sub-setting, image classification and recording of features. Supervised classification which allows the user to define the areas of interest and recognize the features on the image was carried out to develop training sites. The training sites were collected for the various LULC categories, based on prior knowledge of the study areas and based on the uniformity in appearance using ArcGIS 10. The training sites were then used to create spectral signatures to be used to process land use and land cover classes in unsupervised classification.

To improve on the visualization of different objects on the imagery in this study, different color composites were used. Infrared color composite, Near Infrared, and Red were applied in the identification of varied levels of vegetation growth and in separating different shades of vegetation. In the identification of the built-up areas and bare soils, color composites such as Short Wave Infrared, Near Infra-red and Red combination which are sensitive to variations in moisture content were applied (Cheruto *et al.,* 2016). The spectral signatures for the respective LULC types obtained from the satellite imageries were then recorded by use the pixels enclosed by the polygons. Reclassifying classes to assign a common class was carried out by utilization of ARCGIS 10 software, which has the capability of integrating the other data with the extracted information. It was also utilized for displaying and subsequent processing and to enhance the images and clip out the area of interest (Njoro and Kamweti River Catchments) from the images using topographical maps.

Assessment of the changes in LULC in the Njoro and Kamweti River Catchments for 1988 and 2019, for the different cover classes, was carried out following Othow *et al.* (2017) using the formula:

$$\%\ \text{Cover change} = \frac{OC}{ASC} \times 100$$

$$\%\ Cover\ change\ in\ a\ year = \frac{Y2 - Y1}{Y1} \times 100$$

$$Average\ rate\ of\ cover\ change = \frac{Y2 - Y1}{T2 - T1} \times 100$$

$$\%Average\ rate\ of\ cover\ change = \frac{Average\ rate\ of\ cover\ change\ (\frac{ha}{yr})}{Difference\ in\ years} \times 100$$

Where: OC is the observed change; ASC is absolute sum of change i.e., fixed year (starting year); Y2–Y1 is the observed change; Y2 is the ending year; Y1 is the starting year; T2-T1 is the periodic interval between the initial period and the final period.

Land use and land cover categories were classified into seven different informational classes as described in Table 3.2 for this study. The classes were categorized from the different Landsat images included forests, disturbed forests, farm land, built-up areas, shrublands, bare ground, and water body. The categorization was based on image interpretation and sample trainings that were developed during image classifications.

Table 3- 2: Description of land cover classes used in the two river catchments.

Cover class	Description
Forests (F)	A continuous stand of trees, many of which can reach a height of 50 m, which includes both natural and planted forest.
Disturbed forests (D F)	Any forest that has been logged and is recovering naturally or artificially
Farm land (F L)	land under cultivation or capable of being cultivated perennial and annual crops
Built-up areas (B U A)	The entire residential, commercial, and industrial area, as well as the transit infrastructure and settlements (may include greenhouse plastic covers).
Shrubland (S L)	Landscape consisting of scattered grasses, shrubs, and trees.
Bare / open -ground (BG)	Uncultivated farmlands with bare soil and rock outcrops that lack vegetation cover.
Water body (WB)	A body of water that serves as a physiographic feature.

3.3. Results

3.3.1 Land use and Land cover maps of the study areas

The maps obtained for the years 1988, 2001, 2011 and 2019 based on the Landsat imageries were prepared with seven land-cover types, namely, forests, disturbed forests, farm land, built-up areas, shrublands, bare ground, and water body for the Njoro and Kamweti River Catchments for comparison. Figures 3.2 and 3.3 show the final output of the maps for the Njoro and Kamweti River Catchments respectively, showing the substantial changes in the catchments in the 31 years.

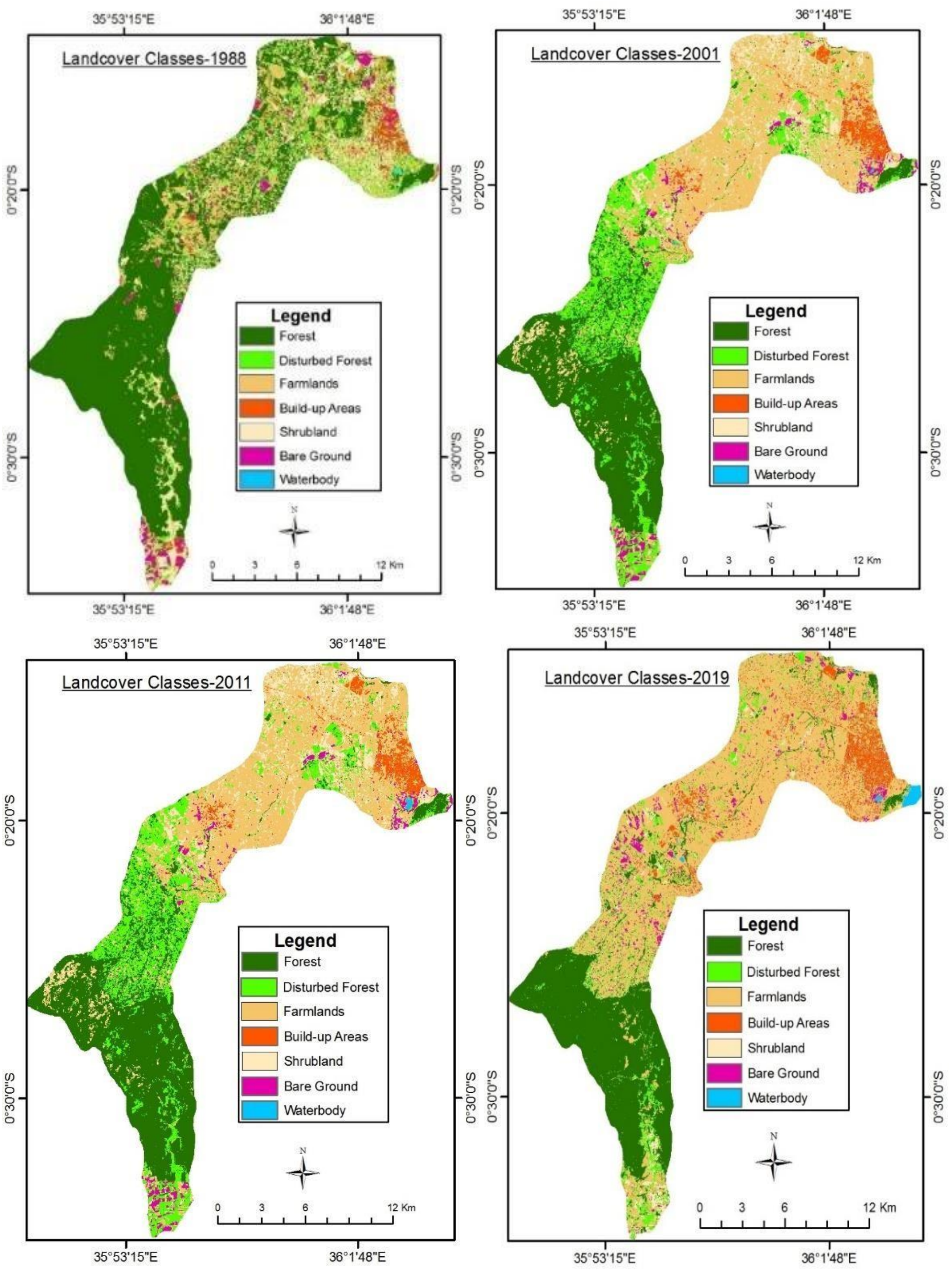


Figure 3- 2: Landsat images showing changes in land use and land cover classes in the Njoro River Catchment (1988, 2001, 2011 and 2019).

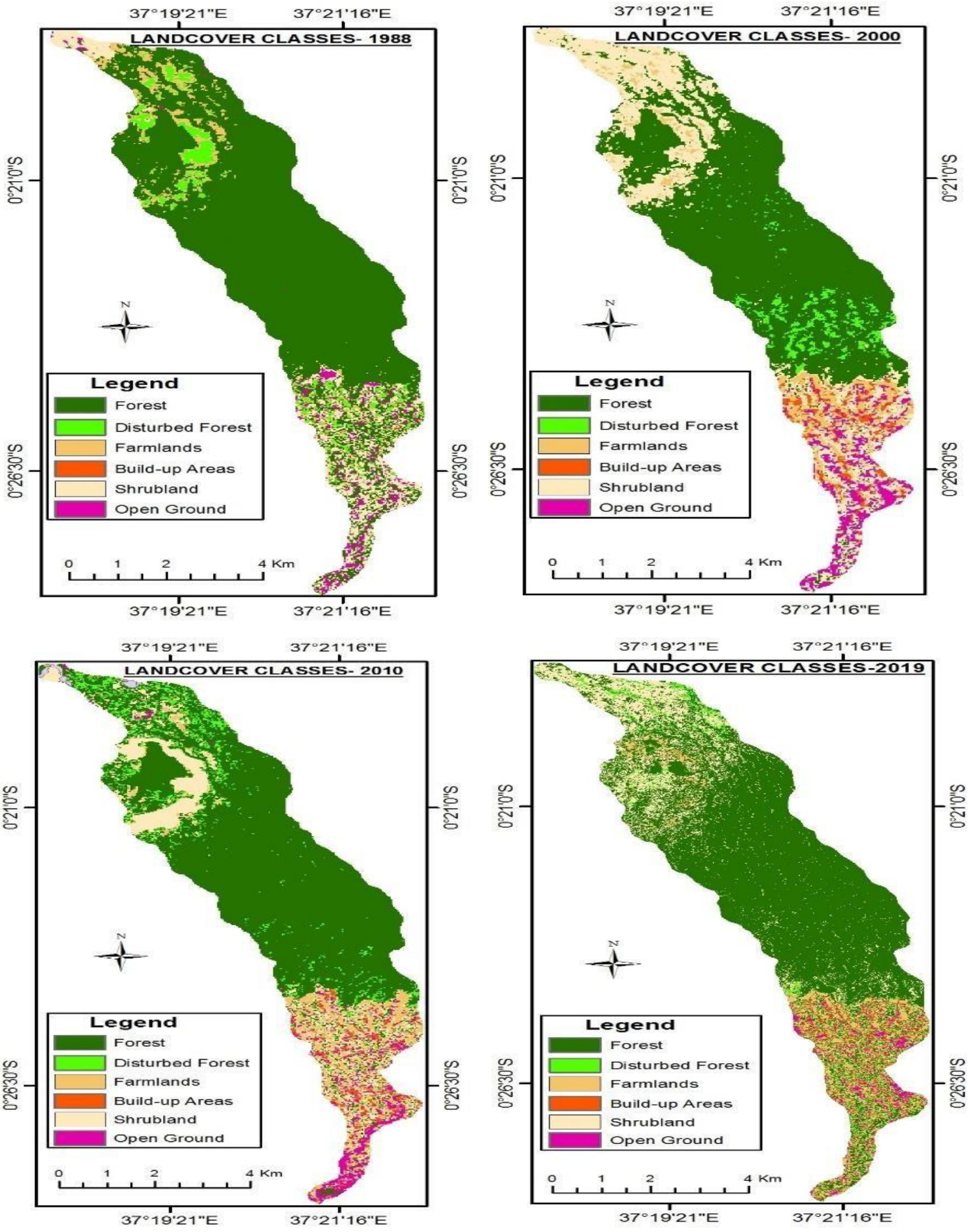


Figure 3- 3: Landsat images showing changes in land use and land cover of Kamweti River (1988, 2001, 2011 and 2019).

3.3.2 Temporal variations in land use and land cover changes

Results revealed major transformation occurring the two catchments. The Njoro River Catchment has an area of 284.39 Km^2 while Kamweti River Catchment covers an area of 48.33 km^2.

In 1988, the dominant land cover/use class in the Njoro River Catchment (Figure 3.2) was forest cover. It had a coverage of 57 % and since then it has shown a decreasing trend to the year 2019 where coverage of 29.31% was recorded. A sharp decline was noted between 1988 and 2001 where forest cover reduced by 26.52% as shown in Table 3.3 A. Disturbed forests covered 6.94% in 1988 and since then it has been increasing. On the other hand, in 1988, Kamweti River Catchment had a dense closed tree canopy and also was the most dominant LULC covering 36.66 Km^2 (75.87%). In 1988, the disturbed forest coverage was 2.10 Km^2 whereas shrubland covered 4.88 Km^2 (Table 3.3 B) which dominated mostly on the northwestern section of the catchment. Farmlands covered a smaller area of 3.28 Km^2 and were present mostly along the edges of the forest which were the tea plantations on the ground.

Table 3- 3: Changes in land use and land cover in the Njoro River Catchment from 1988 to 2019.

YEAR	**1988**		**2001**		**2011**		**2019**	
Class type	Cover (km^2)	%	Cover (km^2)	%	Cover (km^2)	%	Cover (km^2)	%
F.	**162.11**	57.00	86.68	30.48	85.75	30.15	**83.36**	29.31
D F	19.73	6.94	**52.37**	18.41	37.69	13.25	**19.92**	7.00
F L	46.65	16.40	94.99	33.40	119.82	42.13	**143.13**	50.34
B UA	7.23	2.54	8.61	3.03	11.72	4.12	**14.90**	5.24
S L	**40.40**	14.21	33.91	11.92	24.29	8.54	11.87	4.17
B/O G	8.09	2.85	7.73	2.72	4.85	1.72	**9.39**	3.30
W B	0.18	0.06	0.1	0.04	**0.27**	0.09	1.82	0.64
Total	**284.39**	**100**	**284.39**	**100**	**284.39**	**100**	**284.39**	**100**

Table 3- 4: Changes in land use and land cover in the Kamweti River Catchment from 1988 to 2019.

YEAR	**1988**		**2000**		**2010**		**2019**	
Class type	Cover (km^2)	%	Cover (km^2)	%	Cover (km^2)	%	Cover (km^2)	%
F	**36.66**	75.85	28.04	58.02	30.38	62.86	**30.13**	62.34
D F	**2.10**	4.34	1.68	3.48	2.81	5.81	**3.90**	8.07
F L	**3.28**	6.79	2.76	5.71	1.58	3.27	1.59	3.29
B UA	0.41	0.85	1.38	2.86	1.44	2.98	**1.48**	3.06
S L	4.88	10.10	11.83	24.48	9.83	20.34	**8.25**	17.07
B/O G	1.00	2.07	2.64	5.46	2.29	4.74	**2.98**	6.17
W B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	48.33	**100**	48.33	100	48.33	100	48.33	**100**

Note: **F**-Forest, **D F**- Disturbed Forest, **F L**- Farm Land, **B U A**-Built Up Areas, **S L**- Shrub Land, **B/O G** – Bare/Open Ground, **W B** – Water Body.

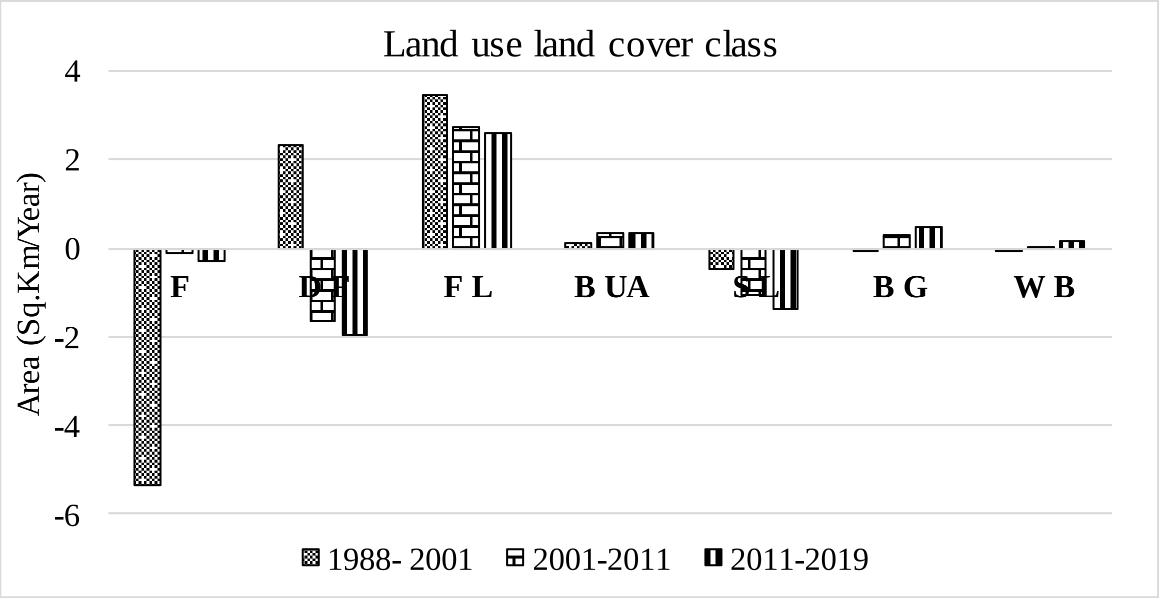
Between 1988 and 2001, forest cover in the Njoro River Catchment reduced by 26.52%. During the second period, between 2001 and 2011, the forest coverage has decreased by 0.93 Km^2 at a rate of 0.09 Km^2/year. In the third period between 2011 and 2019, the forest cover reduced further by 2.39 Km^2 (0.3 Km^2/year) within eight years. In Kamweti River Catchment, between 1988 and 2000, the forest covered an area of 28.04 Km^2 and also it had reduced by 17.85% at a yearly average rate of 0.72 Km^2/annum (Fig. 3.3 B). Disturbed forests had reduced to 1.68 Km^2 and farmlands reduced to 2.76 Km^2 however noted was the increase in the area of shrubland to 11.83 Km^2 as shown in Table 3.3 B.

Farmland areas in the Njoro River Catchment in 1988 constituted a spatial coverage of 46.65 Km^2 and it has been in an increasing trend. A greater conversion of vegetation cover into farmlands was noticed between 1988 and 2001 where a change of 48.48 Km^2 occurred with an annual average rate of change of 3.72 Km^2/year. Vegetation cover in the catchment decreased from 51.94% to 40.3% as farmlands increased from 46.65 Km^2 to 143.13 Km^2 as shown in Table 3, at a yearly average rate of 3.21 Km^2/year. On the contrary the area of farm land coverage in the Kamweti Catchment was noted to be on a decreasing trend where farmlands covered 3.28 Km^2 and in 2019 it covered 1.59 Km^2.

Built-up areas in both catchments during the study periods showed a steady increase. In 1988, the Built-up areas in the Njoro River Catchment covered an area 7.23 Km^2 and in 2019 it had increased to 14.9 Km^2 at a rate of 0.25Km^2/yr within the study period. Bare/open ground between 1988- 2001 continuously revealed a decline in area by 0.13 % in the Njoro River Catchment. This occurred at a diminishing rate of 0.36 Km^2/year. From 1988 to 2019, built up area in Kamweti River Catchment increased from 0.41 Km^2 to 1.48 Km^2. Rivers were the main water bodies and in Kamweti River Catchment, there was a 0% area of water coverage between 1988 and 2019 as shown in Table 3 B. In Njoro River Catchment water bodies in 1988 covered 0.18 km^2 (0.06%). A decrease to 0.1 km^2 was noted in 2001. In 2011 area of water coverage increased to 0.27 km^2 and declining to 1.82 km^2 in 2019 (Figure 3.4 A).

The rate of changes of forests, disturbed forests, farm land, built up areas, shrubland, bare/open ground and water body cover for the study period of the two catchments are presented in Figures 3.4 A and B. The negative numbers reflect a decrease in the ratio of LULC categories at that period, whilst the positive values represents a rise in the proportion of the land cover categories at the period of study.

A



B

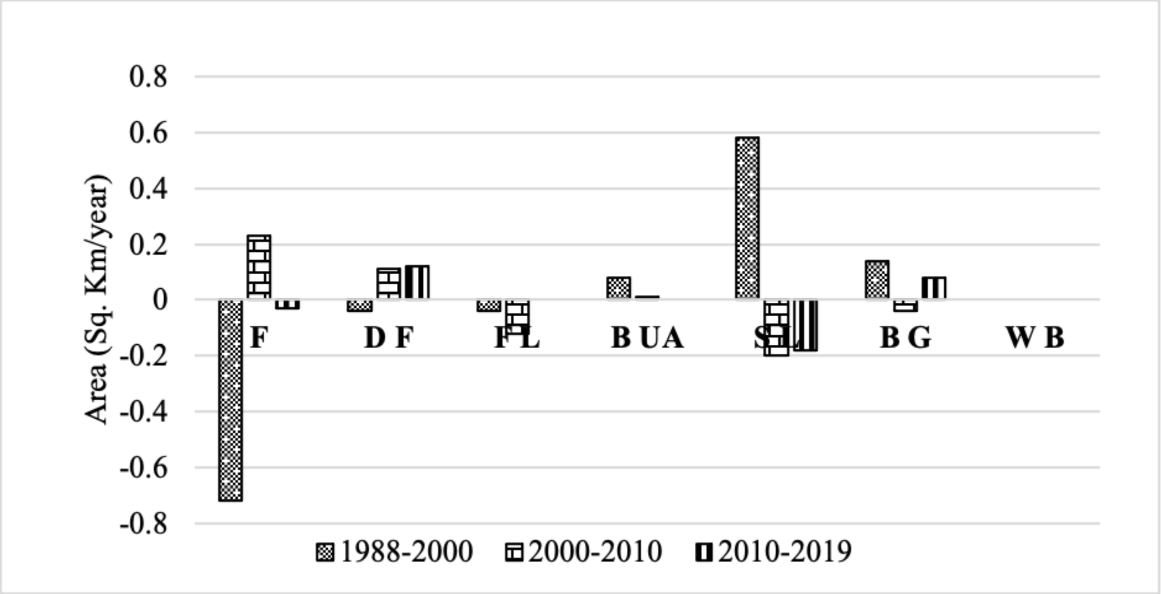


Figure 3- 4: Changes in land use and land cover classes A: Njoro River Catchment and B: Kamweti River Catchment in Km^2/year from 1988 to 2019.

Note: F-Forest, D F- Disturbed Forest, F L- Farm Land, B U A-Built Up Areas, S L- Shrub Land, B G – Bare Ground, W B – Water Body.

3.4 Discussion

3.4.1 Land use and land cover maps of the study areas

Utilisation of remote sensing to acquire data used to detect changes in land cover indicated that both catchments were degrading, with the causes being attributed to anthropogenic activities such as deforestation, agricultural expansion, infrastructure, riverbank cultivation, and unsustainable resource utilization. Wu and Lu (2021) reported that human population expansion has an influence on environmental sustainability. Some of the repercussions include biodiversity loss, reduction in the quality of land and increased soil degradation (Leah *et al.*, 2021). Meshesha *et al.* (2016) documented that human population is on the rise and especially in newly developed countries, resulting in clearing of vegetative cover for agricultural uses. Similar results were found in this study in Njoro River watershed, where the farmlands together with settlements were observed to increase in area of coverage as vegetation decreased.

According to Baldyga *et al.* (2008) between 1986 and 2003, about a -fifth of the forests in the upper part of the watershed of the Njoro River were destroyed. Unauthorized encroachments in the 1990s, as well as a political move in 2001 to exclude roughly 353 km^2 of the Eastern Mau tropical rainforest for settlement, were also contributors in forest loss. (Were *et al.,* 2013). Water is extracted for irrigation reasons in some areas of the river, reducing river flows. This has encouraged farming on steep slopes and along river banks, where water is available and the atmosphere is conducive for agricultural purposes. This supports the findings of Jebiwott *et al.* (2021), who documented a loss in tree cover in the Mau Catchment due due to competition for farmland. Also the Built-up areas in both catchments were observed to be on the rise continuously since 1988, exerting pressure on building materials and finally resulting to land degradation through sand mining and quarries, which has impacted the ecosystem and functioning of the catchment.

3.4.2 Variations in land use and land cover in space and time.

Dynamics of land usage transformations in the two catchments analysed have changed dramatically during the last 31 years. Reduction in area under vegetation cover observed mainly in the Njoro River Catchment could be the result of human population increase in the catchment as observed through the increase in area covered by farmlands and built-up areas (Shivoga *et al.,* 2007). Population increase has been identified as LULC driver (Boakye *et al.,* 2008) which exerts pressure on vegetation cover. The same was observed by

Mainuri and Owino (2013) who observed that the population in the Njoro River Catchment has been on the rise. Baldyga *et al.* (2004) reported that the catchment had a population of about three hundred thousand (300,000) people with more than three thousand (3000) individual farm holding units.

The increased population in the Njoro River area has exerted immense pressure on the available natural resources. The high population growth rates reported coupled with land fragmentation has been studied to exert pressure on land causing soil erosion and other forms of degradation as reported by Boakye *et al.* (2008), this may be the case in the Njoro River Catchment. Some of the effects of soil erosion and runoff that can be felt downstream include the silting up of ponds, increase in water-caused illnesses, contamination of surface water as well as sedimentation on fertile land (Maitima *et al.,* 2009; Meshesha *et al.,* 2016). Overgrazing in catchments, according to Muhati *et al.* (2018) hinders establishment of the forest under-storey through trampling seedlings and saplings, over-grazing and over-browsing of desirable species of trees, and increasing soil loss through topsoil loosening.

Contrary to the observations made, in the Kamweti River Catchment, forest class coverage in 2010 had increased to 30.38 km^2 (62.86%). In 2019 a reduction by 0.25 Km^2 was noted (Table 3 B). Also noted was the shrubland decreased by 1.58 km^2 as well as a rise in the area of disturbed forests by 1.09 Km^2 and bare land by increases by 0.69 Km^2/year. The main reason for the above changes could be attributed the rising human population and economic growth in the area. A study by Mwaniki and Möller (2015) reported similar results in some sections of Central Kenya about a massive forest on the decline between 1995 and 2002, and a slight rise of forest areas between 2002 and 2010. At this time the Kenyan government had addressed the issue of deforestation and was putting measures to curb the problem. For example, Nyayo Tea Zones were introduced in the 90s thus creating a “tea boundary” at the national park (Willkomm *et al.,* 2016).

Mismanagement of the shamba system, also known as Non-Residential Cultivation (NRC) (Mugo, 2007) which was introduced in Kenya in 1910 and has since been renamed Plantation Establishment and Livelihood Improvement Scheme (PELIS), may have contributed to the substantial reductions in forest cover in the catchments (Mugo, 2007). The government's ban originally affected the restoration efforts and resulted in enormous expanses of land being under cultivation (Kagombe & Gitonga, 2005). The low forest cover was mostly caused by rising population in the vicinity of the forest and the demand for more land in the Njoro and Kamweti River Catchments. In the year 2007, the PELIS system was reintroduced, which contributed to the increase in forest cover in the Kamweti River Catchment between 2000 and 2010, as well as natural rehabilitation within degraded sections. Similar observations were made by Althof (2005) and Kelly *et al.* (2016) who reported that the PELIS program may be the reason of increased forest cover in Kakamega forest. In general, the program recorded an increase in land under PELIS from 2933 hectares in 2010 to 9939 hectares in 2013 (Kagombe & Gitonga, 2005).

The area under farmlands in the Njoro River Catchment has been on the increase during the study period as the vegetation cover declined. This is evident in areas that were initially covered by grass and large scale farms where, built-up areas and settlements now stand. The upper section of the catchment was also a forested area in the year 1988 which has now been converted into farmlands and built-up lands. A study by Shivoga *et al.* (2005) reported that in 2003, the Njoro River Catchment constituted of 5% forest, 7% woodland, 82% agriculture and 6% built-up area. According to the study, the loss of forest cover in the reserves was triggered by both clear cutting and increasing thinning as a result of encroachment by local residents.

Forest land transformation to farmlands and built-up regions areas has been shown to have an impact on riverine vegetation (Auble *et al.,* 1994; Chebii, 2016; Shiferaw & Singh, 2011) which has been the case in the Njoro catchment where the riparian resource has been diminished (Mathooko, 2001). In comparison to Kamweti River Catchment, farm lands in 1988 covered an area of 3.28 Km^2 and since then recording a decrease to 1.59 Km^2 in 2019. This is because a section of the Kamweti River Catchment is under the management of Mt. Kenya National Park. It is a designated forest reserve for animal protection with limited anthropogenic activities that are beneficial to conservation (Muhati *et al.,* 2018). Establishment of tea plantations around the edges of the Mt. Kenya forest was a measure to reduce encroachment, and has significantly contributed to observed higher forest cover.

Other forms of land cover classes have replaced bare land. This is due to the availability of farmed land combined with increased human population expansion, which has resulted in a decrease of barren land. Between 2011 and 2019 bare ground showed an increase to 3.3% this could be due to the increased use of greenhouses in flower farms which are detected as bare by satellites or the satellite images were taken before the planting season. In the Kamweti River Catchment, there was decrease in the forest cover as other LULC categories including disturbed forests, built-up areas, shrubland and bare ground increased in their areas of coverage. Bare ground increased at a degree of 0.06 Km^2/year between 1988 and 2019. In this watershed, the observed deforestation trend was one of a shift from closed forest to open rainforest, cultivation and habitation, and, in some cases, bare ground. Gashaw et al. (2017) and Hassen and Assen (2018) observed a similar trend in Ethiopia, where agriculture and settlement areas were reported to expand at the expense of forest cover, bare land, and grazing land with no significant conservation measures in place.

The removal or change in vegetation cover, affects the flow of water across the landscape, as well as the amount retained in the soil. Under conditions such as dense natural vegetation cover, the flow of water over land is usually slow, and water infiltrates into the soil. With the existence of bare land, water flows more freely across the landscape and does not have an opportunity to infiltrate the soil (Baker & Miller, 2013; Mainuri, 2018). The result is a change in the timing and amount of runoff to the river. Surface flows are also increased, as water rushes from the landscape into the river channel. Changes in the watershed are associated with upland vegetation changes, floods and high flows have increased in recent years within the River Njoro watershed. Increase in soil erosion has been an additional concern, for instance, at Lake Nakuru National Park, reports indicated that sediment yields from the river to the lake were worsening (Mainuri, 2018).

Kamweti River Catchment had a 0% area of water coverage between 1988 and 2019 which could be explained by the size of the pixels selected for the study which could not catpture the river, however the use of the collected GPS coordinates and the riparian vegetation was used to assess the length of the stream. The area covered by water in the Njoro River Catchment showed fluctuations which could be caused by the changing patterns of rainfall in the area.

The impact of alterations in land use on aquatic environment can be seen in the lowering of natural recharge and discharge (Guzha *et al.*, 2018). Currently, surface and groundwater sources are dwindling as evidenced in the River Njoro which used to flow throughout the year and now it is almost becoming intermittent. Some boreholes which have dried up, were sunk within Egerton University in 1974 and 1978 when the Mau was still intact (Baker & Miller, 2013). Reductions in groundwater recharge were also found to have damaged Lake Nakuru by diminishing the amount of water available for recharge, which could have detrimental consequences for wildlife populations in the park that rely on the lake (Baker & Miller, 2013). The recent rise in Lake Nakuru water levels has been attributed in part to excessive river inflows into the lake during the rainy season. Increased river discharge has been ascribed to the ongoing transformations in the land utilization patterns in the catchments.

3.5 Conclusions and Recomendations

The observations made on the patterns of land utilization in the Njoro and Kamweti River watersheds from 1988 to 2019 were linked to the rise in human population and related processes. For Njoro River Catchment, between 1988 and 2019, major reductions were noted to have occurred in the area under forest cover and shrubs. Major changes also occurred in areas under farm lands, where in the year 1988, farmlands covered an area of 16.4 % which later increased to 50.34% of the catchment in 2019. Vegetation cover has been converted into built up areas and farm lands especially in the upstream areas where they are highly productive due to the fertile soils and availability of water for irrigation. In the Kamweti River Catchment, forest cover decreased from 75 % to 62.34 % between 1988 and 2019 whereas the area under shrubs and disturbed forest increased. Also observed was the rise in built up areas increased whereas the area cover by farmlands decreased from 6.79 % to 3.29 %. The changes observed were attributed to human population increase and the decline in the productivity of land. With the current trends in land transformations, if continued, they will have an influence on rising soil loss and the flow of the evaluated watersheds. As a result, restoring the observed conditions is critical for sustaining the productivity of the Njoro and Kamweti River catchments.

The current study's findings highlight the importance of long-term interventions by all stakeholders and experts of environment, restoration, sustainable environmental planning and management, ecology, biodiversity, and ecosystems. A plan for integrated watershed management for the long-term usage of the sites should be devised to ensure their functioning for succeeding generations. It is critical that the key stakeholders participate in integrated and long-term watershed management, which can be accomplished through better sustainable land management methods including soil and water preservation technologies, which are critical for reversing land degradation. Better agronomic supplies (such as improved seed varieties, herbicides, fertilisers, fungicides, and organic fertilisers) have the potential to boost agricultural output while decreasing cropland expansion. Promoting non-agricultural growth and alleviating demographic pressure on land, as well as providing contemporary alternative energy sources, are essential to sustainable land use.

CHAPTER FOUR

LAND USE EFFECTS ON THE RIPARIAN VEGETATION COMPOSITION, PLANT ABUNDANCE AND DIVERSITY ALONG THE NJORO AND KAMWETI RIVERS, KENYA

Abstract

Riparian areas play a significant role in river health and provide various ecosystem goods and services for human well-being. Riparian areas are under threat due to intensive human activities which alter riparian ecosystem structure and composition. This objective determined how variation in land utilization impacted the riparian vegetation in the Njoro and Kamweti Rivers. Along each river, five sampling sites were selected for sampling. Three 70-m quadrats parallel to the stream were made and three blocks were methodically formed, spaced by a 5-m gap. Data analysis was performed using Paleontological Statistics Software Package (PAST). Njoro River recorded 124 species from 40 families and Kamweti River recorded 128 species from 44 families. One way ANOVA at the level of $p \leq 0.05$, statistical significant spatial differences were not observed in abundance of the dominant plant families encountered amongst the sampling sites and the land use categories in both rivers. T-test indicated that between the rivers no significant differences in plant abundance were observed amongst the dominant communities (Asteraceae $t(8)=1.42$, $p=0.19$; Fabaceae t(8)=1.57, $p=0.16$; Poaceae $t(8)=0$, $p=1$ and Lamiaceae $t(8)=0.25$, $p=0.81$) except Malvaceae ($t(8)=2.54$, $p=0.04$). Community similarities were highest in the Forest area and the built up areas of both rivers. The variations in species diversities observed were linked to human centered disturbances which had no significant impact on vegetation composition and distribution across the different land uses. There is a pressing need for the enforcement of the policies based on the integrated approach for the management of riparian zones.

4.1 Introduction

Fresh water bodies are regarded as roots of human civilization globally. Humans' reliance on water is evidenced by the availability of irrigated farms, communities, towns and factories near the banks of the water bodies. Humans consume majority of the physically accessible runoff worldwide (Postel *et al.,* 1996) thus their enormous impact, particularly on the form and function of riparian ecosystems, is unsurprising. River systems environments are among the most vulnerable to human impact and are on the verge of extinction. The ever-increasing population has a continuing strain on natural resources, notably remnant native riparian woodlands (Sunil *et al.,* 2010).

The word "riparian" was deduced from the word *"riparius"*, which is a latin word meaning "land close to a body of water" (Sunil *et al.,* 2010). Riparian area is the convergent boundary found between the terrestrial and the water based ecosystems that occurring along the bank of rivers (Dufour *et al.,* 2019) Riparian vegetation along rivers comprises unique biological communities (flora and fauna) high species diversity, structure, and regeneration processes (Mligo, 2017; Sabo *et al.,* 2005). They have distinctive traits including hydric soils, floral and faunal composition, and community structural linkages, making them an ideal environment for floral and faunal communities (Sunil *et al.,* 2010). A healthy riparian ecosystem is crucial for sustaining quality of surface waters and ecological integrity, and its loss typically results in degradation of nearby aquatic ecosystems (Sunil *et al.,* 2010).

Occurances such as periodic flooding, tree fall, altitudinal climate shifts are natural factors that have influence on fluvial corridors which impacts on the composition, structure and diversity of riparian vegetation (Méndez-Toribio *et al.,* 2014). Increased human activities, combined with changes in land use and land cover within river corridors and neighboring uplands, have consistently strained riparian ecosystems (Aguiar & Ferreira, 2005; Villarreal *et al.,* 2012). Riparian loss is contributed by anthropogenic disturbances that occur at various degrees, frequency and intensities, putting strain on riparian vegetation and biodiversity.

The development of agricultural fields and urban areas has been shown to fragment riparian vegetation, exposing existing organisms to circumstances in a distinct surrounding environment (Méndez-Toribio *et al.,* 2014). Edge impacts are changes that occur between the new matrix and the residual vegetation, including as changes in the transfer of solar radiations, wind, water, and nutrients. These changes result in changes in species composition and abundance, vegetation structure, and the ecosystem's biological processes.

When there are considerable variations between the surrounding matrix and the ancient flora, local plant and animal species may become extinct (Méndez-Toribio *et al.,* 2014).

Livestock grazing (Mathooko & Kariuki, 2000), farming (Corbacho *et al.*, 2003) and hydrological modification are some of the disruptions that occur due to dynamics in land use that influence riparian populations (Shafroth *et al.*, 2002). Crop production along riparian areas causes excessive siltation and sedimentation, limiting plant species complexity and diversity (Moffatt *et al.*, 2004). Uncontrolled animal grazing promotes erosion, reduces plant vigour, and alters plant age structure and species diversity. By transferring seeds from far regions and/or from the immediate riparian vegetation (Mathooko & Kariuki, 2000), livestock, on the other hand, can contribute to an increase in plant species variety (Mligo, 2017).

The insufficient and unreliable rainfall amounts and the extended periods of drought, have led to the scarcity of pasture and thus the pastoralists have gradually introduced livestock along the Njoro River's middle and lower sections. When the rainy season is over, the river provides enough water for the riparian flora along the river bank to thrive, encouraging further grazing during the dry weather, when forage performance in terrestrial areas deteriorates. As a result, during dry seasons, the riverine vegetation groups are the principal source of forage for livestock in the area, and the green zone becomes overgrazed since they are so small. This diminishes bankside riverine vegetation, which is frequently lost during storm water runoff and when the river channel recedes. Similar anthropogenic activities and problems define the riparian vegetation of the Kamweti River downstream.

The determination of riparian vegetation structure and composition along lotic systems provide knowledge about the environment and thus have the potential to be utilised for bio-monitoring (Alemu *et al.*, 2017). The vegetation types in the riparian zones have the ability to guide on the significant causal links between biodiversity and ecological functioning, which can be measured using indices such as the riparian condition index (RI) and floristic quality index (FQI) (Alemu *et al.*, 2017) which can be utilised as biological indicators of stream state. The bio-indicators have the ability to integrate the geographical and temporal impacts of environmental circumstances on dwelling species and therefore useful for determining the potential impacts of several dynamics in water based environments. However the application of such surveys of the environmental status of tropical lotic systems and especially Africa are uncommon (Alemu *et al.*, 2017).

The objective was to determine how land utilization (forestry, farmlands and settlement areas) influences the composition, structure and diversity of riverine vegetation along the Njoro (frequently disturbed) and Kamweti (less disturbed) Rivers. Increased human population and agricultural expansion have been demonstrated to have both direct (e.g., vegetation clearance) and indirect (e.g., water contamination) effects on riparian vegetation (Mathooko & Kariuki, 2000; Allan, 2004; Mligo 2017). The vegetation cover along the Njoro River as a result of intensive land use showed changes in vegetation structure and diversity, manifested as a lower abundance of stems and individuals and fewer species, but with a greater quantity of multi-stemmed plants, a feature associated with chronic disturbances (Mathooko, 2001; Mbaka *et al.*, 2014). This is not the situation near riparian vegetation, where land use is less intensive (such as forestry in the study).

The study of the two catchments provides an ideal model for analyzing vegetation changes associated to adjacent land uses. Since the structure and diversification of riverine communities are dependent on a diverse set of environmental variables (e.g., latitude and altitude) that are distinct per each site and are directly responsible for the diversity present in each area (Méndez-Toribio *et al.,* 2014) it was also important to broaden the geographic scope of this type of study.

4.2 Materials and methods

4.2.1 Description of the study areas

The research study was carried out in two Kenyan tropical rivers, Njoro river and Kamweti river, between August 2018 and 2019. The climatic condition, geological structure, natural vegetation, topography, land usage, and the frequency and magnitude of disruptions on their bottom sediment layers vary between the two rivers.

The Njoro River catchment with an approximate area of 284.39 km^2, is positioned at latitudes 0° 15' S and 0° 25' S and longitudes 35° 50' E and 36° 05' E. The upper part of the catchment of this river constitutes the Rongai-Njoro plains and slopes of the eastern mau escarpment. The watershed’s geography is primarily undulating land, having contour slopes of varying degrees and elevations from 1750 m ASL at the mouth of Lake Nakuru to 3000m above sea level at Entiyani, Narok County. Njoro River, which flows into Lake Nakuru, drains the catchment. The average yearly rainfall is between 840 and 1250 mm. The average monthly rainfall ranges from about 30 mm to more than 120 mm, with peaks in April, May, August, and November were the wettest months, while January and February were the driest.

The average monthly minimum and maximum temperatures range from 5^0 to 28^0 C from 1987 to 2016, meteorological data from the Egerton weather station (ID: 9035092) reported that the mean annual rainfall was 1073 mm and the average air temperature was 21 ^{0}C. The average rate of Pan Evaporation was 3.9 mm / day.

Njoro River (Figure 4.1 A) is a second-order stream emanating from the Eastern Mau hills (S 00°34.588´; E 035° 54.684´; altitude, 2887 m. ASL) (Mbaka *et al.,* 2018). The river's largest tributary, Little Shuru, which joins it at 2,293 metres above sea level. The river flows for around 55 kilometres before discharging into Lake Nakuru (at 1,750 m Above Sea Level) (M’Erimba *et al.,* 2014), an internationally recognized Ramsar site. The river traverses agricultural areas and built-up areas (M’Erimba *et al.,* 2014). The river is laid out in a conventional riffle-pool pattern (Shivoga *et al.,* 2007). Pools are appealing for anthropogenic activity because they are large, with a moderately depth, and conveniently accessed, resulting in high levels of disruption. Disturbed pools feature deteriorated stream banks with little or no vegetation cover because the riparian vegetation has been substantially altered to enable access to the stream for animal watering and water abstraction for residential use (Yillia *et al.,* 2008). In the Njoro River, the riparian vegetation is composed of two primary vegetation types: montane: *Juniperus procera, Olea europaea ssp. Africana* and sub-montane: *Acacia abyssinica forest* (M'Erimba *et al.,* 2014). Canopy cover over this hydro system ranges from 0% to about 80% (Shivoga *et al.,* 2007).

Kamweti River catchment, covers an area of 48.33 km^2. It is positioned at a latitude 0º 20´S to 0º 22´ S and longitude 30º 25´E to 37 ° 30´E (Kaberia, 2007). Kamweti River catchment is on the southern slopes of Mount Kenya National Park in a well-preserved landscape consisting of rocky afro-montane forests at higher elevations and highly diverse riverine forests in the valleys. The weather in the region is cool and humid, with temperatures ranging from 16.6°C – 20.1°C on average. The rainfall pattern is bimodal with two peaks, one from March to May (long rains) and the other from October to December (short rains) (Kaberia, 2007) with the annual rainfall ranging from 800 to 2150 mm (Ali, 2021). Soils in the region are dark grey to reddish brown, formed from schistose rock, and the area is of volcanic origin. Soils in some locations are reddish and have a smeary consistency. Brown loamy soils retain an amount of moisture and contain a significant amount of organic material (5 to 20%). These soils are productive, well-drained, and well-structured (Kaberia, 2007).

The Kamweti River, which runs for about 24 kilometres, is the principal feeder of the Thiba River and drains into the Tana River. It is a fast flowing permanent river which supplies water to various parts of the region and serves as the main source of water for irrigation (Kaberia, 2007). Kamweti River traverses through a tropical rain forest therefore the upper reaches were located inside a protected forest with dense canopies of indigenous vegetation. Downstream Kamweti River, The land has been cleared in preparation for cultivation and settlement. The Nyayo Tea Zone (Kenya tea zone and forest protection) serves as a barrier between the rainforest and the agricultural farmers (Kaberia, 2007).

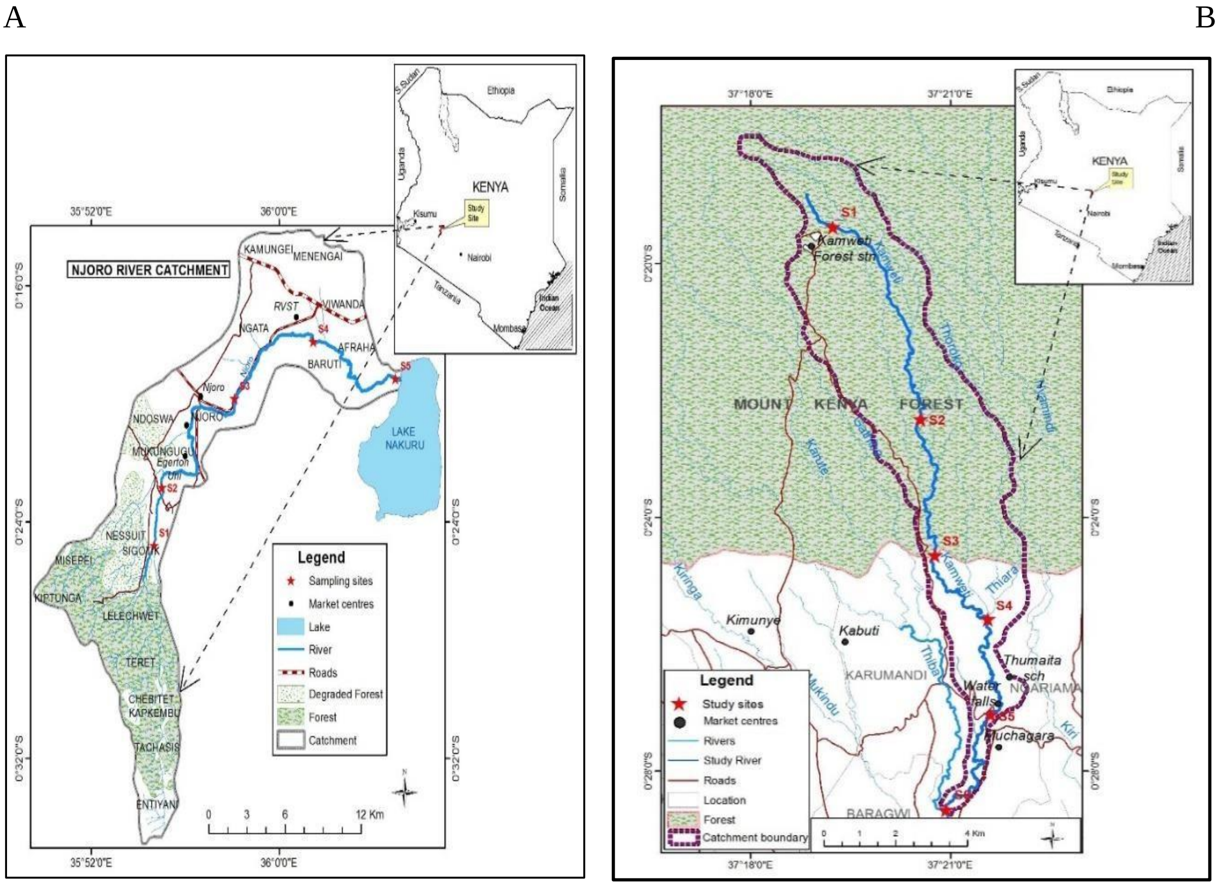


Figure 4- 1: Maps of the study areas and the sampling sites. A: Njoro River Catchment. B: Map of the Kamweti River Catchment: (Map of Kenya inset).

4.2.2 Description of sampling sites

Amongst the principal land use, five sampling stations were chosen from each river (Figure 4.-1). In the Njoro River, they were coded as N1, to N5 whilst in the Kamweti River the coding was K1 to K5. In the Njoro River a total of five sites were chosen, where one site was located in the forest dominated area, two sites in the agricultural areas and two in the built up areas. In Kamweti River, two sites were selected in the forest areas, two in the agricultural area and one in the built-up areas for the collection of vegetation data.

4.2.2.1 Njoro River study sites

Site N1, (Plate 4-1) positioned at a latitude of 00^0 26'52"S and at a longitude of 35^0 54'14"E, upstream the Njoro River Catchment at 2,281m ASL. The river was 4.63 ± 0.20 m wide, and 2.22 m deep. Vegetation was of indigenous type forming a canopy cover of 60%. This site had more stable banks as compared to the other sites, the riparian vegetation were also protected and riparian vegetation zone width were also high. Epifaunal substrate was optimal, and with minimum levels of embeddedness. Minimal substrate constituted of boulders (55%), cobbles (25%), and sand and gravel (20%) was exposed as water covered the lower parts of both banks. Visible in these site was small scale agricultural farms were observed around the area. Settlements were present though the area was sparsely populated. Livestock rearing were also identified to be present upstream. Riparian vegetation was still intact, since the site was not frequently visited by people and domestic animals. Habitat score was 83% at the time of sampling (Table 4-1) implying a slight modification from the natural conditions (Kleynhans, 1996).

Plate 4- 1: Site N1, Forest Dominated, up-stream Njoro River.

Site N2 (Plate 4-2) was located at a latitude of 00^0 22'30"S and longitude of 35^0 56'03"E at the midstream section of the river near settlements. The site had around 50% canopy cover from indigenous riparian plants. The substrate consisted of boulders (20%)

cobbles (25%) as well as sand and gravel which dominated the streambed (55%). The left bank was more stable than the right bank, yet there were evidence of erosion. There was a minimal epifaunal layer and a modest amount of embeddedness. Water reaches both bottom banks, exposing only a little quantity of substrate. There were no traces of channel alteration, the stream flow was normal with relatively few riffles. The site was frequently visited by people and the activities noted included water abstraction, linen washing and wood fuel harvesting. The habitat quality score obtained for the site was 68%.

Plate 4- 2: Site N2 at the Agricultural area, Mid-stream Njoro River.

Site N3 (Plate 4-3) was located at latitude 00^{0} 20' 04" S and a longitude 35^{0} 56' 31"E at 2,146 m ASL, midstream the river near settlements. It was observed that the streambed was dominated by sand and gravel (94%), cobbles (5%), and boulders (1%). The site had the least stable banks, eroded banks and high scores for sedimentation. Epifaunal substrate was marginal and a low level of embeddedness was observed. Water levels did not reach the banks and substrate was exposed. The stream's pattern was normal, with a moderate frequency of riffles. The site was frequently visited by people and the activities noted included water abstraction, linen washing and wood fuel harvesting. The sites were located near several residential areas, school buildings and other institutions making the areas highly populated. The upper part of site N3 is a golf course. The habitat quality score recorded for the site at the time of sampling was 56%.

Plate 4- 3: Site N3, at the Built up area, Midstream Njoro River.

Site N4 (Plate 4-4) was located at latitude 00^0 17' 41" S and longitude of 36^0 00'05" E at an elevation of 2,032m ASL. At the period of data collection, the station scored least with regards to habitat quality (54%). The river was recorded to be 3.88 ± 0.44 m wide and 2.30 ± 0.02m deepIt had a 2% canopy cover. Along the banks, an exotic *Eucalyptus* species dominated the riparian vegetation. The streambed was dominated by sand and gravel (60%), cobbles (30%), and boulders (10%). Both banks were less stable, with significant sediment accumulation. The site also had the lowest scores for vegetative protection and riparian vegetation zone widths. The site was frequently visited by people for water abstraction and livestock watering especially during the dry seasons.

Plate 4- 4: Site N4, at the Agricultural areas, downstream Njoro River.

Site N5 (Plate 4-5) was located at latitude 00^0 17' 47 " S and longitude 36^0 01'22" E, at an elevation of 1,906 m ASL, which was downstream. Canopy cover in this site was approximately 30 % which was created by the exotic trees which were observed to be dominan in the area in the farms and along the banks of the river. The banks of the river at this site were observed to be less stable, and the riparian area showed signs of erosion and thus increased sedimentation. In terms of both banks were less stable, and signs of erosion were observed. The sites was located near several residential areas, making the area populated. The upper parts of site N5 was noted to have upcoming developments (hotel businesses) and residential areas.

Plate 4- 5: Site N5, at the Built up areas, Downstream Njoro River.

Further downstream, close to the site was populated close to the river channel with families living near the Njoro River. Table 4-1 shows the habitat characteristics and the geographical locations for the different sites along the Njoro River.

Table 4- 1: Geographical position and habitat characteristics in Njoro River.

Parameter	**N1**	**N2**	**N3**	**N4**	**N5**
Altitude	2, 281	2,240	2, 146	2, 032	1, 906
Latitude (S)	00^{0}26'52"	00^{0}22'30"	00^{0}20'04"	00^0 17'41"	00^0 17'47"
Longitude (E)	35^{0}54'14"	35^{0}56'02"	35^{0}56'31"	36^0 00'05"	36^0 01'47"
Width (m)	4.63 ± 0.20	4.25± 0.20	3.88 ± 0.15	3.88 ± 0.44	4.24 ± 0.6 m
Depth (m)	2.22 ± 0.01	2.11± 0.01	2.58 ± 0.03	2.30 ± 0.02	2.22 ± 0.01
Velocity (m/s)	0.04	0.07	0.03	0.03	0.03
Discharge (m^3/s)	2.11	3.60	2.58	2.59	2.58
Substrate					
% boulders	55	20	1	10	5
% cobbles	25	25	5	30	15
% sand and gravel	20	55	94	60	80
% canopy cover	60	50	10	<2	30
*HQA score	83	68	56	54	58

*HQA score_ Habitat Quality Assessment

4.2.2.2 Kamweti River study sites

Site K1 (Plate 4-6) was positioned at 0^{0}22'22" S and 37^0 20'30" E at 1,935 m ASL. The site was 3.46 m wide and depth of 0.28 m deep. The over head canopy was approximately 80%. The vegetation type in the site was mostly native. As assessed using the Kleynhans method, the site K1 scored the highest having the best habitat qualities 96%. This implied that the site was largely natural with few natural modifications. Both the banks were stable, the epifaunal substrate was optimal and the cobbles was the major substrate which was minimally exposed as water reached both sides of the banks. The flow of the system was normal with riffles. No anthropogenic activitieas were noted at the time of sampling.

Plate 4- 6: Site K1, in the forest, upstream Kamweti River.

Site K2 (Plate 4-7) was located at latitude $0^0$23'42"S and longitude of $37^0$20'23" E at 1,808 m ASL. The site had was 6.21 m wide and 2.71m deep, the site was also located upstream with no signs of human disturbances. The site had similar characteristics to those of the K1 the most upstream site and the similar vegetation types existed. The habitat quality value obtained from this site was 94%, which implied that the site was similar to site K1, the site was also largely natural with few modifications.

Plate 4- 7: Site K2, in the forest, upstream Kamweti River.

Site K3 (Plate 4-8) was located at latitude 0^0 24'45"S and longitude of 37^0 20'47" E at 1676m ASL. The rivers’ mean width and depth were 8.75± 0.6, and 4.46± 0.04, respectively. Cobbles dominated the streambed (60%), followed by sand and gravel substrates (36%) and lastly boulders which covered 4%. The site was adjacent to the tea plantations (“Nyayo Tea Zone”) which serves as a barrier between the forest and the farmers' fields. Human activities such as fishing, washing, livestock grazing and watering and bee keeping were identified to be present. Indigenous vegetation species were common the major species being syzygium. At the site, however the riparian vegetation was not intact. The stream was wide at this site with and the bed composition was bedrock with a pool, riffle, and run pattern with habitat quality scores of 35-40 %.

Plate 4- 8: Site K3, midstream at the agricultural area after the forest at the Nyayo Tea Zone.

Site K4 (Plate 4- 9) was located at latitude 0^0 27' 07" S and longitude 37^0 21' 35" E, at 1,559 m ASL. The site had a mean width of 3.75 ± 0.45 m, and was 5.21 ± 0.04 m deep. A waterfall was located nearby. The site scored the least (62%) with regards to habitat quality assessment at the period of sampling implying that the site was largely modified. The canopy cover less than 2 %. Exotic riparian vegetation was dominant along the banks. Sand and gravel (45%), cobbles (30%), and boulders (25%) was the subatrate. Sediment deposition was high at the site. The area had been cleared for small scale farming of maize, beans, vegetables and arrow roots which were planted to the banks of the river. Eucalyptus species and nappier grass were planted by the farmers. *Urtica diversifolia* was identified as the most common weed in tea plantations and maize fields. Site K4 had the mostly impacted riparian vegetation. Minimal rural settlement was in the vicinity.

Plate 4- 9: Site K4 located after the waterfall, closer to maize, bananas, and vegetable farms.

Site K5 (Plate 4-10) was located at latitude 0^{0}28'26" S and longitude 37^{0} 21' 01" E, at 1,524 m ASL close to Thiba River. Sediments deposits were lower as compared to site K4. The site was located near commercial and residential areas. Mixed farming was also identified to be close to the site. Exotic tree species such as *Eucalyptus globus* was introduced by the farmers in the area. The site was close to the road. Rural settlement was in the vicinity. The habitat quality score for the site K5 was 65% at the time of sampling.

Plate 4- 10: Site K5, downstream with farming activities and settlements nearby.

Table 4-2 shows the positions and attributes of the habitats across the selected sampling sites in Kamweti River from upstream (K1) to downstream (K5).

Table 4- 2: Geographical position and habitat characteristics in Kamweti River.

Parameter	**K1**	**K2**	**K3**	**K4**	**K5**
Altitude	1, 935	1, 808	1, 676	1, 559	1, 524
Latitude (S)	0^0 22' 22"	$0^0$23'42"	$0^0$24'45"	0^0 27'07"	$0^0$28'26"
Longitude (E)	37^0 20'30"	$37^0$20'23"	$37^0$20'47"	$37^0$21'35"	$37^0$21'01"
Width (m)	3.46 ± 0.30	6.21± 0.52	8.75± 0.6	3.75±0.45	4.13 ± 0.40
Depth (m)	0.28 ± 0.12	2.71 ± 0.01	4.46±0.04	5.21± 0.04	4.18 ± 0.04
Velocity (m/s)	0.25	0.24	0.08	0.03	0.04
Discharge (m3/s)	3.75	3.57	4.45	5.21	4.17
<u>Substrate coverage</u>					
% boulders% cobbles	3	2	4	25	45
% sand and gravel	77	80	60	30	50
	20	18	36	45	30
% canopy cover	80	80	35-40%	<2	20
*HQA score	96	94	86	62	65

*HQA score_ Habitat Quality Assessment score

4.2.3 Site characterization

The Njoro and Kamweti Rivers' habitat integrity condition was assessed using methodologies published by Kleynhans (1996) and Barbour *et al.* (1999). The substrate composition was determined and classified following Mbaka and Schäfer, (2016) as boulders, cobbles, sand and silt. Overhead canopy cover and embeddednes were also both visually assessed and categorised as stated by Gordon *et al.* (2004).

During sampling, river width, depth, velocity, discharge, and selected physico-chemical characteristics were assessed at each of the selected sites. A measuring tape was used to measure the width of the stream on four transects at 5 m intervals along the reach. To determine the depth of the river at the sites, a 1-m ruler was which was done along each transect, as Masese et al. 2014 described. A flow metre, model 0012/B was used to determine the velocity at approximately 60% stream depth, as illustrated in Plate 4-11. The rates of discharge was determine following Gordon *et al.* (2014) where the data on velocity, width and depth was used.

Plate 4- 11: Measurement of discharge in the Kamweti River.

4.2.4 Study design and sampling design

Multiple strategies were used in this work to identify sampling locations along the Njoro and Kamweti Rivers. The study first relied on basin delineation to determine the hydrological parameters of the Njoro and Kamweti River catchments. For the research areas, image classification produced LULC maps. The primary land use types traversed by the two rivers were identified from the maps as forest dominated sites (FDS), agricultural Dominated sites (ADS), and Built-up Areas (BUA). The FDS represented the least disturbed locations, whereas the others represented the sites that experienced disturbance. The ecological survey study design was utilised, and the sampling sites were chosen using by purposive systematic random sampling strategy guided by the land use classes along the river.

4.2.5 Data Collection

A preliminary survey was first carried out in the Njoro and Kamweti Rivers to determine the varied flora groups alongside the distinct land use patterns. The plant survey was conducted after the wet season when most herbaceous species were apparent following Mligo *et al.* (2017). Along each river, sampling sites in the forest, agricultural and built-up areas were selected for the purpose of this study based on the adjacent land uses. Three 70-m-long quadrats parallel to the riverbank were formed for every station. The three blocks were formed in a in a methodical manner, spaced by a 5-m interval along either quadrant. If portions of quadrats contained agricultural crops, fewer sample stations were established. A 1010 m plot was utilised for tree sampling, and a 52 m plot was employed for shrub sample, each of which were stacked in the 10×10 m plot area. The grasses and herbs were examined in smaller plot areas of 2×0.5 m all of which were evenly stacked within the larger plot areas of 10×10 m. In the 10×10 m plot areas, all plant life forms examined in the subplots were pooled to generate a composite sample. As riparian vegetation cover exists as a narrow vegetation structure edge along a stream channel that could also sporadically extend via alluvial plains, the area of these plots were then defined for optimum collection of data in riparian plant communities. The plants communities found in these locations were subsequently identified and their populations approximated (abundance). The plants were also classified to the species level, and for those that were difficult to identify in the field, specimens were gathered in a temporary herbarium at Egerton University for later identification. The herbarium specimen were identified where possible, following Dale and Greenway (1961) and Dharani (2000). Stream and forest canopy cover was estimated as a percentage.

4.2.6 Data analysis

Data obtained from the selected sites of the Njoro and Kamweti River riparian areas were analyzed for indices which included species richness, abundance, diversity and dominance using PAST software by Hammer *et al.* (2001). One way Analysis of Variance was performed to identify whether any significant spatial differences in species abundance existed amongst sampling sites and land use categories. The T-test was also performed to identify whether any significant variations in vegetation abundance existed between the rivers studied.

Sorensen’s Index of Similarity was also computed to express the degree of similarity between communities between the different sampling sites and the different land use categories as described by Sorensen (1948) using the formula:

$$\text{Similarity Index} = 2Z/X + Y$$

Where X denotes the amount of species in one community, Y represents the number of species in the other community, and Z represents the species shared by both (Sunil, 2010). Sorenson's Index of Similarity expresses the similarity across communities and ranges from 0 to 1. The more similar the communities are, the closer the value is to 1. Complete community overlap equals 1; complete community dissimilarity equals 0.

4.3 Results

4.3.1 Distribution of plant communities across sites and land use

Along the rivers studied, the dominant plant species were determined and their distribution across the different sites. It was observed that plant species from the Asteraceae, Fabaceae, Poaceae, Malvaceae and Lamiaceae families were identified across all sampling locations of the Njoro River. Asteraceae family was dominant in the Kamweti River being present in all the sites whereas Fabaceae, Poaceae, Malvaceae and Lamiaceae families were encountered in sites K1, K2, K3 and K5 and absent in K4. The families which were found in all sites along the Njoro River include Acanthaceae and Rubiaceae as Salicaceae and Hypericaceae communities being limited to the downstream sections. Celastraceae and Cupressaceae were observed present upstream and midstream, whereas Phyllanthaceae was present at sites N1, N2 and N4. Those which were only present in the Kamweti River included Podocarpaceae, which was observed to be present in sites K2 and K3 only. Euphorbiaceae, Balsaminaceae, Gentianaceae were observed to be present in all sites except at K4. Plant species from the Meliaceae and Rosaceae communities were not observed to be limited to the downstream at site, K5. Table 4-3 presents 70% of the observed dominant plant families, indicating the presence (+) /absence (-) along the different sites Njoro and Kamweti Rivers.

Table 4- 3: Plant community distribution at different sites of the Rivers.

Vegetation communities	**NJORO RIVER SITES**					**KAMWETI RIVER SITES**				
	N1	**N2**	**N3**	**N4**	**N5**	**K1**	**K2**	**K3**	**K4**	**K5**
Asteraceae	+	+	+	+	+	+	+	+	+	+
Fabaceae	+	+	+	+	+	+	+	+	-	+
Poaceae	+	+	+	+	+	+	+	+	-	+
Malvaceae	+	+	+	+	+	+	+	+	-	+
Lamiaceae	+	+	+	+	+	+	+	+	-	+
Podocarpaceae	-	-	-	-	-	-	+	+	-	-
Myrtaceae	+	+	+	-	+	-	-	+	+	+
Solanaceae	+	+	+	-	+	-	-	+	+	+
Amaranthaceae	+	+	+	+	+	+	+	-	+	+

Polygonaceae	+	+	-	+	-	+	+	-	+	+
Convolvulaceae	+	+	-	+	-	-	-	+	+	+
Acanthaceae	+	+	+	+	+	-	-	-	-	-
Cyperaceae	+	+	-	+	+	+	-	+	+	
Euphorbiaceae	-	-	-	-	-	+	+	+	-	+
Balsaminaceae	-	-	-	-	-	+	+	+	-	+
Gentianaceae	-	-	-	-	-	+	+	+	-	-
Meliaceae	-	-	-	-	-	+	+	+	+	-
Rubiaceae	+	+	+	+	+	-	-	-	-	-
Rosaceae	-	-	-	-	-	+	+	+	+	-
Salicaceae	-	-	-	+	+	-	-	-	-	-
Celastraceae	+	+	+	-	-	-	-	-	-	-
Cupressaceae	+	+	-	-	-	-	-	-	-	-
Hypericaceae	-	-	+	+	+	-	-	-	-	-
Phyllanthaceae	+	+	-	+	-	-	-	-	-	-

Note : (+) denotes presence and (-) denotes absence.

The dominant vegetation species in Njoro and Kamweti Rivers riparian zones across the land use categories identified are displayed in Table 4.3. The Asteraceae family was dominant. The herbs dominant from this family in the Njoro River include *Ageratum conyzoides*, *Bidens pilosa* and *Conyza floribunda*. From the same family, herbs such as *Bidens pilosa* and *Senecio vulgaris* and Shrubs such as *Vernonia lasiopus, Tarchonanthus camphoratus* and *Gutenbergia cordifolia* were identified to be common in the Kamweti River.

The Fabacea family was present along the Njoro and Kamweti Rivers as shown in Table 4-3. In Njoro River, the vegetation type common from the Fabacea family were mostly the *Acacia abyssinica*, *Acacia xanthophloea*, *Acacia mearnsii*, and *Acrocarpus sp*. Which were mainly the trees. In the Kamweti River, shrubs such as *Crotalaria agatiflora* and trees such as *Tipuana tipu* were common. Poacea family (grasses) was common in both riparian areas in which *Cynodon dactylon* and *Pennisetum Clandestinum* were common in Njoro River and *Pennisetum clandestinum* and *Leersia hexandra* in the Kamweti River. Malvacea family was represented by trees and shrubs such as *Dombeya torrida*, *Hibiscus diversifolius* and *Hibiscus rosa-sinensis* in the Njoro River whereas in Kamweti River, trees species such as *Dombeya torrida* and *Cola greenwayi var keniensis* and herbs such as *Urena lobata* were identified from the Malvacea family.

Table 4- 4: Plant community distribution at different land use categories.

Vegetation communities	**NJORO RIVER**			**KAMWETI RIVER**		
	FDS	**ADS**	**BUA**	**FDS**	**ADS**	**BUA**
Asteraceae	+	+	+	+	+	+
Fabaceae	+	+	+	+	+	+
Poaceae	+	+	+	+	+	+
Malvacea	+	+	+	+	+	+
Lamiaceae	+	+	+	+	+	+
Euphorbiaceae	+	+	+	+	+	+
Cupressaceae	+	+	-	+	-	-
Polygonaceae	+	+	+	+	+	+
Amaranthaceae	+	+	+	+	+	+
Solanaceae	+	+	+	+	+	+
Balsaminaceae	-	-	-	+	+	+
Meliaceae	-	-	-	+	+	-
Myrtaceae	+	+	+	-	+	+
Acanthaceae	+	+	+	-	-	-
Rubiaceae	+	+	+	-	-	-
Apiaceae	-	-	-	+	+	+
Rosaceae	-	-	-	+	+	-
Oleaceae	+	+	+	-	-	-
Verbenaceae	+	+	-	-	-	-
Zingiberaceae	+	+	+	+	+	+
Commelinaceae	-	-	-	+	+	-
Convolvulaceae	+	+	+	+	+	+
Thelypteridaceae	-	-	-	+	+	+
Hypericaceae	+	+	+	-	-	-
Rutaceae	+	+	-	-	-	-
Apocynaceae	-	-	-	+	+	-
Anacardiaceae	+	+	-	-	-	-

Basellaceae	+	+	+	-	-	-

Note: (+) indicates the presence and (-) absence.

Euphorbiaceae was represented by tree species such as *Croton megalocarpus* and *Ricinus communis* in the Njoro River and *Neoboutonia macrocalyx* and *Macaranga capensis* in the Kamweti River which were common. Shrub species such as *Plectranthus spp* and herbs species such as *Leonotis nepetifolia, Leucas martinicensis,* were common in the Njoro River from the Lamiacea family whereas in Kamweti River, shrubs species such as *Clerodendron johnstonii* and *Plectranthus spp* and herbs such as *Leonotis mollissima* were common. Vegetation types which were unique identified in the Njoro River were from the families of Acanthaceae, Rubiaceae, Oleaceae, Hypericaceae, Verbenaceae, Rutaceae, Anacardiaceae, and Basellaceae whereas vegetation types unique to the Kamweti River were from the Balsaminaceae, Meliaceae, Apiaceae, Rosaceae, Commelinaceae, Thelypteridaceae, and Apocynaceae families.

4.3.2 Riparian vegetation structure and composition along the rivers

The riparian vegetation community in Njoro River Site N1, which was the most upstream site was dominated by trees followed by herbs. The common type of land use activity in this site was crop cultivation and forest cover. The site was dominated mostly by tree species such as *Juniperus procera,* and *Dombeya goetzenii* which had an open canopy and shrubs species such as *Rubus steudneri* and *Rumex orthoneurus* were also noted to be dominant. Herbs such *Ipomoea spp.* and *Bidens pilosa* were present. Mid-stream Site N2, is an agricultural area, and dominated by tree and shrub species. The number of herbs were slightly lower than the shrubs. Some of the tree species identified included, *Syzygium cordatum, Syzygium guineense* and *Dombeya torrida* while the common shrub species included *Hibiscus fuscus* and *Indigofera arrecta.*

Site N3, is a built up area with agricultural lands. Dominant were herbs mostly from the Asteraceae family such as *Galinsoga parviflora* followed by trees and the common tree species were from the Fabaceae family. Grass and lianas were also present which were represented as single individuals. At site N4, the percent cover site was 0%. Dominant in this area was herbs such as *G. parviflora, Vernonia newii,* and *Ageratum conyzoides* and a belt of shrubs such as *Lantana trifolia,* and *Hypericum revolutum.* Grass species from the Poaceae family such as *Pennisetum clandestinum* and *Cynodon dactylon* were present and a few tree species. Site N5, also had almost similar species to N4, dominated by tree species such as *Albizia gummifera, Girardinia diversifolia, Acacia xanthophloea,* and *Acacia abyssinica* and a species of shrubs which formed a dense vegetation. Herbs such as *Achyranthes aspera* were also noted in N5 and few species of grasses and lianas as presented in Figure 4.2.

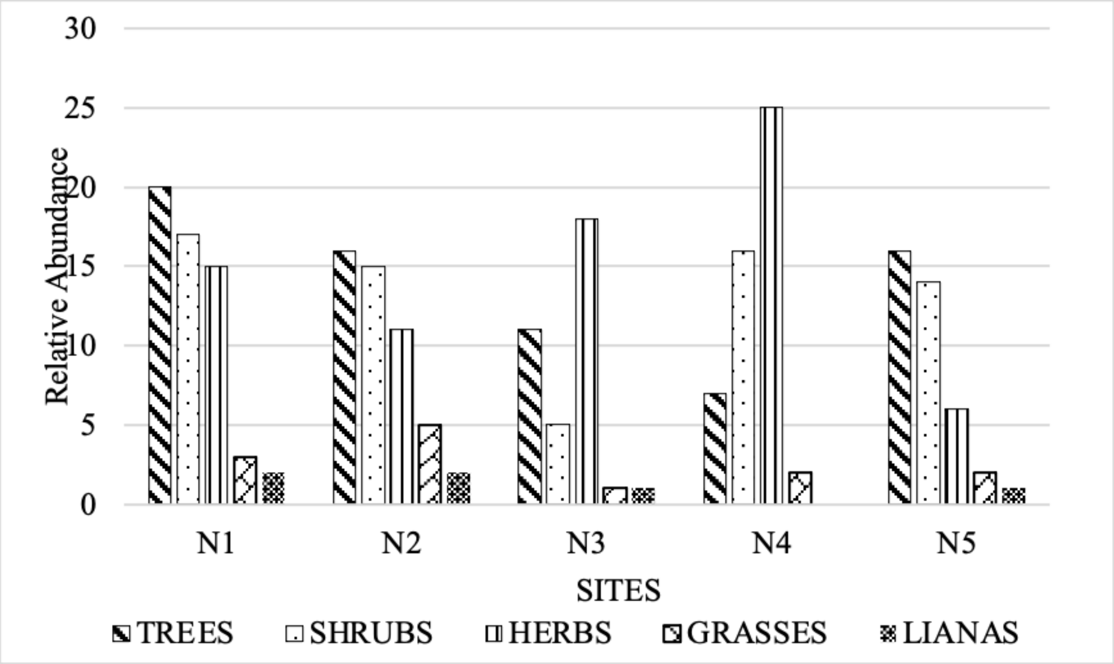


Figure 4- 2: Longitudinal riparian vegetation structure at different sites along the Njoro River.

Overall species indices computed using PAST software differed between the two rivers. Table 4.4 displays the various computed indices at the sites of the Njoro River where Taxa richness and Margalef's Index portrayed similar trends across sites, each revealing higher values in sites N1, and N2, the lowest values being observed at site N4 (Taxon richness (S) N1 (30), N2 (30) and N4 (19); Margalef Index N1 (7.11), N2 (7.38) and N4 (4.82)). Shannon Diversity, Simpson index and Pielou's evenness index (j), maintained a similar trend where Shannon Diversity Index and Simpson richness index (1-D) values were the highest at sites N1 and N2 and also the least at site N4. Fisher-alpha Index also indicated that site N2 was the most rich (40.35) followed by N2 (30.56). Dominance index (D) displayed varying trends where site N4 recorded the highest values (0.08) followed by site N5 recording 0.07. Similarly, Berger-parker Index also showed Site N4 as most dominant (0.19), followed by N5 (0.18) as shown in Table 4.5.

Table 4- 5: Vegetation community diversity indices at different sites in the Njoro River.

SITES / **INDICES**	**N1**	**N2**	**N3**	**N4**	**N5**
Taxa_S	30	30	23	19	26
Dominance_D	0.05	0.05	0.06	0.08	0.07
Simpson_1-D	0.95	0.95	0.94	0.92	0.93
Shannon_H’	3.23	3.23	2.98	2.71	2.97
Margalef	7.11	7.38	6.41	4.82	6.57
Equitability_J	0.95	0.95	0.95	0.92	0.91
Fisher_alpha	24.42	30.56	40.35	13.37	25.68
Berger-Parker	0.12	0.10	0.16	0.19	0.18

Vegetation structure and composition showed variations also across the land use gradient presented in Figure 4-3. In the forested areas along the Njoro River, shrubs were dominant. The shrubs displayed a slightly higher value than that of the trees encountered. The herbs were present and their abundance was higher than that of the grasses and the lianas. The Shannon index was the highest in the forested area in comparison to the other land use categories (H’=3.08). At the ADS, the abundance of trees, shrubs, grasses and vines was observed to decrease. Herbs were dominant in the area. The ADS had the lowest Shannon Weiner diversity index (H’=2.73). At the BUA, the trees were observed to increase as the shrubs, grasses and vines showed a further decreased in abundance at the lower reaches. Just like the ADS, the herbs were also dominant in the BUA. Shannon index was slightly higher than the one obtained at the ADS (H’=3.05).

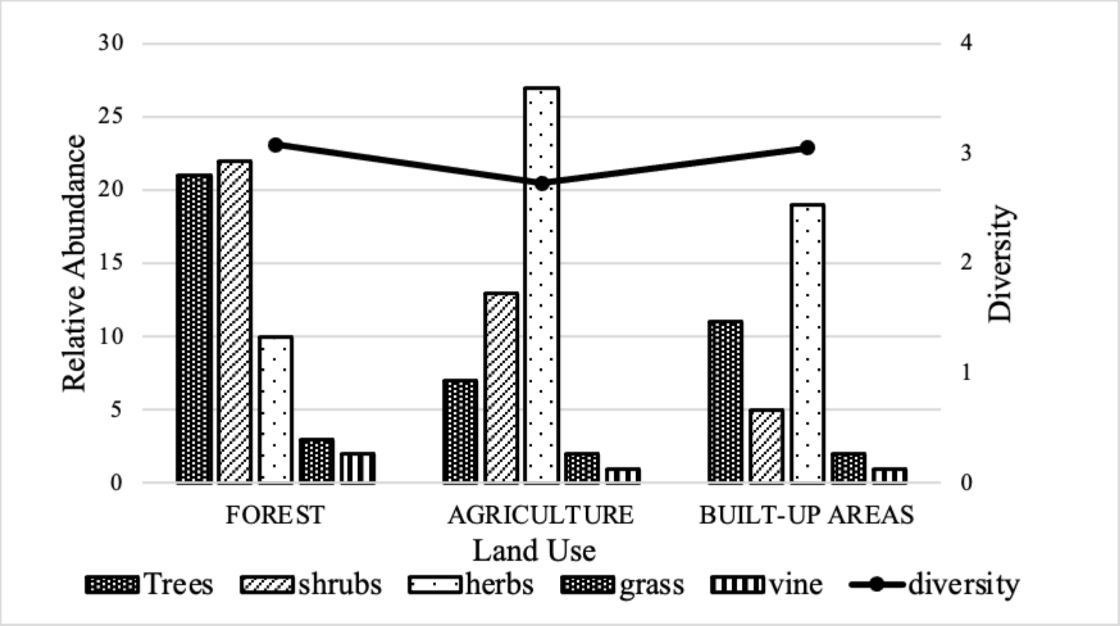


Figure 4- 3: Riparian vegetation structure and diversity across different land use gradients in the Njoro River.

Sites K1 and K2, were located in a forested landscape of Kamweti River, both having 80% canopy cover. Both sites were dominated by herbs followed by shrubs however the tree species count in K2 was higher than in K1. The herbs which were common in both sites were from the Balsaminaceae family such as *Impatiens tinctoria,* Cyperaceae family such as *Cyperus immensus* and Asteraceae family such as the *Senecio montuosun.* In both sites, tree species which were common included *Neoboutonia macrocalyx* which is mostly present habitats with moist conditions. Also noted in these sites were few grass species from the Poaceae family and some lianas. Site 3 (K3), was dominated by trees followed by herbs with a canopy cover of 45%. Shrubs were also present with few grass represented. Most of the tree species identified in this site were from the Euphorbiaceae family such as *Croton species, Macaranga capensis* and *Neoboutonia macrocalyx* Herbs in this site were mostly from the Asteraceae family.

Site 4 (K4), is an agricultural area and the site was dominated by herbs and grass species. The site had 2% canopy cover with few trees noted while the shrubs and liana represented by single individuals. Most of the herb species were from the Asteracea family and the grass from the Poaceae family. Site 5 (K5) had 60% canopy cover and is a mixed land use region with farmland and built up areas. Some of the tree species identified were indigenous and exotic such as *Eucalypus globulus* and *Grevillea robusta* were present. Similar to K4, the site was dominated by invasive species and herbs such as *T. capensis,* *Lantana camara* and *Mimosa pigra*. The sites where the species was identified were severely impacted by siltation caused by farming and soil erosion.

Plant communities identified in K4 and K5 of the Kamweti River were nearly identical to those found in the middle and the lower segments of the Njoro River as a result of livestock grazing, built-up areas, and cultivation, resulting in differences in plant species composition from the forest landscape. Figure 4-4 shows how the riparian vegetation differed longitudinally along the sites of the river.

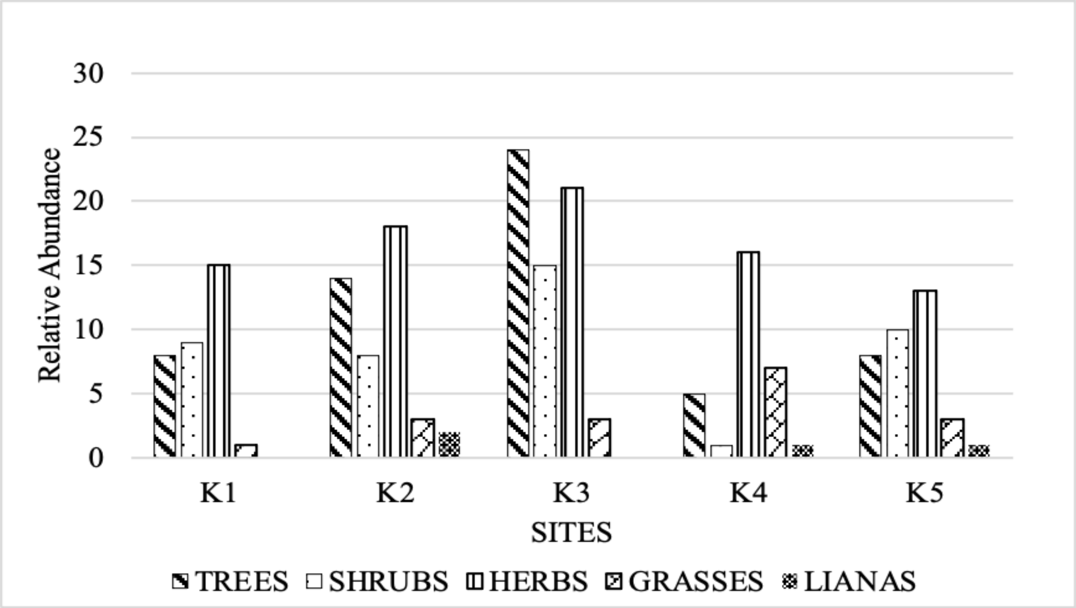


Figure 4- 4: Longitudinal riparian vegetation structure at different sites of the Kamweti River.

Kamweti River also displayed wide ranges in the indices computed as shown in Table 4-6. It was observed that taxa richness was the highest midstream (site K3) recording 31 followed by site K2 (29). However Margalef's Index was higher at K2 than K3 recording values of 7.44 and 6.97. Fisher-alpha Index indicated that the richest site was K1 followed by K2 with values of 60.12 and 39.08. Shannon Diversity Index showed variations in the downstream pattern where the highest reading was observed at site K2 recording values of 3.25 and the least at K4 (2.52). Evenness values also showed variations where values were observed to be the highest at sites K1 and the least at site K3. Dominance index (D) was highest at Site K4, (0.10) with Berger-parker Index maintaining K4 being the most dominant (0.21).

Table 4- 6: Vegetation community diversity indices at different sites in the Kamweti River.

SITES **INDECIES**	**K1**	**K2**	**K3**	**K4**	**K5**
Taxa_S	25	29	31	15	24
Dominance_D	0.05	0.04	0.07	0.10	0.06
Simpson_1-D	0.95	0.96	0.93	0.90	0.94
Shannon_ H’	3.15	3.25	3.04	2.52	3.04
Margalef	6.99	7.44	6.97	4.16	6.42
Equitability_J	0.98	0.97	0.89	0.93	0.96
Fisher_alpha	60.12	39.08	20.06	12.50	31.47
Berger-Parker	0.10	0.09	0.16	0.21	0.11

Riparian vegetation structure across the different land use categories in Kamweti River are presented in Figure 4.5. The forested landscape was dominated by herbs followed by trees. The herbs which were common were from the Balsaminaceae, Cyperaceae and Asteraceae families. The grass and vines species was observed to have a lowest abundance in comparison to the other land use categories and the dominant grass species being *P. purpureum,* which are mostly present habitats with moist conditions.

Similar to the forested area, the ADS was dominated by herbs from the Asteracea family followed by tree species. Most of the tree species identified in this site were from the Euphorbiaceae family. Shrubs were also present and the site also recorded the highest abundance of grass mostly represented from the Poaceae family. The relative abundance of trees and shrubs increased in the BUA. The Shrubs encountered had a recording which was slightly higher than that of the trees. The tree species present were indigenous and exotic (*Eucalyptus species* plantations). Similar to the agricultural area, invasive species of herbs were observed to be dominant and this site also had the highest abundance of vines. The forest habitats recorded a Shannon Index of (H’= 3.40) which was the highest, followed by the built up areas (H’=3.03) and lowest was in in the agricultural area (H’=2.59) as displayed in Figure 4.5.

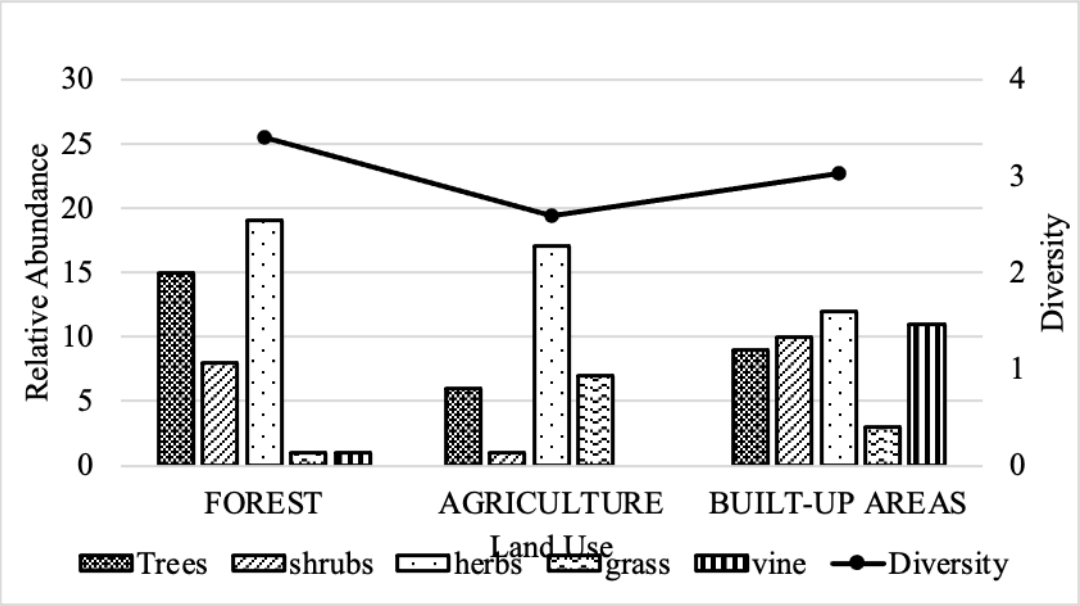


Figure 4- 5: Riparian vegetation structure and diversity across different land use in the Kamweti River.

With One way ANOVA, spatial variations in riparian plant species abundance amongst the sampling locations were not revealed to be significant statistically at the level of p ≤0.05 for the most dominant vegetation families in the Njoro River, which were Asteraceae (F=0.022; p=0.978), Fabaceae (F=0.2; p=0.833), Poaceae (F=1.88; p=0.347), Malvaceae (F=0.04; p=0.962) and Lamiaceae (F=1; p=0.5). For the Kamweti River, no significance differences amongst the sites were observed in the dominant families.

The dominant families not significantly different in terms of plant abundance amongst the different land use categories in Njoro River, with (Asteraceae (F=0.4; p=0.714), Fabaceae (F=0.2; p=0.833), Poaceae (F=1.88; p=0.347), Malvaceae (F=1; p=0.5) and Lamiaceae (F=1; p=0.5). In Kamweti River, statistically significant differences existed in terms of abundances of the dominant plant families with Asteraceae (F=2.195; p=0.235), Fabaceae (F=0.062; P=0.819), Poaceae (F=1.838; p=0.268), Malvaceae (F=0.014; p=0.913), and Lamiaceae (F=0.037; p=0.859). The findings appear to indicate that land use had little effect on vegetation abundance. Except for Malvaceae (t(8)=2.54, p=0.04), no significant variations in plant abundance were identified between rivers, as revealed by T-Test (Asteraceae t(8)=1.42, p=0.19; Fabaceae t(8)=1.57, p=0.16; Poaceae t(8)=0, p=1 and Lamiaceae t(8)=0.25, p=0.81).

4.3.3 Plant community similarities

Community similarities across the different sites of the Njoro and Kamweti Rivers are shown in Tables 4.7 A and B respectively. In the Njoro River (Table 4.7 A), Sorenson’s Index of Similarity, was in the range of 0.09 and 0.37. The highest similarity was found between the vegetation communities in the sites N1 and N2 (0.37) whereas the lowest was found between sites N4 and N5 (0.09). Sites K1 and K2 in the Kamweti River had the highest Sorenson's Index of Similarity (0.2), while sites K4 had the lowest values.

Table 4- 7: Sorenson’s Similarity Index at different sites in the Njoro (A) and Kamweti River (B) riparian areas

A

SITES	**N1**	**N2**	**N3**	**N4**	**N5**
N1	1				
N2	0.37	1			
N3	0.18	0.16	1		
N4	0.13	0.13	0.11	1	
N5	0.23	0.17	0.13	0.09	1

B

SITES	**K1**	**K2**	**K3**	**K4**	**K5**
K1	1				
K2	0.2	1			
K3	0.16	0.17	1		
K4	0.07	0.07	0.09	1	
K5	0.11	0.13	0.16	0.09	1

Community similarities across the different land use categories showed that the highest Sorenson’s Index of Similarity, in Kamweti River was found between the FDS and BUA (0.37) while the lowest was between the FDS and ADS (0.26). The index of similarity between the ADS and BUA was 0.30. In the Njoro River, Sorenson’s Index of Similarity, was in the range of 0.28 and 0.34 where the highest similarity was found between the vegetation communities in the FDS and the BUA (0.34) whereas the lowest was found between the FDS and ADS (0.28). The ADS and BUA had an index of 0.29.

4.4 Discussion

4.4.1 Riparian vegetation distribution

In the study areas, plant species from the Asteracea family was present categories of land utilization in the two river systems. *Bidens pilosa*, fast-growing herb from the Asteracea family had a widespread distribution across different land use categories within the study areas. Sankaran and Suresh (2013) documented that the herb behaves as a common weed of farming areas and areas of grazing livestock, but can also occur in undisturbed sites. *Bidens pilosa*, is a fast seed producer and they can easily be dispersed through the attachment to animals, birds, human clothes or by means of wind and water. It is a contaminant in crop seeds and agricultural products and it is also known as major weed in cultivated lands and forest margins (Sankaran & Suresh, 2013). *Ageratum conyzoides* which was also common from the Asteracea family is known to be invasive in parts of Kenya, Tanzania and Uganda (Witt *et al.,* 2018). The weed is also known to thrive in agricultural soils and is also very common in disturbed sites and degraded areas.

The Poacea family was also present in the riparian zones of the Njoro and Kamweti rivers represented by species such as *Cynodon dactylon,* a stoloniferous grass. According to Holm *et al.* (1977) the species is listed as a "serious" agricultural and ecological weed globally. The presence of the grass species in the study areas was attributed to its ability to grow fast and that it spreads by seeds and stolons and rapidly colonizes new areas and grows forming dense mats. Studies by Pandey and Singh (2020) highlighted that the species has the potential to alter ecosystem functions by altering fire regimes, hydrological cycles, biophysical dynamics, nutrients cycles, and community composition. The grass species is also exceptionally resistant to drought, with root system surviving water shortages dormancy for up to 7 months. It may easily re-sprout from rhizome and rooted runners after dormancy. The grass species also has the ability to recover swiftly after fire and can withstand significant flooding for at least many weeks (Pandey & Singh, 2020). Chen *et al.* (2015) also pointed out that roots of the *C. dactylon* community effectively enhanced the stability of riparian shallow soils and riverbank.

Pennisetum clandestinum was a common species of grass encountered in the study areas. It is known to be native to the highlands of Eastern Africa but it has been widely introduced elsewhere for forage and for soil conservation (Holm *et al.,* 1977). In well managed situations it does not generally spread very far but it is highly tolerant of grazing and mowing and can steadily invade poorly managed plantations resulting to loss of biodiversity. *L. hexandra,* a semi aquatic species found in a variety of moist, usually freshwater habitats (Miller & Sharitz. 2000) was common in the Kamweti River riparian zone.

Dombeya torrida, an under-storey timber tree of wetter highland forests of East Africa and Ethiopia from the Malvacea family was common in the study area with *Juniperus, Podocarpus* and *Olea capensis*. Studies show that the species grows in all regions in dry, moist and wet agroclimatic zones, of 1,600–3,400 m (Bekele-Tesemma & Tengnäs, 2007). *Ricinus communis* from the Euphobiacea family occurs as a shrub or small tree with a fast maturity rate and was common in the reaches of the Njoro River. *Ricinus communis* produces many hazardous seeds that are highly adaptable to many settings and has been widely dispersed by man. It has been found to be invasive in many areas, particularly in the tropics, and because dense thickets shade out native flora, it has the potential to negatively harm ecosystems. Studies by Buddenhagen *et al.* (2009) and Bridgemohan and Bridgemohan (2014) in the Weed risk assessments, pointed out that due to its high invasive nature, its use as bioenergy crop have been rejected in the in the USA and Caribbean. *Macaranga capensis* and *Neoboutonia macrocalyx,* a sub canopy constituent in evergreen forest, usually in wet areas and along stream banks was common in Kamweti River riparian zone. From the Lamiacea family, the *Plectranthus species* which occurs in a range of habitats was also present in the study sites across the different land uses. Lukhoba *et al.* (2006) reported that *Plectranthus species* occurs mostly in disturbed areas.

In the study, it was observed that vegetation communities which were found in the forest areas were in better conditions, and they had high percentage recordings of canopy cover. They were also characterized by higher quantities of leaf litter and organic matter as well as number of seedlings. Such variables, according to Corbacho *et al.* (2003) indicate a more natural condition and low anthropogenic pressure. To the contrary, it was noted in this study that ripaian zones which were adjacent to areas of agriculture, their conditions observed were moderate, which were attributed to disturbances such soil compaction caused by anthropogenic activities such livestock herding and farming activities and this was also affirmed by Valero *et al.* (2014). Mligo (2017) also pointed out that the hoof action and intensive animal stomping of soils on the banks of the rivers and nearby hill slopes causes siltation and sedimentation to descend to the low plains in the stream channel, leading to a deteriorated ecosystems inappropriate to sustain the emergence of riparian plants and aquatic macrophytes thus, reducing species richness and diversity.

The zones which were adjacent to built-up areas were heavily impacted. This affirmed the previous studies which showed that rapid urbanisation is one of the land use patterns that has the greatest severe effects on riparian zones (Burton & Samuelson, 2008; Pennington *et al.,* 2010; White & Greer, 2006). In this study, it was noted that, soil compaction was the main impact associated with the built-up areas in both study areas. This has been known to have an impact on surface water quality in river channels (Paul & Meyer, 2001) as well as the environmental integrity of riparian areas by modifying flood capability and habitat abundance (Pennington *et al.,* 2010). Studies by Booth and Bledsoe (2009) and Díaz-Pascacio *et al.* (2018) highlighted that paving and compaction increases the number of impermeable surfaces, which seem to be great predictors of the severity of the process of urbanization since they may hasten the deterioration of fluvial habitats.

4.4.2 Riparian vegetation composition and structure

Disturbance, whether natural or anthropogenic is an important agent as it influences the structure, composition, abundance and diverisities of plant communities in an ecosystem (Mligo, 2017). The site located upstream in the Njoro River was a forested area, dominated by shrubs and tree. The site was the least impacted by anthropogenic disturbances which included wood fuel harvesting and livestock grazing. Previous studies by Mathooko and Kariuki (2000) reported the upstream Njoro River which was the location of the sampling station was initially a dense native woodland with few shrubs. Anthropogenic disturbances experienced at this site could have resulted in the formation of different shrub, lianas and some herb communities (Morara *et al.*, 2003). In Kamweti River Forest habitat where sites K1 and K2 were located, herbs were dominant followed by the trees. Tree and shrub species which were common in both study areas were from the Fabaceae, Malvaceae and Euphorbiacea families. The presence of Fabaceae in the forest lands has also been noted as being the most species rich family in the majority of forest establishments (Egbe *et al.*, 2021). The high species abundance of these taxa found in the research areas could be related to their excellent seed dispersal processes, which allow them to invade different woodland sections, as well as the ability to generate many seeds that eventually be establish at favourable places (Egbe *et al.*, 2021).

Mligo (2017) on riparian structure and functions pointed out that the riverine vegetationperforms various functions such as buffering the loads of nutrients and sediments from agricultural runoff, make the river banks stable and increases the canopy cover thereby minimizing the rate of water loss through evaporation and also lowers the in-stream water temperatures. Similar observations were made in the forested areas of Njoro and Kamweti rivers riparian zones were minimally disturbed by human activities. Also noted was that the banks at these sites were stabilized and the ecosystem were cool and moist which supported the diverse plant species such as *N. macrocalyx*, *C. Denatus* and *P. Purpereum* which were present in these sites.

Herb species dominated the agricultural areas of Njoro Rivers riparian zones followed by the shrub species whereas as in the Kamweti Rivers riparian zone, herbs and vines were dominant with few tree species. Herbs' dominance over other growth patterns in the sampling sites could be attributed to their shorter life cycles, which allows them to withstand the ecosystem's unpredictability as explained by Al Robai *et al.* (2017). The riparian vegetation in the sites were found to be altered, with some areas having small patches tree cover or none, which has led to severe loss of original habitat. Due to intensive cultivation to the banks of the river, the sites appeared to be more disturbed as the process entails the clearance of the original vegetation and siltation. These impacts on the habitat negatively and eventually leads to a decrease in plant species diversity (Mligo, 2017).

Along with cultivation, the agricultural areas were heavily disturbed by unregulated cattle grazing and water abstraction for domestic use which has caused the left side of the bank bare, with 0% canopy cover. Studies by Roper and Saunders (2021) have shown that disturbance caused by livestock affects the riparian structure and community. Mathooko and Kariuki (2001) pointed out that livestock perturbation could boost the variability of mud flora by transferring seeds from remote locations and/or from the nearby vegetative cover. This has been observed along the Njoro River, where uncommon species were also identified, in addition to the introduction of various vines and herbs as a result of instability. The frequent and consistent livestock disruptions reported in the Njoro River might well have resulted in the formation of unusually tree sapling species observed along farming regions (Mathooko & Kariuki 2001).

The built up areas along the Njoro River riparian zone were dominated by herbs and trees. Kamweti River riparian zone was dominated by invasive species of herbs such as *T. capensis*, *L. camara*, and *M. pigra*, followed by tree species. Some of the tree species identified were indigenous, and exotic such as *E. globulus* and *G. robusta*. Built up areas are associated with many anthropogenic activities closers to the riverine vegetation which has resulted to the loss of ecological stability and edge effect which can be considered an ecological factor which affects riparian vegetation (Méndez-Toribio *et al.,* 2014). The effect that arise from the transition of the built up area and riparian vegetation is that the microclimate of the continuous habitat is affected in terms of ambient air temperatures, soil moisture levels, and photoperiod. These alterations can strain species past their physiologic tolerance levels, altering their ecological efficiency (survivability, development, or reproductive ability) and long-term viability in the environment (Méndez-Toribio *et al.*, 2014).

The small size of the patches of riparian vegetative cover left due to land use transformations the nucleus of the patch of vegetation shrinks leading to the absence of an interior habitat (Méndez-Toribio *et al.*, 2014). This was noted in the agricultural and built-up areas of Njoro and Kamweti River systems. The changes altered the riparian vegetation composition and structure which has reduced the habitat quality for the riparian vegetation species. A study by Cao and Natuhara (2019) also reported that urbanization affects riparian areas by increasing the impervious surface thereby affecting the infiltration rates.

The diversity values for the forest areas of Njoro and Kamweti Rivers riparian zone, were 3.08, and 3.40, respectively. The high species diversity in the Kamweti River riparian zone could be attributed to the protection status of the Mt. Kenya National park from human disturbances such as logging, livestock grazing and wood fuel harvesting. The undisturbed plant community structure in these sites may reflect the influence of the natural, physical and chemical environment of the plant communities present as described by Bullock *et al.* (1995). Tropical forests such as the Mt. Kenya forest, are usually characterized by high species richness and diversities (Kehlenbeck *et al.,* 2011; Kindt *et al.,* 2007). The high species diversities in these sites are an indication that the forest provides an optimal environment for plant growth (Fekadu, 2021) and reproduction due to the weather conditions which were witnessed during the sampling periods.

The diversity values recorded in agricultural and built-up areas of the Njoro River were 2.73 and 3.05 respectively whereas those of Kamweti River were 2.59 and 3.03 respectively. The higher values recorded at the built up areas was as a result of the disturbances that may have increased habitat heterogeneity which creating favourable conditions that brought about nurse effects to support varieties of plant species. In the agricultural areas, disturbances decreased the ability of the plant species to regrow spontaneously in anthropogenically disrupted environments. The riparian vegetation in the sites were found to be altered, with some areas having small patches tree cover or none, which has led to severe loss of original habitat. It was also noted that many plant communities which contributed to the high ecological parameters in these sites were mostly colonizers arising from different forms of disturbances (Mligo, 2017).

The Sorenson Similarity Index calculated for the plant communities from the two catchments did not display a closer linkage. The similarity index calculated between forest area and agricultural area was 0.28 for the Njoro River and 0.26 for the Kamweti River, indicating that the species encountered between the two sites were found to be dissimilar. Slightly higher values of similarity were recorded between the forest and built-up areas in both Njoro and Kamweti riparian zones. The local climatic conditions and the pressures fom the biotic factors on riverine areas and the vicinity may have contributed to this observed similarity between these zones as explained by Sunil (2010).

The forest areas of Njoro and Kamweti Rivers experienced intermediate disturbances both natural and human induced which contributed to high riparian plant species diversities at these sampling locations. Observations were also made in riparian plant species diversities across the different land use categories in both rivers studied can be explained based on the Intermediate Disturbance Hypothesis (IDH) theory that points that local species diversity is usually maximized when environmental perturbations are neither too rare nor too frequent. (Connell, 1978). From the results obtained from the study, the forest areas in both riparian zones registered higher species diversities which could be aligned to the theory. The agricultural and built up areas of Njoro River and Kamweti River were affected by the land use at higher levels which their ability to establish and thrive in areas receiving unique pressures from human actions as highlighted by Mligo (2007).

4.5 Conclusion and Recommendations

Forested habitats in both riparian areas studied provided conditions which contributed to the high abundance of trees and shrubs which decreased downstream. As the levels of disturbance increased at the midstream and downstream sections at the Agricultural Dominated Sites, the herbs became dominated. In the settlement areas both rivers, most trees species present downstream were exotic plantations. The vegetation community structures observed revealed that huge trees were few or absent in agricultural and built-up regions due to overexploitation, but were abundant in forested places, particularly the Kamweti River protected area. The diversity indices were high at the least impacted sites, the FDS, while the lowest values were encountered at the most disturbed sites the ADS. Similarly, Sorenson’s Index of Similarity values obtained was the highest in between the FDS and BUA while the lowest values were between the FDS and ADS.

This highlights the need of protecting and conserving natural habitats for plant biodiversity in the Njoro and Kamweti River ecosystems since many individuals could reach their maximal growth sizes in the natural habitat if human-induced disturbances are maintained to a minimum. In light of the findings, alterations to land-use management purposed for the maintenance of riverine habitats, as well as improved watershed management is necessary. This will reduce the impacts on riparian ecosystems since anthropogenic disturbance will be minimized. Agreements should be formed among the various stakeholders so that conservation efforts for the Njoro and Kamweti Rivers, and the local population should be involved because they are the ecosystem's local beneficiaries. The continual disruptions and degradation of riparian areas of Njoro and Kamweti River ecosystems will be greatly reduced as a result of such initiatives.

CHAPTER FIVE

IMPACTS OF LAND USE ON SELECTED PHYSICO-CHEMICAL PARAMETERS IN THE NJORO AND KAMWETI RIVERS

Abstract

Transformations in land utilization modifies the biophysical and hydrological functionalities in watershed areas, causing stream water quality to deteriorate. The higher sections of the Njoro River basin, have lately witnessed land use changes that have resulted in forest degradation, followed by human habitation and agricultural activity. These land use changes are a source of contaminants and nutrients, which induce changes in river and lake water quality. The objective was assess the influence of land utilization on physico-chemical characteristics water the Njoro River and the Kamweti River. The parameters selected included Temperature (Temp), pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Nitrite nitrogen (NO_2-N), Nitrate nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soluble Reactive Phosphates (SRP), Total Phosphorus (TP), and Total Nitrogen (TN). Temp., pH, DO, and EC were measured in site using a Hanna HI 9829 Multi-parameter meter and nutrient analysis were carried out in the laboratory following APHA protocols. Between the rivers, T-test at level of $p \leq 0.05$, revealed statistical significant difference parameters tested except for temperature *t* (1198) = -0.24; p=.81). Amongst the sampling sites, One way ANOVA at $p \leq 0.05$ revealed significant spatial differences in all the parameters measured except for EC (F=1.308; p=0.266) in the Njoro River and NO_3-N (F=1.00; p=0.41 in the Kamweti River. Amongst the different land uses, one way ANOVA at $p \leq 0.05$, indicated significant spatial differences in all the parameters measured except for DO (F=2.542; p=0.08) and EC (F=0.373; p=0.09) in Njoro River. In Kamweti River, significant spatial differences across land uses were also observed in all the water quality parameters with the exception of NO_3-N (F=0.749; p=0.473) and TN (F=2.47; p=0.08). The variations in parameters observed were attributed to the anthropogenic disturbances in the river catchment however the recordings were recommended guidelines, provided by the WHO, USEPA, and NEMA. Continuous monitoring of water quality and regulation of anthropogenic activities in rivers' catchment in order to enhance ecosystem services and human health is recommended.

5.1 Introduction

Water resources and the quality of those resources are viewed as important to human survival (Flint, 2004). Monitoring the status of water is crucial to determine a healthy ecosystem, a sanitary environment, and residential and other applications such as recreation, farming, extraction, as well as usage (Muriithi & Yu, 2015). As a result, precise and consistent water quality information is crucial for improved water management. Concerns have been expressed around the world regarding the worsening of surface water quality caused by increased human activity and changes in climatic conditions (Kayitesi *et al.*, 2022). Because anthropogenic activities are immediately reflected in land use features, a rise in the global human population has resulted in greater resource exploitation, which has compromised water quality. Water quality has been impacted by both point sources (manageable) and non-point sources contaminants from diverse land utilization patterns, particularly agriculture and fluvial streams (Umwali *et al.*, 2021).

Lotic systems of lower orders (mostly the first to third orders) are common in the riverine environment and they have a significant contribution to the overall efficiency, condition and diversity of the channel systems. Terrestrial inputs have a substantial influence on low-order streams, making them vulnerable ecosystems that can be severely impacted by land-use changes. Despite its relevance for the watershed, the correlation between land use transformations and the quality of surface water especially in river channels of lower orders is not well researched especially in the African tropics. Therefore it is vital to comprehend the dynamics in these river systems since they determine the accountable for the channel flow, organic material and the nutrients and the sediment loading rates downstream (de Mello *et al.*, 2018).

Water quality in aquatic settings is influenced by a variety of chemical, biological, and physical elements (Bell, 2007). As a result, assessing and quantifying a large number of variables is difficult, as is dealing with the high unpredictability generated by both human and natural forces. The quality of surface water as impacted Land Use Land Cover (LULC) has become an issue of concern as the human population grows. This has been indicated by the patterns of water quality in diverse places, Land use has a considerable impact on river water quality, according to comparative research, and the causes are complex (Ding *et al.*, 2015). Land surface characteristics (White & Greer, 2006), runoff volume (Tong & Chen, 2002), water temperature (Lee *et al.,* 2009) pollution, algal production, and dissolved oxygen concentrations in water bodies are all affected by deforestation, agricultural operations, and urbanisation. As a result, research on showing the link between LULC and water quality conducted by Chen *et al.* (2020), Clément *et al.* (2017), and Ding *et al*. (2015) concluded that a correlation between water quality indices and land utilization patterns at different catchment scales.

Globally, research that have been conducted illustrate the correlation between the transformation of land use pattern and the status of water quality (Allan, 2004). However, whether urban or agricultural land utilization has a bigger impact of surface water quality at a watershed scale remains unknown. According to Donohue *et al.* (2006) the main patterns that influenced the quality of water in Irish rivers were developed areas and pasture fields. Similarly, Lee *et al.* (2009) found that urbanisation, rather than agricultural land use, was a key contributor to the worsening of water quality in South Korea. To reduce agricultural non-point source contamination in Georgia's Upper Oconee watershed, Ding *et al.* 2015 proposed that agricultural impacts be prioritised in natural resource management.

Kenya has undertaken similar research, for example Kithiia *et al.* (1991) reported on the downstream rise in water contaminants and degradation of water quality for three rivers evaluated in Kenya's upper-Athi River basin. Similarly Muriithi and Yu (2015) highlighted that variations in water quality, was linked to the presence of heavy metal residues. These were attributed to the widespread application of phosphatic fertilisers and agrochemicals containing copper to the agricultural farms. Njue *et al.* (2016) also reported that variations in water quality parameters were connected with diverse land utilization patterns adjacent the stream channels. According to Raburu and Okeyo-Owuor (2006), agricultural activities were the key contributors’ changes in water quality. Anthropogenic activities have also been identified as contributing to the basin's high nutrient levels (Gichana *et al.,* 2015; M’Erimba, *et al.,* 2014). These contradictory conclusions are attributable, in part, to the distinct characteristics of each watershed.

Njoro and Kamweti Rivers are tropical rivers in Kenya's fast growing areas in terms of agriculture, urbanization and human settlements. For the past 20 years, the catchments have experienced significant transformations in land usage (Koskey *et al.,* 2021). Njoro River catchment, severe transformations in land occurred in the periods from 1987 - 2000, when human settlement increased by 52% (Mainuri, 2018). The Njoro River provides the catchments’ population with water for both domestic and commercial use, allowing for rapid socioeconomic development. It is also the principal water source for Lake Nakuru, a RAMSAR site (Yillia *et al.,* 2008). Concerns regarding the deterioration of water quality within the catchment have intensified in recently (Aera *et al.,* 2019; Huckett, 2010; Mokaya *et al.,* 2004; Shivoga *et al.,* 2005; Yillia *et al.,* 2008). The upper part of the watershed in the Eastern part of the Mau Forest has experienced the rapid degradation leading to loss in vegetation cove thus endangering the river's flow and environment (Jebiwott *et al.,* 2021; Koskey *et al.,* 2021).

Several research conducted to determine the link between land use patterns and the status of water quality in the Njoro River have been done (Enanga *et al.,* 2011; Mainuri & Owino, 2014; Shivoga *et al., 2005*; Shivoga *et al.,* 2007). However, information of the effects of the adjacent land uses and seasons is limited. Understanding variations of water quality parameters as influenced of land use is important and thus objective of this research sought to determine the influence that land use has on water quality in the Njoro and Kamweti Rivers catchments.

5.2 Materials and methods

5.2 1. Description of the study areas and sites

Chapter four contains a detailed explanation of the areas of study areas and the description of the selected sampling sites.

5.2.2 Research design

Chapter four explains the study and research design employed.

5.2.3 Collection of water samples

Based on the research objectives, the sampling locations on both rivers were carefully chosen to represent the key land use groups in the areas (see chapter 4 for detailed site description). The samples of water collected randomly from sampling stations in the Njoro and Kamweti Rivers in the forest, agricultural, and built-up areas. Between August 2018 and February 2020, four (4) sample cycles were carried out. Thirty (30) replicate samples of water were taken from the sampling stations on each sampling occassion. Thus 600 water samples from one river had been collected by the end of the study for analysis of water quality parameters (a total of 1200 samples from the two rivers (30 replicates*5 sites*4 sampling occasions in one river).

Water temperature, (Temp), pH, electrical conductivity (EC), and dissolved oxygen (DO) were measured *in situ* by use of a Hanna HI 9829 Multi-parameter metre. The probes of the metres were immersed at around a 5cm depth of water in different sections of the streams at the selected sites and the readings were recorded. All water measurement sections at all sampling sites were less than one metre deep. Readings for the water characteristics were recorded when the figures displayed by the multi-parameter metre appeared to be stable. Samples of water were also collected in sterile plastic bottles from each site and transported inside a refrigerated box to Egerton University's laboratory for analysis of nutrients. The levels of nutrients were determined in the laboratory according to APHA guidelines (APHA, 2005)

Nitrite Nitrogen (NO_2-N), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), and Soluble Reactive Phosphorus (SRP) were assessed in filtered water samples, whereas Total Phosphorus (TP) was determined in unfiltered water samples after persulfate digestion to SRP. Using the ascorbic acid technique, the levels of SRPin the water samples was determined as explained by Fekadu (2021) and the absorbance measured at 885 nm. NO_3-N was analysed using the salicylate technique, and the spectrophotometric absorbance was obtained at 420 nm. By analysing the pink colour produced due to chemical reaction of sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride, the concentration of NO_2-N was calculated. The reaction of sodium salicylate and hypochloride solutions was employed in determining the concentration of ammonium-nitrogen (NH_4-N), and the spectrophotometric absorbance of the green colour at 655 nm was measured. The measured absorbance values were used to compute concentrations using formulae derived from standard calibration curves for each nutrient examined.

5.2.3 Statistical analysis

For data analysis, SPSS package version 25 was used (IBM Corp 2010). The normality and homogeneity of the data obtained was determined using Kolmogorov-Smirnov and Levene's tests. Data that was not normally distributed was log-transformed. To test for any statistical significant differences between the water qualities parameters tested between the two rivers, students T-test was performed on pooled data. The one-way ANOVA was also used to indicate if any statistical significant differences existed amongst the sampling sites and amongst the land use categories. Descriptive statistics (mean± standard deviation/SD) were used to present the mean concentration values of the physico-chemical variables and nutrients. The ordination of sampling sites and the physico-chemical characteristics was performed using Principal Component Analysis (PCA).

5.3 Results

5.3.1 Water quality parameters in the Njoro and Kamweti Rivers

Selected physico-chemical parameters that are critical to public health and ecosystem health risk management were measured, and compared to existing water quality standards from various regulatory agencies.

From the results obtained, the Njoro River water temperatures ranged from 12.10 ^{0}C to 26.50 ^{0}C with a mean of 15.97±1.63 ^{0}C. In Kamweti River, the water temperatures recorded a slightly higher reading than the Njoro River with a mean value of 15.99±1.82 ^{0}C ranging from 13.3^{0}C to 19.9 ^{0}C (Figure 5.1, left). T-Test at the level of $p \leq 0.05$ revealed no statistically significant differences in water temperature between the rivers with *t* (1198) =-0.24, *p*= .81. The level of pH in the Njoro River was in the range of 4.71 to 8.41 and recorded a mean value of 6.56 ± 1.35. The dissolved oxygen values registered a mean of 7.76±0.80 Mg/L which ranged between 6.73 Mg/L and 9.04 Mg/L (Figure 5.1 right). The values obtained for pH and DO were observed in Kamweti River (Figure 5.2) were noted to be higher than those from the Njoro River (7.78±0.47 and 9.13±1.39 Mg/L respectively).

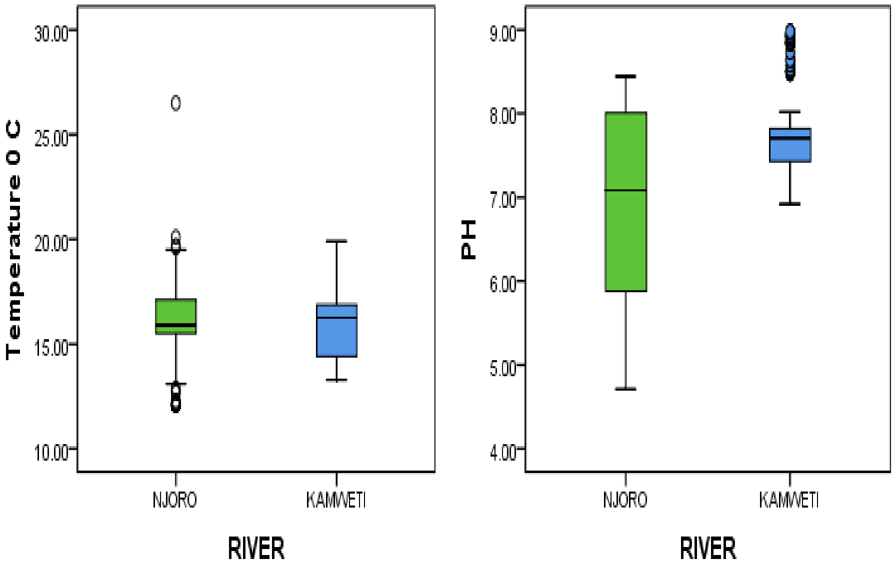


Figure 5- 1: Temperature (left) and pH (right) Box – and Whisker plots for the Njoro and Kamweti Rivers.

Electrical Conducting values (EC) obtained ranged from 64 µs/cm - 570 µs/cm, in Njoro River recording a mean value of 254.27 µs/cm whereas the EC values obtained from Kamweti River ranged between 20.98 µs/cm to 39.15 µs/cm recording a mean concentration of 28.93 ±5.46 µs/cm as shown in Figure 5.3 (right). T-Test analysis found statistically significant differences measurement of pH, DO, and EC between the two rivers with t (1198) = -19.51, p=.00); t (1198) = -31.73, p=.00) and t (1198) = -31.73, p=.00 respectively.

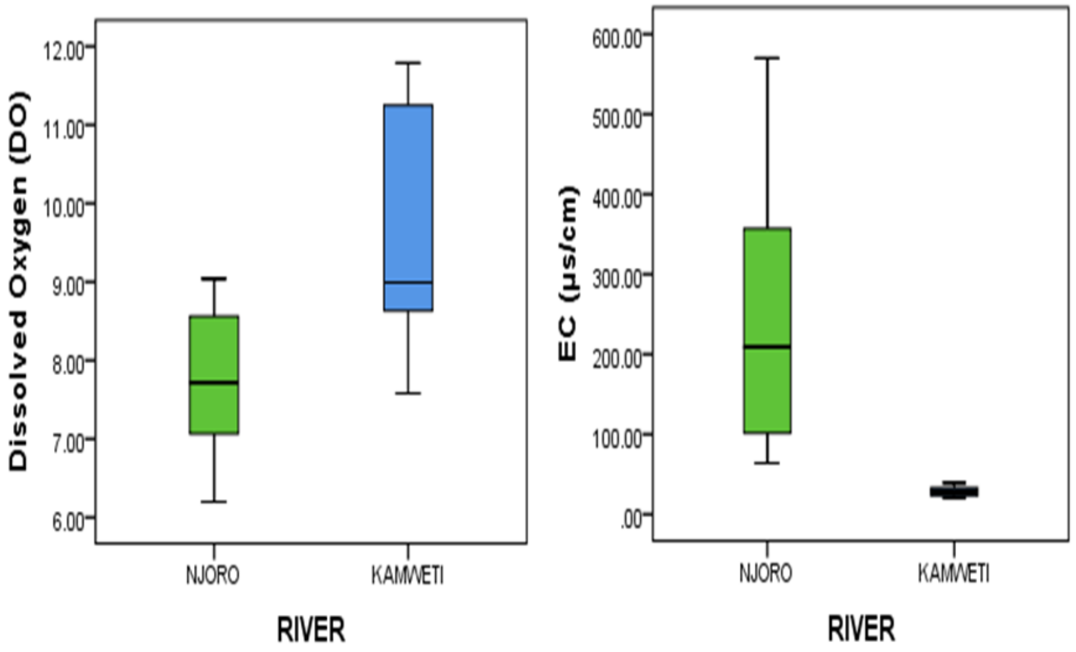


Figure 5- 2: Dissolved Oxygen (left) and Electrical conductivity (right) Box – and Whisker plots for the Njoro and Kamweti Rivers.

The mean concentration of Nitrite Nitrogen (NO_2-N) was 0.01± 0.01 Mg/L ranging from 0.00 Mg/L to 0.07 Mg/L. Nitrate nitrogen (NO_3-N) concentrations were detected in low concentrations (0.0006 Mg/L) whereas in Kamweti River, NO_2-N and NO_3-N were not detected. The Ammomium Nitrogen (NH_4-N) concentrations ranged from 0 Mg/L to 0.15 Mg/L recording a mean concentration of 0.33±0.02 Mg/L in the Njoro River while in Kamweti River, the concentrations of NH_4-N were also low, which ranged from 0.00 Mg/L – 0.06 Mg/L recording a mean concentration of 0.01 ± 0.008 Mg/L. In the Njoro River, the mean value obtained for Total Nitrogen (TN) was 0.17 ±0.00 Mg/L which was in the range of 0.17 Mg/L - 0.18 Mg/L, the Soluble reactive Phosphates (SRP) in the river registered mean concentration of 0.02 ± 0.02 Mg/L as Total Phosphates (TP) recorded a slightly higher a mean of 0.13 ± 0.28 Mg/L. For the Kamweti River, mean concentrations of SRP and TP obtained from the river were 0.004 ± 0.006 Mg/L and 0.045 ± 0.034 Mg/L rspectively while the value of TN was 0.17 ±0.002 Mg/L. Significant differences existed between the two rivers in all the nutrient concentrations determined with NO_2-N *t* (1198)=28.62, *p*=.00); NO_3-N *t* (1198)= 10.24, *p*=.00); NH_4-N *t(*1198)= 18.27, *p*=.00; SRP *t* (1198)=17.85, *p*= .00; TP *t*(1198)=7.00, *p*= .00) and TN *t* (1198)=17.39, *p*=.00.

5.3.2 Spatial variations of water quality parameters across different sites

Tables 5.1 and 5.2 shows how the parameters tested varied amongst the different sites of rivers studied. In the Njoro River, site N1 recorded the lowest water temperature values of 13.87±1.46^{0}C, followed by site N3 which had water temperatures of 15.65 ± 0.27^0 C, and the highest reading was recorded site N4 (17.23 ±1.67^0 C) downstream. In Kamweti River, the most upstream site (K1) also recorded the lowest water temperatures (13.89±0.52 ^{0}C) and the highest were recorded downstream at site K5 (15.99 ±1.83 ^{0} C). In terms of pH values, it was observed that in Njoro River, the site which registered the highest value of 7.08±0.91, was midstream (N2) as the site downstream (N5) recorded the lowest value (6.56 ± 1.34). In Kamweti River, the pH of the river was observed to be higher at the downstream sites K4 and K5 as compared to the upstream sites where the least value was obtained from site K1 (7.49 ± 0.21) as shown in Table 5.2.

Site N3 in Njoro River recorded the lowest levels of Dissolved Oxygen (DO) (7.54 ± 0.63 Mg/L) while site N1 registered the highest value of 7.86±0.83 Mg/L. Kamweti River displayed higher DO values than the Njoro River, with the site K3 recording the highest value, (10.15±1.32 Mg/L) and K5 having the lowest levels of DO (9.48±1.77 Mg/L). Sites N5 and N1 of the Njoro River recorded the highest and the lowest EC readings of 68.11±194.496 µs/cm and 224.59±128.05 µs/cm respectively. The EC values of Kamweti River were low compared to those of Njoro River. Site K1 recorded the least values of 25.87± 4.38 µs/cm, which increased downstream site K5 registering the highest readings of 33.40± 5.38 µs/cm. The trend of EC was observed to be increasing downstream in both rivers. Further analysis with one way ANOVA at the level of $p \leq 0.05$, significant spatial differences were noted for temperature (F=170.24; p=0.00) and pH (F=5.50; p=0.00), amongst the sampling sites whereas no significant spatial differences were observed with DO (F=3.48; p=0.08) and EC (F=1.31; p=0.27) amongst the sampling stations in Njoro River as displayed in Table 5.1.

Table 5- 1: Mean (±SD) values of water quality parameters at different sampling sites in the Njoro River.

Water parameter (Units)	N1	N2	N3	N4	N5	ANOVA	
						F value	P value
Temp. (^{0}C)	13.87±1.48	16.11± 0.81	15.65 ± 0.27	17.23± 1.67	16.96± 0.78	170.24	0.00
PH	6.68± 1.17	7.08± 0.91	7.01± 0.80	6.95± 0.93	6.56± 1.35	5.40	0.00
DO(Mg/L)	7.86±0.83	7.85± 0.63	7.75 ± 0.88	7.75± 0.88	7.82± 0.75	3.48	0.008
EC (µs/cm)	224.59±128.05	249.43±162.28	264.45±182.44	264.78±190.76	268.11±194.49	1.308	0.266
NO_2-N (Mg/L)	0.012± 0.007	0.014± 0.006	0.008± 0.004	0.013± 0.015	0.005± 0.004	15.06	0.00
NO_3-N(Mg/L)	0.001±0.001	0.001± 0.001	0.001± 0.001	0.000± 0.000	0.000± 0.000	25.715	0.00
NH_4-N (Mg/L)	0.040±0.024	0.032± 0.028	0.025± 0.016	0.004± 0.044	0.025± 0.015	12.63	0.00
SRP (Mg/L)	0.015±0.008	0.014± 0.010	0.013± 0.015	0.032± 0.025	0.024±0.022	22.78	0.00
TP (Mg/L)	0.091±0.040	0.059± 0.054	0.068± 0.063	0.301± 0.559	0.118±0.238	15.78	0.00
TN (Mg/L)	0.172±0.003	0.173± 0.004	0.174± 0.005	0.174± 0.005	0.174±0.004	4.211	0.002

Table 5.2 shows that there were significant regional variances in all of the characteristics evaluated in situ among the sampling locations in the Kamweti River. Generally, low NO_2-N concentrations values were recorded across the different sites of the Njoro River with the highest concentration at site N2 (0.014 ± 0.01 Mg/L). Site N1 had higher concentrations of NO_2-N as compared to the midstream site N3 (0.123 ± 0.01 Mg/L) and downstream site N5 (0.005 ± 0.04 Mg/L) indicating that the sites located at the agricultural areas had higher concentrations of NO_2-N. The concentrations of NO_{3}-N concentrations were detected on low levels with mean concentrations of 0.001 ± 0.001 Mg/L. Similarly, in Kamweti River the NO_2-N levels were below the limits of detection and NO_3-N concentrations were detected in very low concentrations having a mean of 0.001± 0.001 Mg/L. Similarly, NH_4-N concentrations registered low values across the different sites in both rivers that in Njoro River, the highest reading obtained from the site N4 (0.04± 0.04 Mg/L) and the least was at site N5 downstream (0.01± 0.00 Mg/L) whereas in Kamweti River, the lowest concentrations of NH_4-N registered at K3 (0.006 Mg/L).

The levels of SRP and TP recorded were 0.019 ± 0.019 Mg/L and 0.127 ± 0.288 Mg/L respectively in Njoro River. It was observed that for both nutrients, the highest mean values were obtained from site N4 (0.032± 0.029 Mg/L and 0.30 ± 0.55 Mg/L) respectively. Kamweti River registered lower levels of SRP were also recorded, the lowest being at site K1 (0.003±0.004 Mg/L) while the midstream site, K3 recorded slightly higher concentrations 0.011±0.001 Mg/L. The TN concentrations in Njoro and Kamweti Rivers displayed a constant values of 0.17±0.00 Mg/l from upstream to downstream. At $p \leq 0.05$, one way ANOVA indicated significant spatial variations in the nutrient concentrations across the different sites of the Njoro River (Table 5.1). In Kamweti River (Table 5-2), statistical significant differences were revealed in concentrations of NH_4-N, SRP, TP and TN amongst the sites whereas NO_3-N levels did not display any significant spatial differences amongst the sites

Table 5- 2: Mean (±SD) values of water quality parameters at different sampling sites in the Kamweti River.

Water param (units)	**K1**	**K2**	**K3**	**K4**	**K5**	**ANOVA**	
						F value	**P Value**
Temp. (^{0} C)	13.90± 0.52	15.72± 0.83	14.65± 0.46	17.58± 0.93	18.09± 1.23	551.51	0.00
PH	7.50 ± 0.21	7.56± 0.26	7.59± 0.19	8.04± 0.47	8.23 ± 0.57	93.67	0.00
DO (Mg/L)	9.85± 0.91	9.61± 1.04	10.15± 1.32	10.10± 1.57	9.48± 1.78	5.55	0.00
EC (µs/cm)	25.87± 4.38	26.99± 4.22	27.63± 4.60	30.72± 4.92	33.41±5.39	51.20	0.00
NO_2-N (Mg/L)	0.000± 0.00	0.000± 0.00	0.000± 0.00	0.000± 0.00	0.000± 0.00	.	.
NO_3-N(Mg/L)	0.000± 0.00	0.000± 0.00	0.000± 0.00	0.000± 0.00	0.000± 0.00	1.00	0.41
NH_4-N (Mg/L)	0.010± 0.01	0.008± 0.009	0.006± 0.007	0.012± 0.007	0.017± 0.01	25.85	0.00
SRP (Mg/L)	0.003± 0.004	0.004± 0.006	0.007± 0.009	0.004± 0.006	0.004±0.006	6.67	0.00
TP (Mg/L)	0.032± 0.019	0.042± 0.032	0.046± 0.025	0.050± 0.037	0.053± 0.04	7.73	0.00
TN (Mg/L)	0.17± 0.00	0.17± 0.00	0.17± 0.00	0.17± 0.00	0.17± 0.00	3.13	0.02

5.3.3 Spatial variations of Water quality parameters across different land use

The variations of water quality parameters along the rivers land use categories were determined and given in Tables 5-3 and 5-4. In Njoro River, It was observed that the FDS had the lowest water temperatures and the lowest pH values (13.87±1.46^0 C and 6.67 ± 1.17 respectively). The ADS recorded the highest readings of the same parameters, (16.67 ± 1.42 ^{0} C for water temperature and 7.01 ± 0.92 for pH). Similarly, in Kamweti River, the least water temperatures were registered at upstream the FDS, 14.81 ±1.15 ^{0} C and it showed an increase downstream at the ADS and the BUA with readings of 16.11±1.715 ^{0} C and 18.09±1.23 ^{0} C, respectively. Similarly, the lowest pH values (7.53±0.23) was recorded also at the FDS displaying an increasing pattern downstream where the BUA registered the highest reading of 8.23±0.57.

The BUA of Njoro River had the lowest DO levels (7.67±0.71 Mg/L) and the FDS had the highest reading of 7.86±0.83 Mg/L. The ADS of Kamweti River registered the highest DO values, 10.12±1.45 Mg/L as the FDS recorded the least values (9.73 ± 0.97 Mg/l). Electrical Conductivity values displayed an increasing pattern downstream on both rivers and the FDS and the BUA displayed the lowest and the highest readings of 224.59±128.05 µs/cm and 266.28±188.18 µs/cm respectively for the Njoro River while Kamweti River registered lower EC values of 26.43± 4.33 µs/cm (at the FDS) and 33.41±5.45 µs/cm (at the BUA). In the Njoro River, at $p \leq 0.05$, one way ANOVA revealed significant spatial differences in water temperature (F=217.83; p=0.00) whereas for pH, DO, and EC, no statistically significant spatial differences were observed. In Kamweti River, significant spatial differences were revealed for all the physico-chemical parameters tested as presented in Tables 5-3 and 5-4.

Table 5-3 also displays nutrient concentration variations across the different land use in Njoro River. Low NO_2-N values were displayed generally across the different land use categories (0.01 Mg/L). Similarly, NO_3-N levels recorded were low across the different land uses (0.006 ± 0.001 Mg/L). The NH_4-N levels across the land uses were also recorded low, with the FDS and ADS registering almost a similar reading of 0.039± 0.02 Mg/L and 0.038± 0.02 Mg/L respectivelyas the BUA displayed the least concentration (0.025± 0.02 Mg/L). For the SRP concentrations, the FDS registered the least values 0.015± 0.008 Mg/L while the ADS registered the highest reading of 0.022±0.023 Mg/L. As for the TP concentrations, low concentrations were observed at the FDS (0.091±0.04 Mg/L) then the BUA (0.093± 0.18 Mg/L) with the highest readings were obtained from the ADS (0.18±0.41 Mg/L). The TN concentrations displayed a constant value of 0.17±0.00 mg/l across the different land use categories. At the level of $p \leq 0.05$, one way ANOVA, revealed significant spatial differences in nutrient concentration amongst the land use categories in the Njoro River (Table 5.3).

Table 5- 3: Mean (±SD) values of water quality parameters across different land-uses along the Njoro River.

Water parameter (Units)	FDS	ADS	BUA	ANOVA	
				F value	P value
Temp. (^{0} C)	13.87±1.46	16.67± 1.43	16.31± 0.87	217.83	0.000
pH	6.68± 1.17	7.01± 0.92	6.78 ± 1.12	4.998	0.007
DO (Mg/L)	7.86±0.83	7.85± 0.85	7.68 ± 0.71	2.542	0.08
EC (µs/cm)	224.59±128.05	257.10±128.05	266.28±176.89	2.373	0.094
NO_2-N (Mg/L)	0.012± 0.007	0.013± 0.011	0.006± 0.004	48.338	0.00
NO_3-N(Mg/L)	0.001±0.00	0.001± 0.001	0.001± 0.001	15.861	0.00
NH_4-N(Mg/L)	0.040±0.024	0.038± 0.036	0.025± 0.015	18.861	0.00
SRP (Mg/L)	0.015±0.008	0.023± 0.023	0.019± 0.019	6.832	0.001
TP (Mg/L)	0.091±0.040	0.18 ± 0.41	0.093± 0.18	6.756	0.001
TN (Mg/L)	0.172±0.003	0.174± 0.004	0.174± 0.005	7.454	0.001

The variations of nutrient concentrations in Kamweti River across the different land use types are presented in Table 5.4. It was observed that the levels of NO_2-N, and NO_3-N not detected. Higher levels of NH_4-N and TP were recorded at the BUA, 0.017±0.011 Mg/L and 0.053 ± 0.05 Mg/L. For the NH_4-N and TP concentrations, the FSD and the ADS registered similar readings of 0.009±0.01 Mg/L and 0.04±0.03 Mg/L respectively. For the SRP concentrations, the FDS recorded the lowest values of (0.003±0.01 Mg/L then the BUA with 0.004±0.01 Mg/L and the ADS recorded the highest reading of 0.006±0.01 Mg/L. For the TN concentrations, similar readings across the different land uses, which registered values of 0.170±0.000 Mg/L. Statistically significant spatial differences were observed amongst the land use categories in the concentrations (at the level of $p \leq 0.05$) with NH_4-N (F=35.94; p=0.000), SRP (F=7.24; p=0.001), TP (F=12.18; p=0.000), while TN did not reveal any significant spatial differences in their concentrations amongst the land use types as presented in Table 5-4.

Table 5- 4: Mean (±SD) values of physico–chemical water quality and nutrients parameters across different land-uses along the Kamweti River.

Water parameter (units)	FDS	ADS	BAU	ANOVA	
				F Value	P Value
Temp. (^{0} C)	14.81 ± 1.15	16.12± 1.64	18.09 ± 1.23	227.86	0.000
pH	7.53 ± 0.23	7.81± 0.42	8.24± 0.57	126.22	0.000
DO (Mg/L)	9.73± 0.99	10.12± 1.45	7.71± 0.03	10.09	0.000
EC (µs/cm)	26.43± 4.33	29.18± 5.00	33.41± 5.38	84.06	0.000
NO_2-N(Mg/L)	ND	ND	ND	.	.
NO_3-N(Mg/L)	ND	ND	ND	.	.
NH_4-N(Mg/L)	0.009± 0.01	0.009± 0.008	0.017± 0.01	35.94	0.000
SRP (Mg/L)	0.003± 0.005	0.006± 0.008	0.004± 0.006	7.24	0.001
TP (Mg/L)	0.037± 0.03	0.048± 0.031	0.045± 0.033	12.18	0.000
TN (Mg/L)	0.170± 0.002	0.17± 0.002	0.170± 0.000	2.47	0.085

Principal Component Analysis (PCA) method was used to compare the resemblance between the sites based on the physicochemical water quality metrics measured in the two rivers (Figures 5.2 and 5.3). In Njoro River, axes 1 and 2 accounted for 59 % and 19% of the total variation, respectively (Figure 5.2). Therefore, 78% of the variation in the water quality parameters could be accounted for by the axes 1 and 2. The water quality parameters and the nutrients measured showed variations where the PCA clustered sites N1 (FDS) and N2 (ADS) from the sites N4 (ADS), N3 and N5 (BUA) which were linked to increased DO levels, TP and NO_2N. Sites N1, N4 and N5 were linked to increased values of NH_4-N, SRP and pH. Higher values of Temperature, and TN were observed at sites N2 and N3.

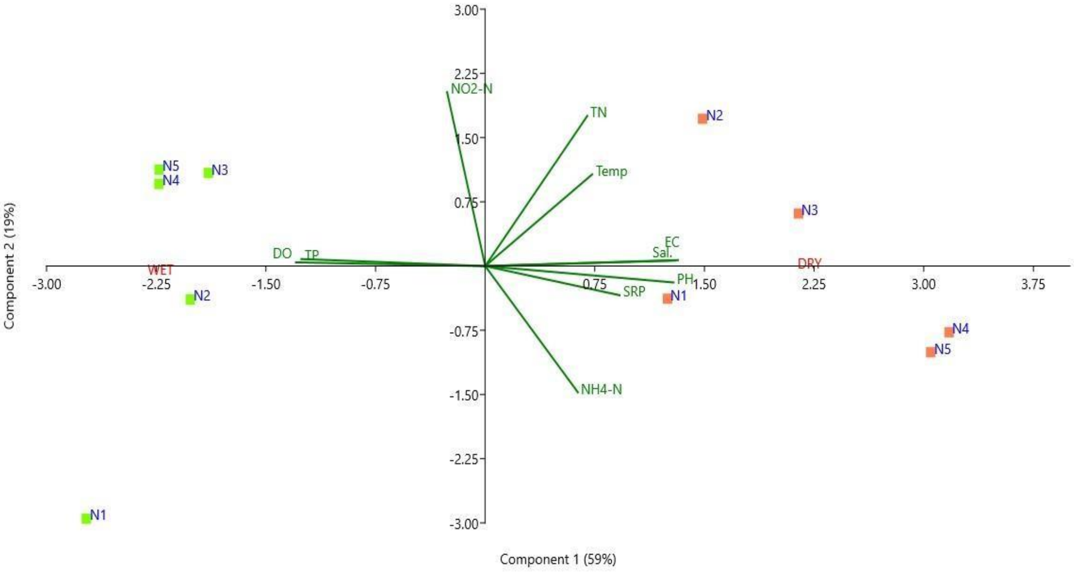


Figure 5- 3: The PCA plots for water quality variables at the five (5) sampling locations in the Njoro River across diverse land-use types.

Note: The length of the arrow is related to the relative relevance of the parameters. Temp, temperature; EC, Electrical Conductivity; DO, Dissolved Oxygen; NO_3-N, Nitrate Nitrogen; NO_2-N, Nitite Nitrogen; NH_4-N, Ammonium Nitogen; SRP, Soluble Reactive Phosphorus; TP, Total Phosphorus and TN, Total Nitrogen.

On the other hand, Kamweti River, PCA axis 1 and axis 2 accounted for 42 % and 21% of the total variation respectively (Figure 5.3). The observed 63% of the variation in the water quality parameters could be accounted for by the axes 1 and 2. Higher concentrations of NO_3-N were associated with sites K2 (FDS) and K3 (ADS). Sites K1 (FDS), K4 (ADS) and K5 (BUA) were clustered together and contained higher values of pH DO and SRP. Also site K5 was observed to contain higher values of NH_4-N, temperature and EC as TN and TP were associated with sites K1, K2, K3 and K4.

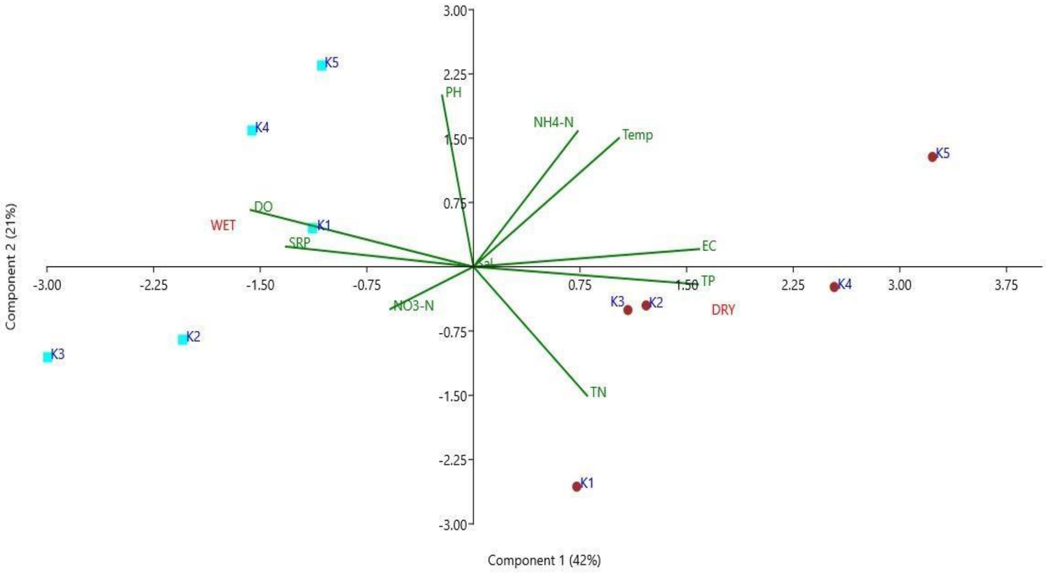


Figure 5- 4: The PCA plots for water quality variables at the five (5) sampling sites across various land-use types in the Kamweti River.

Note: The length of the arrow is related to the relative relevance of the variables Temp, Temperature; EC, Electrical Conductivity; DO, Dissolved Oxygen; NO$_3$-N, Nitrate Nitrogen, NO2-N Nitrite Nitrogen; NH4-NAmmonium Nitrogen; SRP, Soluble Reactive Phosphorus; TP, Total Phosphorus and TN, Total Nitrogen;

5.4 Discussion

5.4.1 Concentration of selected water quality parameters in comparison to reference values

The assessment of water quality status, as well as comparison of measured water quality indicators with water quality criteria, is crucial for risk management in public health and ecological health in the Njoro and Kamweti River catchments. The mean values for each of the measured water quality indicators were compared to water quality criteria provided by the National Environment Management Authority (NEMA, 2006), the World Health Organization (WHO, 2004), and the United States Environmental Protection Agency (USEPA, 2014). Table 5-5 shows that the parameters that exceed NEMA, WHO, or USEPA water quality requirements for domestic and surface waters suggest a decline in water quality and quantity, endangering the public health and Njoro and Kamweti River Catchments ecosystem. Except for TP, the results showed that all of the water quality metrics were within the required range.

Table 5- 5: Permissible quality standard limits for domestic and surface water.

water Quality Parameters (Units)	NEMA 2006		WHO 2004	
	Domestic Water	Surface Water	Domestic Water	Surface Water
Temp (^{0} C)		<30		
pH	6.5-8.5	6.5-8.5	<8	6.5-9.2
DO (Mg/L)	>6	>6	>4	>6
EC (µs/cm)	-	400	-	400
NO_2-N (Mg/L)	3	3	3	
NO_3-N (Mg/L)	10	10	3	10
NH_4-N (Mg/L)	0.5	0.5	-	<0.2
SRP (Mg/L)	-	-	-	-
TP (Mg/L)	-	-	0.05^^	0.05-0.1^^
TN (Mg/L)	-	-	10^^	10^^

Notes: - No set guideline, ^^USEPA Drinking water standards

The readings obtained for water temperatures in both rivers varied depending on the time of sampling. However, the mean values were within Kenya's acceptable surface water temperature limit of 30 ^{0}C (NEMA, 2006). The registered pH levels in both rivers were likewise found to be within the permissible ranges for surface water of 6.5 to 9.2 (WHO, 2004) and 6.5 to 8.5 (NEMA, 2006). Higher pH values were recorded on some sampling occasions, which could be attributed to a concentration of base cations caused by low water levels during the dry season (Ghoul *et al.*, 2023) or to an excess of primary productivity over respiration during that season, which consumes carbon dioxide and lowers Hydrogen ions (Woldeab *et al.*, 2018). According to Delpla *et al.* (2009) meteorological variables such as ambient air warming can also alter water pH concentration, resulting in fluctuations in water quality. For example, a rise in pH concentration was reported in the Rhine and Meuse rivers during the dry season as a result of water warming by about 2 °C following the severe drought of 2003 (Van Vliet & Zwolsman, 2008). Precipitation and pH were shown to have negative significant associations in the lower Mekong River in the same study. Since a result, this appears to be validated in this study, aside from anthropogenic causes, as the ambient heat condition during the dry season may have altered the pH concentration.

Because it influences practically all chemical and biological processes within water bodies, dissolved oxygen (DO) has been deemed extremely important as a water quality indicator. It is a significant limnological measure that indicates the degree of water quality and the amount of organic contamination in the water body (Hassan *et al.,* 2017). The mean DO measured in the Kamweti River was higher than in the Njoro River. However, the mean values obtained for both rivers were above the recommended values by NEMA 2006 for surface and domestic water quality which DO should be >6 mg/l and WHO recommended guidelines of > 4 mg/l for domestic water quality and >6mg/l for surface water quality. The DO values obtained was possibly due to the influence of temperature. The DO values found could possibly be attributed to microbial digestion of biodegradable organic materials. High DO readings upstream in the Kamweti River could be attributable to increased oxygen dissolution at lower water temperatures as reported by Hassan *et al.* (2017).

NO_2-N, NO_3-N, and NH_4-N concentrations were found to be low in the Njoro River, and the NO_2-N and NO_3-N concentrations were found also to be low in the Kamweti River. Nitrate nitrogen is a highly oxidised form of nitrogenous compounds that is commonly found in surface water as the end product of aerobic decomposition of organic nitrogenous matter present in animal waste, and its concentration can vary depending on microorganism nitrification and denitrification activities.

According to Olaniran *et al.* (2014) unpolluted natural waterways normally contain traces of nitrates, therefore the low levels of NO_3-N detected in both rivers could imply that the rivers are not substantially polluted. Ammonium Nitrogen levels in the Kamweti River were also low. NH_4-N is a water-soluble gas that exists in natural waters at low amounts (0.1 Mg/L). Ammonia is formed from nitrogen-containing organic material and gas exchange between water and the atmosphere, which could be derived from waste biodegradation as well as home, agricultural, and industrial wastes (Akindele *et al.,* 2014). The NO_2-N, NO_3-N, and NH_4-N concentrations measured in this study were within the NEMA and WHO maximum acceptable limits of 3 Mg/l, 50 Mg/l, and 0.5 Mg/l, respectively and those of TN were below the USEPA guidelines of 10 Mg/l for surface and domestic waters.

Phosphorus is an important indicator for evaluating water quality since it is the first limiting factor for plant growth in freshwater systems, regulating phytoplankton production in the presence of nitrogen (Umwali *et al.,* 2021). Because it is an important part of the biogeochemical cycles in the ecosystem. The nutrient levels is frequently determined during water quality monitoing and evaluation programmes. The nutrient is known to be prevalent especially in natural waterways as phosphates and the nutrient is not common to be in elevated levels since it is quickly absorbed by vegetation. Therefore, increased phosphate availability is a sign of pollution and a global cause of eutrophication and DO depletion in rivers, resulting in a range of negative ecological repercussions (Akindele *et al.,* 2014). The main sources of the nutrient in water bodies include effluent discharge from sewage treatment plants, domestic wastewater, runoff from agricultural fields sprayed with phosphate fertilisers, and phosphate additions used in laundry detergents.

The increased quantities of phosphorus and nitrate in the rivers evaluated were linked to farming activities in the surrounding area, as soil erosion washes nutrients from nearby land and river banks into bodies of water (Riemersma *et al.,* 2006). The incorrect use of inputs, especially chemical fertilisers, particularly urea and NPK, which are commonly utilised in the research areas, explains cropland effect. The changes in nutrient concentrations as reported by Najar and Khan (2012) and Qureshimatva *et al.* (2015) indicated that they are occasionally driven by an increase in adaptability by biota due to their peak development and the usage of plankton or aquatic plants for metabolic activities.

5.4.2 Spatial variations of water quality parameters across land use

Temperature affects the solubility of oxygen in rivers, and it has a significant impact on their ecological health (Sonal & Kataria, 2012). Variations in water temperatures were observed at the various sampling locations in the rivers studied. With changing land uses, water temperature increased from the uplands to the lower catchment areas. Increase in the number of families residing close to the river coupled with the haphazard waste disposal in the river observed, may be contributing to the rise in water temperature. The trees were close in the upstream sections of the Njoro and Kamweti Rivers, forming dense vegetation in the riparian zone, influencing the cooler temperatures of the water in comparison to the mid-stream and downstream sections where the trees were scattered, providing open space in the riparian zones, which allowed direct sunlight into the river, and potentially increasing the temperatures. The presence of canopy cover may have contributed to the low temperature by reducing solar radiation reaching the water surface. The findings of this study are in agreement with those by Kasangaki et al (2008) and Kilonzo *et al* (2014) who observed low temperatures in forested headwater streams in Uganda and Kenya, respectively. Gichana *et al* (2015) and Gituanja (2020) also observed similar spatial trends in which temperature values were lower in forested areas and higher in agricultural and built-up areas where air temperatures were higher.

In Njoro River, The ADS had the highest pH reading (7.01± 0.92), while the BUA had the lowest (6.78 ± 1.12). The FDS of Kamweti River had the lowest pH reading which increased downstream. The pH levels were greater in the ADS and BUA, which can be attributed to an increase in communities along the riparian zones, indicating a likely increase in the use of alkaline soaps by residents who bathe and wash in the rivers (Mainuri, 2018). Both rivers have been identified as having this practise, notably in the lower and middle sections (for instance the presence of man-made bathing pool areas with signs of soap and detergent wrappers and containers).

The rise in pH levels downstream of the BUAs can also be attributed to haphazard solid waste disposal, particularly near residential areas. The drainage from roads into the rivers, which may carry chemical contaminants into the river systems, was also observed. Changes in mean pH values across land use can also be attributed to the geology of the underlying water sources. The higher pH levels recorded at the Kamweti River ADS was attributed to the presence of tea plantations, which necessitates different agricultural supplies than the variety of food crops grown along the Njoro River, such as corn, vegetables, and tubers. Despite differences in land use along the rivers which caused increased pH concentrations, the registered mean pH levels were within the recommended guidelines for surface water of 6.5 to 9.2 (WHO, 2011) and 6.5 to 8.5 (NEMA. 2006).

Inorganic particles such as nitrates, chlorides, and phosphate anions can have an impact on electrical conductivity, which is a good predictor of total dissolved solids in water (Hamaidi-Chergui & Errahmani, 2019; Nyairo *et al.*, 2015). Electrical conductivity is a useful indicator of many natural and anthropogenic effects on water, and it can be used to compute the concentration of ionised compounds in water indirectly (Stevenson *et al.*, 2010). Natural variables such as the geology underlying the creation of the catchment through which the water flows, as well as human-induced causes such as farming, which may release fertiliser runoff, can have a substantial impact on stream water conductivity.

The mean Electrical Conductivity values for the Njoro River were higher compared to Kamweti River however, the values obtained were within the permissible limits (WHO, 2004). For both rivers, higher mean conductivity values were recorded at the downstream at the BUA. The Njoro River had higher electrical conductivity levels than the Kamweti River, suggesting that anthropogenic activities in the Njoro River basin are releasing too many ions into the river water system, which enhances electrical conductivity at higher temperatures when water evaporates and ion concentrations rise. Lower EC values observed especially during the wet seasons as a result of the dilution effect of the ions by the rains increasing subsurface flow quantities (Ngabirano *et al.*, 2016). As a result, to avoid future damage of the ecosystem, activities should be reduced or maintained at existing levels.

This study's findings were comparable Fekadu (2021) who highlighted that high EC values around built-up regions, which could be influenced by EC levels in river water from anthropogenic activities. This could be the case with the Njoro River at the built-up area, which was located downstream from the residents' agricultural activities. Similar conductivity trends were noted by Stevenson *et al.* (2010), who reported that in the lower plains streams in both rural and urban areas display high variability in conductivity levels. This was ascribed to high conductivity groundwater inflows, which took up ions as water flowed through soils, as well as pollutants inputs from neighbouring intense agricultural and urban land uses. In a previous study, Aera *et al.* (2019) also found conductivity values of 125.73±4.81 µs/cm on non-impacted organic effluent sites and values of 159.14±7.14 µs/cm on impacted organic effluent sites along the Njoro River.

Water temperature, turbulence, salinity, and altitude all have an impact on the amount of DO in surface waters. In natural waters in equilibrium with the atmosphere, DO concentrations range from about 5 to 14.5 Mg of oxygen per Litre. The ideal value for acceptable water quality is between 4 and 6 Mg/l of DO, which ensures healthy aquatic life in a body of water (Chapman, 1996). Dissolved Oxygen concentrations below 4 Mg/l may have an adverse effect on the functioning and survival of biological communities, while DO concentrations below 2 Mg/l may result in the threshold levels for most fish lives (Chapman, 1996).

The levels of DO readings in this study were taken in the morning and early afternoon. Comparing the DO levels in the Njoro River across different land uses, it was observed that values decreased downstream. In Kamweti River, The BUA had the lowest DO levels (7.71±0.03 Mg/L), while the ADS had the highest (10.12±1.45 Mg/L) a value higher that the FDS which recorded (9.73± 0.99Mg/L). The reported increasing values of Dissolved Oxygen downstream may be attributable to higher altitudes' low atmospheric pressure, which reduces Dissolved Oxygen absorption. Additionally, the steep slope on the Kamweti River lead to high water velocity which can raise DO concentration as a result of enhanced water re-aeration. The lower DO levels observed in the Njoro River and downstream Kamweti River can be attributed to several factors; nitrification activity along the river's course, some level of pollution from waste water leakage, fertilizer runoff, and wastes from industrial and domestic activities.

Nitrogen is a nutrient that is required by both plants and animals. Excess nitrogen in water can alter dissolved oxygen levels, threatening the health of plants and animals. Nitrogen in streams can come from a number of sources, including fertiliser runoff from agricultural fields, septic system leakage, waste treatment plants, animal dung runoff, and discharge from industrial zones (Arias-Navarro *et al.*, 2017; Jacobs *et al.*, 2017). When nitrate concentrations surpass tolerable limits, high NO3-N concentrations in drinking water can cause poisoning in humans. The availability of NO3-N in river water can be influenced by a number of factors. When plants and animals decompose, for example, the amount of dissolved oxygen drops, causing NO3-N concentrations to rise. Agriculture (e.g., fertiliser runoff) and untreated sewage water and septic system overflow to rivers can also contribute to nitrate levels in river water (Nyairo *et al.*, 2015).

The NO_2-N and NO_3-N concentrations in the Kamweti River were not detected. Leaf litter was observed to be in abundance in the FDS of both rivers, which after decomposition, leaf litter can be a source of nitrates (Jacobs *et al.*, 2017). Ammonium Nitrogen levels in the Kamweti River recorded in the downstream were attributed to agricultural activities in the vicinity which can potentially release chemical runoff ending up in a lotic system especially during the rainy season.

Phosphorus is essential however, it be harmful to aquatic life in high concentrations in water. Excessive phosphorus levels in surface water bodies are typically associated with eutrophication. The analysis of TP is a water quality indicator that can be influenced by phosphate-containing sewage, industrial, and agricultural effluents (Mainstone & Parr, 2002). High TP concentrations in water bodies promote algae growth, making it unsuitable for the survival of organisms in water based ecosystems. Anthropogenic activities are mostly linked to the presence of this nutrient in water bodies (Withers & Lord, 2002).

The soluble reactive phosphorous (SRP) levels in both rivers could be attributed to phosphorous input from agricultural activities during the crop planting season. Due to the high cost of inputs and application operations, the use of fertilisers and insecticides may be low in most agricultural plants. As a consequence, any TP contamination source into the stream channel might be reduced. Another factor contributing to the Kamweti River's low variability in TP levels is the river's flow rate levels during the dry periods, which resulted in reduced surface sediment erosion and runoff erosion. Inorganic fertilisers, manure, and cattle droppings from grazing nearby waterways, as well as other effluents, could all be possible sources of TP and SRP in this location. The Njoro River's phosphorus levels were slightly higher above the USEPA's recommended guideline of 0.05 Mg/L for domestic waters and 0.05- 0.1 Mg/L for surface water.

Studies by Masese *et al.* (2014), Bu (2014), Ding (2015) and Hamaidi-Chergui and Errahmani, (2019) reported of a difference in the downstream sites from the upstream sites where water quality appeared to deteriorate due to different human activities, nutrients input from cultivated areas, and livestock directly watering from the river, and as such, these sites exhibited high nutrients' concentrations. The results of this study revealed a distinction between upstream and midstream sites and downstream sites in terms of water quality which is evidence of the consequences of the changes in land use patterns and transformation of forests to farmlands and also Built-up zones. Agriculture is linked to increased water abstraction for domestic purposes and irrigation of the cultivated crops, as well as poor agricultural practices with application agrochemicals and fertilizers. Water diversion for domestic and municipal water sources is increased by urban land use. The above practices have detrimental effects surface waters, leading to the impairement of water quality.

5.5 Conclusion and Recommendations

The results from both rivers studied revealed that the tested physico-chemical parameters were within the permissible standards except for Total Phosphorus which did not meet USEPA's standards for domestic water quality and surface water quality. The results also indicated significant changes in physico-chemical parameters which varied spatially across forest land, agricultural and built-up regions. From the results, the forest dominated site, water quality was high as compared to the agricultural and the built-up areas with constant disturbances from humans and domestic animals that may lead to water degradation as well as reduction of habitat heterogeneity due to sediment compaction.

Due to agricultural and urbanisation pressures, there is a need for optimal farming practises that are compatible with the aquatic ecosystem and those that can be able to address non-point pollution sources in order to reduce nutrient and sediment loading in the both rivers. There should be more inclusion of local communities in the conservation of riparian vegetation which will in turn improve water quality status and the biological integrity of streams. To increase the ecological integrity of rivers, forest area should be protected, conserved, and maintained. Growth rates in built-up areas should be lowered as well. In the future, adequate monitoring measures for the ecological integrity of river basins should be developed to aid in mitigation and adaptation initiatives to enhance the water quality of river ecosystems.

CHAPTER SIX

INFLUENCE OF LAND USE ON MACROINVERTEBATE ASSEMBLAGES IN THE NJORO AND KAMWETI RIVERS, KENYA

Abstract

Land use is a major concern becauses it is associated with disturbances to aquatic habitats and biological communities. Land-use changes along the Njoro and Kamweti have has affected water quality and thus macroinvertebrate assemblages. The objective determined how land use influenced benthic macroinvertebrates by comparing Njoro and Kamweti Rivers. The site for sampling were selected which corresponded to the major land use categories as areas for sample collection. Their abundance was determined and compared amongst the sampling sites and the land use categories using one way ANOVA test. SIMPER analysis determined the species that caused for observed variations in the benthic macoinvertebrate community structure between land use categories. A total of 15 taxa were encountered from both rivers, with total counts of 180, 475 individuals and 204, 917 individuals from the Njoro and Kamweti Rivers respectively. At $p \leq 0.05$, one way ANOVA displayed significant spatial differences amongst the different sampling sites in terms of the abundance of Heptageniidae and Simuliidae families (F=3.17; p=0.02 and (F=8.94; p=0.00 respectively). Amongst the land use categories, all the dominant organisms with exception of Heptageniidae revealed significant spatial differences (F=1.19; p=0.31). Amongst the sampling sites and the land use categories of Kamweti River, significant spatial differences were observed in all the dominant families with exception of Baetidae (F=0.97; p=0.43 and F=0.46; p=0.63 respectively). Between the rivers, significant differences were revealed in all the dominant organisms. One way ANOSIM did not reveal any significant dissimilarities in Njoro River (R= -0.27, p=0.92) whereas Kamweti River revealed significant dissimilarities (R = 0.65, *p* = 0.01) in macroinvertebrates assemblages between the sampled land use categories. From the results of this research study, disruptions from adjacent land utilization practises had an effect on the benthic macroinvertebrate habitat, structure and composition. To protect the quality of surface waters and aquatic organisms therein, riparian assessment, monitoring and management land use practices should be prioritized within the catchments.

6.1 Introduction

Water contamination has been regarded a prevalent problem that demands immediate attention globally. This is definitely the outcome of the continually rising human population which has caused radical shift to landscapes. While significant progress has been achieved in limiting the acute effects of point sources of water pollution, it has become increasingly obvious that non-point-source contamination from agricultural, mining and urban land uses has contributed long-term, cumulative harm to stream ecosystems (Mwedzi *et al.*, 2016).

The greatest stressor on stream environmental condition has been identified as land-use change. Agriculture, for instance is known to enhance the vulnerability of a paricular landscape to surface runoff, resulting in the loss of riparian complexity and in-stream habitats, changes in hydrology, and higher inputs of herbicides/pesticides and fine sediments into the river (Zhang *et al.,* 2012). Similarly, metropolitan areas have a disproportionately harmful impact on the stream system. This influence has been proven to rise with increase in percentage area under urban development. Urban areas provide impermeable areas (e.g., parking lots, roof tops, etc.), which increases surface runoff, changes channel shape, and increases sediment, nutrient, and pollutant loads (Walsh, 2004).

The patterns of these biota are responsive to the nature of the prevailing physical and chemical circumstances in-stream, therefore, the effects of these land-use changes are evident in changes in biotic communities (Sponseller *et al.,* 2001). Because it incorporates reactions to a variety of contaminants happening at different times, changes in macroinvertebrate structure and composition can be used to indicate changes in surface water quality over time in lotic systems in a more integrated manner than standard monitoring of water chemistry (Chapman, 1996).

Benthic macroinvertebrates have been widely studied and they are utilized globally to indicate the water quality status of lotic systems. These bottom-dwelling aquatic animals are found in freshwater systems during their larval stages and include many orders of insects, but also non-insect species such as mollusks, annelids, nematodes, and platyhelminths. Macroinvertebrate surveys in streams have proved to be an efficient method to determine the health of streams or monitoring changes to biodiversity within the watershed (Wallace & Webster, 1996), because they are vulnerable to pollution and other environmental disturbances.

The design of research can also have an impact on the outcomes. The methods used to examine macroinvertebrate communities in streams have evolved over time. Rapid bio-assessments for invertebrates were frequently utilised in government stream sampling and several large-scale research investigations in the 1990s and early 2000s. Rapid assessments enable researchers to collect macroinvertebrates, identify, count, and release them while still in the field, which allows for faster data collection but may result in higher error in macroinvertebrate identification and counting accuracy. It has become more customary in recent decades to return macroinvertebrate samples to a laboratory for identifying using high-powered microscopes, which allows for greater precision in macroinvertebrate identification and abundance counts (Sprout, 2020).

Even though laboratory analysis is now the standard practice, there seems to be presently no criterion for the stream numbers survey conducted, total count of locations per river, or reproducibility per location, as these are established by the research scientist and might vary widely among studies. Regional and local effects, such as elevation, can also be evaluated using well-replicated trials. Biodiversity indices are particularly sensitive to sample size, therefore repeatability, number of locations, and number of streams are significant considerations when evaluating diversity among macroinvertebrate groups. Although replication is well understood, it is frequently disregarded in several ecological studies (Sprout, 2020).

Macroinvertebrate surveys have allowed stream ecologists to understand how a community responds to abiotic or biotic changes, such as seasonality, gradients of disturbance, and relationships between in stream biota and riparian biota. Sprout (2020) documented that natural disturbances such as wildfires and floods have been found to cause short-term changes to macroinvertebrate food source availability, nutrient availability and other environmental variables that decrease overall biodiversity, while increasing densities of genera tolerant of disturbance in streams. Macroinvertebrate taxa are often divided into two groups: tolerant insects (diptera) and sensitive taxa (Ephemeroptera, Plecoptera, and Trichoptera (EPT). However, on a long-term scale, it has been observed that the invertebrate community, regardless of sensitivity, can recover the original biodiversity lost from natural disturbance and return to a previous state if stream chemistry recovers (Jackson & Füreder, 2006; Tang *et al.,* 2009).

Regeneration from human disturbance may be less likely since these consequences are irreversible and continuous, with no recovery period for habitat restoration. Mining may cause irreparable harm to waterways and macroinvertebrate ecosystems by lowering pH, releasing metal ions, and replacing the native substrate with poisonous sediment layers. Animal husbandry can also induce chemical changes such as pH decrease, nitrogen variations, full canopy cover removal, and sediment disturbances. However, there has been a dearth of understanding of how such anthropogenic perturbations may effect settings that are already under stress from natural factors, such as the hard physiological circumstances at high elevation (Sprout, 2020).

Various studies around the world have documented how land development have impacts on the macroinvertebrate structure and composition in lotic systems. Azrina et al. (2006), for example, observed that various macroinvertebrate indices such as dominance and diversity responded to changes in water quality as a result of the presence of pollutants along the river continuum. Moore and Palmer (2005) found that various land utilization patterns had deleterious impacts on the macroinvertebrate diversities. Kasangaki *et al.* (2008) found that wooded areas of the watershed had greater mean taxonomic richness, diversity, and evenness measures than cultivated areas, whereas grazed areas had intermediate findings. Aura et al. (2010) reported significant changes in community structures along land use gradients in a comparative study of the Kipkaren and Sosian rivers. According to Gichana *et al.* (2015) the macroinvertebrate sensitive orders; Ephemeroptera, Plecoptera and Trichoptera dominate environment with minimum disturbance levels, while the order Diptera dominate disturbed regions that are recipient to different pollutants including nutrients from different sources.

Typically, the reaction of benthic macroinvertebrates to the transition of forest land to agriculture and urban areas is studied from the standpoint of taxonomic variety (Kayitesi *et al.,* 2022). Alteration in land use types, for example, can drastically affect population structure within a location by modifying the physicochemical properties of the aquatic environment. Macroinvertebrate taxonomic diversity falls dramatically along land use intensification and urbanisation gradients. However, taxonomy-based techniques often simply quantify biodiversity, ignoring the links between environmental variables and macroinvertebrate features in the ecosystem (Lu *et al.,* 2022).

Unlike the Kamweti River, the Njoro River watershed has experienced land use changes as a result of the clearance of the Mau Forest where the watershed is located (Jebiwott *et al.,* 2021; Koskey *et al.,* 2021). Consequently, during the dry season, pressures on the Njoro River are heightened (M'Erimba *et al.,* 2014), owing to the fact that the river is the main water supply supporting the water demands of many people within the catchment (Mathooko, 2001; M'Erimba *et al., 2014*). Gichana *et al.* (2015) highlighted that during the dry seasons, the low water flows coupled with the different suites of pressures from various land uses such as the contamination from pollutants and the high water abstractions rates offer serious consequences and threats to the catchments water resources. This leads to the deterioration in the quality and quantities.

This objective compared the responsiveness of benthic macroinvertebrate communities to modifications in water quality in diverse land-use categories (forest, agricultural, and built-up zones) in the Njoro and Kamweti Rivers. The information obtained will contribute to the understanding of how the bethic macroinvertebrate structure and composition can be influence by land use in the catchment. This is regarded as a first step toward conserving and management of these fragile ecosytems. This research objective hypothesised that the changes in the quality of water caused by the patterns of land utilization affected the composition of benthic macroinvertebrate populations in the rivers that were studied.

6.2 Materials and methods

6.2.1 Description of the study areas

The research was carried out in two tropical rivers, the Njoro and Kamweti Rivers. The catchments of the rivers differ in terms geology, riparian vegetation, height and land usag eas well as the frequency and severity of both human and animal impacts on their sediment surfaces. The Njoro River, is a second-order stream with an approximate catchment area of 284 km^2 (M’Erimba *et al.,* 2014). The river runs through agricultural areas, communities, and cities (Lelo *et al.,* 2005). The Kamweti River is roughly located between latitude 0 ° 20'S to 0 ° 22' S and longitude 30° 25'E to 37 ° 30'E. It is a fast-flowing river that drains to the Thiba River from the southern slopes of Mount Kenya. Because the river meanders through a tropical rain forest, the upper portions are protected forest with extensive canopies of indigenous plants. The lower portions of the river's riparian vegetation has been degraded through agricultural land usage and settlements and exotic species of vegtation has replaced the indigenous species. (The research areas and study sites are described in detail in Chapter 4).

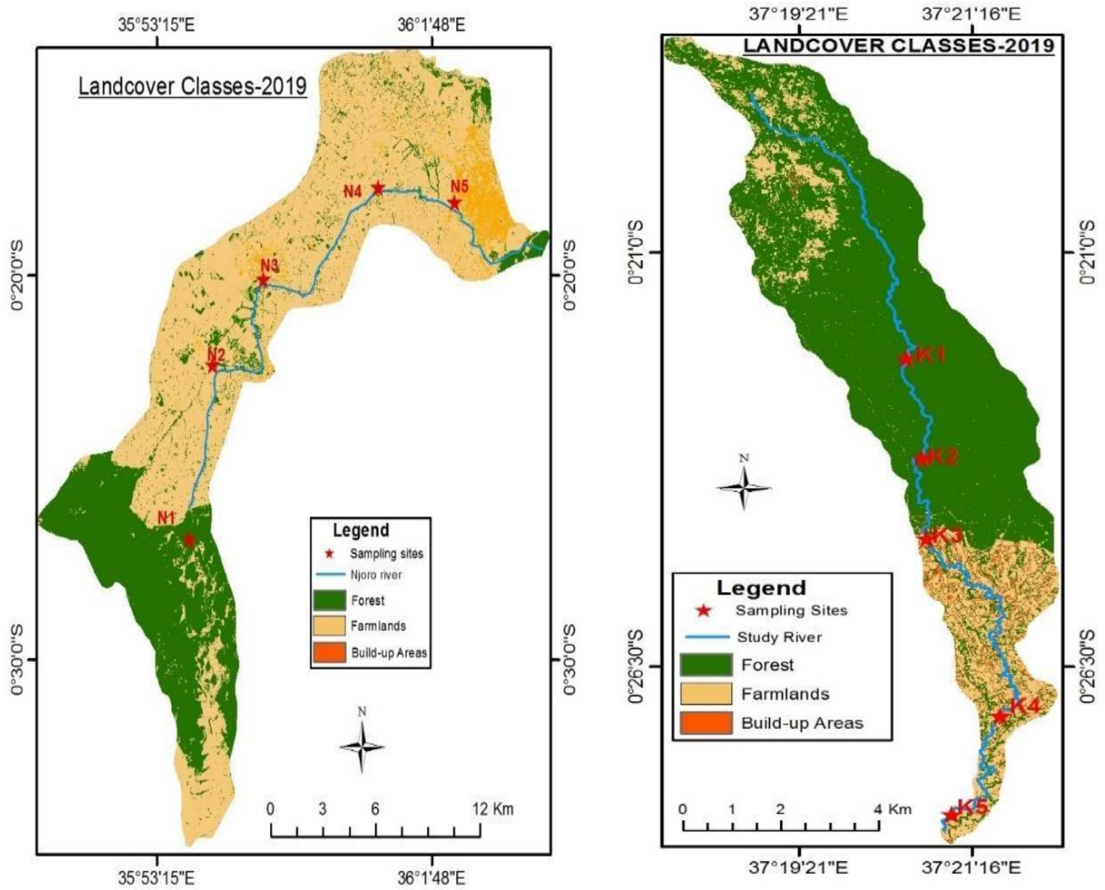


Figure 6- 1: Maps depicting the various sampling points in the Njoro (A) and Kamweti (B) rivers within the principal categories of land use (Satellite images of 2019).

6.2.2 Research design

The research design employed for the objective was similar to that of objective two (see chapter 4 for a thorough research plan), with the exception of the collection of macroinvertebrate samples.

6.2.3 Macroinvertebrate sample collections

In this study, sampling of benthic macroinvertebrates was carried out in both rivers between August 2018 and 2019. Quantitative sampling was carried out in accordance with Barbour (1999) rapid bio-assessment protocols for rivers and wadeable streams. Kick samples of benthic macroinvertebrates were collected from the Study Rivers selected sampling sites and they were collected within the rivers biotopes using a D-frame kick netnet with a mesh size of 500 µ m and from an effective area of 0.0484 m^2. The open end of the kick net was held against the water current while kicking the upper side to remove benthic macroinvertebrates (Gichana *et al.*, 2015) Thirty samples were taken from the riffles, runs, and pools at the chosen sites. The collected benthic macroinvertebrate samples were placed in clearly labelled bottles and fixed with 4% formalin before being transported to the laboratory for further processing and analysis. To remove formalin, debris, and fine sand, the benthic macoinvertebrate samples then thoroughly rinsed by use of 500µm mesh sieve in the laboratory. The samples were then uniformly distributed across a sorting pan. Following standard keys by Gebber and Gabriel (2002) the specimen were identified to the family levels by use of dissecting microscopes and sorted. The species were then placed into pre-labeled glass vials and preserved in 70 %.

6.2.4 Data analysis

Before performing any statistical tests, macroinvertebrate count data were log10 (x + 1) converted to meet the statistical criterion for normalcy. To see if there are any notable variations between the sampling sites and the land use categories, one way ANOVA test was utilized. Macroinveterbrate assemblage structure, metric characteristics were determined for each site and land use category using presence, absence, and abundance data per site and land use. The composition of macroinvertebrates was determined using the relative abundance, being calculated as the proportion of each taxon in a station as explained by Gichana *et al*. (2015) as follows:

$$\text{RA}=\frac{\text{Number of individuals}}{\text{Total no.of individuals in that site}} * 100$$

Richness index, Margalef's index, and Simpson’s Index were used to compute and compare evenness and dominance of taxa per site, while Shannon- Wiener index and Fisher-alpha Index computed and compared diversities and the richness of taxa across sites in different land-uses. Compositional similarities of macroinvertebrates in the sampled sites of the Njoro and Kamweti Rivers was determined by performing One-way (ANOSIM). The SIMPER (similarity percentages) analysis indicated species responsible for observed differences in population structure between the sites. The statistical procedures were performed using SPSS version 25 (IBM Corp, 2010) and PAST programme by Hammer et al (2001). All tests were significant at the $\alpha \leq 0.05$ level.

6.3 Results

6.3.1 Macroinvertebrate assemblages in the Njoro and Kamweti Rivers.

Eight orders of benthic macoinvertebrate were encountered from the sampling sites of the Njoro River which were Ephemeroptera (May Flies), Trichoptera (Caddis flies), Crustacea, Coleoptera (Beetles), Diptera (Flies), Odonata (Dragon Flies), Turbellaria and Annelida. Within the orders, several families were identified as follows: Ephemeroptera - four (4) families, Trichoptera - one (1) family, Crustacea - one (1) family, Coleoptera –three (3) families, Diptera - six (6) families, Odonata - two (2) families, Turbellaria - one (1) family and Anelida - one (1) family. Figure 6.2 (A) displays the dominant families in Njoro River which were from the Ephemeroptera and Diptera orders with an abundance of 180,475 individuals/m^2. The families were distributed as follows; Heptageniidae 30% (Ephemeroptera), Baetidae 19% (Ephemeroptera), Simuliidae 18% (Diptera), Teloganodidae 10% (Ephemeroptera), while the other families constituted of 23 %.

In Kamweti River, the macroinvertebrates identified were grouped into a total of seven (7) orders with several families, as follows; Ephemeroptera- seven (7) families, Trichoptera - three (3) families, Plecoptera -one (1) families, Coleoptera - five (5) families, Diptera- seven (7) families, Crustacea - one (1) family, and Odonata - two (2) families. The dominant orders were the Ephemeroptera, Trichoptera and Plecoptera. The total counts of the dominant taxa was 204, 917 individuals/m^2 which were distributed as percent as follows; Heptageniidae (Ephemeroptera) 29%, Baetidae (Ephemeroptera) 37%, Hydropsychidae (Trichoptera) 14%, Perlidae (Plecoptera) 5% while the other families constituted 15 % of the total as shown in figure 6.2 (B).

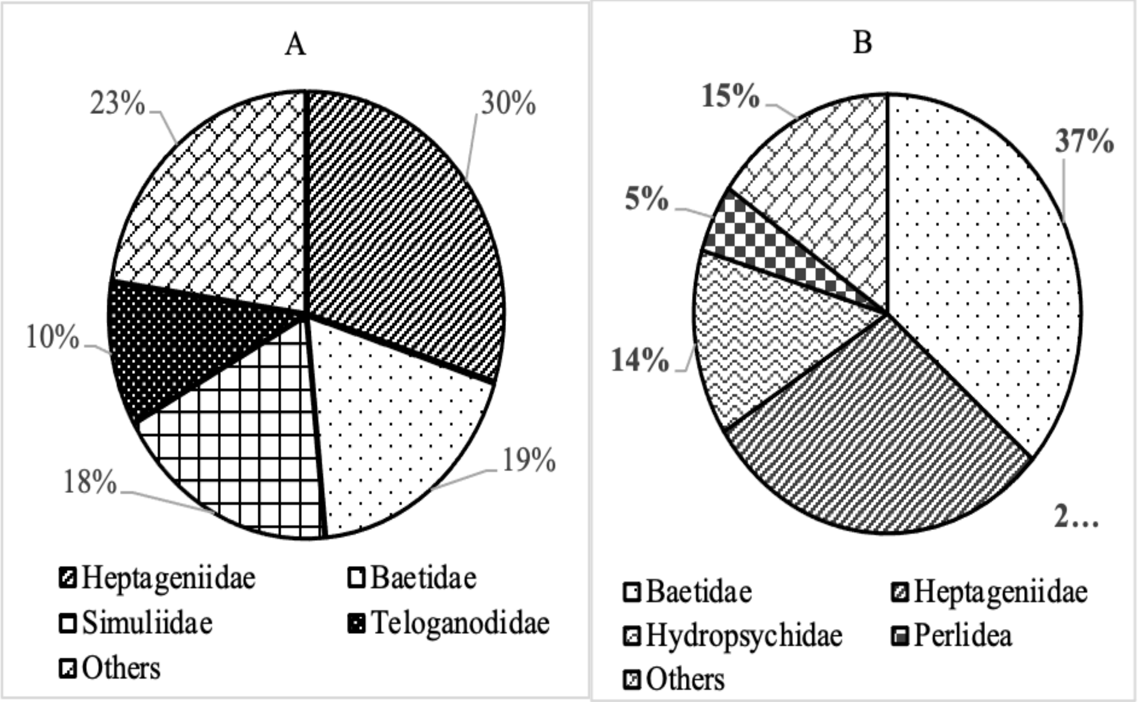


Figure 6- 2: Macroinvertebrate dominant family distribution in the Njoro River (A) and Kamweti River (B).

Table 6.1 indicates the distribution of macroinvertebrates that constituted about 70 % of the total in the Njoro and Kamweti Rivers across different sampling sites. The macroinvertebrate families which were found to be common at sites of the Njoro and Kamweti Rivers included, Baetidae, Heptageniidae, Hysdropsychidae, Elmidae, Potamonautidae, Simuliidae, Chironomidae, Tipulidae and Ceratopogonidae. They were identified in all sites along the Njoro River, whereas these organisms were identified in the upper and the lower segments of the Kamweti River. Teloganodidae and Oligochaeta were only present in the Njoro River while Perlidae was uniquely identified to the Kamweti River.

Table 6- 1: Taxa distribution of benthic macroinvertebrates at various sampling sites in the Njoro and Kamweti Rivers.

TAXA	NJORO RIVER					KAMWETI RIVER				
	N1	N2	N3	N4	N5	K1	K2	K3	K4	K5
Baetidae	+	+	+	+	+	+	+	+	+	+
Heptageniidae	+	+	+	+	+	+	+	+	+	+
Teloganodidae	+	+	+	+	+	-	-	-	-	-
Hydropsychidae	+	+	+	+	+	+	+	+	+	-
Perlidae	-	-	-	-	-	+	+	+	-	-
Simuliidae	+	+	+	+	+	+	+	-	-	-
Athericidae	+	+	-	+	-	+	-	-	-	-
Chironomidae	+	+	+	+	+	+	-	+	+	+
Tipulidae	+	+	+	+	+	+	-	+	+	+
Ceratopogonidae	+	+	+	+	+	+	-	-	-	-
Elmidae	+	+	+	-	-	+	+	+	+	+
Helodidae	+	+	+	-	-	+	-	-	-	-
Potamonautidae	+	+	+	-	-	+	+	+	+	+
Oligochaeta	+	+	+	+	+	-	-	-	-	-

Note: + denotes the existence of taxa; - denotes the absence of taxa.

Table 6.2 presents 70 percent of the dominant families across the different land use categories. It was observed that families Baetidae, Heptageniidae Hydropsychidae, Tipulidae, Elmidae and Turbellaria were present in both rivers as shown in Table 6.4. As observed in the different sampling sites, Teloganodidae was noted to be present in all sites along the Njoro River while in Kamweti River, it was found downstream the BUA. Similarly, Chironomidae were identified in the ADS of the Kamweti River but not in the Njoro River. Helodidae were identified in the Njoro River, but Perlidae were found only in the Kamweti River.

Table 6- 2: Taxa distribution of benthic macroinvertebrates at different land use sites in Njoro and Kamweti Rivers.

Family	Njoro River			Kamweti River		
	FDS	ADS	BUA	FDS	ADS	BUA
Baetidae	+	+	+	+	+	+
Heptageniidae	+	+	+	+	+	+
Ceanidae	+	+	+	+	+	-
Teloganodidae	+	+	+	-	-	+
Hydropsychidae	+	+	+	+	+	+
Perlidae	-	-	-	+	+	-
Chironomidae	+	+	+	-	+	-
Tipulidae	+	+	+	+	+	+
Potamonautidae	+	+	+	+	+	+
Helodidae	+	+	-	-	-	-
Elmidae	+	+	+	+	+	+
Planaria	+	+	+	+	+	+
Oligochaeta	+	+	+	+	+	-

Note: Note: + denotes the existence of taxa; - denotes the absence of taxa.

6.3.2 Abundance and distribution of macroinvertebrates across sampling sites

Benthic macroinvertebrate abundance showed variations across the different sites of both rivers. Ephemeroptera and Diptera were the major orders in the Njoro River. Diptera were represented by the Ephemeroptera families; Heptageniidae, Baetidae, Teloganodidae, and Simuliidae (Diptera) with total counts of 180,475 individuals /m^2. In all sites, the order Ephemeroptera was dominant with Heptageniidae being dominant in the river. Site N1, had a total of 28,636 individuals/m^2 the most dominant being Baetidae (5,186 counts), followed by Heptageniidae (3,264 counts) and the least abundant was Telagonididae with 868 counts. Midstream N2 was the least abundant site with a total of 19, 607 individuals /m^2 dominated by Baetidae (7,541 counts) followed by Heptageniidae with 7,149 counts. Site N3 had a total of 66,818 individuals/m^2 being dominated by Ephemeroptera but family Simuliidae had the highest counts. At N4 and N5 number of individuals counted were 37,810 /m^2 and 27,603 /m^2

respectively, and it was observed that the Heptageniidae was dominant at these downstream sites as shown in Figure 6.3 A. At the level of $p \leq 0.05$, one way ANOVA revealed statistically significant spatial differences to exist in the abundance of Heptageniidae (F=3.18; p=0.02) and Simuliidae (F=8.94; p=0.00), but no significant spatial differences existed in the abundance of Telagonididae (F=2.09; p=0.08) and Baetidae (F=2.07; p=0.09) amongst the Njoro River sampling sites.

Figure 6.3 B displays the distribution of macroinverbrates across the different sites in Kamweti River. The Ephemeroptera, Plecoptera and Trichoptera (EPT) orders were dominant with total counts of 204,917 individuals /m^2. Baetidae family was the most abundant in the river while Perlidae was the least abundant. Site K1 and K2 had total counts of 58,430 and 35,455 individuals /m^2. Dominant at site K1 was Heptageniidae (22,665 counts) followed by Baetidae with 21,983 counts. K1 had the highest counts of Hydropsychidae. At K2, Baetidae was the most dominant with 19,153 counts followed by Heptageniidae. Hydropsychidae counts reduced to 4,132. Site K3 was the most abundant with 60,992 individual/m^2. Dominant in the site were Heptageniidae followed by Beatidae with 34,525 and 14,265 individuals/m^2 respectively. The site showed a decrease in Hydropsychidae counts but had the highest counts of Perlidae (8,657).

Site K4 had the least abundant site with total counts of 20,186 individuals /m^2. In this site, the Baetidae family was dominant followed by Heptageniidae family, with 12,231 and 4,174 individuals /m^2 respectively. A decrease in Hysropsychidae abundance was also observed whereas Perlidae recorded zero (0) individuals /m^2. An increase in macroinvertebrates individuals /m^2 was observed at K5 downstream (29,855 individuals /m^2). The abundance of Baetidae slightly decreased as Heptageniidae were observed to increase (12,231 and 10,909 individuals /m^2 respectively). It was also observed that Hydropsychidae counts increased in this site and Perlidae were present though in low abundance. Further analysis using One way ANOVA revealed significant spatial differences in the abundance of Heptageniidae (F=47.69; p=0.00), Perlidea (F=26.10; p=0.00) and Hydropsychidae (F= 4.75; p=0.01) whereas no significant spatial differences was observed in Baetidae abundance amongst the sampling sites (F=0.97; p=0.43).

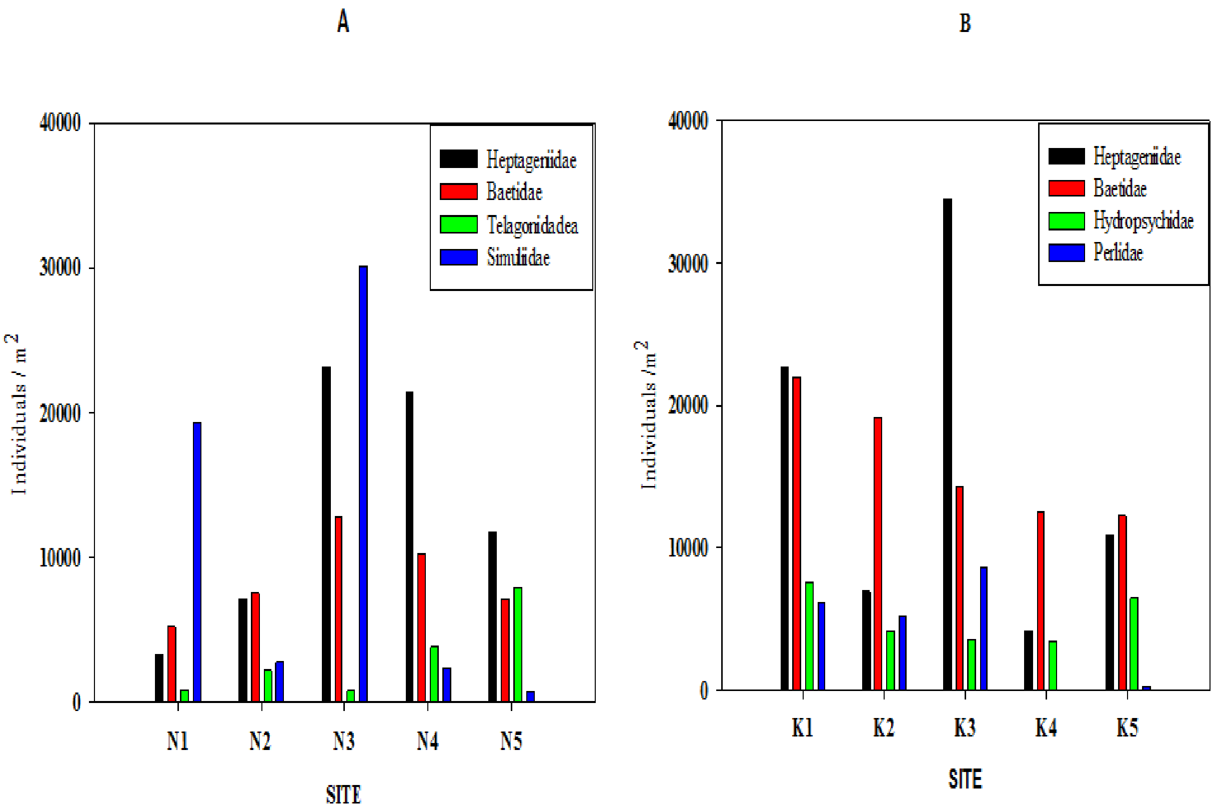


Figure 6- 3: Macroinvertebrate family distribution in different sampling sites the in (A) Njoro and (B) Kamweti Rivers

6.3.3 Macroinvertebrate Diversity indices at different sites

Various diversity indices presented in Tables 6.3 and 6.4 for the Njoro and Kamweti Rivers respectively at the different sites. In Njoro River, Taxa richness and Margalef's Index portrayed similar trends across sites, each revealing higher values in site N2 and N4 and at N5 (Taxon richness (S) N2(18), N4 (17) and N5 (17); Margalef Index N2 (1.69), N4 (1.49) and N5 (1.52). Site N3 had the least values followed by N1. Shannon diversity, Simpson index and Pielou's eveness index (j), maintained a similar trend where Shannon diversity index and Simpson richness index (1-D) values were the highest at site N2 and also at the downstream sites N4 and N5. Fisher-alpha Index also indicated that site N2 was the most rich (1.91) followed by N5 (1.67). Dominance index (D) displayed varying trends whereas site N3 recorded the highest values (0.33) followed by site N1 recording 0.32. Berger-parker Index deviated and showed Site N1 as most dominant (0.54), along with N4 (0.45) as shown in Table 6.3.

Table 6- 3: Benthic macroinvertebrates indices in Njoro River at different sites.

Site Indices	N1	N2	N 3	N4	N5
Taxa_S	16	18	15	17	17
Dominance_D	0.33	0.22	0.33	0.27	0.19
Simpson 1_D	0.67	0.78	0.67	0.73	0.81
Shannon_ H’	1.61	1.80	1.29	1.72	1.89
Margalef	1.43	1.69	1.26	1.48	1.52
Equitability_J	0.58	0.62	0.48	0.60	0.67
Fisher_alpha	1.60	1.91	1.39	1.66	1.70
Berger_parker	0.54	0.32	0.43	0.45	0.31

Kamweti River also displayed wide ranges in the measures in the different sites as shown in Table 6.4. It was observed that taxa richness upstream K1 and midstream K3 recorded a similar value (18), however Margalef’s Index was higher at K1 than K3 recording values of 2.09 and 2.06 respectively. Fisher-alpha Index indicated that site the richest site was K1 followed by K2 with values of 2.50 and 2.49. Shannon Diversity Index and evenness was highest at site K2 recording values of 2.04 and 0.72 respectively while the lowest values was at K5 recording 1.50 and 0.58. It was also noted that site K2 recorded higher values than the most upstream site K1, which displayed values almost similar to site K3 located at the agricultural area. The pattern observed was of downstream decrease in diversity and evenness values from K2 to K5. Dominance index (D) was highest at Site K4, (0.31) with Berger-parker Index maintaining K4 being the most dominant (0.50).

Table 6- 4: Benthic macroinvertebrates indices in Kamweti River at different sites.

Site **Indices**	**K1**	**K2**	**K3**	**K4**	**K5**
Taxa_S	18	17	18	10	13
Dominance_D	0.23	0.21	0.26	0.31	0.28
Simpson 1_D	0.77	0.79	0.74	0.69	0.72
Shannon_ H’	1.84	2.04	1.83	1.51	1.50
Margalef	2.09	2.07	2.06	1.27	1.63
Equitability_J	0.64	0.72	0.63	0.66	0.58
Fisher_alpha	2.50	2.49	2.46	1.49	1.93
Berger_parker	0.33	0.40	0.45	0.50	0.37

6.3.4 Abundance and spatial distribution of macroinvertebrates across different land uses

The Built-up area (BUA) of the Njoro River was the most abundant site (47,210 individuals /m^2) while the least abundant site was the Forest Dominated Site (FDS) with counts of 28, 636 individuals /m^2. At the FDS, Simuulidae (19,318 individuals /m^2) was dominant followed by Baetidae (5,185 individuals /m^2). At the ADS, Heptageniidae was the most abundant (14,245 individuals /m^2) followed by Baetidae (8,904 individuals /m^2) while Simuliidae was the least abundant (2561 individuals /m^2). At the BUA Heptagemiidae was the most abundant 17, 458 individuals /m^2) followed by Simuliidae and the least abundant was Telagonidade (4,369 individuals /m^2) as shown in Figure 6-4. One way ANOVA at the levels of $p \leq 0.05$, revealed significant spatial differences in the abundance of Telagonididae (F=3.96; p=0.02), Baetidae (F=3.80; p=0.02) and Simuliidae (F=4.31; p=0.02) whereas no statistically significant spatial differences were revealed in abundance of Heptageniidae (F=1.19; p=0.31) amongst the land use categories of the Njoro River. The highest Shannon Weiner diversity index value was obtained from the FDS (H′=1.75) then followed by the ADS (H′=1.70) whereas the BUA recorded the lowest value (H′=1.65).

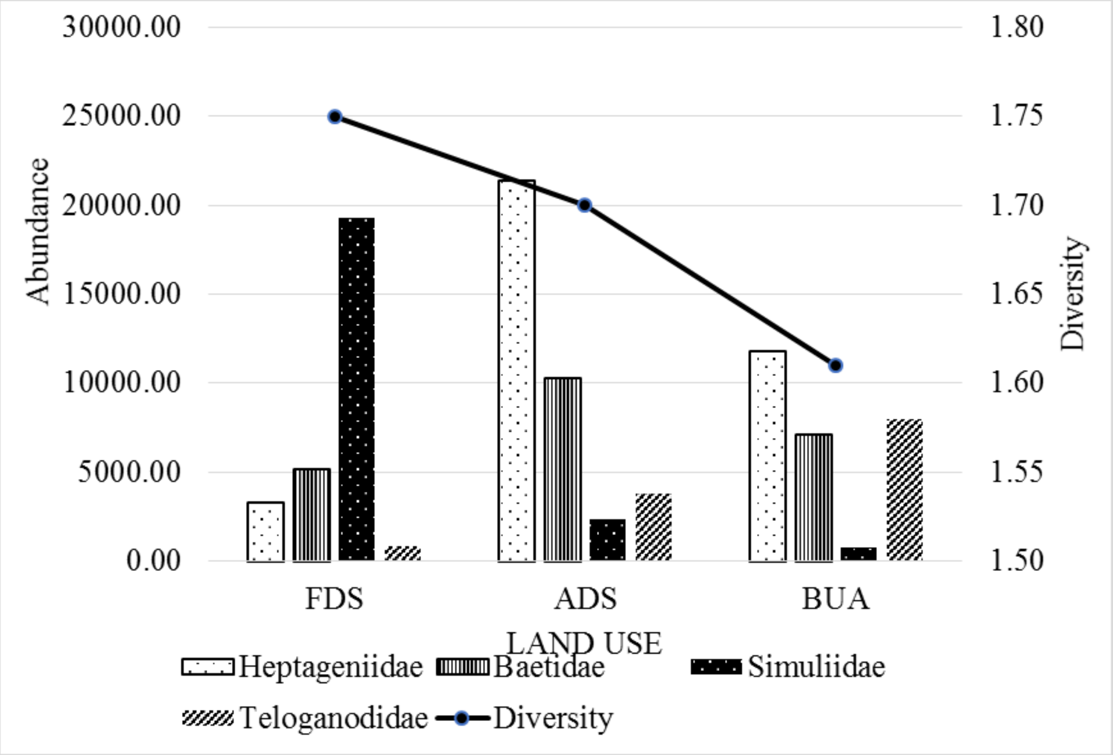


Figure 6- 4: Macroinvertebrate family distribution in different land use categories in the Njoro River.

Figure 6.5 shows how the dominant taxa were distributed across the different land uses in the Kamweti River. Noted was that the FDS was dominated by the Heptageniidae family with 22,665 individuals /m^2 followed by Baetidae 21,938 individuals /m^2 and the least abundant family at the FDS was Perlidae with 6,177 individuals /m^2. Downstream the ADS, Heptageniidae was dominant followed by Hydropsychidae with 8,782 and 7260 individuals /m^2 respectively while Perlidae were not recorded. Downstream the BUA had the highest counts of Hydopsychidae (28,472 individuals /m^2). These sites were dominated mostly by Baetidae (25,734 individuals /m^2) with Perlideae recording the least counts of 521 individuals /m^2 as shown in Figure 6-4. One way ANOVA, at the level of $p \leq 0.05$, revealed statistically significant spatial differences in the abundance of Heptageniidae, Perlidea and Hydropsychidae with values of F=9.74; p=0.00, F=40.45; p=0.00 and F=7.07; p=0,01 respectively and no significant spatial differences was observed in Baetidae abundance (F=0.46; p=0.63) amongst the land use categories. Shannon Weiner diversity index was the highest at the FDS (H′=2.04) followed by the ADS (H′=1.99) whereas the BUA recorded the least value (H′= 1.77) as shown in Figure 6-5.

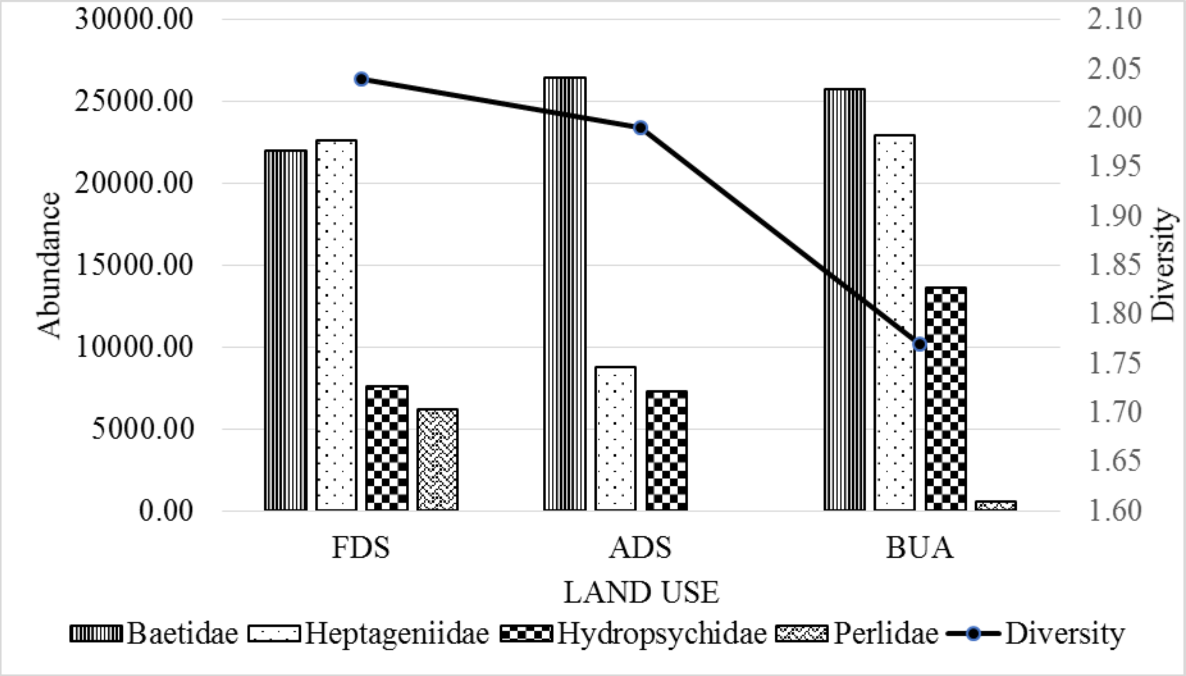


Figure 6- 5: Macroinvertebrate family distribution in different land use categories in the Kamweti River.

Comparing the Njor and Kamweti Rives, analysis using T-Test at the level of p≤0.05 indicated that statistical significant differences in the abundance of all the dominant macroinvertebrate families existed with Heptageniidae *t*(499)= -3.438; p=.00, Teloganodidae *t*(190)= 4.186; p=.00, Baetidae *t*(536)= 4.03; p=.00, Perlidae *t*(319)= -15.58; p=.00 and Simuliidae *t*(277)= 8.40; p=.00.

6.3.5 Similarities in macroinvertebrates taxa composition in the different land use categories

One-way (ANOSIM) analysis was used to determine the compositional similarities of macroinvertebrates in the sampled sites in the rivers studied. The Njoro River sites were revealed to be similar (R=-0.27, p=0.92) and the Kamweti River sites being dissimilar (R = 0.65, p = 0.01) in macroinvertebrates assemblages among land use classes.

With pair-wise SIMPER analysis, the benthic macroinvertebrate taxa abundance between land use categories of the Njoro and Kamweti Rivers were determined to indicate the percent contribution of different taxa to dissimilarity in benthic macroinvertebrate composition structure displayed in Table 6-3 and 6-4 respectively. In Njoro River the major families identified to contribute to the greatest dissimilarities between the FDS and the ADS were Heptageniidae (38.36%), Simuliidae (35.95%) and Baetidae (10.79%). The overall percent Bray Curtis dissimilarity between the FSD and the ADS was 56.67%. It was observed that Heptageniidae (43.35%), Telagonididae (18.73%) and Baetidae (14.33%) were the major families which contributed to the dissimilarities between the ADS and BUA with an overall percent dissimilarities 25.76%. The overall average percent dissimilarity between the FDS and BUA was 56.1% and was contributed majorly by Simuliidae (44.48%), Heptageniidae (20.41%), and Telagonididae (16.99%) families as shown in Table 6-3.

Table 6- 5: SIMPER results showing Average dissimilarities and Contribution percentage of the top ranked (in bold) macroinvertebrates taxa across land uses in the Njoro River.

TAXON	**FDS vs ADS**		**FDS vs ADS**		**ADS vs BUA**	
	Av. dissim	Contrib. %	Av. dissim	Contrib. %	Av. Dissim	Contrib. %
Arthericedae	0.07	0.13	0.17	0.30	0.07	0.28
Ashnidae	0.00	0.00	0.03	0.05	0.02	0.09
Baetidae	6.11	**10.78**	2.59	4.607	3.69	**14.32**
Caenedae	0.10	0.17	0.08	0.14	0.02	0.09
Ceratopoginidae	0.20	0.35	0.05	0.10	0.14	0.56
Chironiidae	2.01	3.55	2.25	4.01	0.00	0.00
Culicidae	0.00	0.00	0.03	0.05	0.02	0.09
Elmidae	0.25	0.44	0.45	0.79	0.14	0.56
Gomphidae	0.00	0.00	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00
Helodidae	0.20	0.35	0.33	0.59	0.10	0.37
Heptageniidae	21.74	**38.36**	11.45	**20.41**	11.17	**43.35**
Hydrophilidae	0.17	0.31	0.00	0.00	0.17	0.65
Hydropsychidae	0.35	0.61	1.75	3.12	1.86	7.21
leptophelibidae	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00
Oligochaeta	0.77	1.36	1.42	2.53	0.48	1.87
Oligoneuridae	0.00	0.00	0.00	0.00	0.00	0.00
Perlidae	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	0.00	0.00	0.00	0.00	0.00	0.00
Turbellaria	0.03	0.04	0.14	0.25	0.10	0.37
Potamonautidae	0.22	0.40	0.56	0.99	0.27	1.03
Prosopistomatidae	0.00	0.00	0.00	0.00	0.00	0.00

Psychodidae	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00
Pyralidae	0.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	20.37	**35.95**	24.95	**44.48**	1.88	7.30
Tabanidae	0.00	0.00	0.00	0.00	0.00	0.00
Telagonididae	3.55	6.27	9.53	**16.99**	4.82	**18.73**
Tipulidae	0.52	0.92	0.33	0.59	0.80	3.09
Overall percent dissimilarity	**56.67%**		**56.10%**		**25.76%**	

In Kamweti River the overall percent dissimilarities between the land use categories were lower than those obtained from the Njoro River as presented in Table 6-6. In Kamweti River, the FSD and ADS recorded a percent dissimilarity of 51.17% which was contributed majorly by Heptageniidae (38.09%), Baetidae (19.4%) and perlidea (12.72%). With a greater mean abundance in the FDS, the same taxa, Heptageniidae (31.42%), Baetidae (26.01%), and Perlidea (15.85%), contributed to the largest dissimilarity between the FDS and the BUA. Between the FSD and BUA recorded percent dissimilarity was 36.37%. Between the ADS and the BUA, the percent dissimilarity was 24.24% where Heptageniidae, Hydrospychidae and Potamonautidae contributed to the dissimilarities in the sites with 47.52%, 21.28% and 9.03% respectively.

Table 6- 6: SIMPER results on Average dissimilarities and Contribution percentage of the top ranked (in bold) benthic macroinvertebrates taxa across land uses in the Kamweti River.

TAXON	**FDS vs ADS**		**FDS vs BUA**		**ADS vs BUA**	
	Av. dissim	Contrib. %	Av. dissim	Contrib. %	Av. Dissim	Contrib. %
Ashnidae	0.07	0.13	0.24	0.66	0.32	1.31
Athericidae	1.42	2.77	1.31	3.59	0.00	0.00
Baetidae	9.92	**19.40**	9.48	**26.06**	0.57	2.33
Ceanedae	0.26	0.51	0.24	0.66	0.00	0.00
Ceratopogonidae	0.28	0.55	0.26	0.72	0.00	0.00
Chironomidae	1.50	2.94	0.82	2.26	0.99	4.08
Elmidae	0.09	0.17	0.88	2.43	1.41	5.83

Gomphidae	0.11	0.21	0.00	0.00	0.18	0.73
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00
Helodidea	2.16	4.21	1.99	5.47	0.00	0.00
Heptageniidae	19.48	**38.07**	11.43	**31.42**	11.52	**47.52**
Hydroplibidae	0.07	0.13	0.10	0.28	0.07	0.29
Hydropsychidae	4.37	8.55	1.11	3.04	5.16	**21.28**
Leptophlebiidae	0.30	0.60	0.28	0.77	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00
Oligochaete	0.00	0.00	0.00	0.00	0.00	0.00
Oligoneuridae	0.39	0.77	0.36	0.99	0.00	0.00
Perlidae	6.51	**12.72**	5.76	**15.85**	0.42	1.75
Philopotamidea	0.59	1.15	0.04	0.11	0.88	3.64
Turbellaria	0.00	0.00	0.00	0.00	0.00	0.00
Potamonautidae	1.22	2.38	0.12	0.33	2.19	**9.04**
Prosopistomatidae	0.00	0.00	0.00	0.00	0.00	0.00
Psychodidae	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.15	0.30	0.08	0.22	0.11	0.44
Pyralidae	0.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.33	0.64	0.30	0.83	0.00	0.00
Tabanidae	0.00	0.00	0.00	0.00	0.00	0.00
Teloganodidae	0.00	0.00	0.00	0.00	0.00	0.00
Overall % dissimilarity		**51.16**		**36.37**		**24.24**

6.4 Discussion

6.4.1 Community structure, composition and distribution of benthic macoinvertebrates.

This research study assessed at how benthic macroinvertebrate assemblages changed in the Njoro and Kamweti Rivers. From the results obtained, it was noted that the makeup of macroinvertebrate communities differed between locations and rivers, and that diverse sets of dominant taxa emerged. This was ascribed to both in-stream environmental conditions and land-use considerations, which altered not only the macroinvertebrates themselves, but also their relative abundances as reported by Mwaijengo *et al.* (2020). In both rivers it was observed that Heptageniidae and Baetidae (Ephemeroptera) were the most dominant families in both rivers.

The highest abundance of organisms from most major taxonomic groupings were observed during the egg hatching season (Chi *et al.,* 2017). The results from this study indicate the dominance of Ephemeroptera (Mayflies) in the Njoro River, being represented by the families of Heptageniidae, Baetidae, Ceanedae and Teloganodidae. Their abundance could be attributed to hatching period for mayflies and thus results in the rapid growth in individuals (Chi *et al.,* 2017) Another explanation could be that the organisms retreated to the cooler surfaces of the stones to avoid direct sunlight (Alhejoj *et al.,* 2014) at the period of sample collection..

Baetidae was the most abundance in both rivers as it has been reported that the larvae of Baetidae family are widely spread in different water conditions and usually associated with Caenidae larvae in lotic systems (Alhejoj *et al.,* 2014) which was the case in Njoro River. The high abundance of the Baetidae family in both the Njoro and Kamweti River was because Baetidae shows a moderate tolerance degree to pollution and often are found in very clean water to moderately polluted water, therefore their presence is usually an indicator of relatively very clean to moderately polluted water (Alhejoj *et al.,* 2014)

Simuliidae (Black flies) are significant macroinvertebrates in stream ecosystems. Human disturbance has an impact on black fly communities. The changes in stream structure caused by urbanisation and farm land use can have a significant impact on the community structure and diversity of black flies; consequently, changes in black fly population structure could be utilised as an indication of habitat degradation (Pramual & Kuvangkadilok 2009).

The high abundance of black flies (Diptera) in Njoro River observed could be attributed to the time of high discharge, the black flies moved away from the strong current forces. The finding agrees with that of some earlier reports in which they showed that rainfall has a direct correlation with black fly abundance, with black fly numbers increasing during wet season were in contrast to this finding in which they reported higher black fly abundance during the dry season as compared with wet season in southern Nigeria (Oforka *et al.,* 2019). The resukts which were obtained from this study suggest that the observed high abundance of black flies was due to increased rainfall which in turn created rapids and conditions suitable for development of preimaginal stages into adults. In contrast, the dry season had lower water volume and almost no rapids to support preimaginal development which could result in low black fly population as reported by Oforka *et al.* (2019).

Oforka *et al.* (2019) also documented that on the seasonality of the black flies, complex populations in two ecologically distinct foci in Northern Sudan showed that in the Galabat focus (savannah zone), adult black fly population was significantly higher during wet season than the dry season but reverse was the case at the Abu-Hamed focus (desert zone). The marked seasonality in abundance of black flies was attributed to rainfall and flooding.

The sensitive taxa (EPT) are usually associated with a pristine environments or areas with minimal disturbances because they are intollerant to pollution (Gituanja, 2020). The dominance of Baetidae, Heptageniidae, Hydropsychidae (Trichoptera) and Perlidae (Plecoptera) in Kamweti River which is regarded as semi-pristine can be attributed to that fact. Taxa Trichoptera is made up of families that are entirely aquatic and thrive in EPT-dominated lotic settings. Their supremacy stems from their ability to spin silk, which is employed for defence, reproducing, gathering food, and clinging to the bottom substrate material. The taxa also has a variety functional feeding groups (Gituanja, 2020). Plecoptera are the most intolerant of the EPT group, having a tight niche that includes only running water, high dissolved oxygen levels, cold water temperatures, and substrate with tree inputs (Gituanja, 2020). This may explain why the Hydropsychidae (Trichoptera) and Perlidae (Plecotera) were discovered to be prominent in the Kamweti River.

Potamonautidae (freshwater crabs) are significant components of African freshwaters. There are over a hundred species, which can be found in all types of freshwater settings. They are the primary source of food for a variety of freshwater carnivores (Dobson, 2004). As a result, crab population size and species composition may have significant bottom-up ramifications for the river catchment ecology. Dobson *et al.* (2007) reported that crabs were widely distributed across Mt. Kenya area by quantifying the spatial distribution and the densities of freshwater crabs through a comprehensive analysis of the rivers draining the Mt Kenya region. In this study, there was high abundance of fresh water crabs in Kamweti River as compared to the Njoro River. The high abundance observed was because the riverine species are also able to persist during drought conditions by burrowing into the substratum (Zimmerman & Covich, 2003) where they remain buried in remain buried in refugia, either squeezing into interstitial spaces or excavating shallow depressions in sand under boulders. The current findings, on the other hand, appear to be similar to with those of Abdallah *et al.* (2004) on highland Tanzanian rivers, where freshwater crabs (Potamon sp.) dominated the benthos.

6.4.2 Spatial distribution of benthic macroinvertebrates

The higher densities of benthic macroinvertebrate families identified in the FDS in the Njoro and Kamweti Rivers may attributed to the less disruptions from the anthropogenic and natural actions present in the sampling locations which promoted a broader environmental conditions which were capable of supporting a diversified benthic macroinvertebrate ecosystem. Similar studies have found that streams draining forested land use have more taxonomic diversity than rivers which tranverses through other land use patterns such as pasture areas, farmlands, commercial and residential (Fekadu, 2021). The orders with low tolerance levels to pollution (Ephemeroptera, Plecoptera and Trichoptera) were found to be more abundant in the Kamweti River FDS than in the ADS and BUA. The larger number of vulnerable EPT species and the high variety and richness of macroinvertebrates in the sampling stations was attributed to the broader habitat diversities and complexities in these sites, together with adequate physico- chemical parameters in-stream (Lubanga *et al.,* 2021).

Fekadu (2021) highlighted that due to contamination of the river channel by pollutants leading to unfavourable changes in water quality, the composition, distribution and structure of the pollutant intolerant orders (the EPT) will decrease while tolerant orders such as Diptera have higher abundances. On the contrary, some taxa belonging to the EPT orders for example Baetidae, Caenidae and Hydropsychidae can register higher abundances and diversities in waters that are polluted by organic material and for this reason, they can their utilization of this index as a measure of the levels of disturbance in a river system can be compromised Fekadu (2021). This was the case observed in the FDS of the Njoro River.

The EPT to class is normally associated with undisturbed ecological conditions and it has been observed that macroinvertebrates orders Plecoptera, Ephemeroptera and Trichoptera, *Gammarus*, *Assellus*, red midges, *Chironomidae* and *Tubificidae* will disappear in their mentioned order as organic pollution increases in the stream channel (Gituanja, 2020). This was observed in the Kamweti River, the upstream sites were rich and had high relative abundances of the EPT orders and was observed to decrease downstream along the changing land use categories. The most sensitive order Plecoptera (perlidae) to be was observed to be totally absent in the areas with intensive farming activities.

In Kamweti River, the fresh water crabs (Potamonautidae) were noted to have high abundances as compared to the Njoro River which decreased from upstream to downstream. The findings of this study are in agreement with those by Dobson *et al.* (2007) which the authors documented that the high abundance of the fresh water crabs were in the forest sites than the agricultural sites. The authors documented that most of the rivers dissecting the Mt.

Kenya originates in or above the forest that covers the the upper slopes of the mountain. The forested landscape act as a spawning sites which crabs then migrate downstream as they mature. Dobson *et al.* (2007) also documented that juveniles of the freshwater crabs in Puerto Rico were more abundant in a stream running through undisturbed forested landscapes than in a similar stream whose catchment forest had been cleared and then re-established. The finding indicated that the freshwater crabs may be impacted by land use, in that densities can be lowered and reproduction rates may be impaired through the clearance of forest for agricultural purposes.

Agricultural land use pattern is often linked to changes in quality of waters in the channel and habitat degradation. This has resulted to changes in macroinvertebrate assemblages in terms of population structure and lowered taxonomic richness and abundance of pollution tolerant taxa in the rivers (Matomela *et al.,* 2021) and the results obtained from this research were found to be consistent with this general tendency. From the observations made from this study, it was noted that the abundance of mayflies could be an indicator of agricultural disruptions as their abundance decreased in the ADS regions of both rivers. This was in agreement with the studies by Matomela *et al*. (2021) who highlighted that the mayflies, specifically Baetidae, Caenidae and Trichorythidae families were commonly associated with streams which experienced disturbances from agricultural practices.

In Kamweti River, the abundance of Ephemeroptera was lower at the cultivated sites than the values at the built-up regions. Higher values downstream the built-up regions could be attributed to the substrate variations which provided more niche, the availability of riffles and pools which supported higher abundances and varieties of benthic macroinvertebrate species. Another factor which contributed to the higher abundance was the enriching and healing of the river downstream as reported by Gituanja (2020). The findings from this research agree with those of Dorigo et al. (2010) where the authors observed a decline of metal content in benthos with increasing distance downstream that revealed recovery of the river. The dilution effect of tributaries and the floodplain have been found to influence the healing of rivers downstream.

The farmland site with the highest pesticide use had the lowest abundance of Ephemeroptera, most likely due to the higher mortality induced by the elevated agrochemical levels at the site. Pesticides kill non-target organisms such as mayflies, according to Sartori and Brittain (2015) in a study conducted in Lausanne. Arimoro and Muller (2010) reported that the population of Ephemeroptera larvae decreased downstream of the Orogodo River in Nigeria as chemical concentration increased. It was also discovered that the homogeneity of the Substratum in the farmland lowered the niche, lowering the quantity of the Ephemeroptera. Furthermore, an overabundance of nutrients was shown to cause an increase in primary production and amounts of organic matter, as well as depletion of oxygen as a result of decomposition, both of which have a negative influence on the Ephemeroptera group (Paul & Meyer, 2001).

The enhanced abundance was most likely caused by increased water transparency, DO, and decreased conductivity and TDS. Land-use disturbance caused by urban development and agriculture activity deteriorated water quality in the lower reaches, resulting in a fall in macroinvertebrate abundance. This pattern is consistent with prior research by Paul and Meyer (2001) and Turner and Rabalais (2003), which found that urbanisation and agriculture increase nutrient loadings. Higher phosphorus and nitrogen inputs are associated with wastewater from metropolitan areas and fertilisers from agriculture catchments, both of which have an impact on steam benthic macroinvertebrates (Broussard & Turner, 2009). Stream and river ecosystem degradation draining urbanised landscapes causes urban stream syndrome, which is characterised by flashier hydrographs, increased nutrient loads and pollutant concentrations, changed stream morphology, and diminished biodiversity (Meyer *et al.,* 2005; Walsh *et al.,* 2005).

6.4.3 Diversity of Macroinvertebrates.

Headwater streams are significant lotic habitat given that they frequently make up the vast majority of network length (Jonsson *et al.,* 2017). These small streams serve as the major link between land and aquatic ecosystems, facilitating vital ecosystem processes including degradation of organic matter and nutrient retention, which are essential for the operation of lower aquatic systems. Furthermore, headwater streams may hold varied taxonomic compositions that are not just functionally essential but it also boost to diversity. Changed environmental circumstances, on the other hand, may result in the extinction of headwater taxa, altered community composition, and community homogenization, resulting in diminished regional biodiversity with possible ramifications for the operation of these habitats (Jonsson *et al.,* 2017).

Diversity is a structural character of an ecosystem (Bretschko, 1995). High species diversity allows for complex population interactions involving energy transfer, competition and niche apportionment. The un-impacted habitats are generally predicted to have diverse benthic ecosystems. Anthropogenic disturbances caused by changes in land-use practises have been shown to affect invertebrate diversity patterns in streams draining modified catchments often resulting in a decrease in the total number of taxa as well as a shift to a more unevenly distributed community in which one or two taxa are numerically dominant (Kibichii *et al.,* 2007). Studies have shown that rivers which are continuously visited by people for various activities and for livestock watering leading to continuous disturbance of its substrates (Aura *et al.,* 2010; Gichana *et al.,* 2015; Mathooko, 2001). Their habitats experience a high disturbance frequency and low refuge availability thus are predicted to have low macroinvertebrate diversity and abundance, in contrast to habitats experiencing low disturbance frequency and high refuge availability (M'Erimba *et al.,* 2014). From this results it was concluded that the Njoro and Kamweti Rivers site with good substrate coverage recorded high diversity values.

The Shannon diversity index (H′) values in the Njoro River was in the range of 1.65 to 1.75, while it ranged from 1.77 to 2.04 in the Kamweti River. The Shannon-Wiener diversity index typically ranges from 1.5 to 3.5, with values surpassing 4.5 on rare occasions (Magurran, 1988). Fekadu (2021) reported that high diversities indicates a suitable environment, while low diversity indicates a lack of habitat availability. The pattern observed in both rivers, higher diversity values were observed at the FDS with readings of H′=1.75 for the Njoro River and H′=2.04 for the Kamweti River which was slightly above that of the ADS (H′=1.99). The findings corroborated those of M'Erimba *et al.* (2014) who observed substantial macroinvertebrate diversity at moderately disturbed locations.

The highest diversity value (2.04) was obtained from the FDS of Kamweti River. Similar results were recorded by Kibichii *et al.* (2007) and highlighted that forests, particularly those containing native tree species, helps to maintain the water flows relatively stable by reducing the speed of storm water runoff from in the catchments and can trap sediments. This enables for the growth of a diverse and rich invertebrate community. In comparison to the sites of this river, the ADS and the BUA recorded much lower values of 1.99 and 1.77 respectively. The observed decrease in benthic macroinvertebrate diversities downstream could be attributed to the increasing sediment loading rates and high plant material decomposition rate at these locations (Fekadu, 2021). Increase in sediment transfer from nearby land uses and negative anthropogenic impacts within a catchment and along the riparian zones are the pincipal contributors to diminishing benthic populations in rivers and streams. Increased sedimentation in the river channel have an impact on the aquatic community structure by limiting habitats, modifying flow velocity, food quality, and interstitial spacing (Gichana *et al.,* 2015). This seemed to explain the low diversity recorded downstream in the Kamweti River and the Njoro River.

The observed variations in the diversities values obtained could also be attributed to several factors scuh as; daily pertubations which occurred in the sites interfered with the growth and development of the macroinverebrates thus not giving enough time for the organisms to form and stabilize. Also the accumulated impacts from disruptions that occurover short periods of time also stress the river system and changes water quality. This results in the dominance of taxa that can be able to tolerate pollution at different levels. Another explanation could be discrepancies in patchy food distribution caused by uneven surficial disturbances on these rivers' silt (M'Erimba *et al.,* 2014).

The observed difference in diversities in benthic macroinvertebrate assemblages in the different land use categories from upstream to downstream of both rivers was contributed by elevation. Elevation is thought to reduce macroinvertebrate diversity as it effects numerous aspects of the ecosystem, which may in turn affect species diversity (Sprout, 2020). For instance, if the temperature of the water is colder at higher elevations, metabolism and development may be reduced compared to warmer streams, causing certain macroinvertebrates to avoid this circumstance. Water temperature also has an effect on dissolved oxygen; dissolved oxygen normally increase as water temperature falls; conversely, dissolved oxygen reduces with altitude due to reduced atmospheric pressure. Because some species demand substantial oxygen levels to develop, a decrease in oxygen in streams can reduce biodiversity (Sprout, 2020).

Elevation also alters the riparian ecosystem of streams, which alters the substrate content. For example, streams above the tree line will be devoid of organic materials, which many aquatic species rely on for herbivorous or detritivorous diets. Given the ability of elevation to alter so many features of habitat, it stands to reason that macroinvertebrate diversity declines as these resources become less desirable to invertebrates, and such observations have been made numerous times in the literature. Human activities such as urbanisation, transportation, and agriculture have less of an impact on high elevation ecosystems than low elevation environments. Land uses that disrupt freshwater ecosystems, as opposed to elevation, can alter a lot more than water temperature and dissolved oxygen. Land uses such as agriculture, mining, and damming can alter the hydrology and chemical composition of streams over time, including changes in pH, dissolved oxygen, nutrient availability, organic matter, substrate, and the addition of hazardous compounds. As a result, any examination into elevation differences must take into account any confounding disruptions within the vicinity (Sprout, 2020).

Pair-wise SIMPER analyses of macroinvertebrate species abundances revealed that the FDS and ADS had the highest total percentage Bray Curtis dissimilarity in both rivers assessed. In Njoro River, the highest dissimilarities were observed between the FDS and the ADS whereas in Kamweti River the major differences were between the FDS and the BUA. The dissimilarities between the sites were majorly the different disturbance levels at the sites as a result of the different land covers. Another reason might be the presence of competitive exclusion, in which strong competitors out competed weak counterparts (M’Erimba *et al.,* 2014).

6.5 Conclusion and Recommendation

The Ephemeroptera and Diptera orders dominated the Njoro River, whereas the Ephemeroptera, Plecoptera, and Trichoptera orders dominated the Kamweti River. Changes in the composition and distribution of taxa (EPT) were found as a result of agriculture activities and human activities in the settlement areas downstream, which influenced both the riparian regions and the in-stream water quality.

The results on the distribution of benthic acroinvertebrate assemblages obtained from this study presented how changes in surface water quality physico-chemical parameters affected the benthic macroinvertebrate assemblages. The dominant benthic macroinvertebrates in the Njoro and Kamweti rivers mainly displayed significant variations spatially in terms of their abundances amongst the sampling sites and the lnd use classes. Variations were also observed in terms of taxon richness, eveness and the diversities. From this results its is affirmed that benthic macoinvertebrates can give information which can be important in monitoring any modest changes in water quality parameters which can influence their structure, composition and distribution and the general status of the river system as long as they are persistent, especially in areas under small-scale agricultural and built-up areas.

From the results, the study recommends that the forest cover and riparian zones along the Njoro and Kamweti Rivers be conserved in order to preserve the biotic communities in the rivers. By analyzing how benthic macroinvertebrates respond to changes land use that occur in the catchment coupled with other anthropogenic actions contributes to the ongoing development of biomonitoring indices in the regions. It is also recommended that the bethic macroinvertebrate from the rivers studied should be classified to the major Functional Feeding Groups (FFG) which will aid in giving information on trophic dynamics in water bodies.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 General Discussion

7.1.1 Spatio-temporal trends in patterns of land use and and cover.

For a period of 31 years, from 1988 to 2019 (ten year epoch), change detection by use GIS and remote sensing techniques indicated that there were changes in land use and land cover in the Njoro and Kamweti River catchments. several land use classes were identified from both catchments and the principal LULC categories (Forest, Agricultural and buil-up areas) in this study represented anthropogenic disturbances which guided the understanding of the effects of adjacent land utilization patterns on receive water bodies. In 1988, forests farmlands, and built-up zones covered 57.00 %, 16.4 %, and 2.54 % of the Njoro river watershed, respectively, while in 2019, the classes covered 29.31 %, 50.34 %, and 5.24 % respectively. The principal LULC classes in Kamweti River covered 75.85 %, 6.79 %, and 0.85 % respectively in 1988, and 62.34 %, 3.29 %, and 3.06 % correspondingly in 2019.

Area under agricultural land use was observed to increase between 1988 and 2019, particularly the Njoro river catchment where land was majorly utilized for small-scale mixed farming activities which was evident across the catchment. Kamweti River mid-catchment, tea cultivation is extensive. Small holder subsistence farming is mostly rainfed in both catchments' wet seasons but is irrigated with river water during the dry seasons.

The built-up regions are made up of commercial, residential and industrial areas. These zones also includes the areas with constructions such as green houses and roads netweorks. Most of the natural vegetation in the Mau and Mt. Kenya forests, respectively, may be found in the upper sections of the studied catchments. Other forest cover is primarily made up of woodlots in agricultural areas where *Grevillea robusta* and *Eucalyptus species* predominate. Evidence of forest transformation to other land cover classessuch as agriculture, was more prevalent in the middle and downstream regions of both rivers. Riparian habitats serve crucial ecological services (Wantzen *et al.,* 2008). Obtained results are comparable to those by Musa and Odera (2015) who indicated that between 1984 and 2009, agricultural land decreased from 39.7% to 15.8%. In the Ruiru and Ndarugu River basins, Wambugu, 2018 noted similar developments. More impermeable surfaces are created with urbanization impares water quality further downstream.

Additionally, it was noted that the expansion of areas under agricultural land contributed to the degradation of riparian vegetation along the rivers. The biological productivity and diversity of riparian habitats, according to Wantzen *et al*. (2008), render them vulnerable to settlement, agriculture, and grazing. Gituanja (2020) highlighted that that clearing riparian vegetation has an impact on the topology the channel, the ecosystem services provided by the riparian vegetation are reduced, and the macoinvertebrate abundances and the diversities are impacted.

7.1.2 Land use influence on vegetation composition, abundance and diversities

Riparian vegetation serves a variety of ecological roles. Mendez-Toribio *et al.,* (2014) reported that riparian areas perform poorly when vegetation is removed or degraded in general. Fierro *et al.* (2017) reported that land use transformation, particularly in agricultural watersheds, negatively impacts on aquatic food webs and stream water quality, which alter the species composition and organisation of the biota. It was clear from this study that riparian plant diversity and composition were impacted by local anthropogenic activities in built-up regions and agriculturally dominant sites. The growth of agricultural land and built areas exposed riparian vegetation to anthropogenic influences, supporting the idea that intensive land uses impaired the riparian habitat conditions.

Dominant plant communities were found in both rivers, although they were identified at specific locations and types of land use. Some vegetation communities were found to be specifically linked to particular river systems. From site N1 (upstream) to N3 (downstream), trees and bushes were seen to have a pattern of decreasing abundance (Midstream). In the middle and downstream stretches, there were more herbs. The forest ecosystems across the land use offered characteristics that helped to sustain the high quantity of trees and shrubs that declined downstream. The herbs became more predominate as the levels of disturbance increased at the midstream and downstream portions at the Agricultural Dominated Sites. A similar pattern was seen along the Kamweti River, where herbs similarly predominated at the heavily degraded downstream areas. Most of the trees present downstream in both rivers' built-up areas were exotic species. According to Bowers and Boutin (2008) the floristic quality of the plant community decreases as the level of disturbance in a region increased.

Furthermore, it was evident that a greater diversity of species and structural complexity in the community were observed as the quality of the riparian environment increased. Given that many individuals could attain their maximum development sizes in the natural habitat if human-induced disturbances are kept to a minimum, this emphasises the need of safeguarding and conserving natural habitats for plant biodiversity in the Njoro and Kamweti River ecosystems. The diversity indices in both rivers were highest at the FDS, which had experienced the least influence, and lowest at the ADS, which had experienced the most disturbance. Similar to this, the FDS and BUA had the greatest Sorenson's Index of Similarity values, while the FDS and ADS had the lowest values. It was concluded that intermediate disturbance increased habitat variability creating providing an ideal environment for nurse effects to support species diversity.

7.1.3 Impacts of land use on water quality

With increase in human population there is need for economic development. For the production food and the need for housing materials, vast land has been deliberately transformed into built-up areas and farm lands. In the situation of declining cultivated area and decreasing productivity, humans use substantial quantities of pesticides and fertilisers leading intentisive agriculture which has severe consequences on the receiving water bodies, human and environmental health (Cheng *et al.,* 2022).

In this study, agricultural and built-up areas had a significant effects in the water quality status whereas the forested class land has a less negative impact on both rivers. Agricultural land had a relatively big negative influence on water quality. To some extent, forest areas were seen to be a buffer to against water quality degradation. Built up zones were densely populated areas and the impervious surface runoff increased as the buffer zone expanded. Industrial effluent and sewage discharge produced pollutants which ended up into to the aquatic systems. The contamination of water of the Njoro and Kamweti rivers was linked to the agricultural inputs, the fertilizer and pesticide types utilized in the catchment for maximum crop production attributed to the use of pesticides and fertilisers (Cheng *et al.,* 2022).

Physico-chemical characteristics of the water in the Njoro and Kamweti Rivers displayed spatial variations that can be linked to human activity and the usage of the land along the rivers. Increased temperature, conductivity, and nutrient concentration are results of the alterations. The Njoro and Kamweti Rivers' spatial variation in water temperature was primarily attributed to altered riparian vegetation in sampling sites at the lower reaches, which left most areas with little to no canopy cover and high water temperatures as a result of increased solar radiation reaching the water's surface (Gichana *et al.*, 2015).

Higher dissolved oxygen values registered at the upstream locations may be linked to the lower temperatures as a result of canopy cover. The sites' turbulent water may have oxygenated the water as well. Reduced flow velocity and elevated temperature may have contributed to the drop in DO at downstream sites in both rivers. The solubility of oxygen in water reduces with increasing water temperature, but the amount of oxygen in the water increases with increasing velocity (Allan, 2004). Another element that may have contributed to lower DO concentration levels in downstream sites was a high organic load. During decomposition, dissolved oxygen in water is heavily utilised by organic wastes (Busulwa & Bailey, 2004). Urban areas and residential areas release organic wastes into the stream. This was noticeable at Njoro River site N3. The results support those of Fekadu (2021) who reported low dissolved oxygen concentration in Kipsinende River, Kenya.

Compared to the Njoro River, the electrical conductivity measurements taken from the Kamweti River registered lower values. It was noted that EC increased downstream. This was ascribed to runoff from agricultural regions and the release of sewage effluents into the stream. The Njoro River's upstream location recorded low conductivity levels, which can be attributed to less disturbance there as opposed to the downstream site, which recorded high conductivity levels that also rose as nutrient levels rose. This is consistent with Minaya's (2010) findings, who found that the Mara River's electrical conductivity varied significantly.

The pH measurements made in the Njoro and Kamweti Rivers showed longitudinal changes, with the higher readings attributable to the agricultural activities which lead to leaching of fertizers. The tea plantations and farms that grow maize use the fertiliser. Less influence on the stream was attributed to low pH measurements at sites K1 and K2 (Kamweti River). However, the pH readings in both rivers were within the permitted limit for naturally occurring waters (6.0-8.5).

The most nutrients in both rivers did not significantly vary between sites and land use types. However, excessive use of nitrogenous fertilisers in maize farmlands, which cause runoff of these fertilisers into streams, may be the cause of the rise in nitrate concentrations downstream. This was more pronounced at Njoro River midstream and downstream sites since they were significantly impacted as a result of crop cultivation and the regular input of livestock wastes. The nutrient levels in both rivers recorded low values in the upstream sites as a slight increase in concentrations observed in the lower reaches as a result of agricultural activities including crop growing with heavy fertiliser use, which likely leached into streams during the wet season. High flows that caused waste to be carried into the stream by runoff from agricultural land may be the source for the temporal volatility of nitrite levels in the stream. McCarteny (2010) reported similar findings in the Mara River.

The Njoro River's middle and lower reaches (N3, N4 and N5) recorded higher TP concentrations, and this is likely due to wastewater discharge from neighbouring industrial operations. The highest SRP and TP concentrations found at the sites also ascribed to human activities such as swimming and washing in streams, which increased the amount of phosphorus owing to the use of detergents, as well as agricultural operations such as the use of fertilisers. This could account for the elevated the levels of Total Phosphorus and Soluble Reactive Phosphates levels during the rainy season.

7.1.4 Benthic macroinvertebrate community composition, distribution and structure as influenced by land use

Ephemeroptera and Diptera taxa were noted to be dominant in the Njoro river system. Ephemeroptera abundance was observed to decrease downstream with the increase in human activity. Reduced allochthonous energy inputs from human activities like cutting down riparian vegetation may have led to low abundance, which in turn led to less food being available for aquatic insects (Masese & McClain, 2012). In the Moiben River, Masese *et al.* (2009) made similar observations. Higher ecological deterioration may be linked to a higher number of Diptera taxa in the Njoro River's downstream sites. Sedimentation runoff from can be linked to the impairment. The Njoro River's middle and lower reaches show that the Diptera dominated agricultural areas. This could be because the taxa can adapt to low oxygen conditions and survive organic pollution by using haemoglobin to breathe more effectively during periods of low oxygen concentration in streams. When there is a disruption, the number of tolerant organisms increases (Barbour *et al.*, 1999).

Human activities predominant in the Njoro River included livestock rearing and maize plantations, which became more intense downstream. In sites N4 and N5, the riparian zone is used for maize farming, and is frequently used for grazing and animal drinking (Sites N3 and N4). Agriculture pollutants, such as fertilisers, can alter the biotic and abiotic qualities of streams, and cattle can alter the stream substrate, damaging invertebrate habitats. Higher abundance values of macroinvertebrates found may be related to ecological balance and the low velocity of the channel during the dry periods, whereas during the rainy season changes such as increased discharge rates result macroinvertbrate drifts that often results in uniform distribution of the population within the river channel (Gichana, 2013).

Kamweti River sites K1 and K2 recorded the highest EPT taxa, which then reduced downstream, the stream's middle and lower sections recorded a complete lack of plecopterans (Perlidae) in terms of abundance. Because it is susceptible to pollution and is linked with pure environments. The EPT taxa predominated in sites K1 and K2 Site K1 was an undisturbed headwater station with high habitat quality. Agriculture-related activities, which discharge agricultural runoff into the stream and affect the status of water quality were noted to be predominant in the middle and lower portions of the river. Sites K4 and K5, which are used as watering abstraction stations, were also characterised by agricultural operations with little to no canopy cover. This is consistent with the findings documented by Gichana (2013) that that densities of the EPT orders were high in sampling stations located in the forested landscapes and they were observed to reduce along different land use gradients which caused disturbances in the streams.

Macroinvertebrate diversity was high in forest regions. The forest provides a variety of high-quality habitats for invertebrates and is a reliable source of plant organic materials. The results indicated that the diversity of macroinverebrates decreased from upstream to downstream with the increase in sedimentation and organic matrial from the catchments in the sampling sites located in the middle and the lower sections of the rivers. Increase in sediment loading rates due to intensive anthropogenic activities within the catchment is a key contributor to the decline of benthic macroinvertebrates in lotic systems (Fekadu, 2021). Because suspended solids in fine sediment absorb heat from sunlight, causing temperature to rise and, as a result, a decrease in dissolved oxygen, the diversity of instream biotic groups is reduced. This explains why the Njoro and Kamweti Rivers have lower diversity values downstream the agricultural and built-up areas.

Few or no riparian plants, livestock grazing, bank erosion, garbage dumping, and other factors were present in the agriculturally dominant and built-up. Since sensitive macroinvertebrates are replaced by the tolerant ones, the low diversity values in the lower reaches of the streams can be explained by the organisms' tolerance to environmental conditions. The natural vegetation and varied macrohabitats, such as riffles, runs, and pools that are present in the Forest-dominant areas contribute to the high species richness. The disturbances causing the lack of many macrohabitats, led to the lower richness values midstream and downstream. Aura *et al.* (2010) also reported similar observations that hydrological regimes and perturbations can affect the richness of macroinvertebrates.

7.2 Conclusions

Satellite data obtained indicated that in both catchments, forest cover has been declining but at different rates. Between 1988 and 2019, the forest covered 57.00 % and decreased to 29.31 %. Farmland land use had increased from 16.40% to 50.34 % and built-up areas increased from 2.54 % to 5.24 %. In the kamweti river catchment, the forest covered 75.85 % and decreased to 62.34 %. Farmland land use had decreased from 6.79 % to 3.29 % and built- up areas increased from 0.85 % to 1.48 %. Agriculture, settlements and logging were considered reason for the decrease in the area under of forest cover.

Riparian plant species composition, richness, diversity and evenness was high in the upstream sections of as compared to midstream and downstream sections. From the observations, anthropogenic disturbances as a result of the adjacent land uses disrupted the natural vegetation community in the agricultural areas dragging it into its early stage of ecological succession. Large indigenous trees in these sites were also missing due to overexploitation, but they were found in the forest areas, upstream. Overgrazing and overexploitation of riparian resources impacted on the composition and diversities. The differences observed between both riparian zones brings about the need for rehabilitation and conservation of natural resource through designation of protection as observed in the forested areas of Kamweti River.

The upstream sites had positive effects on temperature, dissolved oxygen and Elecrical Conductivity. Due to land disturbance brought on by agricultural and urban land use activities, the parameters were affected. Agronomic techniques and riparian encroachment had negative influences on nutrients due to agricultural land usage. Comparing built-up areas to agricultural and forest land, built-up area had the greatest effects on the quality of water overall.

Because of changes in water quality, the richness, composition, diversity, and water quality of benthic macroinvertebrates decreased in the downstream direction. In Njoro River, Ephemeroptera was dominant followed by Diptera whereas in Kamweti River, the EPT orders was dominant and their abundance were highest at the less impacted sites and lowest at the agicultural areas with the absence of the most Plecoptera order which is the most sensitive to pollution.

7.3 Recommendations

Monitoring changes in land cover in all of the watersheds should be done using the extensive history and richness of data currently available through remote sensing. This will make a substantial contribution to the conservation of water resources from deterioration and pollution.

To buffer the stream from the consequences of nearby land uses, it is important to manage riparian land use and restore buffer zones by reclaiming them and replanting them with indigenous trees.

The many stakeholder groups in both catchments should be continually educated and included in discussions on the best approaches to maintain and restore the catchments. This will guarantee a healthy ecology that may support a variety of aquatic life forms and other water users.

A continuous bio-assessment procedure based on EPT biotic indicators of rivers should be carried out on a regular basis in order to develop a long-term profile of the state of water resources and environmental stability. In order to reduce the negative impacts that jeopardise the water quality of the Njoro and Kamweti Rivers, a protective criterion needs to be established.

7.4 Further research

Additional research should be conducted along the Njoro and Kamweti Rivers, to analyse the status of water quality in these catchments during different seasons as influenced by land use.

Future studies that combine both physico-chemical and responses of benthic macroinvertebrates assemblages to effects (both short and long-term) of land-use and related anthropogenic activities over Spatio-temporal scales are recommended in the bioassessment of these of the Njoro and Kamweti Rivers.

The many stakeholder groups in both catchments should be continually educated and included in discussions on the best approaches to maintain and restore the catchments. This will guarantee a healthy ecology that may support a variety of aquatic life forms and other water users.

A continuous bio-assessment procedure based on EPT biotic indicators of rivers should be carried out on a regular basis in order to develop a long-term profile of the state of water

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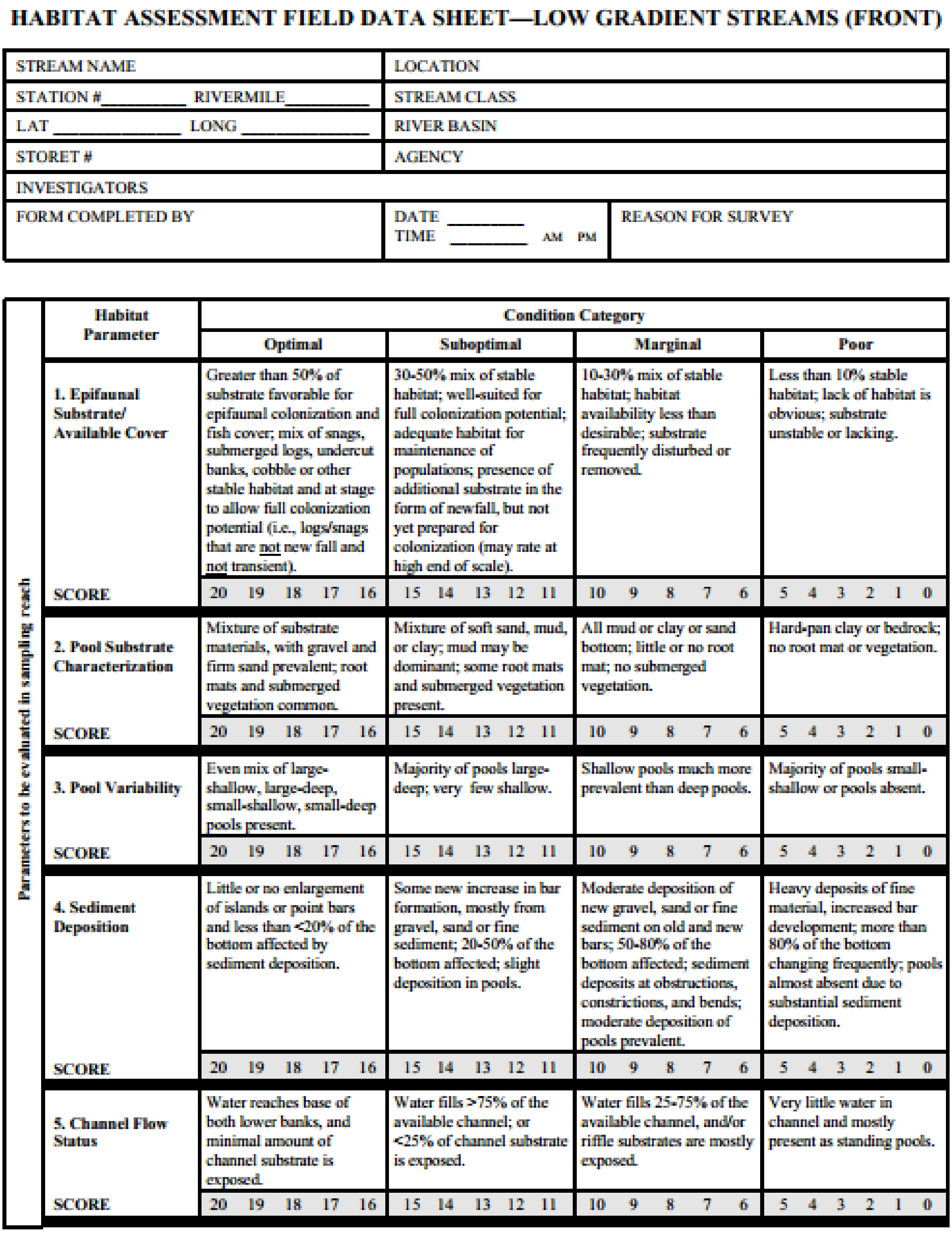
APPENDICES

Appendix A: Habitat quality assessment classes

CLASS	**DESCRIPTION**	**SCORE (% OF TOTAL)**
A	Unmodified, natural	100
B	Largely natural with few modifications. A small change from the natural habitats and biotas may have taken place, but the ecosystem functions are essentially unchanged	80 - 99
C	Moderately modified. A loss and change from the natural habitats and biotas has occurred but the ecosystem functions are still predominantly unchanged.	60 - 79
D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.	40 - 59
E	The losses of natural habitats, biotas and basic ecosystem functions are extensive.	20 - 39
F	Modifications have reached a critical level and the lotic system has been completely modified, with an almost complete loss of natural habitats and biotas. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.	0 - 19

Appendix B: Habitat scoring sheet



HABITAT ASSESSMENT FIELD DATA SHEET—LOW GRADIENT STREAMS (FRONT)

STREAM NAME	LOCATION
STATION #_________ RIVERMILE_________	STREAM CLASS
LAT ____________ LONG ____________	RIVER BASIN
STORET #	AGENCY
INVESTIGATORS	
FORM COMPLETED BY	DATE ________ TIME ________ AM PM
	REASON FOR SURVEY

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than <20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

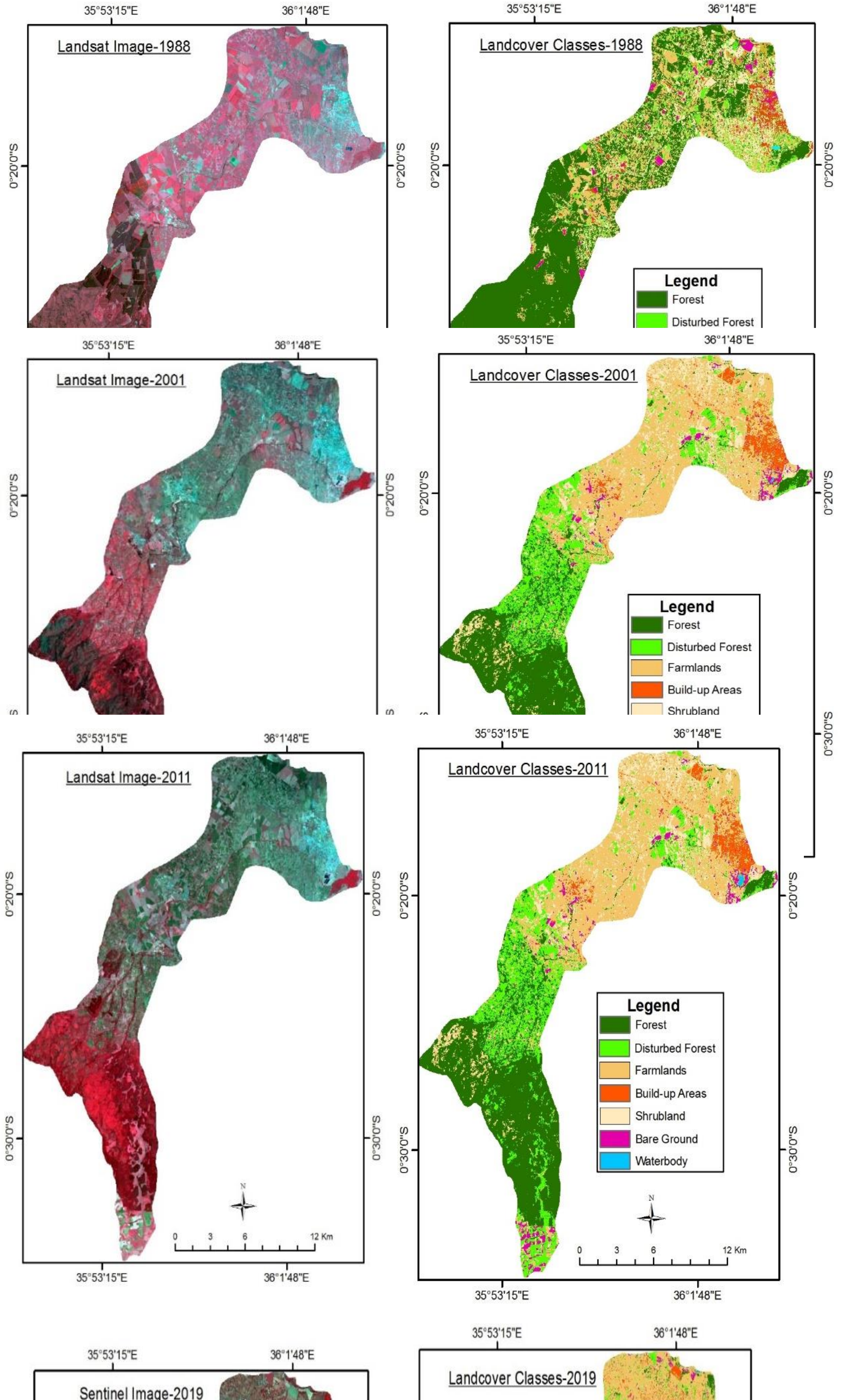
HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS (BACK)

	Habitat Parameter	Condition Category			
		Optimal	**Suboptimal**	**Marginal**	**Poor**
Parameters to be evaluated broader than sampling reach	**6. Channel Alteration**	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
	SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
	7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
	SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
	8. Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
	SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
	9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
	SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
	10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
	SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
	SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

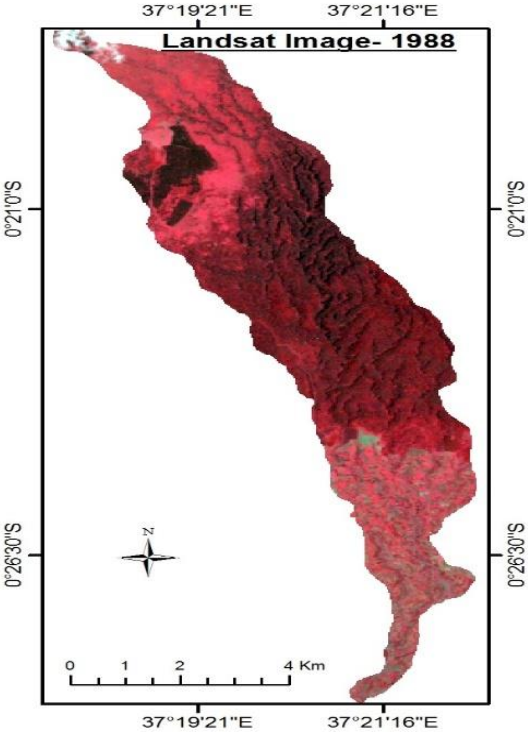
Total Score __________

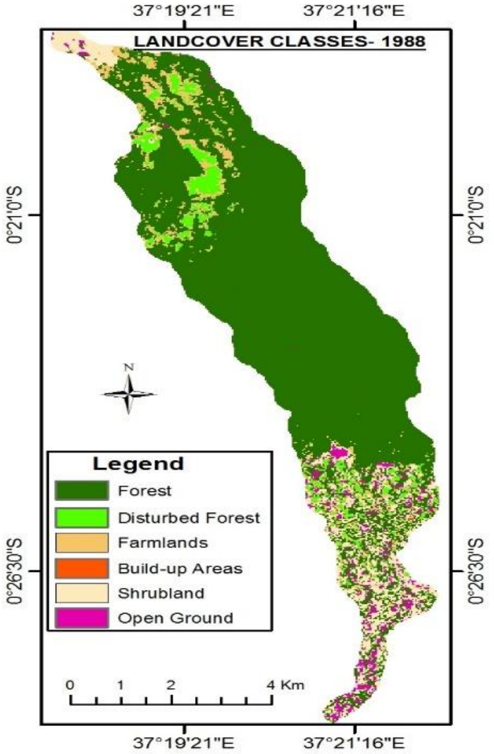
Appendix C: Key data analysis outputs

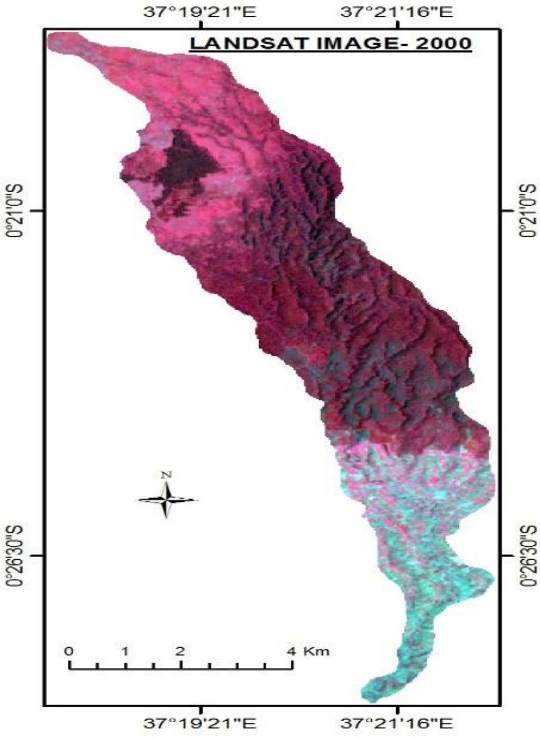
Land Use Land Cover maps - Njoro River Catchment

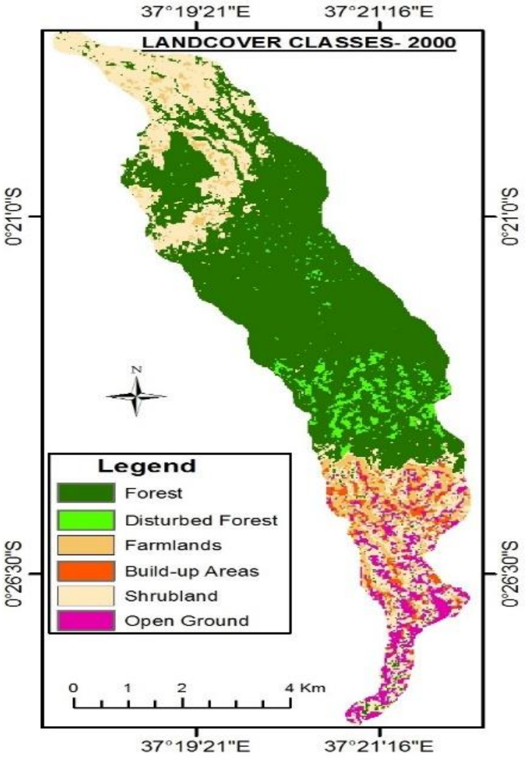


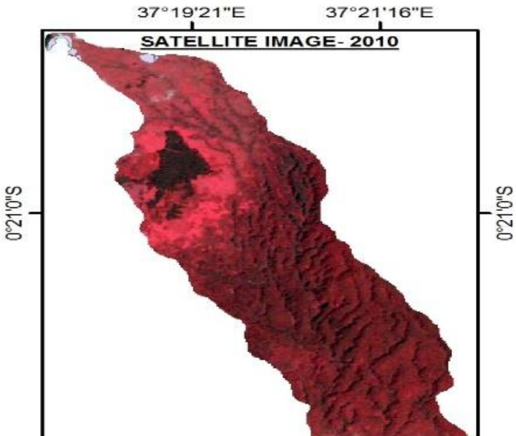
Kamweti River Catchment











Vegetation abundance variation across sites in Njoro and Kamweti River

NJORO RIVER ANOVA

Numbers

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	9.118	4	2.279	1.226	.303
Within Groups	228.757	123	1.860		
Total	237.875	127			

KAMWETI RIVER-ANOVA

Numbers

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	23.031	4	5.758	2.575	.041
Within Groups	266.090	119	2.236		
Total	289.121	123			

Multiple Comparisons

Dependent Variable: Numbers

Tukey HSD

		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
(I) Sites	(J) Sites				Lower Bound	Upper Bound

K1	K2	-.243	.408	.976	-1.37	.89
	K3	-1.147*	.402	.040	-2.26	-.03
	K4	-.693	.488	.616	-2.05	.66
	K5	-.260	.427	.974	-1.44	.92
K2	K1	.243	.408	.976	-.89	1.37
	K3	-.904	.386	.139	-1.97	.17
	K4	-.451	.476	.878	-1.77	.87
	K5	-.017	.413	1.000	-1.16	1.13
K3	K1	1.147*	.402	.040	.03	2.26
	K2	.904	.386	.139	-.17	1.97
	K4	.454	.470	.870	-.85	1.76
	K5	.887	.407	.194	-.24	2.01
K4	K1	.693	.488	.616	-.66	2.05
	K2	.451	.476	.878	-.87	1.77
	K3	-.454	.470	.870	-1.76	.85
	K5	.433	.492	.904	-.93	1.80
K5	K1	.260	.427	.974	-.92	1.44
	K2	.017	.413	1.000	-1.13	1.16
	K3	-.887	.407	.194	-2.01	.24
	K4	-.433	.492	.904	-1.80	.93

*. The mean difference is significant at the 0.05 level.

Variation of water quality across land uses- Njoro River

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
TEMP	Between Groups	677.162	2	338.581	203.919	.000
	Within Groups	592.751	357	1.660		
	Total	1269.913	359			
PH	Between Groups	7.596	2	3.798	3.947	.020
	Within Groups	343.561	357	.962		
	Total	351.157	359			
DO	Between Groups	6.608	2	3.304	5.337	.005
	Within Groups	221.021	357	.619		
	Total	227.629	359			
EC	Between Groups	128150.509	2	64075.254	2.233	.109
	Within Groups	10242685.475	357	28690.996		
	Total	10370835.984	359			
NO_2-N	Between Groups	.002	2	.001	8.397	.000
	Within Groups	.036	357	.000		
	Total	.038	359			
NO_3-N	Between Groups	.000	2	.000	.	.
	Within Groups	.000	357	.000		
	Total	.000	359			
NH_4-N	Between Groups	.025	2	.013	13.730	.000

	Within Groups	.329	357	.001		
	Total	.354	359			
SRP	Between Groups	.026	2	.013	34.264	.000
	Within Groups	.133	357	.000		
	Total	.158	359			
TP	Between Groups	3.949	2	1.974	18.640	.000
	Within Groups	37.812	357	.106		
	Total	41.761	359			
TN	Between Groups	.000	2	.000	9.469	.000
	Within Groups	.008	357	.000		
	Total	.009	359			

Kamweti River_ ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
TEMP.	Between Groups	1256.143	2	628.072	703.036	.000
	Within Groups	318.933	357	.893		
	Total	1575.076	359			
PH	Between Groups	35.014	2	17.507	88.243	.000
	Within Groups	70.827	357	.198		
	Total	105.841	359			
DO	Between Groups	1158.102	2	579.051	14.004	.000

	Within Groups	14761.658	357	41.349		
	Total	15919.760	359			
EC	Between Groups	676.001	2	338.001	4.150	.017
	Within Groups	29078.710	357	81.453		
	Total	29754.711	359			
NO_2-N	Between Groups	.000	2	.000	.	.
	Within Groups	.000	357	.000		
	Total	.000	359			
NO_3-N	Between Groups	.000	2	.000	.	.
	Within Groups	.000	357	.000		
	Total	.000	359			
NH_4-N	Between Groups	.003	2	.002	16.724	.000
	Within Groups	.034	357	.000		
	Total	.037	359			
SRP	Between Groups	.000	2	.000	2.037	.132
	Within Groups	.012	357	.000		
	Total	.012	359			
TP	Between Groups	.033	2	.016	12.881	.000
	Within Groups	.452	357	.001		
	Total	.485	359			
TN	Between Groups	.000	2	.000	3.916	.021

	Within Groups	.001	357	.000		
	Total	.001	359			

Benthic macroinvertebrate variations across sites - Njoro River

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
perlidea	Between Groups	4524.840	4	1131.210	19.545	.000
	Within Groups	8392.333	145	57.878		
	Total	12917.173	149			
Heptageniidae	Between Groups	49578.733	4	12394.683	43.826	.000
	Within Groups	41008.100	145	282.814		
	Total	90586.833	149			
leptophlebiidae	Between Groups	14.240	4	3.560	2.034	.093
	Within Groups	253.733	145	1.750		
	Total	267.973	149			
hydrophlibidae	Between Groups	28.493	4	7.123	5.129	.001
	Within Groups	201.400	145	1.389		
	Total	229.893	149			
Hydropsyche	Between Groups	1106.200	4	276.550	6.454	.000
	Within Groups	6213.133	145	42.849		
	Total	7319.333	149			
Baetidae	Between Groups	5840.693	4	1460.173	3.346	.012

	Within Groups	63283.900	145	436.441		
	Total	69124.593	149			
Potamonautidae	Between Groups	378.667	4	94.667	6.349	.000
	Within Groups	2162.167	145	14.911		
	Total	2540.833	149			
Elmidae	Between Groups	179.733	4	44.933	1.957	.104
	Within Groups	3329.767	145	22.964		
	Total	3509.500	149			
Tipulidae	Between Groups	398.427	4	99.607	8.841	.000
	Within Groups	1633.633	145	11.266		
	Total	2032.060	149			
Simuliidae	Between Groups	511.507	4	127.877	1.471	.214
	Within Groups	12600.867	145	86.903		
	Total	13112.373	149			
Helodidea	Between Groups	223.440	4	55.860	7.484	.000
	Within Groups	1082.300	145	7.464		
	Total	1305.740	149			
oligoneuridae	Between Groups	23.867	4	5.967	3.079	.018
	Within Groups	280.967	145	1.938		
	Total	304.833	149			
chironomidae	Between Groups	176.040	4	44.010	3.556	.008

	Within Groups	1794.333	145	12.375		
	Total	1970.373	149			
psephenidae	Between Groups	85.533	4	21.383	10.342	.000
	Within Groups	299.800	145	2.068		
	Total	385.333	149			
ceanedae	Between Groups	3.467	4	.867	2.770	.030
	Within Groups	45.367	145	.313		
	Total	48.833	149			
Gomphidae	Between Groups	4.573	4	1.143	1.856	.121
	Within Groups	89.300	145	.616		
	Total	93.873	149			
ceratopoginidae	Between Groups	6.760	4	1.690	5.244	.001
	Within Groups	46.733	145	.322		
	Total	53.493	149			
Culicidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
arthericedae	Between Groups	140.760	4	35.190	12.970	.000
	Within Groups	393.400	145	2.713		
	Total	534.160	149			
Ashnidae	Between Groups	6.840	4	1.710	3.198	.015

	Within Groups	77.533	145	.535		
	Total	84.373	149			
philopotamidea	Between Groups	18.827	4	4.707	4.415	.002
	Within Groups	154.567	145	1.066		
	Total	173.393	149			
pyralidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
muscidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
gyrinidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
teloganodidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
psychodidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
philopotamidae	Between Groups	.000	4	.000	.	.

	Within Groups	.000	145	.000		
	Total	.000	149			
planaria	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
tabanidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			

Kamweti River- ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
perlidea	Between Groups	4524.840	4	1131.210	19.545	.000
	Within Groups	8392.333	145	57.878		
	Total	12917.173	149			
Heptageniidae	Between Groups	49578.733	4	12394.683	43.826	.000
	Within Groups	41008.100	145	282.814		
	Total	90586.833	149			
leptophlebiidae	Between Groups	14.240	4	3.560	2.034	.093
	Within Groups	253.733	145	1.750		
	Total	267.973	149			
hydrophlibidae	Between Groups	28.493	4	7.123	5.129	.001
	Within Groups	201.400	145	1.389		

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Baetidae	Between Groups	5840.693	4	1460.173	3.346	.012
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oligoneuridae	Between Groups	23.867	4	5.967	3.079	.018
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	Total	304.833	149			
chironomidae	Between Groups	176.040	4	44.010	3.556	.008
	Within Groups	1794.333	145	12.375		
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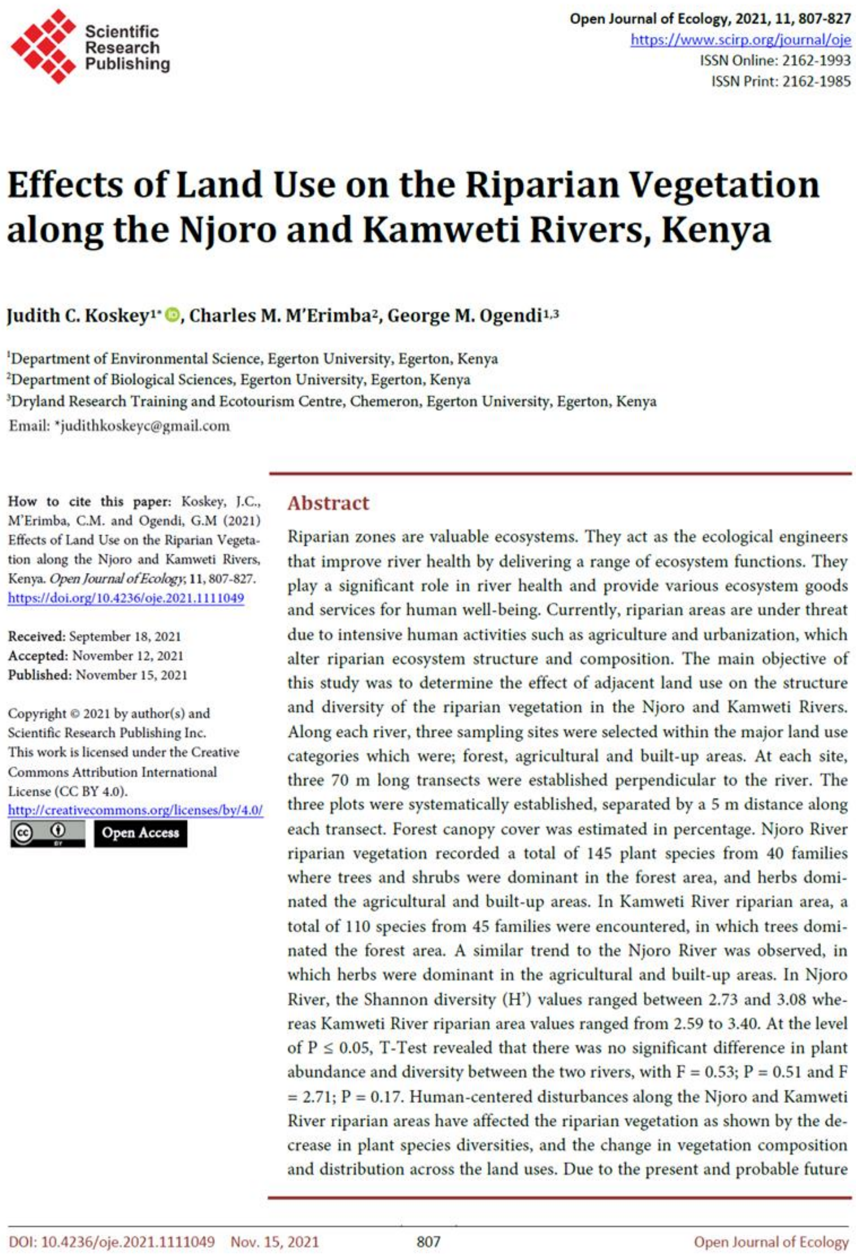
psephenidae	Between Groups	85.533	4	21.383	10.342	.000
	Within Groups	299.800	145	2.068		
	Total	385.333	149			
ceanedae	Between Groups	3.467	4	.867	2.770	.030
	Within Groups	45.367	145	.313		
	Total	48.833	149			
Gomphidae	Between Groups	4.573	4	1.143	1.856	.121
	Within Groups	89.300	145	.616		
	Total	93.873	149			
ceratopoginidae	Between Groups	6.760	4	1.690	5.244	.001
	Within Groups	46.733	145	.322		
	Total	53.493	149			
Culicidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			

arthericedae	Between Groups	140.760	4	35.190	12.970	.000
	Within Groups	393.400	145	2.713		
	Total	534.160	149			
Ashnidae	Between Groups	6.840	4	1.710	3.198	.015
	Within Groups	77.533	145	.535		
	Total	84.373	149			
philopotamidea	Between Groups	18.827	4	4.707	4.415	.002
	Within Groups	154.567	145	1.066		
	Total	173.393	149			
pyralidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
muscidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
gyrinidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
teloganodidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			

psychodidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
philopotamidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
planaria	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			
tabanidae	Between Groups	.000	4	.000	.	.
	Within Groups	.000	145	.000		
	Total	.000	149			

Appendix D: Authors own publications

Koskey, J. C., M'Erimba, C.M. and Ogendi, G.M (2021). Effects of Land Use on the Riparian Vegetation along the Njoro and Kamweti Rivers, Kenya. Open Journal of Ecology, 11, 807-827. https://doi.org/10.4236/oje.2021.1111049



Scientific Research Publishing

Open Journal of Ecology, 2021, 11, 807-827
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Effects of Land Use on the Riparian Vegetation along the Njoro and Kamweti Rivers, Kenya

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Abstract

Riparian zones are valuable ecosystems. They act as the ecological engineers that improve river health by delivering a range of ecosystem functions. They play a significant role in river health and provide various ecosystem goods and services for human well-being. Currently, riparian areas are under threat due to intensive human activities such as agriculture and urbanization, which alter riparian ecosystem structure and composition. The main objective of this study was to determine the effect of adjacent land use on the structure and diversity of the riparian vegetation in the Njoro and Kamweti Rivers. Along each river, three sampling sites were selected within the major land use categories which were; forest, agricultural and built-up areas. At each site, three 70 m long transects were established perpendicular to the river. The three plots were systematically established, separated by a 5 m distance along each transect. Forest canopy cover was estimated in percentage. Njoro River riparian vegetation recorded a total of 145 plant species from 40 families where trees and shrubs were dominant in the forest area, and herbs dominated the agricultural and built-up areas. In Kamweti River riparian area, a total of 110 species from 45 families were encountered, in which trees dominated the forest area. A similar trend to the Njoro River was observed, in which herbs were dominant in the agricultural and built-up areas. In Njoro River, the Shannon diversity (H') values ranged between 2.73 and 3.08 whereas Kamweti River riparian area values ranged from 2.59 to 3.40. At the level of $P \leq 0.05$, T-Test revealed that there was no significant difference in plant abundance and diversity between the two rivers, with $F = 0.53$; $P = 0.51$ and $F = 2.71$; $P = 0.17$. Human-centered disturbances along the Njoro and Kamweti River riparian areas have affected the riparian vegetation as shown by the decrease in plant species diversities, and the change in vegetation composition and distribution across the land uses. Due to the present and probable future

Koskey, J. C., Ogendi, G. M., M'Erimba, C. M., & Maina, G. M. (2021). Spatial and temporal variations in land use and land cover in the Njoro and Kamweti River catchments, Kenya. *East African Journal of Science, Technology and Innovation*, *2*(3). https://doi.org/10.37425/eajsti.v2i3.243

EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 2 (3)): June 2021

Spatial and temporal variations in land use and land cover in the Njoro and Kamweti River catchments, Kenya

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Abstract

The Njoro and Kamweti River catchments are productive catchments that have and continue to experience major land use changes with consequences on land cover and the associated environmental resources. It is therefore crucial to understand the type of changes occurring, spatial patterns and the rates at which these changes are occurring. In this study, we quantified the changes in land use and land cover that occurred between 1988 and 2019 identifying areas of change and the average annual rate of change. Thematic Mappers (TM) and Enhanced Thematic Mappers Plus (ETM +) and Sentinel images were obtained for 1988 and 2019. Ground truthing was carried out to enable us to verify the accuracy of the remotely sensed data using in-situ observations to refine the classification output. The results obtained indicated that both catchments have experienced intense land use changes but at different levels. Njoro River catchment's forest cover and shrubland had decreased at a rate of 6.06 Km^2/year and 0.92 Km^2/year respectively and the most increase was recorded in farmlands (3.11 Km^2/year) as the other land use classes also increased. In the Kamweti River catchment, forest cover showed a decrease at a rate of 0.21 Km^2/year and farm lands also a slight decrease of 0.1 Km^2/year while the other land cover classes increased in area coverage during the period 1988-2019. The changes in land use and land cover were attributed to increased demand for food and housing and thus continued degrading the two catchments especially the Njoro River catchment. Results obtained indicated that anthropogenic activities were the major contributing factors to the changes in Land Use Land Cover experienced in both catchments. We recommend continued analysis of the trends and rates of land cover conversions owing to their potential use by development planners. Further, such information is essential when establishing a rational land use policy which is key to sustainable development and the enhancement of livelihoods.

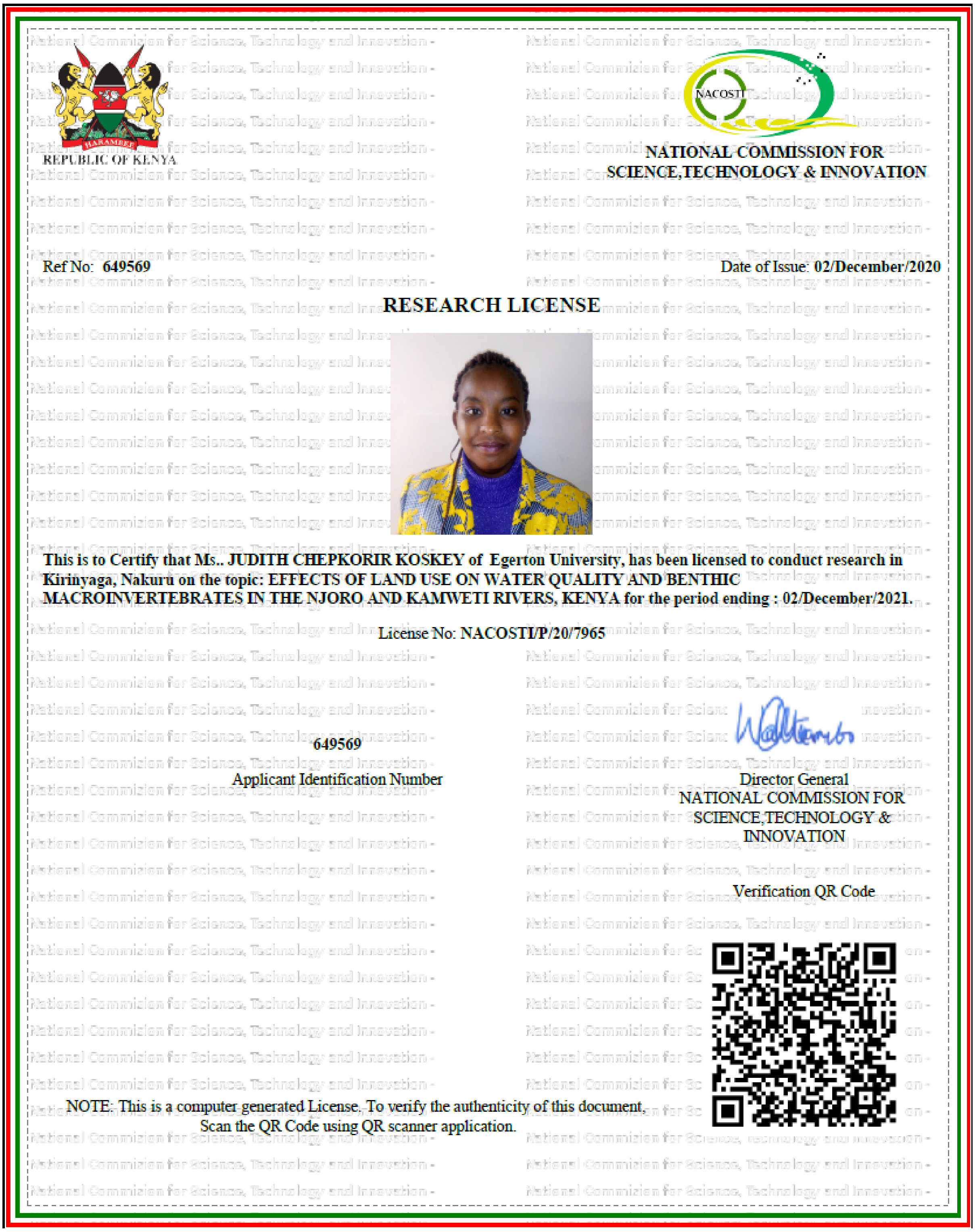
Keywords: *Land use; land cover; anthropogenic activities; change detection; remote sensing; Njoro River catchment*

Cite as: *Chepkorir et al., (2021).* Spatial and temporal variations in land use and land cover changes in the Njoro and Kamweti River catchments, Kenya. *East African Journal of Science, Technology and Innovation 2(3)*	Received: Accepted: Published:	21/10/20 10/05/21 25/06/21

Introduction

Land use and land cover (LULC) change detection and analysis have been applied globally and in different ecosystems of the world (Mishra *et al.*, 2019; Serra *et al.*, 2008) to monitor environmental changes and manage natural resources (Twisa & Buchroithner, 2019). Changes in LULC are a key component of global environmental change as they impact climate, ecology, and human society and therefore of

Appendix E: Reasearch permit



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