Impacts of Land use and Land cover on Water Quality and Benthic Macroinvertebrates in Theta River Catchment

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Gituanja George Gachie

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DECLARATION

This research project report is my original work and has not been presented for degree examination in any other university.

Gituanja George Gachie C50/7966/2017

Signature………………………………………… Date…**05/11/2020………………...**

Declaration by Supervisors

This research project report has been submitted for examination with our approval as university supervisors.

Dr. Thuita Thenya

Senior Lecturer

Wangari Maathai Institute for Peace & Environmental Studies (WMI)

University of Nairobi.

Signature…………………………………………Date……05/11/2020…………………...

Prof. Francis Mwaura

Associate Professor

Biodiversity, Ecosystem &NRM

Department of Geography and Environmental Studies

University of Nairobi.

Signature………………………………………………Date…05/11/2020…….

DEDICATION

"It is easy to throw anything into the water, but difficult to take it out" (Kashmiri Proverb on water pollution).

To my son Gituanja Gachie and wife Nyambura Gachie especially for your company in the field and the peace of mind I needed at home during data analysis and report writing. Similarly to my mother Waithera Gituanja and my sister Wanjiru Gakure for their moral, material, and financial support during my course work, field research, and report writing.

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ACRONYMS AND ABBREVIATIONS

ANOSIM	-	Analysis of Similarity
CCA	-	Canonical Correspondence Analysis
DCA	-	Detrended Correspondence Analysis
DEM	-	Digital Elevation Model
DO	-	Dissolved Oxygen
EC	-	Electrical Conductivity
EPT	-	Ephemeroptera, Plecoptera, and Trichoptera
GIS	-	Geographic Information Systems
GPS	-	Global Position System
IWRM	-	Integrated Water Resources Management
IPCC	-	Intergovernmental Panel on Climate Change
LULC	-	Landuse and Landcover
KNBS	-	Kenya National Bureau of Statistics
RCC	-	River Continuum Concept
RDA	-	Redundancy analysis
SDG	-	Sustainable Development Goal
STRM	-	Shuttle Radar Topographic Mission
TDS	-	Total Dissolved Solids
MDS	-	Multidimensional Scaling
NMK	-	National Museums of Kenya
NMDS	-	Non-Metric Multidimensional Scaling
NTU	-	Nephelometric Turbidity Units
USGS	-	United States Geological Survey
UNEP	-	United Nations Environmental Program
WHO	-	World Health Organization
WRA	-	Water Resources Authority
WRUA	-	Water Resource Users Association

ABSTRACT

Landuse and landcover (LULC) changes continue to pose a threat to water quality, and aquatic biodiversity in many watersheds across the world. There is a growing scientific consensus of the close relationship between land use and land cover types and water quality. Understanding this relationship is vital for water management. This study addressed the impacts of land use/cover types on water quality and benthic macroinvertebrates in Theta River catchment in Kiambu County of Kenya. Theta River spans Lari, Gatundu South, Githunguri, Ruiru, and Juja Sub-Counties covering a total area of approximately 143 km^2.

The objectives of the study were to: - a) detect the spatial changes in LULC types along Theta River gradient, b) establish the influence of spatial LULC on water quality along Theta River, c) assess the influence of LULC changes on macroinvertebrates composition in Theta River; and d) analyze the relationship between water quality and macroinvertebrates composition in Theta River. Primary data included water quality parameters and benthic macroinvertebrates. The physico-chemical water quality parameters were measured *in situ* using Hanna H1 9829 this included turbidity, pH, dissolved oxygen (DO), salinity, temperature, and electrical conductivity. Nitrates were determined in the laboratory using the Brucine method. Macroinvertebrates were sampled using D net following 1-minute standard kicks in the river biotopes and identified to family level. The secondary data comprised of remote sensing datasets made up of digital elevation model (DEM), Sentinel 2a satellite image for 2018 sourced from the United States Geological Survey (USGS).

Results of the study showed that the main land use and landcover were agriculture (61.4 %,), grassland/shrub (19.9%), urban-settlements (6.7%), forest land (4.9%), riverine vegetation (6.4%), and open water (0.7%). Forest, agricultural, and urban-settlement land uses where used to represent the human disturbance gradient of how these land use affect water quality and macroinvertebrate community structure. There were clear differences in relationships between water quality characteristics and the land uses. The correlation of determination from spearman rank showed that forest land explained 64% variation in temperature and 60.8% variation in dissolved oxygen, while Agricultural land explained 51.8% of the variation in nitrates, and urban-settlement explained 46.2% of variations in temperature, 98% of variation in turbidity, and 59.3% of variations in nitrates. Water samples from stations in forest land had high levels of dissolved oxygen, low temperature, nitrates, electrical conductivity, and turbidity compared to those from agricultural and urban-settlements. The impairment of water quality along the human disturbance gradient was colloborated by macroinvertebrates data. Forested site had high family level diversity, and high abundance of the sensitive taxa of the order EPT than agricultural and urban-settlement land uses. The differences in macroinvertebrates community structure among the land uses was showed to be statistically significant from analysis of similarity (ANOSIM) test. The study recommended water pollution preventive measures such as enhancing the protection of forest, land, improvement and protection of riparian zones, and mitigation of pollution loads from agricultural land use through sustainable farming practices.

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Chapter 1: INTRODUCTION

1.1 Background of the study

Water is regarded as a critical resource for human existence and underpins growth and prosperity, and has no known substitute like some other natural resources. (Postel *et al*., 1996). However, freshwater faces numerous threats associated with deterioration of water quality due natural and anthropogenic factors primarily changes in land use and land cover (Ngoye & Machiwa, 2004). Land use refers to the activities that define how land is utilized (Brown *et al.*, 2000).The impacts of anthropogenic activities, such as water pollution, soil erosion, forest loss and degradation, on the natural environment results from land use changes. Urban and agricultural land uses have been identified as the main land use types that affect both ground and surface water resource as the water drains from the land surface (Chin, 2006; Wu *et al*., 2012; Cheng *et al*., 2018). Globally, rivers have been shown to be most vulnerable and impacted ecosystems as a result of land use and land cover (LULC) changes, resulting in deterioration of stream water quality (Ding *et al*., 2015; Malmqvist & Rundle, 2002; Saunders *et al*., 2002). The human-related river pollution from land use activities can be categorized into the point and nonpoint sources by organic, inorganic, and organometric materials. Natural (background) sources are connected to geological and climatological characteristics of a given watershed through weather elements, leaching, and runoff.

Rivers have a critical role in underpinning to social, economic, and environmental sustainability. They are crucial to human wellbeing, development, water cycle and ecological integrity (Gupta & Orban, 2018). Historically, river have been a major driver of civilization as has been the case along River Nile, Tigris and Euphrates (Malin & Widstrand, 1992). The water cycle they are part of is a lifeline of the planet, as well as rivers form a crucial habitat for diverse species. In Kenya, rivers are important for irrigation, water for domestic consumption, electricity generation, fishing, recreation, and industrial use. Despite their importance, rivers are threatened by degradation of catchment areas, uncontrolled development, dumping of wastes beyond their assimilative capacity. These facts reiterate the importance of water quality monitoring in rivers in order to determine the suitability of water for particular use and to inform remedial action to improve existing conditions. Water quality has been defined in broad context as suitability of water to sustain certain uses or processes (Meybeck *et al*., 1996). Water quality monitoring has twofold importance. One, Water quality can be used as an ideal and appropriate proxy indicator of the health of the surrounding ecosystems, at a watershed level, when properly selected, measured, and evaluated. Two, good quality water can assist governments in achievement of sustainable development goals (SDGs) particularly SDG 3 on health and wellbeing, and SDG 6 on clean water and sanitation (UN Water, 2016).

The difficulty faced in water quality monitoring program arises from the complexity of the relationship between land use and water quality as highlighted by (Tong & Chen, 2002). The hydrological and geographical dynamics that affect stream ecosystems imply that physico-chemical conditions determined instantaneously will be a snapshot reflection of the status of ecological health. To overcome this challenge, Mangadze *et al*., (2019), advocates for the use of an integrated approach that utilizes biological indicators such as macroinvertebrates. Benthic macroinvertebrates are bottom-dwelling organisms that are large enough to be seen with the unaided eye. The potential of macroinvertebrates in forecasting the health status of aquatic ecosystems is well documented by (Cairns & Schalie, 1980), they have a high responsiveness to changes in water quality (Gordon *et al*., 2004), and have best documented response to organic pollution as a result of land use changes (Hellawell, 1986).

The regular and systemic use of living organism or their response behavior to changes in the environment defines the concept of biological monitoring (Cairns & Pratt, 1993). Macroinvertebrates can also be applied in long-term trend analysis, as well as the effectiveness of pollution control or environmental protection programs. This can be achieved by either studying community structure of macroinvertebrates or when macroinvertebrates are used as indicator species (Resh & Unzicker, 1975). Macroinvertebrates remains the most researched biodiversity aspect among the stream ecologists around the world (Tornwall *et al*., 2015). This can be attributed to the low cost and simplicity of macroinvertebrates collecting methods (Carter *et al*., 2006). Despite this advantage and adoption in many parts of the world, the national water-quality program in Kenya is still dependent on traditional physico-chemical measurements. Biomonitoring is however popular among the scientific community in Kenya (Gichana *et al*., 2015; Raburu *et al*., 2017; Wambugu, 2018).

1.2 Problem statement

Water quality is a description of physical, chemical, and biological characteristics of water that defines its suitability for a variety of uses and for protection of health and integrity of aquatic ecosystems. Surface water resources such as rivers are susceptible to both anthropogenic influences such as land use and land cover changes and natural influences. Pollution results to loss of species, decline in water quality and supply, changes in distribution and structure of aquatic life. The polluted river ecosystems cannot render ecosystems goods and services (Pereda *et al*., 2019). This negatively affects human socio-economic development such as provision of safe drinking water, food security, and water for industries. This scenario is not different to Theta River and its tributaries.

Theta River flows from its source in Kinale Forest covering 15km to its confluence with Thiririka River. Along its profile, Theta River faces catchment degradation which has been identified as key problem across river basins in Kenya, which detrimental to river flow regime and ecological integrity (Kipampi *et al*., 2017). The Sub-catchment Management Plan for WRUA of, 2012, identified a number of problems facing Theta River catchment that is low water quality and quantity, encroachment of riparian, deforestation and cultivation of slopes. Others were replacement of indigenous vegetation with exotic tree species such as *Eucalyptus sp*, river diversion and abstraction. All these problems persist in the backdrop of freehold land ownership systems, with multiple uses. Additionally, the existing environmental laws are not effectively enforced at catchment scale due financial and technical constrains experienced by relevant institutions (Quesne *et al*., 2010).

The other main issue in the Theta River catchment arises from the growing population. Theta River catchment is spanned by four constituencies: Lari, Gatundu South, Githunguri, and Juja, which have some of the highest population growth rates in Kenya and have high population density (KNBS, 2019). This results in increased competition for land at the rural-urban fridges resulting in land use and land cover, which impacts river water quality and aquatic biodiversity negatively. For example, the population in the upper zones is largely rural and dependent on cash crops such as coffee, tea, and dairy sub-sectors leading encroachment into riparian zones, cultivation of steep slopes, and changes in land cover. In the mid zones, the large-scale coffee estates are being converted into settlements which will alter the water demand, runoff generation, and domestic water disposal. The high-density settlements, industries, and businesses located downstream in the lower zones presents challenges in monitoring pollution and possibilities of urban flooding (Wambugu, 2018).

Information generated from this study will be useful in informing catchment and riparian river management for improved water quality and aquatic biodiversity.

1.3 Research questions

The study was guided by the following three research questions:

1. What are the existing spatial land use and cover patterns in the Theta River catchment?
2. How does the spatial land use and cover impacts on water quality in the Theta River catchment?
3. How does the spatial land use and cover types, impact on the benthic macroinvertebrates community structure in Theta River catchment?
4. How does the changes in water quality characteristics along the Theta River profile influence benthic macroinvertebrates community structure?

1.4 Research objectives

The overall objective of this study was to evaluate the impacts of different landuse and landcover types on the water quality and the implications on the ecological integrity of rivers by evaluating the benthic macroinvertebrates community structure in Theta River catchment.

The four specific objectives of the study were to:

i. Analyse the spatial land use land cover patterns along Theta River profile.

ii. Establish the influence of spatial land use land cover changes on water quality in Theta River.

iii. Assess the influence of spatial land use and land cover changes on macroinvertebrates composition in Theta River and.

iv. Analyze the relationship between water quality and macroinvertebrate composition in Theta River.

1.5 Research hypotheses

The research was guided by the following null hypotheses:

1. Ho: There is no significant relationship between water quality characteristics and the spatial land use landcover patterns in Theta River catchment
2. Ho: There are no significant differences between benthic macroinvertebrates community structure and spatial land uses and cover types in Theta River catchment and;
3. Ho: There is no significant relationship between benthic macroinvertebrates community assemblage and water quality characteristics along Theta River profile.

1.6 Scope of the study

The research study had a geographical scope of an area covered by Theta River catchment as defined by watershed boundaries derived from the Digital elevation model (DEM). The catchment has Theta River as the main river, which has six tributaries, but the focus was on Theta River, Mugutha River, and Thumara River. The study also covered a catchment length that stretched from wadeable tributary of Theta River located in the Kinale Forest in the upstream to the confluence of Theta River and Thiririka River downstream.

In terms of water quality assessment the study was organized around water quality parameters and benthic macroinvertebrates, each of these samples was collected once. The water quality parameters of concern in the study were pH, dissolved oxygen, electrical conductivity, temperature, turbidity, salinity, and nitrates. With regards to benthic macroinvertebrates, the sampled fauna was restricted to the water column and the disturbed substrate. The sampling points were restricted to three land use types that comprised of agricultural land, forest land, and urban land. The temporal scope of the study involved collection of samples for dry season in the month of March 2019. The detection of land use using remote sensing techniques was limited to the spatial analysis using 2018 satellite image.

1.7 Justification of the study

The study area is located in the upper zone of the wider Athi catchment area (ACA). ACA is approximated to cover 10.2% of Kenya's total land area and about 25% of total population as per 2009 Census (Kokusai, 2013). Within the ACA the water stress ratio is about 76%, while there is projected increase in demand for water use in industrial, domestic, fisheries, and irrigation amid the reduction in water resources. Apart from threats from climate variability and change, catchment degradation, population increase, and deforestation of the headwaters remain the greatest challenges in the ACA (Kokusai, 2013). Davies & Gustafsson (2015), describes ACA is one of the most vulnerable catchments in Kenya. The vulnerabilities arise from water pollution, catchment degradation, over-abstraction, flooding, and increased irrigation demand.

Theta River catchment is of critical importance both to the residents within the catchment and to Kenya, due to its contribution to Athi River waters. The study is therefore designed to identify the spatial land use and land cover patterns along the river profile, and their implications to the water quality characteristics. The relationship between water quality and land use and cover has been shown to be complex (Tong & Chen, 2002).The legacy impacts of land use and land cover on water quality characteristics and stream ecological quality is colloborated by incorporating benthic macroinvertebrates as a biomonitoring tool.

The effects of land use and land cover on water quality and macroinvertebrates has received limited academic attention from researchers in Theta River catchment. It is evident from literature review that studies on the study subject have been done in the neighboring basins of Ruiru and Ndarugu such as the study by (Wambugu, 2018). However, the study by Wambugu (2018), did not deeply link land use and land cover changes to water quality and macroinvertebrates due to the methodological approach used. At national level few studies have been done whose findings need to be re-tested in a different context which differ in ecological, socio-economic, physical characteristics that are unique to Theta River catchment.

This study will contribute to methodological approach of determining the health of river ecosystems in Theta River catchment. By incorporating macroinvertebrates in water quality monitoring, governmental agencies, interested groups, and laypeople from surrounding communities can work together in water resources monitoring. The availability of cost effective and easy to use water quality testing kits now available physicochemical water quality characteristics can be determined on a regular basis. Macroinvertebrates-based methods on the other hand have rapid field techniques that require locally available equipment's. The laboratory techniques have been simplified by availability of identification manuals that are easy to use.

1.8 Operational terms

1) **Benthic macroinvertebrates-** are bottom dwelling organisms that are large enough to be seen by unaided eyes and that have no backbone (Sallenave, 2015).
2) **Biological indicator-** is an organism or part of an organism that carries information about the quality of environment (Hellawell, 1986).
3) **Biological monitoring**-systematic use of biological responses to evaluate changes in the environment with intent of using such information in a quality control program (Mathews *et al*., 1982).
4) **Biotope**- in a river ecosystem refers to environment of a community of closely associated organisms defined by river flow characteristics (Gerber & Gabriel, 2002).
5) **Catchment** – the area above a specific point on a stream from which water drains towards the streams (Gordon *et al.*, 2004).
6) **Land cover-** the surface cover on the natural ground, it can be natural cover by vegetation, water, bare soil or rocks. Anthropogenic influenced cover include urban infrastructure (Brown *et al*., 2000).
7) **Land use-** refers to economic use of land by humans involving modification of natural environment to agriculture fields and settlement (Brown *et al*., 2000).
8) **Substrate-** is material that constitute the bottom of a river it could be clay or sand, or bed rock, logs of trees (Gerber & Gabriel, 2002).
9) **Water quality** - a set of physical, chemical, and biological conditions that define the state of water for a particular use (Hydrologic Engineering Center, 1972).

Chapter 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature on the concept of land use and land cover spatial patterns in a watershed. It goes further to look into the documented relationship between spatial land use and land cover patterns on water quality characteristics in various watershed around the globe including Kenya. In addition the literature on the changes benthic macroinvertebrates community structure in different land uses and land cover that represent a human disturbance gradient. Thereafter, the chapter examines the relationship between benthic macroinvertebrates and water quality characteristics, and the various methodologies used to elucidate this relationship.

2.2 Land use and Land cover Spatial Patterns along a river gradient

According to Juan *et al*.(2013), changes in land use and land cover are the main cause of change in watershed landscape pattern. Land use is a manifestation of anthropogenic activities on natural environment. Therefore, the study of the dynamics of land use patterns is an important step in understanding the relationship between society and nature (Shen, 2011).

The study on land use and cover spatial patterns can provide an insight into better watershed management. In order to address the problem of surface water quality deterioration, there is need to elucidate the relationship between water quality and watershed land use/cover patterns. In pollution studies, land use patterns are considered as important regulators of pollutants in overland and interflows(Cheng *et al.*, 2018). Differences in land use and cover spatial patterns have been observed by authors in various watersheds. Wang *et al*., (2013), studied the influence of land use patterns on water quality in the Daliao River Basin, Liaoning Province of China. The study revealed that land use types comprised of forest, agriculture, urban land, grassland,bareland, and open water. The dominant land uses in the Daliao Basin were forest (64%), followed by agriculture (28%), urban areas (5%) while water, bareland, and grassland combined comprised of 3% of the total area. Forest land was located in the upper zones of the catchment, while the land uses (agriculture and urban) that are indicative of human impacts on the natural environment were located in the midstream and downstream areas of the Daliao basin.In Fuluasou River catchment in Samoa the main land use types were agriculture, forest, grassland, and urban areas (Faiilagi, 2015). The spatial land use patterns in Fuluasou catchment followed a similar longitudinal patterns as that observed in the Daliao River Basin. The forest area comprised of 36.6%, agriculture had 32.1%, urban areas (27%), and Grassland (4.3%). The author observed that both forest and grassland had a decreasing trend in proportion while agriculture and urban had an increasing trend from results of temporal analysis. In Kenya, Ndarugu and Ruiru Rivers basins had the main land use types consisiting of forest (14.93%, 16.25%), small scale agriculture (54.02%, 60.93%), Large scale agriculture (11.93%, 15.54%), urban areas (14.69%, 5.8%), Grassland (4.18%, 1.29%), water (<1% for both) (Wambugu, 2018). The forest land was shown to be on a decreasing trend, while agriculture and urban areas were on an increasing trend from a temporal analysis. The author attributed this to increasing demand for residential areas due to population growth and urbanization. Spatially, the forest land was located in upstreams areas while the other land use types were located in mid and downstream areas. Urban land was dominate in the flat and dry downstream zones. The increase of land use heterogeneity downstream has been explained by Shen (2011), to be contributed by natural factors such as low gradient. Such natural factors, allow the domination of human-disturbed land uses to coexist natural land covers such as grassland and wetlands. This is not however the typical spatial distribution of land types in a catchment. Nyangores River catchment, in Kenya had land use types consisting of farmland (38.8%), forest land (26.8%), tree plantations (11.9%), and shrub land (22.5%) (Ngeno, 2016). The natural forest in this case located in the mid-stream of the catchment, while the more human influenced land covers located in the upstream and downstream sections of the watershed.

2.3 Relationship between water quality and Land use and land cover patterns

Water quality has been shown to be intractably linked to land use and landcover in a given watershed (Sutherland *et al*., 2002;Ngoye & Machiwa, 2004). The spatial land use and land cover patterns can serve as a general indicator of water quality in river basins (Wear *et al*., 1998). However, these linkages are not straight forward and can be complex when both natural and human processes within a watershed are considered (Wang *et al*., 2013). In general, certain land uses such as agriculture, forestry, industrial zones, and urban areas can be associated with given water quality outcomes in rivers that traverse them. Agricultural land uses are for example associated with nutrients such as nitrogen (Bu *et al.*,2014), pesticides, salts, pathogens and eroded soils that often degrade water sources (Abler *et al.*,2002). While urban and industrial areas can be linked to heavy metal pollution such lead, organic pollution such as raw sewage, and nutrients pollution such as phosphorous and nitrogen (Bu *et al.*,2014).

A study in the Gilgel Gibe reservoir watershed in southwest Ethiopia, revealed that agriculture land was the dominant land use and had the most influence on water quality (Woldeab *et al.*, 2019). The authors recorded various water quality parameters such as pH, DO, conductivity, turbidity, nitrates, and total dissolved solids in the four streams within the Gilgel Gibe watershed. The study recorded DO concentration that ranged from 4mg/l to 6mg/l, while the DO concentrations in agriculture dominated areas was 4.4mg/l. These values were significantly different from the concentration values recorded in areas under vegetation cover which was 5.6mg/l. The pH values did not show any significant differences among the land uses in the Gilgel Gibe watershed, however conductivity values ranged from 107 µS/cm to 145 µS/cm were agriculture dominated areas averaged 129 µS/cm. Total dissolved solids values followed similar trends whereby the values ranged from 90mg/L to 115mg/L within the agricultural land use ,which recorded an average of 108mg/L, compared to settlement land use which recorded an average of 100mg/L, while natural vegetation cover .had an average concentration of 96mg/L.

These findings are similar to those observed in Ndarugu and Ruiru Rivers Kenya, where the maximum turbidity value was 35NTU in agricultural dominated land use compared to 35NTU in settlement dominated areas and<10 NTU in forest dominated. .(Wambugu, 2018). The nitrates levels were highest in agriculture dominated land use with a median concentration of 1.4mg/L compared to 1.13mg/L and 1.07mg/L in urban land and natural vegetated areas respectively. Further research has shown that in Chemosit River catchment in Kenya, the nitrate concentration in smallholder agriculture (<1mg/L) was significantly lower than the concentration within the plantation farmlands (1.7mg/l) (Jacobs *et al*, 2017). The authors of this study attributed this to the nature of agronomic practices within each of the land use classes.

Studies by different authors have shown that forest dominated land use tend to have good water quality outcomes. In Uganda for example, research conducted in high altitude forest located in Bwindi National Park revealed that turbidity values ranged from 1.8NTU to 69.4NTU, the lowly turbid conditions were between 1.8 and 2.8NTU in forest dominated sites, compared to turbidity values of between 27.5NTU to 69.4NTU in agriculture dominated sites. Electrical conductivity values ranged between 33.3 to 47.0 µS/cm in forested areas compared to range of 127-156.7 µS/cm in agriculture dominated areas. (Kasangaki *et al.*, 2007). The water temperature showed similar trends, the temperature values ranged from 15.3-16.6 ˚C in forest dominated areas while in agriculture dominated areas the water temperature ranged from 17-18.5˚C. These authors attributed the low water temperature to canopy cover of forest trees that reduced insolation by the sun. However, the falling leave litter into streams formed humic acid and therefore the pH values of acidic waters in forest dominated areas ranged from 5.0 and 6.9. While the pH values in areas with no canopy cover and hence no terrestrial inputs in agricultural dominated sites the values ranged from 6.2-7.6. The low turbidity, conductivity, and water temperature values were attributed to absence of human disturbances ground cover by the forest undergrowth. The findings in Bwindi National Park are similar to those of a study conducted in Nyangores River catchment in Kenya (Gichana *et al*., 2015). The forest dominated areas in Nyangores catchment had temperature values that ranged from 12.8 to 15.1 ˚C in forest dominated areas, compared to a range of 20.8 to 22.9 ˚C in smallholder agricultural sites, and a range of 18.4 to 19.5 ˚C in urban dominated sites. Conductivity values increased downstream along the human disturbance gradient. Conductivity values ranged between 55.5 to 58.3 µS/cm in forest dominated areas, compared to a range of 74.5 to82.0 µS/cm in agriculture dominated sites, and a range of 85.2 to 87.8 µS/cm in urban dominated sites. In addition, the authors recorded low nutrients load particularly nitrates (<0.1 mg/l), but the trend showed a downstream increase where forest dominated areas recorded values of nitrates concentration of <0.1 mg/L compared to 0.5mg/L for urban dominated sites.

Urban land use was shown to be positively correlated with temperature, electrical conductivity, and nitrates but negatively correlated with dissolved oxygen in the Dongjiang River basin in China (Ding *et al*., 2015). Similar findings on the effects of urban land on water quality were found in Nairobi River catchment were the mean values of conductivity ranged from233µScm^{-1} - 611 µScm^{-1}, TDS ranged from 59mg/L to 349 mg/L, while turbidity ranged from 28.5 - 98NTU. (Kithiia, 2006). Further, the study reported biological oxygen demand (BOD) and chemical oxygen demand (COD) that ranged from 6.92 to 143.25mg/L and 55.73 to 301.30m/L respectively. These COD and BOD values are an indicator of low oxygen concentration in water and the author attributed them to point pollution from broken sewage pipes and general lack of sanitation facilities in settlements in close proximity to Nairobi River and its tributaries.

2.4 Application of benthic macroinvertebrates in assessing water quality

According to Tornwall *et al.,* (2015) benthic macroinvertebrates are the most commonly used bioindicators. They have characteristics that enable them to be easy to collect and identify, residence at certain location within rivers in their entire long-life cycles, as well as cost effectiveness in monitoring. They also allow their application in holistic and robust water-quality assessment of human impact on rivers. Their longitudinal community structure in rivers is reflective of stream ecological condition and heterogeneity of a habitat.

In Lithuania benthic macroinvertebrates were used to assess the most appropriate macroinvertebrate families for river quality by studying 15 varying sized rivers (Višinskienė & Bernotienė, 2012). The study indicated that some families such as Caenidae cannot be reliably used as indicators of clean water. While Families such as Sphaeriidae, Oligochaeta, Erpobdellidae were recommended as indicators of organic pollution. The study recommended that some families such as Gomphidae should be applied cautiously in water quality assessment because of their contradicting responses to environmental variable. In Velhas River, located in Minas Gerais Brazil, benthic macroinvertebrates were applied in determination of headwaters as reference sites for future biomonitoring programs (Oliveira & Callisto, 2010). The authors achieved this by creating an inventory of benthic macroinvertebrates fauna and then carrying out a seasonal and spatial comparison. The results of benthic macroinvertebrates sensitivity to pollution loads aided in identification of reference sites in the Velhas catchment. In Ethiopia water quality assessment using macroinvertebrates was applied to study rivers and streams that are tributaries of upper Awash River, located near Sebeta town in Oromia Region State (Mezgebu *et al.,* 2019). These authors used benthic macroinvertebrates to detect general river degradation and to identify the potential impacts on rivers in close proximity to anthropogenic activities such as agriculture and industrial activities such tanneries, breweries, and textile. The study results showed that the pollution gradient (least impacted sites to most impacted sites) was related to abundance and diversity of the benthic macroinvertebrates fauna. For instance, a highest total family numbers of 13 was recorded in less impacted sites upstream while the lowest number of 5 was recorded in areas with point pollution from tannery effluents. In terms of diversity distribution, the less tolerant taxa such as Muscidae, Culicidae, Gyrinidae, Hydropsyhidae, and Corixidae were in streams with low pollution loads. While the tolerant taxa (Oligochaeta, Chironomidae, Psychodidae, and Lymnaeidae) that are indicative of poor water quality status were in are areas with higher pollution loads. The findings from these results recommended that there was imperative to regular monitoring of the streams for an appropriate remedial action in a participatory manner.

In Kenya benthic macroinvertebrates have been used to study the effectiveness of pollution control measures used in sugarcane and molasses processing factories in Western region (Raburu *et al*., 2017). In this study authors studied the macroinvertebrates community structure in the cascade of effluent stabilization ponds based on their sensitivity to COD, BOD, and nutrients. The authors developed a biotic index based on tolerance values of different macroinvertebrates taxa. The sensitivity levels of macroinvertebrates were 0-3 for intolerant taxon, 4-6 moderately tolerant, and 7-10 most tolerant taxon. These levels corresponded to effluent quality levels of "good", "fair", and "poor". The effluent in flow ponds were dominated by the tolerant taxon such as Syrphidae, but in subsequent ponds towards the outflow, more sensitive taxa in EPT and Elmidae were dominate taxa. These changes in community structure corresponded to a lowered level of measured pollution. These findings demonstrate the usefulness of macroinvertebrate-based index in evaluating waste water before release into rivers.

2.5 Relationship between water quality parameters and benthic macroinvertebrates

The distribution of benthic macroinvertebrates fauna in lotic systems is influenced by a number of factors, key among them are the water physicochemical characteristics. Some of the physicochemical parameters that influence the macroinvertebrate community structure identified by Hershey *et al*. (2010), include water temperature, total dissolved solids (TDS), electrical conductivity (EC), salinity, turbidity, pH, dissolved oxygen concentration (DO), and nitrates.

Studies on benthic macroinvertebrates have demonstrated the relationship between water temperature and benthic macroinvertebrates community composition because taxa have different sensitivity to reduced oxygen. According to Canning & Death (2018), water temperature is an important physical environmental factor that influences other environmental factors such as gas saturation and species community composition. Studies in Rivers Nemunas, Virinta, and Riešė in Lithuania revealed that in the entire study areas, water temperature influenced macroinvertebrates (Višinskienė & Bernotienė, 2012). The results showed that water temperature had an influence on 11 families out of 39 families recorded during the study. Some families showed tolerance to water temperature, these included Oligochaeta, Sphaeriidae, and Erpobdellidae. The abundance of some taxa such as Hydraenidae, Goeridae, and Limnephilidae showed to be negatively impacted by water temperature. In rivers within Bwindi National Park in Uganda, water temperature ranged from 16˚C to 19.6◦C (Kasangaki *et al*., 2007).Water temperature was found to be positively correlated with tolerant taxa of the families Athericidae and Ceratopogonidae (Order Diptera), Veliidae, Pleidae, and Naucoridae (Hemiptera), Caenidae, Prosopistomatidae, and Trichorythidae (Ephemeroptera), and Dytiscidae and Elmidae (Coleoptera) Water temperature was negatively correlated with Perlidae a sensitive family in the order Plecoptera. Similar findings were reported in Nyangores River catchment were the upstream areas recorded lower temperature, though the temperature range was between 12˚C and 22 ˚C (Gichana *et al*., 2015). In Nyangores catchment the families Corbiculidae, Naucoridae, and Coenagriidae were found to be positively correlated with water temperature, while like in the Bwindi National Park streams, Perlidae was negatively correlated with water temperature.

Turbidity is an important water quality parameter in river systems and affects macroinvertebrates fauna in different ways (Gordon *et al.*, 2004). A study in the Alligator Rivers Region, in Australia on the effects of turbidity exposure on benthic macroinvertebrates, revealed persistent exposure had more impact than sporadic exposure on community structure (Gael, 2000). At turbidity levels of >50 NTU Chironomidae and Simulidae were found to drift in response to induced physical stress. Therefore, these taxa were absent in sites that had recorded higher persistent turbidity levels. Different observations were made in streams in upper Awash River catchment, in Ethiopia (Mezgebu *et al.*, 2019). The researchers found out that Thiaridae and Syrphidae were codominat in sites with high turbidity levels ranging from 50NTU to 100 NTU and therefore concluded that these taxa could be used as an indicator of turbidity in rivers. Studies conducted in Upper Mara River basin in Kenyan Highlands, showed that Oligochaeta and Chironomidae to be positively correlated to high turbidity levels while Elmidae and Leptoceridae to be negatively correlated (Masese *et al.*, 2014). In Nyando River catchment Kenya, Elmidae and Culidae were found to be positively correlated with high turbidity levels which ranged from 56 NTU to 160 NTU (Abong'o *et al*., 2015).

Water chemistry comprises of pH, acidity, and alkalinity factors that determine the occurrence and abundance of macroinvertebrates fauna. Hershey *et al*. (2010), noted that extreme values of pH have significant effect on macroinvertebrates communities. Such values have been recorded in in acidified rivers, when pH values as low as 5 have been recorded. Such rivers are depauperate in macroinvertebrates species diversity, because the optimum pH range in freshwater is between 6.5 and 7.5. Similar observation were made in Cache la Poudre River catchment in Colorado, USA (Courtney & Clements, 1998). The results by these authors revealed that streams with higher acidity of pH 4.0 had lower abundance and diversity of benthic macroinvertebrates. Further, this study established that the streams with low pH had nine times higher percentage of stress related drift among the Ephemeroptera which affected the macroinvertebrates community structure. In Kenya, a study by Aura *et al*. (2011)in Rivers Sosiani and Kipkaren recorded a pH range of between 6.8 and 7.1. These values showed weak association with some species such as the *Tubifex sp, Chironomus sp, Pisidium sp, and Lumbricus sp*. In Nyangores River catchment, Kenya benthic macroinvertebrates taxa did not show preference to pH which ranged from 7.3 to 7.8 (Gichana *et al*., 2015).

DO is one of the key factor that influence the composition of aquatic species assemblage and an important parameter that influences distribution of macroinvertebrates (Kahlon *et al*., 2018). Macroinvertebrates fauna have different DO levels requirements due to their diverse behavior and morphological features. For instance, some *Chironomidae* have hemoglobin-like pigment that stores oxygen in their bodies allowing them to have tolerance to anoxic conditions (Merritt & Cummins, 1996). In rivers within the East Kalimantan in Indonesia a sampling station with the lowest DO level of 3.97 mg/l was dominated by Chironomidae, Thiaridae (*Melanoides tuberculata*), and Gastropoda (Patang *et al*., 2018). These families are particularly known to be tolerant to low DO levels in water. Similar findings were reported in a study carried out at Burguret River catchment in Laikipia Kenya (Kosgei, 2016). The study revealed the presence of a high number of red pigmented midges in sampling station that had lowest level (6.94mg/l) of dissolved oxygen concentration.

Nitrogen pollution gradient was shown to have effects on particular macroinvertebrates taxa among streams within the Canterbury Plains in New Zealand (Moore, 2014). The nitrogen levels in Canterbury streams ranged from 0.4 mg/l to 11.3 mg/l. Within this spectrum of nitrate concentration species of the order Trichoptera *Triplectides, Neurochorema*, and *Oeconesus* were found in sites with lower nitrate levels. Conversely, Elmidae, *Chironomus*, and *Microvelia* (Veliidae), were found in sites with highest nitrate concentration. In the upper Mara River Kenya the relationship between nitrates concentration and benthic macroinvertebrates revealed different results (Gichana *et al*, 2015). The results revealed that the sensitive taxa in the order Perlidae were negatively correlated with nitrates concentration while *Coenagrionidae* in the order Odonata were positively correlated.

Studies conducted in Mkondoa River Catchment, Tanzania showed high levels of electrical conductivity that ranged from 147 μScm^{-1} to 680 μScm^{-1} (Shimba & Jonah, 2016). Conductivity correlated negatively with benthic macroinvertebrates diversity, whereas *Caenis sp* of the order Ephemeroptera showed negative relationship. In Nzoia River basin, Kenya Kipkaren and Sosiani Rivers recorded conductivity that ranged from 101 μScm^{-1} to 121 μScm^{-1} (Aura *et al*., 2011). The sites with highest conductivity levels were dominated with more tolerant, and less mobile taxa such as *Lumbricus sp*, *Tubifex sp*, and *Chironomus sp.* The taxa in the EPT group was dominant in sites with low conductivity levels. Nyangores River catchment in Kenya recorded relatively low levels of conductivity that ranged from 70 μScm^{-1} to 90 μScm^{-1} (Gichana *et al*., 2015). Even at these low conductivity levels, conductivity had negative correlation with stone flies of the order Perlidae, but had positive correlation with more tolerant taxa such as *Naucoridae* in the order Hemiptera.

2.6 Relationship between benthic macroinvertebrates and land use

Land use landcover has been shown to have influence on both water quality and the biological components (Ometo *et al*., 2000). The existing literature has shown that different land uses landcover contribute to the observed differences in stream pollution loads along the river gradient for example studies by (Kithiia, 2006; Gichana *et al*., 2015; Wambugu, 2018). Macroinvertebrates are found along river gradient from headwaters to estuary. They have different degrees of sensitivity and therefore are impacted in different ways by organic pollution , hence their community assemblages vary (Azrina *et al*., 2005).

The impacts of land use/cover on the macroinvertebrate diversity along the river continuum has been recorded by various studies around the world. Azrina *et al*. (2005), studied the anthropogenic impacts on the distribution and diversity of macroinvertebrates fauna in Langat River, Malaysia and their results showed that macroinvertebrates metrics of richness, evenness and diversity responding to pollution gradient along the river continuum. The less impacted areas located upstream had higher species diversity than more human disturbed areas downstream. In the Langat River basin the upstream stations were characterized by high vegetation cover and the main land use was recreational. In these stations the researchers recorded high number of sensitive Chironomidae taxa and Trichoptera Caddisflies. Downstream areas were dominated by townships, large scale intensive farming establishments, and a paper factory. Within this zone authors recorded high count of the tolerant *Limnodrilus sp*, which thy attributed to direct and indirect discharge of waste from townships and runoff from commercial farms were agrochemicals are applied.

Moore & Palmer (2005), studied impact of land use gradient on macroinvertebrate biodiversity between agricultural and urban land use within the Chesapeake Basin in Maryland USA. The researchers showed that land use had a significant influence on the diversity of macroinvertebrates. The sampling stations located within the agricultural land use had significantly higher diversity and richness of the sensitive EPT group than the stations within the urban land uses. However, land use had no significant influence on eveness and and density of macroinvertebrates.

Kasangaki *et al*. (2007), studied the land use impact on the ecology of macroinvertebrates in high altitude forest streams of Uganda. The author observed the presence of torelant taxa from the families *Oligoneuridae* and *Tricorythiidae* in deforested areas and areas with agricultural activities. Forest dominated areas had high presence of Calamoceratidae, Perlidae, Tipulidae, and Lepidostomatidae. The plant material from the forest provides food for Tipulidae and materials for case-building caddisflies such Lepidostomatidae. These taxa were therefore absent in areas which had human distubances such as agricultural and deforested areas. Comparative study by Aura *et al*. (2011), on similar river systems of Kipkaren and Sosiani Rivers within the Nzoia Basin, in Kenya revealed significant differences in macroinvertebrate community structure along the land use gradient. In both rivers, authors associated the observed differences in richness and abundance to the anthropogenic activities such as farming and settlements establishments. In terms of spatial species distribution, authors observed the tolerant taxa such as *Tubex, Chironomus, and Lumbricus* in agriculture and urban land uses, while the less tolerant taxa *Caenis*, *Heptagenia,* and *Baetis sp* were observed in the forest, and areas with less intensive agriculture.

2.6.1 Multivariate approaches

Multivariate approaches used in biological monitoring studies include hierarchical clustering, constrained ordination techniques such as canonical correspondence analysis (CCA), and unconstrained ordination such as Non-Metric Multidimensional Scaling (NMDS) (Cao, *et al* 1996). The complexity and multidimensionality of water quality data from biomonitoring programs, requires multivariate statistics for analysis and interpretation (Singh *et al., 2004).*

According to Achieng *et al*. (2017), multivariate techniques can be applied to characterize and evaluate water quality and to verify the spatio-temporal variations due to anthropogenic or natural causes. Complex data is processed using multivariate statistics to generate numerical vector matrix and graphical outputs from which the user can deduce relationships.

2.6.1.1 Application of multivariate techniques in water quality monitoring

Multivariate techniques have been used in water quality studies and in biological monitoring research studies when combined with macroinvertebrates metrics. In this section a few examples of how these techniques have been used will be highlighted. Studies that have been done in Kenya used different multivariate approaches depending on the objectives. For example, cluster analysis was used by Masese et al. (2014) in a study on macroinvertebrates FFGs in streams within the upper Mara River Basin. Cluster analysis help in classifying the macroinvertebrates species into the different FFGs which is important in the understaing of the ecologal function of streams, and the impact of land use changes on streams. NMDS is one of the ordination technique that was used by Gichana et al. (2015) to cluster sampling sites based on the macroinvertebrates abundance data. The technique allowed the researchers to separate sites according to the human impact gradient within Nyangores River Basin. The canonical correspondence analysis (CCA) was used by Abong'o et al. (2015), to elucidate the relationship between benthic macroinvertebrates and environmental variables which included physico-chemical parameters, width, discharge, and altitude in Nyando River catchment. The results of the study showed that the physico-chemical parameters namely dissolved oxygen, pH, turbidity, total nitrates, and temperature contributed 15% of the variation in macroinvertebrates structure observed in Nyando River catchment areas.

2.7 Research gaps

The literature review in this study identified two main research gaps:

a. Lack of research studies in the study area whose objective was to link land use and land cover spatial changes to water quality and macroinvertebrates assemblage.
b. The need to shift to the use of biological indicators that are cost effective and that present an integrative freshwater ecosystem status. There is however inadequate data to provide reference point if restoration efforts are implemented. This study will contribute to the existing paucity of knowledge of benthic fauna in tropical streams.

2.8 Theoretical framework

2.8.1 Introduction

The dynamics of land tenure and land-use changes and their subsequent impact in the study area can be explored with the domain of political ecology. The political ecology perspectives help to shape our understanding of the overlaps among natural resource management, development, and social-economic aspects such as such as agriculture related activities. This study therefore used von Thunen's theory (1826) of the location of agricultural production to understand the interactions among the land use and land cover types, such as agriculture, forest, and wetlands. The model explains why some land uses are preferred by users hence others are lost and we end up with a dominant land use in a given geographical space. The von Thunen's model is supplemented by Sinclair's theory of urban sprawl (1967) to explain the observed land-use patterns at the urban-rural fridge, where urban-settlement and associated land use are the dominant land uses. The study was also designed to answer the question of how spatial land use patterns impacts on the river water quality characteristics and the biological community structure in particular the benthic macroinvertebrates. The river continuum concept (RCC) Vannote *et al* (1980), explains the complexities of the river function across landscapes and how the macroinvertebrates community structure change longitudinally. The three theories are then used in the conceptual model of the study to understand how land use and land cover changes together with pollution impacts on river water quality and ecological integrity.

2.8.2 Thunen's location theory

The research problem was to understand how the changes in spatial LULC patterns impacts on water quality and benthic macroinvertebrates and subsequently leads to watershed degradation. To analyses this process, a general theoretical framework put forward by Johann von Thunen 1826 provided an appropriate entry point. The tenents of the model are that land is allocated to the use generating the highest land rent (profit/ return). Therefore, the changes in land rent for different uses reveals the underlying causes of the observed changes in land uses and land cover in a particular area. In this case along Theta river land use changes from forested catchment area with low use and thus no impact on water ecology to high intensive use near urban areas resulting in changes in water quality and low aquatic biodiversity. The model has been used for instance to explain the allocation of forestland to non-forest land uses such as agriculture and infrastructure by(Angelsen, 2007). Some authors including (Angelsen, 2007; Karakayaci, 2017), recognized that von Thunen model was deficient in explaining the underlying causes of the land rents that are the key driver of the changes nor does it explain what the feedback mechanisms that are at play in all these changes.

2.8.3 Sinclair's theory of urban sprawl

Therefore, von Thunen was combined with the Sinclair (1967) model of urban sprawl. The model explains why lands in and around urban sprawl have reduced intensity for agricultural use or other non-commercial uses, instead these lands are allocated for settlement or transport due to speculative tendencies by land owners.

2.8.4 The river continuum concept

The River Continuum Concept (RCC) by Vannote *et al* (1980) is a generalized idea that the biological components and processes of rivers show changes along a longitudinal downstream continuum as depicted in Figure 2.1. The RCC concept explains the predictable and quantifiable changes along the stream clinal gradient in the stream biota structure and function.

The changes observed in the RCC can be attributed to external processes outside the river ecosystem such as climate, hydrological, and geomorphological. The external factors in turn influence the physical and biological processes in respect to entropy gain, velocity, depth, width, nutrients, and temperatures.

Vannote *et al*. (1980) argues that the river ecosystem is continuum flowing from its headwaters (order 1-3 streams) to its mouth. The river ecosystems consist of several elements that include riparian, river bank, river channel, flood plains, and adjoining land uses. Changes in land uses such as alteration of riparian vegetation through clear-cutting or grazing, forests, and development of structures such as impoundment have negative effects on functioning of river ecosystem.

According to the RCC in upstream areas near the source of the stream, macroinvertebrates communities are dominated by shredders and collectors. This is due to availability of course particulate organic matter (CPOM) from leaf litter due to riparian vegetation. Downstream, the stream width and discharge increase as CPOM and shading effect of riparian vegetation decreases. The macroinvertebrates communities are dominated by grazers and collectors. Further downstream where the stream has a relatively large channel width, deep and turbid waters. There is an abundance of fine particulate organic matter from upstream areas, as a consequence the macroinvertebrates communities are dominated by collectors, filter-feeders, and a few predators.

Statzner & Higler (1985), highlights some limitations of RCC that researchers should take into account when assessing the macroinvertebrates invertebrate community structure along the stream longitudinal gradient. These limitations include: (1) the stream is assumed to be pristine and undisturbed, (2) The general entropy patterns along the river may differ for streams in high elevations and latitudes, and deeply incised valleys; (3) depending on the volume and characteristics of inputs from tributaries, localized effects from the tributaries vary, (4) various sources of rivers such as lakes and mouth such as deltas and effects of natural reservoirs along the river, are not addressed within the RCC framework.

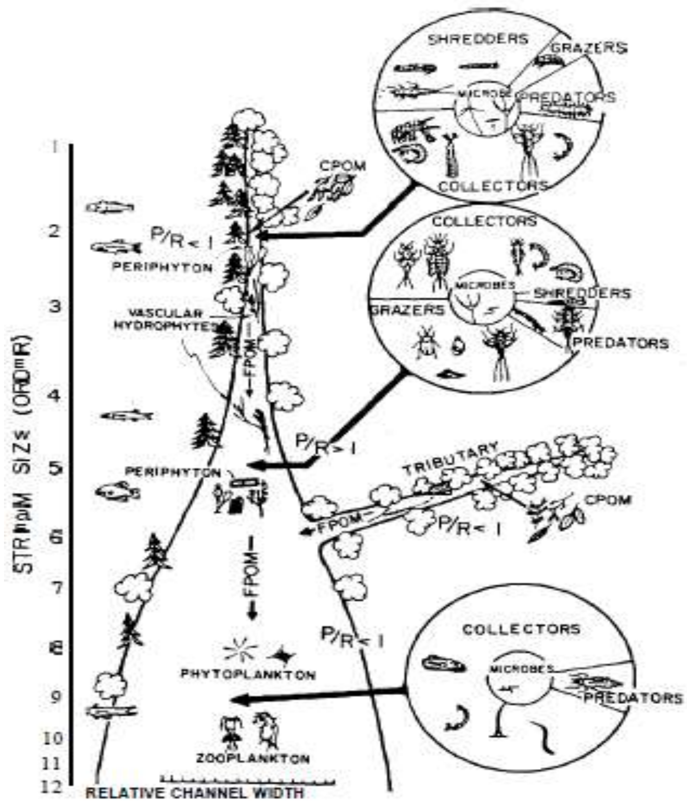

Figure 2.1: Diagram of a stream depicting the river continuum concept
Source: Vannote *et al* (1980).

2.9 Conceptual model

The anthropogenic influences on stream water quality characteristics, benthic macroinvertebrates structure, and ecological quality can be explained in a conceptual model. Figure 2.2 shows a conceptual model that is used in this study which shows that factors such as catchment modification arising from land use and land cover and pollution from point and nonpoint sources interact jointly or separately have impact on stream water and ecological quality. These impacts in the immediate impair water physicochemical characteristics. When these changes in water quality persists, the legacy effects are seen through the changes in benthic macroinvertebrates community structure. The benthic macroinvertebrate fauna that are not able to respond or adapt to these changes either migrate, drift, or die resulting in changes in benthic macroinvertebrates community structure. The changes in water quality are usually mediated by natural mechanisms such as succession changes where for example the disturbed areas regenerate or are colonized by new species. Anthropogenic interventions led by research, water quality monitoring, or through enforcement of laws that prohibit or example the dumping of domestic or industrial effluents into streams. These measures help to mitigate the impacts of stress factors on streams.

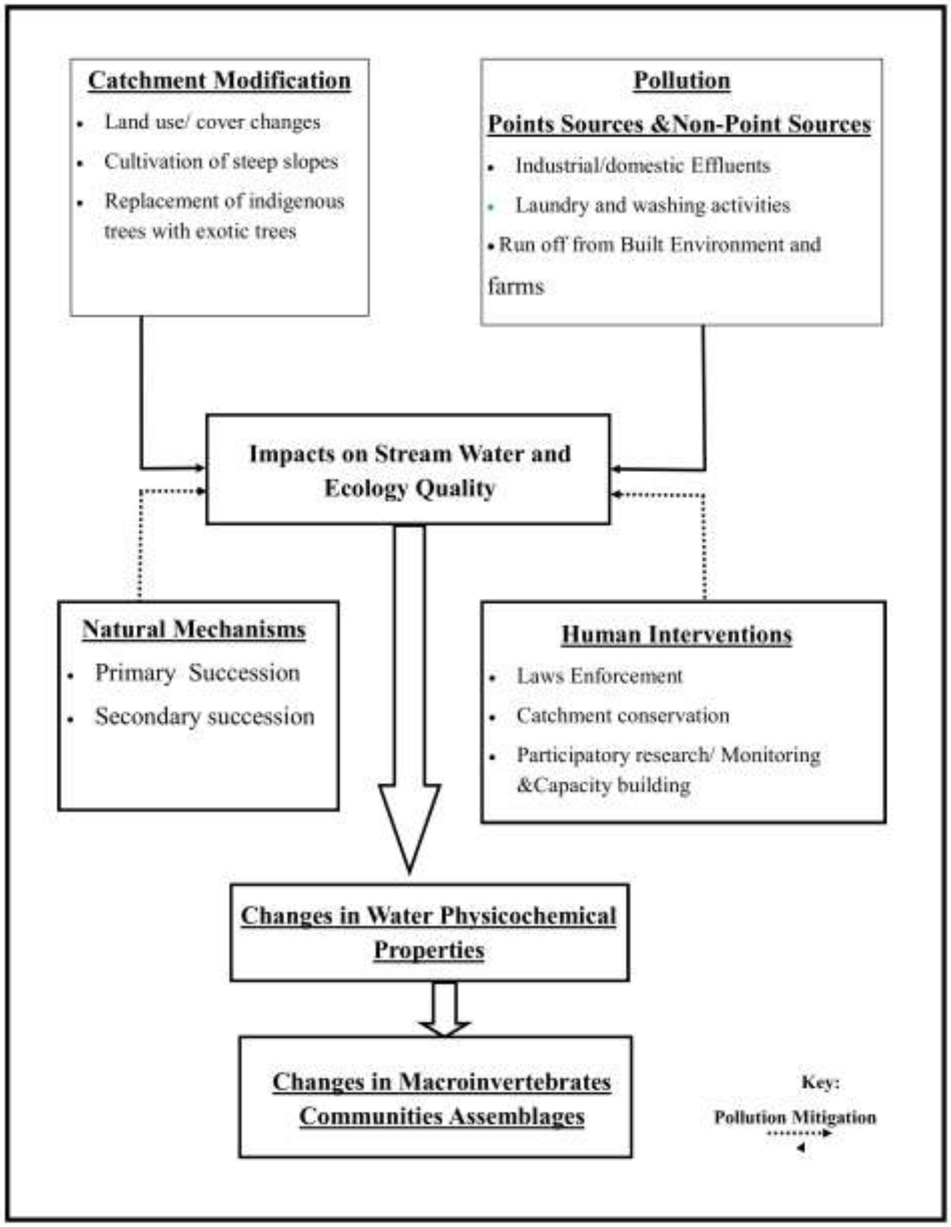

Figure 2.2: Conceptual Model for effects of land use/cover on stream water quality and benthic macroinvertebrates
Source: Researcher, 2019

Chapter 3: RESEARCH METHODOLOGY

3.1 The study area geographical scope

The study area is located within Kiambu County where Theta River and its tributaries span parts of Lari, Githunguri, Gatundu South, Ruiru and Juja Constituencies as shown in (Figure 3.1). The catchment covers an area of approximately143 km^2 between longitude 36.70º E, latitude 0.92º S and 37.03ºE, 1.18º S. Theta River catchment is part of the larger Athi River catchment which is one of the six main drainage systems in Kenya.

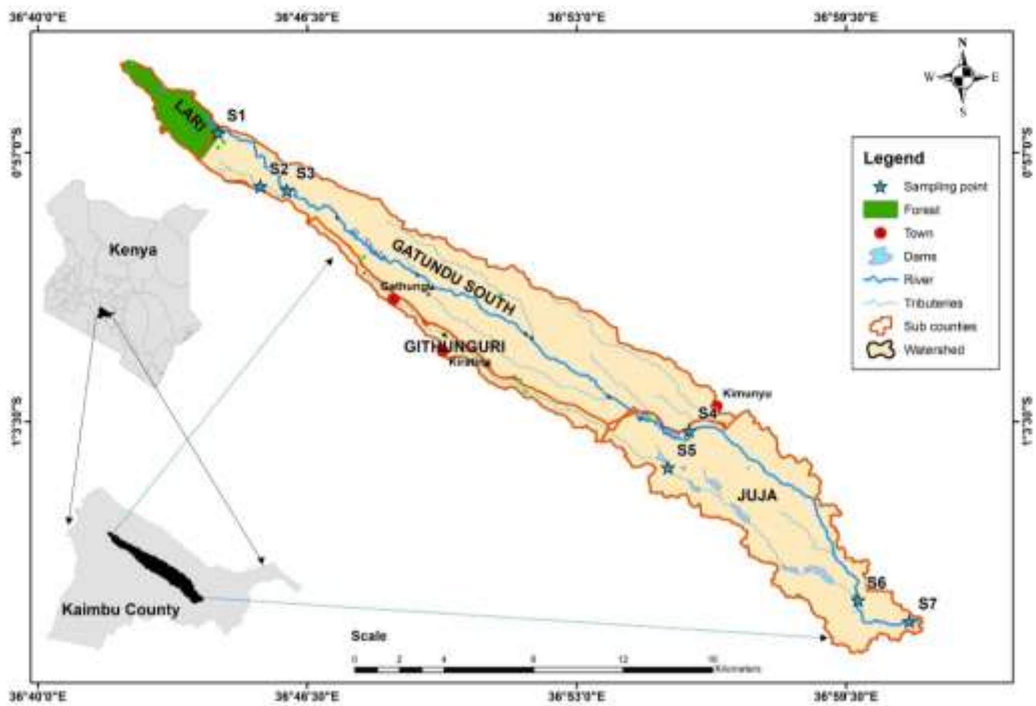

Figure 3.1: Location of study area, in Kiambu County in Kenya

Source: Researcher, 2018

3.2 Topography

According to Jaetzold & Schmidt (1982), Kiambu County can generally be classified into four main topographical zones: Upper highlands, Lower highlands, Upper midlands, and Lower midlands. These zones influence the climate, soils, drainage, land-use, and settlement patterns. Most springs that form tributaries emerge within valleys, while settlements are located on the hilltops.

The study area spans three topographical zones where altitude ranges from 2366m above sea level (a.s.l) in Kinale Forest to 1485m a.s.l downstream in Juja. The upper highlands and lower highlands consist of steep ranges and valleys whose gradient reduce downstream. The upper highlands are subdivided into several upper highland (UH) agro-ecological zones namely: UH_0 (Forest reserve), UH_1 (2280-2550m a.s.l).

The lower highlands consist three lower highlands (LH) agroecological zones: LH_1 (1820-2280m a.s.l), LH_2 (1980-2280m a.s.l), LH_3 (1950-2070m a.s.l). The upper midlands comprise of gentle sloping plains and can be categorized into upper midland (UM) agroecological zones: UM_1 (1700m-1820m); UM_2 (1580-1760m); UM_3 (1520-1580m); UM_4 (1360-1520m).

Kinale forest spans the upper highlands in $LH_{1,}$ where the edge of the forest lies at 2151m a.s.l. Tea is mainly grown in the upper and lower highland which lies between 1820 m and 2,280m a.s.l. However, the last tea farm was mapped at an altitude of 1933m a.s.l (latitude: S00˚59.629', longitude: E036˚47.831'). Within this zone, coffee and tea are grown side by side in some farms but coffee farms are fewer towards high altitude areas.

3.3 Climate

The average annual rainfall in the study area decreases from the northwestward to the southeastward. The mean annual rainfall ranges from 1600mm in Kinale Forest to 800mm in Juja. The study area receives bimodal rainfall patterns, 'long rains' have onset in mid-March and cessation in late May, while 'short rains' have onset in mid-October and cessation in late December.

The hot and dry season is between January and March, and between September and October. The cool dry season falls between June and August. The temperature and rainfall distribution are influenced by altitude, cold zones and areas with high rainfall are observed in high elevation areas. Low elevation areas are characterized by warm temperatures and low rainfall.

3.4 Geology and hydrology

The study area falls under the Athi River drainage system which generally has pyroclastics and lavas volcanic rocks which are traversed by the rivers draining the area. The Pyroclastic rocks are of different ages and are associated with Sattima Series (Thompson, 1964).

The study area lies within the hydrological zone 3BD located within the Nairobi Aquifer, the water source is mainly from the surface and ground water sources. Kiburuti and Theta Springs are the main sources of Theta River, and are located within Kinale Forest. Theta River has been impounded at the source within the Kinale Forest to form Theta Dam, for municipal water supplies by Gatundu Water and Sanitation Company Ltd.

Theta River flows for more than 15km to confluence with Thiririka River in Ndarasha Juja. The main tributaries of Theta Rivers are Thaara, Kaihinga, Kimaratia, Thembere, and Kabindu/Ngenda. The other streams that are investigated in this study are Thumara and Mugutha Rivers. Thumara and Theta Rivers are the only rivers in the study area that have their sources located within the Kinale Forest. Figure 3.2 represents the rivers that traverse the study area. The other streams have their sources located within unprotected areas within farmlands and drain agriculture dominated areas before their confluence with the main Theta River. Mugutha River is the most affected river in the study area in terms of presence of dams in the main river channel. Mugutha River has a series of seven dams with an upstream-downstream order of Brad Gate, Karimu, Karangi, Ruera, Nyakinywa/ Rumera, Twiga 2, and Twiga 1 as shown in Figure 3.2. The dams were built during the colonial period to provide water for irrigation in the coffee and sisal estates.

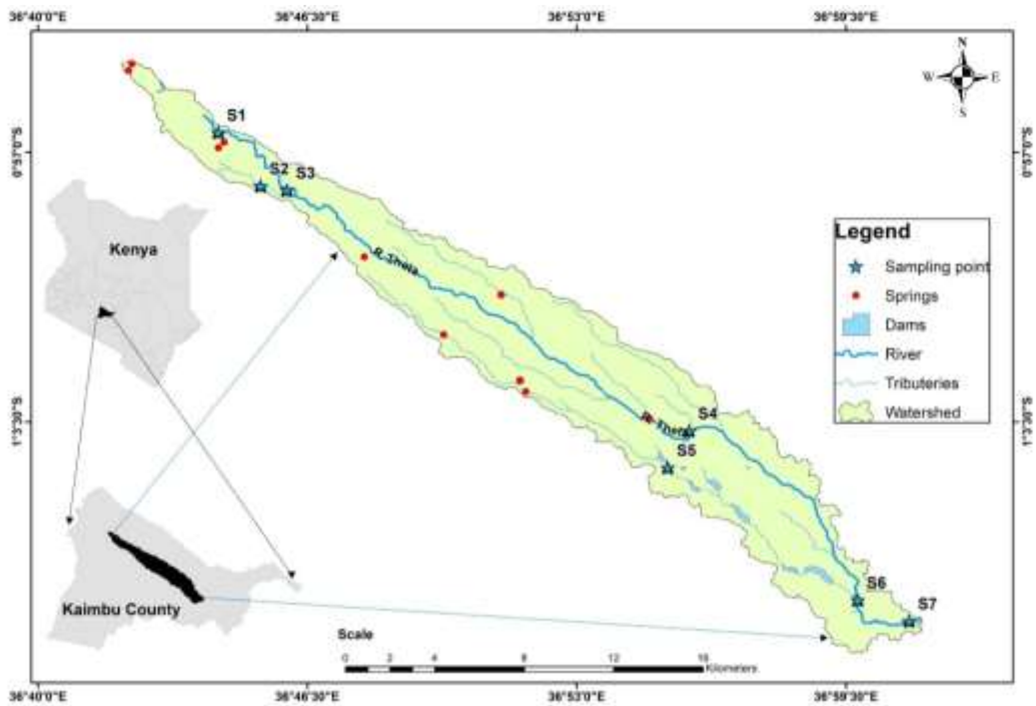

Figure 3.2: Key hydrological features in study area
Source: Researcher, 2019

3.5 Vegetation

The part of study area covered by Kinale forest is dominated by a natural indigenous forest. Some of the indigenous trees observed were: *Syzygium guineense, Croton macrotachyus, Podocarpus latifolius, Ocotea kenyensis, Ocotea usambarensis, Rauvolfia caffra, Macaranga Kilimandscharica, Vitex keniensis, Olea capensis, Ochna ovata, Garcinia volkensii, Ekebergia capensis, Pschotria franctinervata, Teclea nobilis*. The forest had good cover of leave litter and forest undergrowth. Beyond the natural forest, there is little natural vegetation due to intensive farming activities taking place in other parts of the study area. However, there are remnants of natural vegetation in form of shrubs and grasslands in the lower catchment areas but this is changing due to the rapid expansion of settlements.

Agroforestry is a common practice among the smallholder farmers where exotic and indigenous fast growing species are planted alongside crops. The main exotic tree species are *Eucalyptus spp,* Silky oak (*Grevillea robusta*), and cypress (*Cupressus lusitanica*), while the main indigenous species is *Cordia africana* which is commonly intercropped with coffee bushes by both smallholder farmers and large coffee estates. The other trees species include various fruit trees such as mango- and avocado trees for domestic and commercial purposes.

3.6 Socio-economic activities

3.6.1 Population

According to the 2019 census, Kiambu county had an estimated population of 2,417,735 and a population density of 952 persons per square kilometer (KNBS, 2019). The study area overlaps 4 constituencies and 8 wards namely: Kinale, Kiganjo, Komothai, Kiamwangi, Theta, Murera, Juja, and Kalimoni. The summary of population in the wards and respective constituencies is summarized in (Table 3.1).

Table 3.1: Population size in different wards within the study area

		Gender		Total Population
Constituency	**Ward**	**Male**	**Female**	
Gatundu South	Kiamwangi	9,740	10,631	20,371
	Kiganjo	13,057	13,983	27,040
Githunguri	Komothai	14,580	15,394	29,974
Juja	Murera	7,955	7,891	15,846
	Theta	10,965	11,455	22,420
	Kalimoni	10,040	9,532	19,572
	Juja	16,980	16,560	33,540
Lari	Lari/Kirenga	13,649	14,080	27,729
Total				196,492

Source: Modified from (Ngugi, Kipruto, & Samoei, 2013)

3.6.2 Economic activities

The economic activities within the study area vary based on natural and anthropogenic factors. Agriculture is the main economic activity, where different crops are grown based on the agro-ecological zones. Agriculture consists of subsistence and commercial farming of tea, coffee, beans, maize, potatoes, hass avocado, pineapple, vegetables, and woodlots. Depending on the agro-ecological zone, the subsistence farms practice polyculture while the commercials farm are monocultures. Tea is grown in high altitude areas in upper and lower highlands, the farms consist of smallholder farmers and large plantations mainly Nyayo Tea Zone which is a buffer strip between individual farms and Kinale Forest.

3.6.2.1 Commercial farms

Large commercial farms that grow single crops are mainly located in the upper midlands, these consists of farms of more than ten acres that were previously owned by white settlers. The location of the farms was mainly influenced by the 1954 Swynerton Land use Plan (Wambugu, 2018). The key estates are: Ruera, Karogo, and Oaklands with a combined acreage of 600 Ha of coffee and managed by Coffee Management Services (CMS). Nado Farm which has 200 acres of Macadamia trees. Gitamaiyu Farm is Hass avocadoes estate planted with 10,000 seedlings on 56 acres.

3.6.2.2 Trade and commerce

The study area has about 15 trading centers and an urban center in Juja. Trade of goods and services is done through the retail and wholesale registered traders and markets. Tourism has not been fully exploited despite the existing opportunities within the study area. However, the hospitality industry is showing positive trend as hotels, restaurants, and sport clubs e.g. the Ruiru Sports Club are mushrooming around the dams located downstream particularly around Twiga Dam 1 and 2. Buying and selling of land and properties is common in downstream areas which are in peri-urban and urban. In these areas the soils are less suitable for farming activities. The demand for high-end housing by the middle class has led to conversion of some of the coffee estates into subdivided plots for establishment of residential areas Table 3.2.

Table 3.2: List of real estate development projects in the study area

Estate	Acreage	Housing Units	Former Land use
Daykio Investment: Bustani Estate	500: 200 Acres Bustani. 300 Acres sold as 50 Acres and 25 Acres blocks for real estate development	590 Housing units on 100m by 100m plots	Hived from Ruera Coffee Estate
Ruiru Villa	100	372 Houses on 100m by 100m Plots	Hived from the Twiga Farm
Ebenezer Ridges	375	600 Housing units on 100m by 100m plots	Hived from Brad Gates Coffee estate

Source: Researcher, 2019.

3.7 Objective specific methods

In this sub-section the sampling techniques, data needs, methods of data collection for each study objective are described.

3.7.1 Spatial land use and landcover patterns and riparian conditions

The first objective of the study was to detect the spatial changes in land use and land cover along Theta River gradient.

3.7.1.1 Data types and sources

The Shuttle Radar Topographic Mission (STRM) Digital Elevation Model (DEM) data, acquired by STRM satellite on February 10th 2010, was collected from United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). This data was used to delineating the Theta River catchment, understanding surface water flow, and terrain of the study area. The DEM data had a resolution of 1 arc second, which is approximately 30m resolution, and consisted of three DEM tiles (s02-e37, s02-e36, s01-e37, and s01-e36) that are traversed by Theta River catchment. Figure 3.3 presents a mosaic of the three DEM tiles the overlaid by a shape-file of Kiambu County and that of study area.

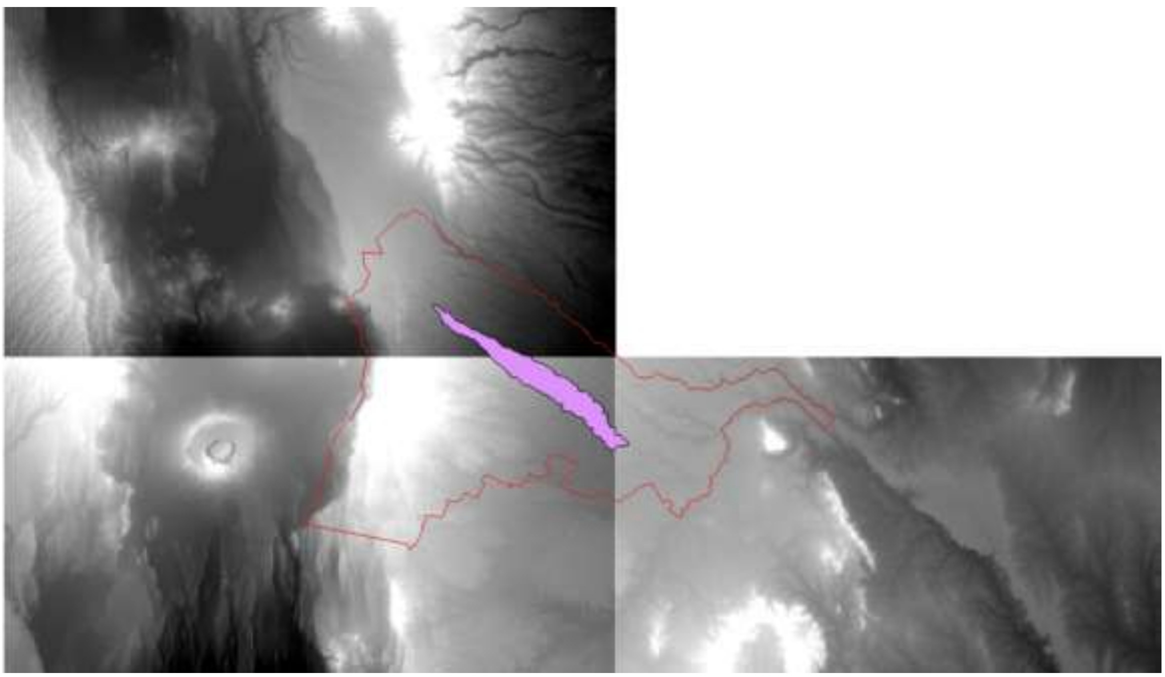

Figure 3.3: DEM tiles overlaid by a map of Kiambu County and the map of study area
Source: Researcher, 2019

The multispectral satellite image for the year 2018 was collected from United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). This data was used in analyzing the spatial land use and land cover patterns in the study area. Theta River catchment was covered by a single image of path 169 and row 61. During the image selection cloud and shade free imagery were set as the search criteria. The image was acquired by Sentinel 2a satellite on September 16th 2018 which according to ESA (2019), Sentinel 2a satellite was launched in June 2015 for application in disaster mapping, water bodies, vegetation health, and land use and land cover change assessments. The satellite has a repeat cycle of 10 days at equator, the spectral bands are 13 with resolutions of 10, 20, and 60 meters. The spectral characteristics of the image are summarized in Table 3.3.

Table 3.3: Technical characteristics of Sentinel 2a Sensor

Band	Name	Wavelength nm	Resolution (m)
1	Coastal aerosol	443	60
2	Blue	490	10
3	Green	560	10
4	Red	665	10
5	Vegetation Edge Red	705	20
6	Vegetation Edge Red	740	20
7	Vegetation Edge Red	783	20
8	NIR	842	10
8a	Vegetation Edge Red	865	20
9	Water Vapor	940	60
10	SWIR-Cirrus	1375	60
11	SWIR	1610	20
12	SWIR	2190	20

Source: Modified from https://earth.esa.int

3.7.1.2 Data analysis

In analyzing the land use and cover patterns of the study area qualitative and quantitative analysis was done using geographical information systems (GIS) software:

i. Catchment delineation

The process of catchment delineation was done by applying GIS tools to the acquired DEM to create an inferred network of rivers and to create catchment boundary. Mosaicking the tiles was first done followed by sub setting of area of interest (AOI) using the shapefile of administrative boundaries that span the study area. The subset AOI was then subjected to removal of all sinks in the DEM by filling their elevation to the nearest neighboring cells. This was followed by application of flow direction function that helped to determine the flow direction for each grid. The basin tool was used to delineate all the basins within the area of interest in raster form. Conversion tools used to convert raster output to vector data. The output from this process was subjected to flow accumulation function which computed the flow accumulation grid that contains the accumulated number of cells upstream of a cell. This was then followed by pour points placement and snapping pour points to discriminate the sub-basin that falls within Theta River catchment. Finally, the delineated catchment in raster format was converted into a shapefile with individual sub catchments individual polygons. This process was done using ArcGIS 10.4.

ii. Satellite image pre-processing

The remote sensing data was first pre-processed by layer stacking of the red, green, and blue (RGB) bands which have the same spatial resolution of 10m. Layer stacking resulted into conversion of bands into a single layer. The resultant shape-file of Theta River catchment boundary produced through the process of watershed delineation, was then used to subset the mosaicked image, to speed up the processing time. Figure 3.4 shows a subset of natural color composite of bands 2, 3, 4 that was used in classification.

iii. Land use and land cover classification

Supervised classification was adopted in this study according to (Richards & Jia, 2006). This was achieved using ArcGIS 10.4 software image classifier tool. The training sites were identified by drawing polygons over the known land cover classes in all areas of a representing a given class. These representative sites described minimal confusion among the land cover classes to be mapped All the polygon representing a given class were then merged in a single class and assigned a particular color. This process was repeated for all other classes, using a training sample manager a signature file containing all the classes was created and saved. Maximum likelihood algorithm option was selected to generate a land cover map. The misclassified or invalid areas generated by maximum likelihood classification were reclassified or merged with adjacent land cover classes. The area of each of the class was calculated based on the pixel count and total area of the study area and calculated as percentages and summarized in a table 3.4.

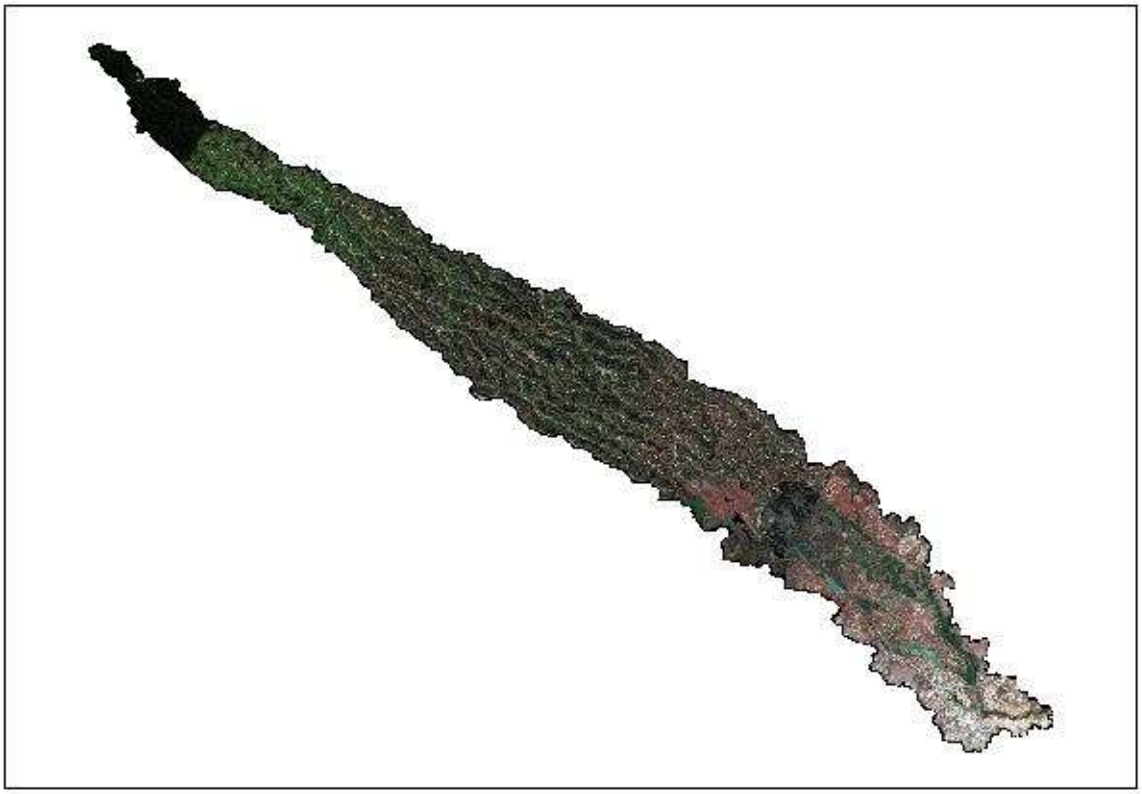

Figure 3.4*:* Subset of a composite Sentinel 2a using bands 2, 3, and 4.
Source: Researcher, 2019

iv. Riparian conditions

The ecological quality of riparian zone in each site was determined qualitatively by recording in an observation sheet supplemented by photography. The recorded information included the presence or absence of vegetation cover, human activities, and presence or absence of incompatible physical structures within the riparian zone within 100m reach and a of about 30m from the river center according to (Mwiti, 2014). The collected data was analyzed qualitatively by describing the conditions observed in the sampling stations and from photographs taken.

3.8 Influence of spatial land use/cover types on water quality

The second objective of the study was to determine the influence of spatial land use and land cover changes on water quality in Theta River.

3.8.1 Sampling design

Multiple techniques were employed in the identification of the sampling sites along Theta River gradient as summarized in Figure 3.5. At the initial stages, the study relied on the watershed delineation to get the hydrological boundaries of the Theta River watershed. The image classification generated a LULC map for Theta River catchment. From this map the dominant land use types traversed by Theta River and tributaries were identified as forest dominated, agriculture dominated, and settlement dominated areas that follow human disturbance gradient. Agricultural dominated areas were then subdivided into large-scale coffee farming, small-scale coffee dominated areas, subsistence cropland, and tea farming dominated areas. Forest dominated areas represented the least impaired sites, while the rest represented the putatively impaired sited. Carter *et al.* (2006), advances the argument that there is rarity of pristine sites in many study areas hence the adoption of the phrase 'least impaired' sites. This is true for the Theta River catchment where there is clear evidence human activities within the Kinale Forest due to the construction of Theta Dam.

In each LULC type, two sampling stations from each LULC type were selected except one sampling station from forest dominated area Figure 3.5. The process employed stratified random sampling and generated a total of 7 sampling sites. Two sampling stations were selected from Theta River tributaries, i.e. Site 2 in Thumara River (tea dominated) and Site 5 in Mugutha River (large-scale-coffee dominated) these are highlighted in blue in Figure 4.3. The remaining five sites where selected along the main Theta River. Site 1 (forest dominated), Site 3 (tea dominated), Site 4 (small-scale coffee dominated), Sites 6&7 (urban-settlement dominated).

3.8.2 Study period

The study was done during the dry season where each site was visited once between March 11th and March 16th 2019. Water quality sampling preceded benthic macroinvertebrates sampling and recording of geomorphological characteristics of the river. At each station sampling was done from downstream to upstream direction. During the sampling the actual coordinates were recorded using a GPS receiver as the new coordinates.

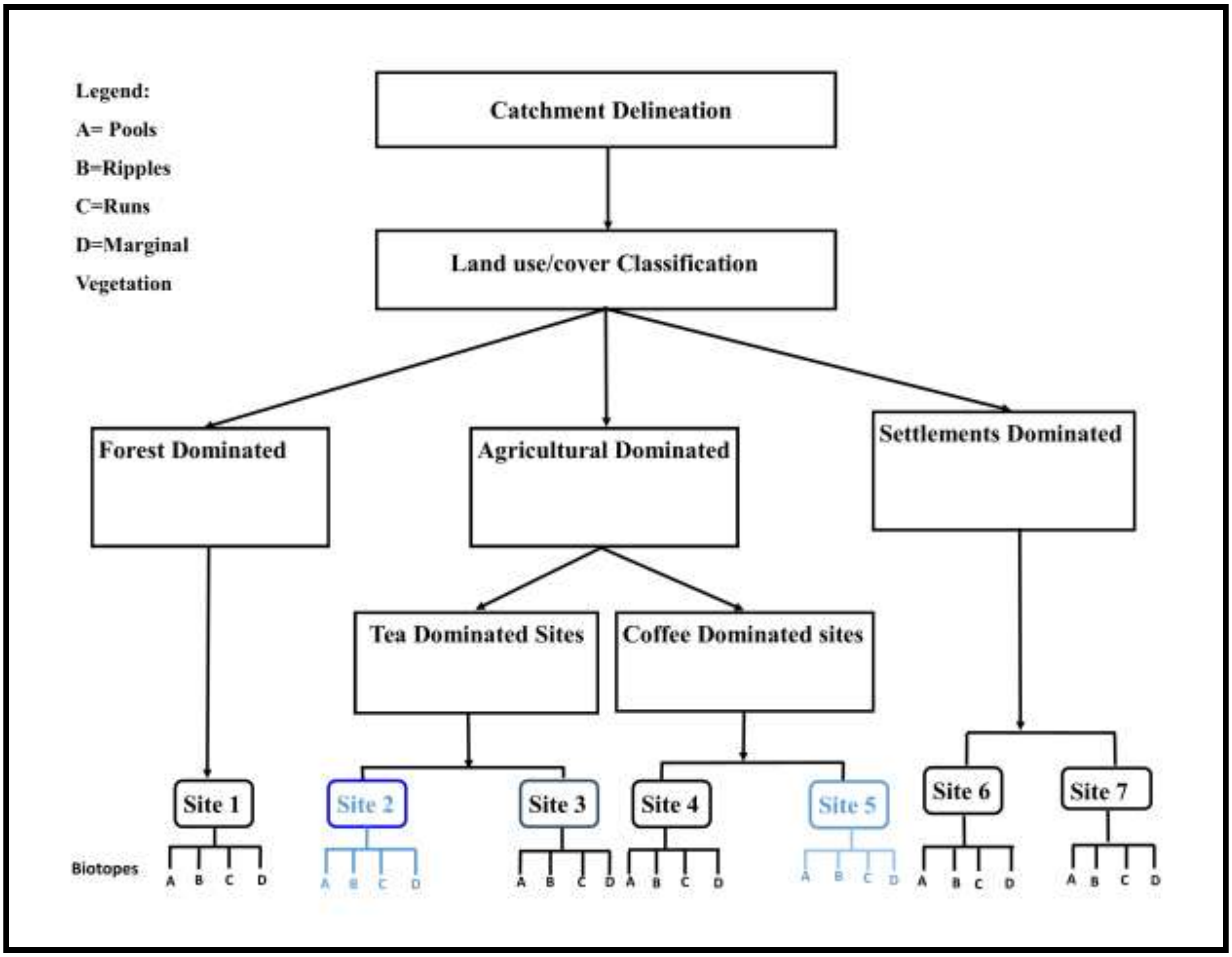

Figure 3.5: Schematic showing the sampling designed.

Source: Researcher, 2019

3.8.3 Methods of data collection

The objective relied on data set collected through primary (field data) and secondary sources.

i. Primary data

Primary data types consist of data collected in the field using standard and designed systematic procedures, tools, and field observations. These data included water quality data collected using *in-situ* and *ex-situ* techniques and tools.

Water samples for water quality assessment were collected in seven sites along the main stem and major tributaries of Theta River. The sampling points were in a variety of the land uses in the study area. The sample collection was carried out once per each sampling point during the dry season (March 2019). Triplicate water samples were taken below the water surface in the middle of the river. During the sampling seven water parameters were measured, they were deemed to be important indicators of water pollution caused by human activities. Water pH, Temperature (˚C), turbidity (NTU), dissolved oxygen (DO, mg◦L^{-1} & %), electrical conductivity (EC, µS/cm*)*, and Salinity (ppt) were measured *in-situ* using Hanna H1 9829 Multiparameter meter (Hannah Instrument, Ltd, Bedfordshire UK) The samples were taken by dipping the probes in the river and the readings recorded after parameter averaging from downstream to upstream within the sampling point reach as shown in Plate 3.1. Before measurements were taken the instrument was rinsed in distilled water as per the manufacturer's guidelines.

Plate 3.1: *In-situ* water quality assessment using potable Multiparameter meter in Site4

Water samples were collected below the water surface from each sampling stations by dipping a 60ml sterile bottle to exclude air. The bottles were subsequently stored in a cool box with ice, and delivered to University of Nairobi School of Engineering laboratory for determination of nitrates. Nitrates were determined using Brucine method. The method involves the reaction of brucine sulfate and nitrite ions at 100˚C in a solution of (Sulphuric acid) $H_2 SO_4$ to produce a yellow colored compound that can be used for colorimetric estimation of nitrate concentration. The quantity of nitrate in the water samples was then determined by measuring the absorbance the yellow compound at a wavelength of 410nm (Nano meters) (EPA, 1971).

ii. Secondary data

Secondary data used in this objective includes land use metrics.

3.8.4 Data analysis

In analysis the relationship between land use types and water quality both qualitative and quantitative techniques were employed. The data of the replicate samples of water taken from each site along the land use gradient, was used in various statistical analysis. The raw data was organized and cleaned in excel. Boxplots and statistical summaries were used to describe the variability of water quality parameters at each land use and site. Boxplots provide a graphical display of the data distribution as well as in identification of outliers. While statistical summaries provided the numerical descriptive measures that illustrate the center of distribution of the data.

All inferential statistics was done using R program version 3.5.3 (R Core Team, 2019) . The water quality data was first subjected to normality test numerically using Shapiro-Wilk test. Shapiro-Wilk test is sensitive to small sample sizes where sample size $(n) < 50$ samples. The data that indicated normality condition under Shapiro-wilk test, was analyzed using one-way analysis of variance (one-way anova). *Post hoc* Tukey's HSD test was then performed to compare the water quality variation between sites and land use and cover types. The data that did not meet normality was subjected to non-parametric Kruskall-Wallis test this was followed by *post hoc* Dunn test with Bonferroni correction (Dinno, 2017). In both cases homogeneity of variances was checked using Levene's test. Data that did not meet homogeneity was $\log_{10}(x+1)$ transformed.

Spearman rank correlation analysis was then used to explore the relationship between water quality and land use and landcover in Theta River catchment. The results of Spearman-rank correlation were used to test the null hypothesis that there is no relationship between water quality characteristics and spatial land use and cover types in Theta River catchment. This correlation was done using the rcorr function in the package corrr of the R program.

3.9 Influence of land use/cover types on benthic macroinvertebrates community structure

The third objective of the study was to determine the influence of spatial land use and land cover changes on macroinvertebrates community composition in Theta River catchment.

3.9.1 Sampling Design

The sampling strategy for this objective was similar to that of objective two, the only difference was in the samples collection. The samples were collected in four representative biotopes of pools, ripples, runs, and marginal vegetation coded as A, B, C, and D respectively identified within a 100m reach as depicted in Figure 3.5.

3.9.2 Methods of data collection

This objective relied on primary data (field data) and secondary data sources from objective one.

i. Primary data

Sampling of benthic macroinvertebrates was done using a D-net with a mesh size of 500 µm (0.5mm) by disturbing an area of approximately $1m^2$ for 1 minute following Abong'o *et al.* (2015) methodology. Kick and sweep method for 1 minute was the standard procedure in ripples and runs as shown in Plate 3.2 while in pools and marginal vegetation, scooping was the main method used.

Plate 3.2: Macroinvertebrates sampling: kick method on a ripple using a D net

The large debris were removed after carefully being washed against the net to remove attached organisms. The contents were then poured into a basin where sorting was done in the field as shown in (Plate 3.3). Macroinvertebrates specimens were poured into vials containing 70% ethanol, which were then tightly closed and labeled accordingly. All samples were taken to the Invertebrate section at Zoology Department National Museums of Kenya for identification and counting.

Plate 3.3: Benthic macroinvertebrates sorting in the field

3.9.3 Laboratory analysis

In the laboratory a dissecting microscope (Leica Zoom 2000 x30) was used for the analysis of the specimen morphological parts. Identification was done to the lowest possible taxonomical level i.e. order and family level using the using identification keys and taxonomic manual by (Gerber & Gabriel, 2002). The identification process was supervised by a taxonomic expert. All *Oligochaeta* were considered as one family because of the difficulties involved in identification of this taxa (Lenat, 1988). The data was entered into excel sheet for organization and to facilitate multivariate and multimeric analysis in R program.

3.9.4 Data analysis

The counts of individuals belonging to each macroinvertebrate family and order individual were recorded. The aggregate numbers were calculated for replicates in each biotope from each site. All analysis was performed using untransformed abundance data, data transformed as log (count+1), and binary (absence or presence) data. Species similarity among sites was calculated using binary data to determine the Sorensen index of dissimilarity using the vegdist function in the vegan package. The other biological indices Pielou, Shannon and Simpson (1-D) were calculated using abundance data. Species richness based on the sampling effort was summarized in a species accumulation curve plotted using specaccum function in vegan package using the Kindt's exact method (Krebs, 1999).

Inferential statistics involved correlations between biological data percentage land use landcover metrics using Spearman-rank correlations. The multivariate analysis was used to identify structure of macroinvertebrates community. The structure was visually assessed using NMDS plot performed using the metaMDS function in the vegan package this was computed as Bray-Curtis measure.

The non-Euclidean distances among the different land uses and sites were calculated as Bray-Curtis this was done using vegan package. Homogeneity of multivariate dispersions of macroinvertebrates community among land uses was done using betadisper function. The anova *post hoc* used was Turkey honest significant difference (HSD) test for unequal sample sizes to show the pair-wise differences between land use/cover types. Significant differences in macroinvertebrate community composition between the dominant land use types was tested for using, one-way analysis of similarity (ANOSIM). ANOSIM was used to test the null hypothesis that there is no spatial difference in benthic macroinvertebrates assemblages between land use types in Theta River catchment. All the statistical significance was assessed at probability level of 0.05.

According to Chapman & Underwood (1999), the R value generated in ANOSIM ranges from -1 to +1, where zero indicates that there is no differences among groups. R values close to zero indicate no distinguishable differences and therefore the null hypothesis (no difference among a given set of values) is accepted. Conversely, values close to 1 indicate differences among groups in a sample or dissimilarities. The p value of 0.05 represents the significance level of this difference. ANOSIM has been used in many studies to test hypotheses in spatial differences in macroinvertebrates community assemblage for example (Kasangaki.,*et al* 2007; Zhang *et al*., 2014).

3.10 Relationship between water quality and macroinvertebrates

The four objectives of the study were to analyze the relationship between water quality and macroinvertebrate composition in Theta River catchment.

3.10.1 Data needs and sources

The data used to realize this objective was water quality data from objective two and macroinvertebrates data from objective three.

3.10.2 Data analysis

Relationship between water quality parameters and macroinvertebrates index was assessed using constrained ordination techniques. Constrained analysis is more robust than the correlation analysis between water quality and diversity indices and has been criticized by (Washington, 1984). Washington argues that biological indices measures community structure that change with time while physico-chemical parameters are specific measures of pollution.

The biological data was first subjected to detrended correspondence analysis (DCA) to assess the response model and the length of the axis gradient using the decorana function in R program. Where DCA axis 1 length is <3 standard deviations (SD), RDA is the appropriate, while for DCA axis 1 length >3SD canonical correspondence analysis (CCA) is appropriate for testing the relationships between environmental variables and benthic macroinvertebrate community.

Multicolinearity was assessed to explore the linear dependencies water quality parameters using vif.cca function in vegan package. This was achieved by calculating variance inflation factors (VIFs) which show the extent to which the variance of a regression coefficient is inflated together with other repressor variables. According to Borcard *et al*. (2011), in an CCA model explanatory variables with VIFs greater than 20 should be eliminated from analysis, because they could make the model unstable. In this study, the criteria was set that all parameters with VIF of more than 20 and a correlation value was ≥ 0.75 was eliminated from the study. This led to decision to eliminate, dissolved oxygen percentage, electrical conductivity, nitrites and salinity from ordination analysis.

The DCA axis length had a length of 3.7 standard deviation (SD). The response variables (benthic macroinvertebrate data) therefore the data had a unimodal distribution, hence the adoption of CCA (ter Braak & Prentice, 1988). The unimodal response model approximates the response variables in which abundance of a biological organism increases to a maximum then declines as the environmental variable increases. The constrained/canonical correspondence was done using the function cca from vegan package where the benthic macroinvertebrates data was constrained by four water quality parameters namely pH, dissolved oxygen, temperature, and electrical conductivity. The output of CCA was a two-dimensional biplot in which physico-chemical parameters which were plotted as arrows and benthic macroinvertebrates families plotted as points. The CCA biplot allowed for simultaneous examination of the influences of water quality parameters on benthic macroinvertebrates families assemblages, all the analysis were run under the vegan package in R program (Oksanen *et al*., 2019). The CCA results were then subjected to permutation in order to test for significant at $p<0.05$ according to Borcard *et al*. (2011). This was used to test the null hypothesis that there is no relationship between macroinvertebrates and water quality.

Chapter 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings of the research study done in Theta River catchment. The results are on the spatial changes in LULC along the river gradient, sampling sites riparian characteristics, and substrate material characteristics. The results of physico-chemical characteristics of water along the river gradient, and how these physico-chemical parameters are associated with the surrounding LULC. Then the results on macroinvertebrates fauna abundance and composition, as well as the changes in assemblages among the sites and LULC types. Finally, the association between physico-chemical parameters and macroinvertebrates metrics are presented.

4.2 Sampling sites characteristics

Table 4.1: Summary of study sites characteristics

Sites	Stream	Latitude	Longitude	Elevation (m)	Biotopes sampled	Main Substrate
1	Theta	S00˚56.516’	E036˚44.350’	2151	pools, marginal vegetation	mud, with logs and leave litter
2	Thumara	S00˚58.047	E0036˚46.117’	1998	pools, runs, ripple, and marginal	Bedrock
3	Theta	S00˚58.038’	E0036˚46.162’	1981	pools, ripples, runs, and marginal vegetation	bed rock and boulders
4	Theta	S01˚03.711’	E036˚55.716’	1572	pools, ripples, and runs	bedrock, boulders, with logs, twigs and leaf litter
5	Mugutha	S01˚04.599’	E036˚55.204’	1580	pools	cobbles& boulders with leaf litter
6	Theta	S01˚07.797’	E036˚59.790’	1505	pools and marginal	Cobbles
7	Theta	S01˚08.305’	E037˚01.026’	1488	pools and marginal	Mud

Source: Field data March 2019

4.2.1 Altitude

The Digital Elevation Model (DEM) of the study area revealed that the height above sea level ranges from 2,366m to 1,485m as shown in (Figure 4.1). Site 1 was located at the highest altitude with a high of 2151 m, while Site 7 was located at lowest point at 1488 m. The altitudinal range was 663m, the sites located in upstream (Site 1,2, and 6) had an average altitude of 2043m, while in mid-stream reaches there were Site 4 and Site 5, which had an average of 1576m. In the downstream reaches there were Site 6 and Site 7 which had an average of 1496 m. This altitudinal range was large enough to reflect the disturbance gradient from less disturbed areas in the forest to highly impacted areas in settlements.

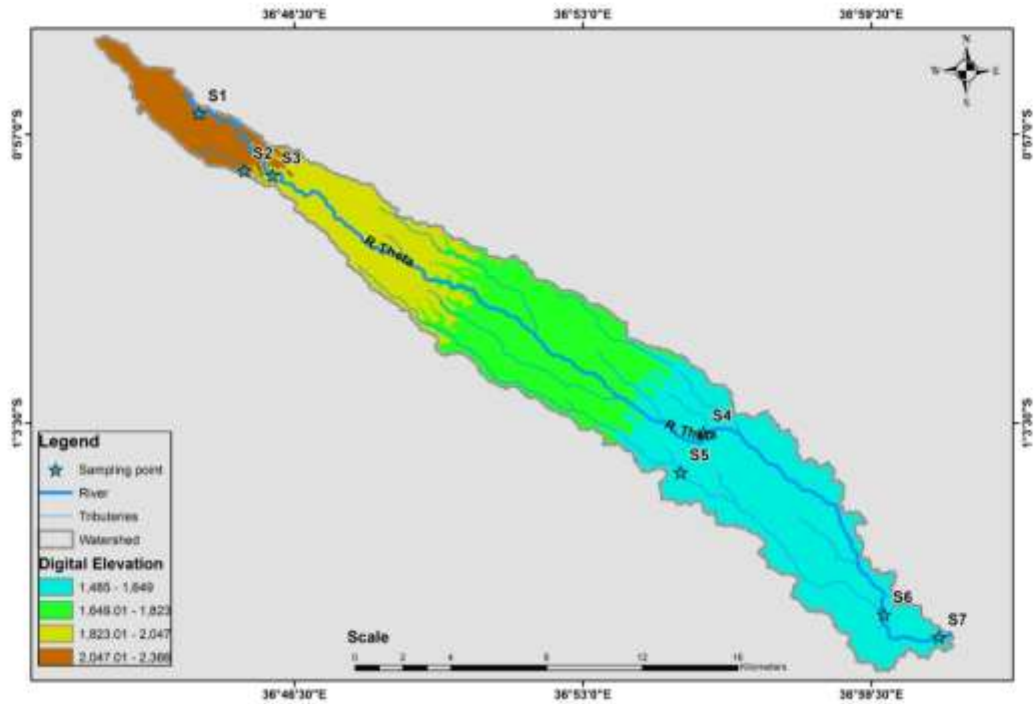

Figure 4.1: Altitude map generated by DEM
Source: Modified from Shuttle Radar Topographic Mission 2013

4.2.2 Riparian ecological conditions

Table 4.2: Description of sampling sites on Theta River catchment

Sampling Station	River's name	Riparian conditions description and land use/cover
Site 1	Theta	Reference site located in headwaters. Forest dominated area, evidence of cattle grazing and drinking water point. Laundry activities
Site 2	Thaara	Located upstream reaches. Agriculture dominated area, surrounded by small and medium size tea farms. There is vegetable farming within the riparian and laundry activities.
Site 3	Theta	Located in upstream reaches in agriculture dominated areas with tea farms. The riparian is dominated by *Eucalyptus sp* woodlots. Farming of vegetables, maize, and arrow roots; application of herbicides.
Site 4	Theta	Located in the mid-stream reaches within the small-scale coffee farms. Right side of the river bank is dominated by riparian forest in the entire reach. Left side of the river bank is devoid of tree cover and is dominated by small-scale irrigated vegetable farms. There is additional human impact of washing clothes within the river channel.
Site 5	Mugutha	Located mid-stream reach in an agriculture dominated area mainly large-scale coffee plantations. The river flow is regulated by a dam upstream of the sampling station. The right river bank is dominated by a riparian forest with undergrowth. On the left bank the riparian is devoid of tree cover; farming activities of maize and bananas, other human impact includes use of pesticides.

Site 6	Theta	Located in downstream reaches within the settlement dominated area. Human impacts included diversion canal for irrigation on the farms within the riparian. Cattle water drinking point, washing and bathing area. The site is devoid of tree cover.
Site 7	Theta	Located in downstream reach within the settlement dominated area. Stream with low flows, with scattered turbid water in ponds. Human impacts include farming activities, washing.

Source: Field data March 2019

Table 4.2 is a summary of the riparian conditions in the immediate vicinity of the sampling sites. Site 1 was located in Theta River headwaters in the forest dominated area that was to act as a reference site. Sampling was done at the river section at the forest edge due to absence of an appropriate sampling reach within the dense forest. Between Kinale Forest and Nyayo Tea Zone, there was a narrow strip an area that had been cleared to provide way leave for electric fence as shown in Plate 4.1. This area was mainly covered by grass were local farmers graze their cattle and can access the part of Theta River flow from the forest the human impact of this is evident by animal hoof prints depicted in Plate 4.2.

Plate 4.1: Electric fence way leave at the edge of Kinale Forest in Site 1

Plate 4.2: Evidence of human impacts at the forest edge (Site 1)

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Site 2 and Site 3 were located in the upstream of areas near the confluence of Rivers Theta and Thaara. Their riparian zone was covered with *Eucalyptus sp*. woodlot and were surrounded by tea plantations Plate 4.3. There were also intensive farming activities consisting of vegetables and maize 4.4. The use of agrochemicals was evident by the spraying of herbicide on a one of the farms on the bank of Thaara River as shown in Plate 4.5.

Plate 4.3*: Eucalyptus sp* woodlot along the River Thaara in Site 2

Plate 4.4: Vegetable and maize farming activities on the Thaara River banks

Plate 4.5: Strip of dried grass due to spraying of herbicide next to Theta River

Site 4 and Site 5 were located in the mid-stream reach of the catchment and had similar riparian conditions in terms of vegetation cover. Site 5 was located along Mugutha River which had a riparian forest cover on the right side of the bank and no tree cover and intensive farming activities on the left side of the river bank. Mugutha River marks the boundary between Oaklands Coffee Estate that is managed by Coffee Management Services (CMS) and privately owned smallholder farms. The Oaklands Coffee Estate adheres to agronomy principles and standards of the Rain Forest Woods to protect water resources from the impact of coffee farming activities. This explains the presence of a buffer strip along the estate's boundary with rivers, while there is no buffer strip on private farms across the river as shown in Plate 4.6.

Plate 4.6: Riparian buffer strip dichotomy between the smallholder and large farms in Site 5

Site 6 and Site7 were located in down-stream reaches in urban dominated areas. There was evidence of river modification by canal diverting water from Theta River min channel. Cattle drinking point upstream of the sampling station resulted in extremely turbid waters at this point as shown by Plate 4.7. The diversion of the water caused the section of Theta River to dry as sampling station 7, which was characterized by remnants water pools as shown in Plate 4.8.

Plate 4.7: Turbid water and a canal at Site 6

Plate 4.8: The last pool in Theta River at Site 7

The other human impacts observed in Site 7 included removal of riparian wetland vegetation such as papyrus and trees to make way for some farming activities. However, this land is under speculation and settlements are expanding rapidly as some houses were observed to be built close to Theta River as shown in Plate 4.9.

Plate 4.9: Clearing of riparian vegetation and expanding settlements (the house in the background)

4.3 Land use and land cover spatial structure in the study area

Supervised classification using maximum likelihood algorithm was carried out at the study area. This classification generated a LULC map with aggregated agriculture land use classes shown in Figure 4.2. The area of each class was calculated taking into account the pixel count and the total area of the study area. The allocation of each classified class area and proportional distributions is summarized in Table 4.3. Agriculture was found to be the dominant land use covering about 61% of the study area, followed by grasslands/shrubs covering about 20% of the study area. The least cover was water bodies which covered about 0.7% of the study area.

Agriculture land use comprised of tea farms, areas under smallholder mixed farming, and both large-scale and small-scale coffee farms Figure 4.3. Smallholder subsistence farming was observed in the upper and lower section of the catchment, while large scale commercial farming in the mid-section of the Theta River catchment Smallholder subsistence farming is mainly rain fed, while the plantation farming is irrigated with water abstracted from Mugutha and Theta Rivers as well as the open water bodies in the catchment. The urban and settlement areas consisted of human settlements and built up areas with structures such as greenhouses, roads, and other structures other than houses. Grasslands/shrubs consisted of areas with bushes/ shrubs or areas covered by grasses in some areas, in other areas. Lantana *camara* was common. In the lower parts of Theta River catchment *Acacia sp* and short hardy grass was the dominant cover.

Forest land consisted of the natural forest which is part of Aberdare Forest that spans Nyeri, Murang'a and Kiambu Counties. The other forest cover is mainly the woodlots in the farmlands which are dominated by *Eucalyptus sp* in the tea growing areas and *Grevillea robusta* in the coffee growing areas. Water bodies consisted of reservoirs created during the colonial era to provide water for irrigation in the coffee farms. The riverine vegetation consisted of a wetland at the confluence of Mugutha and Theta Rivers downstream near the Toll station. The main aquatic vegetation observed were *Cyperus papyrus, Persicaria lapathifolia, and Typha latifolia* among others.

Table 4.3: Land use/cover characteristics in Theta River catchment

Land use/cover in 2018	Area(km^2)	% of Total area
Agriculture	87.5	61.4
Forest	7.03	4.9
Settlement	9.6	6.7
Water Bodies	0.96	0.7
Riverine Vegetation	9.1	6.4
Grassland/Shrubs	28.4	19.9
Total	142.59	100

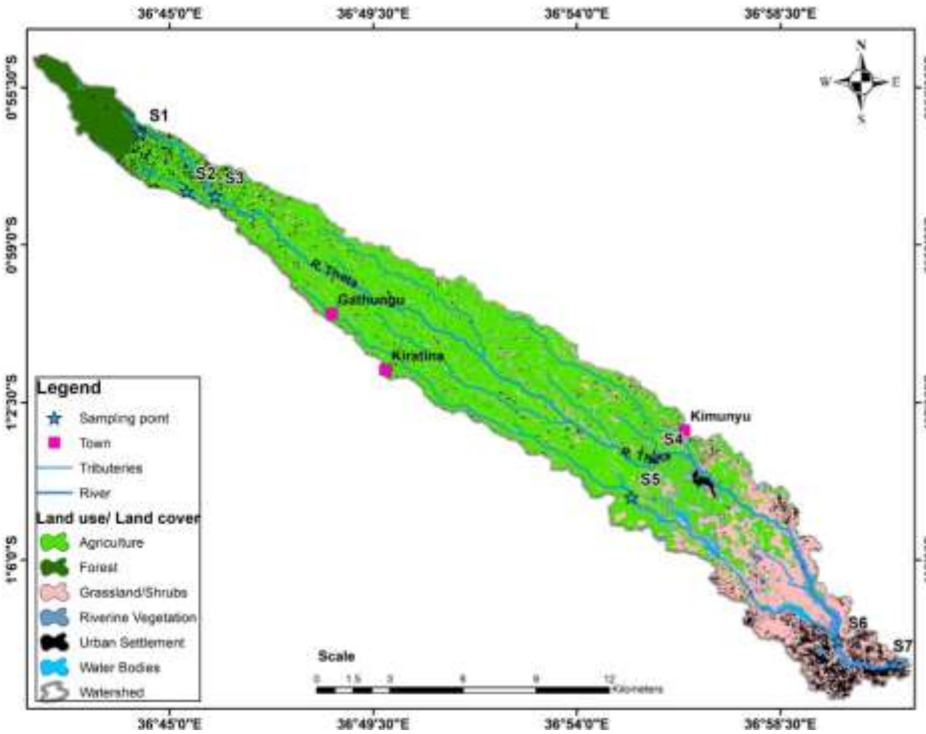

Figure: 4.2: Spatial land use/cover characteristics of Theta River catchment in 2018
Source Researcher, 2019

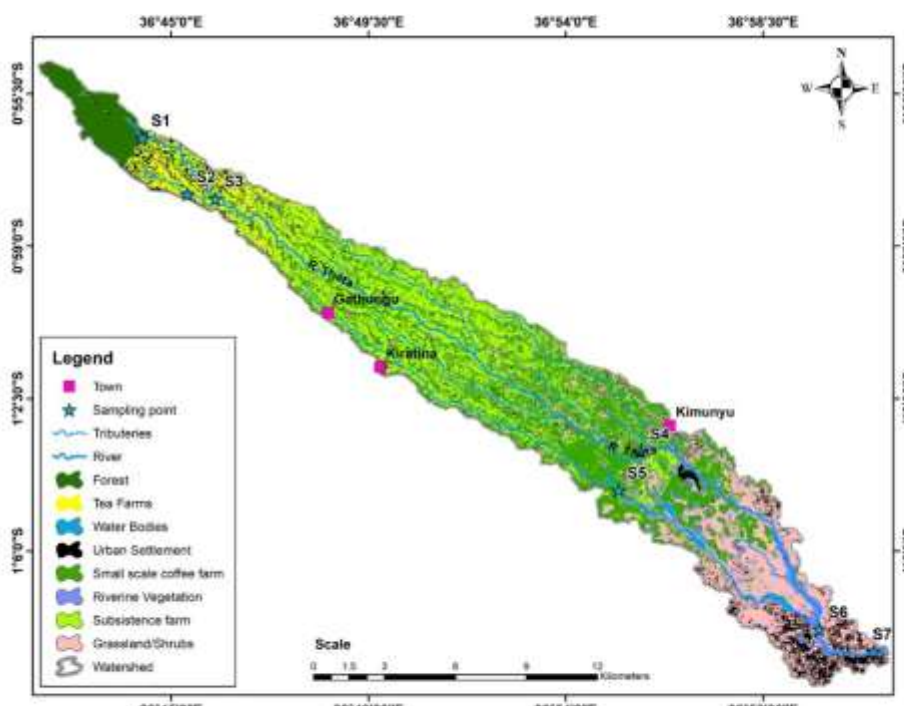

Figure 4.3: Spatial Land use/cover characteristics showing all agriculture classes
Source: Researcher, 2019

The wetland depicted in the LULC map is an example of riparian wetland which according to Wantzen *et al*. (2008), is a narrow strip adjacent to the channel of low order streams. These river sections have vital ecological functions such as retention areas for sediments, agrochemicals as well as hydrological buffers, they are also important to the structure of benthic macroinvertebrates assemblage. There is evidence of expansion of settlement land into other land uses such as agricultural land as shown in (Plate 4.10), these conversions are more pronounced in the in the lower catchment near Juja and areas close to Nairobi Thika Highway.

Plate 4.10: Expansion of settlements into agricultural land in Juja area

The study results are similar to those of Kiio & Odera (2015) and (Wambugu, 2018). Kiio& Odera (2015), showed that the general trends in land use changes in Kiambu County were the study area is located, are that agricultural land had reduced from to 15.8% from 39.7% between 1984 and 2009. Wambugu (2018), showed similar trends in a watershed specific study, done in Ruiru and Ndarugu Rivers basin. The expanding urban settlement will lead to more impervious surface resulting in increased Horton overland flow due to higher runoff coefficient values which may have deleterious effect on water quality downstream (Gwenzi & Nyamadzawo, 2014; Kithiia, 2006). There was also evidence that in other areas of Theta River catchment, agricultural land use is expanding into wetlands through digging and slash and burn methods of the wetland vegetation as depicted in (Plate 4.11). These observed human alteration of the riparian wetlands are similar to those observed by (Wantzen *et al*., 2008). The authors argue that the biological productivity and diverse nature of the riparian wetlands make them vulnerable to human colonization, agriculture or grazing. According to Sweeney *et al*.(2004), the removal of riparian cover leads to alteration of the morphology of the stream channel; decline in quality of ecosystem services by the riparian vegetation; and reduced abundance and diversity of macroinvertebrates.

Plate 4.11: Conversion of wetland into farmland by burning

4.4 Physical and chemical water quality parameters.

Table 4.4: Statistical summary of water-quality samples for all sites

	pH	DO	DO%	Temp	Turbidity	EC	Salinity	Nitrates
Min	6.870	2.69	30.20	16.50	1.00	31.0	0.01	0.50
Max	8.00	6.53	68.40	28.18	60.00	240.0	0.1	2.690
Mean	7.105	3.93	47.04	21.66	16.86	104.8	0.049	1.549
Median	6.960	3.90	47.90	22.35	3.36	104.0	0.050	1.500
WHO standard	6.5-8.8.5	5mg/l	100%	25	0.2-0.5	400*	<600*	10mg/l
Sample size	21	21	21	21	21	21	21	7

*Based on taste not on health concerns

Table 4.5: Summary of physical and chemical water quality parameters among sites

Dominant Land uses	Sites	PH	DO (Mg/L)	DO %	Temp ˚C	Turbidity (NTU)	EC (µS/cm)	Salinity PPT (PSU)	Nitrates (Mg/L)
		Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**
Forest	1	6.99±0.02	5.73±0.52	59.63±5.50	16.66±0.09	3.36±0.00	32.00±0.58	.01±0.00	1.50±0.00
Agricultural	2	6.91±0.02	2.83±0.07	30.93±0.68	20.02±0.06	2.69±0.00	41.00±3.51	.02±0.00	2.69±0.00
	3	7.97±0.03	4.17±0.09	46.60±2.10	22.67±0.07	5.43±0.28	103.33±1.76	.05±0.00	2.00±0.00
	4	6.91±0.01	2.90±0.09	32.60±0.98	21.15±0.01	2.79±0.00	56.33±0.33	.03±0.00	1.00±0.00
	5	7.06±0.02	4.61±0.22	53.63±2.97	22.35±0.08	1.00±0.00	135.00±0.00	.06±0.00	2.65±0.00
Urban-Settlement	6	6.98±0.02	4.52±1.10	42.03±2.94	23.70±0.50	55.00±2.89	156.33±4.06	.07±0.00	0.50±0.00
	7	6.91±0.02	3.76±0.12	46.10±0.46	25.07±1.56	47.73±1.27	210.33±16.25	.01±0.00	0.50±0.00
p values		0.006	0.016	0.007	0.004	0.003	0.003	0.003	0.423

4.4.1 pH

The pH values ranged from 6.87 to 8.00 (Table 4.4, Figure4.4), these values are within the recommended WHO guidelines range (6.5-8.5) for drinking water quality standards. The highest mean pH value of 7.97 was recorded at Site 4 in the agriculture dominated area, while the lowest mean pH value was 6.91 recorded in Site 3 and Site 2 in agriculture dominated areas. The high mean pH value at Site 3 can be possibly linked to the use of alkaline detergents emanating from the communal laundry which is located within Theta River channel. The spatial variation of pH values indicated no predictable trend along the human disturbance gradient. Similar findings were reported in upper River Njoro catchment, Kenya (Kibichii *et al*., 2007). The pH values indicated non normality after Shapiro-Wilk test was done by sites and land use. Kruskall-Wallis test was therefore done to elucidate the variations among the sites and land use types. The results showed no significant difference in pH among sampling sites as well as among the land use types (Kruskall-Wallis, $p>0.05$) as shown in Table 4.5.

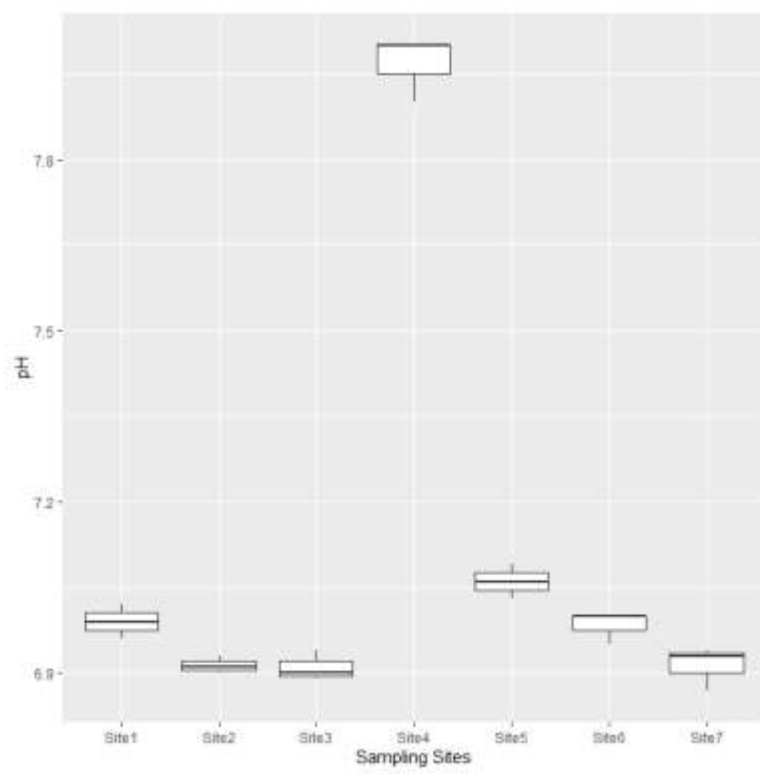

Figure 4.4: Boxplot of pH field measurement for sampling sites

Table 4.6: Summary of environmental factors for the three land uses categories

Environmental Factors	Forest Mean±SD	Agriculture Mean±SD	Settlement Mean±SD
pH	6.99±0.02	7.21±0.13	6.95±0.02
DO(Mg/L)	5.73±0.52	3.63±0.24	3.64±0.14
DO%	59.63±5.50	43.31±2.59	48.20±0.13
Temperature ˚C	16.66±0.09	21.55±0.32	24.37±0.80
Turbidity (NTU)	3.36±0.00	2.98±0.48	51.37±2.15
EC (µS/cm)	32.00±0.58	83.75±11.23	183.33±14.21
Salinity (PSU)	0.01±0.00	0.04±0.00	0.09±0.01
Nitrates (Mg/L)	1.50±0.00	2.09±0.00	0.50±0.00
Altitude	2151.00±0.00	1780.25±117.95	1496.50±8.5

4.4.2 DO concentration and DO percentage

The observed dissolved oxygen concentration values ranged from 2.69 to 6.53 mg/l the lowest value was recorded at Site 3 in agriculture dominated area, while the highest value was recorded at Site 1 in the forest dominated area in the headwaters (Table4.4, Figure 4.5). The results are consistent with the findings of Gichana *et al.* (2015), who recorded high oxygen concentration in the headwaters of Nyangores River catchment. Shapiro-Wilk test indicated normality ($p>0.05$) One-way-anova showed significant difference in mean DO values ($p<0.05$) among sites and among land use types. TurkeyHSD *post hoc* test showed significant differences in mean DO concentration between forest and agriculture, forest and settlement but there were no significant differences between urban settlement and agricultural land use.

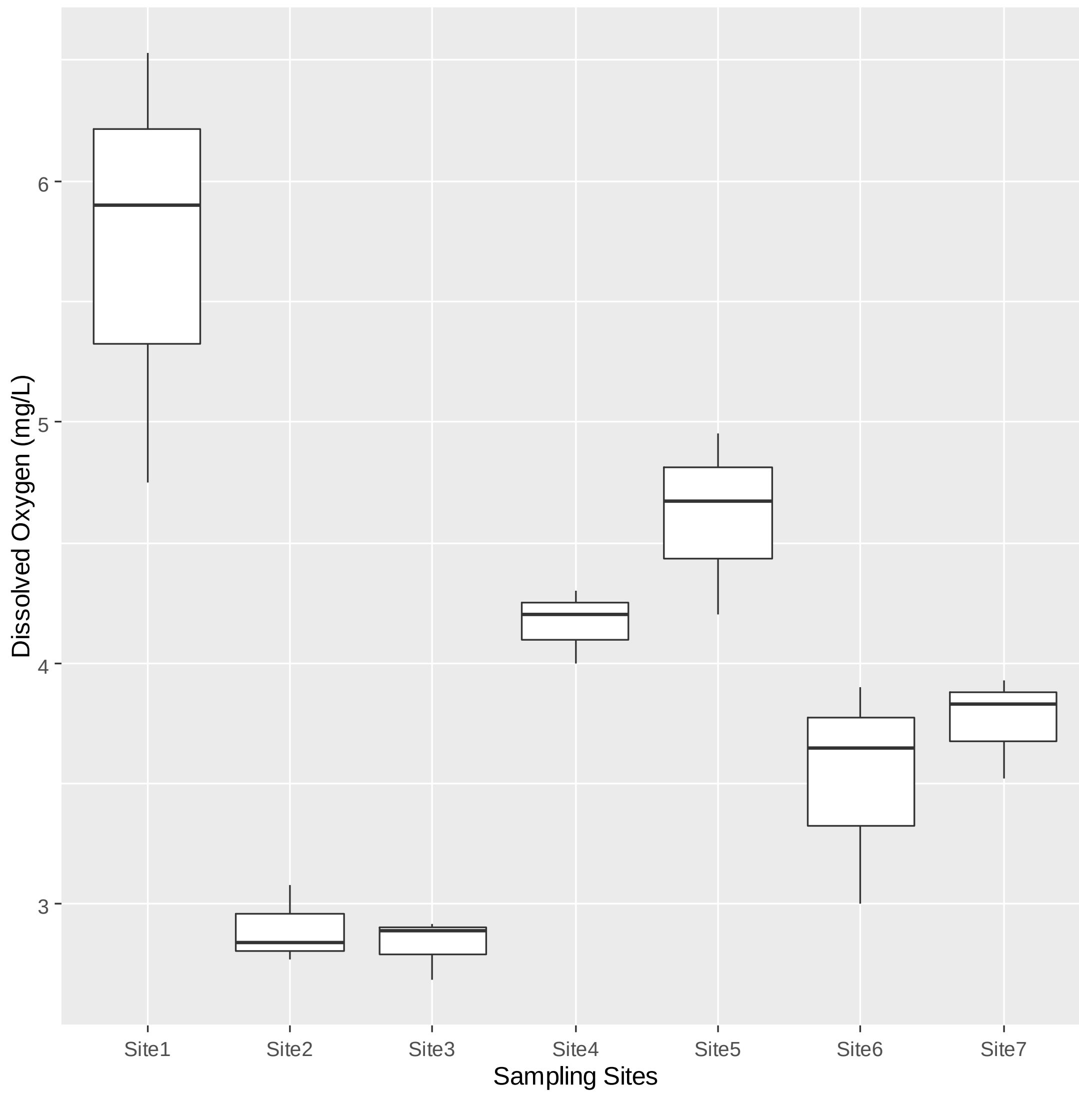

Figure 4.5: Boxplot of dissolved oxygen concentration field measurements

4.4.3 Temperature

The overall water temperature values ranged from 16.50 to 28.18˚C, the lowest value was recorded in Site 1 in forest dominated area, while the highest was recorded in Site 7 in urban settlement dominated area, the water temperature values showed an increasing downstream trend (Table 4.4, Figure 4.6). The observations made in Theta River catchment are similar to those made in Nyangores River catchment by Gichana *et al*. (2015). The authors found out that water temperature was lower in the headwaters in areas dominated by forest land, they attributed this observation to the presence of canopy cover that attenuated the sunlight reaching the water surface. In this study Site 1, had no complete canopy cover because of its location at the forest edge where there is way leave for electric fence. Shapiro-Wilk test for normality indicated that temperature was normally distributed ($p>0.05$). One-way anova test showed significant differences in mean temperature measurements among sites and land uses $Pr(>F) <0.05$. Pair wise *post hoc* showed there were significant differences in water temperature values between sites and land use types. Site 1 differed significantly with all other sites (p adj<0.05) except site 5 which can be attributed to the canopy cover in the riparian zone. The low temperatures recorded in site 1 could be attributed to high altitude from the Spearman rank test results that revealed a significant strong negative correlation (-0.96) between temperature and altitude (Table 4.7). Similar observations were made in a study done in the Eastern highland streams, Zimbabwe by Dalu *et al*. (2017), where low water temperature was observed in streams located in very high elevation areas.

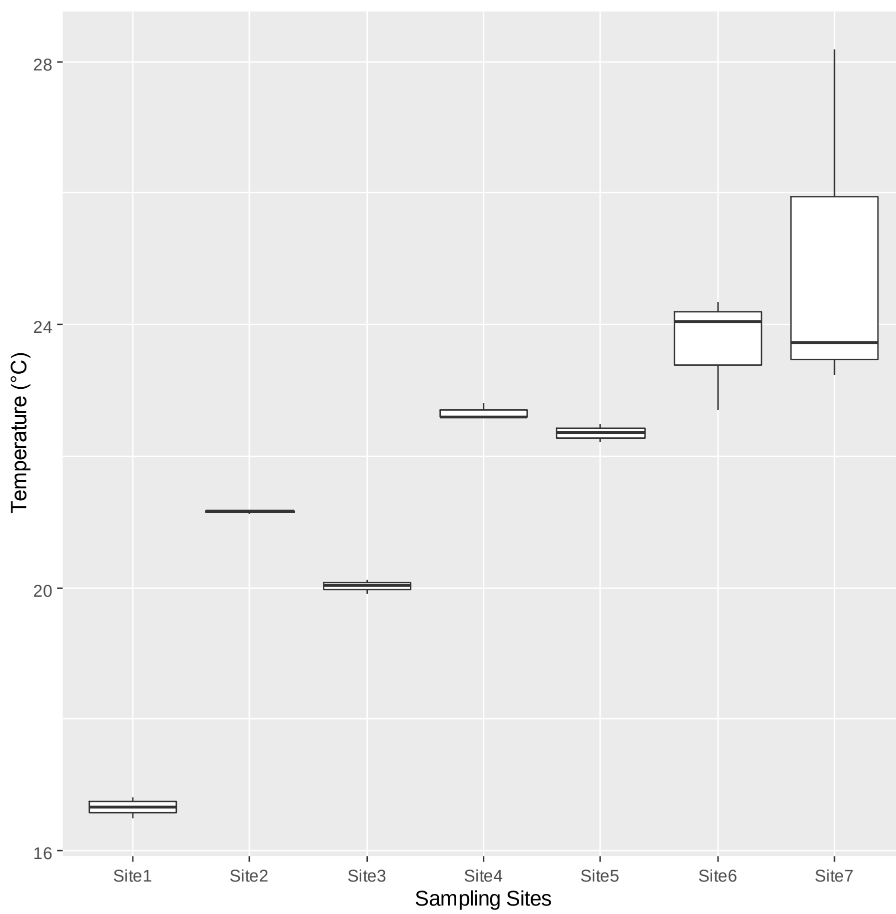

Figure 4.6: Boxplot of water temperature measurements for sampling sites

4.4.4 Turbidity

Turbidity values ranged from 1.0 to 60.00 NTU, the lowest observation being at Site 5 in agricultural dominated area, while the highest observation was in Site 6 in urban-settlement dominate area (Table 4.4, Figure 4.7). The high turbidity values could be attributed to human activities such as trampling by cattle at a drinking point, washing and bathing, and agriculture activities. While in Site 5 the low turbidity can be attributed to riparian buffer strip on one side of the river bank as well as little farming activities on the opposite river bank because it was a harvesting season. There was no discernible trend in turbidity levels in upstream and midstream sites, but compared to downstream sites there was an increase downstream in Theta River catchment. However, sites in agricultural areas recorded the lowest turbidity while sites in urban land uses recorded the highest values. These findings contradict the findings in Ruvu River catchment, Tanzania by Ngoye & Machiwa (2004) who observed higher turbidity values in agricultural areas and lowest values in forest dominated areas. In this study forest dominated site had a higher turbidity values that agriculture dominated areas which can be attributed to human activities such as grazing, laundry, and logging evident from observations made at the forest edge (Plate 4.12). Shapiro-Wilk test indicated non-normality for turbidity ($p<0.05$) even after log transformation. Kruskall-Wallis test was subsequently run to reveal variations in turbidity values. The test showed that there were significant differences in turbidity values ($p<0.05$) between sites and land uses. Pair wise *Post hoc* Dunn test was then run to assess the significant differences indicated by Kruskall-Wallis test.

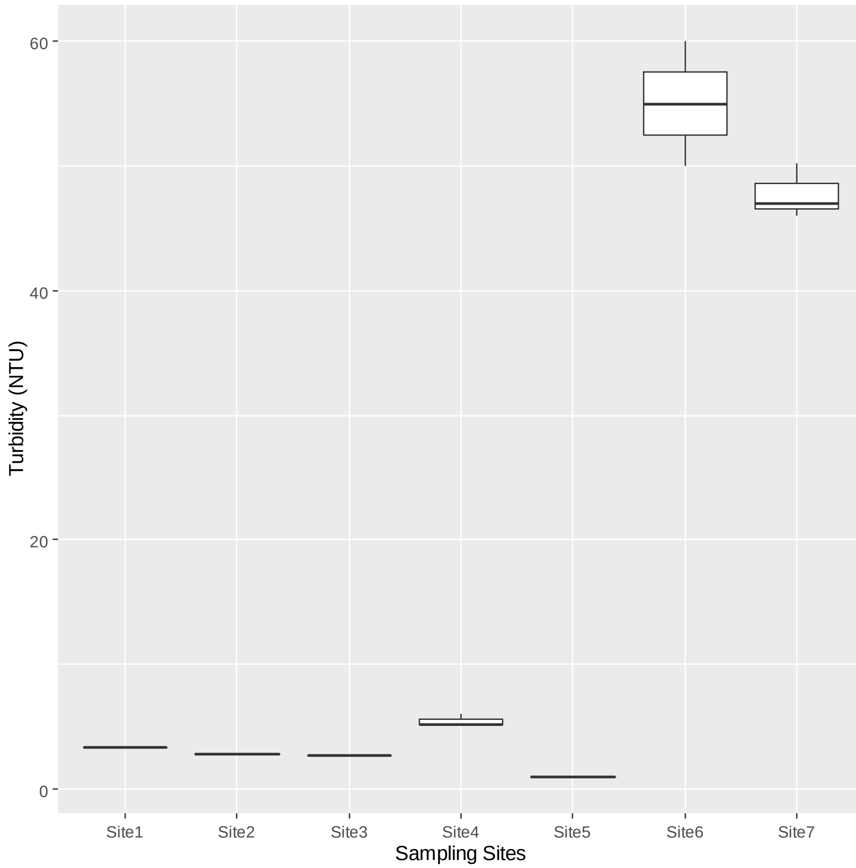

Figure 4.7: Boxplot of turbidity field measurement for sampling sites

Plate 4.12: Evidence of grazing (a) and cattle trampling (b) in Site 1

4.4.5 Electrical conductivity

The overall conductivity values for the sites varied from 31 to 240 μS/cm, the lowest value was recorded in Site1 in forest dominated area, while the highest was recorded in Site 7 in urban settlement dominated area (Table 4.4, Figure 4.8). The electrical conductivity showed an increasing downstream trend that follows the human disturbance gradient. Similar findings were reported in Nyangores River catchment by Gichana *et al*. (2015). Authors attributed these findings to anthropogenic activities within the riparian and geological factors that contribute to augmentation of dissolved and suspended matter in water leading to high levels of EC values downstream. Shapiro-Wilk test indicated normality for electrical conductivity data ($p>0.05$), and subsequently one-way ANOVA test and *Post hoc* TurkeyHSD test done to reveal significant ($p<0.05$) differences among sites and land use types. Spearman rank test results among the physicochemical parameters revealed that conductivity values in Theta River catchment had a significant positive correlation with settlement land use (Table 4.7).

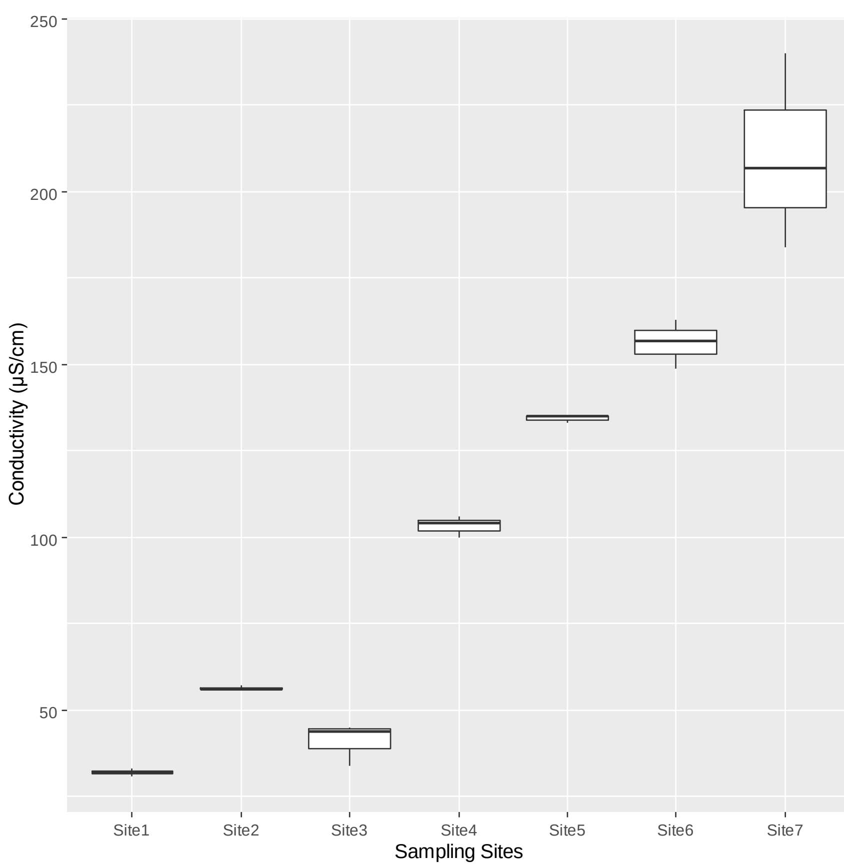

Figure 4.8: Boxplot of electrical conductivity field measurement for sampling sites

4.4.6 Salinity

Salinity values ranged from 0.010 to 0.10 psu, the lowest value was recorded in Site 1 while the highest was recorded in Site 7, however salinity levels were generally low in all sites (Table4.4, Figure 4.9). Salinity showed normal distribution (Shapiro-Wilk test>0.05), one-way ANOVA showed significant differences among sites and land uses Pr (>F) <0.05. *Post hoc* pair-wise TurkeyHSD test showed significant differences in salinity values (p adj<0.05) in all sites. There were also significant differences among the land uses (p adj<0.05).

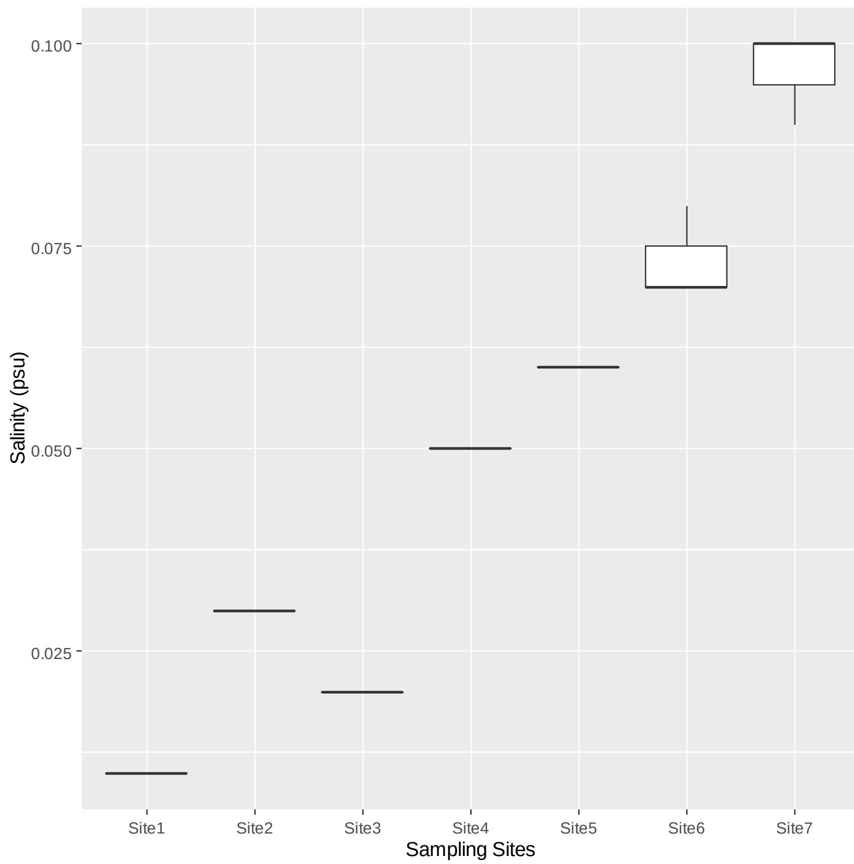

Figure 4.9: Boxplot of salinity field measurement for sampling sites

4.4.7 Nitrates (NO^{-3})

The nitrates values for all sites ranged from 0.5 to 2.690 mg/l, the lowest values were observed in Sites 4 and 5 which are located in settlement dominated area, while the highest value was observed in Site 3 located in agriculture dominated area (Table 4.4, Figure 4.10). Agriculture dominated areas had higher mean nitrate values, the results are similar to findings by Ngoye & Machiwa (2004), in Ruvu River catchment, where higher nitrates levels were recorded in sampling stations adjacent to agricultural land. The authors attributed this to probable use of chemical fertilizers.

Nitrates showed non-normality with Shapiro-Wilk test $p<0.05$. The non-parametric Kruskall-Wallis test was subsequently run to reveal variations in nitrate values among the sampling sites and the land use types. The test showed that there were significant differences in nitrates values ($p<0.05$) between sites and land uses. Pair wise *Post hoc* Dunn test was then run to assess the specific significant differences indicated by Kruskall-Wallis test.

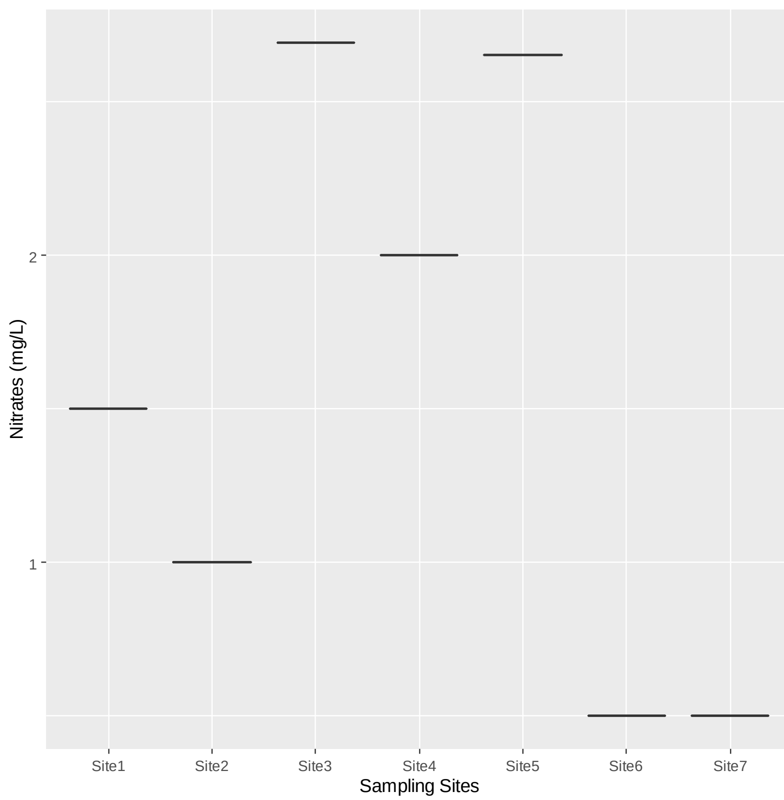

Figure 4.10: Boxplot of salinity field measurement for sampling sites

4.5 Spatial relationship between land use/cover types and water quality

The spearman rank correlation was used to assess whether any of the water quality parameters were correlated to land use/cover types. The results of the study suggested that percentage of urban-settlement land use had the most significant influence on water quality parameters as shown in Table 4.7. The percentage of forest land use showed negative relationship with some water quality parameters (temperature, conductivity, and salinity), with temperature having a strong negative significant (<0.05) relationship of -0.80 and a correlation coefficient of determination of 64%. This means that 64% of variation in temperature was explained by 4.9% of the of the land use in the study area which is forest land. Dissolved oxygen concentration had a strong positive significant ($p<0.05$) correlation of 0.78, which means that 60.8% of the variation in dissolved oxygen concentration was explained by the proportion of forest land use. This implies that a higher percentage of forest land could translate to better water quality in terms of temperature and dissolved oxygen concentration. Percentage of urban-settlement land use was found to have strong significant ($p<0.05$) positive correlation with temperature, turbidity, salinity, and conductivity with coefficient of determination of 46.2%, 98%, 62.4%, 65.6% respectively. But had a strong negative significant ($p<0.05$) correlation with nitrates, with a coefficient of determination of 59.3%. These results hint that higher percentage of urban-settlement land use could be linked to possibility of higher pollution loads from point and nonpoint sources that are a common place in urban dominated land uses. This finding is consistence with the findings of Tong & Chen (2002), in a study on Little Miami River catchment, USA, the study results showed that conductivity had a significant positive correlation with settlement land use. The higher temperatures recorded in urban land uses can be attributed to devoid of tree cover within the riparian zones and low elevation. Percentage agricultural land use had strong significant ($p<0.05$) positive correlation with only nitrates, with a coefficient of determination of 51.8%. This result is consistent with the findings of other studies which have shown significant positive relationship between percentage agriculture and nutrients such as nitrates (Duka *et al.*, 2017; Wambugu, 2018). This observation could be attributed to use of chemical fertilizers within or close to the riparian zones. From the Spearman rank correlation results, the study rejected the null hypothesis that there is no spatial relationship between land use types and water quality in favor of the alternative hypothesis.

Table 4.7: Spearman rank correlation results between water quality parameters and land use/cover types.

	Land use types					
	Forest		**Urban-settlement**		**Agricultural**	
Water quality parameters	**R**	**R^2 %**	**R**	**R^2**	**R**	**R^2**
pH	-0.212	4.5	-0.328	10.8	0.35	12.3
DO(Mg/L)	**0.78**(0.04)	**60.8**	-0.20	4	-0.37	13.7
DO%	0.62	38.4	0.09	0.8	-0.52	27
Temperature ˚C	**-0.80**(0.03)	**64**	**0.68(***0.034***)**	**46.2**	-0.05	0
Turbidity (NTU)	-0.25	6.3	**0.99(***0.000***)**	**98**	-0.73	53.3
Conductivity (µS/cm)	-0.48	23	**0.81(***0.034***)**	**65.6**	-0.40	16
Salinity (PSU)	-0.54	29.2	**0.79**(0.033)	**62.4**	-0.34	11.6
Nitrates (Mg/L)	-0.02	0	**-0.77**(0.043)	**59.3**	**0.72(***0.032***)**	**51.8**

Significant values are in bold and p values in brackets, correlation is significant at α=0.05

R is correlation coefficient, R^2 is coefficient of determination in %

4.6 Composition of macroinvertebrates

A total of 642 benthic macroinvertebrates specimens were collected, comprising of 30 families belonging to 12 orders. They were summarized according to their tolerance values and functional feeding groups (see Appendix 2). The macroinvertebrates that were sampled in all the sampling sites were dominated by insect invertebrates comprising of larvae, pupae, and nymph of the order: Trichoptera (Caddisflies), Odonata (Dragonflies and Damselflies), Diptera (aquatic & semi-aquatic true flies), Plecoptera (stoneflies), Ephemeroptera (Mayflies), Lepidoptera (aquatic moths), Megaloptera (Dobsonflies/Fishflies), Coleoptera (aquatic beetles), and Hemiptera (aquatic &semi-aquatic true bugs). The non-insect invertebrates consisted of Gastropoda (Snails & Limpets), Oligochaeta (aquatic worms), and Decapoda (Crabs). The most diversified orders were Diptera and Odonata each with five families, followed by Ephemeroptera with four families.

The species richness (number of species in the study area) possible from the sampling effort using kick method in the seven sites is shown by a species accumulation curve in Figure 4.11. Species richness has been shown to increase with the time spent in sampling and the number of individual collected (Dejong, 1975). This relationship is logarithmic and species sampled reaches a asymptotic curve (Dejong, 1975; Soberon & Llorente, 1993). The relationship between sampled area in freshwater ecosystem and species diversity is not linear or obvious. Study by Davies *et al*. (2008), revealed that species richness is dependent more on habitat type than habitat size.

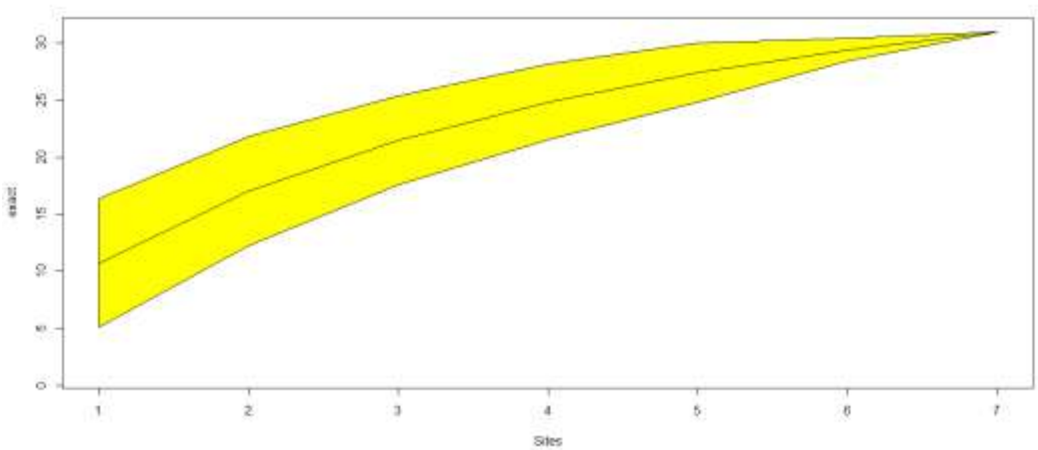

Figure 4.11: Species accumulation curve for 7 sites

The y axis represents the number of cumulative families, the shaded area shows the confidence intervals from standard deviation.

4.6.1 Macroinvertebrates distribution by sites

Macroinvertebrates were identified to family level in the study of Theta River catchment. Observations from biotopes across all sites was used for analysis and the richness was summarized in Figure 4.12. The study used data from four biotopes identified from the sampling site stream reach. According to Figure 4.13, not all biotopes were present in all sites. The value of family richness from some biotopes show zero values in the Cleveland dotplot indicating that there were no biotopes in those sites. The highest family richness was in Site 1(13 families) in head waters, while the lowest was Site 6 with a total of 4 families. Site 1 comprised of orders EPT, Decapoda, Coleoptera, Hemiptera and Odonata that represented the 13 families. In Site 6, the orders Oligochaeta, Diptera, Odonata and Trichoptera represented the four families as shown in Figure 4.14.

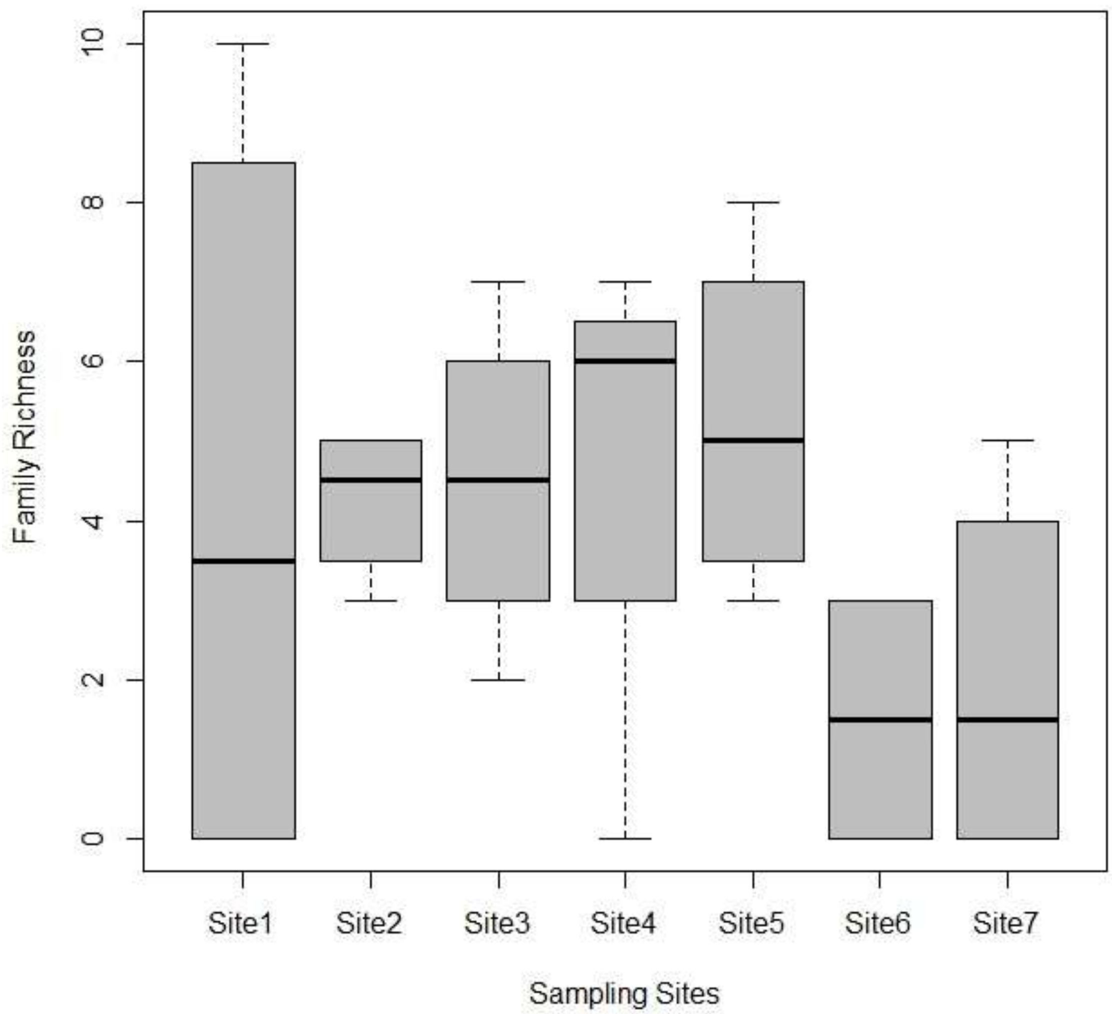

Figure 4.12: Boxplot showing variation of family richness by sites
Median value is shown in each box, vertical bar represents the minimum and maximum values.

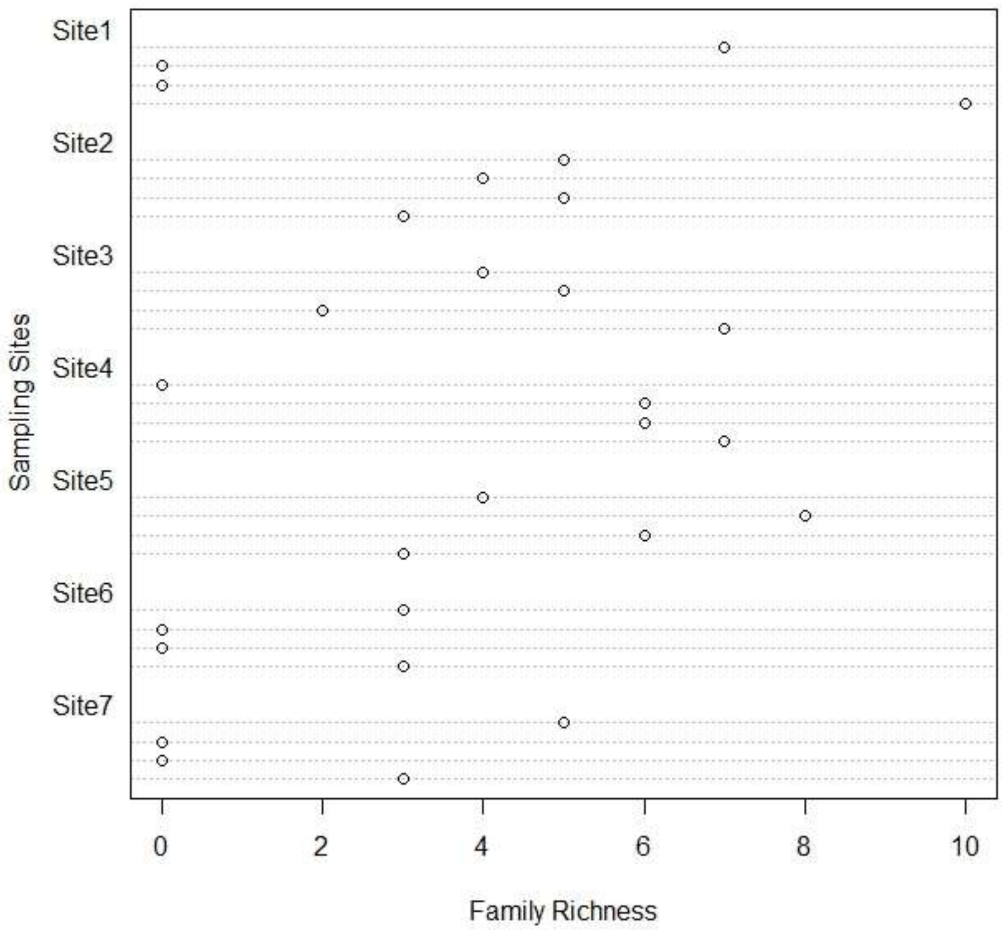

Figure 4.13: Cleveland dotplot of family richness across sites

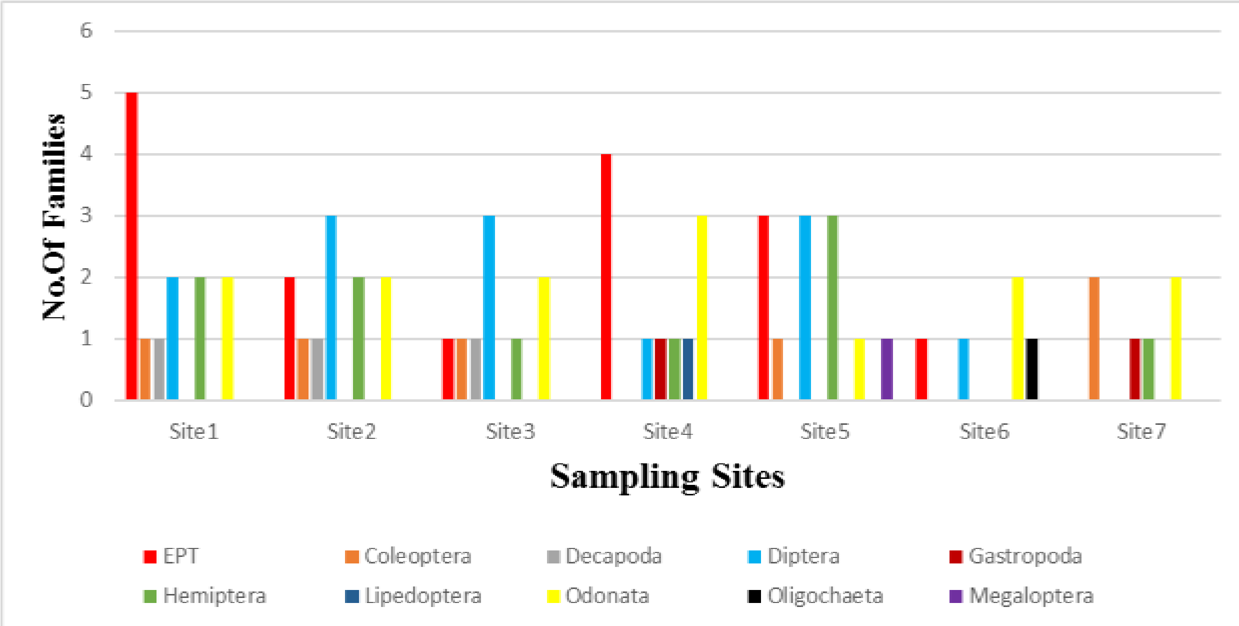

Figure 4.14: Macroinvertebrates family richness by order in sample sites

In the seven sampling sites 317 individuals (49.4% of individuals collected) collected belonged to ecologically sensitive orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) distributed into 8 families. The families representing the order Ephemeroptera were *Heptageniidae, Teloganodidae, Beatidae, and Caenidae*. The order Trichoptera had the families *Hydropsyhidae, Polycentropodidae,* and *Leptoceridae*. The order Plecoptera was represented by the family *Perlidae* which was only present in Site 1. Therefore, in Sites 2, 3,4,5,6, and 7, the metric EPT refers to individuals in Ephemeroptera-Trichoptera (Figure 4.15). The EPT group consisted of 53 Ephemeroptera (16.7%), 7 Plecoptera (2.2%), 257 Trichoptera (81.1%).

According to Barbour *et al*. (1999), EPT group is associated with a pristine environment, because they are sensitive to pollution, which explains their decrease in richness and relative abundance downstream along the human disturbance gradient and total absence in Site 7. According to Czerniawska-kusza (2005), macroinvertebrates orders Plecoptera, Ephemeroptera, and Trichoptera, *Gammarus, Asellus*, red midges, *Chironomidae*, and *Tubificidae* will disappear in their mentioned order as organic pollution increases. The characteristics of EPT orders explain why they are used in the monitoring of organic pollution in lotic systems, their disappearance from polluted sites precedes that of other macroinvertebrates taxa. The characteristics unique to

EPT group has been successfully applied in water quality assessment in rivers for example by (Kasangaki *et al*., 2007; Bonzemo, 2013; Gichana *et al*., 2015 ; Aura *et al*., 2016).

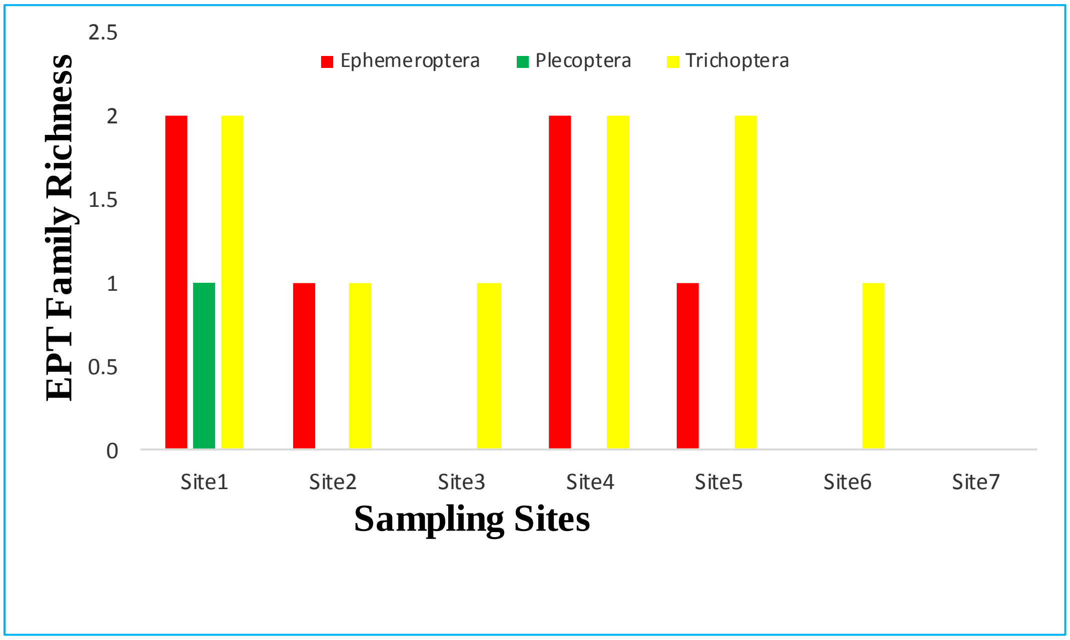

Figure 4.15: EPT family richness in the 7 sample sites

According to Bouchard (2004), Trichoptera consists of families that are all fully aquatic and the most successful among the EPT in dominating lotic systems. Their dominion can be derived from their capabilities to construct cases by spinning silk that are used protection, breeding, collecting food, and holding on to the substrate material. Trichoptera exhibit a number of feeding habits such as gatherers/collectors, filter/collectors, shredders, predators, herbivores/piercers, and scrappers. Plecoptera are the most intolerant in the EPT group, they have a narrow niche that consists of only running water, high dissolved oxygen levels, low water temperature, and substrate with inputs from trees (Bouchard, 2004). This seems to suggest the reasons for *Perlidae* being the most abundant among the EPT group, in sites with less anthropogenic impacts such as Site 1 that met these conditions.

NMDS ordination plots indicated a clear separation of sites with the benthic macroinvertebrates assemblage. The forest dominated Site 1 has it distinct position on the NMDS plot. Sampling Sites 2, 6, 3 with similar community structure tend to cluster together, while Site 4 and Site 5 that indicate polluted areas have distinct position from other sites Figure 4.16 and Figure 4.17.

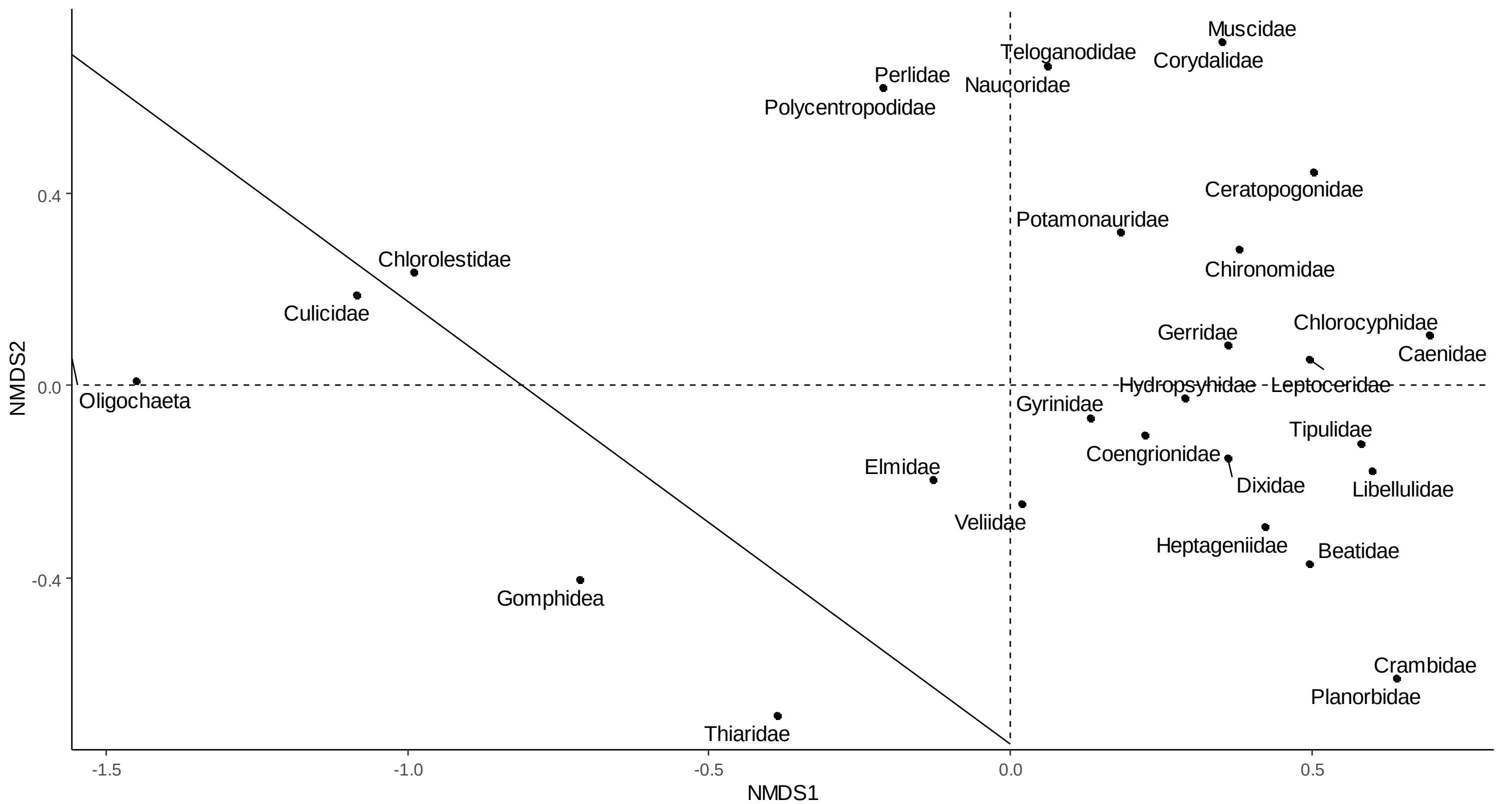

Figure 4.16： Non- metric multidimensional scaling (NMDS) plot of benthic macroinvertebrates community composition

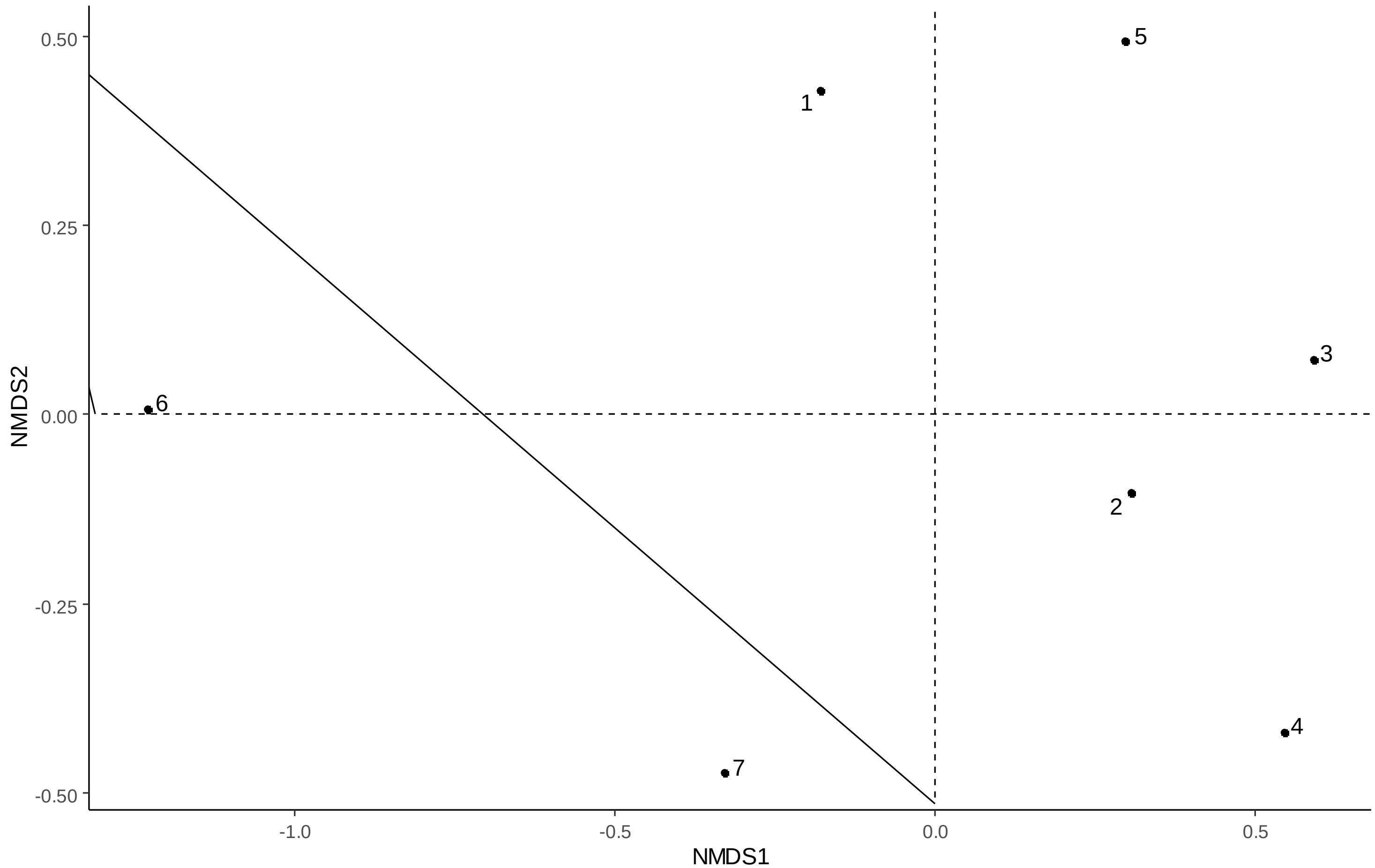

Figure 4.17:Non-metric multidimensional scaling plot of sites based on macroinvertebrates abundance data

Figure 4.16 and Figure 4.17 have been separated for clarity; the stress for the NMDS is 0.09 indicating that only 9% of the dissimilarity is not explained by the plots.

1. **Macroinvertebrates diversity**

a. **Shannon diversity index**

The mean values of Shannon Index ranged from 0.317 to1.15. The lowest value was for Site 7 a settlement dominated site and the highest was for Site 5 in agriculture dominated site (Table 4.8). According to Figure 4.18, most of the Shannon index value in the sites were within the Shannon Index proper range of (1.5-3.5), except for Sites 6 and 7. According to Türkmen & Kazanci (2010), Shannon index value of less than 1.0 is indicative of a polluted and a degraded ecosystem, this observation holds true for habitat conditions in Site7.

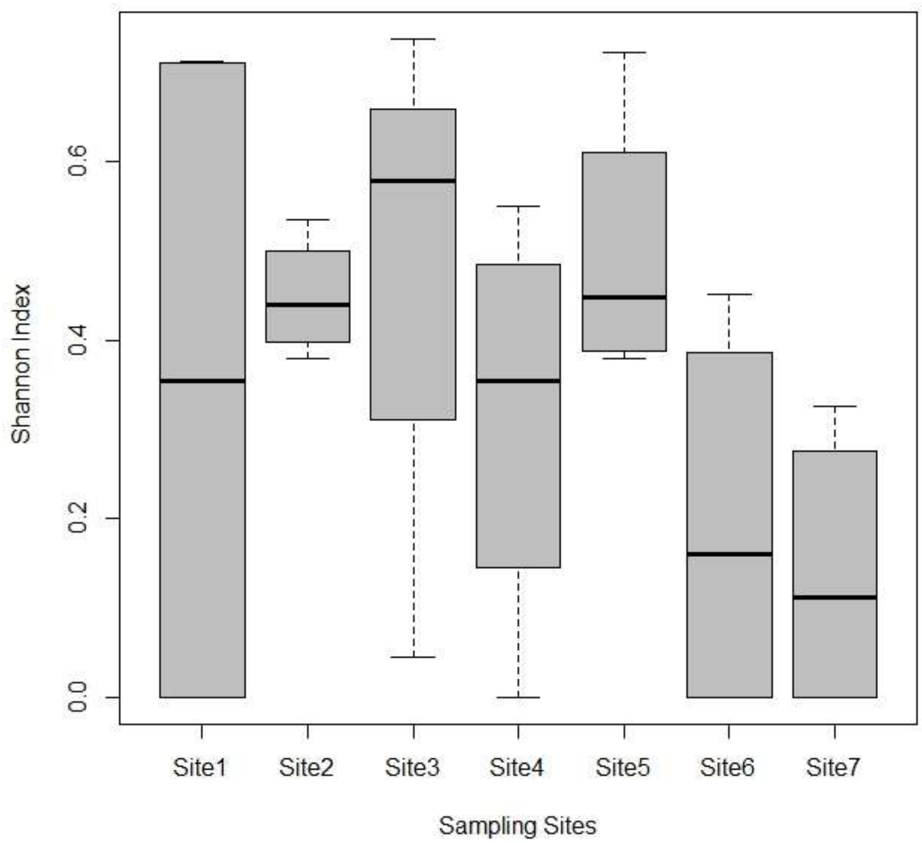

Figure 4.18: Boxplot of Shannon index values by Sites

b. Simpson diversity index

The values of Simpson Index ranged from 0.38 to 0.84. The highest value was in Site 1 while the lowest value was in Site 5 (Figure 4.19, Table 4.8). The results of the Simpson Index mirrored those of Shannon Index among the sites. The sites with the highest values (Site 1, 2, and 6) where the same for both indices. High diversity is associated with the overall health of assemblage and indicates robust ecosystem with adequate of niche space, food and habitat for the survival of diverse species (Barbour *et al*., 1999). Despite the anthropogenic disturbances within Site 6, there were higher values of Shannon and Simpson Indices (1.58 and 0.76 respectively) than in Sites 3, 4, and 5.

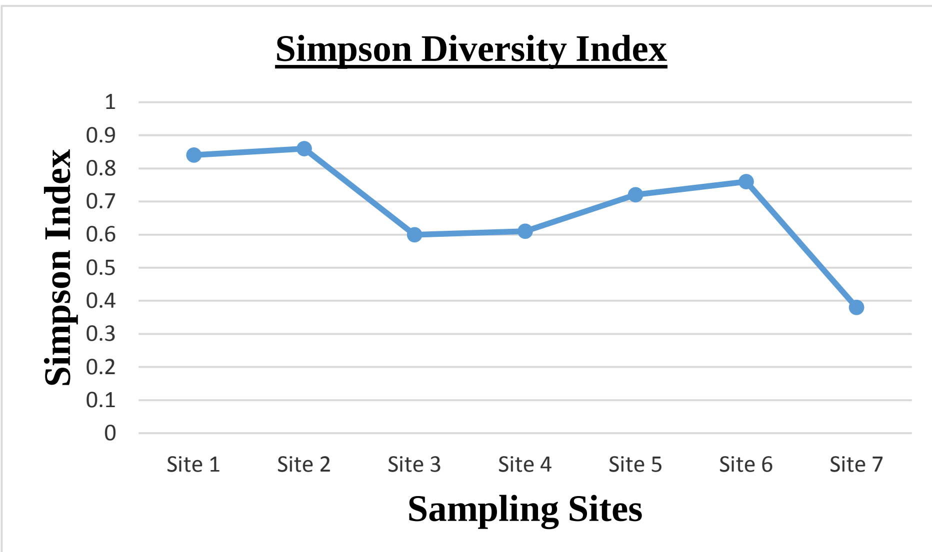

Figure 4.19: Simpson Index by Sites

Pielou evenness index

The values of Pielou Evenness Index ranged from 0.16 to 0.42, the lowest values being site 3 and the highest in site 6 (Figure 4.20, Table 4.8).

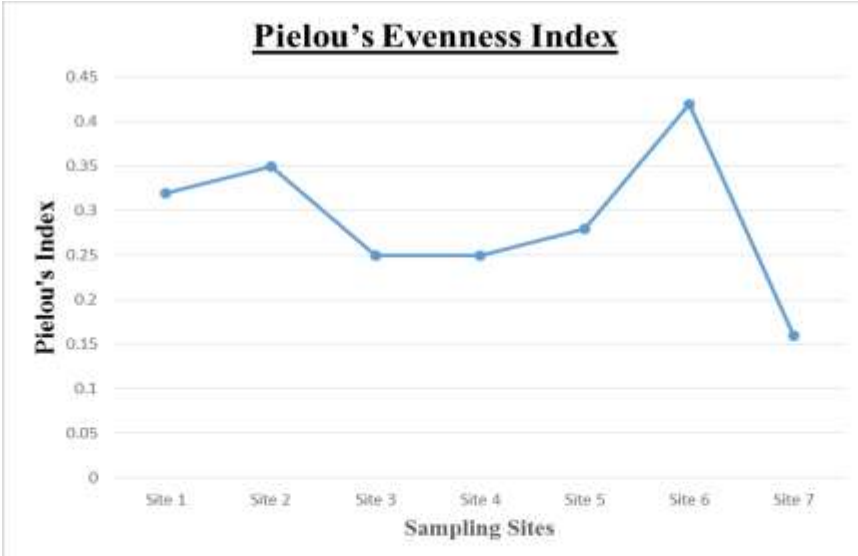

Figure 4.20: Pielou's index by sites

Table 4.8: Macroinvertebrates metrics in Theta River catchment

Site	Abundance	Family Richness	Shannon Index	Simpson Diversity	EPT/N Ratio	Pielou's evenness
1	76	13	0.818±0.945	0.84	0.14	0.32
2	100	11	1.03±0.155	0.86	0.34	0.35
3	88	10	1.12±0.697	0.6	0.64	0.25
4	186	11	0.724±0.542	0.61	0.8	0.25
5	113	12	1.15±0.362	0.72	0.58	0.28
6	12	5	0.444±0.527	0.76	0.17	0.42
7	67	6	0.317±0.378	0.38	0	0.16

2. Macroinvertebrates similarity

Sørensen abundance index was calculated using abundance data of macroinvertebrates families and the results summarized in Table 4.9. When Sorensen abundance index is used as a dissimilarity index a value close to 1 means that macroinvertebrates communities are totally different, while a value close to 0 means the communities share all the species (Chao *et al.*, 2006). The highest dissimilarity was between Site 5 and Site 6 with a dissimilarity index value of 0.882. Other sites with similarly high dissimilarity values were Site 6 and Site 7, Site 2 and Site 4 each with 0.875 dissimilarity index value. The lowest dissimilarity was between Site 2 and Site 3 explained by their proximity to each other.

Table 4.9: Sørensen abundance index of dissimilarity values based on sampling sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Site 2	0.565					
Site 3	0.666	0.619				
Site 4	0.666	0.866	0.750			
Site 5	0.789	0.875	0.764	0.818		
Site 6	0.500	0.333	0.454	0.875	0.647	
Site 7	0.520	0.636	0.651	0.882	0.666	0.565

4.6.2 Macroinvertebrates assemblage among the land use/cover types

The macroinvertebrates abundance data from the seven sampling sites and biotopes was aggregated according to land uses Figure 4.21. This was meant to detect how macroinvertebrates abundance varied along the increasing gradient of human impacts. Anthropogenic activities within a watershed that define land uses results in morphological alterations and sediment yields in rivers. These with other confounding factors such as altitude, discharge, and substrate influence macroinvertebrates community, although their synergistic effects remain poorly understood.

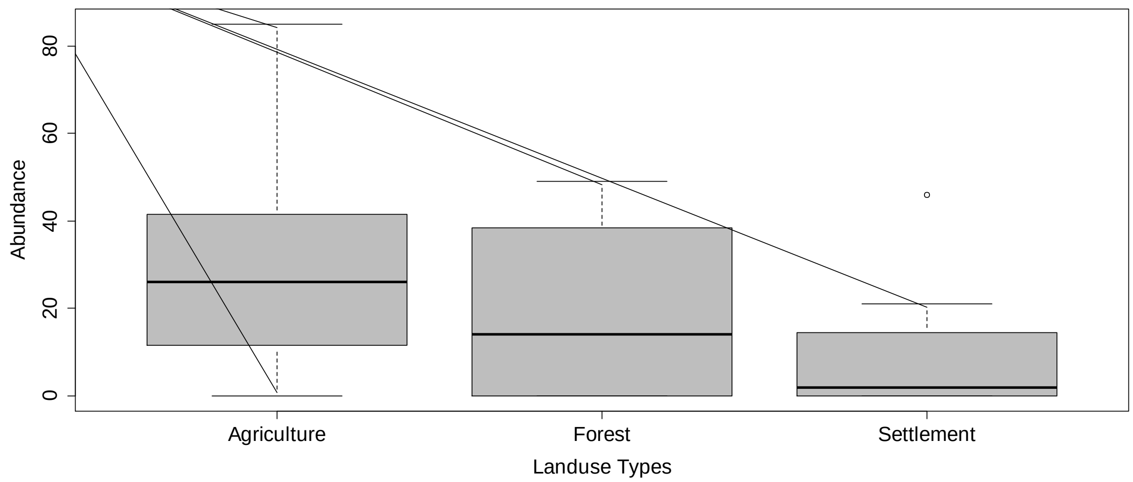

Figure 4.21: Boxplot of macroinvertebrates abundance in the land use types

Forest land use represented the least-impacted sites relative to other sites with the influence of agriculture and settlements. Within the forest there was presence of highly sensitive order Plecoptera (Stone flies), while there was a progressive increase of tolerant taxa as human influence amplified. These finding agrees with the general conclusion that sensitive taxa are abundant in pristine areas such as forested headwaters of streams, and rapidly decline along the anthropogenic disturbance gradient.

The family richness varied across land use types, the greatest variations in family richness was in forest land, followed by agricultural land as shown in Figure 4.22. The community structure of the ecologically sensitive taxa of the orders EPT showed a clear variation along the anthropogenic disturbance Figure 4.16. All the families of the order EPT were present in forest dominated land use, while agriculture dominated areas had Ephemeroptera and Trichoptera, Settlements dominated areas were only represented by Trichoptera mainly the *Hydropsyhidae*. The rare and highly sensitive *Perlidae* family of order Plecoptera was only present in forest dominated areas, the family *Hydropsyhidae* were present in all the land uses (Figure 4.23).

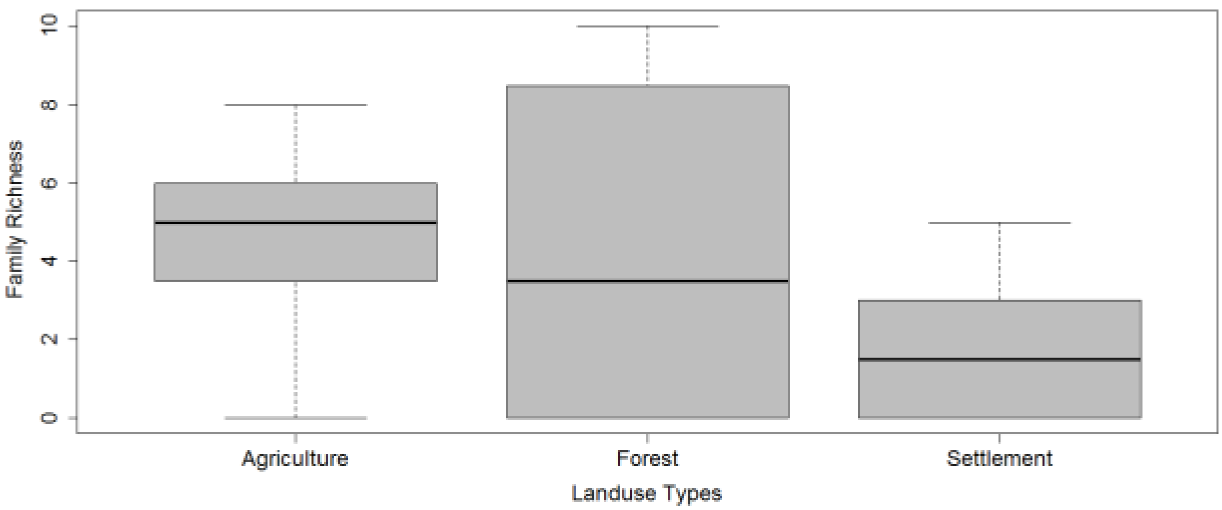

Figure 4.22: Boxplot of family richness among the land use types

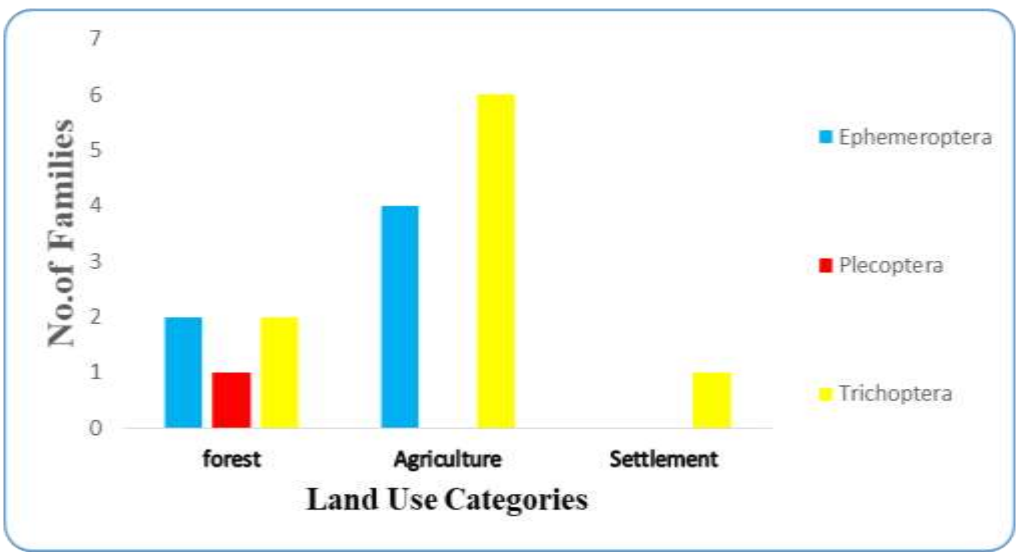

Figure 4.23: EPT family richness among the land use types

Table 4.10: TurkeyHSD pairwise test results for land use/cover types

Turkey multiple comparisons of means				
95% family-wise confidence level				
Fit: aov(formula=distances group, data=df)				
$group	**Diff**	**lwr**	**upr**	**p adj**
Forest-Agriculture	**-0.32**	**-0.523**	**-0.12**	**0.01**
Settlement-Agriculture	**0.1**	**-0.052**	**0.26**	**0.16**
Settlement-Forest	**0.42**	**0.205**	**0.65**	**0.01**

The ANOSIM test results showed that there was a strong significant spatial difference in benthic macroinvertebrates among the land uses types (Global R=0.898 and p=0.02).

Call:
anosim(x = benthos2, grouping = factor, permutations = 999, distance = "bray")
Dissimilarity: bray
ANOSIM statistic R: 0.898
Significance: 0.016
Permutation: free
Number of permutations: 5039

The result of ANOSIM were generated by the function anosim() in the vegan package, the p-value of 0.016 is less than 0.05 which indicates that within group similarity is greater than the between-group similarity at 0.05 significance level. From these results the study rejected the null hypothesis for there were significant difference between the land use and land cover in terms of benthic macroinvertebrates assemblages.

Pairwise comparison using Turkey's test indicated a significant difference in benthic macroinvertebrates assemblage between forest and agriculture, and urban-settlement and forest (p adj=0.01). However, there was no significant difference (p adj=0.16) between urban-settlement and agriculture (Table 4.9). In terms of benthic macroinvertebrates assemblages. Forest dominated site were dominated by Polycentropodidae, Perlidae, Potamonauridae, and Naucoridae, were good indicators of least disturbed site in the forest land. While agricultural dominates sites consisted of families such as *Chironomide*, *Leptoceridae*, and *Gerridae*. These taxa were best bioindicators of agriculturally impacted sites. While the most impacted sites in the urban-settlements comprised of tolerant taxa such as *Thiaridae*, *Gomphidae*, *Oligochaeta*, and *Culidae* where the best indicators of human disturbed sites.

4.6.3 Macroinvertebrates diversity indices among the land use types

The three land uses from which the macroinvertebrate samples were collected represent the human disturbance gradient. The diversity indices of Shannon and Simpson varied across the land uses as summarized in Table 4.10. Shannon index varied most in the forest land dominated site, perhaps due to the higher diversity in observed there. Forest land was followed by agricultural land and urban-settlement land Figure 4.24.

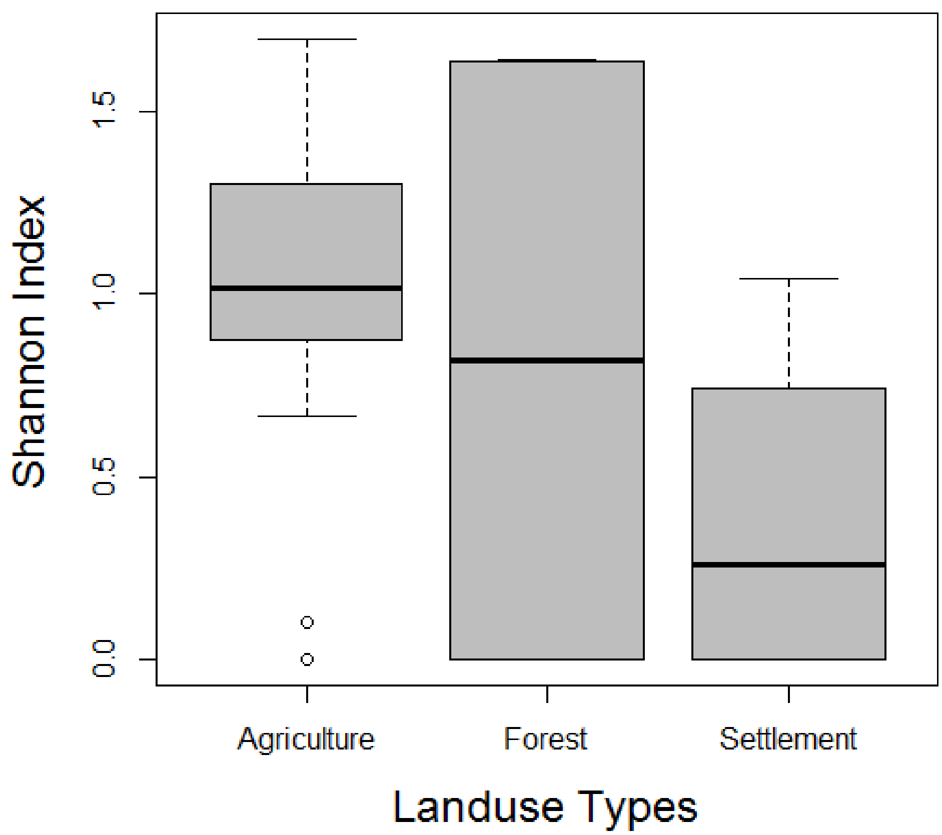

Figure 4.24: Boxplot of Shannon diversity index among the land use types

Table 4.11: Biotic indices among the land use/cover classes

Land use categories	Multimetric indices				
	Abundance	**Shannon**	**Simpson Diversity**	**EPT-ratio**	**Pielou's evenness**
Forest	76	0.818±0.945	0.84±0.00	0.14±0.00	0.32±0.00
Agriculture	487	1.01±0.466	0.70±0.06	0.59±0.10	0.28±0.02
Settlement	79	0.381±0.430	0.57±0.19	0.09±0.09	0.29±0.13

4.1 Relationship between macroinvertebrates assemblage and water quality

Only four water quality parameters (pH, DO, temperature, and turbidity) were used in the ordination analysis. Dissolved oxygen percentage was found to be redundant with dissolved oxygen concentration, conductivity was redundant with temperature and turbidity, salinity was redundant with turbidity, temperature, and conductivity Figure 4.25. From the results dissolved oxygen percentage (DO_per) was highly correlated with dissolved oxygen concentration (DO_Conc), similarly, electrical conductivity (EC) was highly correlated turbidity and temperature (Temp), the same case applied to salinity and nitrates. The physico-chemical parameters that exceed the set threshold of 0.75 were removed because they would not have any meaningful contribution in the canonical correspondence analysis (Karaouzas *et al*., 2007).

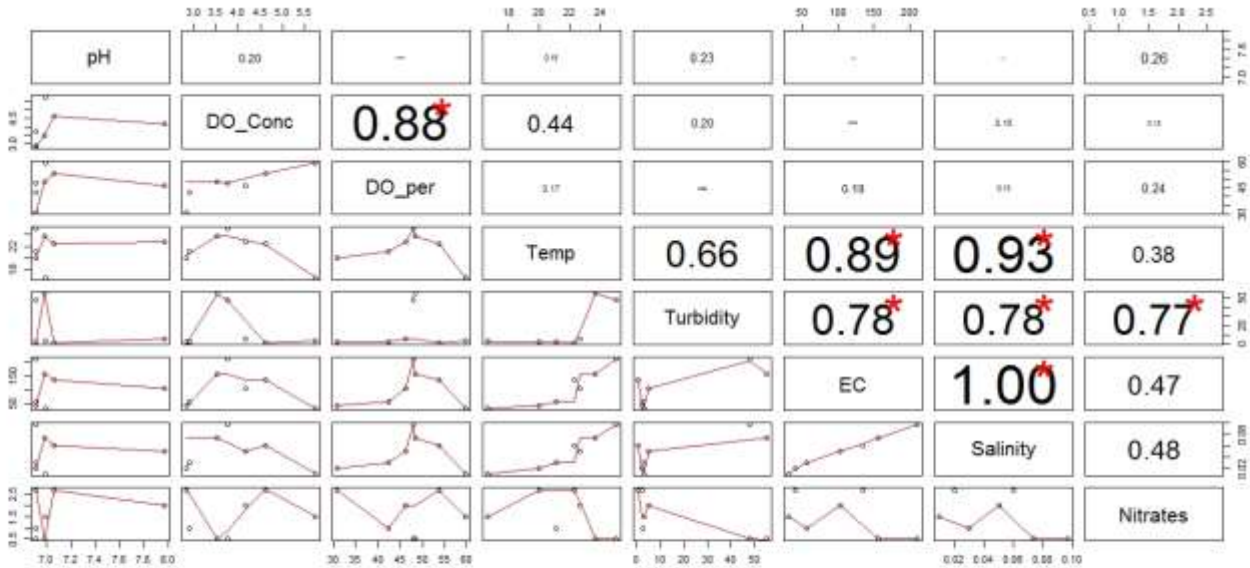

Figure 4.25: Multicolinearity results for water quality parameters
*indicates the correlation greater than the set threshold of .0.75

The CCA biplot depicts the patterns of benthic macroinvertebrates community assemblages according to the physico-chemical parameters (Figure 4.26). Perlidae, Polycentropodidae, Potamonauridae, and Culidae were associated with high dissolved oxygen concentration. Perlidae and Polycentropodidae were recorded in sampling sites with high DO concentration levels such as Site 1. Gyrinidae and Oligochaeta were associated with low DO concentration while Planorbidae was negatively correlated with DO concentration. Oligochaeta, Thiaridae, and Gomphidae were associated with high turbidity levels. *Gomphidae* and Oligochaeta are tolerant taxa that were recorded in Sites 6 and 7 that exhibited high turbidity and temperature levels. Planorbidae, Crambidae, and Elmidae were associated with high temperature and pH levels. While Elmidae was associated with high temperature and pH levels.

The relationship benthic macroinvertebrates and physicochemical variables was shown not to be significant with p-value of 0.112 as shown in Table 4.12. Then the significance of each axis was tested and the results showed that none of the axis where statistically significant Table 4.13. Subsequently the significance of each physicochemical variable was tested. From the anova results only temperature was significant with p-value of 0.033 Table 4.14. The null hypothesis that there was no significant difference between benthic macroinvertebrates community assemblage and water quality characteristics along Theta River gradient was accepted. The study therefore, concluded that there is no evidence that the observed macroinvertebrates assemblages are caused by physicochemical parameters than we would expect by random chance.

Table 4.12: The results of anova on CCA permutations

Permutation test for cca under reduced model				
Number of permutations: 5039				
Model: cca(formula = cca.benthos ~ pH + DO_Conc + Temp + Turbidity, data = cca.waterq)				
Permutation: free				
	Df	**Chi Square**	**F**	**Pr(>F)**
Model	4	1.71612	1.5937	0.112
Residual	2	0.53842		

Where

Pr(>F) is the p-value associated with the F statistic, in which the threshold is p= 0.05,

Table 4.13: The results of anova on CCA permutations by axis

Permutation test for cca under reduced model				
Forward tests for axes				
Permutation: free				
Number of permutations: 5039				
Model: cca(formula = cca.benthos ~ pH + DO_Conc + Temp + Turbidity, data = cca.waterq)				
	Df	**Chi Square**	**F**	**Pr(>F)**
CCA1	1	0.80964	3.0075	0.148
CCA2	1	0.54518	2.0251	0.336
CCA3	1	0.21286	0.7907	0.898
CCA4	1	0.14843	0.5514	0.708
Residual	2	0.53842		

Table 4.14: The results of anova on CCA permutations by term

Permutation test for cca under reduced model				
Terms added sequentially (first to last)				
Permutation: free				
Number of permutations: 5039				
Model: cca(formula = cca.benthos ~ pH + DO_Conc + Temp + Turbidity, data = cca.waterq)				
	Df	**Chi Square**	**F**	**Pr(>F)**
pH	1	0.30741	1.1419	0.274
DO_Conc	1	0.32490	1.2069	0.260
Temp	1	0.56756	2.1082	**0.033 ***
Turbidity	1	0.51625	1.9176	0.107
Residual	2	0.53842		

Significant. Codes: 0 '***' 0.001 '**' 0.01 '*' **0.05** '.' 0.1 ' ' 1

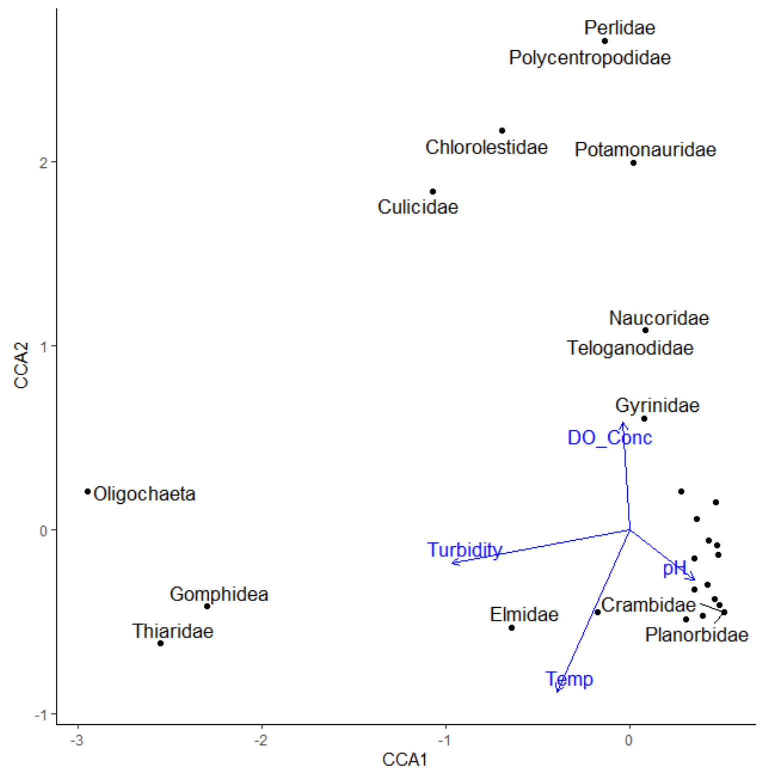

Figure 4.26: CCA biplot for water quality parameters and benthic macroinvertebrates

Chapter 5: SUMMARY OF THE FINDINGS, CONCLUSION, AND RECOMENDATIONS

5.1 Summary of the findings

5.1.1 Spatial land use/cover patterns in the study area

The spatial land use and cover types in Theta River catchment in descending order by area(in km^2) were agricultural land(87.5), grassland land (28.4), urban-settlement(9.6), riverine vegetation(9.1), forest land(7.03), and water bodies(0.96). However, agricultural land, forest land, and urban-settlement land use were selected in this study as they signify the human disturbance gradient that helps in understanding land use and cover impacts on streams along a pollution gradient. Theta River catchment is highly populated in the upstream areas which are dominated by small-holder farming. There is also a high population density in the downstream areas that are located at the urban-rural fringe, while the mid-stream areas are dominated by commercial large-scale coffee farms, hence sparsely populated. Agricultural land is important for livelihood and food for both rural and urban dwellers, hence it is the dominant land use in the study area. The demand for housing for a growing population in downstream areas in the peri-urban makes the urban land the dominant land use in the downstream zones. The forest land is located in Theta River headwaters in protected area hence it is the dominant land use in the headwaters. Along the Theta River and Mugutha River channel there are patches riverine wetlands, the most prominent being at their confluence, but their ecological significance is masked by the surrounding more human influenced land uses. This land cover is moving out of its remote use to active use through conversion into agriculture or urban use especially construction of hotels.

The study also established that the spatial land use pattern along Theta River are not static. Agricultural and urban land are likely to expand into other land uses. For example, urban land is expanding into agricultural and grassland at the urban-rural fringe. While agricultural land is expanding into riverine vegetation zones in the rural areas. Similarly, due to demand for water in the catchment there is construction of water infrastructure in the forest land such as dams and interbasin water transfer systems.

5.1.2 Influence of spatial land use and cover types on water quality

The water quality parameters varied spatially across forest land, agricultural, and urban-settlement land uses, representing the longitudinal human disturbance gradient. The statistical analysis of the relationship between land use types and water quality using spearman rank at 5 percent level of significance(p=0.05), established that there is significant relationship between land use types and water quality parameters. Urban-settlement land use was found to the most influence on water quality parameters explaining 46.2% of variations in temperature, 98% of variation in turbidity, and 59.3% of variations in nitrates. The proportion of the forest land explained 64% variation in temperature and 60.8% variation in dissolved oxygen. Agricultural land use was the least influential land use and had a strong positive correlation with nitrates and explained 51.8% of the variation in nitrates. The presence of nitrates were associated with anthropogenic loadings that arise from agronomic practices such as fertilizer use can result to presence of this kind of pollutant in the water.

5.1.3 Influence of spatial land use types on benthic macroinvertebrate community structure

Even though macroinvertebrates are aquatic organisms, they are influenced by some terrestrial components such as Land use/cover types. Land use types have influence on water quality aspect such as diurnal temperature changes due to shading effect from the canopy. Land use also determines the kind of inputs going into rivers such as litter or sediment which in turn influences key water quality parameters such as pH, turbidity and conductivity. The diversity and abundance of macroinvertebrates was generally low in sites located in human disturbed land uses such as urban land. The intolerant taxa were observed in forest land dominated areas which had less human disturbance and had less pollution loads.

Statistical analysis of macroinvertebrate community structure using ANOSIM and collaborated with an NMDS plot, established that there is strong significant difference in macroinvertebrate assemblage among the land uses/cover. Further, pairwise comparisons between the land uses revealed that agricultural land and urban land had no significant differences. This can be explained by the near similar influences these land uses have on Theta River. The sites located in these land uses had near similar riparian characteristics such as devoid of riparian canopy cover and encroachment.

5.1.4 Relationship between macroinvertebrate assemblage and water quality

Multicolinearity test results prior to the canonical correspondence analysis should that pH, DO, temperature, and turbidity were the most important parameters that influence the distribution of benthic macroinvertebrates in Theta River catchment. The pollution sensitive taxa such as Perlidae and Potamonauridae, were correlated with high DO levels while the tolerant taxa such as Oligochaeta were correlated with high turbidity. However, statistical analysis using permutations and anova revealed that overall there was no significant relationship between benthic macroinvertebrates communities and water quality characteristics, but looking at individual parameters temperature had significant effect on benthic macroinvertebrates community structure.

5.2 Conclusion

Theta River catchment was used as a case study to assess the relationships between spatial land use types and water quality as well as the benthic macroinvertebrate community structure. The results of the findings was based on 7 sampling sites distributed in Forest land (1 site), agricultural land (4 sites) and settlement/ urban land (2 sites). The study results showed that forest land had strong negative impacts on salinity, temperature and conductivity, as well as strong positive impacts on DO. These relationships were not however statistically significant. The percentage urban land had negative impacts on temperature, conductivity, and turbidity which can be attributed to land disturbance associated with urban land use activities. Agricultural land had negative impacts on nitrate concentration associated with agronomic practices and riparian encroachment. Overall urban land use had the strongest impacts on water quality in comparison with forest land and agricultural land.

The patterns of impact of land use on water quality was similar to that of the benthic macroinvertebrate community assemblage. The urban land use sites being the most depauperate, which the forest land having the highest diversity and abundance. The multivariate statistic techniques used in this study elucidated the relationship between land use and benthic macroinvertebrates, as well as the relationship between benthic macroinvertebrates and water quality. The cause-effect relationships were not however reached conclusive because multiple factors have an effect on macroinvertebrates assemblage and well as water quality in streams at a watershed level. A general overview of these relationships was however shown to exist.

5.3 Recommendations

The study recommended several interventions to address the identified research gaps in the evaluation of the influence of LULC on water quality and benthic fauna in Theta River catchment. Areas of further research are also outlined.

5.3.1 Management recommendations

5.3.1.1 Catchment land use and landcover

The results of this study elucidated the relationship between water quality and land use/cover types, and the relationship between land use/cover and benthic macroinvertebrates. The results support the importance of forest land preservation and protection in the upstream areas. There is therefore need to amplify positive contribution of forest land on water quality and benthic by including more areas under forest cover such the riverine riparian zones with fast growing indigenous trees as an incentive for farmers to meet demand for domestic biomass.

There is need to address the best farming practices that are in harmony with riparian zones and that can address the non-point pollution to mitigate nutrients loads in streams in Theta River catchment. In addition, the role played by riparian vegetation in mitigating non-point pollution and regulating the micro-climate within the river ecosystems should be applied to justify riparian zone protection along all rivers in Theta River catchment. This can be done by upscaling the already existing collaborative efforts in pegging and marking the riparian zone along Theta River catchment using a multistakeholder. Such efforts include the already on going protection of riparian vegetation on a 4km stretch of Theta River riparian marking by residents of Sweet Waters Estate in Juja.

5.3.1.2 Water quality monitoring

For effective water quality monitoring in rivers, there is need to operationalize Water act 2016, adopt watershed approach, and Water Resource Users Associations (WRUAs). The water quality monitoring done under this framework should be catchment specific in which the findings are taken into consideration as well as the development of a coherent multi-institution field methods that complements the physico-chemical parameters data. There is also need to adopt preventive measures in the urban dominated areas by having mandatory requirement of all households and industries being connected to the newly constructed sewer line within the lower zone of Theta River catchment.

5.3.2 Policy recommendations

The water development in the catchment geared towards augmenting water for domestic use has not been done in a sustainable manner. There is much emphasis on the grey infrastructure specifically Theta Dam constructed in the forest and the proposed weir near Kiganjo for domestic water supply further downstream. The grey infrastructure is already compromising the green infrastructure evident by the drying of Theta Dam and destruction of natural forest along the pipeline way leave and, in the area, occupied by the dam. In lower reaches of the catchment the conversion of wetland into farmlands could hinder natural filtration by wetland vegetation and exacerbate diffuse pollution and sediment load into reservoirs and rivers downstream.

5.3.3 Recommendations for further research

i. The study was carried in Mugutha, Thaara and Theta Rivers within the study area in the month of March during the dry season. A more comprehensive study needs to be done during wet season to facilitate a seasonal comparison.

ii. The study found out evidence of use of agrochemicals in the catchment farmland as well as within the riparian zone. There is need for a detailed assessment of impacts of agrochemicals on macroinvertebrates using a multi-metric approach including the functional feeding group indices to determine the cumulative effects along the river gradient.

iii. A detailed study using site-specific approach on the impacts of specific land use/cover types on benthic macroinvertebrate assemblages while taking into account landscape features to elucidate all the interactions at play in the catchment.

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APPENDICES

Appendix 1: Summary of physico-chemical parameters

Sites	PH			DO (Mg/L)			DO %			Temp ˚C			Turbidity (NTU)			EC (µS/cm)			Salinity PPT(PSU)			Nitrates (Mg/L)
1	7.02	6.99	6.96	6.53	5.9	4.8	68.4	61	49.5	16.82	16.5	16.66	3.36	3.36	3.36	33	31	32	0.01	0.01	0.01	1.5
2	6.94	6.9	6.89	2.69	2.89	2.9	30.2	30.3	32.3	20.12	20.04	19.9	2.69	2.69	2.69	34	44	45	0.02	0.02	0.02	2.69
3	6.91	6.93	6.9	2.77	2.84	3.1	31.2	32.1	34.5	21.16	21.16	21.13	2.79	2.79	2.79	56	56	57	0.03	0.03	0.03	1
4	8	8	7.9	4.2	4.3	4	48.5	47.9	42.4	22.6	22.8	22.6	5.15	5.15	6	106	100	104	0.05	0.05	0.05	2
5	7.09	7.06	7.03	4.95	4.67	4.2	58.7	53.8	48.4	22.49	22.35	22.2	1	1	1	135	135	133	0.06	0.06	0.06	2.65
6	6.95	7	7	3.9	3.65	3	46.5	43.1	36.5	22.71	24.05	24.35	55	60	50	163	157	149	0.08	0.07	0.07	0.5
7	6.87	6.94	6.93	3.52	3.83	3.9	46.7	45.2	46.4	28.18	23.72	23.23	50.2	47	46	184	240	207	0.09	0.1	0.1	0.5

Appendix 2: Summary of macroinvertebrates orders, families and abundance per sampling station

	Forest	Agricultural				Settlement			
Taxon	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**FFG**	**Tolerance Values**
Coleoptera									
Gyrinidae	8	7		11			2	Prd	4(moderate)
Elmidae					2		1	Scr	4(moderate)
Decapoda									
Potamonauridae	12	3		1				Cg	6(moderate
Diptera									
Tipulidae		4	1	2				Prd	3(low)
Chironomidae	3	9		14	24			Cg	8(high)
Muscidae					4			prd	6(moderate)
Culicidae	2					1		Cf	8(high)
Ceratopogonidae		1			3			prd	6(moderate)
Dixidae				3				Cf	1(low)
Ephemeroptera									
Heptageniidae	1		7					Scr	3(low)
Teloganodidae	1				1			Shr	4(Moderate
Beatidae			21	21				Cg	5(Moderate)
Caenidae		1						Cg	6(Moderate)
Gastropoda									

Planorbidae			9					Scr	7(High)
Thiaridae							56	Scr	
Hemiptera									
Gerridae	5	3	3	21	5			Prd	4(Moderate)
Naucoridae	1				1			Prd	5(Moderate)
Veliidae				3	1		1	Prd	6(Moderate)
Lipedoptera									
Crambidae			1					Shr	
Odonata									
Libellulidae		3	2	1				Prd	2(Low)
Gomphidea			1			2	6	Prd	3(low)
Coenagrionidae	10		21	10	6		1	Prd	8(High)
Chlorocyphidae		2						prd	
Chlorolestidae	24					6		Prd	
Oligochaeta						1		Cg	8(High)
Plecoptera									
Perlidae	7							Prd	2(Low)
Trichoptera									
Hydropsychidae	1	55	114	13	57	2		Cf	4(Moderate)
Polycentropodidae	1							Cf	6(Moderate)
Leptoceridae			6		8			Shr	4(Moderate)

Megaloptera									
Corydalidae					1			Prd	2(Low)
Total Individuals	76	88	186	100	113	12	67	642	
Total Families	13	9	10	10	12	5	6		

Prd-Predator, Cg- Collectors- gatherers, Cf- collectors-filters, Scr-Scrapers

Appendix 3: Photo of macroinvertebrate specimen under microscope

Flathead Mayfly

Appendix 4: Research clearance permit no: NACOSTI/P/19/71930/28669

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