IMPACT OF LAND USE CHANGE IN WATER QUALITIES, HABITAT QUALITIES AND BENTHIC MACROINVERTEBRATES ASSEMBLEGES IN KIPSINENDE RIVER, LAKE VICTORIA BASIN, KENYA

BY

MASRESHA BIRARA FEKADU

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FISHERIES AND AQUATIC SCIENCES (AQUATIC SCIENCE OPTION) IN THE SCHOOL OF NATURAL RESOURCE MANAGEMENT, UNIVERSITY OF ELDORET, KENYA

APRIL, 2021

DECLARATION

DECLARATION BY THE STUDENT

This thesis is my original work and has not been presented for award of any certificate or degree in any other institution or university. No part of this work should be reproduced without prior permission from the candidate and / or University of Eldoret.

MASRESHA BIRARA FEKADU

________________________ ________________________

SNAT/FAS/M/008/18 **DATE**

DECLARATION BY THE SUPERVISORS

This thesis has been presented with our approval as University supervisors.

________________________ ________________________

Dr. Agembe Simon **DATE**

University of Eldoret, Kenya

________________________ ________________________

Eng. Dr. Clement Kiprotich Kiptum **DATE**

University of Eldoret, Kenya

________________________ ________________________

Dr. Minwyelet Mingist **DATE**

Bahir Dar University, Ethiopia

DEDICATION

To my lovely family members for their spiritual and moral support throughout my studies.

ABSTRACT

Kipsinende River is being impacted by anthropogenic activities from upstream to downstream. The main pollution sources are agricultural activities, washing, bathing, logging, deforestation and grazing. The main objective of this study was to assess the impact of water and habitat qualities on the abundance and distribution of benthic macroinvertebrates in the Kipsinende River, Lake Victoria Basin. This study was conducted from November 2019 to March 2020 in the wet season at six sampling stations. Six water quality parameters were tested in situ, namely temperature, power of hydrogen, dissolved oxygen, total dissolved solid, conductivity and salinity. Other parameters namely: (ammonia, total suspended sold, nitrate, nitrite and soluble reactive phosphorus) were tested in the laboratory. The weighted arithmetic index method was used to assess the water quality index of the river. The benthic macroinvertebrates were sampled by using a kick net against water current and habitat quality was also evaluated by using rapid bioassessment protocols. Water quality data were analyzed by using descriptive statistics, Pearson's correlation, One-way analysis of variance (ANOVA) and followed by Post hoc Turkey's honest significance differences tests to know the significance differences between sites. Benthic macroinvertebrate assemblages were determined by, number of taxa, and the total number of individuals, by computing various indices. Canonical correspondence analysis was also applied to evaluate the relationship between benthic macroinvertebrate community and physicochemical water parameters. The current water quality parameters of the river were within acceptable standards, except for ammonia and soluble reactive phosphorus. Based on the weighted arithmetic index method the water quality status was unsuitable for drinking and fish culture. In this study 20,040 macroinvertebrate individuals were counted and identified, belonging to 13 orders, 48 families, and 68 genera. The relative abundance of Dipteran was 51% followed by Ephemeroptera 27%. The relative abundance of dipteran and taxon group of percent Ephemeroptera, Plecoptera and Trichoptera (% EPT) had inverse relation across study sites. The highest relative proportion (81.18%) for predators feeding group occurred in agricultural land use and the lowest (11.02) in the forested area. Whereas, gatherer (57.53%), shredders (4.16%), and scraper (11.9%) were highest in the forested site. All sites were strongly heterotrophic, non-performing, and presence of plentiful loading of fine particulate organic matter. Physico-chemical parameters affected the macroinvertebrates communities in the river. Further studies should be carried out along the river, covering different seasons, in order to establish the status of water quality of the entire river.

TABLE OF CONTENTS

DECLARATION II
DEDICATION III
ABSTRACT IV
TABLE OF CONTENTS V
LIST OF TABLES VIII
LIST OF FIGURES IX
LIST OF PLATES X
LIST OF APPENDICES XI
ABBREVIATIONS AND ACRONYMS XII
ACKNOWLEDGMENT XIII
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background Information 1
1.2 Statement of the Problem 3
1.3 Justification of the Study 4
1.4 Objectives Study 5
  1.4.1 General Objective 5
  1.4.2 Specific Objectives 5
1.5 Hypotheses of the Study 5
1.6 Scope and Limitation of the Study 6
1.7 Operational definitions of terms 6
CHAPTER TWO 8
LITERATURE REVIEW 8
2.1 Water Quality in Rivers 8
  2.1.1 Water Quality Parameter 8
  2.1.2 Water Quality Index 12
2.2 Pollution on Rivers as a Result of Anthropogenic Activities 13
2.3 Effects of Deforestation on Water Quality 15
2.4 Benthic Macroinvertebrates Assemblages 16
  2.4.1 Benthic Macroinvertebrates Distribution, Abundance and Composition 16

2.4.2 Benthic Macroinvertebrates Diversity. 18
2.4.3 Macroinvertebrates Functional Feeding Groups..18
2.5 The Relationship between Water Quality and Benthic Macroinvertebrates. 21
2.6 Habitat Quality Modification and their Relationships with Macroinvertebrates. 22
CHAPTER THREE..26
MATERIALS AND METHODS..26
3.1 The Study Area...26
3.1.1 Sampling Design...29
3.1.2 Sample Station Selection 31
3.2 Sample Collection 37
3.2.1 Field Sampling..37
3.2.2 Laboratory work and Analyses. 41
3.3 Data Analyses..45
3.3.1 Physical-chemical Parameters, Morphological Variables and Nutrients...............45
3.3.2 Water Quality Index (WQI)..46
3.3.3 The Benthic Macroinvertebrate Assemblages 47
3.3.4 The Relationship between Water Quality and Benthic Macroinvertebrates..........49
3.3.5 The Habitat Quality Determination and their Relation with Benthic Macroinvertebrates 50
CHAPTER FOUR 51
RESULTS...51
4.1 Water Quality in River Kipsinende 51
4.1.1 Physico-chemical Parameters and Nutrients...51
4.1.2 Correlation between Different Physico-chemical Parameters. 54
4.1.3 Water Quality Index (WQI) of River Kipsinende 55
4.1.4 Hydro-morphological Variables. 55
4.2 Benthic Macroinvertebrates Assemblages. 57
4.2.1 Macroinvertebrates Abundance and Composition...57
4.2.2 Diversity of Macroinvertebrates. 59
4.2.3 Functional Feeding Group of Macroinvertebrates and Ecosystem Attributes.......61
4.3 The Relationship between Water Quality and Benthic Macroinvertebrates. 63

4.4 The Habitat Quality Assessment and their Relationships with Benthic Macroinvertebrates....64
4.4.1 Habitat Quality Assessment....64
4.4.2 The Relationship between Habitat Quality and Benthic Macroinvertebrates....67
CHAPTER FIVE....68
DISCUSSION....68
5.1 Water Quality in River Kipsinende....68
5.1.1 Physico-chemical Parameters....68
5.1.2 Nutrients....71
5.1.3 Correlation between Different Physico-chemical Parameters....73
5.1.4 Water Quality Index (WQI) of River Kipsinende....73
5.1.5 Hydro-morphological Variables....74
5.2 Macroinvertebrates Abundance, Composition, Diversity and Functional Feeding Group....75
5.2.1 Macroinvertebrates Abundance and Composition....75
5.2.2 Diversity of Macroinvertebrates....78
5.2.3 Functional Feeding Group of Macroinvertebrates and Ecosystem Attributes....80
5.3 The Relationship between Water Quality and Benthic Macroinvertebrates....85
5.4 The Relationship between Habitat Quality and Benthic Macroinvertebrates....86
CHAPTER SIX....88
CONCLUSIONS AND RECOMMENDATIONS....88
6.1 Conclusions....88
6.2 Recommendations....89
REFERENCES....90
APPENDICES....113

LIST OF TABLES

Table 2.1: Water Quality Index ranges, status, and possible usage (Hülya, 2009). 13

Table 2.2: Functional feeding groups and their food source from (Merritt & Cummins, 2006; Merritt *et al.,* 2008 and Merritt *et al*., 2014) CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter. 20

Table 2.3: Functional feeding group ratios serving as surrogates for stream ecosystem attributes (Merritt & Cummins, 2006; Merritt *et al.,* 2008) P = production, R = respiration CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter, P = predator/ prey...20

Table 2.4: Classes for assessment of river habitat (King *et al.,* 2000) 24

Table 4.1: Means of water quality parameters for different stations (DO = dissolved oxygen, pH = power of hydrogen, TSS = total suspended solid, TDS = total dissolved solid)53

Table 4.2: Correlation coefficient matrix between different physicochemical parameters (Tem = temperature, DO = dissolved oxygen, pH = power of hydrogen, TDS = total dissolved solid, cond = conductivity, Salin = salinity, SRP = soluble reactive phosphorus) 54

Table 4.3: List of macroinvertebrate taxa (x indicates the presence of macroinvertebrates in station 58

Table 4.4: Various metric categories based on benthic macroinvertebrates taxa...............60

Table 4.5: Functional feeding groups on benthic macroinvertebrates 62

Table 4.6: Ecosystem attributes based on the ratio of FFG (functional feeding group) 63

Table 4.7: Habitat quality assessment with their (average ranked) during study period in six sampling stations in River Kipsinende (H = the Kruskal -Wallis test which is rank based). 66

LIST OF FIGURES

Figure 2. 1: Conceptual frame work linking anthropogenic activities and River Kipsinende ecosystem 25

Figure 3. 1: Map of the study area showing stations (Source: Author, 2020)....................27

Figure 3. 2: Sampling design and procedure modified from (Veronica, 2010) 30

Figure 4. 1: Calculated Values of WQI in River Kipsinende during the study period. ……………………………………………………………………………………55

Figure 4. 2: Measured values of hydro-morphological parameters at sampling stations (a=depth (m), b= width (m), c = velocity (m/s), d = discharge (m^3/s)........................56

Figure 4. 3: The canonical correspondence analysis (CCA) biplot of the macroinvertebrates in relation to the physico-chemical parameters..64

Figure 4.4: The canonical correspondence analysis (CCA) biplot of the benthic macroinvertebrates in relation to the habitat quality parameters. 67

LIST OF PLATES

Plate 2. 1: Cutting down of trees for charcoal burning, agriculture and wood fuel (Source: Author, 2020) 16

Plate 3. 1: Agricultural activities and the status of bank stability in station KA (Source: Author, 2020). 32

Plate 3. 2: Human activities around the bank of the stream in station KB (Source: Author, 2020). 33

Plate 3. 3: Indicating the river channel and bank stability after the two streams mix each other in station KC (Source: Author, 2020) 34

Plate 3. 4: Shows the river channel and riparian vegetation in station KD (Source: Author, 2020) 35

Plate 3. 5: Canopy cover of Kaptagat forest and riparian vegetation in station KE (Source: Author, 2020). 36

Plate 3. 6: Riparian vegetation status and some disturbances (cattle drinking) in station KF (Source: Author, 2020)....37

Plate 3. 7: *In-situ* measurement of physicochemical parameters (a) Measuring velocity (b) (Source: Author, 2020)....38

Plate 3. 8: Sampling (a) and sorting (b) of macroinvertebrates (Source: Author, 2020) ...40

Plate 3. 9: Running water samples via Cadmium column for nitrate (a) and reading the absorbance of nutrients with spectrophotometers (b) (Source: Author, 2020) 43

Plate 3. 10: Sorting (a), identification (b) and genera identified (c) (Source: Author, 2020) 45

LIST OF APPENDICES

Appendix I: The standard plotted graph for nutrients (ammonia, soluble reactive phosphate, nitrate and nitrite) with absorbance vs. concentration 113

Appendix II: Calculated Values of WQI in River Kipsinende during the study period (Si = Standard value, Wi = relative weight, qi = quality rating).......................................114

Appendix III: Abundance and composition of the functional feeding group of macroinvertebrates in Kipsinende River...115

Appendix IV: Rapid assessment protocol for habitat measurement or characteristics of the river ecosystem field sheet (Barbour *et al.*, 1999) 117

Appendix V: Similarity report..119

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
CCA	Canonical correspondence analysis
CPOM	Coarse particulate organic matter
DO	Dissolved Oxygen
DPSIR	Drivers-Pressure-State-Impact-Responses
EPT	Ephemeroptera, Plecoptera and Trichoptera groups together
FFG	Functional feeding groups
FPOM	Fine particulate organic matter
GF/F	Glass Fibre Filters
PAST	Paleontological Statistics
pH	Potential hydrogen or acidity level
RCC	River Continuum Concept
SRP	Soluble Reactive Phosphorus
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WAWQIM	Weighted Arithmetic Index Method
WHO	World Health Organization
WQI	Water Quality Index
YSI	Yellow Spring Instruments

ACKNOWLEDGMENT

First of all, I want to thank the Almighty God for the free gift of life and for giving me a heart to tolerate the challenges that were ahead from the beginning up to the end. I am grateful to many people, organizations and institutions. First and foremost, I take great pleasure to thank my supervisors, Dr. Agembe Simon, Eng. Dr. Clement Kiprotich Kiptum and Dr. Minwyelet Mingist for their availability, guidance, criticisms, and advice during this study that has led to the fulfilment of this thesis. Secondly, I thank Collaborative Training in Fisheries in East, Central and Southern Africa (COTRA) project and the inter-Africa academic mobilities scheme of the European and African union for the scholarship and financial support. Thirdly, my special compliments go to the teaching staff and technical team of the Department of Fisheries and Aquatic Sciences, University of Eldoret, especially Mr. Lunaligo Lubanga, Mr. Augustine Sitati and Mr. George Alal for their professional input (data collection, identification) and their wonderful guidance towards the realization of this fulfilment.

I would like also to express my deepest gratitude to Bahir Dar University, School of Fisheries and Wildlife and all academic staff for granting me a study leave and for contributing their academic inputs and advices during my earlier study.

Lastly, I thank my family, wife and friends for their love and support, and for all the joy, they brought to my life in the study period. I sincerely thank you all those who in one way or the other contributed towards the attainment of this research work.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Water is an essential and dynamic renewable natural resource that sustains all forms of life including human beings. The availability of good quality water in sufficient quantities is critical for human survival and other aquatic species (Khwakaram *et al*., 2012). Indicators for monitoring the consequences of wastewater discharges in aquatic ecosystems have included macroinvertebrate assemblages (Elias *et al.,* 2014; Chikodzi *et al.,* 2017). Because they are less mobile, found at the bottom of a stream and have short life cycles that enable quick response for various environmental conditions (Dalu & Froneman, 2016).

Rivers are the most significant natural water resources for human development, but they are polluted by indiscriminate sewage dumping, industrial waste, and a variety of human activities that alter the physico-chemical and microbiological quality of the water (Chauhan & Singh, 2010). The importance of water to human beings cannot be overemphasized. A person may go longer without food, but not without water, which is needed for cooking, cleaning, sanitation, drinking, as well as growing crops and operating factories (Etim *et al*., 2013). As a result, it is critical to monitor and assess water quality as well as safeguard it from the various forms of pollution.

Changes in land and water use have resulted from human population increase, posing a growing threat to biodiversity and ecosystem services (Lindborg, 2015; Selemani *et al.*, 2018). Physico-chemical and biological diversity are very important to the health of an aquatic ecosystem like rivers and other freshwater systems (Venkatesharaju *et al.,* 2010).

Currently, the physico-chemical and biological water quality parameters changed from point to point and consequently affect macroinvertebrates composition in a stream or river (Monoj & Padhy, 2013). Therefore, can be inferred the health of river between system and by checking the availability of certain macroinvertebrates (Griffin *et al*., 2015). There is a high probability that the rising temperature due to climate change will negatively affect the water quality of river systems (FAO, 2018). The threat to water quality will be severe in Africa where annual stream flow is the lowest in the world as compared to other continents (Brooks *et al*., 2007).

Groundwater in springs, wetlands and precipitation are sources of quality water in rivers and streams. However, water is being polluted by point and non-point anthropogenic sources consequently affecting the ecosystem resulting in loss of biodiversity and changes in species composition (Bhaskar & Dixit, 2013). Indeed, nutrient pollution from nitrates and phosphates is expected to increase in sub-Saharan Africa (UNEP, 2017) and hence the need to monitor the health of streams in these areas particularly the world's longest River Nile and its watershed. Sources of water to River Nile come from around 11 countries including Kenya and in particular Lake Victoria Basin.

Keiyo highlands are the origins of rivers like Kipsinende that drain into the Lake Victoria basin. Water from Kipsinende River is used for domestic purposes like drinking, washing clothes and cars. Besides, the water is abstracted during the dry season for irrigation purposes and livestock gets water from this river. There is a water treatment plant that supplies water to residents of Chepkorio ward. This shows that the river is serving various human and livestock demands.

1.2 Statement of the Problem

Lotic systems (flowing water) are influenced by anthropogenic pollution and their effects can be felt miles away downstream. According to the UNESCO (2017), report 80% of wastewater flows back into river ecosystem without being treated. In East Africa, the population growth is increasing at an alarming rate, this leads to accelerated deforestation, urbanization, industrial expansion and commercial irrigation or agricultural activities threatening freshwater bodies (GWP, 2015) and this is also true in Kenya and Elgeyo Marakwet County where the study area is situated. The Kipsinende River is one of the major tributaries in the Nzoia River catchment systems of the Lake Victoria Basin. However, the river has been polluted from time to time due to numerous activities taking place in its basin. Recently, there has been an increase in agricultural activities, deforestation, logging and human settlements in the River Kipsinende catchment. This might cause an alteration of the ecosystem and the water quality which also may affect the lower river. Forests strongly contribute to the presence of high-water quality and most sustainable water resources. Furthermore, water quality in rivers which is important in the management of rivers and their ecosystems (Oates & Parker, 2016).

In Kenya, 81% of population use wood fuel for cooking and various domestic purposes (Fuchaka *et al*., 2020). This leads to logging (cutting down of trees) for charcoal burning and other commercial purposes as indicated in (Plate 1). Logging influences water quality, habitat quality and biodiversity of the ecosystem (Stednick, 2008). This can be determined by a variety of factors, including slope, harvest type, harvest equipment used, weather conditions during and after harvest, and many others. Illegal logging for cedar posts, commercial purpose and building materials, as well as encroachment of forests like

Kaptagat forest coupled with the Plantation Establishment and Livelihood System (PELIS) practiced in the study area, where Kipsinende River flows through, is likely to affect water resources and biological diversity (ROK, 2018). As a result, it's critical to examine the river's current status and determine the influence of human activities on water quality and aquatic biota. This contributes to water management.

1.3 Justification of the Study

The destruction of forests and increasing population is expected to severely impact heavily on the water flowing in the rivers and hence the need to study water and habitat quality of Kipsinende River. Water quality deterioration greatly affects biotic communities and human health, pollution of water into the water body makes it detrimental to the health, safety of the public and the environment (Niculae *et al*., 2013). Kibria *et al.* (2016), suggested that agricultural, domestic, soil erosion and industrial wastewater contributes to produce heavy metals when discharged into rivers. Because of the heavy metals persistence and potential for bioaccumulation and biomagnification in the food chain (Barata *et al*., 2010; Ricart *et al*., 2010), they are one of the most serious hazards to aquatic biota (fish and invertebrates). A study like this one gives the status of freshwater ecosystems that are known to be sensitive to climate change (FAO, 2018). Moreover, there is little information on Kipsinende River about biological indicators or macroinvertebrates, and the status of water quality. Therefore, undertaking this study can provide scientific information on macroinvertebrate abundance, distribution, diversity, functional feeding group and status of water quality in river Kipsinende catchment and enable to determine the effect of anthropogenic activities and the possible source of pollution in the catchment. Also, the information would be useful for ecological conservation and management of the rivers as well the Elgeyo Marakwet County leading to the attainment of sustainable development goal number 6.3 of reducing pollution on water bodies (UN, 2015).

1.4 Objectives Study

1.4.1 General Objective

To assess the impacts of land use change in water qualities, habitat qualities and benthic macroinvertebrates assemblages in kipsinende river, Lake Victoria Basin.

1.4.2 Specific Objectives

i. To assess selected water quality parameters (temperature, DO, pH, TDS, TSS, salinity conductivity, ammonia, nitrite, nitrate and soluble reactive phosphorus) for River Kipsinende.

ii. To figure out the abundance, composition, distribution, diversity and functional feeding group of macroinvertebrate assemblages in River Kipsinende.

iii. To investigate the effects of water quality on the benthic macroinvertebrates' occurrence in River Kipsinende.

iv. To determine the habitat characteristics and their relationship to macroinvertebrate's distribution/abundance in River Kipsinende.

1.5 Hypotheses of the Study

i. There is no water quality variation among different land uses in River Kipsinende.

ii. There is low abundance, composition, distribution and diversity of macroinvertebrate assemblages in agricultural area as compare to the forested site.

iii. Water quality has no impact on the distribution/abundance of benthic macroinvertebrates along River Kipsinende.

iv. There is lack of relationship between habitat quality and macroinvertebrate's distribution/abundance in River Kipsinende.

1.6 Scope and Limitation of the Study

The study focuses on analyses of selected physicochemical parameters (temperature, DO, pH, conductivity, TDS, TSS, salinity, ammonia, nitrite, nitrate and soluble reactive phosphorus), habitat quality and their impact on macroinvertebrates assemblages. The analysis of water quality, habitat quality and identification of macroinvertebrates needs intensive financial cost, time (dry and wet season) and full laboratory facilities. For example, to obtain the representative data the data collection should be carried out in both dry and wet season. However, due to unpredictable climate change the dry season data was not collected because it was wet throughout the year. The other challenge was laboratory facilities to do water quality parameter analysis. Thus, the study was carried out with some of the physico-chemical parameters and water variables measured that need future studies for the remaining water quality parameters like heavy metals. The scope of the study was restricted to around 10 km stretch of Kipsinende River and its surroundings up to 30 m from the river bank.

1.7 Operational definitions of terms

Abundance: Number of invertebrates in a sample

Bank stability: Measure whether the stream banks are eroded (or have the potential for erosion.

Biotope: The environment in which a community of closely related organisms lives.

Channel flow status: The degree to which the channel is filled with water (flow decrease as a result of dams and other obstructions, diversion for irrigation or drought).

Embeddedness: Refers to the extent to which substrates like rocks, gravel, cobble, boulders, and sand, or mud of the stream bottom.

Epi faunal substrate: A wide variety of submerged structure in the stream provided niches for macroinvertebrates.

Kick net: It is one of the standard benthic macroinvertebrate sampling gear types which has a dimension of net 1meter (m) x 1 m attached to 2 poles and mostly effective for sampling riffles and runs biotopes.

Pool: Characterized by slow and smooth water surface usually where the stream widens.

Riparian vegetation zone: Measure the width of natural vegetation from the edge of the stream bank out through the riparian zone.

Taxon richness: The number of distinct taxa, which is represents the diversity within a sample.

V**elocity-depth combination:** relates to the ability of a stream to provide and maintain a stable aquatic environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Quality in Rivers

Water quality can be defined as a measure of physical, chemical, biological, hydro-morphological and aesthetic properties of water (Giri & Qiu, 2016). The weather, altitude, position, source of pollution and time determine the changes in water parameters (Giri & Qiu, 2016). Good water quality has various uses such as drinking, nature conservation, industrial, agricultural recreational, and habitat of aquatic ecosystems (Angweya *et al*., 2012). However, the quality of water is rapidly declining in many areas, and this is one of the key issues that people are facing (Bhateria & Abdullah, 2015). The main causes of the deteriorations are both natural (for example, changes in precipitation and erosion) and anthropogenic (excessive human exploitation of water resources in urban settlements, industrial areas, and agricultural operations) (Bhateria & Abdullah, 2015, Selemani *et al*., 2018). Therefore, on the basis of water quality the study looked at physical, chemical and biological parameters. This provides insights into the quality of surface water in the Kipsinende River basin.

2.1.1 Water Quality Parameter

As discussed by Rangeti *et al*. (2015), the first stage in determining water quality is parameter selection. This is due to the lack of resources, which makes it difficult to monitor all water quality parameters and therefore only few but most crucial parameters should be taken into account. The type of chemical and physical analysis done on each sample is determined by the goal of the study, and available resources (Agency *et al.*, 2001).

Temperature, dissolved oxygen (DO), TSS (total suspended solids), TDS (total dissolved solids), electrical conductivity, pH (power of hydrogen), salinity, nitrate, nitrite, ammonia, and soluble reactive phosphate are selected parameters for this study because mainly they influence the quality of aquatic ecosystems (Chang *et al*., 2019). TDS shows the general nature of salinity of water (Gupta *et al*., 2013). TDS also determines the total amount of inorganic and organic elements present in water and as a result of this, it serves as a general diagnostic of the presence of a wide range of chemical pollutants.

Temperature

Temperature influences several physicochemical and biological processes in the aquatic ecosystems, making it one of the most essential elements. Latitude, altitude, season (sampling time), air circulation, tree cover (shading), flow properties and water depth are some of the significant factors that influence temperature regimes of most surface waters (Bhateria & Abdullah, 2015). An increase in temperature which may occur due to climate change (Air temperature, solar radiation), increasing of some parameters (turbidity, conductivity, shallow, surface waters) and human activities like pollution, runoff and deforestation (Zeiger *et al*., 2016). Consequently, it has the potential to shifts in species composition, distribution and loss of endemic species (Carr & Rickwood, 2008). There exists daily, monthly and annual fluctuations in water temperature of surface water bodies, a phenomenon that is responsible for the shift in chemical properties of a variety of range of parameters.

Dissolved oxygen

Dissolved oxygen is the quantity of gaseous oxygen dissolved in an aqueous solution (Carr & Rickwood, 2008). Adequate dissolved oxygen is crucial for the survival of many organisms in order to sustain life in aquatic ecosystems. It also has an impact on the solubility of several nutrients as well as their periodicity of occurrence in aquatic ecosystems. When domestic wastewater containing food particles, human wastes and animal wastes among other organic and inorganic substances are discharged into rivers they get oxidized and, in the process, DO depleted in water. The depletion of DO in water threatens fish that require not less than 4.0 mg/L of DO. To monitor the level of DO in water, the US EPA, suggests that DO should not fall below 5.5 mg/L (Davies & Cornwell, 2017). Despite DO fluctuations across spatial and temporal scales, it serves the purpose of indicating the biological health of rivers. DO being temperature dependent changes along the river due to biological processes like photosynthesis, respiration and decomposition of organic matter (Kuligiewicz *et al*., 2015). Between January and December of 2009, a study of three rivers in Machakos County in Kenya in an area called Kithimani in Yatta district revealed that Athi River had DO of between 5.0 and 7.3 mg/L, Kauthulini had DO ranging from 7.1 to 8.8 mg/L and Languni River had DO values of between 5.9-7.9 mg/L (Sila, 2019). Similarly, in 2013, a study was done on Nairobi River, a tributary of Athi River, observed DO of between 17.23 and 24.29 mg/L in wet season (November, 2013) and for dry season (June, 2013), the values ranged from 8.10 to 22.72 mg/L (Chebet *et al*., 2016).

pH

The pH value in water represents the amount of hydrogen ions present. This determines the acidity and alkalinity of the water. Water with a pH of more than 9 or less than 4.5 is unfit for domestic uses, such as drinking. (Bhateria & Abdullah, 2015). The pH value in water is temperature dependent and can be changed through various factors for example, low pH values increases the solubility of metals and nutrients such as phosphates and nitrates making them available for uptake by plants and animals (Mero, 2011; Gandaseca *et al*, 2011). Overall, a pH range of 6.5 to 9 is mostly suitable for aquatic life (WHO, 2011). Because high and low pH may be detrimental in nature, it is critical to keep pH ranges in aquatic ecology within this range.

Electrical conductivity

Electrical conductivity (EC) is measuring the ability of water to conduct an electrical current (Carr & Rickwood, 2008). The increase in land use practices in the catchment influences higher TDS. This is also contributing to increase EC. High EC indicates that the water is salty which is not acceptable for macroinvertebrates because some of them cannot tolerate such conditions (Carr & Rickwood, 2008). Inorganic dissolved particles such as nitrate, sulphate, and salt, as well as temperature, influence conductivity in water. Generally, most conductivity in fresh water range from 10 to 1000 μS/cm (WHO, 2011).

Nitrate-Nitrite

According to Bwalya (2015), nitrogen-containing elements (nitrates, nitrites) are essential for all biotic processes in the aquatic environment. The increase of nitrate concentration in watercourses is due to anthropogenic activities. When it rains, the runoff from agricultural activities carries fertilizers to the watercourses that cause pollution of water bodies. The increase of nitrate causes excessive algal growth. Upon decomposition excessive algal growth lowers oxygen levels thereby some aquatic organisms that cannot tolerate anaerobic conditions (Mwangi, 2014). Human activities and various land use patterns contribute to high nitrate levels in surface waterways (agricultural runoff, cattle grazing or their waste, washing activities and discharge from sewage) (Mwangi, 2014). Nitrate beyond their acceptable level affects organisms including human beings. Nitrate, on the other hand, is far less harmful than ammonia and nitrite (Romano & Zeng, 2007; Ward, 2009). Similarly, excessive ammonia and phosphorus in water results in an undesirable color, taste, and odor. (Hellar- Kihampa *et al.*, 2013).

Major ions

Major ions such as; K^+, Na^+, CL^- are essential for the plant's growth, in aquatic ecosystems. However, nutrients such as nitrogen and phosphorous exceeds the acceptable limit affects aquatic ecosystem by decreasing the oxygen after excess algal growth (eutrophication condition) (WHO, 2008; Bwalya, 2015). Domestic effluents particularly which contain detergents fertilizers, after being used for agricultural activities, are washed down to the water bodies bringing in high loads of phosphorus (Gasim, *et al.*, 2012; Hellar -Kihampa *et al*., 2013; Bwalya, 2015).

2.1.2 Water Quality Index

Water Quality Index (WQI) is a simple, effective, and helpful technique for determining whether or not water is suitable at a certain location and time (Lumb *et al*., 2011;

Chowdhury *et al*., 2012) as shown in (Table 1). WQI operates by assigning a single number to water quality criteria in order to assess the state of a region's water sources (Akoteyon *et al*., 2011; Bharti & Katyal, 2011; Balan, *et al*., 2012). WQI is calculated mathematically in different ways one of such method is the weighted arithmetic index method (WAWQIM) described by (Akudo, *et al*., 2010) and (in equation 9). The selected approach is basic, straightforward, and requires fewer factors for computation, making it popular among academics in underdeveloped nations with limited infrastructure used for data acquisition (Tyagi *et al*, 2013; Aktar & Moonajilin, 2017).

Table 2.1: Water Quality Index ranges, status, and possible usage (Hülya, 2009).

S/N	Water Quality Index	Water Quality Status	Possible Usage
1	0-25	Excellent	Drinking, irrigation, and industrial
2	26-50	Good	Drinking, irrigation, and industrial
3	51-75	Poor	Drinking, irrigation, and industrial
4	76-100	Very poor	Irrigation
5	Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use

2.2 Pollution on Rivers as a Result of Anthropogenic Activities

Most developments globally have been centered on freshwater habitats, because of their vital role in ecological, economic, social and cultural functions (Reddy, 2014). According to Béné *et al*. (2016), freshwater ecosystems are a vital resource for human survival, supplying clean water, food, livelihoods, and other ecosystem services worth more than $4 trillion yearly. Rivers are one of the most vital sources of freshwater for human life, which contribute water supplies, electricity generation, waste disposal, fishing, irrigation and aesthetic value (Pan *et al*., 2012; Huang *et al*., 2014). However, because to a growing pollution load from polluted runoff water originating from households, land-use changes, and industrial, these freshwater habitats are now endangered all over the world (Banetti & Garrido, 2010; Reddy, 2014). According to Pan *et al*. (2012) and Kibena *et al*. (2014), human activities, such as cattle husbandry, washing, logging, deforestation, and agriculture, all have a part in polluting river systems. As a result, there results untimely destruction of habitat, degradation in water quality, and decreased ecosystem services delivery.

River ecosystems are extremely sensitive to a variety of human activities (intensive agricultural activities, urban development and industrialization) that introduce point and non-point pollution (Javier *et al.*, 2017). The non-point sources of pollution originate from urbanization and agricultural activities that promote nutrient enrichment and pesticide contamination in the surface water (Nowak & Schneider, 2017). These human activities which produce pollutants putting pressures on aquatic ecosystems, by changes in flow patterns, sediment delivery, loss of biodiversity, a decline in the quality of water and habitats, affecting aquatic ecosystems as well as human health (Wang *et al*., 2012; Morrissey *et al.*, 2013). According to Ekpo *et al*. (2012), decline in water quality, changes in aquatic biota composition, eutrophication, and a decline or loss of ecological integrity are some of the negative repercussions of human influence on the aquatic environment. Therefore, adequate management of riverine ecosystems needs monitoring, assessing and evaluating the health of streams and rivers condition, by using surveys and other direct measures, to determine the anthropogenic impacts on ecosystem structure and function (Parsons *et al.*, 2016).

2.3 Effects of Deforestation on Water Quality

Rivers are the world's most abundant sources of water for both home and industrial use. However, human pressure, habitat fragmentation, removal of vegetation cover, and land cover conversion for agricultural purposes, particularly in riparian areas, have resulted in physical habitat degradation, increased sedimentation rates, and hydrological changes, all of which have resulted in reduced water quality (Ferreira *et al.*, 2012). In Sub-Saharan and East Africa, the loss of indigenous forests and their subsequent conversion to agricultural land usage is on the rise. Only approximately 28% of the original East African rain forests remain, with the majority of land clearance linked with subsistence farming and fuelwood harvesting. (Kasangaki *et al*., 2007). According to a research by the World Bank (2007), significant water catchment regions in Kenya have lost forest cover over time, with the closed canopy forest cover presently at a meager 2.0%. Overall, these activities are the major threats to the tropical forest with freshwater streams, surface water quality and highly degraded habitats in the world (FAO, 2010). The amount and quality of water resources in developing nations, especially Africa, are key concerns jeopardizing economic and social growth, particularly in dry and semi-arid regions (FAO, 2010). Countries experiencing scarcity of water resources, Kenya included (WRI, 2007), in order to maintain their capability to produce excellent quality water throughout the year, catchment areas must be properly managed.

As indicated (Plate 2.1) deforestation for production of farmland, for building, timber production and for other commercial purpose has led to soil erosion, sedimentation, nutrient enrichment into rivers resulting in eutrophication, increase in the levels of water temperature, electrical conductivity, total suspended solids (TSS), and total dissolved solids

(TDS) due to flow modification (Narany *et al*., 2017). Consequently, there is a reduction in sunlight penetration, decrease dissolved oxygen, affecting biological processes and degradation of ecosystems (Camara *et al*., 2019). Agricultural activities have been reported to cause the most non-point source pollution (Tashighi *et al*., 2017). This is due to fertilizer inputs that an increase in nitrate and phosphate leaching into the rivers (Sebilo *et al*., 2013). Similarly, Boggs *et al*. (2016) confirmed that forested watershed has lower nitrate concentrations than agricultural areas, after comparing the two land uses. Understanding the potential effects of changes in land use and land cover on water resources is thus essential for effective water resource management.

Plate 2. 1: Deforestation for charcoal burning, agriculture and wood fuel

(Source: Author, 2020)

2.4 Benthic Macroinvertebrates Assemblages

2.4.1 Benthic Macroinvertebrates Distribution, Abundance and Composition

As indicated by several studies, macroinvertebrates are used as water quality and biological sentinels of environmental atrophy as well as the health status of the river (Elias *et al*., 2014; Karaouzas *et al*., 2015; Chikodzi *et al*., 2017). The main reason is that they are normally found at the bottom of a stream and less mobile. Thus, makes them difficult to migrate away from environmental stress (Ghosh & Biswas, 2015). In addition, many recent studies suggested that macroinvertebrates have relatively short life cycles that enable quick reflection of environmental changes via community composition transitions in their responses to water column and sediment pollutants that aid in the provision of a record of environmental conditions (Pellan & Piscart, 2018). Likewise, their diversity and distribution also deems them good indicators for assessing the status of aquatic systems as reliable, suitable, and widely commended worldwide (Dalu & Froneman, 2016).

According to Ding *et al*. (2017), human disturbances affect taxonomic composition, richness and the functional structure of benthic macroinvertebrate assemblages. Similarly, Souto *et al*., (2011) and Kennedy *et al.*, (2015) also reported that macroinvertebrates greatly respond to environmental changes basing on their composition and relative abundance of species and groups. Reduction in species distribution and richness has generally be linked to land use change (Kasangaki *et al*., 2008; Allan *et al*., 2012; Masere *et al*., 2012; Minaya *et al*., 2013; Masese *et al*., 2014a, b). Chikodzi *et al*., (2017). Tan *et al*., (2017) also reported that the diversity of organisms from aquatic ecosystem were negatively affected by various natural stress and pollution   Thus, diversity indices are used to evaluate the responses of a biological community to environmental variation by integrating species richness, evenness and abundance (Li *et al.*, 2010; Friberg, *et al.*, 2011). On the other hand, Oligochaete worms are known to be able to withstand adverse circumstances such as low DO and high pollution concentrations (Karrouch *et al*., 2017). Freshwater scientists agree that benthic macroinvertebrates community structure effectively reflects the environmental condition as the difference between predicted and actual fauna assemblage informs on the levels of pollution in the system as well as necessary conservation measures that need to be effected (Birk *et al*., 2012; Efe *et al*., 2012). Therefore, this provided motivation to investigate the health status of freshwater ecosystem particularly the river system through benthic in fauna community.

2.4.2 Benthic Macroinvertebrates Diversity.

Currently, freshwater benthic macroinvertebrates taxa are severely threatened due to various human activities and habitat degradation (Reddy, 2014; Lindborg, 2015). Human activities lead to habitat degradation through changes water and habitat quality and land that increasingly impact biodiversity structure and ecosystem service provision in rivers (Kibena *et al*., 2014). According to Ding *et al*. (2017), different human disturbances affect taxonomic distribution, abundance, composition, richness, and the functional composition of macroinvertebrate assemblages. In other words, high diversity, richness, and abundance of macroinvertebrates is a characteristic in stable environmental settings. (Andrade *et al*., 2020; Hasan *et al.*, 2020). But this is not always true especially for the abundance case. Therefore, the diversity and distribution of macroinvertebrates are a good indicator for evaluating the overall status of aquatic environments as they are reliable, suitable, and widely commended worldwide (Dalu & Froneman, 2016).

2.4.3 Macroinvertebrates Functional Feeding Groups

Functional feeding groups (FFGs) are a classification approach, based on morphological mechanisms and behavioural characteristics of macroinvertebrates to acquire food rather than their taxonomic group and it is also used as a tool for evaluating environmental conditions and variables (Merritt & Cummins, 2006; Cummins, 2016). The presence of different composition of functional feeding groups (FFGs), of macroinvertebrate communities has essential implications for ecosystem functioning (Uwadiae, 2010). Currently, in most parts of the world, land use changes, particularly loss of riparian vegetation, and other human activities have resulted in a loss of diversity, composition and major shifts in the structural and functional organization of macroinvertebrates in rivers (Jinggut *et al*., 2012; Allan *et al*., 2015).

Macroinvertebrates functional feeding groups serve as useful surrogates for ecosystem attributes and they reflect the status of the environment. This approach uses the relative abundance of various functional group of invertebrates as indicators of ecosystem conditions. For example, the relative importance of autotrophy to heterotrophy used as the basis for the aquatic food chain in the rivers (Cummins *et al*., 2005; Merritt & Cummins, 2006; Ramírez & Gutiérrez-Fonseca, 2014). Generally, the functional composition of invertebrates in tropical streams/rivers is important to understand organic matter processing, energy flow, and trophic relationship and management activities needed to minimize the impairment of ecosystem functioning (Boyero *et al*., 2011; Ferreira *et al*., 2012). The River Continuum Concept, (RCC) and other literature (Brasil *et al*., 2014). It can be hypothesized that 1) There is a longitudinal zonation of macroinvertebrate functional feeding groups (FFG) along with the profile of a river due to the presence of the differential distribution of energy inputs and matter transfers, 2) Riparian conditions and availability of leaf litter play important roles in the distribution and abundance of macro invertebrates especially the shredders, and 3) The ratios of the various FFGs can be used as surrogates for ecosystem attributes to assess the ecological condition of the rivers.

Table 2.2: Functional feeding groups and their food source from (Merritt & Cummins, 2006; Merritt *et al.*, 2008 and Merritt *et al.*, 2014) CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter

Functional groups	Particle size feeding ways	Dominated food source	Particle size (mm)
Shredders	Chewing litter or vascular plant tissue	CPOM-decomposing From vascular plant	>1.0
Filtering	Suspension feeders (filter particles from the water)	FPOM-decomposing detrital particles like algae	0.01-1.0
Gathering	Deposit feeders (ingest sediment loose particles)	FPOM-decomposing detrital particles like faeces	0.05-1.0
Scrapers	Graz rock, wood, stems	Periphyton attached and non-filamentous algae	0.01-1.0
Predators	Capture and engulf prey (ingest body fluids)	Prey living organisms	>0.5

Table 2.3: Functional feeding group ratios serving as surrogates for stream ecosystem attributes (Merritt & Cummins, 2006; Merritt *et al.*, 2008) P = production, R = respiration CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter, P = predator/ prey

Ecosystem attributes	Represented by	Functional Feeding Groups for attributes	The suggested threshold from previous studies
Ratio of autotrophic to heterotrophic	P/R	The ratio of scrapers to (shredders+ total collectors)	Autotrophic system ≥ 0.75
Coarse particulate organic matter (CPOM) to fine particulate organic matter (FPOM) index	CPOM/FPOM	The ratio of shredders to total collectors	Expected linkage between riparian vegetation and shredders Fall-winter shredder populations > 0.50 Spring-summer shredder populations > 0.25
FPOM in transport (Suspended) to FPOM in storage	TFPOM/ BFPOM	Filtering collectors to Gathering collectors	Expected quantity and quality (i.e., sufficient to support

(Deposited in Benthos)			suspension feeders) of FPOM in transport > 0.25
Habitat (channel stability)	Stable habitat	The ratio of (scrapers +filterers) to (shredders+ gatherer)	Adequate stable substrates > 0.50
Top-down predator control to prey	P/P	The ratio of predator to prey (total all groups)	Expected predator-prey balance = 0.10 – 0.20

2.5 The Relationship between Water Quality and Benthic Macroinvertebrates.

The distribution pattern of biological diversity among taxonomic groups in rivers and streams variations are connected to differences in physical habitat characteristics, water quality (physico-chemical factors), frequency and magnitude of disturbances (Payakka & Prommi, 2014; McGarvey & Terra, 2015). Stressors in an aquatic ecosystem such as physicochemical or habitat degradation lead to diversity decreases, similarly when macroinvertebrates diversity decreasing, which has also a great potential to affect taxonomic composition (Gaskill, 2014). Pollution and sedimentation are considered as the major contributors to the decline of macroinvertebrates by changing the movement and quality of food and water as well as the interstitial spacing with the sediment regime (Akaahan *et al*., 2014). That is why Kithiia (2012), and UNEP (2012) stated that the ecological balance, normal functioning, and population dynamics of the aquatic environment along the river's passage are all affected by water quality degradation.

According to various investigators, macroinvertebrates have varying tolerance levels to fluctuations in environmental conditions due to human activities that may lead to changes in assemblages and biodiversity of the macroinvertebrates (Akaahan *et al*., 2014; Bere *et al*., 2014). Species are extremely sensitive to certain alterations, some species are moderately susceptible to pollution, with others having the ability to withstand a wide range of contamination, and therefore inform on their use as water quality indicators (Odume *et al*., 2012; Adu *et al*., 2016). Trichoptera and Coleoptera taxa are more sensitive to human disturbance or pollution than others and hence good indicators of degraded habitat and important for taxa biomonitoring in many types of freshwater habitats (Olomukoro & Dirisu, 2014; Houghton, 2015). Some groups such as Baetidae and Caenidae are tolerant to human disturbances (Lakew & Moog, 2015). The EPT Index can be used to detect water quality status by using aquatic insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The EPT Index is based on the assumption that high-quality rivers and streams contain the most species diversity (Akaahan *et al*., 2014; Masese & Raburu, 2017).

In general, a healthy aquatic environment is dependent on water's physicochemical and biological features, which give important information about the ecosystem's available resources for supporting life (Thirupathaiah *et al*., 2012). Macroinvertebrates are the most abundant and diverse species in stream and river ecosystems, and they are also the most vulnerable to poor water quality, as evidenced by their composition, variety, and quantity (Adeogun & Fafioye, 2011). Here it is important that today’s environment if not properly managed would lead to an unsustainability in environmental resources.

2.6 Habitat Quality Modification and their Relationships with Macroinvertebrates.

According to Bere *et al*. (2014), habitats can be defined as a certain area that helps to understand the function of the ecosystem within a known ecosystem. Whereas, habitat quality is described as the occurrence of riverine and riparian biodiversity features, including diversity, rarity and suitability for individual species or biological assemblages. Anthropogenic activities of habitat and water quality alteration have an impact on the composition, distribution, and diversity of benthic macroinvertebrates in a river system (McGarvey & Terra, 2015). Currently, in Africa forested streams are continuously being degraded for agricultural land use and other purposes and these also affecting stream channel, altering riparian habitat and stream flows by increasing inputs of pollutants (Ndaruga *et al*., 2004; Kasangaki *et al*., 2006; Kibichii *et al*., 2007; Kasangaki *et al*., 2008; Masere *et al*., 2012; Minaya *et al*., 2013; Masese *et al*., 2014a, b). These effects are reflected through a decline in habitat indexes, habitat quality, bank stability and disruption of aquatic-terrestrial linkage (Allan *et al*., 2012; Niculae *et al*., 2013). As a result, habitat availability, features, and appropriateness are regarded significant determinants in determining the physiology, development, local abundance, and structure of species assemblages, as described by Leahy (2016). Suitable environments, in other words, are thought to promote an individual's fitness by boosting food availability while lowering predation risk and metabolic expenditure (Gosselain *et al*., 2005).

A longitudinal physical habitat evaluation gives scientifically valuable information on the availability of biotopes for macroinvertebrates, as well as the quality, quantity, and variety of these habitats (Nichols, 2012). Variation in habitat features like as channel shape, riparian vegetation, and stream bed sediment composition can assist predict where certain management interventions would be most beneficial and may be used to track mitigation strategies once they are implemented in the ecosystem. (Miller *et al*., 2010). Therefore, assessing the current status and quality of water and habitat together with the benthic macroinvertebrate’s structure is very essential for the development of more prescriptive conservation and management strategies for freshwater ecosystems (Zajac *et al.*, 2013). The total habitat score management classes used to group river habitat can be categorized as either excellent, good, fair or poor (Table 2.4).

Table 2.4: Classes for assessment of river habitat (King *et al*., 2000)

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

The conceptual diagram which is modified from the concept of driver-pressure-state-impact-response (DPSIR) illustrated in (Figure 2.1). DPSIR is a flexible framework that can be used to assessing and analysing the effects of human demands on ecological water quality and aquatic biodiversity (Benini *et al*., 2010).

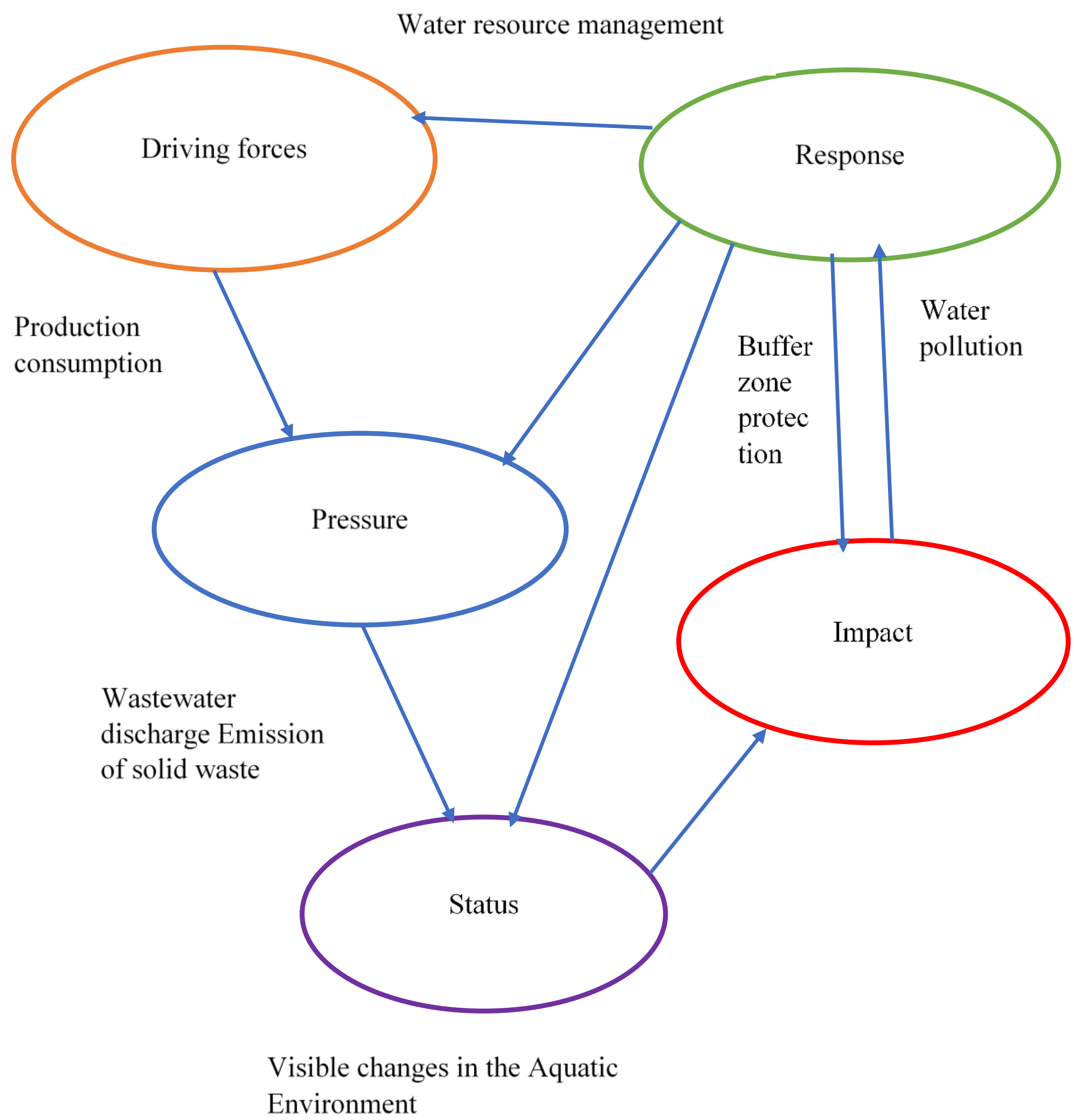


Figure 2.1: Conceptual frame work linking anthropogenic activities and River Kipsinende ecosystem

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

The study on impacts of water and habitat qualities on abundance and distribution of benthic macroinvertebrates was conducted in the Kipsinende River and its tributaries Yatiene and Kipkwen. The river starts from Elgeyo Marakwet County and flows through Kaptagat forest to Uasin Gishu County as shown in (Figure 3.1). The study area boosts of the Kaptagat and Cherangany which are two important forest ecosystems and water towers. Many rivers originate in these forest ecosystems, which constitute the primary water divide that runs along the steep slope. East of the water divide is Kerio (Rift Valley) catchment area which drains into Lake Turkana. While the Western part drains into Lake Victoria. Several rivers and streams flow to Lake Victoria Basin, among those is Kipsinende River which is flows through Kaptagat forest. The river is one of the tributaries to River Sosiani like Kipkaren River and empties on River Nzoia that feeds Lake Victoria. These rivers' catchments are being strained by a number of human activities (Aura *et al*., 2010).

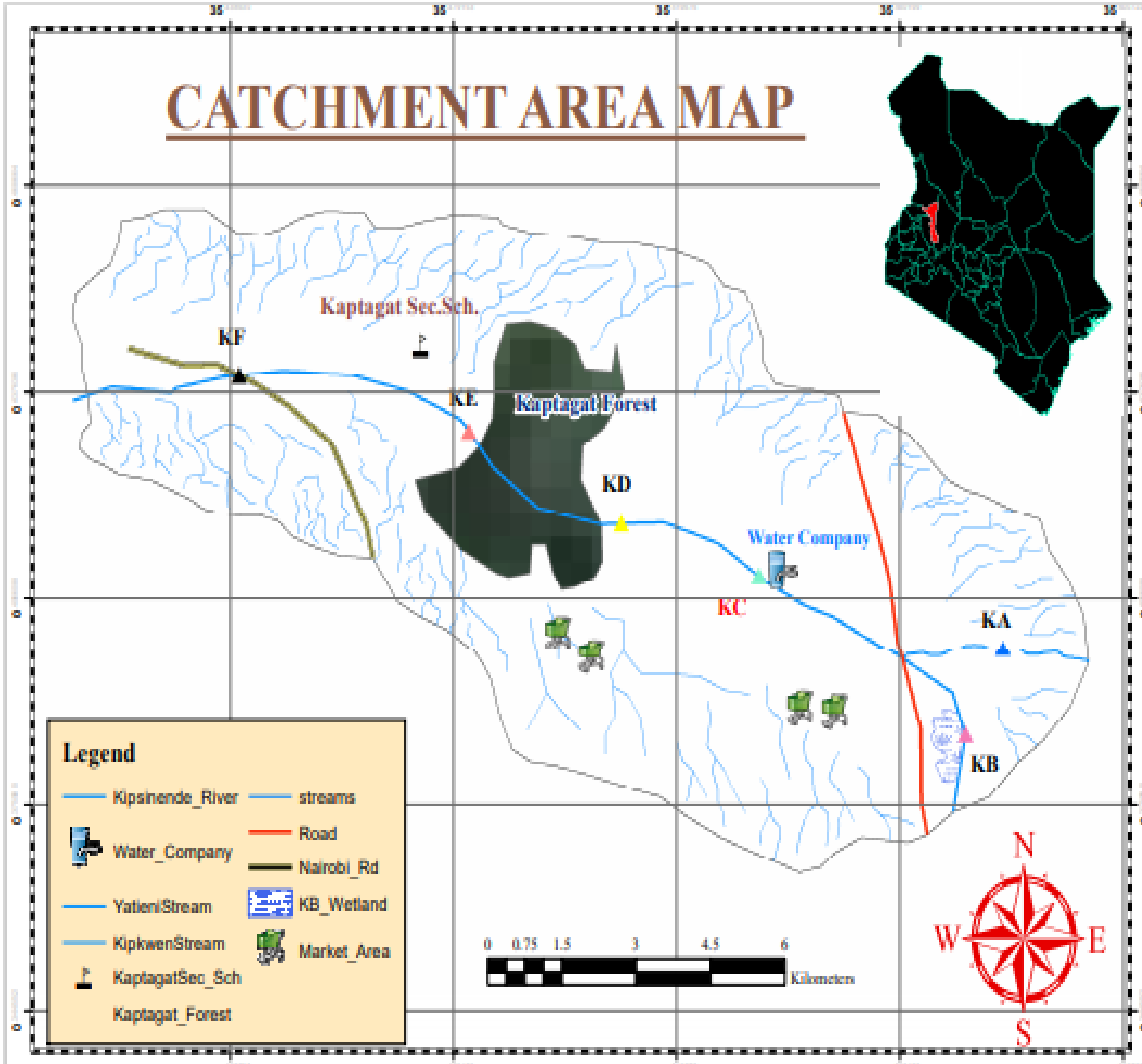


Figure 3.1: Map of the study area showing stations (KA, KB, KC, KD, KE and KF) Climate (Author, 2020)

The rainfall is varied from 1000 mm to 2000 mm with an average annual rainfall of 1112 mm (Kiptum *et al.*, 2013). The rainfall is bimodal because it has two peak months of April and August. The average annual temperature is 18 °C. A dry season exists between December and February (Kiptum *et al.*, 2013).

Soils and geology

The rock formations of the study area are tertiary volcanic or extrusive igneous rocks formed one to ten million years ago (Kiptum *et al*., 2013). The rocks of such highlands are overlain by nitisols. Nitisols are deep well-drained, red loam soils, have more than 35% clay content and a pH of less than 5.5 due to leaching of soluble bases (Lomurut, 2014). The main minerals in the clay part of the nitisols are dominated by Kaolinite and its hydrated phase Meta-Halloysite. Kaolinite chemical composition contains Silicon, Aluminium, Oxygen and Hydrogen elements. Nitisols are used for agricultural purposes and are intensely used for potato, maize and vegetable production (ROK, 1985).

Vegetation

Natural and plantation forest types are found in River Kipsinende. The community use these forests for timber, honey, firewood, building materials, herbal medicine and source of grass. Vegetation found in the study area include both indigenous and alien species. The common Indigenous trees and riparian vegetation include: *Podocarpus milanjianus* (Rendle), *Juniperus procera* (Hochst), *Vitex kiniensis* (Turill), *Acacia xanthophlea* (Benth) and *Olea Africana* (Mill.). Alien vegetation consisted of *Acacia saligna* (Port Jackson willow), *Eucalyptus, Sesbania punicea* and *Populus canescensus* (white poplar). On the other hand, in the wetland system and river bank composed of low grasses and sedges such as *Pennisetum clandestinum, bulrushes* (Typha capensis), *Cyperus brevis* and *Nymphaea spp* (CIDP, 2018).

Land use activities

Agricultural activities, deforestation, illegal logging, overgrazing, and charcoal burning are the main anthropogenic activities that cause soil erosion, landslides, mudslides, and rockfall in the study area. The sub-catchment population mainly rely on firewood, charcoal and paraffin as their main sources of household cooking energy (CIDP, 2018). As a result, vegetation degradation (deforestation) occurs, resulting in an increase in related health complications among the population. Overgrazing has resulted in the loss of natural flora, which has aided soil erosion, particularly during the rainy season, and, as a result, has harmed the river ecosystem (Abdi *et al.*, 2013). Agriculture is the county's economic backbone, with more than 80% of the people involved in farming or associated activities (CIDP, 2018). Maize, beans, wheat, bananas, green grams, groundnuts, sorghum, and millet are among the most important food crops in the region. In addition, irish potatoes, avocado, passion fruit, mangoes, tea, and coffee are among the horticultural and industrial crops that are predominantly farmed for sale (personal filed observation). This agricultural intensification has resulted in the use of fertilizers and manure to maintain productivity. The inorganic fertilizers that are carried by runoff and reaching the rivers result in non-point pollution of the rivers. As a result, a river had reduced flows and destructed water catchment areas especially during the dry season (Cooper *et al*., 2013). As a result, the decrease in water flow has affected horticulture growers who rely on large amounts of water from these water sources to irrigate their farm produce.

3.1.1 Sampling Design

Sampling was done for a period of three months starting from 13th November 2019 to March 11th 2020. Sampling was done within wet season due to unpredictable climate change during the study period. The six sampling stations were sampled within two days in each month, which meant that three sampling points were sampled in a day. Before field sampling started, a reconnaissance survey was carried out to obtain the representative sampling station. Sampling stations along the river were selected basing on purpose and accessibility, physical proximity, habitat diversity and riparian land uses for the collection of water samples and macroinvertebrates. Each sampling station was marked using a Geographical Positioning System (GPS) to be sure that samples were collected from the same place at each sampling time and divided into four biotopes namely; riffle, pool, run and marginal vegetation to obtain representative data. The sampling of physico-chemical parameters was carried out with triplicates from various biotopes (riffle, run and pool). Whereas, macroinvertebrates were collected from riffle, run, pool and marginal vegetation biotopes in each station which was a total of 6 x 4 x 3 = 72 samples, as well as habitat quality characteristics, were also evaluated monthly through visualization. A 100 m long stretch upstream of the river at each station was used as a unit for sampling macroinvertebrates and habitat assessments. In general, the sampling design and procedure of data collection shown in (Figure 3.2).

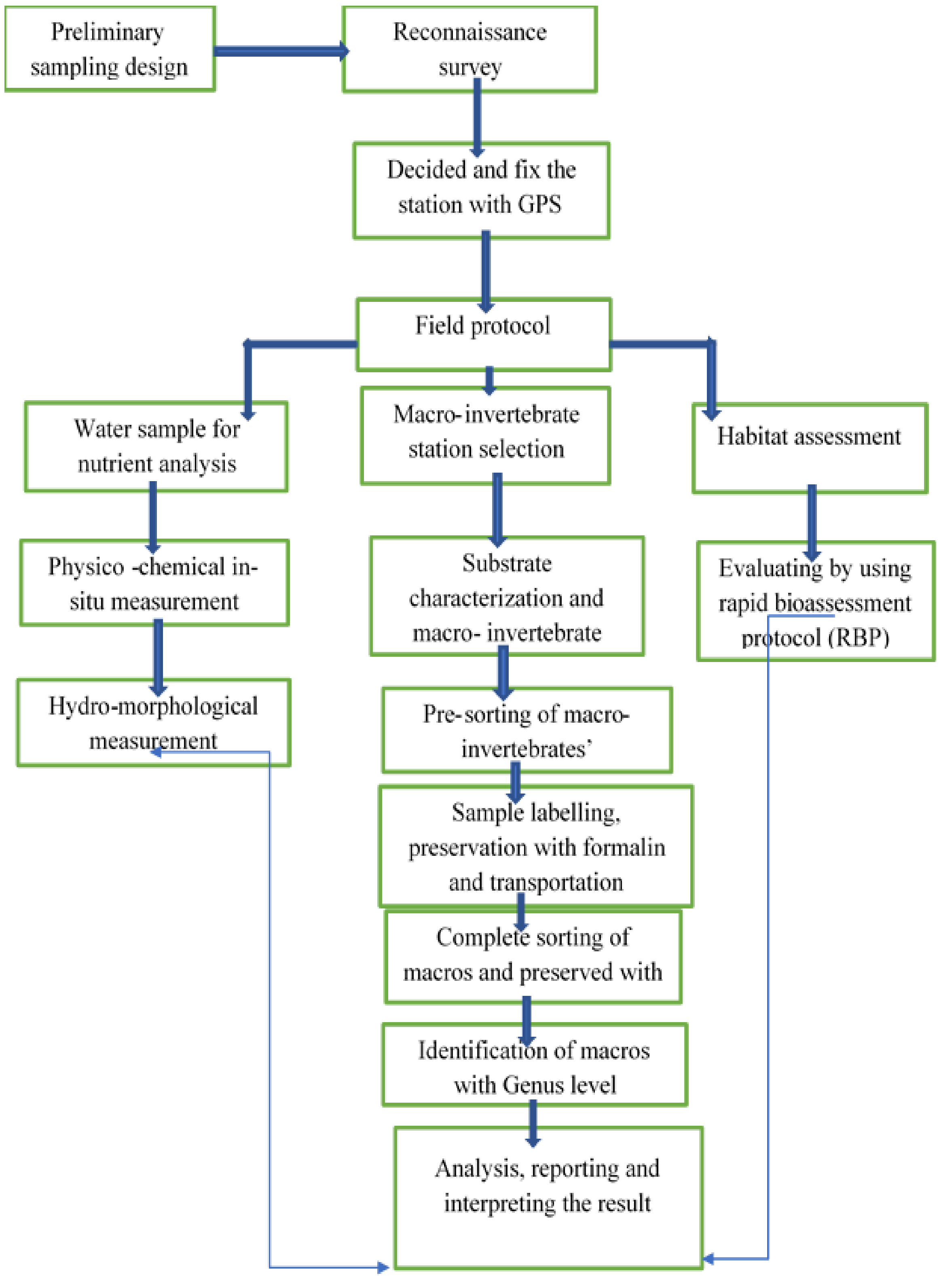


Figure 3.2: Sampling design and procedure modified from (Veronica, 2010)

3.1.2 Sample Station Selection

The sampling stations in the study area were selected on the basis of differing habitat conditions, land uses and human activity. River Kipsinende is a source of water supply for institutions, homes, urban centers, animal watering and washing activities. To obtain a representative data the river was divided into three streams orders (longitudinal sections) based on gradient, geomorphology and the level of branching system namely upper, middle and down streams. The upper stream consisted of the two tributaries called Kipkwen and Yatiene. Similarly, the middle stream was located where after the two streams meet, each other below Kapkenda Bridge before the river enter to the Kaptagat forest. Downstream sites were located where the river exited the forest at Kaptagat Girls and Kaptagat Bridge on the main road. To determine land-use effects on Kipsinende River a total of six sampling stations; two stations from upstream included station one and station two which was assigned as KA and KB, respectively. In the same way, two stations from the middle stream consisted of station three and station four, represented with KC and KD, respectively. While, two stations from downstream which were station five and six assigned by KE and KF, respectively have been selected as indicated in (Figure 3.1).

Station 1

Station one was located at the Yatiene stream which was at latitudes N 00°23.005´ and longitudes of E 035°34.144´. The land use in this station was mostly agricultural activities. Due to this reason the bank stability and the riparian vegetation zone were poor especially the left side of the stream (Plate 3.1). The streambed of the riffles was made of bedrock while the substrate in the runs was composed mostly of cobbles, stones and gravel, but the substrates in the pools were composed of sand, silt and detrital material. Human activities around this station were mainly cutting down of trees for charcoal burning and agricultural activities like crop farming, horticultural activities and cattle rearing.

Plate 3.1: Agricultural activities and the status of bank stability in station KA (Source: Author, 2020)

Station 2

Station two was located at Kipkwen tributary or stream at latitudes N 00°22.117´ and longitudes of E 035°33.574´. The land use in this station mainly included agricultural activities and grazing of cattle. The agricultural activities were found around 30 meters from the station. This station was surrounded by a swamp which was used for grazing, drinking of cattle and for washing activities (Plate 3.2). The substrate of the riffle consisted most of boulders. The runs had a mixed substrate of sand and stones. Likewise, the pools were dominated with sand, silt, mud and detritus. Human activities were: crop farming, cattle rearing, car washing and cloth washing around the bank of the stream.

Plate 3.2: Human activities around the bank of the stream in station KB

(Source: Author, 2020)

Station 3

Station three was the point where the two tributaries meet each other at the Kapkenda Bridge. The sampling station was located approximately 200 meters downstream of the bridge at latitudes N 00°23.184´ and longitudes of E 035°33.023´. In this station the riffle had bedrocks and the run consisted of stones and cobble whereas, pools were composed of sand, clay and silt substrate. The anthropogenic activities around this station were connected to agricultural activities included crop production and horticulture such as maize and potato respectively. Grazing of cattle and water pumping was also observed through the water company office (Plate 3.3).

Plate 3.3: Indicating the river channel and bank stability after the two streams mix each other in station KC (Source: Author, 2020)

Station 4

Station four was located where the river entered to the Kaptagat forest at latitudes N 00°23.598´ and longitudes of E 035°32.416´. The substrate composition in the riffle 80% composed of bedrock and the run consisted of stones and gravel. While pools had clay, sand, silt and to some extent there was also detrital material. In this station the land use mostly consisted around 60 % is forest, 25 % used for grazing of cattle and 15% used for agricultural activities (via visual estimation) (Plate 3.4).

Plate 3.4: Shows the river channel and riparian vegetation in station KD

(Source: Author, 2020)

Station 5

Station five was a point at which the river exited the forest near Kaptagat girls which was located at latitudes N 0025°.589´ and longitudes of E 035°27.865´. Riffles are composed of bedrock and run made from boulders and stones. Whereas pools dominated with detrital material and some silts. This station was in forested area with no human disturbance. Due to this, the bank stability and riparian vegetation were well protected. Thus, it was considered as a reference site (Plate 3.5).

Plate 3.5: Canopy cover of Kaptagat forest and riparian vegetation in station KE (Source: Author, 2020)

Station 6

Station six was at the Kaptagat Bridge on the main road which was located at latitudes N 0025 ° .606´ and longitudes of E 035 ° 28.659´while sampling was done few meters above the bridge. In this station, rifles consisted of bedrocks and boulders. Substrate was composed of stones and clay soil. While, the pools had sand, silt and detritus. There were some farming activities, rearing of cattle, washing of clothes and cars (Plate 3.6).

Plate 3.6: Riparian vegetation status and some disturbances (cattle drinking) in station KF (Source: Author, 2020)

3.2 Sample Collection

3.2.1 Field Sampling

3.2.1.1 Physico-Chemical Parameters and Morphological variable's

Physico-chemical parameters such as water ambient temperature, DO, pH, TDS, conductivity and salinity were measured in-situ using YSI 556 MPS portable multi-probe (Plate 3.7). The parameters were selected for study due to their commonness and being easy for water quality assessment in the field under various conditions. The hydro-morphological variables such as velocity, width and depth of the river were measured by using a flow meter and tape measure respectively. The depth was measured along the width of the river at a minimum of five points and the width also was measured three times in each sampling station. On the other hand, the discharge of the river was estimated with velocity - area method (Gordon *et al*., 1993) calculated as:

$$Q = A * V \tag{1}$$

Where Q = stream discharge, in m^3s^{-1}

A = cross sectional area, in m^2

V = average velocity, in ms^{-1}

Cross sectional area (A) can be estimated = wetted width*average depth

Plate 3.7: In-situ measurement of physicochemical parameters (a) Measuring velocity (b) (Source: Author, 2020)

3.2.1.2 Nutrients

The nutrients nitrate, soluble reactive phosphorus, ammonia, and nitrite were chosen for this study because of their popularity in aquatic ecology. For nutrients analysis surface water was collected at 20 - 30 cm depth of the river and stored in two clean plastic bottles (0.5 litre) in each bottle or totally l litter. Water quality samples were collected before kicking for macroinvertebrates and started from downstream to upstream to avoid contamination. The plastic bottles were thoroughly cleaned and rinsed with deionized (distilled) water, and samples were preserved in the field with four drops of 10% concentrated sulphuric acid. After labelling, these samples were kept in a cooling box for transportation and stored at 4°C in refrigerator until analysis was done.

3.2.1.3 Benthic Macro invertebrates

The benthic macroinvertebrates sampling was taken by using a kick net (1 m^2, 0.5 mm mesh size) against water current and dragged along the riverbank up to a distance of 1m from all sampling stations (Dickens & Graham, 2002). Quantitative triplicate samples were collected from runs, riffles, pools and marginal vegetation from each station. Similarly, the substrate types and their percentage were estimated in situ at the same station based on % sand (2 mm), % gravel (2-25 mm), % coarse subtraction (25-250 mm), % rocks (>250 mm) at the same time as macroinvertebrates sampling (Dedieu *et al*., 2015). Every large boulder or cobble in the area was picked up if it could be lifted and organisms were immediately washed by hand into the net. Finally, the substrate with smaller boulders was sampled for a standard three minutes by disturbing a 1 m^2 area for each microhabitat which included: riffle, run, pool and marginal vegetation. As illustrated in (Plate 3.8) visible organisms were removed with forceps from the substrate and put into the specimen bottles and were preserved with 4% formalin in the field until laboratory analysis and counting had been done. The specimen bottles were well labeled two times inside and outside the container for better and reliable information. The labeled included the sampling code, date, time and other important information.

Plate 3.8: Sampling (a) and sorting (b) of macroinvertebrates (Source: Author, 2020)

3.2.1.4 Habitat Quality Determination.

Cover, channel morphology, alterations, riparian quality, bank stability, diverse substrates, and erosion were assessed for the habitat characteristics. In general, those physical habitat structures, such as hydrological, geomorphological, riparian vegetation, and anthropogenic impacts were evaluated using a multi-habitat approach. This approach is called rapid bioassessment protocols (RBP) in stream and rivers (Barbour *et al.* 1999). Therefore, habitat quality data were collected at each site using the RBP habitat assessment technique, and quick habitat scores assigned based on visual assessment of 10 environmental factors, with values ranging from 0 to 20 for each parameter (Appendix v). As shown in the table, the final score of habitat parameters was used to evaluate the river reach as exceptional, good, fair, or poor management (Table 2.4). While, the substrate type was grouped based on their dimensions, using a modified version of the Wentworth scale (Jones, 2011).

3.2.2 Laboratory work and Analyses.

3.2.2.1 Nutrients

In the laboratory, water samples were filtered via 0.45 µm GF/F (Glass Fiber Filters) papers for determining the concentration of nitrates, nitrites, ammonia, and soluble reactive phosphorus by using standard spectrophotometric methods described in APHA (1998). Altogether, for each inorganic nutrient, the reading was taken at least 2 times at each sampling site to cross check each reading. Nitrates and nitrites were determined using the cadmium reduction method followed by diazotization with sulphanilamide and coupling with N-(1-naphthyl)-ethylenediamine to form a highly coloured azo dye (Plate 3.9). Sulphanilamide was used as amino acid compounds and served as a reagent to accelerate the dissolution. The sulphanilamide reagent was prepared by dissolving 2 g of sulphanilamide in a mixture of 20 ml concentrated hydrochloric acid and 60 ml of distilled water. N-(1-naphthyl)-ethylenediamine dihydrochloride solution (NEDD) also was prepared by dissolving 0.1 g of amine in 100 ml of distilled water. At the end, 0.1 sulphanilamide solution was added to 25 ml water and well mixed each other. After 5 minutes, in the same way, 0.1 ml of (NEDD) solution added. After waiting around two hours the absorbance of solution was measured by ultraviolet spectrophotometer at 543 nm wavelength. The standard solution was prepared for each nutrient by applying the standard procedures. Based on the standard concentration and absorbances of each nutrient linear graph was plotted (Appendix ii**)**. Therefore, the concentration of nitrite and nitrate was calculated based on the graph value or equation. Thus, the equation of the graph and calculation is as follows,

$$Y= 0.0581X+4E\text{-}05 \text{ then, } X = (Y-0.000000)/ (0.0582) \qquad (2)$$

Where, Y = the absorbance of nitrite and nitrate (water samples and its reagent) which read through a spectrophotometer, X = the concentration of nitrite and nitrate which is calculated.

Ammonia was analysed using a phenate method which forms a blue indophenol colour. The phenol solution was mixed from 100 ml of 95 % ethyl alcohol and 5 g of crystal phenol. Then added these solutions and other oxidizing agents like hypochlorite to 25 ml of water and measured at a wavelength of 640 nm (Plate 3.9). Whereas soluble reactive phosphorus was analysed by thiomolybdate ascorbic acid method which results in a formation of intense blue colour developed measured at a wavelength of 885 nm. Similarly, the concentration of ammonia (NH_3) was estimated as,

$$Y = 0.0081X+0.001 \quad \text{therefore, } X = (Y-0.001)/0.0081) \qquad (3)$$

The representation of y and x is the absorbance and concentration of ammonia respectively.

In the same way, the concentration of soluble reactive phosphorus calculated

$$Y = 0.1015X+0.0048 \text{ thus, } X = (Y-0.0048)/0.1015) \qquad (4)$$

Total suspended solid (TSS) was estimated on Whatman GFC filters paper with 0.45 µm size. The water sample (a volume of 200 ml) was filtered for nutrients analysis in the laboratory. The filtration process was done with the aid of a filter pump. Those filter papers were carefully folded and wrapped in an aluminium foil for drying in the oven at 500 $^{\circ}$C for four hours up to loss of all the moisture or to constant weight. The filter papers were further dried in an oven for 72 hours at 60 °C to estimate residue. Finally, weighing was done with the help of an electronic balance. TSS was calculated as

$$TSS = (W_f \text{ mg/l.} - W_i \text{ mg/l}) * 10^3 / V \quad (5)$$

W_i = Weight of pre-combusted filter in grams or initial weight

W_f = Weight of filter + residue in grams or final weight

V = Volume of water sample in this case = 200 ml

Analyses of blanks and replicate samples according to laboratory analytical process ensured data quality. This was done in the laboratory of fisheries and aquatic Science and biotechnology laboratory at University of Eldoret.

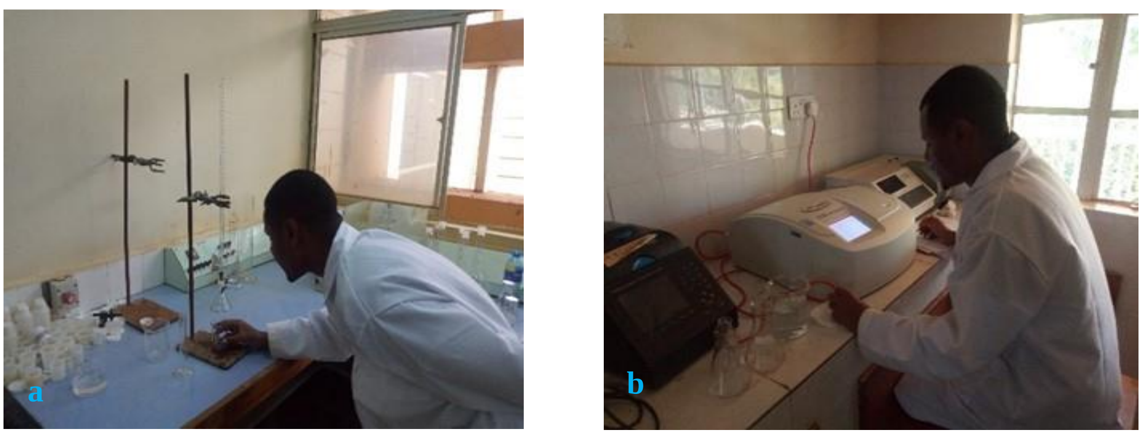


Plate 3.9: Running water samples via Cadmium column for nitrate (a) and reading the absorbance of nutrients with spectrophotometers (b) (Source: Author, 2020)

3.2.2.2 Benthic Macroinvertebrates

In the laboratory, samples were washed through a 300 µm mesh size sieve, using tap water and were sorted in a white plastic tray and then poured into vials. After sorting and identification, the organisms were preserved with 70% alcohol (ethanol) and benthic macroinvertebrates organisms in the sample were enumerated. Macroinvertebrates were counted for relative abundance determinations, diversity, composition, for calculating various ecosystem attributes and percentage of functional feeding group along the river. The identification was done at the genus level using a dissecting microscope and standard keys (Merritt *et al*., 2008) in the laboratory of Fisheries and Aquatic Sciences department, University of Eldoret as illustrated in (Plate 3.10).

a

b

c

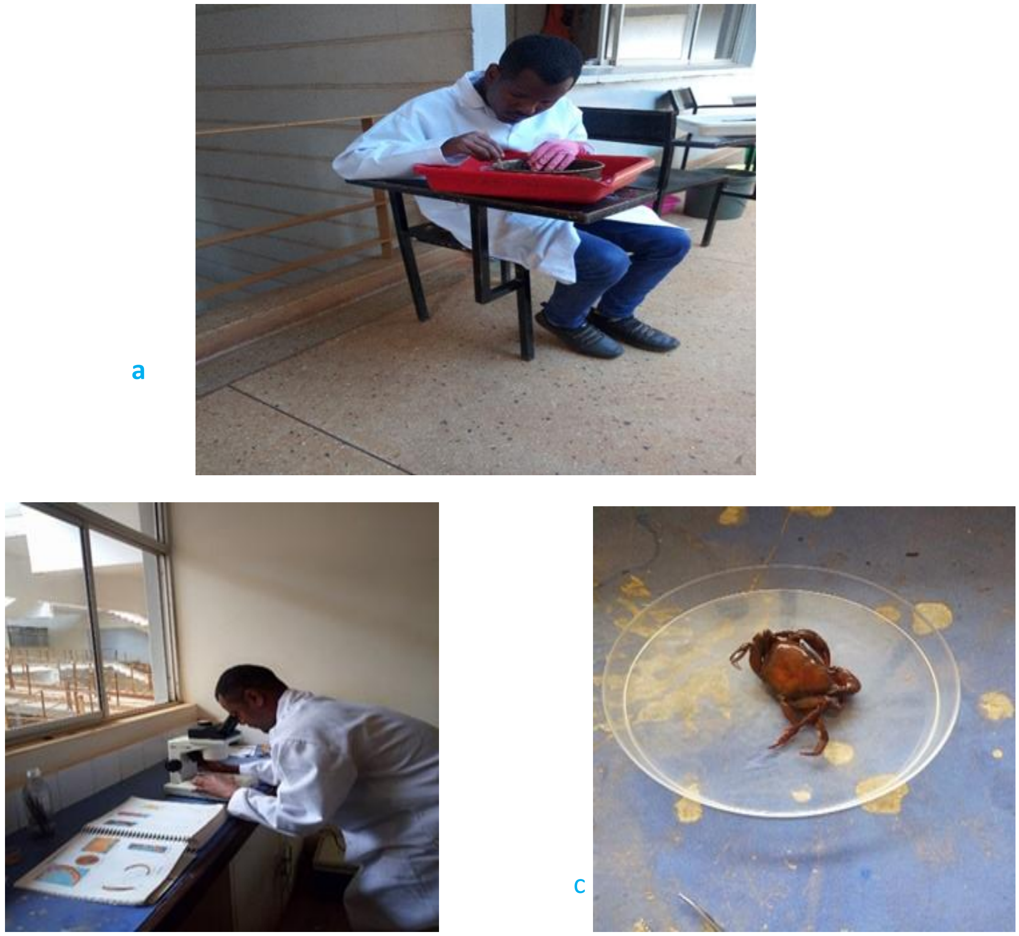


Plate 3.10: Sorting (a), identification (b) and genera identified (c) (Source: Author, 2020)

3.3 Data Analyses

3.3.1 Physical-chemical Parameters, Morphological Variables and Nutrients.

Data for physical-chemical parameters, morphological variables and nutrients were analysed using descriptive statistics and presented as mean, and standard error (mean±SE). Pearson correlation coefficient was carried out to determine the relationship between each parameter and nutrients in the river. One-way analysis of variance (ANOVA) was used to evaluate the differences in the means of physico-chemical parameters and nutrients in each station. Post hoc Turkey's honest significance differences (HSD) tests were performed to show pairwise differences when significant differences among sampling sites were observed. As well, for each sampling station, the data were presented in tables and bar graphs. During analysis, a 95% level of significance was used as a critical point for all analysis.

3.3.2 Water Quality Index (WQI)

In using the weighted arithmetic index method (WAWQIM), seven water quality parameters were selected: dissolved oxygen (DO), electrical conductivity (EC), pH (power of hydrogen), ammonia, nitrite, nitrate, and soluble reactive phosphorus. These metrics have shown utility as indicators of major ecological water quality issues such as oxygen depletion, nutrient pollution, acidification, and salinization, as well as being widely utilized in the literature on water quality measurement (Said *et al*., 2004; Parparov *et al*., 2006).

Relative (unit) weight (W_i) was calculated by a value inversely proportional to the recommended value by WHO guideline (S_i) for each parameter using the following equation

$$W_i = \frac{K}{S_i} \qquad (6)$$

K is proportionality constant calculated using equation 7.

$$K = \frac{1}{\sum \frac{1}{S_i}} \qquad (7)$$

The quality rating scale (Q_i) for each parameter was calculated by using equation 8

$$Q_i = \left(\frac{V_{measured} - V_{ideal}}{V_{standard} - V_{ideal}}\right) \times 100 \qquad (8)$$

Where Q_i is the quality rating of the i^{th} parameter for a total of n water quality parameters, $V_{measured}$ is the observed value of the water quality parameter obtained from laboratory analysis, $V_{standard}$ is the water quality parameter obtained from the WHO guideline. V_{ideal} for pH = 7, for DO V_{ideal} = 14.6 mg/L and for other parameters V_{ideal} is zero.

WQI was calculated by aggregating the quality rating with the unit weight linearly by using equation 9 to get different water status as shown in (Table 2.1).

$$WQI = KW_iQ_i \qquad (9)$$

Where WQI is the water quality index K is the proportionality factor, Wi = Relative weight Qi = Quality rating.

3.3.3 The Benthic Macroinvertebrate Assemblages

The benthic macroinvertebrate diversity, richness, composition, abundance and functional feeding groups were determined from each sampling station and sampling occasion;

- The relative abundance was calculated as: R.A = $\frac{No.of\ individuals\ of\ one\ taxon * 100}{Total\ No.of\ individuals\ in\ a\ station}$ (10)
- The Shannon-Weaver diversity index (Shannon & Weaver, 1949) was calculated as follows:

$$H' = -\sum PiIn(Pi) \qquad (11)$$

where,

H' = the Shannon-Weaver Diversity Index

Pi = the relative abundance of each group of organisms

ln = natural logarithm

- The genera richness was estimated by Margalef richness index (Margalef, 1958).

$$\text{Margalef richness index (d)} = \frac{(S-1)}{\ln N} \quad (12)$$

where N is the number of individuals and S is the number of taxa. A higher Margalef index value indicates greater richness, while a lower one indicates less richness.

Measuring diversity via Simpson's diversity index (Simpson, 1949)

- Simpsons diversity index (D) = $\frac{\mathbf{1-\sum_{i=1}^{S} ni(ni-1)}}{\mathbf{N(N-1)}}$ (13)

where n denotes the number of individuals per species and N is the total number of individuals across all species.

- The taxa richness was determined
  - Total No. of taxa
  - No. of EPT taxa
  - The No. of Ephemeroptera
  - The No. of Plecoptera
  - The No. of Trichoptera
- The composition of the order was estimated
  - %EPT= $\frac{(E+P+T)*100}{N}$ (14)

Whereas,

E = The number of Ephemeroptera

P =The number of Plecoptera

T= The number of Trichoptera and

N=Total number of individuals in a station

- % Diptera

- % EPT: % Diptera
- % Odonata, %Hemiptera and % Oligochaeta

- Functional Feeding groups and ecosystem attributes

The benthic macroinvertebrates were allocated into five functional feeding groups (shredders, scrapers, collector-gatherers, collector-filterers, predators) based on Dobson *et al*., (2002); Merritt & Cummins (2006); Merritt *et al*. (2008); Masese *et al*., (2014) and Merritt *et al*. (2014) (Table 2.2). The relative contribution of each functional feeding group to the microbenthic community was calculated on the basis of numerical abundance. Ecosystem attributes for assessing the ecological health of the river the autotrophy and heterotrophy (production/respiration index was calculated by the ratio of scrapers to (shredders plus total collectors) (Table 2.3). While, the linkage between riparian inputs and streams food webs in other words coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM) was calculated as the ratio of shredders to the total collectors. Top-down predator control was calculated as the ratio of predators to prey (total of all groups) and the channel stable index was also calculated as the ratio of scrapers plus filterers to shredders plus gatherers. Similarly, the quantity and quality FPOM in transport organic portion of suspended load that can serve as a food source for suspension feeders.

3.3.4 The Relationship between Water Quality and Benthic Macroinvertebrates.

Canonical correspondence analysis (CCA) was used to evaluate the relationship between benthic macroinvertebrate assemblages and measured physico-chemical parameters as well, nutrients in study stations in order to determine which parameter contributes to the spatial distribution of macroinvertebrate taxa. Before (CCA) analysis done macroinvertebrate counted data were transformed using log10 (x+1) to check the statistical normality and principal component analysis (PCA) was also applied to minimize rare abundances (to illustrated obvious graph).

3.3.5 The Habitat Quality Determination and their Relation with Benthic Macroinvertebrates

For each site, habitat quality parameters were recorded by using the rapid bioassessment protocol (RBP) approach (Hannaford & Resh, 1995; Fitzpatrick & Emrick, 2019). The rapid habitat scores were carried out based on visual assessment of 10 habitat parameters, with scores ranging from 0 for a poor condition to 20 for an optimal condition for each parameter (Appendix v). The final score of habitat parameters was used to classify the habitat as excellent, good, fair or poor management classes as indicated in (Table 2.4). A Kruskal-Wallis test was used to compare the mean rank of habitat scores among sampling sites.

Canonical correspondence analysis (CCA) was used to determine the relationships between habitat quality parameters and macroinvertebrates. All of the analysis was done using Ms-Excel, Minitab for Windows (Version 17) and PAST (Version 3.21) software.

CHAPTER FOUR

RESULTS

4.1 Water Quality in River Kipsinende

4.1.1 Physico-chemical Parameters and Nutrients

The mean values of physico-chemical parameters are presented in (Table 4.1). The mean surface water temperature varied from 16.54 ± 0.21 to 19.17 ± 0.43°C. The highest value was observed in site KD (before water enters into the forest) and the lowest was in site KE. The temperature increased progressively from upstream to the middle of the river but decreased after entering the forest and there were statistically significant differences between sampling stations (ANOVA, $P < 0.05$).

The dissolved oxygen (DO) varied significantly among sites (ANOVA, $P < 0.05$) and the values were between 5.81 ± 0.4 to 8.78 ± 0.75 mg/L. The maximum value was observed in station KE. Whereas, the minimum was in station three (KC) below the Kapkenda Bridge.

The pH values did not differ significantly among sites (ANOVA, $P > 0.05$) and the values varied from 7.02 ± 0.03 to 7.37 ± 0.18. The highest value was found in station KF (downstream of the river). While, the lowest was obtained at station KC.

The electrical conductivity values varied from 28.89 ± 3.1 to 45±2.82 (µS/cm). The highest value was recorded in station KF. However, the lowest was observed at station KA. It differed significantly between sampling points ($P < 0.05$).

The mean value of TSS (total suspended solids) varied from 0.04 ± 0.01 to 0.08 ± 0.01 mg/L. The highest value was found at station KB and KF. But the lowest was at station KC.

Statistically there were no significant differences among sampling stations (ANOVA, $P > 0.05$).

Likewise, total dissolved solids (TDS) during this study period ranged from 21.27 ± 0.65 to 23.41 ±1.22 mg/L. Station KF, which is located downstream of the river, had the highest value, whereas, KA had the lowest value. However, no significant differences were found between the stations (ANOVA, $P > 0.05$).Salinity readings ranged from 0.11 ± 0.003 and 0.14 ± 0.005 mg/L with the maximum value observed in station KD. While, the lowest was in station KA and KE.

The ammonia concentration observed in the water was between a maximum (1.05 ± 0.40 mg/L) in station (KF) located at downstream of the river and the minimum (0.39 ± 0.13) in station KC. There were no significant differences between stations (ANOVA, $P > 0.05$). The concentration of nitrate varied from 1.87 ± 0.15 to 2.40 ± 0.14 mg/L. The highest value was observed in sampling point two (KB) in the upstream part of the river. Whereas, the lowest was in station KE where the river exit to the forest.

The highest nitrite level was found at station KF, downstream of the river and the lowest in station KB. While, significant differences were not found between sampling stations (ANOVA, $P > 0.05$). The concentration of soluble reactive phosphorus (SRP) was found in the range of 0.19 ± 0.04 to 0.74 ± 0.28 mg/L. The maximum value was observed in site KB (mixed land use) and minimum in station KE (forested land use).

Table 4.1: Means of water quality parameters for different stations (DO = dissolved oxygen, pH = power of hydrogen, TSS = total suspended solid, TDS = total dissolved solid)

	Agricultural		Mixed		Forested			
Parameters	**KA**	**KB**	**KC**	**KD**	**KF**	**KE**	**F. Value**	**P. Value**
Temperature(°C)	16.87±0.23[bc]	17.06±0.29[b]	18.52±0.55[a]	19.17±0.43[a]	17.14±0.21[c]	16.54±0.21[b]	16.34	0.000
DO (mg/L)	7.35±0.89[ab]	6.71±0.62[ab]	5.81±0.4[b]	6.35±0.38[ab]	8.57±0.82[ab]	8.78±0.75[a]	3.23	0.014
pH	7.03±0.05	7.21±0.08	7.02±0.03	7.25±0.13	7.37±0.18	7.36±0.15	1.71	0.150
Conductivity (µS/cm)	28.89±3.1[b]	31.78±3.03[b]	32.22±1.8[b]	33.56±3.43[ab]	45±2.82[a]	39.4±2.19[ab]	4.26	0.003
TSS (mg/L)	0.06± 0.01	0.08± 0.01	0.04± 0.01	0.06± 0.01	0.08± 0.01	0.05± 0.01	2.49	0.053
TDS (mg/L)	21.27±0.65	22.47±1.4	22.78±1.54	22.91±1.04	23.41±1.22	23.04±0.99	1.11	0.367
Nutrients								
Salinity(mg/L)	0.11±0.003	0.12±0.01	0.13±0.01	0.14±0.005	0.13±0.01	0.11±0.008	1.95	0.104
Ammonia (mg/L)	0.78±0.27	0.41±0.16	0.39±0.13	0.53±0.18	1.05±0.40	0.58±0.15	1.14	0.363
Nitrate (mg/L)	2.09±0.14	2.40±0.14	1.91±0.31	2.03±0.26	2.16±0.07	1.87±0.15	0.98	0.448
Nitrite(mg/L)	0.42±0.12	0.39±0.12	0.43±0.09	0.50±0.13	0.56±0.04	0.45±0.06	0.41	0.841
Phosphate(mg/L)	0.20±0.02	0.74±0.28	0.23±0.05	0.55±0.32	0.49±0.13	0.19±0.04	1.57	0.198

[a-c] different letters in the same column indicate significantly different from each other (HSD, $P < 0.05$).

4.1.2 Correlation between Different Physico-chemical Parameters.

The correlation of physicochemical parameters and nutrients along River Kipsinende are presented in (Table 4.2). Parameters that had very strong positive correlations were conductivity with pH (r = 0.827), soluble reactive phosphorus (SRP) with nitrate (r = 0.823). Similarly, pH, NH_3 and conductivity had strong positive correlations with DO (r = 0.715, 0.683, 0.736), respectively. DO had a strong negative correlation with temperature and weak negative correlation with nitrate and salinity. Similarly, SRP with temperature, total suspended solids, conductivity, ammonia and nitrite had extremely weak relationships with each other (almost none).

Table 4.2: Correlation coefficient matrix between different physicochemical parameters (Tem = temperature, DO = dissolved oxygen, pH = power of hydrogen, TDS = total dissolved solid, cond = conductivity, Salin = salinity, SRP = soluble reactive phosphorus)

	DO	Tem.	pH	TDS	Cond.	Salin	NH_3	NO_2	NO_3	SRP
DO	1									
Tem.	-0.776	1								
pH	0.715	-0.311	1							
TDS	0.460	0.105	0.682	1						
Cond.	0.736	-0.481	**0.827***	0.302	1					
Salin.	-0.393	0.449	0.154	-0.260	0.287	1				
NH_3	0.683	-0.759	0.354	-0.236	0.607	0.012	1			
NO_2	0.399	-0.181	0.583	-0.016	0.771	0.632	0.696	1		
NO_3	-0.084	-0.344	0.045	-0.300	-0.119	0.025	0.099	-0.137	1	
SRP	-0.223	0.064	0.303	-0.041	0.045	0.455	-0.109	0.112	**0.823***	1

*** Correlation** is significant at the 0.05 level (2-tailed).

4.1.3 Water Quality Index (WQI) of River Kipsinende

The value of water quality index is shown in (Figure 4.1). The water quality index value ranged from 62.6 to 145.33. The maximum (145.33) value was found at site KF, followed by 126.01(KB) and 112.69 (KD). Whereas, the minimum (62.6) was observed in site KC.

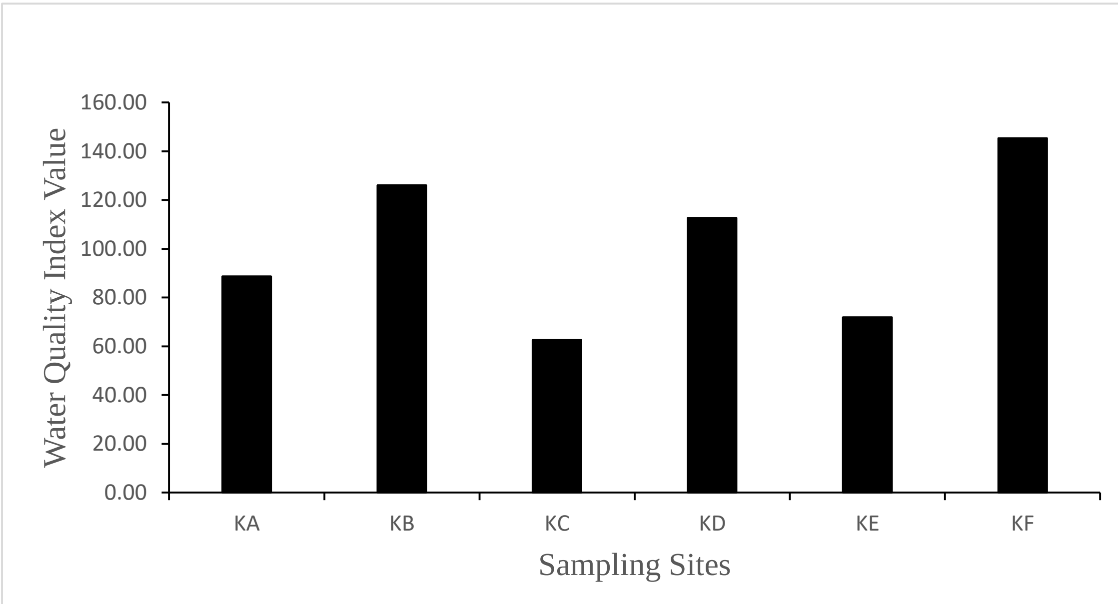


Figure 4. 1: Calculated Values of WQI in River Kipsinende during the study period.

4.1.4 Hydro-morphological Variables.

The highest mean depth was 0.45±0.1 m observed at station KE and the lowest 0.29±0.05 m was observed at station KD (Figure 4.2a). Station KC and KD had the same value. There was no significant difference (ANOVA, $P > 0.05$) in depth among sampling stations. The width (Figure 5b) of the River ranged from 2.71 ± 0.19 to 10.28 ± 0.31 m. Station KF recorded the highest value, while station KB recorded the lowest. There were significant differences between widths in the sampling sites (ANOVA, $P < 0.05$). The width of the river increased after the two streams merged. Velocity ranged 0.46±0.17 to 0.87±0.24 m/s

(Figure 4.2c). The highest value was recorded in station KD (before the river entered the Kaptagat forest) and the lowest at site KE (forest site). On the other hand, the discharge of the river during the study period was highest (3.00±0.53 m^3/s) at site KF (downstream of the river) and lowest (0.66±0.18 m^3/s) in station KB (upstream of the river) as shown in (4.2b).

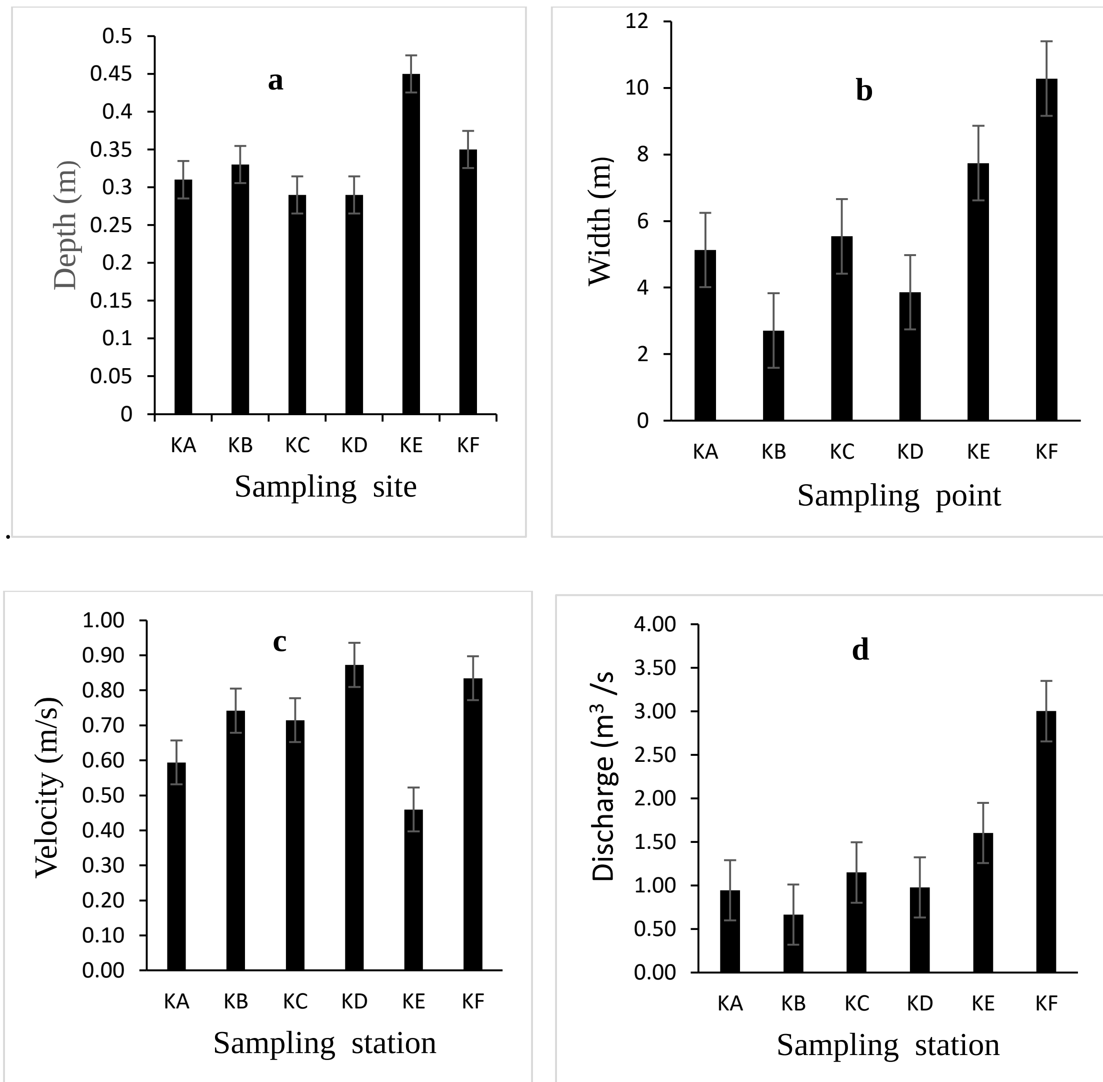


Figure 4. 2: Measured values of hydro-morphological parameters at sampling stations (a=depth (m), b= width (m), c = velocity (m/s), d = discharge (m^3/s)

4.2 Benthic Macroinvertebrates Assemblages.

4.2.1 Macroinvertebrates Abundance and Composition.

During this study out of the 72 collected samples, 20,040 macroinvertebrate individuals belonging to 13 orders, 48 families and 68 genera were identified and counted (Table 4.3 and Appendix iv). The main taxonomic groups were Diptera (11 families, 15 genera, 10,187 individuals = 51%), followed by the Ephemeroptera (6 families, 10 genera, 5,457 individuals = 27%), Trichoptera (6 families, 10 genera, and 1,123 individuals = 6%), and Bivalvia (6%). Whereas, the remaining relative abundance consisted of Coleoptera, Hemiptera, Oligochaeta, Odonata, Decapoda, Arhynchobdellida, Tricladida, Lepidoptera, and Araneae. The highest taxa richness was found in station KB (40) and station KE (40) and the lowest was in station KD (32) (Table 4.4). But, regarding the individual abundance, the highest abundance was observed in station KC (5,025). Whereas, the lowest was in station KE (1,490).

Spatially, the highest relative abundance of Diptera (79%) was found in the station KA (agricultural land use pattern) and lowest the lowest (7%) was in station KE (forested site) (Table 4.4). The five genera (*Simulium, Tipula, Chironomus, and Tanyderus*) under order Diptera were found in all stations.

The highest relative abundance (55 %) for taxon groups of EPT% (Ephemeroptera =51%, Plecoptera = 0%, and Trichoptera = 4%) were recorded in station KE and the lowest (12%) was in station KA. During this study period, order Plecoptera was not found. The relative abundance of Diptera and group of % EPT had inverse relation at each sampling station. *Baetis*, *Acanthiops*, *Afronurus*, and *Caenis* from Ephemeroptera as well as *Hydropsyche* and *Trianodes* from Trichoptera were frequently observed in all stations. While *Anisocentropus* was recorded only at stations KE. On the other hand, order Coleoptera, Hemiptera, Odonata, Oligochaeta, and Bivalvia had higher abundance in station KB than other sites.

Table 4.3: List of macroinvertebrate taxa (x indicates the presence of macroinvertebrates in station

			Sampling stations					
Order	**Family**	**Genus**	**KA**	**KB**	**KC**	**KD**	**KE**	**KF**
Diptera	Simuliidae	*Simulium*	+	+	+	+	+	+
	Tipulidae	*Tipula*	+	+	+	+	+	+
		Hexatoma		+				
		Limonia					+	+
		Antocha		+	+		+	+
	Chironomidae	*Tanypodinae*	+	+	+	+	+	+
		Chironomus	+	+	+	+	+	+
	Ceratopogonidae	*Bezzia*		+	+	+	+	+
	Tanyderidae	*Tanyderus*	+	+	+		+	+
	Dolichopodidae	*Dolichopodid*		+				
	Chaoboridae	*Chaoborus*	+	+	+	+		
	Syrphidae	*Syrphinae*			+			
	Ephydridae	*Ephydrid*	+					
	Dixidae	*Dixa*				+		
	Muscidae	*Musca*			+			
Ephemeroptera	Baetidae	*Baetis*	+	+	+	+	+	+
		Acanthiops	+	+	+	+	+	+
		Demoreptus			+			
		Rheoptilum						+
	Heptageniidae	*Afronurus*	+	+	+	+	+	+
	Caenidae	*Caenis*	+	+	+	+	+	+
		Afrocaenis	+	+				+
	Leptophlebiidae	*Adenophlebia*	+		+	+	+	+
	Ephemerellidae	*Ephemerella*	+	+		+		
	Tricorythidae	*Disercomyzon*					+	+
Trichopetra	Hydropsychidae	*Hydropsyche*	+	+	+	+	+	+
		Leptonema.sp			+			
		Cheumatosyche		+	+	+	+	
	Leptoceridae	*Trianodes*	+	+	+	+	+	+
		leptocerus	+	+				
		Adicella	+				+	+
	Lepidestomatidae	*Lepidostoma*		+	+		+	
	Pisuliidae	*Pisulia*				+		
	Calamoceratidae	*Anisocentropus*					+	
	Philopotamidae	*Chimarra*		+			+	

Hemiptera	Gerridae	*Eurymetra*	+				+	
		Gerris	+		+	+	+	+
	Hebridae	*Hebrus*		+				
	Nepidae	*Ranatra*	+	+				
		Boborophilus			+	+	+	
	Naucoridae	*Naucoris*			+			
	Veliidae	*Mesovelia*	+				+	
	Corixidae	*Corixa*	+		+			+
	Notonectidae	*Notonecta*		+	+	+	+	+
	Hydrometridae	*Hydrometra*				+		
Coleoptera	Gyrinidae	*Orechygrus*	+	+		+	+	
		Orectogyrus	+	+				
		Orectochilini					+	
		Dineutus.sp	+	+	+	+		+
	Scirtidae	*Elodes*		+			+	+
	Elmidae	*Elminae*	+	+			+	+
	Dytiscidae	*Hydaticus*		+	+	+	+	
		yola		+				
Decapoda	Potamonautidae	*Potamonaute*	+	+	+	+	+	+
Bivaliva	Sphaeriidae	*Pisidium*	+	+	+	+	+	+
	Thiaridae	*Thiaridae*	+					
Oligochaeta	Tubificidae	*Tubifex*	+	+	+	+	+	+
	Lumbriculidae	*Lumbricus*	+	+			+	+
Odonata	Gomphidae	*Gomphus*	+	+	+	+	+	+
	Lestidae	*Lestes*	+	+	+	+	+	+
	Aeshnidae	*Ashena*	+					
Arhynchobdellida	Hirudinea	*Hirudo*	+	+	+	+	+	+
Tricladida	Planariidae	*Dugesia*		+			+	
Lepidoptera	Crambidae	*Paraponix*				+		
		Syndita				+	+	
Araneae	Dictynidae	*Argyroneta*						+
Total (13)	**48**	**68**	**37**	**40**	**34**	**32**	**40**	**34**

4.2.2 Diversity of Macroinvertebrates

The diversity of macroinvertebrates in River Kipsinende is indicated in (Table 4.4). The value of Shannon-Wiener diversity index in the sampling station varied from 1.05 to 2.39. The highest value was observed in station KB and the lowest was in station KA. Similarly, in Simpson index, the highest value (0.84) and the lowest (0.39) were found in station KB and KA respectively. The trend of evenness along the river was also high in KB and low in KA like Shannon diversity index and Simpson index. However, the Dominance (D) was highest in KA and lowest in KB. On the other hand, the highest recorded value (5.34) for

Margalef richness index was observed in station (KE) and the lowest (3.87) was in station KC.

Table 4.4: Various metric categories based on benthic macroinvertebrates taxa

Category	Agricultural		Mixed			Forested
	KA	**KB**	KC	KD	KF	KE
Richness measures						
Total No. of individuals	4538	2959	5025	2885	3143	1490
Total No. of taxa	37	40	34	32	34	40
No. of EPT Taxa	11	12	11	10	11	13
No. Ephemeroptera Taxa	7	6	6	6	6	8
No. Trichoptera Taxa	4	6	5	4	3	7
No. Hemiptera Taxa	6	3	5	4	4	5
No. Coleoptera Taxa	4	7	2	3	3	5
No. Diptera Taxa	7	10	10	7	8	8
No. Odonata Taxa	3	2	2	2	2	2
No. Oligochaeta Taxa	2	2	1	1	2	2
Composition measures						
% EPT	12	51	31	48	25	55
% EPT: % Diptera	0.15	5	0.5	1	0.4	8
% Ephemeroptera	12	40	23	38	23	51
% Trichoptera	1	10	8	9	2	4
% Hemiptera	0.4	1	0.2	1	0.1	2
% Coleoptera	0.4	1	0.2	1	0.3	1
% Diptera	79	10	62	42	58	7
% Odonata	1	5	1	3	0.3	2

% Oligochaeta	2	10	2	0	6	18
Diversity and Richness Measures						
Dominance_D	0.61	0.16	0.31	0.27	0.35	0.17
Simpson_1-D	0.39	0.84	0.70	0.73	0.65	0.83
Shannon_H	1.05	2.39	1.73	1.75	1.64	2.28
Evenness_e^H/S	0.08	0.27	0.17	0.18	0.24	0.15
Margalef's index (S)	4.28	4.88	3.87	3.89	4.10	5.34
Equitability_J	0.29	0.65	0.49	0.51	0.46	0.62

4.2.3 Functional Feeding Group of Macroinvertebrates and Ecosystem Attributes.

The functional feeding groups in River Kipsinende were dominated by predators (47.19%), followed by collector-gatherer (33.14), collector- filterer (12.86%), scraper (4.70%) and shredders (2.11%) (Table 4.5 and Appendix iv). Regarding the spatial distribution, the highest percentage of collector-gatherer (57.53%), scraper (11.90%) and shredders (4.16%) were all recorded in the forest area (station KE). Whereas, the lowest percentage for gatherer (12.6%) and shredders (0.79%) were both observed in station (KA) as well as for scraper (0.28%) was in station KD. The percentage of collector- filterer (CF) varied in the range of 4.72% to 26.7%. The highest percentage (26.7%) was found in station KB and the lowest (4.72%) was in station KA. On the other hand, the highest predators’ composition (81.18%) was observed in agricultural area (station KA) and the lowest (11.02) in the forested area (station KE).

Table 4.5: Functional feeding groups on benthic macroinvertebrates

Categories	Agricultural	Mixed			Forested	
	KA	KB	KC	KD	KF	KE	Mean
% Scrapers	0.71	4.36	1.47	0.28	9.45	11.90	4.70
% Filterers	4.72	26.7	10.27	11.92	8.18	15.39	12.86
% Gatherers	12.6	46.84	23.28	38.44	20.17	57.53	33.14
% Shredders	0.79	1.76	0.98	1.46	3.53	4.16	2.11
% Predators	81.18	20.34	64	47.9	58.67	11.02	47.19

The ratio of production to respiration (P/R) based on the numerical value indicated that all sampling stations were heterotrophic (P/R<0.75 or threshold value) (Table 4.6). Similarly, the ratio of CPOM/FPOM < 0.25 showed that all sites had a non-functioning riparian area. The habitat stability index in station KB (0.64) and KF (0.74) were greater than the threshold (0.5) value and indicating that there were adequate stable substrates for scrappers and filters. For the remaining station, habitat stability index was less than 0.5 which means that there wasn't an adequate stable habitat. Based on the proposed threshold values all sampling zones during study in River Kipsinende had plentiful loading of fine particulate organic matter for filters [TFPOM (suspended)/BFPOM (sediment) > 0.25]. Whereas, the top-down predator control to prey in the river for station KE (0.12) had normal predator-prey balances (P/P of 0.1 - 0.2). While, the other stations were over burdened with predators (P/P > 0.2) and this contributed to the overall overburden of predators for the entire river.

Table 4.6: Ecosystem attributes based on the ratio of FFG (functional feeding group)

Ecosystem attributes	Agricultural	Mixed				Forested
	KA	KB	KC	KD	KF	KE
P/R	0.04	0.06	0.04	0.01	0.30	0.15
CPOM/FPOM	0.05	0.02	0.03	0.03	0.12	0.06
Top-down predators	4.31	0.26	1.78	0.92	1.42	0.12
Stable channel index	0.40	0.64	0.48	0.31	0.74	0.44
TFPOM/BFPOM	0.37	0.57	0.44	0.31	0.27	0.41

4.3 The Relationship between Water Quality and Benthic Macroinvertebrates.

Based on the canonical correspondence analysis (CCA) the relationship between the physicochemical parameter and macroinvertebrates communities illustrated in (Figure 4.3). The first and the second canonical axes explained 41.75% (eigenvalue of 0.066) and 30.2% (eigenvalue of 0.047) of the variation in the macroinvertebrates data respectively. The macroinvertebrates and physicochemical correlation of the first axis were not statistically significant in a Monte Carlo permutation test ($P > 0.05$). The CCA ordination showed that variation in benthic macroinvertebrates communities were related to temperature, conductivity, soluble reactive phosphate, nitrate, dissolved oxygen, ammonia, and other variables. In the first axis temperature and salinity were positively correlated with *Gerris*, *Cheumatosyche*, *Chironomus*, and *Hydropsyche* at station KD and KC. Similarly, Nitrate and soluble reactive phosphate (SRP) were positively correlated with *chaoborus*, *Ephemerythus, Lestes* and *Hirudo* at station KA and KB. In contrast, *Baetis, Adenophlebia*, *Disercomyzon*, and *Potamonaute* had a negative correlation with nitrate and soluble reactive phosphorus (SRP).

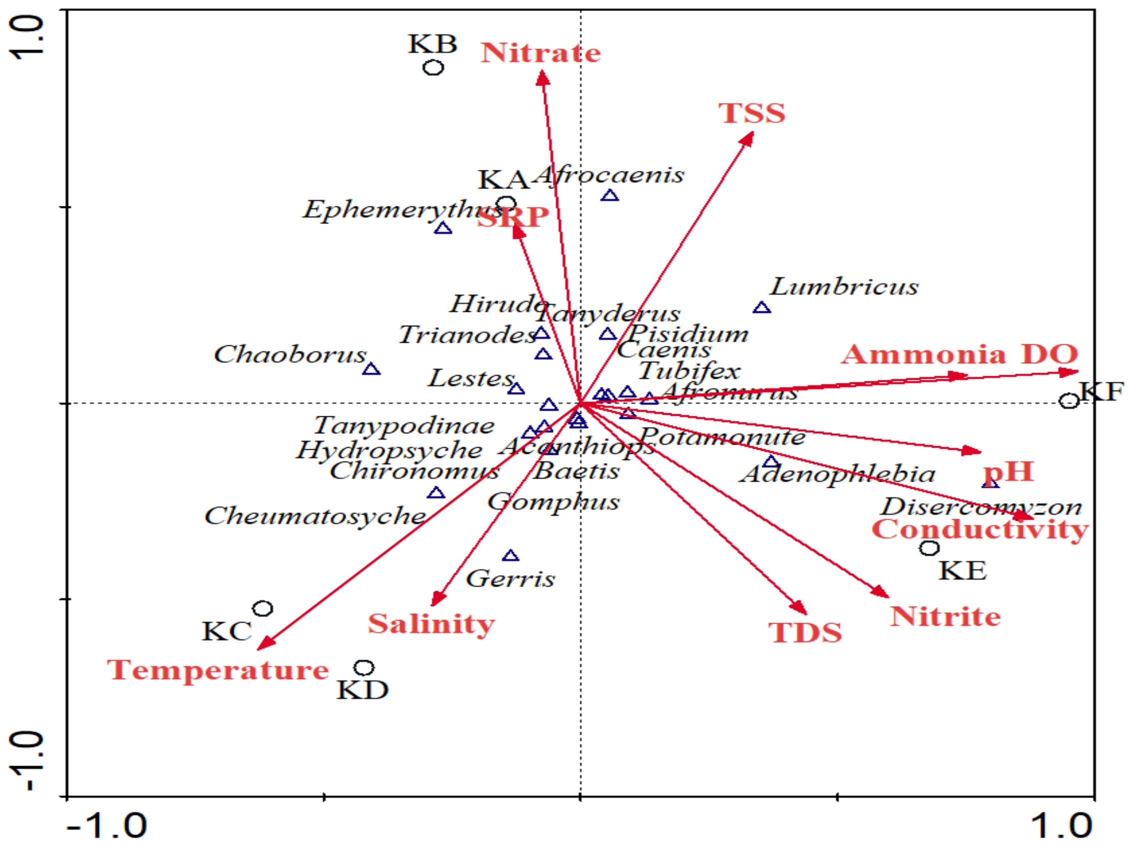


Figure 4.3: The canonical correspondence analysis (CCA) triplot of the macroinvertebrates in relation to the physico-chemical parameters

4.4 The Habitat Quality Assessment and their Relationships with Benthic Macroinvertebrates

4.4.1 Habitat Quality Assessment

Based on the rapid bioassessment protocols the habitat measurement characteristics shown in (Table 4.7). As a result, habitat parameters like epifauna substrate, channel flow status, bank vegetation protection, bank stability, and the riparian vegetation zone were relatively maximum at station KE than others. Whereas, the channel alteration and frequencies of riffles (bends) were maximum in station KA (upstream of the river). In general, the highest (72) total habitat scoring was found in station KE where the river exited from the forest and the lowest (58) was in station KB. Most habitat parameters had significant differences among sampling stations (ANOVA, $P < 0.05$) except embeddedness, bank stability and total habitat scoring.

Table 4.7: Habitat quality assessment with their (average ranked) during study period in six sampling stations in River Kipsinende (H = the Kruskal -Wallis test which is rank based)

Habitat parameters	Agricultural		Mixed		Forested			
	KA	KB	KC	KD	KF	KE	H-value	P-Value
Epifauna substrate	6.2	3.8	5.0	12.5	12.5	17.0	15.01	0.010
Embeddedness	5.7	7.8	7.0	11.8	16.8	7.8	10.43	0.064
Velocity-depth combination	8.2	2.0	9.3	6.8	13.8	16.8	14..90	0.011
Sediment deposition	12.5	10.7	6.3	6.0	17.0	4.5	12.95	0.024
Channel flow status	7.5	6.2	11.5	13.5	3.3	15	12.53	0.042
Channel alteration	15	4.7	12.2	13.5	9.3	2.3	14.05	0.015
Frequencies of riffles	16.0	13.0	12.7	8.0	2.3	5.0	14.92	0.011
Bank stability	10.2	11.8	10.2	7.3	4.5	13.0	6.44	0.266
Bank vegetative protection	7.5	11.8	5.5	7.5	7.7	15.0	11.38	0.044
Riparian vegetation zone	6.0	3.8	7.7	9.2	14.8	15.5	12.5	0.029
Total habitat score	64	58	63	66	68	72	9.39	0.094

4.4.2 The Relationship between Habitat Quality and Benthic Macroinvertebrates.

As illustrated in (Figure 4.4) the habitat quality parameters such as sediment deposition, bank vegetative protection, embeddedness, riparian vegetation, avalibablity of cover and velocity depth combination had a signficant positive relationship with the genera of *Dicercomyzon, Adenophlebia, Potamonaute, Baetis, caenis, Afronorus, Afrocaenis, Lumbricus* and *pisidium* in axis one at station KE and KF. Whereas, genera *Cheumatosyche, Gerris, Chironomus, Gomphus, chaoborus, Ephemerythus, Lestes* and *Hirudo* had a negative correlation from those habitat parameters.

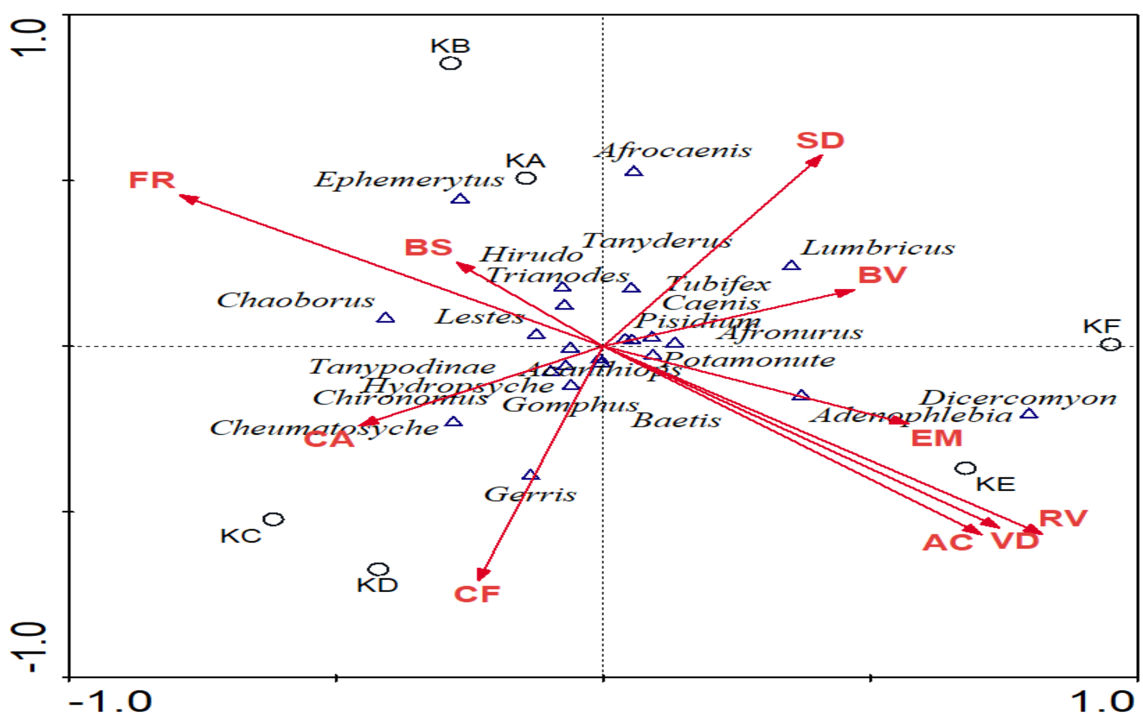


Figure 4.4: The canonical correspondence analysis (CCA) biplot of the benthic macroinvertebrates in relation to the habitat quality parameters. Representation where: AC (available canopy cover), EM (Embeddedness), VD (Velocity -Depth combination), SD (sediment deposition), CF (channel flow), CAl (channel alteration), FR (frequency riffle), BS (bank stability), BV (bank vegetation protection) and RV (riparian vegetation).

CHAPTER FIVE

DISCUSSION

5.1 Water Quality in River Kipsinende

5.1.1 Physico-chemical Parameters

The biological nature of lotic systems and the ecological integrity of their watersheds are determined by their physico-chemistry. Maximum temperature was observed at station KA and the lowest was in station KE (in forest area). Significant differences were observed among sites (ANOVA, $P < 0.05$) which were attributed to the presence and absence of forest cover/shading effect, anthropogenic activities in the watershed, and water depth. These findings are concordant to those of Dhinamala *et al.* (2015) and Farnham *et al*. (2015) who reported that the intensity of solar radiation, evaporation, shallowness, and surface water broadening all influence the temperature of surface water. The occurrence of excessive evaporation can be caused by the wider surface water. According to WHO (2006), temperatures of surface waters generally range from 5–30°C for the protection of the aquatic species. Beyond this standard temperature affects the distribution, survival and food chain of aquatic organisms by influencing the amount of oxygen that is available for an aquatic organism and their metabolic rates (Mohamed *et al*., 2009). Therefore, according to the above range surface water temperature in River Kipsinende was acceptable.

Mean concentration levels of dissolved oxygen in the water of Kipsinende River were in the ranges of 8.78 ± 0.75 and 5.81 ± 0.4 (mg/L). Highest dissolved oxygen levels were recorded in station KE (forested area) and the minimum in station KC. There were significant differences among sites (ANOVA, $P < 0.05$). Reduced aquatic plant activities such as photosynthesis, the presence of rich organic matter, and the change of other factors such as depth, salinity, and temperature might all have contributed to low DO concentrations at site KC. Similar findings were also reported by Zang *et al*. (2011), who indicated that as pH decreases, dissolved oxygen decreases and according to Kuligiewicz *et al*. (2015), DO being temperature dependant changes along the river due to biological processes like photosynthesis, respiration, and decomposition of organic matter. As a result, aquatic biota survival, development, and mobility are all heavily reliant on the availability of an appropriate dissolved oxygen levels. As reported by Davies & Cornwell (2017), based on the US EPA standard the level of DO in water, suggests that should not fall below 5.5 mg/L. Thus, based on the indicated value the concentration of DO in River Kipsinende is at the required level for those aquatic organisms.

The highest (7.37) pH value was observed in station KF and the lowest value of (7.02) was observed in station KC. However, there were no significant differences among sampling sites (ANOVA, $P > 0.05$). The low pH value measured at station KC might be related to the inflow, waste disposal, and decomposition of organic material such as leaf litter in this site, as well as inputs from surface runoffs during the rains. Whereas, relatively high pH value was recorded at station KF. This may be due to the discharge of fertilizers and various wastes to sampling point. Because pH affects biological and chemical processes in the water body, as well as the solubility and availability of nutrients and their consumption by aquatic species, the pH of water is an essential element in determining its quality (George *et al*., 2012). Naturally occurring freshwaters have a pH range between 6.0 and 8.0 suitable for aquatic organisms (Osman & Kloas, 2010) and the World Health Organization's guideline recommendation for both drinking and irrigation water (6.5–8.5). As a result, levels outside of this range indicate that the variety of aquatic biota inside the water body decrease owing to physiological stress, resulting in lower reproduction and growth. For instance, pH values that are too high (above 9.5) or too low (below 4.5) might create hazardous circumstances for aquatic life, alterations in the ionic and osmotic balance of individual, change in community structure and lethal effects on organisms (WHO, 2006). Therefore, based on the above range pH in River Kipsinende was in a suitable condition.

The electrical conductivity of water was used to determine its purity based on the presence of ions, mobility, relative concentrations, temperature and total amount of ionizable salts in solution (Oyem *et al.,* 2014; Muthulakshmi *et al.*, 2015). The maximum value (45 µS/cm) of electrical conductivity was found in station KA and the minimum (28.89 µS/cm) was at station KF. However, there were no significant differences between sites (ANOVA, $P > 0.05$). Electrical conductivity levels were lower than the WHO standards for household water (1000 S/cm) at all sample stations.

Total Suspended Solid concentration in this study varied from 0.04 to 0.08 mg/L. Station KB and KF had the maximum TSS value. Whereas, the lowest (0.04) was found in station KC even if there were no significant differences among stations. Similarly, the highest concentrations of total dissolved solid (TDS) was found in downstream at station KF and lowest in the upstream of the river. TDS concentrations measured values increased from upstream to the downstream. This was attributed to chemicals used in the farms and in the forest. This finding agreed with Davie (2008) who stated that the higher level of TDS indicated that the water body may be polluted via natural or anthropogenic sources.

5.1.2 Nutrients

Nutrients such as ammonia, nitrite, nitrate and soluble reactive phosphate (SRP) are important for life and growth of living organisms in the aquatic ecosystem (Iqbal *et al*., 2015). These nutrients are generally non-toxic if their concentration is present in acceptable amounts in aquatic ecosystem. However, excess nutrients such as nitrogen and phosphorous can result in nutrient enrichment (Dodds & Smith, 2016).

The ammonia concentrations ranged between a minimum 0.39 ± 0.13 mg/L at station KC and a maximum 1.05 ± 0.40 mg/L at station KF (downstream of the river). There were no significant differences among sampling sites in ammonia value (ANOVA, $P > 0.05$). The source of ammonia in the study area might be due to the application of fertilizer in the watershed, sewage discharge (domestic activities) and the biological degradation of manure (WHO, 2011). Ammonia is a harmful contaminant found in sewage, liquid manure, and liquid organic waste, and it occurs naturally in water bodies as a result of the breakdown of nitrogenous waste in the soil and water, biota excretion, nitrogen gas reduction in water by microorganisms, and gas exchange with the atmosphere. As a result, it can be used to diagnose the condition of natural water bodies like rivers (Deepa *et al*., 2016). The levels of ammonia were higher than the WHO standards for residential water at all sample stations (0.5 mg/L) particularly in station KF, KA and KE respectively. Thus, it can be toxic to some aquatic organisms.

The nitrate concentrations ranged from 1.87 ± 0.15 to 2.40 ± 0.14 mg/L, where the highest concentration was recorded at station KB (mixed land use) and the lowest at station KE (forested site**).** This might have been due to agricultural fertilizer runoff, sewage from the watershed, wastes from animal and humans as well as anthropogenic activities such as washing clothes and cars were prevalent near station KB. This finding also concurs with Gayathri *et al*. (2013), who suggested that fertilizers, decomposing vegetable and animal debris, and home and industrial effluents are the main sources of nitrates. This result is within acceptable limit (50 mg/L) in WHO (2008) standard.

The nitrite concentrations ranged from 0.39 ± 0.12 mg/L to 0.56 ± 0.04 mg/L in the River Kipsinende. The source for nitrite in the study area could be fertilizers, wastes from animal and human sewage with associated untreated municipal wastes (WHO, 2011). Variations in phytoplankton, oxidation of ammonia, and formation of nitrite from nitrate could all contribute to high nitrite levels in surface water, which is an indication of pollution. But the low level of nitrite might be due to fewer river inputs as well as uptake by phytoplankton. This low concentration is also toxic to aquatic life organisms (Deepa *et al*., 2016). The nitrite concentrations at all sampling points were acceptable.

Similarly, the concentration of soluble reactive phosphorus (SRP) in sampling sites ranged from 0.19 ± 0.04 mg/L to 0.74 ± 0.28 mg/L. The highest value was observed in station KB (mixed land use) and the lowest in station KE (forested site). This variation could be because of land use types and anthropogenic activities. For example, for site KB the source of SRP might be the entry of agricultural fertilizers and pesticides from the watershed to the river and other human activities such as cleaning activities and discharge of various wastes. In site KE the anthropogenic activities were minimum (almost none). Soluble reactive phosphorus is a nutrient found in natural portions of aquatic ecosystems that helps autotrophs thrive and therefore providing food through primary productivity and habitat/substrate for aquatic organisms. But if excess phosphate enters the system, it can lead to eutrophication and therefore producing less desirable effects in aquatic systems.

Phosphate/Phosphorous concentration in this study were above the permissible value (0.4 m/L) by WHO (2008), might affect benthic macroinvertebrates.

5.1.3 Correlation between Different Physico-chemical Parameters

From (Table 4.2), it is evident that temperature correlated negatively with DO (r = -0.776) and ammonia (r = -0.759). These results agreed with Vincy *et al*. (2012), and Deepa *et al*. (2016), who found that there is inverse proportionality between DO and temperature. However, pH correlated positively with DO (r = 0.715) and conductivity (r = 0.827). A similar finding was reported by Zang *et al*. (2011), who suggested that as pH decreases when dissolved oxygen decreases and both are affected by similar factors such as, the river productivity, photosynthesis activities and temperature. Navneet & Sinha (2010), also reported strong correlations between conductivity with temperature, pH and alkalinity. Similarly, there existed strong correlations between soluble reactive phosphorus (SRP) with nitrate (r = 0.823) and nitrite which had a strong positive relationship with conductivity (r = 0.771). This might be attributed to nutrients entering the water through fertilizers, livestock, and human waste linked with the municipal waste water system.

5.1.4 Water Quality Index (WQI) of River Kipsinende.

According to water Quality Index ranges as indicated in (Figure 4.1) the water quality index (WQI) at site KC of 62.6 and site KE of 71.96 showed poor status. But in these stations the water could be used for drinking, irrigation, and industrial purpose. The water at site KA (88.7) is grouped under very poor status. However, it could be used for irrigation purpose. WQI observed at sites KB (126.01), KD (112.69), and KF (145.33) are unsuitable for drinking and fish culture. These results concur with those of George *et al*. (2019) following his study in Nyando River. Water contamination was ascribed to agricultural operations within the river watershed, as well as the presence of other human activities such as washing clothes, motorbikes, and vehicles, which were regular practice during the study. In addition, these sites were vulnerable to erosion due to lack of riparian vegetation.

5.1.5 Hydro-morphological Variables.

According to the result in (Figure 4.2a), the highest depth value (0.45±0.1 m) was observed in a station KE. While, the lowest (0.29±0.05 m) was in station KC and KD. There were no statistically significant variations in depths between sampling sites. However, the main source for depth variation could be the availability of canopy cover to the topography, the bank stability, riparian vegetation protection, gradient of the area and types of substrate composition which is found. This is true in station KE which has higher canopy cover and bank stabilities than others. This agrees with Cunningham & Schalk (2011), who proposed that the low water depth might be linked to significant water evaporation and low water input from rain and runoffs.The highest width value (10.28 m) was measure in downstream of the river (station KF) and the lowest (2.71 m) in headwater (station KB). This result agrees with river continuum concept. This variation probably might be due to the status of channel stability, bank vegetation protection, various human activities, and vulnerability to sedimentation deposition, slope differences and the contribution of other tributaries in the watersheds.

The maximum (0.87 m/s) velocity value was measured at site KD and minimum (0.46 m/s) in KE. There were significant statistical differences among sampling sites (ANOVA, $P < 0.05$). Differences in velocity could be because of the shape of channels, slope, and the wideness of channels and the composition of substrates. For instance, the highest velocity found where the area had a steep slope and in narrow channels. Whereas, the lowest velocity appeared in the gentle slope and wide channels. This idea also verified by the river continuum concept (RCC) which states that the velocity of water decreased from headwater (narrow channel) to downstream (wide channel). Dietz & Clausen (2008), also observed that stations which had enough cobble and gravels substrates leads to swift velocity of the water. Whereas, silt and sand substrates can have low water flow. In the same way, the flow rate (discharge) of the river varied from 3 m^3/s to 0.66 m^3/s. The highest value was found in the lower region of the river and the lowest in the upper region. This might be due to the area, depth, width, gradient, channel size, channel stability, types of substrates and other stream attributes contributes for increasing the flow in downstream of the river. This result agreed with the concept of (RCC) elaborating that the channel size, cross-sectional area, nutrients (mineral) and width increased from up to downstream.

5.2 Macroinvertebrates Abundance, Composition, Diversity and Functional Feeding Group

5.2.1 Macroinvertebrates Abundance and Composition

Macroinvertebrates in sampling stations consisted of order Ephemeroptera, Trichoptera, Coleoptera, Hemiptera, Odonata, Diptera, Oligochaeta, Decapoda, Bivalvia, Arhynchobdellida, Tricladida, Lepidoptera and Araneae (Table 4.3). Hence, taxa richness and abundance were much higher compared with benthic macroinvertebrates in other Kenyan rivers with similar sampling design and agroecology such as, 1,499 individuals (Aura *et al.*, 2010) in Sosian River; 13 taxa, (Mbaka *et al*., 2014) in Honi and Naro Moru rivers. Diptera was the dominant taxonomic group during this study period. A similar finding has been reported by Masese *et al.*, (2009) and Raburu *et al.*, (2009)**,** where Diptera was the dominant taxa in the Moiben River and in the upper catchment of Lake Victoria Basin, Kenya respectively. Spatially, the highest relative abundance (79%) of Diptera was found in station KA (agricultural land use pattern) and the lowest (7%) was in station KE (forested site). This could be attributed to increased inputs of organic nutrients from agriculture, which could have resulted in an increase in the population of benthic macroinvertebrates as well as their ability to tolerate high pollution levels. A similar study was done by Deborde *et al.* (2016), who observed that the highest abundance of benthic macroinvertebrates was found in the agricultural and mixed land uses. The probable reason could be due to their tolerance ability to high pollution which implies they are not affected by low dissolved oxygen levels. Bartlett-Healy *et al.* (2012), and Riens *et al*. (2013), also reported that most of the Dipteran families such as Chironomidae, Dixidae, and Culicidae tolerate a wide range of water qualities, especially in polluted waters by using the atmospheric oxygen. Genera *Simuliium, Tipula, Chironomus,* and *Tanyderus* under order Diptera were frequently found in all stations. This could be due to the presence of organic pollution in all sampling sites (Couceiro *et al*., 2014).

Whereas, the highest relative abundance (55 %) for taxon groups of EPT% were recorded in station KE (forested site) and the lowest (12%) was in station KA (agricultural station). The decreasing abundance of intolerant taxa in station KA could be attributed to poor water quality, habitat quality, food availability, and the extent of anthropogenic activities. These observations agrees with Patrick *et al*. (2014), who suggested that the presence of a smaller number of EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) and their individuals in most of the impacted stations indicated that there was poor water and habitat quality as well as low food availability. This finding also agreed with Jun *et al*. (2016), Ephemeropterans are widely recognized for their acute sensitivity to pollution, preference for highly-oxygenated waters, and preference for fast-flowing waterways. The concentration of dissolved oxygen was high in station KE than in others. Hence, a high number of Ephemeroptera taxa existed.

During this study period, order Plecoptera was not found. This could be taxon Plecoptera is one of the most sensitive aquatic insect groups. Thus, they are an indicator of degraded habitat (Olomukoro & Dirisu, 2014). Plecopteran also has a low taxon richness, with only one family found in Kenyan streams (Minaya *et al*., 2013; Masese *et al*., 2014a, b). Relatively the highest abundance of Trichoptera was recorded in station KB and KC (both found in mixed land use). This finding has been supported by Griffin *et al*. (2015), stated that Trichoptera can be able to exist at a various range of water conditions. The relative abundance of Diptera and group of % EPT had inverse relation at each sampling station. Raburu *et al*. (2009) made a similar observation, observing that as the number of Diptera increased, the number of EPT decreased. *Baetis, Acanthiops, Afronurus*, and *Caenis* from Ephemeroptera as well as *Hydropsyche* and *Trianodes* from Trichoptera were frequently observed in all stations. While, *Anisocentropus* was recorded only at station KE. In general, the abundance of these macroinvertebrates in the river system is largely determined by high habitat diversity, ecological factors such as water quality, substrate and food availability (Okarafor *et al.*, 2012; Griffin *et al*., 2015).

On the other hand, order Coleoptera, Hemiptera, Odonata, Oligochaeta, and Bivalvia had a higher abundance in station KB than other sites. This might have been due to the presence of relatively higher pollution in this site due to various human activities such as the washing of motorbikes, clothes, bathing laundry activities, grazing, animal wastes, and agricultural inputs. Similar observations were reported by Masese *et al*. (2014), Mariadoss & Ricardo, (2015), Adu *et al*., (2016), who also stated that the presence of a greater number of Coleopteran, Hemipteran, Oligochaeta, mollusks and Odonata might be an indication of water quality deterioration due to pollution. According to Marius *et al*. (2014), such pollution can occur due to an increase in land use and land cover change as a result of intensive agricultural activities in the catchment and a dramatic increase in the application of fertilizers, pesticides and herbicides as well as urbanization.

5.2.2 Diversity of Macroinvertebrates.

The result indicated in (Table 4.4) the value of the Shannon-Wiener diversity index (H′) in the sampling stations varied from 1.05 to 2.39. This value is greater than what was reported by Mbaka *et al.* (2014). The Shannon-Wiener diversity index usually have values ranging from 1.5 to 3.5, with values occasionally exceeding 4.5 (Magurran, 1988). The highest value (2.39) was observed in station KB, followed by 2.28 in station KE. Whereas, the lowest (1.05) was recorded in station KA. There were minimal variations in Shannon-Wiener diversity between sampling stations. The main reason could be the availability of quality and quantity of food sources, trophic structure, and the level of environmental stress for each site. This result agreed with Morphin-Kani & Murugesan (2014), who suggested that the high macroinvertebrate diversity could be an indication of a good environment and very low diversity showing the environment is under some lack of habitat availability.

Like, Shannon-Wiener index, diversity within the macroinvertebrate community was also described using the Simpson’s diversity index (1-D). According to Mandeville (2002), the Simpson Index (1-D), with values ranging from 0 to 1. The values 0, indicating a low level of diversity and 1 for a high level of diversity. Simpson's diversity index in River Kipsinende varied from 0.39 (KA) to 0.84 (KB). The highest (0.84) value was observed in station KB and the lowest (0.39) was in KA. This probably due to few macrohabitats observed in station KA and it is vulnerable to other invasion due to being open. This recorded value in River Kipsinende more than the given range indicated the presence of almost a high level of diversity. The Shannon-Wiener Index (H′) and Simpson's diversity index (1-D) showed the same trend at each sampling station. However, they had an inverse relation to Dominance (D). This finding agreed with Magurran (2013), who stated that although Shannon's and Simpson's diversity indices have different theoretical foundations and interpretations, they exhibit substantial connections.

Margalef's richness index in River Kipsinende was observed in the range of 3.87 to 5.39. Relatively the highest Margalef richness index was 5.34 followed by 4.88 and 4.28 which were found in station KE, KB, and KA, respectively. Whereas, the lowest (3.87) was recorded in station KC. This could be due to the presence of several macrohabitats in station KE, particularly riffles, marginal areas, and pools, which may have favored the availability of more niches for macroinvertebrates' existence, as well as the absence of major anthropogenic activities such as deforestation, grazing, and washing activities. In the same way, the highest taxa richness was found in station KB (40) and station KE (40). While the lowest (32) was in station KD. The variation among sites might was due to the level of environmental stress in the area via increased human activities for example in station KE the degree of human activities was minimal. This result concurs with Andem *et al*. (2012), who suggested that low taxa richness may indicate the environment is seriously degraded with various anthropogenic activities and thus, affecting the benthic macroinvertebrate community.

The range of evenness varied from 0.08 to 0.27. The highest evenness (0.27) was located in station KB and the lowest (0.08) was in station KA. This might be due to the status of water quality. This result agreed with Dipankar & Jayanta (2015); Upen & Sarada (2015), who observed high evenness resulted in poor water quality and lack of available food. The recorded value indicated that the evenness index and richness index had the same trends from station KA to KD but, in station KE and KF contrasted each other. This was contrary to Chrisoula *et al*. (2011), who suggested that the increasing value for species richness index was responsible for the reduced value of the evenness index. The equitability of benthic macroinvertebrates along sampling sites was found in the range of 0.29 and 0.65. The maximum value (0.65) was observed in station KB and the minimum in KA. It had similar trends with the Margalef richness index at each site.

5.2.3 Functional Feeding Group of Macroinvertebrates and Ecosystem Attributes

The results of this study showed that there was diversified functional feeding groups (FFGs) in Kipsinende River including gathering-collectors, filtering- collectors, predators, shredders and scrapers) (Table 4.5). This is similar to the findings by Boyero *et al.* (2011); Brasil *et al*. (2014) and Masese *et al*. (2014), who observed that many tropical rivers had high diversity feeding groups. This is because of the differential distribution of energy inputs and change in river morphology over time which included variations in channel characteristics (presence of rapids, riffles, plant cover and water flow) and provided rise to a diversity of substrates and microhabitats, which in turn determine the arrangement of FFGs in lotic environments (Brasil *et al*., 2014).

The results have shown that functional feeding groups in River Kipsinende was dominated by predators, gatherer, and filterer respectively (Table 4.5 and Appendix iv). On the other hand, the abundance of shredders feeding group was the least. Spatially, as indicated in (Table 4.5) the highest predators' composition (81.18%) was observed in the agricultural area (site KA) and the lowest (11.02%) was in the forested area (station KE). The difference in predators between sites could be due to the availability of prey like mayflies in each site and the presence /absence of riparian vegetation. However, some predators for example, Odonata use vegetation as a hunting ground for food (prey) and resting positions especially for the less mobile species (Koneri *et al.*, 2017). This is agreement with the river continuum concept the abundance of predator may depend on prey availability and in turn predator abundance also affects prey populations. Favretto *et al*. (2014), reported that the predator functional group can be found with high abundance in anthropic environments.

The highest percentage of collector- gatherer (57.53%), scraper (11.90%) and shredders (4.16%) were recorded in the forested area (site KE). Whereas, the lowest percentage for both gatherer (12.6%) and shredders (0.79%) were observed in site KA and for scraper (0.28%) was in site KD. Gatherers feeding on small particles accumulated on the stream bottom. These fine particles are generated from the decomposition of organic matter by shredders. Hence, the abundance of gatherers determined by the presence of shredders. The scraper feeder was highest in forested site (KE) and lowest in agricultural area. This might be due to the low periphyton productivity, lacking macrophyte as food sources because of greater depth and increased turbidity in agricultural area since scraper grazes the macrophyte that is attached to the bedrock, stones and vegetation (Oliveira & *Nessimian*, 2010). Similar findings reported by Barbee (2005), stated that the densities of scrapers are determined by the presence /absence of algal biomass and production. Families of Heptageniidae, Scirtidae and Elmidae were the common scraper in the river during the study period.

The relative abundance of shredders was the least in all sites as compare to other functional feeding groups. However, in terms of spatial distribution the highest relative abundance recorded in a forested area (site KE) and lowest in an agricultural area (site KA). This is because shredders feed on course organic matter (CPOM) from pieces of living or dead plant material including leaves and woods by breaking down into smaller parts. These smaller particles are also used as source food for other organisms such as collector feeders. Probably variations might also be due to the magnitude of temperature and the availability of riparian vegetation or canopy cover as well as the land use differences on each site. Hence as mentioned above shredders are closely related to the riparian vegetation, because they rely on allochthonous feeding resources and as well contribute much to the degradation of leaf materials dropping into aquatic systems from overhanging vegetation. A similar observation was made by Boyero *et al.* (2011); Brasil *et al*. (2014) and Masese *et al*. (2014). Deforestation and temperature have a negative effect on shredder as this reduces or eliminates their main source of food and also various land-use types use has a significant influence on the functional organization of macroinvertebrate communities with shredder diversity and abundance higher in forest streams (Masese *et al*., 2012).

In the same way, the percentage of collector- filterer varied in the range of 4.72% to 26.7%. The highest percentage (26.7%) was found in site KB and the lowest (4.72%) was in site

KA (agricultural area). The source of variation among the site might be because of water velocity and the degree of disturbances. This idea verified by Parker *et al*. (2013), an abundance of filter feeders to the increased encounter of food particles with increased water velocities, in other words, the velocity of water aids to facilitate filtration. The common families grouped under filter feeder in the study area included; Hydropsychidae, Philopotamidae, Sphaeriidae and Leptoceridae. Generally, the benthic macroinvertebrates composition and the distribution of functional feeding groups showed variations between the different sampling areas (land use). This is probably related to some environmental variation, anthropogenic activities, distribution of energy inputs, change in river morphology which included variations in channel characteristics (presence of rapids, riffles, plant cover, presence of stable substrates, availability of food and water flow) (Brasil *et al*., 2014; Azhar *et al*., 2015; Merritt *et al*., 2017; Atkinson *et al*., 2018).

The counted benthic macroinvertebrate functional groups ratios were used for calculating surrogates five ecosystem attributes (P/R, CPOM/FPOM, TFPOM/BFTOM, habitat stability and P/P) by using a summarized protocol (Table 2.3)**.** The result has shown that in (Table 4.6) the ratio of production to respiration (P/R) varied in the ranges of 0.01 and 0.30. The highest value was observed in site KF and the lowest was in site KD. Thus, according to this numerical value, all sampling stations were heterotrophic (P/R<0.75)**.** The heterotrophic condition recorded in Kipsinende River showing that the carbon present in these waters is originated from the decomposition of riparian vegetation that enters or falls into the river and fewer algae blooming. This idea verified by Merritt *et al*. (2014), suggested that the presence of the heterotrophic condition in the streams indicates carbon in water comes from the decomposition of riparian vegetation. In other words, it never originated from the photosynthetic activity of an autotrophic organism. Secondly, as reported by Masese *et al*. (2014), the predominance of heterotrophy over autotrophic production could be attributed to extensive pollution by livestock waste that tends to promote a high abundance of collectors over scrappers. The riparian area of Kipsinende River was used as a grazing area and cattle wastes are common in most sites (personal Field observation). Masese *et al*. (2014), also reported more heterotrophy in a potentially autotrophic river system in the Kenyan highland streams and attributes it to cattle and human waste in the riparian areas of the rivers.

Similarly, as indicated in (Table 4.6) the ratio of CPOM/FPOM < 0.25 showed that all sites had a non-functioning riparian area which means that the link between shredders and riparian was very poor. The shredders were almost underrepresented. This might be due to the reduction of the riparian forests to supply sufficient litter inputs, for instance, woody vegetation and the presence of various species of riparian plant yields litter. Removal of indigenous vegetation for agricultural and other purposes depletes the allochthonous resources to a river and hence reduces shredder abundances (Minaya *et al*., 2013). Agricultural activities like crop farming are common along Kipsinende River almost all sites except site KE and could be a cause of the non-functional riparian zone. Site KB and KF had adequate stable substrate like bedrocks, boulders, cobbles, debris to provide stable substrates for filter-feeding and scrapping hence the high filter FFG frequency obtained in site KB. However, based on the calculated value the remaining site KA, KC, KD and KE had a lower habitat value from the threshold value (< 0.5). Therefore, this tells us there wasn’t an adequate stable habitat for functional feeding groups of macroinvertebrates. The ratio of TFPOM /BFPOM in all sampling sites was greater than the threshold value (>0.25).

Thus, River Kipsinende had plentiful loading of fine particulate organic matter for filters. In a particular site, KB had very heavy suspended loading of fine particulate organic matter (enough food and good quality of FPOM). While, most of the sites except site KE were overburdened with predators and this also contributed to the overall overburden of predators for the entire river. However, in site KE the top-down predator control to prey was normal. Odonata, Hemiptera and to some extent Diptera are the common predators during this study. In general, the FFG ratios provided evidence of widespread human influences in River Kipsinende in the form of removal of vegetation, livestock grazing, washing activities, and crop farming. This also indicates the extent to which River Kipsinende ecosystem function has been impaired.

5.3 The Relationship between Water Quality and Benthic Macroinvertebrates.

The result on canonical correspondence analysis (CCA) showed the relationship between benthic macroinvertebrates taxa (biological indexes) and water quality parameters. This showed that macroinvertebrates act as bio indicators. Furthermore, most Ephemeroptera genera such as *Adenophlebia*, *Disercomyzon*, *Afronurus* and *Caenis* were abundant in station KE and KF. This could be the presence of high dissolved oxygen in both sites and provide habitat suitable for very sensitive macroinvertebrates. This was in an agreement with Arimoro & Muller (2010); Shelly *et al*. (2011) who related that Ephemeroptera are always the most abundant benthic macroinvertebrates encountered at stations with high dissolved oxygen concentration. Genera of order Diptera (*Chironomus, Chaoborus, Tanyderus*), order Odonata (*Lestes, Gomphus*) and other genera like *Hirudo, Gerris* found in a high abundance at degraded sites (Lyimo, 2012).

In addition, these genera had significant correlation with temperature, salinity, nitrate, and soluble reactive phosphorus (SRP). Benthic macroinvertebrates require the varied optimal temperature to survive, growth and reproduction (Singh & Sharma, 2014; Prommi & Payakka, 2015). In contrast, *Baetis*, *Adenophlebia, Disercomyzon*, and *Potamonaute* had a negative correlation with nitrate and soluble reactive phosphorus (SRP). A similar result was observed in the study by Maneechan & Prommi, (2015), who stated that Baetidae negatively correlated with the concentration of phosphate. Therefore, these taxa can be used as indicators for bioassessment of water quality, as they were limited to clean, oxygenated water and are sensitive to pollutants. Generally, in this study, benthic macroinvertebrates were influenced by the location of the sampling site (upstream or downstream) and also by the sources of anthropogenic activities or land uses (agricultural, mixed and forested area).

5.4 The Relationship between Habitat Quality and Benthic Macroinvertebrates.

The highest total habitat score (72) was recorded at station KE (forested site) and followed by, 68 at station KF, while the lowest results were obtained at station KC (63) and KB (56) (Table 4.7). The observation at site KE can be attributed to less human activities. Human activities (e.g., Animal husbandry, washing and agricultural activities) were common at station KB. Thus, this human activity has the potential to degrade habitat quality in both riparian and river ecosystems. Total habitat quality scores for all stations were generally > 50% (Table 4.7). According to King *et al*. (2000), habitat assessment classification in (Table 2.4) all stations except station KB grouped in class C (60- 79%: moderately modified), where there may have been a loss and modification in natural environment and biota. But site KB grouped underclass 'D' which implies largely modified and loss of natural habitats.

A similar observation was reported by M'Erimba *et al*. (2017), in Mt. Kenya and Aberdare Catchments, Kenya.

The role of habitat quality and physicochemical water quality characteristics determines the presence or absence of benthic macroinvertebrates in aquatic environments (Akasaka *et al*., 2010). The habitat quality parameters such as sediment deposition, bank vegetative protection, embeddedness, riparian vegetation, availability of cover and velocity depth combination had a positive significant positive relationship with the genera of *Disercomyzon, Adenophlebia, Potamonaute, Baetis, Caenis, Afronurus, Afrocaenis, Lumbricus* and *Pisidium* in axis one at station KE and KF. This could be explained by the presence of extensive riparian vegetation along the river's banks which provides them with abundant food resources, allows them to lay eggs, and acts as a refuge zone protecting them from predators. Whereas, genera *Cheumatosyche*, *Gerris, Chironomus, Gomphus, chaoborus, Ephemerythus, Lestes* and *Hirudo* had a negative correlation from those habitat parameters. Similar results were indicated in the Southeast Asian tropical streams (Maneechan & Prommi, 2015). In general, this finding agreed with finding by Brown *et al*. (2011) and Masikini *et al*. (2018), who reported that the abundance, composition structure and of aquatic insect communities is closely related to the physical habitat attributes, substrate type and also influenced by biological factors such as dispersal, competition and predation.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study shown that most water quality parameters in River Kipsinende were within the acceptable limits except for ammonia and soluble reactive phosphorus. However, based on the Water Quality Index on average the water quality status of Kipsinende River was unsuitable for human drinking. The results of this study concluded that sampled stations KB and KE in River Kipsinende had a high macroinvertebrates taxa richness as compared to that of the station KC. The most abundant macroinvertebrate taxa groups were Diptera, followed by Ephemeroptera in station KA and KE, respectively. On the other hand, order Coleoptera, Hemiptera, Odonata, Oligochaeta, and Bivalvia had higher abundance in station KB than other sites. The diversity (Shannon-Wiener values and Simpson's) was high at station KB and KE, but lower in station KA (in agricultural sites).

The results have shown also that there was a high diversity of FFGs namely: predators, gathering-collectors, filtering- collectors, shredders and scrapers. Predators were the most dominant particularly in agricultural sites. However, shredders were the least. Based on functional feeding group ratios ecosystem attributes in River Kipsinende were heterotrophic, a non-functioning riparian area, plentiful of particulate organic matter and overburdened with predators. Thus, this study also concluded that the composition of benthic macroinvertebrates functional feeding groups and ecosystem attributes were affected by the human activities near the river such as agriculture, grazing, deforestation and washing activities which lead to natural habitat quality deterioration and soil erosion.

According to the rapid habitat assessment protocols total habitat quality scores for all stations were generally classified under moderately modified, where a loss and change from natural habitat and biota could have occurred. Environmental variables in the river had a direct and/or indirect impact on macroinvertebrate assemblages, indicating that macroinvertebrates might be used as water quality indicators in the Kipsinende River. In the same way, habitat degradation negatively impacts macroinvertebrate communities.

6.2 Recommendations

On the basis of the findings, it is recommended that:

- To use the water of Kipsinende River for human drinking purposes, it needs special water treatment.
- To minimize the deterioration of the aquatic ecosystem in this area integrated watershed management should be applied.
- Forest ecosystems should be preserved well because of their distinguished role in mitigation of various pollutants as seeing this study.
- The community should be aware (encouraged) to participate in forestry activities either directly through planting trees or indirectly by funding forestry conservation practices.
- To maintain habitat and water quality, the riparian area of River Kipsinende should be free from agricultural activities if possible.
- Further studies to be carried out along the Kipsinende River, incorporating the aspect of seasonality so as to establish the status of water quality during different seasons.

REFERENCES

Abdi, O. A., Glover, E. K., & Luukkanen, O. (2013). Causes and impacts of land degradation and desertification: Case study of the Sudan. *International Journal of Agriculture and Forestry*, 3 (2), 40-51.

Adeogun, O. Aina., and Fafioye, O. Oyebamiji. (2011). Impact of Effluents on Water Quality and Benthic Macroinvertebrate Fauna of Awba Stream and Reservoir. *Journal of Applied Science and Environmental Management,* 15, 105-113. https://doi.org/10.4314/jasem. v15i1.65683

Adu, B. W., Kemabonta, K. A., and Giwa, O. E. (2016). Study of water quality characteristics and benthic macroinvertebrate assemblages of Aahoo stream, Akure, southwestern Nigeria. *Nigeria Journal of Scientific Research*, 15 (3), 499–504.

Agency, E. P., Taft, R. A., and Jones, C. (2001). Sediment sampling guide and methodologies. Columbus, State of Ohio. 43216-1049.

Akaahan, T. J. A., Araoye, P. A. and Azua, E. T. (2014). Phyisco-Chemical Characteristics and Macro Invertebrates of River Benue at Makirdi, Benue State, Nigeria. *The International Journal of Science & Techno ledge,* 1 (06), 66-73. https://doi.org/10.18483/IRJSci.64

Akoteyon, I.S, Omotayo, A.O, Soladoye, O. and Olaoye, H.O. (2011). Determination of water quality index and suitability of urban river for municipal water supply in Lagos, Nigeria. *European Journal of Scientific Research*, 54 (2), 263–271.

Aktar, P., and Moonajilin, M.S. (2017). Assessment of water quality status of Turag River due to industrial effluent. *International Journal of Engineering and Information Systems,* 1 (6), 105-118.

Akudo, E. O., Ozulu, G. U. and Osogbue, L. C. (2010). Quality Assessment of Groundwater in Selected Waste Dumpsites Areas in Warri, Nigeria. *Environmental Research Journal*, 4 (4), 281-285. https://doi.org/10.3923/ERJ.2010.281.285

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., *et al*. (2015). Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecology Letters,* 18, 834-843.

Allan, J. D., Arbor, A., and Allan, J. D. (2012). The Influence of Land Use on Stream Ecosystems, 35, 257–284.

Andem, A. B., Okorafor, K. A., Udofia, U., Okete, K. A., and Ugwumba, A. A. A. (2012). Composition, distribution and diversity of benthic macroinvertebrates of Ona River, Southwest, Nigeria. *European Journal of Zoological Research*, 1 (2), 47-53.

Andrade, I. C. P., Krolow, T. K., Boldrini, R., & Pelicice, F. M. (2020). Diversity of EPT (Ephemeroptera, Plecoptera, Trichoptera) along streams fragmented by waterfalls in the Brazilian Savanna. *Neotropical entomology*, 49 (2), 203-212.

Angweya, R., Okungu, J., Abuodha, J. O. Z., and Hecky, R. E. (2012). Environmental impacts of water quality change on beneficial uses of Lake Victoria, 307-327 pp.

APHA (1998). Standard Methods for the Examination of Water and Wastewater, 20th edn. American Public Health Association, Washington, DC.

Arimoro, F.O., and Muller, W.J. (2010). Mayfly (Insecta: Ephemeroptera) community structure as an indicator of the ecological status of a stream in the Niger Delta area of Nigeria. *Environmental Monitoring Assessment*, 166, 581–594.

Atkinson, C. L., A. C. Encalada; A. T. Rugenski; S. A. Thomas; A. Landeira-Dabarca; N. L. Poff *et al*. (2018). Determinants of food resource assimilation by stream insects along a tropical elevation gradient. *Oecologia*, 187 (3), 731-744.

Aura, C.M., Raburu, P.O., and Herman, J. (2010). A preliminary macroinvertebrate Index of Biotic Integrity for bioassessment of the Kipkaren and Sosiane Rivers, Nzoia River basin, Kenya. *Lakes & Reservoirs: Research and Management*, 15, 119–128. https://doi.org/10.1111/j.1440-1770.2010.00432.x

Ayobahan, S.U, Ezenwa, I.M, Lorogun, E.E, Uriri, J.E. and Wemimo, I. (2014). Assessment of anthropogenic activities on water quality of Benin river. *Journal of Applied Sciences and Environmental Management*, 18 (4), 629-636. https://doi.org/ 10.4314/jasem. v18i4.11

Azhar, B., N. Saadun, C. L. Puan, N. Kamarudin, N. Aziz, S. Nurhidayu, and J. Fischer. (2015). Promoting landscape heterogeneity to improve biodiversity benefits to certified palm oil production: evidence from Peninsular Malaysia. *Global Ecology and Conservation*, 3, 553-561.

Balan, I.N, Shivakumar, M, and Kumar, P.D.M. (2012). An assessment of groundwater quality using water quality index in Chennai Tamil Nadu India. *Chronicles of Young Scientists*, 3 (2), 146–150. https://doi.org/10.4103/2229-5186.98688

Banetti, C.J, and Garrido, J. (2010). The influence of stream habitat and water quality on water beetles' assemblages in two rivers in northwest Spain. *Life & Environment*, 60 (1), 53-63.

Barata, C., Fabregat, M. C., Cotín, J., Huertas, D., Solé, M., Quirós, L., ... & Piña, B. (2010). Blood biomarkers and contaminant levels in feathers and eggs to assess environmental hazards in heron nestlings from impacted sites in Ebro basin (NE Spain). *Environmental Pollution*, 158 (3), 704-710.

Barbee, N. C. (2005). Grazing insects reduce algal biomass in a neotropical stream. *Hydrobiologia*, 532, 153-165. https://doi.org/10.1007/s10750-004-9527-z

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. (1999). Rapid bioassessment protocols for use in streams and wadable rivers: Periphyton, benthic macroinvertebrates, and Fish. 2nd edition. Report number EPA 841-B-99-002. US EPA, Washington, 339p.

Bartlett-Healy, K., Unlu, I., Obenauer, P., Hughes, T., Healy, S., Crepeau, T., *et al*. (2012). Larval Mosquito Habitat Utilization and Community Dynamics of Aedes albopictus and Aedes japonicus (Diptera: Culicidae). *Journal of Medical Entomology*, 49 (4), 813-824.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., *et al*., (2016). Contribution of fisheries and aquaculture to food security and poverty reduction: Assessing the current evidence. *World Development*, 79, 177–196. https://doi.org/10.1016/j.worlddev.2015.11.007

Benini, L., V. Bandini., D. Marazza., and A. Contin. (2010). Assessment of land use changes through an indicator-based approach: a case study from the Lamone river basin in Northern Italy. *Ecological Indicators*, 10 (1), 4–14.

Bere, T., Mangadze, T., and Mwedzi, T. (2014). The application and testing of diatom-based indices of stream water quality in Chinhoyi Town, Zimbabwe. *African Journals online*, 40 (40), 503–512. http://doi.org/ 10.4314/wsa. v40i3.14

Bharti, N., and Katyal, D. (2011). Water quality indices used for surface water vulnerability assessment. *Journal of Environmental Sciences*, 2 (1), 154–173.

Bhaskar, M. and Dixit, A.K. (2013). Water quality appraisal of Hasdep river at Korba in Chhatishgada, India. *International Journal of Science and Research*, 4 (9), 1252-1258.

Bhateria, R., and Abdullah, A. (2015). Analyzing uncertainties in lake water: A review, 5 (6), 155–168. http://doi.org/10.6088/ijes.6018

Birk, S., Bonne, W., Borja, A., Brucet, S., Courrat, A., Poikane, S., *et al*., (2012). Three hundred ways to assess Europe's surface waters: an almost complete overview of biological methods to implement the Water Framework Directive. *Ecological Indicators*, 18, 31-41. https://doi.org/10.1016/j.ecolind.2011.10.009

Boggs, J., Sun, G., and McNulty, S. (2016). Effects of timber harvest on water quantity and quality in small watersheds in the Piedmont of North Carolina. *Journal of Forestry*, 114 (1), 27–40.

Boyero, L., Pearson, R.G., Dudgeon, D., Graça, M.A.S., Gessner, M.O., Albariño, R.J., *et al*. (2011). Global distribution of a key trophic guild contrasts with common latitudinal diversity patterns. *Ecology*, 92 (9), 1839-1848. https://doi.org/10.1890/10-2244.1

Brasil, L.S., Juen, L., Batista, J.D, Pavan, M.G, and Cabette, H.S.R. (2014). Longitudinal Distribution of the Functional Feeding Groups of Aquatic Insects in Streams of the Brazilian Cerrado Savanna. *Neotropical Entomology,* 43, 421–428. https://doi.org/10.1007/s13744-014-0234-9

Brooks, K. N., Hans, M.G., and F. F. Peter (2007). Integrated watershed Management. Connecting People to their land and water. Cambridge: Cambridge University Press. 288 p.

Brown, B. L., Swan, C. M., Auerbach, D. A., Hitt, N. P., Maloney, K. O., and Patrick, C. (2011). Metacommunity theory as a multispecies, multiscale framework for studying the influence of river network structure on riverine communities and ecosystems. *Journal of the North American Benthological Society*, 30, 310–327. https://doi:10.1899/10- 129.1

Bwalya, E. (2015). Assessment of water quality in urban rivers: A case study of Mansa river in Luapula province of Zambia. University of Zimbabwe faculty of engineering department of Civil engineering (MSc Thesis).

Camara, M., Jamil, N. R., Fikri, A., and Abdullah, B. (2019). Impact of land uses on water quality in Malaysia: a review. *Ecological Processes*, 8 (1), 10. https://doi.org/10.1186/s13717-019-0164-x

Carr, G. M., & Rickwood, C. J. (2008). Water quality index for biodiversity technical development document. *UNEP GEMS/Water Programme, Gatineau, CANADA: Prepared for Biodiversity Indicators Partnership: World Conservation Monitoring Center*.

Chang, M., Di, Z., and P. Guo. (2019). Water Quality Evaluation of the Yangtze River in China Using Machine Learning Techniques and Data Monitoring on Different Time Scales. *Water*, 11 (2), 339. https://doi.org/10.3390/w11020339

Chauhan, A., and Singh, S. (2010). Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and opinion*, 2 (9), 53-61.

Chebet, E., Mbui, D., Kamau, G., and J. Kibet. (2016). The State of Water Quality in Nairobi River, Kenya. *Asian Journal of Research in Chemistry*, 9 (11), 579-586. https://doi.org/10.5958/0974-4150.2016. 00078.X

Chikodzi, D., Mabhegedhe, M., and Tunha, T. K. (2017). Biomonitoring of Mucheke and Shagashe Rivers in Masvingo, Zimbabwe Using Macro-Invertebrates as Indicators of Water Quality. *Journal of Geoscience and Environment Protection*, 5 (09), 221-237.

Chowdhury, R.M, Muntasir, S.Y, and Hossain, M.M. (2012). Water Quality Index of water bodies along Faridpur-Barisal Road in Bangladesh. *Global Engineering & Technologists Review*, 2, 1–8.

Chrisoula, B.P., Vasiliki, K. G., and Savvas, C. T. (2011). Abundance, diversity, and distribution of macrophyte communities in neighboring lakes of different trophic states and morphology in north-central GREECE. *Archives of Biological Science, Belgrade*, 63 (3), 125– 142. https://doi.org/10.2298/ABS1103763P

CIDP (County Integrated Development Plan) (2018). Enhancing Food Security, Productive Investments and Social Welfare. County Government of Elgeyo Marakwet.

Cooper, S. D., Lake, P. S., Sabater, S., Melack, J. M., & Sabo, J. L. (2013). The effects of land use changes on streams and rivers in mediterranean climates. *Hydrobiologia*, 719 (1), 383-425.

Couceiro, S., Hamada, N., Sagot, L., and Pepinelli, M. (2014). Black-fly assemblage distribution patterns in streams in disturbed areas in southern Brazil. *Acta Tropica*, 140, 26-33.

Cummins, K. W., R. W. Merritt, and P. Andrade. (2005). The use of invertebrate functional groups to characterize ecosystem attributes in selected streams and rivers in southeast Brazil. *Studies on the Neotropical Fauna and Environment*, 40, 69–89.

Cummins, K.W. (2016). Combining taxonomy and function in the study of stream macroinvertebrates. *Journal of Limnology*, 75 (s1), 235-241.

Cunningham, W.L, and Schalk, C.W. (2011). Ground water technical procedures of the U.S Geological Survey- Measuring water levels by use of a graduated steel tape: U.S Geological Survey Techniques and methods, 1–A1, 151 p.

Dalu, T., and Froneman, P. W. (2016). Diatom-based water quality monitoring in southern Africa: Challenges and future prospects. *Water South A*frica, 42 (4), 551-559.

Davie, T. (2008). Fundamentals of Hydrology. Routledge Fundamentals of Physical Geography. London, UK: Taylor & Francis e-Library.

Davies, M. L., and D. A. Cornwell (2017). Introduction to Environmental Engineering 5th Edition. New York: McGraw Hill Education India. Delta, Nigeria. Environmentalist, 28, 85–98.

Deborde, D. D. D., Hernandez, M. B. M., and Magbanua, F. S. (2016). Benthic macroinvertebrate community as an indicator of stream health: the effects of land use on stream benthic macroinvertebrates. *Science Diliman*, 28 (2), 5-26.

Dedieu, N., Rhone, M., Vigouroux, R., and Céréghino, R. (2015). Assessing the impact of gold mining in headwater streams of Eastern Amazonia using Ephemeroptera assemblages and biological traits. *Ecological Indicators*, 52, 332-340. http://dx.doi.org/10.1016/j.ecolind.12.012

Deepa, P., Raveen, R., Venkatesan, P., Arivoli, S., and Samuel, T. (2016). Seasonal variations of physicochemical parameters of Korattur Lake, Chennai, Tamil Nadu, India. *International Journal of Chemical Studies*, 4 (3), 116-123.

Dhinamala, K., Pushpalatha, M., Samuel, T., and Raveen, R. (2015). Spatial and temporal variations in the water quality parameters of Pulicat Lake, Tamil Nadu, India. *International Journal of Fisheries and Aquatic Studies*, 3 (2), 67-78.

Dickens, C.W.S., and Graham, P.M. (2002). The South African Scoring System Version 5 Rapid Bioassessment for Rivers. *African Journal of Aquatic Science*, 27, 1-10.

Dietz, M. E., and Clausen, J. C. (2008). Stormwater runoff and export changes with development in a traditional and low impact subdivision. *Journal of environmental management*, 87 (4), 560-566.

Ding, N., Yang, W., Zhou, Y., González-Bergonzoni, I., Zhang, J., Chen, K., *et al*. (2017). Different responses of functional traits and diversity of stream macroinvertebrates to environmental and spatial factors in the Xishuangbanna watershed of the upper Mekong river basin, China. *Science of Total Environment*, 574, 288–299. http://dx.doi.org/10.1016/j.scitotenv.2016.09.053

Dipankar, G., and Jayanta, K.B. (2015). Biomonitoring Macrophytes Diversity and Abundance for Rating Aquatic Health of an Oxbow Lake ecosystem in Ganga River Basin. *American Journal of Phytomedicine and Clinical Therapeutics*, 3 (10), 602-621.

Dobson, M., Magana, A., Mathooko, J. M., & Ndegwa, F. K. (2002). Detritivores in Kenyan highland streams: more evidence for the paucity of shredders in the tropics? *Freshwater biology*, 47(5), 909-919.

Dodds, W.K. and Smith, V.H. (2016). Nitrogen, phosphorus, and eutrophication in streams. *Inland Waters*, 6(2), 155-164. http://dx.doi.org/10.5268/IW-6.2.909

Efe, O., Kokoette, E. I., and Alex, U. A. A. (2012). Physico-chemical parameters and benthic macroinvertebrates of Ogunpa River at Bodija, Ibadan, Oyo State. *European Journal of Scientific Research*, 85 (1), 89–97. http://dx.doi.org/10.19026/rjees.5.5722

Ekpo, I.E., Chude, L.A., and Onuoha, G.C. (2012). The use of multivariate analysis for characterization and classification of Ikpa River, Nigeria. *Elixir Agriculture*, 49, 9799-9807.

Elias, J. D., Ijumba, J. N., Mgaya, Y. D., and Mamboya, F. A. (2014). Study on Freshwater Macroinvertebrates of Some Tanzanian Rivers as a Basis for Developing

Biomonitoring Index for Assessing Pollution in Tropical African Regions. *Journal of Ecosystems*, 26, 1-8.

Etim, E.E., Obor, R., Itodo, A.U., Umoh, S.D., and Lawal, U. (2013). Water quality index for the assessment of water quality from different sources in the Niger Delta region of Nigeria. *Frontiers in Science*, 3 (3), 89-95. http://dx.doi.org/10.5923/j.fs.20130303.02

FAO (2010). Food and Agriculture Organization of the United Nations: Global Forest Resources Assessment Main report, FAO Forestry Paper 163, Rome.

FAO (2018). Impacts of Climate Change on Fisheries and Aquaculture. Synthesis of current knowledge, adaptation and mitigation options. Fisheries and Aquaculture Technical paper 627.

Farnham C., Nakao M, Nishioka, M., Nabeshima, M., and Mizuno, T. (2015). Effect of water temperature on evaporation of mist sprayed from a nozzle. *Journal of Heat Island Institute International*, 10, 35-40.

Favretto, M. A., Orlandin, E., Santos, B., and Piovesan, M. (2014). Insetos aquáticos em um lago artificial no sul do Brasil. *Biota Amazônia*, 4 (4), 113-116. http://dx.doi.org/10.18561/2179-5746

Ferreira, V., A. C. Encalada, and M. A. S. Graça. (2012). Effects of litter diversity on decomposition and biological colonization of submerged litter in temperate and tropical streams. *Freshwater Science*, 31 (1), 945–962. http://dx.doi.org/10.1899/11-062.1

Fitzpatrick, J., & Emrick, V. (2019). Using Rapid Bio-assessment and Habitat Evaluation Methods to Understand the Effects of Different Land Uses on a Privately-owned River in Southwest Virginia. *Journal of Young Investigators*, 37 (6).

Friberg, F. N., Bonada, N., Bradley, D. C., Dunbar, M. J., Edwards, K., Grey, J., *et al*. (2011). Biomonitoring of Human Impacts in Freshwater Ecosystems: The Good, the Bad and the Ugly. *Advances in Ecological Research*, 44,1-68. http://dx.doi.org/10.1016/B978-0-12-374794-5.00001-8

Fuchaka, W., Mwamburi, M., and Millicent, M. (2020). Declining Wood Fuel and Implications for Household Cooking and Diets in Tigania Sub-County Kenya. *Scientific African*, https://doi.org/10.1016/j.sciaf.2020.e00417

Gandaseca, S., Rosli, N., Ngayop, J., and Arianto, C. I. (2011). Status of water quality based on the physico-chemical assessment on river water at wildlife sanctuary Sibuti Mangrove forest, Miri Sarawak, *American Journal of Environmental Sciences*, 7 (3), 269–275. http://dx.doi.org/10.3844/AJESSP.2011.269.275

Gasim, M. B., W. N. Azmin, and M. I. Yaziz (2012). Land use change and their impact on water quality in the Semenyih River, Selangor, Malaysia. *Journal Technology Mineral*, 2, 103– 111.

Gaskill, J. A. (2014). Examining the Effects of pH and Macrophyte Diversity on Benthic Macroinvertebrate Assemblages in Adirondack Lakes. Honors Theses. Paper 35.

Gayathri, S., Latha, N., and Mohan, M.R. (2013). Impact of climate change on water quality of Shoolkere Lake, Bangalore. *Journal of Academia and Industrial Research*, 2 (6), 23-34.

George, B., Kumar, J., and Kumar, R.N. (2012). Study on the influence of hydrochemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. *Egyptian Journal Aquatic Research*, 38, 157-70 https://doi.org/10.1016/j.ejar.2012.12.010

George, O. Achieng., Victor, O. Shikuku., Dickson, M. Andala, George, M. Okowa, and James J. Owuor. (2019). Assessment of water quality of the Nyando River (Muhoroni-Kenya) using the water quality index (WQI) method. *International Research Journal Environmental Sciences*, 8 (2), 27-33.

Ghosh, D., and Biswas, J. K. (2015). Macroinvertebrate diversity indices: A quantitative bioassessment of ecological health status of an oxbow lake in Eastern India. *Journal of advances in environmental health research,* 3 (2), 78-90.

Giri, S., and Qiu, Z. (2016). Understanding the relationship of land uses and water quality in twenty first century: a review. *Journal of Environmental Management*, 173: 41–48. https://doi.org/ 10.1016/J.JENVMAN.2016.02.029.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L. (1993). Stream hydrology: an introduction for ecologist. John Wiley & Sons, New York, 526 p.

Gosselain, V. C., Hudon, A. P., Gagnon, D. P., and Rochefort, D. (2005). Physical variables driving epiphytic algal biomass in a dense macrophyte bed of the St. Lawrence River (Quebec, Canada). *Hydrobiologia*, 534, 11–22.

Griffin, D., Myers, S., and Sloan, S. (2015). Implications on Distribution and Abundance of Benthic Macroinvertebrates in the Maple River Based on Water Quality and Habitat Type. *General Ecology*, 381, 1-17. http://hdl.handle.net/2027.42/116397

Gupta, A., Toscano, S., Trivedi, D., Jones, D., Mathre, S., Clarke, J., *et al*. (2013). Phosphatidylinositol 5-phosphate 4-kinase regulates TOR signaling and cell growth during Drosophila development. *Proceedings of the National Academy of Sciences*, 110 (15), 5963-5968.

GWP (Global Water Partnership) (2015). Integrated Water Resources Management in Eastern Africa. Technical Focus Paper.1-50pp.

Hannaford, M. J., & Resh, V. H. (1995). Variability in macroinvertebrate rapid-bioassessment surveys and habitat assessments in a northern California stream. Journal of the North American Benthological Society, 14 (3), 430-439.

Hasan, S. S., Zhen, L., Miah, M. G., Ahamed, T., & Samie, A. (2020). Impact of land use change on ecosystem services: A review. *Environmental Development*, 34, 100527.

Hellar-Kihampa, H., de Wael, K., Lugwisha, E., and van Grieken, R. (2013). Water quality assessment in the Pangani River basin, Tanzania: Natural and anthropogenic influences on the concentrations of nutrients and inorganic ions. *International Journal of River Basin Management*, 11, 55–75. https://doi.org/10.1080/15715124.2012.759119

Houghton, D. C., (2015). Delineation and characterization of Michigan, USA, caddisfly (Insecta: Trichoptera) biodiversity and comparison with Minnesota. *Journal of Freshwater Ecology*, 50 (60), 1-18. https://doi.org/10.1080/02705060.2014.1002544

Huang, J., Huang, Y., and Zhang, Z. (2014). Coupled Effects of Natural and Anthropogenic Controls on Seasonal and Spatial Variations of River Water Quality during Baseflow in a Coastal Watershed of Southeast China. *PLoS ONE*, 9 (3), 137. https://doi.org/10.1371/journal.pone.0091528

Hülya, B., (2009). Utilization of the water quality index method as a classification tool. *Environmental Monitoring and Assessment*, 167 (1-4), 115-24. https://doi.org/10.1007/s10661-009-1035-1

Iqbal, M.A., Maqsood, Q., Ahmad, Z., Saleem, A.M., Afzal, S., and Ahmad, B. (2015). A Preliminary Study on Plant Nutrients Production as Combined Fertilizers, Consumption Patterns and Future Prospects for Pakistan. *Agriculture & Environmental Science*, 15 (4), 588-594.

Javier, Mateo-Sagasta., Zadeh, S. M., Turral, H., and Burke, J. (2017). Water pollution from agriculture: a global review. Executive summary. Rome, Italy: FAO; Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, *Land and Ecosystems* (WLE). 35p.

Jinggut, T., C. M. Yule., and L. Boyero. (2012). Stream ecosystem integrity is impaired by logging and shifting agriculture in a global megadiversity centre (Sarawak, Borneo). *Science of the Total Environment*, 437, 83–90. https://doi.org/10.1016/j.scitotenv.2012.07.062

Jones, N.E. (2011). Electrofishing Rivers: Nearshore Community. Sampling Methodologies for Ontario's Flowing Waters. Ontario Ministry of Natural Resources, Aquatic Research and Development Section, River and Stream Ecology Lab, *Aquatic Research Series,* 6, 11-23.

Jun, Y-C., Kim, N-Y., Kim, S-H., Park, S-H., Kong, D-S., and Hwang, S-J. (2016). Spatial distribution of benthic macroinvertebrate assemblages in relation to environmental variables in Korean nationwide streams. *Water*, 8, 1–20. https://doi.org/10.3390/w8010027

Karaouzas, I., Dimitriou, E., Lampou, A., and Colombari, E., (2015). Seasonal and spatial patterns of macroinvertebrate assemblages and environmental conditions in Mediterranean temporary ponds in Greece. *Limnology,* 16 (1), 41–53. https://doi.org/10.1007/s10201-014-0437-0

Karrouch, L., Chahlaoui, A., & Essahale, A. (2017). Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Boufekrane River, Meknes, Morocco. *Journal of Geoscience and Environment Protection*, 5 (07), 173.

Kasangaki, A., Babaasa, D., Efitre, J., McNeilage, A., & Bitariho, R. (2006). Links between anthropogenic perturbations and benthic macroinvertebrate assemblages in Afromontane forest streams in Uganda. *Hydrobiologia*, 563 (1), 231-245.

Kasangaki, A., Chapman, L. J., and Balirwa, J. (2008). Land use and the ecology of benthic macroinvertebrate assemblages of high-altitude rainforest streams in Uganda. *Fresh water biology*, 53 (4), 681-697. http://doi.org/10.1111/j.1365-2427.2007.01925.x.

Kennedy, M. P., Lang, P., Tapia, J., Varandas, S., Bruce, A., Hastie, A., Lowe, S., *et al*. (2015). Environmental drivers of aquatic macrophyte communities in southern tropical African rivers: Zambia as a case study. *Aquatic Botany*, 124, 19–28. https://doi.org/10.1016/j.aquabot.2015.03.002

Khwakaram, A.I., Majid, S.N., and Hama, N.Y. (2012). Determination of water quality index (WQI) for Qalyasan stream in Sulaimani City/Kurdistam region of Iraq. *International Journal of Plant, Animal and Environmental Science*, 2 (4), 148-157.

Kibena, J., Nhapi, I., and Gumindoga, W. (2014). Assessing the relationship between water quality parameters and changes in land use patterns in the Upper Manyame River, Zimbabwe. *Physics and Chemistry Earth Parts*. 67: 153–163. https://doi.org/10.1016/j.pce.2013.09.017.

Kibichii, S., Shivoga, W. A., Muchiri, M., & Miller, S. N. (2007). Macroinvertebrate assemblages along a land-use gradient in the upper River Njoro watershed of Lake Nakuru drainage basin, Kenya. *Lakes & Reservoirs: Research & Management*, 12 (2), 107-117.

Kibria, G., Hossain, M. M., Mallic, D., Lau, T. C., and Wu, R. (2016). Trace/heavy metal pollution monitoring in estuary and coastal area of Bay of Bengal, Bangladesh and implicated impacts. *Marine Pollution Bulletin*, 105 (1), 393-402. https://doi.org/10.1016/j.marpolbul.2016.02.021

King, J. M., Tharme, R. E., & De Villiers, M. S. (2000). *Environmental flow assessments for rivers: manual for the Building Block Methodology* (p. 340). Pretoria: Water Research Commission.

Kiptum, C. K., Kipkorir, E. C., and T. M. Munyao. (2013). Optimization of Benefits from Cabbage farming by Staggering Transplanting Dates during the Dry Season in

Keiyon Highlands, Kenya. *Research Journal of Chemical and Environmental Sciences*, 1 (3), 56-62.

Kithiia, S.M., (2012). Effects of Sediments Loads on Water Quality within the Nairobi River Basins, Kenya. *International Journal of Environmental Protection*, 2, 16-20.

Koneri, R., Nangoy, M.J., and Saroyo, T.E.T. (2017). Diversity and community composition of dragonfly (Insecta: Odonata) in Tangkoko Nature Reserve North Sulawesi, Indonesia. *Bioscience Research*, 14 (1), 01–08.

Kuligiewicz, A. R., Bialik, R. J., and Rowinski, P. M. (2015). Dissolved oxygen and water temperature dynamics in lowland rivers over various timescales. *Journal of Hydrology and Hydromechanics*, 63 (4), 353-363. https://doi.org/10.1515/johh-2015-0041

Lakew, A., and O. Moog (2015). A multimeric index based on benthic macroinvertebrates for assessing the ecological status of streams and rivers in central and southeast highlands of Ethiopia. *Hydrobiologia*, 751 (1), 229-242. https://doi.org/10.1007/s10750-015-2189-1

Leahy, M. (2016). Habitat determinants of Chaetodon butterflyfish and fishery-targeted coral reef fish assemblages in the central Philippines, PhD Dissertation, James Cook University.1-184.

Li, L., Zheng, B., and Liu, L. (2010). Biomonitoring and Bioindicators Used for River Ecosystems: Definitions, Approaches and Trends. *Procedia Environmental Sciences*, 2, 1510–1524. https://doi.org/10.1016/j.proenv.2010.10.164

Lindborg, R. (2015). Implications of climate and land-use change for landscape processes, biodiversity, ecosystem services, and governance. *AMBIO A Journal of the Human Environment*, 44, 1–5. https://doi.org/10.1007/s13280-014-0596-6

Lomurut, J. A. (2014). A first-generation digital soil map of a portion of the Uasin Gishu Plateau, Kenya.

Lumb, A., Sharma, T. C., and Bibeault, J. F. (2011). A review of genesis and evolution of water quality index (WQI) and some future directions. *Water Quality Exposure and Health*, 3 ,11– 24. https://doi.org/10.1007/s12403-011-0040-0

Lyimo, E. (2012). Amphibian and Benthic Macroinvertebrate Response to Physical and Chemical Properties of Themi River, Arusha, Tanzania, Faculty of Applied Ecology and Agricultural Sciences, Hedmark University College, Elverum, Norway.

M'Erimba, C.M., Mathooko, J.M., Karanja, H.T., and Mbaka, J.G. (2014). Monitoring water and habitat quality in six rivers draining the Mt. Kenya and Aberdare Catchments using Macroinvertebrates and Qualitative Habitat Scoring. *Egerton Journal Science & Technology*, 14, 81-104.

Magurran, A. E. (2013). *Measuring biological diversity*. John Wiley and Sons, New York, USA, 285-286pp.

Magurran, A.E. (1988). *Ecological diversity and its measurements.* London: Croom Helm Press. 24 p.

Mandaville, S. M. (2002). *Benthic macroinvertebrates in freshwaters: Taxa tolerance values, metrics, and protocols* (Vol. 128, p. 315). Nova Scotia: Soil & Water Conservation Society of Metro Halifax.

Maneechan, W., and Prommi, T. O. (2015). Diversity and distribution of aquatic insects in stream of the Mae Klong watershed, western Thailand. *A Journal of Entomology*, 2, 1-7. https://doi.org/10.1155/2015/912451

Margalef, R. (1958). Information theory in ecology. *International Journal of General Systems*, 3, 36–71.

Mariadoss, S., and Ricardo, A. (2015). Water Quality Assessment of Piatua River Using Macroinvertebrates in Puyo, Pastaza, Ecuador. *American Journal of Life Sciences*, 3 (3), 67 https://doi.org/10.11648/j.ajls.20150303.17

Marius, A. R., Gabriel, P., Ștefan, A. S., & Mircea, N. (2014). Study of macroinvertebrate diversity and seasonal dynamics from Bădărău Lake–IAŞI, Romania. *Faculty of Biology, Alexandru Ioan Cuza University, Bd. Carol I, 11*, 700506.

Masere, T. P., Munodawafa, A., and Chitata, T. (2012). Assessment of human impact on water quality along Manyame River. *International Journal of Development and Sustainability,* 1 (3), 754–765.

Masese, F. O., & Raburu, P. O. (2017). Improving the performance of the EPT Index to accommodate multiple stressors in Afrotropical streams. *African Journal of Aquatic Science*, 42 (3), 219-233.

Masese, F. O., Kitaka, N., Kipkemboi, J., Gettel, G. M., Irvine, K., & McClain, M. E. (2014). Litter processing and shredder distribution as indicators of riparian and catchment influences on ecological health of tropical streams. *Ecological Indicators*, 46, 23-37.

Masese, F. O., Muchiri, M., & Raburu, P. O. (2009). Macroinvertebrate assemblages as biological indicators of water quality in the Moiben River, Kenya. *African Journal of Aquatic Science,* 34 (1), 15-26.

Masese, F. O., Kitaka, N., Kipkemboi, J., Gettel, G. M., Irvine, K., & McClain, M. E. (2014). Macroinvertebrate functional feeding groups in Kenyan highland streams: evidence for a diverse shredder guild. *Freshwater Science*, *33*(2), 435-450.

Masese, F.O., McClain, M.E., Irvine, K., Gettel, G.M., Kitaka, N., and Kipkemboi, J. (2012). Macro-invertebrate shredders in upland Kenyan streams; influence of land use on abundance, biomass and distribution. In: 3rd Lake Victoria Basin Scientific conference, Entebbe, Uganda.

Masikini, R., Tunu, L., and Chicharo, L. (2018). Ecohydrology & Hydrobiology Evaluation of ecohydrological variables in relation to spatial and temporal variability of macroinvertebrate assemblages along the Zigi River Tanzania. *Integrative Medicine Research*, 18 (2), 130–141.

Mbaka, J.G., M'Erimba, C.M., Thiongo, H.K., and Mathooko, J.M. (2014). Water and habitat quality assessment in the Honi and Naro Moru rivers, Kenya, using benthic macroinvertebrate assemblages and qualitative habitat scores. *African Journal of Aquatic Science*, 39 (4), 361-368. https://doi.org/10.2989/16085914.2014.976168

McGarvey, D. J., and Terra, B. F. (2015). Using river discharge to model and deconstruct the latitudinal diversity gradient for fishes of the Western Hemisphere. *Journal of Biogeography*, 7, 1436-1449. https://doi.org/10.1111/jbi.12618

Mero, R. (2011). Assessment of water quality and spatial distribution of the major pollutants in Ngerengere River Catchment, Tanzania. University of Zimbabwe faculty of engineering department of Civil engineering (MSc Thesis).

Merritt, R. W., Cummins, K. W., & Berg, M. B. (2017). Trophic relationships of macroinvertebrates. In *Methods in Stream Ecology, Volume 1* (pp. 413-433). Academic Press.

Merritt, R. W., Cummins, K. W., and Berg, M. (2008). *An introduction to the aquatic insects of North America.* Iowa: Kendall/Hunt Publishing Company.

Merritt, R. W., Cummins, K. W., & Campbell, E. Y. (2014). Uma abordagem funcional para a caracterização de riachos brasileiros. *Insetos Aquáticos na Amazônia Brasileira: taxonomia, biologia e ecologia*.

Miller, S.W., Budy, P., and Schmidt, J.C. (2010). Quantifying macroinvertebrate responses to in-stream habitat restoration: Applications of meta-analysis to river restoration. *Restoration Ecology,* 18 (1), 8–19. https://doi.org/10.1111/j.1526-100X.2009. 00605.x

Minaya, V., McClain, M.E., Moog, O., Omengo, F., and Singer, G. (2013). Scale-dependent effects of rural activities on benthic macro-invertebrates and physico-chemical characteristics in headwater streams of the Mara River, Kenya. *Ecological Indicators*, 32, 116–122.

Mohamed, A.F., Toufeek, and Mostafa, A. K. (2009). Physicochemical Characteristics of Water Quality in Lake Nasser Water. *Global Journal of Environmental Research*, 3 (3), 141-148.

Monoj, K., and Padhy, P.K. (2013). Discourse and Review of Environmental Quality of River Bodies in India: An Appraisal of Physico-chemical and Biological Parameters as Indicators of Water Quality. *International Research Journal of Environment of Sciences*, 2 (1), 79-87.

Morphin-Kani, K., and Murugesan, A.G. (2014). Assessment of River Water Quality Using Macroinvertebrate Organisms as Pollution Indicators of Tamirabarani River Basin, Tamil Nadu, India. *International journal of Environmental Protection,* 4, 1-14.

Morrissey, C.A, Boldt, A., Mapstone, A., Newton, J., and Ormerod, S.J. (2013). Stable isotopes as indicators of wastewater effects on the macroinvertebrates of urban rivers. *Hydrobiologia,* 700 (1), 231-244. https://doi.org/10.07/s10750-012-1233-7

Muthulakshmi, L., Arasu, P.T., Ilavarasi, R., and Selvanayagam, S. (2015). Hydrochemical trend of ground water Rajapalayam town, Tamil Nadu, India. *Journal of Materials and Environmental Science*, 6 (4), 1004-1008.

Mwangi, F. N. (2014). *Land use practices and their impact on the water quality of the upper Kuils River (Western Cape Province, South Africa)* (Doctoral dissertation, University of Western Cape).

Narany, T.S, Aris, A.Z, Sefie, A., and Keesstra, S. (2017). Detecting and predicting the impact of land use changes on groundwater quality, a case study in Northern Kelantan. *Malaysia Science of Total Environment*, 599, 844–853. https://doi. org/10.1016/j.scitotenv.2017.04.171

Navneet, K., and Sinha, D. K. (2010). An Approach to River Water Quality Management through Correlation Study among Various Water Quality Parameters. *Indian journal of environmental health*, 51 (2), 253-259.

Ndaruga, A. M., Ndiritu, G. G., Gichuki, N. N., & Wamicha, W. N. (2004). Impact of water quality on macroinvertebrate assemblages along a tropical stream in Kenya. *African Journal of Ecology*, 42 (3), 208-216.

Nichols, J.R. (2012). Macroinvertebrate *Assemblage Composition along a Longitudinal Multiple-Land-Use Gradient in a Midwestern Stream*. Master's Thesis, University of Missouri, Columbia, MO, USA.

Niculae, M., Kiss, T., and Dana, C., (2013). Human impact on the microbiological water quality of the rivers. *Journal of Medical Microbiology*, 62, 1635–1640. https://doi.org/10.1099/jmm.0.055749-0

Nowak, A., and Schneider, C. (2017). Environmental characteristics, agricultural land use, and vulnerability to degradation in Malopolska Province (Poland). *Science of the Total Environment*, 590, 620-632.

Oates, N., and Parker. H. (2016). How do Healthy Rivers Benefit Society? Working Paper 430, 9p.

Odume, O. N., Muller, W. J., Arimoro, F. O., and Palmer, C. G. (2012). The impact of water quality deterioration on macroinvertebrate communities in Swartkop River, South Africa: A multimeric approach. *African Journal of Aquatic Science*, 37,191–200.

Okarafor, K.A., Andem, A.B., Okete, J.A., and Ettah, S.E. (2012). The Composition, Distribution and Abundance of Macroinvertebrates in the Shores of the Great Kwa River, Cross River State, South-east, Nigeria. *European Journal of Zoological Research*, 1 (2), 31-36.

Oliveira, A. L. H., and Nessimian, J. L. (2010). Spatial distribution and functional feeding groups of aquatic insect communities in Serra da Bocaina streams, southeastern Brazil. *Acta Limnologica Brasiliensia*, 22 (4), 424-441. https://doi.org/10.4322/actalb.2011.007

Olomukoro, J.O., and Dirisu, A., (2014). Macroinvertebrate community and pollution tolerance index in Edion and Omodo Rivers in derived savannah wetlands in Southern Nigeria. Jordan *Journal of Biological Sciences*. 7: 19-24. https://doi.org/10.12816/0008208.

Osman, A.G.M., and Kloas, W. (2010). Water quality and heavy metal monitoring in water, sediments and tissues of the African Catfish Clarias gariepinus (Burchell, 1822) from the River Nile, *Egypt. Journal of Environmental Protection*, 1, 389-400. https://doi.org/10.4236/jep.2010.14045

Oyem, H.H., Oyem, I.M., and Ezeweali, D. (2014). Temperature, pH, electrical conductivity, total dissolved solids and chemical oxygen demand of groundwater in Boji-BojiAgbor/Owa Area and immediate suburbs. *Research Journal of Environmental Sciences*, 8, 444–450, https://doi.org/10.3923/rjes.2014.444.450

Pan, B., Wang, Z., Xu, M., and Xing, L. (2012). Relation between stream habitat conditions and macroinvertebrate assemblages in three Chinese rivers. *Quaternary International*. 282, 178–183. https://doi.org/10.1016/j.quaint.2011.06.008

Parker, L.M., Ross, P.M., O'Connor, W.A., Pörtner, H.O., Scanes, E., and Wright, J.M. (2013). Predicting the Response of Molluscs to the Impact of Ocean Acidification. *Biology,* 2, 651–692. https://doi.org/10.3390/biology2020651

Parparov, A., Hambright, K.D., Hakanson, L., and Ostapenia, A. (2006). Water quality quantification: basics and implementation. *Hydrobiologia*, 560 (1), 227–237. https://doi.org/10.1007/s10750-005-1642-y

Parsons, M., Thoms, M.C., Flotemersch, J., and Reid, M. (2016). *Monitoring the resilience of rivers as social- ecological systems: a paradigm shift for river assessment in the* *twenty-first century*. In: Gilvear, D.J., Greenwood, M.T., Thoms, M.C., Wood, P.J. (Eds.), River Science: Research and Management for the 21st Century. John Wiley & Sons, Ltd., West Sussex, UK, 197–220.

Passeport, E., Vidon, P., Forshay, K. J., Harris, L., Kaushal, S. S., Kellogg, D. Q., ... & Stander, E. K. (2013). Ecological engineering practices for the reduction of excess nitrogen in human-influenced landscapes: A guide for watershed managers. *Environmental Management*, *51*(2), 392-413. https://doi.org/10.1007/s00267-012-9970-y

Patrick, O. O., Reuben, O., Eric, O., William, O., and Stephen, M. N. (2014). Composition, Abundance and Feeding Guilds of Macroinvertebrates in Lake Kenyatta, Kenya. *International Journal of Environmental Monitoring and Analysis*, 2 (5), 239-243. https://doi.org/10.11648/j.ijema.20140205.12

Payakka, A., and Prommi, T. (2014). Aquatic insect's biodiversity and water quality parameters of receiving water body. *Current World Environment Journal*, 9 (1), 53–58.

Pellan, L., and Piscart, C., (2018). Macroinvertebrate identity mediates the effects of litter quality and microbial conditioning on leaf litter recycling in temperate streams. *Ecosystems*, 23, 2542–2553. https://doi.org/10.1002/ece3.3790

Prommi, T., and Payakka, A. (2015). Aquatic insect biodiversity and water quality parameters of streams in Northern Thailand. *Sains Malaysiana*, 44 (5), 707–717.

Raburu, P.O., Masese, F.O., and Mulanda, C.A. (2009). Macroinvertebrate Index of Biotic Integrity (M-IBI) for monitoring rivers in the upper catchment of Lake Victoria Basin, Kenya. *Aquatic Ecosystem Health and Management*. 12 (2): 197-205. https://doi.org/10.1080/14634980902907763.

Ramírez, A., and Gutiérrez-Fonseca, P.E. (2014). Functional feeding groups of aquatic insect families in Latin America: A critical analysis and review of existing literature. *Revista de Biologia Tropical*. 62 (2): 155-167.

Rangeti, I., Dzwairo, B., Barratt, G. J., and Otieno, F. A. O. (2015). Ecosystem-specific water quality indices. *African Journal of Aquatic Science,* 40 (3), 1-8. http://doi.org/10.2989/16085914.2015.1054341

Reddy, P.R. (2014). Freshwater ecosystems and biodiversity-A Case Study of Kolleru Lake, India: A Review. *Journal of Indian Geophysical Union*, 18, 2-13.

Ricart, M., Guasch, H., Barceló, D., Brix, R., Conceição, M. H., Geiszinger, A., & Sabater, S. (2010). Primary and complex stressors in polluted Mediterranean rivers: pesticide effects on biological communities. *Journal of Hydrology*, 383 (1-2), 52-61.

Riens, J.R, Schwarz, M.S, Mustaf, F., and Hoback, W.W. (2013). Aquatic Macroinvertebrate Communities and Water Quality at Buffered and Non-Buffered Wetland Sites on Federal Waterfowl Production Areas in the Rainwater Basin, Nebraska. *Faculty Publications: Department of Entomology*, 33, 1025–1036.

ROK (Republic of Kenya) (1985). *District Atlas of Elgeyo Marakwet.* Wageningen: Isric Library. 1-30pp.

ROK (Republic of Kenya) (2018). *A Report on Forest Resources Management and Logging Activities in Kenya.* Findings and Recommendations. Ministry of Environment and Forestry. 27-30 pp.

Romano, N., and Zeng, C. (2007). Effects of potassium on nitrate mediated alterations of osmoregulation in marine crabs. *Aquatic Toxicology*, 85 (3), 202–208. https://doi.org/10.1016/j.aquatox.2007.09.004

Said, A., Stevens, D.K., and Sehlke, G. (2004). An innovative index for evaluating water quality in streams. *Environmental Management*, 34 (3), 406–414. https://doi.org 10.1007/s00267-004-0210-y

Sebilo, M., Mayer, B., Nicolardot, B., Pinay, G., and Mariotti, A. (2013). Long-term fate of nitrate fertilizer in agricultural soils. *Proceedings of the National Academy of Sciences*, 110 (45), 18185–18189. https://doi.org/10.1073/pnas.1305372110

Selemani, J.R., Zhang, J., Muzuka, A.N.N., Njau, K.N., Zhang, G., Mzuza, M.K., *et al*. (2018). Nutrients' distribution and their impact on Pangani River Basin's ecosystem–Tanzania. *Environmental Technology*, 39 (2), 1-15. https://doi.org/10.1080/09593330.2017.1310305

Shannon, C.E., and Wiener, W. (1949). *The Mathematical Theory of Communication Urban*. University of Illinois Press, 125 p.

Shelly, S.Y., Mirza, Z.B., and Bashir, S. (2011). Comparative ecological study of aquatic macroinvertebrates of Mangla dam and Chashma barrage wetland areas. *Journal of Animal and Plant Science*, 21, 340–350.

Sila, O. N. (2019). Physico-chemical and bacteriological quality of water sources in rural areas, a case study of Kenya, Africa. *Scientific African*, 2, 1-13. https://doi.org/10.1016/j.sciaf.2018.e00018

Simpson, E. (1949). Measurement of diversity. *Nature,* 163, 688. https://doi.org/10.1038/163688a0

Singh, N., and Sharma, R. C. (2014). Some important attributes which regulate the life of macroinvertebrates: a review. *International Journal of Recent Scientific Research*, 5 (2), 357-361.

Souto, M. R.D, Facure, K. G., Pavanin, L. A., and Jacobucci, G. B. (2011). Influence of Environmental Factors on Benthic Macroinvertebrate Communities of Urban Streams in Vereda Habitats, Central Brazil. *Acta Limnologica Brasiliensia*, 23 (3), 293–306. https://doi.org/0.1590/S2179-975X2012005000008

Stednick, J.D. (2008). Hydrological and biological responses to forest practices: the Alsea Watershed study. Springer: New York. 316 p.

Tan, X., Zhang, Q., Burford, M. A., Sheldon, F., and Bunn, S. E. (2017). Benthic Diatom Based Indices for Water Quality Assessment in Two Subtropical Streams. *Frontiers in Microbiology*, 8, 601. https://doi.org/10.3389/fmicb.2017.00601

Tashighi, A., Mazdak A., and D.L. Osmond. (2017). The relationship between land use and vulnerability to nitrogen and phosphorus pollution in an urban watershed. *Journal of Environmental Quality*, 46 (1), 113–122. https://doi.org/ 10.2134/jeq2016.06.0239

Thirupathaiah, M., Samatha, C., and Sammaiah, C. (2012). Analysis of water quality using Physico-chemical parameters in lower manair reservior of Karimnagar District, Andhra Pradesh. *International Journal of Environmental Sciences*, 3(1), 172-180. https://doi.org/ 10.6088/ijes.2012030131017

Tyagi, S., Sharma, B., and Singh, P. R. (2013). Water quality assessment in terms of Water Quality Index. *American Journal of Water Resources*, 1(3), 34–8. https://doi.org/ 10.12691/ajwr-1-3-3

UNEP (2012). *UN-Water Status Report on the Application of Integrated Approaches to Water Resources Management.* Nairobi, Kenya.

UNEP (United Nations Environment Programme) (2017). *Towards a Pollution Free Environment*. Nairobi: UNEP.

UNESCO (2017). World Water Development Report.

United Nation (UN) Sustainable Development Goals (2015). *The 2030 Agenda for Sustainable Development;* A/RES/70/1. United Nation Sustainable Development Goals: New York, NY, USA, 20p.

Upen, D., and Sarada, K. S. (2015). Ecological studies of macrophytes of two major wetlands of the Nalbari district of Assam, India. *New York Science Journal*, 8 (1), 67-75. http://www.sciencepub.net/newyork

Uwadiae, R.F. (2010). Macroinvertebrates functional feeding groups as indices of biological assessment in a tropical aquatic ecosystem: implications for ecosystem functions. *New York Science Journal*, 3, 8-17.

Venkatesharaju, K., Ravikumar, P., Somakeshar, R.K., and Prakash, K.L. (2010). Physico-Chemical and Bacteriological Investigation on the river Cauvery of Kollegal Stretch in Karnataka. Kathmandu University *Journal of Science, Engineering and Technology*, 6, 50-59.

Veronica G. M. and Maldonado V. M. (2010). Land use influence on the benthic macroinvertebrate communities of streams in Nyangores and Amala tributaries of Mara River, Kenya.

Vincy, M.V., Rajan, B., and Kumar, P.A.P. (2012). Water quality assessment of a tropical wetland ecosystem with special reference to backwater tourism, Kerala, South India. *International Research Journal of Environmental Science*, 1 (5), 62-68.

Wang, B., Liu, D., Liu, S., Zhang, Y., Lu, D., and Wang, L. (2012). Impacts of urbanization on stream habitats and macroinvertebrate communities in the tributaries of Qiangtang River, China. *Hydrobiologia*, 680, 39- 51. https://doi.org/10.1007/s10750-011-0899-6

Ward, M.H. (2009). Too much of a good thing? Nitrate from nitrogen fertilizers and cancer. Review *Environmental Health*, 24, 357–363. https://doi.org/10.1515/reveh.2009.24.4.357

WHO (2006). Guidelines for drinking - water Quality First Addendum to Third Edition. Recommendations Geneva, Switzerland.

WHO (2008). Guidelines for drinking water quality. World Health Organization, Recommendations Geneva, Switzerland.

WHO (2011). Nitrate and nitrite in drinking-water. Background document for development of WHO guidelines for drinking-water quality, WHO/SDE/WSH/07.01/16/Rev/1.

World Bank. (2007). Strategic Environmental Assessment of the Kenya Forests Act.

WRI (2007). World Resources Institute, Department of Resource Surveys and remote Sensing, Ministry of Environment and Natural resources, Kenya, Central Bureau of Statistics, Ministry of Planning and Development, Kenya; and International Livestock Research Institute: Nature's Benefits in Kenya: An Atlas of Ecosystems and Human Well-Being, World Resources Institute, Washington, DC, and Nairobi.

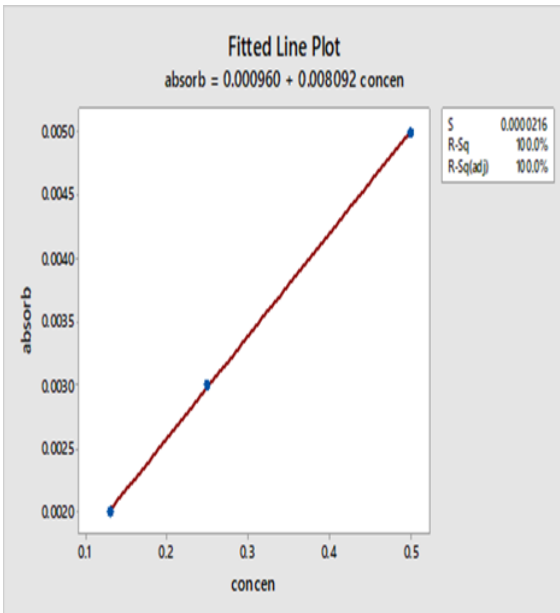
Zajac, R.N., Vozarik, J.M., and Gibbons, B.R. (2013). Spatial and temporal patterns in macrofaunal diversity components relative to sea floor landscape structure. *PLoS ONE*, 8 (6), 65823. https://doi.org/10.1371/journal.pone.0065823

Zang, C., Huang, S., Wu, M., Du, S., Scholz, M., and Gao, F. (2011). Comparison of Relationships Between pH, Dissolved Oxygen and Chlorophyll a for Aquaculture and Non-Aquaculture Waters. *Water Air Soil Pollution*, 219, 157–174.

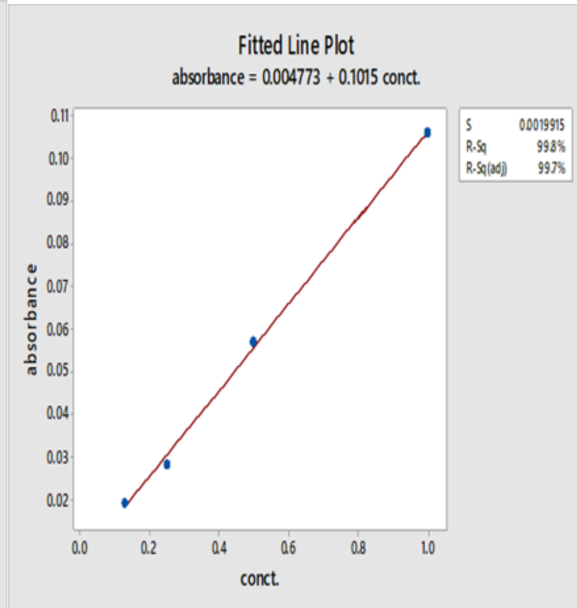
Zeiger, S., Hubbart, J.A., and Anderson, S.H., Stambaugh, M.C. (2016). Quantifying and modelling urban stream temperature: A central US watershed study. *Hydrological Processes*, 30, 503–514.

APPENDICES

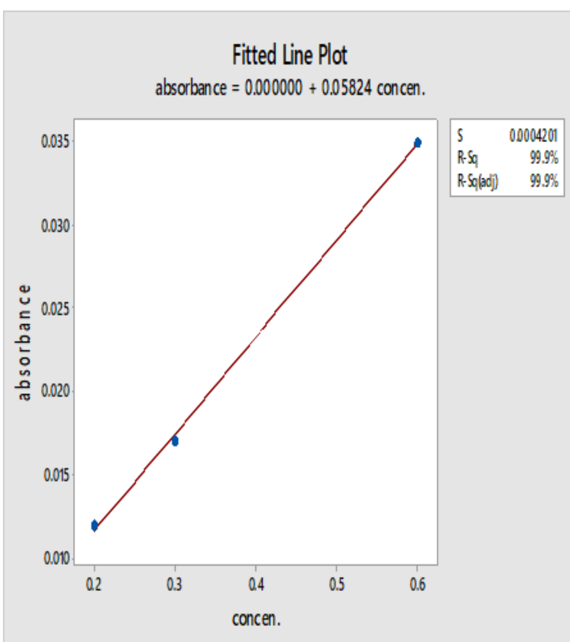
Appendix I: The standard plotted graph for nutrients (ammonia, soluble reactive phosphate, nitrate and nitrite) with absorbance vs. concentration



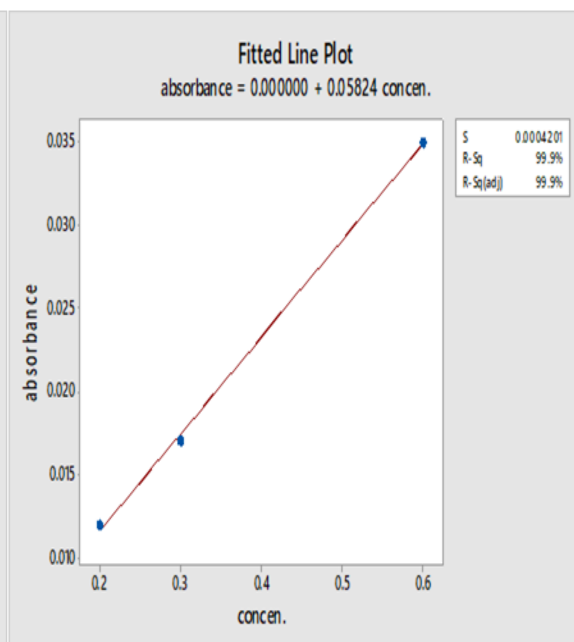
(a). ammonia



(b). soluble reactive phosphate (SRP)



(c). nitrate



(d). nitrite

Appendix II: Calculated Values of WQI in River Kipsinende during the study period (Si = Standard value, Wi = relative weight, qi = quality rating)

S/N	Parameter	s_i	$W_i = 1/s_i$	KA qi	KB qi	KC qi	KD qi	KE Qi	KF qi	KA q_iw_i	KB q_iw_i	KC q_iw_i	KD q_iw_i	KE q_iw_i	KF q_iw_i
1	pH	8.5	0.12	2	14	1.33	16.67	24	24.67	0.235	1.65	0.157	1.96	2.82	2.90
2	DO (mg/L)	6	0.17	84.3	91.74	102.21	95.93	67.67	70.22	14.05	15.29	17.03	15.99	11.28	11.69
3	EC µS/cm	250	0.04	11.6	12.71	12.89	13.42	15.76	18	0.046	0.051	0.052	0.054	0.063	0.072
4	Nitrate (mg/L)	50	0.02	4.18	4.8	3.82	4.06	3.74	4.32	0.084	0.096	0.076	0.081	0.075	0.086
5	Phosphate (mg/L)	0.4	2.5	50	185	57.5	137.5	47.5	122.5	125	462.5	143.75	343.75	118.75	306.25
6	Ammonia	0.5	2	156	82	78	106	116	210	312	164	156	212	232	420
7	Nitrite (mg/L)	3	0.33	14	13	14.33	16.67	15	18.67	4.67	4.33	4.78	5.56	5	6.22
	Total		5.14							456.08	647.92	321.85	579.39	369.99	747.22
	WQI									88.7	126.01	62.6	112.69	71.96	145.33
	Average of WQI in all sites														101.21

Appendix III: Abundance and composition of the functional feeding group of macroinvertebrates in Kipsinende River

	Family	Sampling station						Functional Feeding Groups
		KA	KB	KC	KD	KE	KF	
Ephemeroptera	Baetidae	455	1012	1063	1070	535	388	Collector-Gatherer
	Caenidae	40	57	10	16	35	23	Collector-Gatherer
	Ephemerellidae	5	14	0	2	0	0	Collector-Gatherer
	Heptageniidae	31	115	74	8	174	289	Scraper
	Leptophlebiidae	4	0	1	4	10	34	Collector-Gatherer
	Tricorythidae	0	0	0	0	5	3	Collector-Gatherer
Diptera	Simuliidae	3510	116	2542	1117	47	1788	Predators
	Tipulidae	3	19	5	2	4	8	Predators
	Chironomidae	63	155	518	103	46	33	Predators
	Ceratopogonidae	0	1	4	1	4	3	Predators
	Tanyderidae	1	4	2	0	1	2	Predators
	Dolichopodidae	0	1	0	0	0	0	Predators
	Chaoboridae	6	14	52	1	0	0	Predators
	Syrphidae	0	0	1	0	0	0	Collector-Gatherer
	Ephydridae	1	0	0	0	0	0	Collector-Gatherer
	Dixidae	0	0	0	1	0	0	Collector-Gatherer
	Muscidae	0	0	8	0	0	0	Predators
Trichopetra	Hydropsychidae	25	268	387	267	41	44	collector- Filterer
	Leptoceridae	15	36	4	4	10	3	Collec- Filterer/Ga
	Lepidestomatidae	0	3	2	0	7	0	Shredders
	Pisuliidae	0	0	0	2	0	0	Shredders

	Calamoceratidae	0	0	0	0	1	0	Shredders
	Philopotamidae	0	3	0	0	1	0	Collector- Filterer
Hemiptera	Gerridae	11	0	2	14	2	1	Predators
	Hebridae	0	1	0	0	0	0	Predators
	Nepidae	2	1	2	3	1	0	Predators
	Naucoridae	0	0	1	0	0	0	Predators
	Veliidae	1	0	0	0	1	0	Predators
	Mesorehidae	0	0	0	0	0	1	Predators
	Corixidae	2	0	3	0	0	1	Predators
	Notonectidae	0	30	2	1	20	1	Predators
	Hydrometridae	0	0	0	1	0	0	Predators
Coleoptera	Gyrinidae	12	41	14	41	23	4	Predators
	Scirtidae	0	12	0	0	2	5	Scraper
	Elmidae	1	2	0	0	1	3	Colle-Gatherer/scra
	Dytiscidae	0	3	1	2	1	0	Predators
Decapoda	Potamonautidae	32	25	0	15	41	102	Shredders
Bivaliva	Sphaeriidae	181	500	127	75	183	211	Collector-Gatherer
	Thiaridae	1	0	0	0	0	0	Shredders
Oligochaeta	Tubificidae	67	270	93	14	255	175	Collector-Gatherer
	Lumbriculidae	1	25	0	0	12	13	Collector-Gatherer
Odonata	Gomphidae	12	9	24	31	25	3	Predators
	Lestidae	54	148	41	63	9	6	Predators
	Aeshnidae	1	0	0	0	0	0	Predators
Arhynchobdellida	Hirudinea	6	104	5	5	3	4	Predators
Tricladida	Planariidae	0	6	0	0	1	0	Shredders
Lepidoptera	Crambidae	0	0	0	23	8	0	Shredders
Araneae	Dictynidae	0	0	0	0	0	1	Shredders
Total	**48**	**4538**	**2959**	**5025**	**2885**	**1490**	**3143**	

Appendix IV: Rapid assessment protocol for habitat measurement or characteristics of the river ecosystem field sheet (Barbour *et al*., 1999)

Date …………………………………….   Station…………….   Given code…………...

S/No.	Habitat parameter	Optional (>90%) or 20-16	Sub optional (70-90 %) or 15-11	Marginal (50-70) or 10-6	Poor (<50 %) or 5-0	sum
1	Epifauna substrate cover					
2	Embeddness					
3	Velocity-depth combination					
4	Sediment deposition					
5	Channel flow status					
6	Channel alteration					
7	Frequencies of riffles					
8	Bank stability	<5% or 10-9 affected	5-30 % (8-6)	30-60% or 5-3	Unstable or 60-100% (5-0)	
	Left bank					
	Right bank					
9	Bank vegetative protection	>90% covered or 10-9	70-90% (8-6)	50-70% (5-3)	<50% (5-0)	

	Left bank Right bank				
10	Riparian vegetation zone Right bank Left bank	Width of riparian >18meter 10-9	12-18 (8-6)	8-12 (5-3)	<6 (5-0)

Appendix V: Similarity report

Document Viewer

Turnitin Originality Report

Processed on: 14-Jun-2021 08:37 EAT
ID: 1606091610
Word Count: 29216
Submitted: 1

SNAT/FAS/M/008/18 By Fekadu Masresha Birara

Similarity Index	Similarity by Source	
18%	Internet Sources:	16%
	Publications:	9%
	Student Papers:	6%

include quoted include bibliography excluding matches < 5 words mode: quickview (classic) report Change mode print refresh download

1% match (Internet from 20-May-2016)
http://www.oceandocs.org

1% match (Internet from 05-Oct-2020)
https://www.researchgate.net/publication/262451560_Functional_feeding_groups_of_aquatic_insect_families_in_Latin_America_A_cr

<1% match (Internet from 10-Jun-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/20438/Determination%20of%20Illegal%20Bush%20Meat....pdf?isAllowed=y&sequence=1

<1% match (Internet from 08-Jun-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/19248/Effects%20of%20human%20activities%20on%20water%20quality%20of%20Rupingazi%e2%80%a6.pdf?isAllowed=y&sequence=1

<1% match (Internet from 03-Apr-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/21527/Occurence%20of%20arthropod%20pests....pdf?isAllowed=y&sequence=1

<1% match (Internet from 03-Apr-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/21499/The%20impact%20of%20climatic%20variability%20and%20malaria.....pdf?isAllowed=y&sequence=1

<1% match (Internet from 10-Jun-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/19987/Microbial%20Contamination%20of%20Nile%20Tilapia%20....pdf?isAllowed=y&sequence=1