EFFECTS OF WATER QUALITY ON THE DIVERSITY, ABUNDANCE AND DISTRIBUTION OF BENTHIC MACRO INVERTEBRATES ALONG THE SHORES OF LAKE VICTORIA IN HOMA-BAY COUNTY KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL BIOLOGY OF THE DEPARTMENT OF AGRICULTURE AND ENVIRONMENTAL STUDIES, RONGO UNIVERSITY

2022

DECLARATION

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This thesis is dedicated to my beloved family members whose prayers, motivation and material support played a vital role towards this study.

ACKNOWLEDGEMENT

This thesis has been made possible through support from a number of individuals both within and without Rongo University. First, my gratitude goes to God Almighty for the tender care, mercy and good health he has accorded me during my study period. I would like to thank my supervisors, Prof J.B Okeyo-Owuor and Dr Pamella Were-Kogogo whose professional advice, guidance and constant encouragement yielded this thesis. I am sincerely thankful to Rongo University, School of Science, Agriculture and Environmental Studies for registering me in their Masters of Environmental Science programme and providing me with excellent study environment during this study. I extend my appreciation to the Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu, for allowing me to use its facilities, equipment and laboratory during the Study. The technical staff of KMFRI, especially James Achiya, Moses Umani and John Ouko were extremely valuable during this study and I am very grateful to them all. Finally, to those whom I have not mentioned by name but provided valuable support and contributions during this study I sincerely thank you all.

ABSTRACT

Human-induced landscape alterations adversely affect habitat structure and functions of fresh water ecosystems, as well as flow regime in the Lake Victoria basin. The massive discharge of waste-waters and other pollutants from the surrounding basin do interfere with ecological balance in parts of the lake thereby causing adverse impact on benthic macro-invertebrates especially along the lake shores. The overall objective of this study was to investigate the impact of water quality on the diversity, abundance and distribution of benthic macro-invertebrates along the Lake Victoria shores in Homa-Bay County, Kenya. Specific objectives were to: analyse the physico-chemical parameters of water quality, determine the diversity of benthic macro-invertebrate species, analyse the abundance and distribution of benthic macro-invertebrate species, and determine the impact of selected physico-chemical parameters on diversity, abundance and distribution of benthic macro invertebrate species along the shores of Lake Victoria, Homa-Bay County. The study adopted quasi experimental research design. Stratified random sampling was used to collect samples along Oluch-Kimira River Mouth, Homa Bay sewage discharge point and Mbita beach east of the course way at monthly intervals from September 2019 to February 2020. Samples of benthic macro invertebrate were collected using sweep net and grab sampler, preserved and laboratory identified using stereoscope while water samples were collected using Van Dorn water sampler and nutrient analyses done using APHA (2017) standard methods at KMFRI. Physico-chemical parameters were measured *in situ* using YSI meter and Secchi disc for light intensity. Data was analysed using descriptive statistics, Shannon-Weiner Index, one way ANOVA, Turkey HSD post hoc and Canonical correspondence analysis (CCA). The study established that there was significant difference in diversity (F (2, 15) = 12.49, p= 0.001) and abundance and distribution of benthic macro invertebrate species (F (2, 15) = 14.41, p< 0.05) along the shores of Lake Victoria. Oluch-Kimira river mouth and Homa Bay sewage discharge point recorded significantly lower DO levels (4.0±0.46 to 6.2±0.19 MgL^{-1}) compared to Mbita beach east of the course way (5.6±0.23 to 7.7±0.17 MgL^{-1}), high nutrient load concentration, turbidity (317.47 NTU) and electrical conductivity (147.86 μScm^{-1}) along Oluch Kimira river mouth, high dissolved oxygen concentration along Mbita beach east of the course way, and lower dissolved oxygen concentration along with high pH (8.47) at Homa Bay sewage discharge point. Benthic macro invertebrate diversity was relatively high along Mbita beach east of the course way with *cloeon simile, Agrion splendens, Anodonta cygnea, Baetis* and C*aenis moesta* being the most dominant species, whereas along Homa Bay sewage discharge point *Spaniodoma sp, Sphaerium sp, Tubifex tubifex, Anodonta cygnea, Polycentropus* and *Naids* were most dominant, and along Oluch Kimira river mouth, *Anadonta cygnea, Tubifex tubifex, Melanoides tuberculata, Caenis moesta,* and *Sphaerium sp* were dominant. The study concludes that changes in selected physico-chemical parameters and nutrient loads concentration along the shores of Lake Victoria influence the diversity, abundance and distribution of benthic macro invertebrates. The study provides baseline data for evaluating the trends in water quality and related changes in benthic-macro invertebrates and aquatic biodiversity along Lake Victoria shores in Homa Bay County, Kenya.

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LIST OF ACRONYMS/ABBREVIATIONS

APHA	American Public Health Association
DO	Dissolved Oxygen
GoK	Government of Kenya
IBI	Index of Biotic Integrity
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Standards
MI	Macro-Invertebrates
pH	Potential of Hydrogen
SRP	Soluble Reactive Phosphorus
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNH	United Nation Habitat
USEPA	United States Environmental Protection Agency
WWTP	Waste Water Treatment Plant
NEMA	National Environmental Management Authority

OPERATIONAL DEFINITIONS

Anthropogenic activities	**:** these are activities caused or influenced by humans
Benthic Macro-invertebrates	**:** are aquatic animals without a backbone and insects that can be seen without magnification and live at the bottom of lake.
B**enthic zone**	**:** is the ecological zone at the lowest level of a body of water such as a lake or an ocean, including some sub-surface layers and the sediment surface.
Ecological balance	**:** The ecological balance is the equilibrium between, and harmonious coexistence of, organisms and their environment.
Ecosystem	**:** a biological community of interacting organisms and their physical environment.
Environment	**:** The sum total of all surroundings of a living organism, including natural forces and other living things, which provide conditions for development and growth as well as of danger and damage.
Eutrophication	**:** the process by which a body of water becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen. It is the excessive richness of nutrients in a

lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life

Habitat **:** is the kind of natural environment in which a particular species of organism lives.

Lake shore **:** the interface between the terrestrial ecosystem and the deeper pelagic zone of Lake Victoria stretching to a distance of 200m inshore from shorelines at Homa Bay sewage discharge point, Oluch-Kimira river mouth, and Mbita East beach.

Species Abundance **:** Is the number of individuals observed per species

Species Diversity : Is the number of different species that are represented in a given community.

Water Degradation : Is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater), usually as a result of human activities.

Water Quality : refers to the chemical, biological, physical and radiological characteristics of water. It is a measure of the condition of water in relation to the requirements of biotic species

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Globally, among the resources provided by nature, water is one of the most important and indispensable resource for life for human and other organisms. At the same time water is the backbone of growth and prosperity for mankind (Republic of Kenya, 2007). According to World Health Organization (WHO, 2012) the slogan water is life, underscores the importance of water in all aspects and spheres of life. World Health Organization (WHO, 2012) also affirmed the importance of water as essential necessity after oxygen. Anything that disturbs water provision and supply tends to disrupt the very survival of humanity and other living organisms. Water is a habitat for aquatic organisms and also supports terrestrial life. Benthic macro-invertebrates depend absolutely on water in various ways including habitat, breeding site and life support in general. Contamination and/or pollution of water not only interfere with human beings but also severely affect the aquatic life. Degradation of water quality may come as a result of a number of factors such as farming, poor waste disposal, soil erosion, poor fishing methods among others. When water is contaminated, the aquatic organisms are directly interfered with. The level of dissolved oxygen goes down, the water may become acidic, biological oxygen demand increases and these interfere with the normal body functioning of the aquatic biota including macro-invertebrates (United Nations Development Programme, 2006).

Anthropogenic induced eutrophication continues to be a major threat to lake ecosystems, despite efforts to reduce nutrient inputs into lakes. Many fresh-water lakes still receive substantial inputs of phosphorus (P) and nitrogen (N) from urban and agricultural land use (Sanyanga & Hlanga, 2004; Bernhardt & Palmer, 2006; Carpenter *et al*., 2007) and atmospheric deposition (Vitousek *et al*., 2009). Regardless of the source, inputs of nutrients can substantially alter the ecological function of fresh water bodies such as lakes. According to Devon *et al*. (2015), it has been documented that increased nutrients, especially phosphorus, often result in increased pelagic primary production and algal blooms, which may inhibit the growth of submerged macrophytes and benthic primary production as was also asserted by Vadeboncoeur *et al*., 2003; Egertson *et al*., 2004; and Chandra *et al*., 2005). Moreover, decomposition of algal biomasses may result in anoxic conditions in profundal habitats, adversely affecting community composition. Wibowo and Santoso (2017) revealed the strong relationship between Dissolved Oxygen (DO) concentration and the composition of profundal macro-invertebrate communities. In their view, dissolved oxygen concentration directly influences the well-being of profundal macro-invertebrate communities. They contended that at a lower concentration of DO, activities of these macro-invertebrates are impaired. This was also established by Langdon *et al*. (2006) who got inspired to classify the trophic status of lakes based on the previous studies.

According to Boyle and Fraleigh (2013), excessive loading of domestic waste into rivers can alter the physical, chemical and biological characteristics of such aquatic systems beyond their natural self-purification capacity. Higher levels of turbidity, nutrients, suspended and dissolved solids as well as coliform bacteria in rivers are all indicative of compromised systems attributed to increased pollutant load, resulting largely from anthropogenic activities. Adams and Papa (2010) supported that changes in water quality can alter the community structure of benthic macro-invertebrates and other aquatic biota therein.

According to UN-Habitat (2008), lack of sufficient infrastructure especially in most developing countries in sub-Saharan Africa has led to degradation of water quality thereby affecting aquatic life. Poor waste disposal such as discharge of improperly treated effluents and disposing of waste directly into water bodies are some of the contributors underpinning water quality degradation. Xiao *et al. (*2009) estimated that between one third to a half of solid waste generated in most towns in low and middle-income countries is left uncollected due to lack of capacity and usually ends up as illegal dumps on streets and open spaces, thus polluting nearby water bodies. Fakayode (2010) also posit that waste disposal has rendered many aquatic systems less suitable for primary and in some cases secondary usage which has caused profound impact on the fresh water benthic macro-invertebrates.

Freshwater benthic macro-invertebrates, or more simply “benthos”, are animals without backbones that are larger than ½ millimetres. These animals live on rocks, logs, sediment, debris and aquatic plants during some period in their life. The benthos includes molluscs such as clams and snails, aquatic worms and the immature forms of aquatic insects such as stonefly and mayfly nymphs, and crustaceans such as crayfish. These animals are widespread in their distribution and can live on all bottom types, even on manmade objects. They can be found in hot springs, small ponds and large lakes. Some are even found in the soil beneath puddles (Reese & McDonald, 2012).

Macro-invertebrate communities change in response to changes in physicochemical factors and available habitats. The biotic structure and water quality of streams and rivers reflect an integration of the physical, chemical and anthropogenic processes occurring in a catchment area, leading to the concept of ecological integrity. Human induced hydrological changes, physical disturbances (habitat alteration, urban land use) and point and non-point sources of pollution (chemical contamination, surface runoff, intensive agriculture) are examples of processes responsible for a broad-scale deterioration of lotic ecosystems (Chatzinikolaou *et al.,* 2011).

Surface water bodies including lakes and rivers are open dynamic ecosystems whose physic-chemical and biotic characteristics are greatly influenced by anthropogenic activities in their drainage basins (Mokaya *et al.,* 2012). Rivers and streams which traverse urbanized areas are profoundly impacted by changes associated with urbanization (Bernhardt & Palmer, 2007). Such rivers and streams flowing through low lying points of the landscape are particularly sensitive, prone and lead to increased water pollution from both urban and other anthropogenic activities (Bernhardt & Palmer, 2006).

The intensity at which humans have modified riparian areas and lakeshores has substantially increased during the last decades (Sly, 2011; Schnaiberg *et al.*, 2012). Much of this has been observed in USA (Carpenter *et al*., 2007; and Gonzales-Abraham *et al.,* 2007) and in Central Europe (Schmieder, 2010). It is expected that human use of lakes and lakeshores will increase and is likely extend to areas that are currently unimpaired (Walz *et al*., 2012); Peterson *et al*., 2003); and Carpenter *et al*., 2007). In Africa, Yakub (2008) reported that most surface waters in Nigeria have been used as the most expedient way of disposing wastes especially effluents which cause contamination into the water from point sources. In East Africa, land use changes caused by rapid urbanization and clearance of forests to create room for agriculture have emerged as major stressors of streams, rivers and lakes (Kibichii *et al*., 2007; Kasangaki *et al.*, 2008) leading to degraded water quality, losses of biodiversity and altered hydrography in many streams and rivers draining urban areas (Ndaruga *et al.*, 2004).

Bonada *et al*. (2006) noted that although the physico-chemical water quality parameters provide snapshots of the condition of the aquatic ecosystem at a given point in time, they may not effectively provide an integral measure of the overall health of the water bodies and can, at times, inadequately identify impaired waters. An integrative approach incorporating biological measures like the benthic macro-invertebrate community structure alongside other physico-chemical water quality parameters, can thus provide a more comprehensive assessment of the health of a river or lake over time (Bonada *et al*., 2006). Benthic macro-invertebrate assemblages and distribution frequently change in response to pollution stress in predictable ways, thus, their importance as biological criteria for evaluation of anthropogenic influences of aquatic systems (Boyle & Fraleigh, 2013). The Shannon-Weinner Diversity Index and Evenness Index are also important in determining and comparing species composition between various habitats and will give a reflection of the health of aquatic systems. Orwa *et al.* (2015) revealed that composition of macro-invertebrates is affected by various habitats which they occupy.

Homa Bay County has the longest Lake Victoria shoreline in Kenya. It also contains about 2,200 water facilities spread over the county including boreholes, water pans, wells and springs. There are several forested areas especially at hill tops and lakeshore most of which are degraded by deforestation to provide fuelwood and charcoal. Others have been converted to farming land, grazing areas and settlement. These activities have caused decline in indigenous and plantation vegetation cover (Mugo et al., 2020) leading to land degradation and increased soil erosion, low rainfall and flash floods, continued and indiscriminate accumulation of solid waste mainly in urban centres especially including plastics, nylon papers, packaging materials, food remains and faecal matter at the lakeshores and other water bodies increases water pollution and together have conspired to increase prevalence of water and vectors borne diseases. Such waste materials also clog the natural water ways and drainage facilities in many parts of the county (CIDP, 2013-2017).

Homa Bay County is also home to the famous Ruma National Park located in Lambwe Valley and is the only park where unique and rare species like the roan antelope can be found. There are also several touristic sites such as the Tom Mboya Mausoleum, the Mfangano Rock Art, Homa Hills Hot Spring and Simbi Nyaima (CIDP, 2013-2017). Homa Bay county has over 18 islands, peninsulas and bays many of which host some indigenous and unique fauna and flora and an impressive array of physical features with significant aesthetic value and some beautiful sceneries and landscape (CIDP, 2013-2017). Therefore there is need to ensure fresh and clean water sources in the lakeshore to ensure protection of these resources at all times. Lake shores in the county contain a rich diversity and abundant benthic macro-invertebrate and fish which are of both ecological and economic value and are good indicators of the lakes environmental status in the County. This study examined the influence of the changing water quality on the species diversity, abundance and distribution of benthic macro invertebrates in the Lake Victoria shores.

Lake Victoria is a major source of water supply for domestic, livelihood and industrial purposes. It is also a habitat for freshwater organisms such as benthic macro invertebrates including insects, molluscs, oligochaetes and fresh water prawns (Muli, 1996). Masese et al. (2009) adds that benthic macro-invertebrates are valuable indicators of water quality and ecological health in the lake and associated river mouths. In lower catchments of Lake Victoria Basin - Kenya, streams, rivers and the lake itself serve as major source of freshwater to the riparian communities and their livestock. They are an important source of more than 60% residents' potable water supply although without prior treatment (Ntiba *et al.,* 2010). According to Lung'ayia (2012), the agriculture intensification and deforestation coupled with the rapid growth of urban centres and industrial activities threaten small streams, rivers and lakes with degradation.

1.2 Statement of the problem

Among the resources provided by nature, water is an essential necessity after oxygen and one of the most important and indispensable resource for life of human and other organisms in both aquatic and terrestrial environments. The World Health Organization slogan "water is life", underscores the importance of water in all aspects and spheres of life. As a consequence, anything that disturbs water provision and supply tends to disrupt the very survival of humanity and other living organisms. For instance, according to UN-Habitat (2008), lack of sufficient infrastructure especially in most developing countries like sub-Saharan Africa has led to degradation of water quality thereby affecting aquatic life.

In Africa, Yakub (2008) reported that most surface waters in Nigeria have been used as the most expedient way of disposing wastes especially effluents which cause contamination into the water. In East Africa, land use changes caused by rapid urbanization and clearance of forests to create room for agriculture have emerged as major stressors of streams, rivers and lakes, leading to degraded water quality, losses of biodiversity and altered hydrography in many streams and rivers draining urban areas (Ndaruga *et al.,* 2004). In lower catchments of Lake Victoria Basin- Kenya, streams, rivers and the lake itself serve as the major source of freshwater to the riparian communities and their livestock. However, in Homa Bay County; even as rapid economic growth, urbanization and high population growth rate continues, especially leading to increased human activity and water hyacinth *(Eichormia crassipes*) invasion, the relationships between water quality and status of macro-invertebrates in the lakeshores of Homa Bay County has not been well understood to date (CIDP, 2013-2017). Therefore, it is against this backdrop that the study sought to investigate water quality and relate them to the diversity, distribution and abundance of benthic macro invertebrates along the Lake Victoria shores in Homa-Bay County, Kenya.

1.3 Objectives of the Study

1.3.1 Overall Objective

To investigate the impact of water quality on the diversity, abundance and distribution of benthic macro-invertebrates along the Lake Victoria shores in Homa-Bay County, Kenya.

1.3.2 Specific Objectives

i. To analyse the physico-chemical parameters of water quality along the shores of Lake Victoria, Homa Bay County.

ii. To determine the species diversity of benthic macro-invertebrates along the shores of Lake Victoria, Homa Bay County.

iii. To analyze the abundance and distribution of benthic macro-invertebrates along the shores of Lake Victoria, Homa-Bay County.

iv. To determine the impact of physico-chemical parameters on the diversity, abundance and distribution of benthic macro invertebrates along the shores of Lake Victoria, Homa-Bay County.

1.4 Hypotheses of the Study

i. There is no significant difference in the status of physico-chemical parameters of water quality along the shores of Lake Victoria, Homa Bay County, Kenya.

ii. Species diversity of benthic macro-invertebrates along the various shores of Lake Victoria, Homa Bay County are not significantly different.

iii. There is no significant difference between abundance and distribution of benthic macro-invertebrates along various shores of Lake Victoria, Homa-Bay County.

iv. Selected physico-chemical parameters do not significantly impact on species diversity, abundance and distribution of benthic macro invertebrates along the shores of Lake Victoria, Homa-Bay County.

1.5 Scope of the Study

The study was conducted on selected sites along the lake shores (some area of 1,227 km^2) in Homa Bay County, Kenya. The study was limited to sampling and analysing the species diversity, abundance and distribution of benthic macro-invertebrates as well as measuring and analysing the physico-chemical Water Quality Parameters in the selected sites. The study was conducted for duration of six months.

1.6 Justification of the Study

Considering the environmental principles of nature that provides that everything was created for a purpose and all forms of life are important, the existence and role played by the macro-invertebrates in the ecosystem cannot be overemphasized. The macro-invertebrates help in nutrient recycling, they are food to other organisms like fish and thus aid in ecological balance. Their protection and conservation is therefore crucial. This study is justifiable and has provided the necessary data needed to fill knowledge gaps on factors that relate the water quality parameters and benthic macro-invertebrates in lake shores of Homa Bay County. Studying the changes in community of organism such as benthic macro-invertebrates as affected by water quality factors has helped to elucidate the dynamic characteristics of benthos as influenced by the changing water quality in the lake ecosystem. The study findings will open new avenues for dealing with the worsening situation caused by the various anthropogenic activities on the Lake.

1.7 Significance of the Study

The findings of the study will contribute to improvement on environmental management policy at the County and National Government by providing data and information about how degraded water quality affects the diversity, abundance and distribution of macro-invertebrates. Through this study the key water quality factors that impact on benthic macro-organisms have been identified to enable development of mitigation measures. The findings of this study will provide information on the status of physico-chemical parameters of water quality, and help in identification of areas for further study in environmental field.

1.8 Conceptual Framework

Leedy and Ormrod (2005) posit that in the absence of a theory that can precisely explain the basis of a given study, available literature can be used to formulate a conceptual framework. The conceptual framework (Figure 1.1) was developed on the premise that when water quality is degraded, the physical, chemical, and biological characteristics may alter beyond the natural self-purification capacity, hence affecting the normal functioning of aquatic biota.

The degradation of fresh-water lakes may be as a result of farming practices, poor waste disposal, soil erosion, fishing methods among others. For instance, agricultural activities along the lake shores may subject the land to loss of its cover as vegetation is cleared. This makes land remain bare and becomes susceptible to agents of erosion that in turn leads to siltation and loss of benthic macro invertebrates habitat in water ecosystems. In addition, pollution through poor waste disposal might negatively impact on water quality which in turn affects aquatic life such as benthic macro-invertebrates that suffer the consequences of the chemical contents of inorganic fertilizers together with other herbicides.

Figure 1, therefore illustrates the interrelationship between water quality (independent variable), atmospheric deposition (intervening variable), and diversity, abundance and distribution of benthic macro invertebrates (dependent variables).

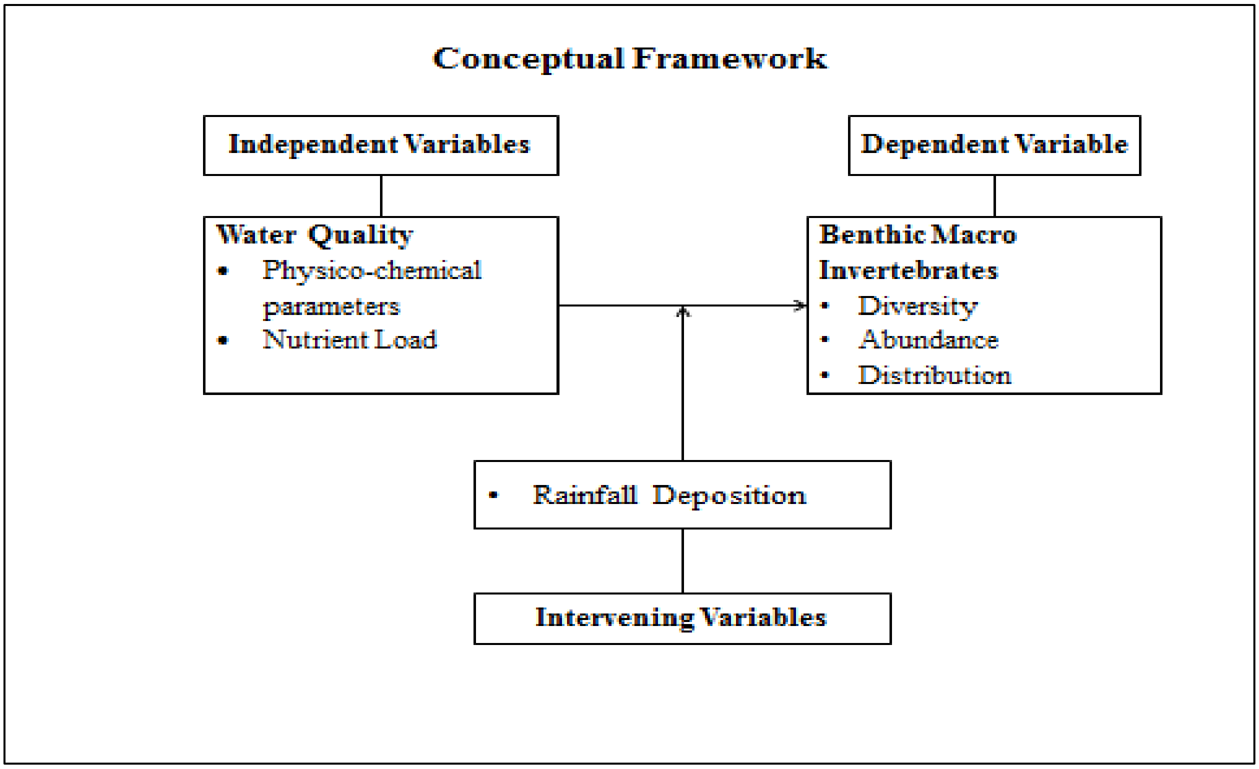

Figure 1.1: A Conceptual Model of Water Quality and Benthic Macro-Invertebrates

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature from relevant studies in accordance with the study variables as presented in the objectives under the following sub-headings: Physico-chemical Parameters and the abundance and diversity of macro-invertebrates and Water Quality and macro-invertebrates assemblages.

2.2 Macro-invertebrate composition, abundance, structure and diversity

Benthic macro-invertebrates refer to small animals living at the bottom of rivers, streams and lakes among sediments, logs, stones and aquatic plants. They are also referred to as "Benthos" (Reese & McDonald, 2012). Such animals lack backbone and are large enough to be seen with the naked eye. The benthic macro invertebrates comprise of insects and non-insects. However, insects make up the largest diversity of these living organisms and include caddis flies, midges, beetles, mayflies, crane flies, stoneflies, dragonflies among others. Some of the non-insects in the benthos community include aquatic worms, clams, and crayfish (EPA, 2021).

2.2.1 Benthic Macro-invertebrates' Habitats

Benthic macro-invertebrates are known to live in a wide variety of habitats including the smallest headwater streams down to the largest rivers. The organisms are most diverse in the run areas and fast flowing riffle of streams as opposed to pools and glides. This is because runs and riffles have higher stream gradients, are shallower, have faster water velocities and are composed of rough materials that create turbulence and oxygenate the water. In addition, many benthic macro invertebrates of the insect community spend most of their lives in the water and only emerge out of water as adults for a short period of time to reproduce and thereafter, fly to new stream locations during their winged terrestrial stage to complete their life cycle (IOWA, 2010). Conversely, the larvae move by crawling on the stream bottom, swimming and drifting with stream currents. Consequently, they are widespread in small creeks, large rivers, small ponds, wetlands, and lakes. Most benthic macro-invertebrates are present throughout the year, although, in the temperate regions they are most easily found in the summer months and in the colder months, many species burrow deep in the sediment or remain inactive on rock surfaces (EPA, 2021).

2.2.2 Benthic Macro-invertebrates Adaptations

Many benthic macro-invertebrates have adaptations that allow them to live in lakes, streams, rivers or oceans, with fast moving water. Some of the adaptations include flattened bodies to allow them hide between boulders and cobbles, thus limiting the stress of fast-moving water and allowing them to escape some predators; and others have suction cups, sharp claws or grasping mechanisms on their bodies to prevent them from being carried away in the swift-flowing current (Merritt & Cummins, 1996). For instance, black fly larvae have posterior hooks that are used to anchor them in place while they face upstream and actively capturing food with their fan-like mouth parts; net-building caddis fly larvae construct funnel-shaped nets, which they attach to stable substrate materials, and then periodically harvest the food caught in the mesh; stonefly species avoid high water temperatures by burrowing deep into the stream bottom substrate; and aquatic insects extract oxygen from the water with their external gills while others rely upon cutaneous respiration to obtain oxygen (EPA, 2021).

2.2.3 Benthic Macro-invertebrates Feeding System

The macro-invertebrates are classified into scrapers, shredders, predators and collector-gatherers based on their feeding strategy. For instance, water penny beetle is classified as a scraper since it has been observed grazing on algae that covers rocks and logs; the stonefly Pteronarcys is in the shredder functional feeding group because they primarily consume decaying leaves that have fallen into the stream from trees along the forested riparian corridor (Abong'o et al., 2015); the mayfly is classified as a collector-gatherer, primarily because it feeds on fine pieces of organic material on the stream bottom; and dobsonfly, more commonly known as hellgrammites, are active predators (Merritt & Cummins, 1996).

2.2.4. Importance of Benthic Macro-invertebrates

In aquatic ecosystems, benthic macro invertebrates play an extremely important and integral part in the food webs. This is because the energy stored by plants is available for consumption by benthic organisms either in the form of leaves that fall into the water or in the form of algae that grows on the stream bottom. The energy derived by the organisms through eating leaves and algae is then transferred to other life forms in and around the stream such as frogs, fish, salamanders, birds, snakes and even fishermen. Being an integral part of the aquatic food web, benthic macro-invertebrates convert energy stored in organic matter into a food source that fish and other vertebrates can utilize. They eat leaves, algae, and bacteria and, in turn, are eaten by fish, amphibians, birds, and other vertebrates. In death, benthic macro-invertebrates release nutrients that are reused by aquatic plants and animals, repeating the cycle (Aluoch, 2012). Also, benthic macro invertebrate species are important for recreational intentions.

In addition, benthic macro-invertebrates provide comprehensive and reliable information on biological monitoring especially on water and habitat quality, therefore, have been used as biological indicators in many parts of the world for the past 100 years. In many circumstances, it has been difficult to identify stressors and pollutants in aquatic ecosystems with physico-chemical data alone. This is because the data only provides information relevant to the precise time of sampling. Similarly, the presence of fish may not be indicative of the status of an aquatic ecosystem and habitat because fish can swim away from unfavourable habitat conditions, only to return when conditions improve. However, many benthic macro-invertebrates are not as mobile as fish and hence, cannot move to avoid changes in water quality. As a result, the community of benthic macro invertebrates living in a given aquatic environment may indicate the water quality conditions of the past.

Furthermore, benthic invertebrate species are excellent biological indicators for assessing water quality because they are extremely diverse, thus, they allow for a wide range of sensitivity and responses to stressors like nutrients, metals and sediments. Therefore, as water quality and habitat conditions change, the benthic macro-invertebrate community also changes (IOWA, 2010). Unlike fish and other vertebrates, benthic macro-invertebrates are less mobile and are unable or unlikely to escape the effects of sediment and other pollutants that diminish water quality. Benthic macro-invertebrates represent a diverse group of aquatic animals. The large number of individual taxa has a wide range of responses to stressors such as toxic pollutants, sedimentation, and habitat disturbance. Therefore, the number and kinds of taxa collected and identified are relatively good indicators of stream health. Having an abundance of different types of taxa, or high biodiversity, is important (IOWA, 2010).

Finally, they are found everywhere and relatively easy to collect and identify, which makes them attractive for a practical means of assessing water quality in aquatic ecosystem. In the view of Aluoch (2012), high species composition, diversity and abundance are normally found in the Lake Shores and riparian wetlands. The area contains discrete units which facilitate estimation of local diversity or alpha-diversity. The study further noted that lake shores are biotopes with many habitats both in water and along the moisture gradient from the water to drier environments. Perturbations in these ecosystems by human activities or natural processes causes biological attributes such as taxonomic richness, community structure, and health of individual organisms to change. For example, in disturbed systems, the number of intolerant individuals typically decreases while that of tolerant individuals increases. The biological community reflects the cumulative effect of multiple stressors, whether they be chemical (e.g. toxic chemical), physical (e.g. sedimentation) or biological (non-native species) (Rader *et. al*., 2001).

Studies assessing the status of and human impact on freshwater ecosystems are typically based on a single taxonomic group. In lakes and rivers, benthic macro-invertebrates is the most commonly surveyed groups, probably because they are better known than any other taxa present in streams and lake shores (Opaa, 2003). Aganmwonyi and Iriabgonse (2015) posited that macro-invertebrate assemblages are integrally linked to physical and chemical characteristics which they have frequently been used as indicators of water quality. He further noted that the assemblages in most cases respond to physical and chemical variables in specific geographical areas.

According to Aina and Oyebamiji *et al.* (2011) macro-invertebrates are especially well suited as taxa to indicate environmental quality. They asserted that macro-invertebrates occur in all but the most degraded waters. They further noted that the ecological and life history attributes of these organisms suggest that they can accurately reflect environmental conditions at numerous spatial, temporal, and organizational scales. Relative to other aquatic taxocenes (e.g. macro-invertebrates or algae), life history and geographic distribution is extensive for many Lake Victoria Basin fishes as was affirmed by Ngodhe *et al.* (2014). Additionally, macro-invertebrates are relatively more visible, understood, and easy to identify than other aquatic organisms such as phytoplankton and zooplankton (Ntiba *et al.*, 2001). However, information on the tolerance limits of macro-invertebrate species within the lake region rely heavily on professional judgement rather than specific studies by drawing from the occurrence of the macro invertebrates species within the basin, habitat quality and water quality in the study areas.

The Lake Victoria Environment Management Project (LVEMP, 2005) revealed that the ubiquitous and sedentary nature of benthic macro-invertebrates as well as their measurable responses to ambient conditions and exposure over time facilitates their use as important environmental indicators in aquatic ecosystem monitoring. As a result of the restricted mobility and habitat preferences associated with the benthos, they are subjected to the full rigor of their local environments (Jones *et al*., 2002). Subsequently, they also can change in composition and distribution with changes in their surrounding environmental conditions (Devon *et al.*, 2015).

According to Orwa *et al.* (2015), benthic macro invertebrates are commonly used in many assessment systems because they are recognized as one of the most reliable biological indicator groups in aquatic ecosystems. Two types of macro-invertebrate assessment systems are commonly used; namely, multi-metric and community approaches. In the multi-metric approach a number of biotic or ecological indices/metrics are combined to form a multi-metric index that is used to assess site quality. The first multi-metric systems were developed by Kalff (2002) using integrated ecological indices. In contrast to multi-metric approaches, the community approach focuses on the complete macro-invertebrate community, using both taxa composition and environmental variables to assess or predict site quality (Davis *et al.,* 2006).

In view of Renata *et al.* (2011), structures, composition and abundance of macro-invertebrate community can be influenced by a variety of factors which contribute to changes in their community. They further contended that long duration of flooding and high frequency altered sediment transport dynamics and favoured species adaptable to unstable habitats such as chironomids and oligochaetes. Tsegazeabe *et al.* (2012) posited that excess sedimentation limits refugial space, so invertebrates are more susceptible to drift. Benthic organic matter, a major food source for invertebrates, has documented capacity to bind many heavy metals and organic contaminants, thus exposing the fauna to potentially toxic effects (Sarkar *et. al*., 2002). An increase in nutrient, organic matter, or contaminant concentrations in surface waters, sediments or food sources result in low diversity of macro invertebrates, with an increase in the abundance of stress tolerant species. Despite all this evidence, little is understood about the effect of human-induced impacts on the life cycle, ecology, population dynamics, and community interactions of aquatic invertebrates in lake shore as was contended by Wibowo and Santoso (2017). However, many studies have been performed on macro invertebrates as biological assessment tools elsewhere at sites similar to Lake Victoria conditions. This study, however, examined the relationship between macro-invertebrate composition, abundance, structure and diversity and the level of pollution at different areas along the Lake Victoria shore.

2.3 Physico-Chemical Parameters Influencing Benthic Micro-Invertebrates

According to Odinga (2015), aquatic organisms' structure and function normally reflect change with increased human influence and physical or chemical conditions. Mary and Macrina (2012) contended that aquatic organisms tend to be controlled mainly by temperature regimes, substratum types and hydraulic variables. In view of Ngodhe *et al*. (2014), a number of factors such as colonisation, stochastic processes of recruitment, dispersal, and local extinction majorly control the macro-invertebrate communities of wetlands and lake shores, particularly those in areas of variable climate. These factors affect the macro-invertebrates themselves and the macrophyte beds that provide much of their habitat. Ram and Deep (2013) also established temperature, turbidity, discharge and specific conductivity as the main physical factors that affect aquatic environments.

Renata *et al.* (2011) perceived temperature to be having the most significant effect on living aquatic resources. This is because it directly influences the organisms' physical, biological and chemical functions. According to Teferi *et al.* (2013), temperature's ecological significance is manifested on its influence on the structure of riverine communities. For example, through combined influences on dissolved oxygen and metabolic activity, temperature has critical effects on species' distributions and density

(Rostgaard & Jacobsen, 2005). Temperature and oxygen levels usually fluctuate seasonally and aid in the structuring of benthic communities, which varies from species to species (Shieh & Yang, 2000). Temperature influences primary production, decomposition and litter processing with consequences for stream energetics (Shieh & Yang, 2000).

Turbidity is another physico chemical parameter that is affected by human activities (Ndiritu *et al.,* 2003) and it is the amount of suspended particles in water (Tsegazeabe *et al.,* 2012). It is important to aquatic organisms because it controls primary productivity. For benthos, turbidity caused by sedimentation is more detrimental because it smoothens interstitial spaces used as habitat and hiding places for organisms. In Nyando River basin for instance pollution caused by sediments has been reported in most river systems (Raburu, 2003). In Lake Victoria basin, Kenya, studies on the river, lake shores and riparian wetlands have indicated that sediments especially from agricultural areas are posing serious environmental concerns (Raburu, 2003).

Conductivity in water is determined by the amount of ions or salts in solution. In any aquatic ecosystem conductivity depends on the associated terrain and drainage area from where most ions are derived during runoff or underground flow. Seasonal differences in conductivity can be observed, being generally lower during the wettest seasons as the rivers are effectively diluted (Busulwa & Bailey, 2004). Spatial differences can also occur downstream in case of rivers and streams where higher values can be due to increased run-off bringing in more ions from the catchment. Differences in electrical conductivity between different aquatic ecosystems may be explained by differences in the underlying geology of their catchments. Conductivity is also influenced by temperature.

Low temperature, which does not facilitate the release of ions (Busulwa & Bailey, 2004), can lower conductivity causing temporal and spatial variations.

Natural differences in pH and alkalinity may be important determinants of macro-invertebrate communities. Makoba *et al*. (2008) contended that highly acidic water results in impoverishment of fauna and low acidities reflect better buffering and higher productivity. Generally, aquatic acidification can alter community structure by being acutely or chronically damaging tissues of invertebrates particularly for species that easily loose sodium ions when pH is reduced. Secondly, it alters algal communities, upon which some invertebrates depend for food and shelter, altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians, and by altering the bioavailability of some other potential stressors, such as heavy metals. Such effects may reduce invertebrate species diversity, increase in abundance of tolerant species and changed community composition (Shieh & Yang, 2000).

According to Abong'o *et al.* (2015) aquatic macro-invertebrates have the ability to occupy different substrata and live under different levels of physico-chemical water conditions. In their view, there are species which are tolerant to low levels of dissolved oxygen. On the other hand, there are some which can only tolerate moderate levels and cannot survive under anoxic conditions. In lowland areas high values of dissolved oxygen can be maintained by minimal interference from man's activities and the contribution by epilithic algae during photosynthesis. Temperature also regulates the amount of dissolved oxygen in water (Kalff, 2002). Increase in temperature lowers its solubility resulting in low values.

The amounts of nutrients in water play a significant role in influencing the chemistry of aquatic ecosystems. As water flow over rocks and soils, it carries some nutrients in solution while others are adsorbed into sediments on their way (Kalff, 2002). Further, he noted that the most important nutrients are those that are often in short supply and those that limit primary productivity, like phosphorus, nitrogen or both. Moreover, nutrient limitation is mostly reported in lakes than in rivers and this is attributed to the enriching effect of water velocity and turbulence. Another reason is that streams are open systems with a large capacity to retain nutrients (Kalff, 2002). Problems of nutrient enrichment that cause eutrophication have, thus, been reported in most aquatic ecosystems of Lake Victoria basin (Raburu, 2003) and the lake itself (Okungu and Opango, 2005).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This Chapter presents the study area and describes the materials and methods used in determining the influence of water quality on the diversity, abundance and distribution of benthic macro-invertebrates at the shores of Lake Victoria in Homa-Bay County. It describes research design, sampling techniques, sample collection and analysis methods.

3.2. Study Area

3.2.1 Physiographic and Natural Conditions

This study was conducted at the shores along Lake Victoria Basin in Homa-Bay County, Kenya. The County lies between latitude $0^{o}15'$ South and $0^{o}52'$ South, and between longitudes 34^{o} East and 35^{o} East and covers an area of 4,267.1 Km^2 including water surface area of 1,227 km^2. (Figure 3.1 (County Integrated Development Plan 2013-2017). Figure 3.2 shows the map for Homa Bay County where the study was undertaken. Homa-Bay County is divided into two main relief regions i.e. the lowlands lakeshore area between 1,163 – 1,219 m asl) and the upland plateau (>1,219m asl). A number of permanent rivers namely Awach Kibuon, Awach Tende, Maugo, Kuja, Rangwe and Riana rivers, most of which originate from Kisii and Nyamira counties and empty their water into Lake Victoria (CIDP, 2013-2017). There are also some seasonal rivers and streams which originate from highlands within the county (CIDP, 2013-2017).

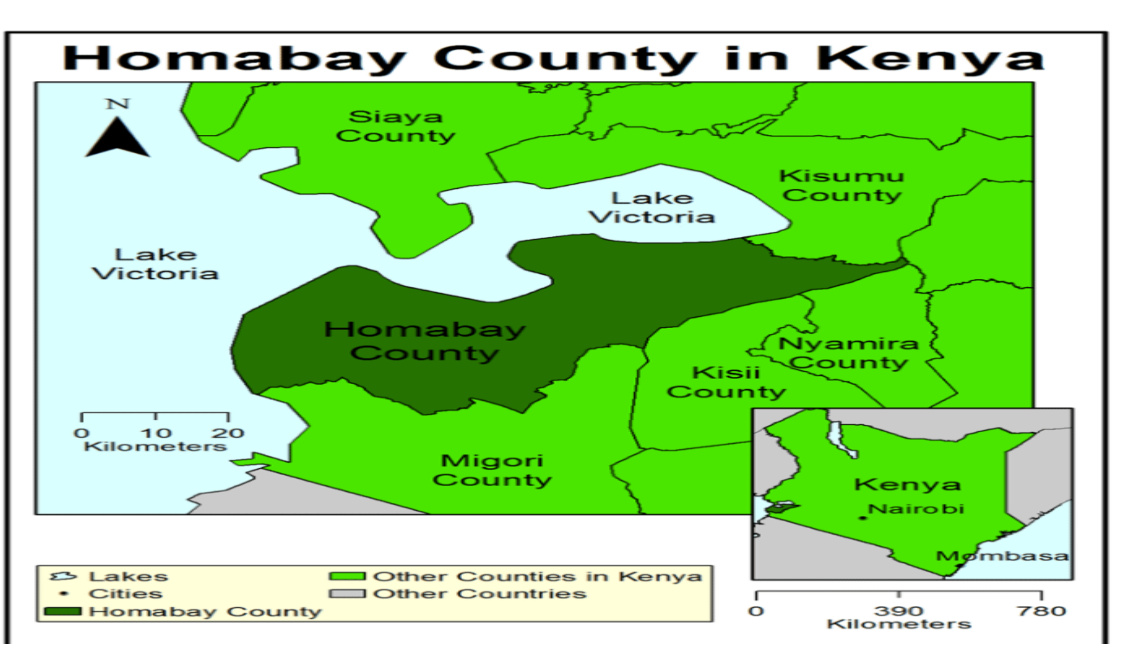

Figure 3.1: Map of Homa-Bay County in Kenyan Context
Source: www.google.com/search?q=homabay+county+map&tbm=isch&source July, 2019

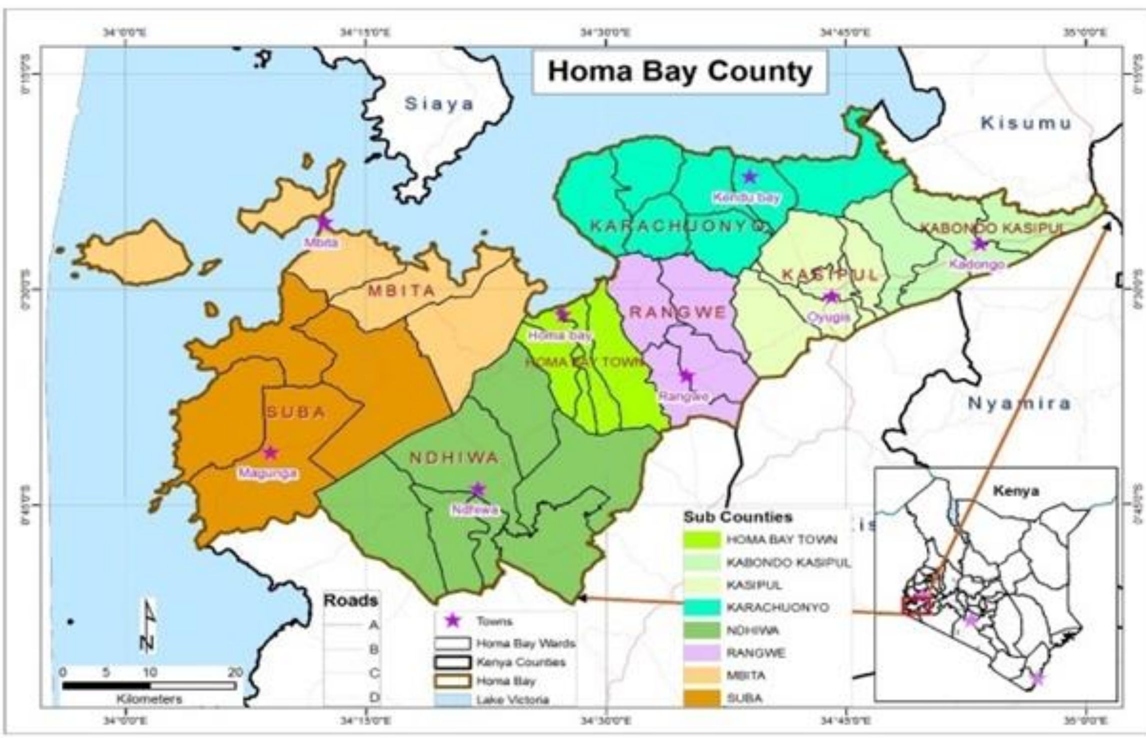

Figure 3.2: Homa Bay County Administrative Units
Source: www.google.com/search?q=homabay+county+map&tbm=isch&source July, 2019

3.2.2. Climatic Conditions

Homa Bay County has an inland equatorial type of climate usually moderated by the effect of altitude and nearness to the lake that lowers temperatures below the characteristic equatorial climate (CIDP, 2013-2017). The county realizes two rainy seasons namely the long rainy season which is 60% reliable and ranges from 250-1000 mm and occurs in March to June. The short rainy season is unreliable and ranges from 500-700 mm and occurs from August to November whereas temperature in the county ranges from 18.33°C to 29.44°C, with hottest months occurring between December and March. The temperatures are however lower in areas bordering the highlands of Kisii and Nyamira Counties and higher in areas bordering the lake. However, during the six months study period running from September 2019 to February 2020, the region experienced unexpected change in weather pattern with an onset of rainfall in December 2019 to February 2020.

3.2.3 Administrative Units

Homa-Bay County has eight Sub-Counties. However, the study was conducted in three selected lake shores within Mbita, Karachuonyo and Homa Bay town Sub-Counties. Table 3.1 presents the coverage, by area, of the three Subcounties.

Table 3.1: Selected Administrative units in Homa Bay County, Kenya

Sub County	**Area (Km^2)**
Mbita	420.8
Karachuonyo	441.2
Homa Bay Town	198.7

Source: *Homa-Bay County Integrated Development Plan (2018-2022)*

3.2.4. Demographic Features

The population of Homa Bay County based on the national census of 2019 Kenya Census gives an estimate of 1,038,858 persons comprising 498,472 males and 540,386 females (CIDP, 2013-2017).

3.3 Research Design

The study adopted quasi experimental research design. Asenahabi (2019) explains that quasi experimental research uses control and experimental groups to establish the causal relationship between independent variable and dependent variable but does not randomly assign subjects to different treatment groups. To obtain longitudinal comparison between the water quality changes and benthic macro-invertebrates parameters, three (3) study sites, namely: Oluch Kimira Bay at the river mouth, Homa-Bay Sewage discharge point in Homa Bay town and Mbita beach east of the course way were selected based on habitat diversity, and riparian land-use along the lake Shore. Data on water physico-chemical parameters collected included; temperature, pH, conductivity, dissolved oxygen (DO), depth, total dissolved solids (TDS), oxidation-reduction potential (ORP), Secchi, and turbidity; major nutrients such as nitrates, nitrites, soluble reactive phosphorus (SRP), Silicon Dioxide (SiO_2), Ammonium (NH_4), total Nitrogen (TN), total phosphorus; and benthic macro-invertebrate parameters was taken on monthly basis for the duration of six consecutive months starting from September 2019 to February 2020. To avoid bias in spatial variations or patchiness, samples were collected from micro habitats in each of the three sampling points at the three study sites. The identification of micro habitats was guided by the knowledge on physiological or behavioural adaptation of benthic macro invertebrates (Jeffries & Mills, 1990). A transect was taken at each sampling site, up to 200m inshore. Samples were taken at three points along the transect; the first point being onshore, the second midway (100m from the shoreline), and the third at 200m inshore. This procedure was replicated once each month for a period of six months at the sampling sites. Figure 3.3 illustrates the three study sites within Homa Bay County, Kenya and the sampling points.

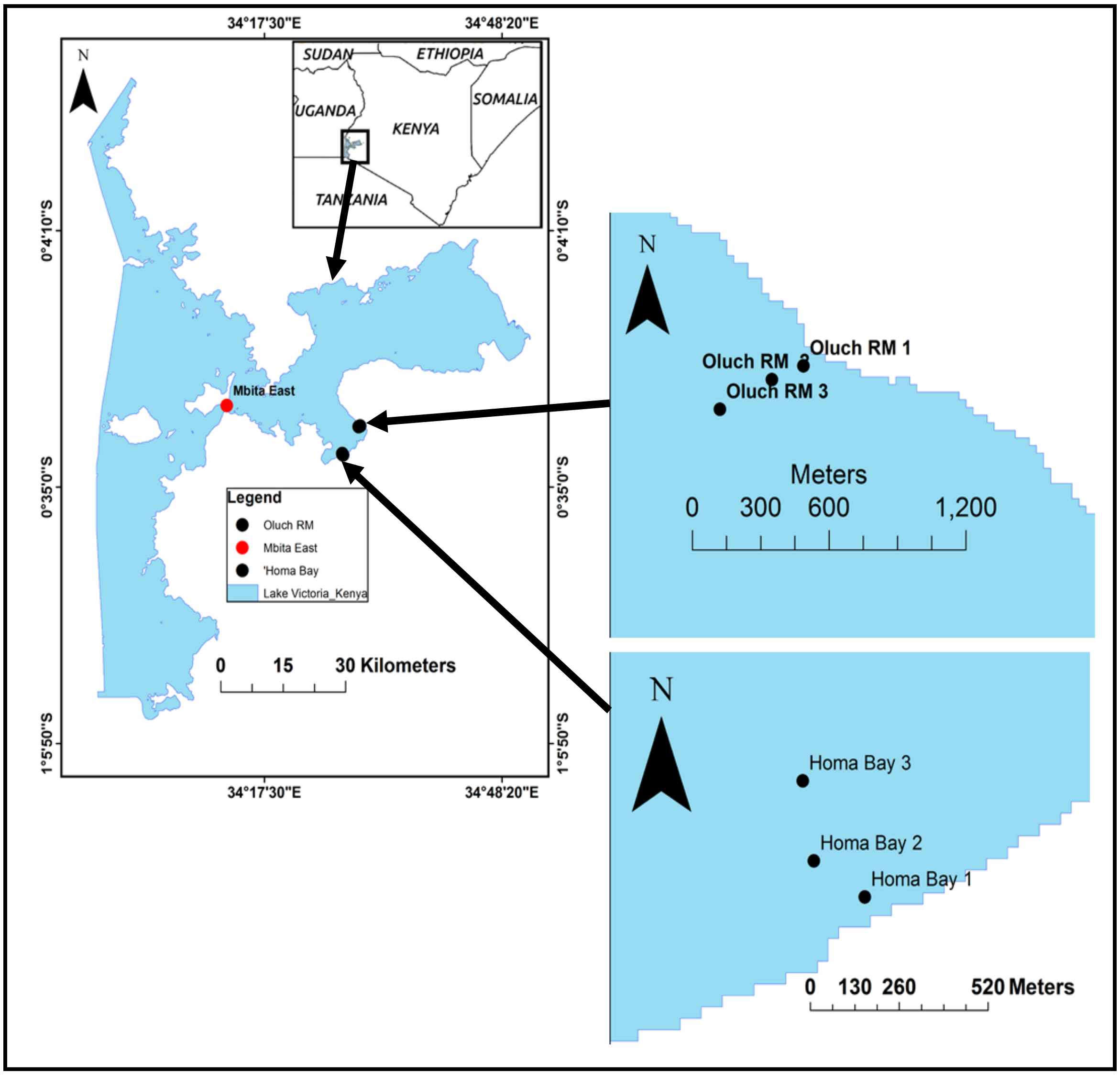

Figure 3.3: Study sites and sampling points within Lake Victoria-Kenya
Source: KMFRI-Kisumu (2020)

3.4 Sampling and Data Collection

The benthic macro invertebrate samples were collected using a sweep net and a grab sampler. At the same points where the Macro invertebrates were sampled, water samples for nutrients analyses were taken using Van Dorn water sampler and measurement of physico-chemical parameters taken in the field *in situ* using YSI meter and Secchi disc for light intensity.

3.4.1 Macro Invertebrate Sampling,

To sample macro invertebrates, the methods of sweep netting and grab sampling were used. Sweep netting was used to sample macro invertebrates in semi-aquatic vegetation (e.g para grass and sedges), tree roots or bare area, and in areas where emergent, sub-emergent and floating macrophytes or aquatic plants were present at relatively shallow depth (0.5-1.0) metres. The macro-invertebrates within the littoral zone were scooped using D frame dip nets of 500µm mesh size with 0.4m diameter. A total of 20 jabs were taken, resulting in sampling an area of approximately $3m^2$. The macro-invertebrates were washed through a 300 µm mesh size sieve, and hand sorted. However, grab sampling method was used to collect sediment-dwelling invertebrates in areas of deep water located at depths more than 1.0 metres but less than 2.0 metres using Ekman dredge grabber, which is a bottom sampling 3.5 litre devise (dimensions 152mmX152mmX152mm). The Ekman grab scoops an area of $0.231m^2$ per grab, and was used at a distance of 100 m and 200 m from the Lake shoreline (Figures 3.4 & 3.5). The contents of the dredge were emptied into 5 litre plastic pails. Using a bucket, clean water was poured on the sediment to break up compacted particles and to facilitate passage of the sediments through a sieve; then sieved using a 0.5 micro-metre soil sieve. Any rocks and large debris free of clinging organisms were removed. The organisms were picked with small soft forceps and kept in 250ml capacity jars and then to the organisms 100ml of 10 % formalin was added for preservation. Each jar was labelled indicating the date, site name, sample location and replicate number and taken to the laboratory at Kenya Marine and Fisheries Research institute (KMFRI), Kisumu, Kenya

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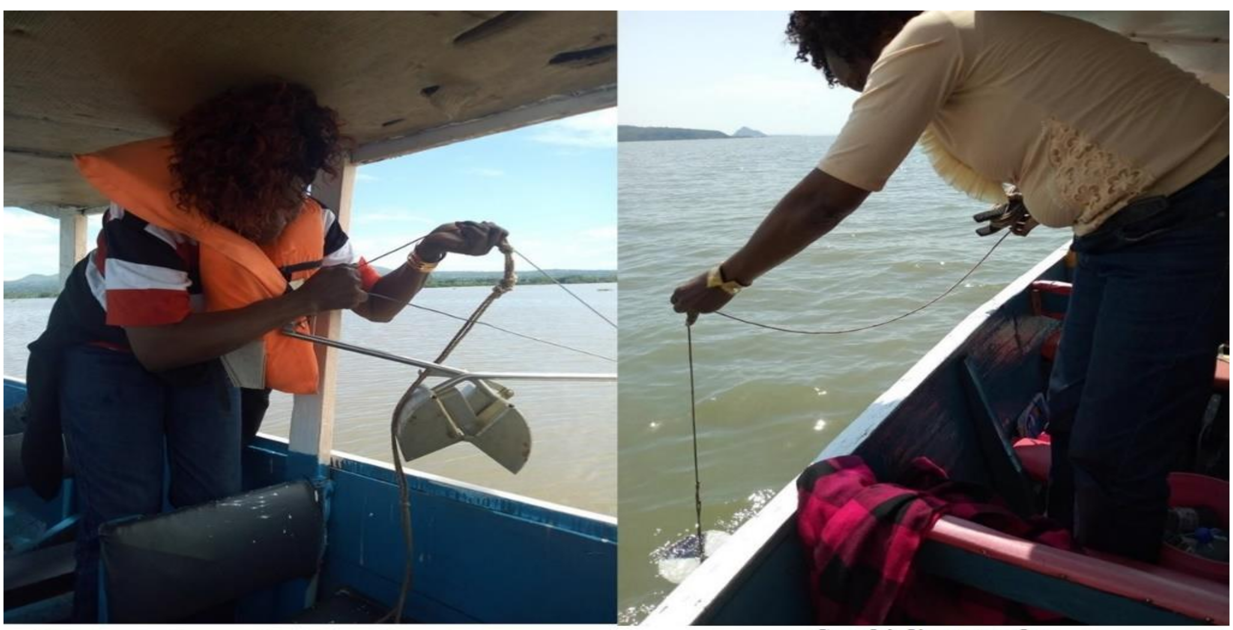
Scoopnet for shoreline sampling macro-invertabrates **Vandon for sampling water**

Figure 3.4: Edge bank sampler and Van Dorn water sampler
Source: Fieldwork photo



Ekman grab sampler for sediments **Secchi disc sampler**

Figure 3.5: Bottom sampling grabber and Secchi disc
Source: Fieldwork photo

3.4.2 Laboratory handling of specimens and determination of benthic macro invertebrates

Within two weeks of their collection, the field preserved samples were rinsed with water through a 250$_{\mu}$m mesh size sieve to remove formalin, mud and fine sand then preserved in 250ml capacity vials with 100ml 70% ethanol (Devon *et al.*, 2015). The benthic macro-invertebrates found in each sample were then sorted and identified using a stereoscope at X10 - X30 magnifications and counted. The macro invertebrates were identified to the lowest taxonomic level, and the names and separate counts for each replicate of a sampling site recorded to allow an evaluation of variability between the sites**.**

3.4.3 Water Sampling and Determination of Nutrients

The water samples were obtained at the macro-invertebrate sampling sites, at the same time and depth using Van Dorn water sampler (Figure 3.4), and transferred to 500ml high density polyethylene (HDPE) sample bottles and labeled with date and site of collection. Prior to taking samples the sample bottles were treated with a 0.5M Hydrochloric acid solution and rinsed well with de-ionized water. They were dried, cupped and stored to prevent any contamination. The bottles were then rinsed thrice with sample water before collecting water samples for nutrients. The water samples were fixed using Hydrochloric Acid (HCl) to reduce precipitation, microbial activity and sorption losses to the container walls. The samples were placed in ice box at 4^0C and stored under dark conditions, to inhibit any biological activities, such as that of bacteria and algae which may consume partially or completely some substrate required for their growth such as oxygen, nitrogen, phosphorous and silicon compound. The samples remained under dark conditions under refrigerator set at 4^oC to prevent freezing. The water samples for nutrients were filtered through Whatman filters of 0.45µm pore size in the laboratory. Nutrient analyses were conducted at the fresh water systems (KMFRI) - Kisumu station based on APHA (2017) methods. The analyses focused majorly on eutrophication compounds of nitrites, nitrates, ammonium, silicates, soluble reactive phosphorous (SRP), total phosphorous (TP) and total nitrogen (TN). The procedural method of analyses for the eutrophication compounds were as follows:

3.4.3.1 Nitrite

Nitrite samples complex directly with sulphanilamide and N-I – Napthyl ethylene diamine dihydrochloride. To 50mls of the sample in a flask, 0.5mls of sulphanilamide was added and mixed. The mixture was allowed to stand for 2-8 minutes, then, 0.5mls of N-1-Napthyl ethylene diamine dihydrochloride was added and mixed thoroughly. After 10 minutes the extinction was measured in the spectrophotometer against the blank at wavelength of 543nm and calculation done using the standards of potassium nitrite.

Working solution (1000mgNO_2-N/l)

10mls of stock solution was taken and diluted to 100mls using distilled deionized water. A series of dilution were then made and the, calibration curve was developed from which the concentration of the nitrites were determined.

3.4.3.2 Nitrate

Nitrates do not complex directly with the sulphanilamide method reagents, hence they were passed through cadmium reduction column to reduce nitrates to nitrite. Activated cadmium fine granules were packed into the reduction column which was buffered with ammonium chloride to maintain optimum pH of 8.5 which favours reduction of nitrate to nitrite at a set flow rate. As the sample flows through the cadmium bed the nitrates are reduced to nitrites. The first 20ml which flowed out from the column was discarded. To the final 25ml collected, 0.5ml of sulphanilamide reagent was added, mixed and allowed to settle for two minutes; and then 0.5ml of N-1-Napthyl ethylene diamine dihydrochloride was added. The pink complex developed was determined in the spectrophotometer at a wavelength of 543mm. The concentration calculated was of both nitrates and the nitrites initially in the water. To get the concentration of nitrates, the concentration of nitrites calculated initially was subtracted from the concentration of the mixture.

3.4.3.3 Silica

Dissolved silica (SiO_2) normally occurs in moderate abundance in fresh water. Silicon in solution as silicic acid (H_4SiO_2) or silicate (SiO_2) reacts with acidic ammonium molybdate to form a yellow silicomolybdate complex. The complex was then reduced by sodium sulphite to form the silicomolybdate complex. The extinction was measured at 700nm in the spectrophotometer. 25mls of filtered sample for silicate analysis was treated with 5mls of 0.25m hydrochloric acid in the flask and swirled. It was then followed by 5mls of 5% ammonium molybdate and mixed. This was followed with the addition of 5mls of 1% EDTA disodium salt and thoroughly mixed. After 5 minutes, 10mls of 17% sodium sulphite was added, mixed and allowed to stand for 30 minutes. A coloured complex was generated and the colour was stable for 3 hours. The extinction was measured by the spectrophotometer at a wavelength of 700mm. The calculation of the silicate was achieved using the calibration curve drawn from silicate standard of series dilution. The dilution ranged from (0.4mg/l) $Si0_2$ - (4mg/l) $Si0_2$.

3.4.3.4 Soluble Reactive Phosphorous (SRP)

Phosphorous was analyzed with mixed reagent made from four different reagents: 100mls ammonium molybdate solution, 250mls sulphuric acid solution, 100mls ascorbic acid solution and 50mls potassium antimonyltartrate solution. The analysis was as the following protocol:-

50mls filtered sample into the flask was followed by addition of 5mls of mixed reagent. The blue coloured complex was formed, after 1 hour then the extinction was determined by spectrophotometer at a wavelength of 885nm. The standard used was potassium dihydrogen phosphate.

3.4.3.5 Total phosphorous

25mls of unfiltered sample, 5mls of potassium persulphate was added and mix well. The sample was then autoclaved at a temperature of 120^0c for 30 minutes. It was allowed to cool to room temperature. The other form of phosphorous was digested to soluble reactive phosphorous (SRP). After digestion, the protocol of soluble reactive phosphorus process was assumed.

3.4.3.6 Total nitrogen

Samples were digested in the autoclave or high temperature and pressure. This was to digest all forms of nitrogen in water to nitrate form. The 10ml of unfiltered sample was measured into digesting bottles and 5mls of the potassium persulphate added. The samples were then digested in the autoclave at high temperature and pressure for 30 minutes and then cooled to ambient temperature. The sample was removed and then nitrate analytical procedure was followed to quantify the concentration of total nitrogen.

3.4.3.7 Ammonium

In high alkaline conditions (pH>9), most of the (NH_3) in freshwater exist in the ionic form ($NH4^{+}$). Ammonium reacts with phenol and hypochlorite under alkaline conditions to form indophenol blue. 50mls of the sample was measured into the flask, 3ml of reagent 1 (phenol and sodium nitroprusside) added and followed with reagent 2 of (sodium citrate dihydrate, sodium hydroxide and sodium hypochlorite). The samples were then kept in the dark at room temperature for 24 hours. The samples extinctions determined by spectrophotometer at a wavelength of 630nm. The calculation of the concentration was determined by the standards made from ammonium chloride calibration curve.

3.4.4 Sampling and Determination of Physico-Chemical parameters

Digital water quality sampling multi-parameter YSI meter (Figure 3.6), was used to sample and measure *in-situ*, physico-chemical parameters at depths of about 5-10cm below the water surface at the time of benthic macro-invertebrate sample collection.

Figure 3.6: YSI meter for water Physico-Chemical parameters
Source: Fieldwork photo

The physico-chemical parameters measured included temperature, pH, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), total dissolved solids (TDS) and turbidity. Transparency of water was measured using “Secchi disc” (a circular disc of 30cm diameter painted black and white), mounted on a pole and lowered slowly into the water. The depth at which it is no longer visible was taken as the measure of the transparency of the water.

3.5 Statistical Analysis

To determine diversity and abundance of benthic macro-invertebrate species in the study sites, Shannon-Wiener Index ($H^{'}$) and relative abundance were computed. According to Nolan and Callahan (2006), Shannon-Wiener Index ($H^{'}$) is a measure of the average degree of uncertainty (synonymous with diversity) of predicting the species of a given individual picked at random from a community. The equation used in the Shannon-Weiner Index- $H^{'}$, as used by Nolan and Callahan (2006) is:

$$H^{'} = -\sum p_i \ln p_i$$

Where: p_i = is the proportion of individuals of each species belonging to the i^{th} species of the total number of individuals

In terms of interpretation, the higher the diversity index, the higher the species diversity and the lower the diversity index, the lower the species diversity.

Relative abundance (R.A) is the percentage composition of an organism of a particular kind relative to the total number of organisms in the area. Relative species abundances tend to conform to specific patterns that are among the best-known and most-studied patterns in macro-ecology. Different populations in a community exist in relative proportions; this idea is known as relative abundance. According to Barbour *et* *al*. (1996), relative abundance (RA) is a composition measure that provides information on the make-up of an assemblage and the relative contribution of the populations to the total assemblage and is determined by the formula.

$$\mathbf{R.A} = \frac{\text{Number of individual species of one taxon x 100}}{\text{Total number of individual species in a station}}$$

Relative abundance is linked to the dominance of species such that high levels of relative abundance imply higher dominance of the species.

The data from water analyses and count data of benthic macro invertebrate were used for descriptive analysis in form of frequency counts, indices, mean and standard deviations to summarize the data characteristics; and inferential analysis in form of one way Analysis of Variance (ANOVA) followed by a Turkey's Post Hoc test.

One-way Analysis of Variance (ANOVA) and Turkey's HSD post hoc Test for multiple comparisons was used to test for differences in water quality parameters, benthic macro invertebrate diversity and benthic macro invertebrate abundance among the study sites.

Lastly, to establish the effect of water quality on diversity, abundance and distribution of benthic macro invertebrate, a Canonical Correspondence analysis (CCA) – in Microsoft Excel using the XLSTAT statistical software was used to help relate the water quality physico-chemical parameters to abundance of benthic macro invertebrate species.

All statistical procedures were performed using Excel and SPSS statistical packages, and 95% level of confidence, at $p < .05$, considered statistically significant.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Status of Water Quality along the Shores of Lake Victoria

The descriptive analysis gives an overview on the variation of water quality parameters in the study sites along the shores of Lake Victoria. It presents the results on the status of physico-chemical and nutrients load parameters at Mbita beach east of the course way, Oluch Kimira river mouth and Homa Bay sewage discharge point, all located along the shores of Lake Victoria in Homa Bay County, Kenya.

4.1.1 Status of Selected Water Physico-Chemical Parameters

Table 4.1 presents the results of the physico-chemical parameters including secchi, temperature, turbidity, total dissolved solids, conductivity, dissolved oxygen, ORP and pH.

Table 4.1: Status of Water Physico-Chemical Parameters along the Shores of Lake Victoria

	Mbita Beach		**Oluch Kimira**		**Homa Bay**		
Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**One way ANOVA Output**
Secchi(m)	1.12	.15	.25	.09	.44	.06	$F(2,15) = 112.49$, $p = .000$
Temp(◦C)	25.81	.45	24.78	.49	26.48	.50	$F(2,15) = 19.11$, $p = .000$
Turbidity(NTU)	23.90	16.12	317.47	53.19	56.48	11.16	$F(2,15) = 145.02$, $p = .000$
TDS(mgL^{-1})	68.04	12.77	84.20	12.63	79.24	13.70	$F(2,15) = 2.42$, $p = .123$
Cond(μScm^{-1})	121.19	11.29	147.86	9.81	143.58	10.47	$F(2,15) = 11.08$, $p = .001$
DO(mgL^{-1})	6.76	.85	5.49	.80	5.09	.22	$F(2,15) = 9.76$, $p = .002$
ORP(mV)	-180.75	30.01	-170.49	29.05	-187.78	24.67	$F(2,15) = .58$, $p = .573$
pH	8.04	.45	7.92	.31	8.47	.47	$F(2,15) = 2.99$, $p = .081$

In regard to the transparency of water, the status at Mbita beach east of the course way (M=1.12m, SD=.15) was significantly different (F (2, 15) =112.49, $p<.05$) with the average status along Homa Bay sewage discharge point (M=0.44m, SD=.06) and Oluch

Kimira river mouth (*M*=0.25m, *SD*=.09). Therefore, indicating that the level of water transparency was relatively higher along Mbita beach east of the course way compared to water transparency along Homa Bay sewage discharge point and Oluch Kimira river mouth. According to European Commission (2008) low water transparency is an indication of deterioration in water quality. Thus, suggesting that the water quality along Oluch Kimira river mouth and Homa Bay sewage discharge point was relatively of lower quality than along Mbita beach east of the course.

Similarly, average temperature along Mbita beach east of the course way (*M*=25.81^{o}C, *SD*= .45) was significantly different (F (2, 15) =19.11, $p< .05$) with the average temperature (*M*=26.48 ^{o}C, *SD*=.50) and (*M*=24.78 ^{o}C, *SD*=.49) along Homa Bay sewage discharge point and Oluch Kimira river mouth respectively. Somero (2010) pointed out that as temperature increases, warm adapted species invaded or dominated a community while cold adapted species were physiologically or competitively excluded. This indicates that the temperature variations as a result of seasonal and spatio-temporal adjustment influenced the diversity, abundance and distribution of benthic macro invertebrate species. The finding concurs with Shieh and Yang (2000) assertion that seasonal temperature fluctuations aid in the structuring of benthic communities, which varies from species to species. Shieh and Yang (2000) continue to report that temperature influences primary production, decomposition and litter processing with consequences for energetics.

Equally, average turbidity along Mbita beach east of the course way (*M*=23.90 NTU, *SD*= 16.12) was significantly different (F (2, 15) =145.02, $p< .05$) from the average turbidity along Homa Bay sewage discharge point (*M*=56.48 NTU, *SD*=11.16) and Oluch Kimira river mouth (*M*=317.47 NTU, *SD*= 53.19). The result indicates that the sites had turbidity levels exceeding the World Health Organization recommended guideline of 5 NTU, for drinking water (World Health Organization, 2008). The high turbidity could be attributed to the organic matter, agricultural runoff, dissolved solids, leaching of soil contaminant and point source discharge from domestic waste and sewage treatment; contributed by anthropogenic activities along the Lake Victoria basin. The finding is consistent with Ndiritu *et al.* (2003) finding that turbidity levels in water bodies increase as a result of anthropogenic activities such as agriculture and human development settlement. This must have been very important in determining the diversity, abundance and distribution of benthic macro invertebrate species along the shores of Lake Victoria since it influences primary productivity of aquatic organisms and poses environmental challenges to aquatic and human life. This is in line with Raburu (2003) who reported that studies on Lake Victoria shores indicated that sediments especially from agricultural areas are posing serious environmental concerns.

Conversely, average total dissolved solids (TDS) along Mbita beach east of the course way (*M*=68.04 mgL^{-1}, *SD*=12.77) was not significantly different (F (2, 15) = 2.42, p>.05) with the averages along Homa Bay sewage discharge point (*M*=79.24 mgL^{-1}, *SD*=13.70) and Oluch Kimira river mouth (*M*=84.20 mgL^{-1}, *SD*=12.63), suggesting same levels of total dissolved solids along the shores of Lake Victoria. The average values of total dissolved solids were below recommended limit of 500–1000 (mg/L) permissible for drinking (World Health Organization, 2017). The finding points out that spatio-temporal variation in total dissolved solids could not influence significant variations in diversity, abundance and distribution of benthic macro invertebrates.

In regard to water electrical conductivity, the average (M=121.19 μScm^{-1}, SD= 11.29) along Mbita beach east of the course way was significantly different (F (2, 15) =11.08, p<.05) with the conductivity along Homa Bay sewage discharge point (M=143.6 μScm^{-1}, SD=10.47) and along Oluch Kimira river mouth (M=147.86 μScm^{-1}, SD=9.81). Consequently, turkey post hoc analysis was conducted and revealed that there was significant difference between the average electrical conductivity along Mbita beach east of the course way and Homa Bay sewage discharge point, and between Mbita beach east of the course way and Oluch Kimira river mouth. The result indicates that there was relatively low salt content since the conductivity values were below the permissible limit of 1400 µS/cm (World Health Organisation, 2012). Therefore, suggesting that conductivity could not influence significant variations in diversity, abundance and distribution of benthic macro invertebrates along the shores of Lake Victoria.

With regard to dissolved oxygen, the average status along Mbita beach east of the course way (M=6.76 mgL^{-1}, SD=.85) was significantly different (F (2, 15) =9.76, p<.05) with the average dissolved oxygen (M=5.09 mgL^{-1}, SD=.22) along Homa Bay sewage discharge point and (M=5.49 mgL^{-1}, SD=.80) along Oluch Kimira river mouth. The turkey post hoc test indicated that average dissolved oxygen level along Mbita beach east of the course way was significantly greater than the dissolved oxygen levels along Homa Bay sewage discharge point and Oluch Kimira river mouth. However, there was no statistically significant difference between dissolved oxygen along Homa Bay sewage discharge point and Oluch Kimira river mouth. The result indicated that dissolved oxygen concentration along Mbita beach east of the course way was within WHO permissible levels (6.5-8.0 mgL^{-1}), whereas dissolved oxygen concentration along Oluch river Mouth and Homa Bay sewage discharge point were below permissible levels (World Health Organization, 2017). EPA (2022) opine that; while each organism has its own DO tolerance range, generally, DO levels below 3 milligrams per liter (mg/L) are of concern and waters with levels below 1 mg/L are considered hypoxic and usually devoid of life. Therefore, the findings suggest that the water quality along Mbita beach east of the course way would relatively support survival of most oxygen dependent benthic macro invertebrate species as opposed to the water quality along Oluch river Mouth and Homa Bay sewage discharge point which would influence survival of most benthic macro invertebrate species tolerant to low dissolved oxygen.

Conversely, oxidation-reduction potential (ORP) along Mbita beach east of the course way (*M*= -180.75mV, *SD*= 30.01) was not significantly different (F (2, 15) = .58, p >.05) with the average oxidation-reduction potential along Homa Bay sewage discharge point (*M*= -187.78 mV, *SD*= 24.67) and Oluch Kimira river mouth (*M*= -170.49 mV, *SD*= 29.05). The negative values indicate reducing conditions and the presence of contaminants such as organic matter along the shores of Lake Victoria; however, this could not have significant influence on diversity, abundance and distribution of benthic macro invertebrate species along the shores because the averages were within permissible limits.

Similarly, the average pH levels along Mbita beach east of the course way (*M*=8.04, *SD*=.45) was not significantly different (F (2, 15) =2.99, p>.05) from the average pH levels (*M*=8.47, *SD*=.47) along Homa Bay sewage discharge point and (*M*=7.92, *SD*=.31) along Oluch Kimira river mouth. Yuan (2004) reported that benthic macro invertebrates are sensitive to pH variation, and values below 5 or >9 are considered harmful. This is an indication that the pH was conducive for sustaining aquatic organisms, hence, had no significant influence on diversity, abundance and distribution of benthic macro invertebrates along the shores of Lake Victoria.

4.1.2 Status of Nutrients Load

EPA (2012) defines nutrients as chemicals elements that all living plants and animals need to grow. When excessive nitrogen and phosphorus enter the water bodies from a wide range of human activities, the water quality deteriorates. Table 4.2 presents the experimental results obtained along the shores of Lake Victoria.

Table 4.2: Status of Nutrient Loads along the studied Lake shorelines in Homa Bay County

	Mbita East		Oluch Kimira		Homa Bay		
Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**One way ANOVA Output**
Nitrates(μgL^{-1})	4.83	1.17	39.83	12.83	13.67	3.14	$F(2,15)= 33.92, p= .000$
Nitrites(μgL^{-1})	2.67	.52	14.50	2.81	9.67	2.94	$F(2,15)= 37.85, p= .000$
SRP(μgL^{-1})	15.17	6.56	24.83	3.49	24.33	9.69	$F(2,15)= 3.58, p= .054$
$SiO_2(mgL^{-1})$	3.17	1.60	16.00	6.87	6.67	2.88	$F(2,15)= 3.65, p= .000$
$NH_4(\mu gL^{-1})$	3.67	1.21	21.67	5.47	13.17	5.19	$F(2,15)= 25.03, p= .000$
TN(μgL^{-1})	91.83	22.48	363.67	152.73	310.33	151.37	$F(2,15)= 7.99, p= .004$
TP(μgL^{-1})	107.67	56.96	266.67	29.62	194.67	56.54	$F(2,15)= 15.59, p= .000$

From Table 4.2, average nitrate level along Mbita beach east of the course way (M=4.83 μgL^{-1}, SD=1.17) was significantly different (F (2, 15) =33.92, p< .05) with the nitrate levels (M=39.83 μgL^{-1}, SD=12.83) and (M=13.67 μgL^{-1}, SD=3.14) along Oluch Kimira river mouth and Homa Bay sewage discharge point respectively. The result indicates that nitrate levels were relatively high along Oluch Kimira river mouth followed by Homa Bay sewage discharge point and lowest in Mbita beach east of the course way. Minu *et al.* (2020) asserted that spatial levels of nutrients are site specific depending on biological and anthropogenic activities. Consequently, the higher levels of nitrate along Oluch Kimira river mouth and Homa Bay sewage discharge point could be attributed to greater levels of biological discharges and anthropogenic activities than along Mbita beach east of the course way. The assertion concurs with EPA (2012) finding that identified the primary sources of nutrients to include sewage treatment plant discharges, animal manure, and runoff of fertilizers among others.

Equally, the status of nitrite along Mbita beach east of the course way (M=2.67μgL^{-1}, SD= .52) was significantly different (F (2, 15) =145.02, $p< .05$) with the status of nitrite along Homa Bay sewage discharge point (M=9.67μgL^{-1}, SD=2.94) and Oluch Kimira river mouth (M=14.50 μgL^{-1}, SD=2.81). The result indicates that the greatest level was along Oluch Kimira river mouth followed by Homa Bay sewage discharge point and Mbita beach east of the course way. This suggests higher nutrient load along Oluch Kimira river mouth and Homa Bay sewage discharge point that could influence deterioration in water quality and hence, affecting diversity, abundance and distribution of benthic macro invertebrates along the shores.

However, soluble reactive phosphorus (SRP) along Mbita beach east of the course way (M=15.17μgL^{-1}, SD=6.56) was not significantly different (F (2, 15) =3.58, $p> .05$ from the average soluble reactive phosphorus levels (M=24.33μgL^{-1}, SD=9.69) along Homa Bay sewage discharge point and (M=24.8μgL^{-1}, SD=3.49) along Oluch Kimira river mouth. The result indicates that the levels of soluble reactive phosphorus could not bring about significant variation in diversity, abundance and distribution of benthic macro-invertebrate species along the shores of Lake Victoria.

On the other hand, silica (SiO_2) levels along Mbita beach east of the course way (M=3.17mgL^{-1}, SD= 1.60) was significantly different (F (2, 15) =3.65, p< .05) with the level of silica along Homa Bay sewage discharge point (M=6.67mgL^{-1}, SD=2.88) and Oluch Kimira river mouth (M=16.00mgL^{-1}, SD= 6.87). However, turkey post hoc test established that level of silica along Oluch Kimira river mouth was significantly different from the levels along Homa Bay sewage discharge point and along Mbita beach east of the course way.

Similarly, ammonium (NH_4) along Mbita beach east of the course way (M=3.67μgL^{-1}, SD= 1.21) was significantly different (F (2, 15) =25.03, p< 0.05) with the average ammonium levels along Homa Bay sewage discharge point (M=13.17μgL^{-1}, SD=5.19) and (M=21.67μgL^{-1}, SD=5.47) along Oluch Kimira river mouth. Turkey post hoc analysis revealed that ammonia concentration was significantly different in the three study sites with the concentration along Oluch Kimira river mouth being the highest followed with levels along Homa Bay sewage discharge point and lowest along Mbita beach east of the course way.

Moreover, total nitrate along Mbita beach east of the course way (M=91.83μgL^{-1}, SD= 22.48) was significantly different (F (2, 15) =7.99, p< 0.05) with total nitrate along Homa Bay sewage discharge point (M=310.33μgL^{-1}, SD=151.37) and along Oluch Kimira river mouth (M=363.67μgL^{-1}, SD=152.73). However, turkey post hoc test established that there were significant differences in total nitrate levels between Mbita beach east of the course way and Oluch Kimira river mouth, and between Mbita beach east of the course way and Homa Bay sewage discharge point. Therefore, suggesting that nutrient load was relatively more along Oluch Kimira river mouth and Homa Bay sewage discharge point than Mbita beach east of the course way.

Similarly, total phosphorus along Mbita beach east of the course way (*M*=107.67$\mu g L^{-1}$, *SD*=56.96) was significantly different (F (2, 15) =15.59, p< .05) from the total phosphorus (*M*=194.67$\mu g L^{-1}$, *SD*=56.54) and (*M*=266.67$\mu g L^{-1}$, *SD*=29.62) along Homa Bay sewage discharge point and Oluch Kimira river mouth respectively. EPA (2017) considers phosphorus as "limiting nutrient" in aquatic ecosystems, since in appropriate quantities; phosphorus can be used by vegetation and soil microbes for normal growth, however, in excess quantities, phosphorus can lead to water quality problems such as eutrophication and harmful algal growth. Therefore, even small increases in the level of phosphorus negatively affect water quality and biological condition.

4.2 Diversity of Benthic Macro-Invertebrates along Lake Victoria

The second objective of the study sought to determine the diversity of benthic macro-invertebrates along the shores of Lake Victoria in Homa Bay County, Kenya.

To realize the objective, the study analysed the seasonal diversity and spatio-temporal diversity of benthic macro invertebrates and the results presented in Tables 4.3 and 4.4.

Table 4.3: Spatial and Seasonal Benthic Macro Invertebrates

	Season	Species Richness
Mbita Beach	Dry	15
	Wet	19
Oluch Kimira	Dry	16
	Wet	22
Homa Bay	Dry	9
	Wet	11

The result in Table 4.3 revealed that during the dry season in the months of September 2019 to November 2020, the study identified 15 benthic macro-invertebrates species along Mbita beach east of the course way, 16 species along Oluch Kimira river mouth and 9 species along Homa Bay sewage discharge point and during the wet season in the months of December 2019 to February 2020, 19 species were identified along Mbita beach east of the course way, 22 species along Oluch Kimira river mouth and 11 species along Homa Bay sewage discharge point. The result shows that the species richness was relatively higher during the wet season in the study sites. This indicates that changes in rainfall and temperature affected species richness of benthic macro-invertebrates. Therefore, suggesting that there was seasonal variability in benthic macro invertebrate diversity along the shores of Lake Victoria, in Homa Bay County, Kenya.

Table 4.4: Spatio-temporal Diversity of Benthic Macro Invertebrates

		Sept. 2019	**Oct. 2019**	**Nov, 2019**	**Dec, 2019**	**Jan, 2020**	**Feb, 2020**
Mbita East	Species Richness	10	12	11	11	8	15
	Shannon Index	1.59	1.84	1.69	1.98	1.65	2.47
Oluch Kimira	Species Richness	14	13	10	12	18	19
	Shannon Index	1.93	1.78	1.52	1.80	2.12	2.21
Homa Bay	Species Richness	6	9	6	10	8	9
	Shannon Index	1.65	1.87	1.64	2.05	1.96	1.90

The results in Table 4.4 shows that the numbers of benthic macro-invertebrate species identified in the months of September 2019 to February 2020 varied based on spatial location of study sites and seasonal changes in the habitats. The highest and lowest numbers of benthic macro invertebrate species identified was fifteen (15) and eight (8) along Mbita beach east of the course way, nineteen (19) and ten (10) along Oluch Kimira river mouth, and ten (10) and six (6) along Homa Bay sewage discharge point, respectively. The findings suggest that there was spatial and temporal variability in benthic macro-invertebrates diversity along the shores of Lake Victoria in Homa Bay County, Kenya. The finding concurs with study finding by Steve *et al.* (2014) reporting that variation in species diversity were as a result of spatio-temporal changes of fresh water bodies.

Also, Table 4.4 shows that diversity index was highest (1.93) along Oluch Kimira river mouth and lowest (1.59) along Mbita beach east of the course way in the months of September 2019, highest (1.87) along Homa Bay sewage discharge point and lowest (1.78) along Oluch Kimira river mouth in the months of October 2019, highest (1.69) along Mbita beach east of the course way and lowest (1.52) along Oluch Kimira river mouth in the months of November 2019, highest (2.05) along Homa Bay sewage discharge point and lowest (1.80) along Oluch Kimira river mouth in the months of December 2019, highest (2.12) along Oluch Kimira river mouth and lowest (1.65) along Mbita beach east of the course way in January 2020, and highest (2.47) along Mbita beach east of the course way and lowest (1.90) along Homa Bay sewage discharge point in the months of February 2020. The result suggests that there was spatio-temporal variability in benthic macro-invertebrates diversity along the shores of Lake Victoria in Homa Bay County, Kenya.

Furthermore, one way ANOVA was performed to test the null hypothesis: *Species diversity of benthic macro-invertebrates along the various shores of Lake Victoria, Homa Bay County are not significantly different*. Table 4.5 presents the results of one way ANOVA.

Table 4.5: ANOVA: Mean Diversity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	183.444	2	91.722	12.489	.001
Within Groups	110.167	15	7.344		
Total	293.611	17			

The result revealed that there were significant differences in diversity of benthic macro invertebrates between the three study sites along the shores of Lake Victoria, (F (2, 15) = 12.49, p= .001). Therefore, it implies that the various anthropogenic activities undertaken along the shores of Lake Victoria differently affect the lake water quality at the shores and as a result impacts differently on species diversity of benthic macro invertebrates. Table 4.6, therefore explores the differences between the means in diversity indices along the three shores of Lake Victoria.

Table 4.6: Turkey HSD Multiple Comparisons

					95% Confidence Interval	
Site	Site	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
Homa Bay	Oluch	-7.667*	1.565	.001	-11.73	-3.60
	Mbita	-5.167*	1.565	.013	-9.23	-1.10
Oluch	Homa Bay	7.667*	1.565	.001	3.60	11.73
	Mbita	2.500	1.565	.277	-1.56	6.56
Mbita	Homa Bay	5.167*	1.565	.013	1.10	9.23
	Oluch	-2.500	1.565	.277	-6.56	1.56

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

Turkey's HSD Test for multiple comparisons found that species diversity of benthic macro invertebrates was significantly different between Mbita beach east of the course way and Homa Bay sewage discharge point (p= .013, 95% C.I. [1.10, 9.23] and between Oluch Kimira river mouth and Homa Bay sewage discharge point (p= 0.001, 95% C.I.

[3.60, 11.73]. However, there was no statistically significant difference in species diversity of benthic macro invertebrates between Mbita beach east of the course way and Oluch Kimira river mouth since the p-value ($p= .277$) was greater than the set level of significance, $\alpha= .05$. The study therefore rejects the null hypothesis and concludes that species diversity of benthic macro-invertebrates along Mbita beach east of the course way, Homa Bay sewage discharge point and Oluch Kimira river mouth, shores of Lake Victoria, in Homa Bay County are significantly different. This finding indicates that the various human activities undertaken along the shores affects the lake water quality which impacts on the species diversity of benthic macro invertebrates. The findings of this study are in agreement with those of the study done by Camara *et al.* (2015) which established that organisms differed according to the human activities along the rivers and Lakes.

4.3 Abundance and Distribution of Benthic Macro-Invertebrates along Lake Victoria

The third objective of the study sought to analyze the abundance and distribution of benthic macro-invertebrates along the shores of Lake Victoria, Homa Bay County. The results on benthic macro invertebrate species abundance and distribution are presented as follows.

4.3.1 Abundance of Benthic macro-invertebrate along Lake Victoria shores

In order to determine the abundance, the study analysed the seasonal abundance and spatio-temporal abundance of benthic macro invertebrates and the results presented in Figures 4.1 to 4.4.

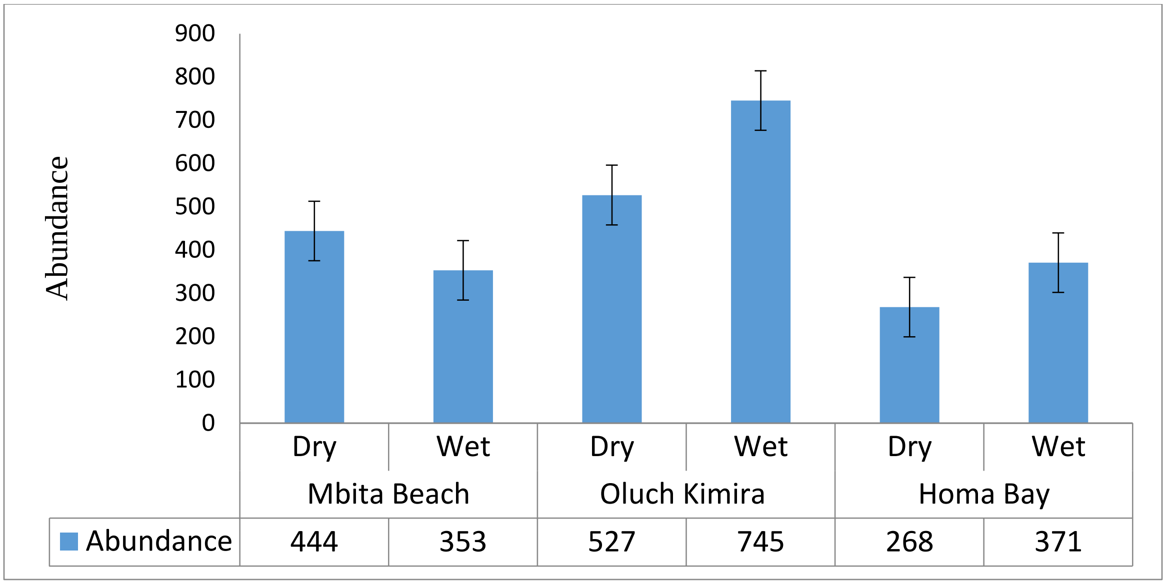


Figure 4.1: Seasonal and spatial Abundance of Benthic Macro-Invertebrates

In regards to species abundance, during dry season in the months of September 2019 to November 2019, 444 individuals of benthic macro-invertebrate species were identified along Mbita beach east of the course way, 268 individuals along Homa Bay sewage discharge point and 527 individuals of benthic macro-invertebrate along Oluch Kimira river mouth. During the wet season in the months of December 2019 to February 2020, 353 individuals of benthic macro-invertebrate species were identified along Mbita beach east of the course way, 371 individuals along Homa Bay sewage discharge point and 745 individuals of benthic macro-invertebrate along Oluch Kimira river mouth. The result indicates relatively high abundance of benthic macro invertebrate species along Homa Bay sewage discharge point and Oluch Kimira river mouth during the wet season. This suggests that there was seasonal variability in benthic macro invertebrate species abundance along the shores of Homa Bay sewage discharge point and Oluch Kimira river mouth. The finding is consistent with Suleiman and Abdullahi (2011) assertion that species abundance of benthic macro invertebrates in water bodies is associated with availability of food, the condition of water and quality of substrate present in the water body. The finding concurs with the finding by Abongo *et al.* (2015) that species abundance increased during wet seasons.

However, along Mbita beach east of the course way the species abundance of benthic macro-invertebrate was relatively lower during the wet season, hence, indicating habitat inhospitality for the survival and growth of benthic macro-invertebrate. The result indicates decline in the number in species abundance of benthic macro invertebrates along the shores of Lake Victoria at Mbita beach east of the course way. Thereby, suggesting that changes in physico-chemical parameters and nutrients levels along the shore during the wet season negatively influenced survival of benthic macro invertebrates. The seasonal fluctuation of benthic macro invertebrates along the shores of Lake Victoria could imply that the water quality was not stable. Sakar *et al.* (2002) explained that a decrease in abundance was due to the adverse effect of silt deposition caused by soil erosion leading to habitat destruction and causing high mortality in some aquatic macro-invertebrate organisms. Ngapula and Kayanda (2008) explained that during wet seasons, the high silt depositions destroy breeding sites for macro-invertebrates leading to decrease in the species abundance.

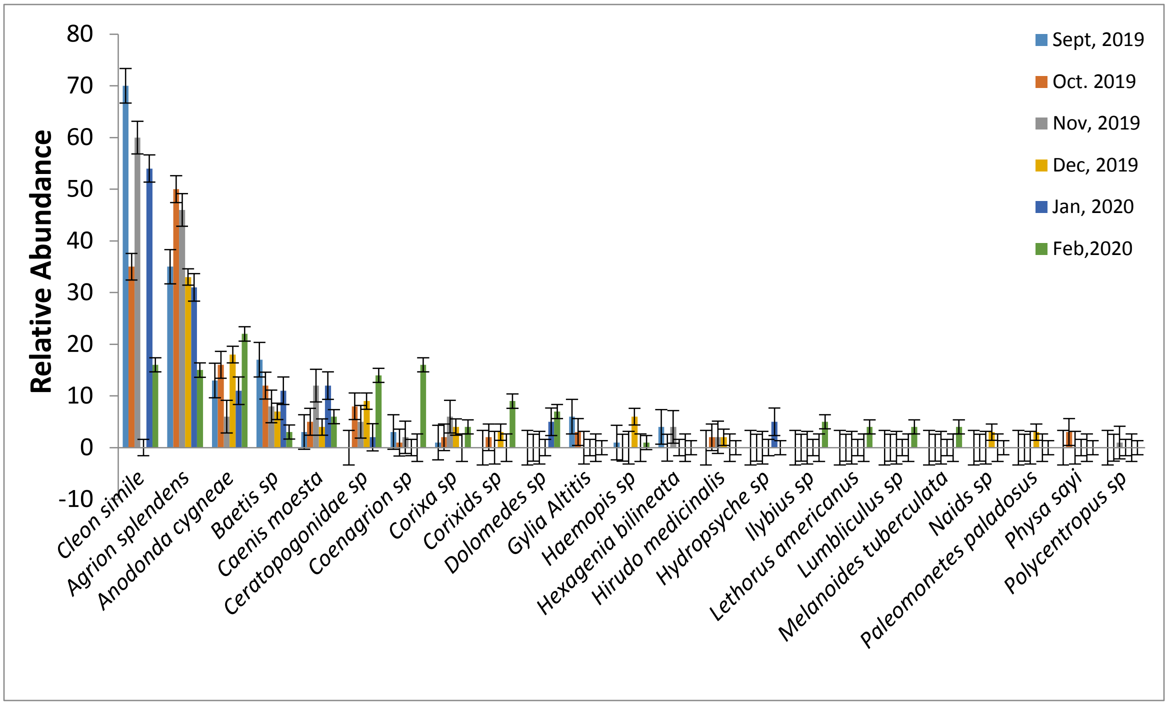


Figure 4.2: Temporal Species Abundance of Benthic Macro-Invertebrates along Mbita

Figure 4.2 shows that the dominant species along Mbita beach east of the course way during the study period were *Cleon Simile*, *Agrion splendens, Anodonta cygneae, Baetis, and Caenis moesta* while the rare species included *Ceratopogonidae, Coenagrion,Corixa, Corixids, Dolomedes, Gylia Altitis, Haemopis, Hexagenia bilineata, Hirudo medicinalis, Hydropsyche, Ilibius, Lethorus americanus, Lumbliculus, Melanoides tuberculata, Naids, Paleomonetes paladosus, Physa sayi and Polycentropus.* The study reveals that most of the dominant species along Mbita beach east of the course way belonged to the order Ephemeroptera (See Appendix VII). Tampo et al. (2021) point out that sensitive taxa comprised of Ephemeroptera, Plecoptera, Trichoptera, and Odonata. Therefore, suggesting moderate water quality along Mbita beach east of the course way. The finding is consistent with finding by Masese, Raburu and Muchiri (2009) reporting that *Baetis sp* are moderately tolerant of nutrient enrichment.

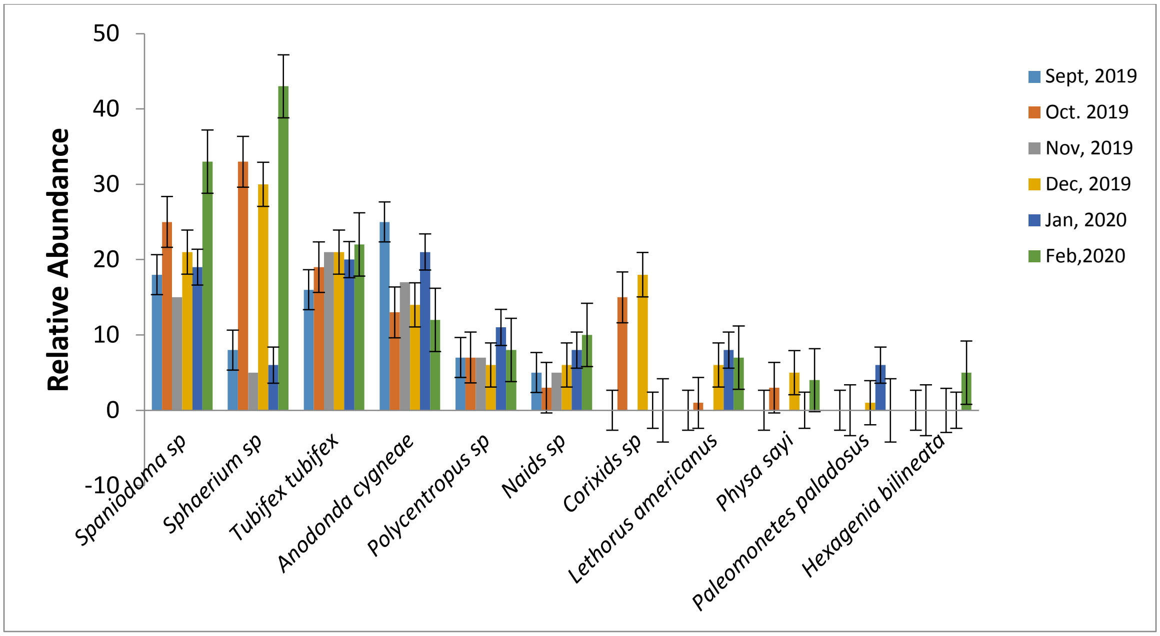


Figure 4.3: Temporal Species Abundance along Homa Bay

In Homa Bay sewage discharge point, the dominant species during the study period were *Spaniodoma, Sphaerium, Tubifex tubifex, Anadonda cygneae, Polycentropus and Naids* while *Corixids sp, Lethorus americanus, Physa sayi, Paleomonetes paladosus* and *Hexagenia bilineata* were rare. Aston (1973) reported that in conditions of low dissolved oxygen concentrations; prevalent in water bodies receiving heavy sewage pollution, *Tubifex tubifex* predominate. Therefore, dominance of *Tubifex tubifex* could be an indication that water quality along Homa Bay sewage discharge point was poor. Smith (2001) noted that *Tubifex tubifex* was tolerant to urban effluent and sewage, dominant in depths greater than one metre of lakes and actively migrated from areas of high dissolved oxygen to areas of low dissolved oxygen, which is the opposite reaction of most benthic macro invertebrates.

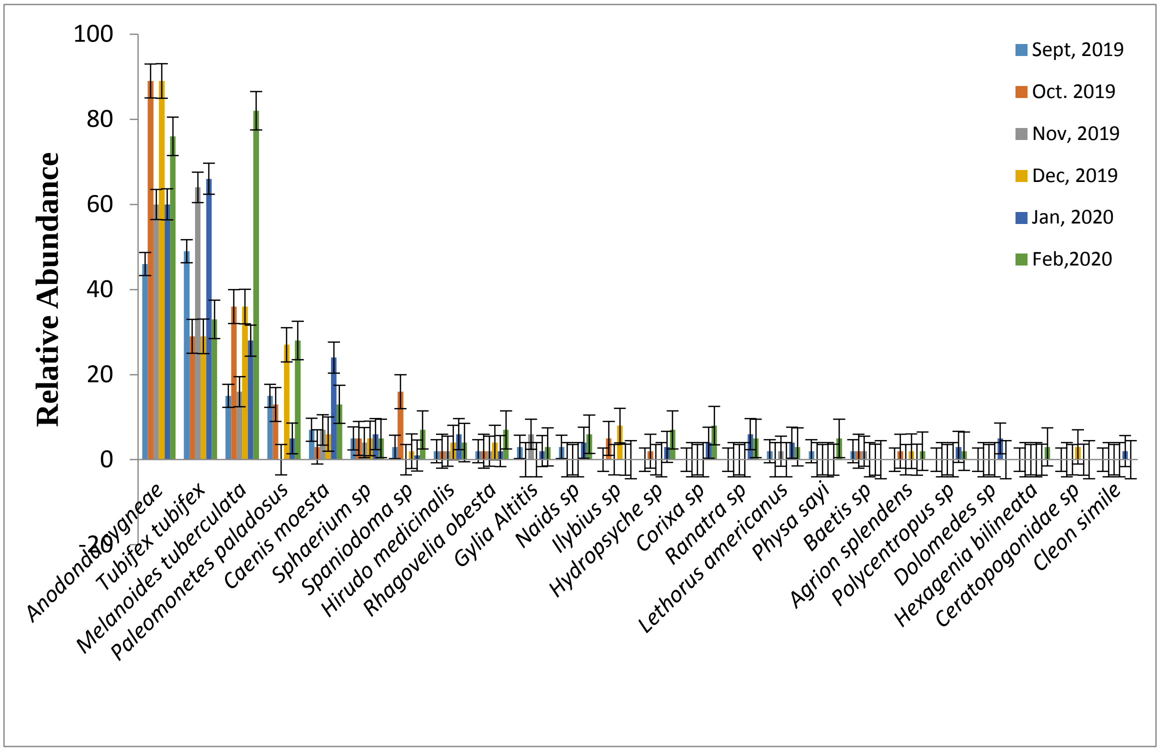


Figure 4.4: Spatio-temporal Species Abundance along Oluch Kimira

In Oluch Kimira river mouth, during the study period from September 2019 to February 2020, the dominant species were *Anodonta cygneae*, *Tubifex tubifex*, *Melanoides tuberculata, Paleomonetes paladosus, Caenis moesta, and Sphaerium,* while *Spaniodoma*, *Hirudo medicinalis, Rhagovelia obesta*, *Gylia altitis*, *Naids*, *Ilibius*, *Hydropsyche*, *Corixa*, *Ranatra*, *Lethorus americanus,Physa sayi*, *Baetis*, *Agrion splendens*, *Polycentropus, Dolomedes, Hexagenia bilineata*, *Ceratopogonidae* and *Cleon simile* were rare species. The occurrence of pollution tolerant species including *Tubifex tubifex* and *Caenis moesta* along Oluch Kimira river mouth suggests deterioration of water quality along the shores. The pollution could be attributed to runoff and penetration of wastewaters from agricultural and household human activities. This is in agreement with Barbour *et al*. (1996) who explained that the *Tubifex tubifex* species exploits oxygen poor habitats because it can survive through the use of haemoglobin which gives it high affinity for oxygen. The presence of *Tubifex tubifex* is bioindicative of polluted mesotrophic waters along Oluch Kimira river mouth shoreline (Patang, Soegianto & Hariyanto, 2018). This finding concurs with Masese *et al.* (2009) reporting that the taxa family observed were found to be tolerant to pollution, thus indicating that Oluch Kimira river mouth shoreline was polluted. The presence of many benthic macro invertebrates at the littoral zone where water is shallow could be attributed to the presence of macrophytes on which they flourish and the silt deposition which provided a breeding site (Ngodhe *et al*., 2014).

Consequently, one way ANOVA was used to test the second null hypothesis stating that; *there is no significant difference in abundance and distribution of benthic macro-invertebrates between the three study sites along the shores of Lake Victoria.* Table 4.7 presents the result of the test.

Table 4.7: ANOVA: Benthic Macro Invertebrates Abundance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	43680.111	2	21840.056	14.405	.000
Within Groups	22742.333	15	1516.156		
Total	66422.444	17			

The test revealed that there were significant differences in abundance of benthic macro invertebrates between the study sites, (F (2, 15) = 14.41, p < .05), along the shores of Lake Victoria. The result indicates that there could be seasonal and spatio-temporal differences in abundance of benthic macro-invertebrate between the three sites of study.

Table 4.8, explores the specific differences in species abundance along the three shores of Lake Victoria.

Table 4.8: Turkey HSD Multiple Comparisons

					95% Confidence Interval	
Study site	Study site	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
Homa Bay	Oluch	-119.16667*	22.48077	.000	-177.5598	-60.7735
	Mbita	-76.00000*	22.48077	.011	-134.3931	-17.6069
Oluch	Homa Bay	119.16667*	22.48077	.000	60.7735	177.5598
	Mbita	43.16667	22.48077	.167	-15.2265	101.5598
Mbita	Homa Bay	76.00000*	22.48077	.011	17.6069	134.3931
	Oluch	-43.16667	22.48077	.167	-101.5598	15.2265

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

Turkey's HSD Test for multiple comparisons found that species abundance of benthic macro invertebrates was significantly different between Mbita East beach and Homa Bay sewage discharge point (p= 0.011, 95% C.I. [17.61, 131.39] and between Oluch Kimira river mouth and Homa Bay sewage discharge point (p<.05, 95% C.I. [60.77, 177.56]. However, there was no statistically significant difference in abundance of benthic Macro invertebrates species between Mbita East beach and Oluch Kimira river mouth since the p-value (p=0.167) was greater than the set level of significance, α=0.05. The study rejects the null hypothesis and concludes that there is significant difference in species abundance of benthic macro-invertebrates along Mbita East beach, Homa Bay sewage discharge point and Oluch Kimira river mouth, along the shores of Lake Victoria, in Homa Bay County. The findings indicate that the human activities undertaken along the shores affect the lake water quality which then impacts on the species abundance of benthic macro invertebrates. The findings of the study are in agreement with that of the study done by Camara *et al.* (2015) that stated" organisms differed according to human activities along the rivers and lakes", thus the finding is reliable.

4.3.2 Occurrence of benthic macro-invertebrates along Lake Victoria

In order to analyse the distribution of identified benthic macro-invertebrate species across the three ecological zones along the shores of Lake Victoria along Mbita beach east of the course way, Homa Bay sewage discharge point and Oluch Kimira river mouth, the benthic macro-invertebrate species were classified based on presence or absence of particular species in the different study sites. Table 4.9 presents the occurrence of benthic macro invertebrate species identified in the sites of the study.

Table 4.9: Occurrence of Benthic Macro-Invertebrate Species in the Study Sites

	Mbita Beach	**Homa Bay**	**Oluch Kimira**
Agrion splendens	+	-	+
Anodonta cygneae	+	+	+
Baetis sp	+	-	+
Caenis moesta	+	-	+
Ceratopogonidae sp	+	-	+
Cleon simile	+	-	+
Coenagrion sp	+	-	-
Corixa sp	+	-	+
Corixids sp	+	+	-
Dolomedes sp	+	-	+
Gylia altilis	+	-	+
Haemopis sp	+	-	-
Hexagenia bilineata	+	+	+
Hirudo medicinalis	+	-	+
Hydropsyche sp	+	-	+
Ilybius sp	+	-	+
Lethorus americanus	+	+	+
Lumbliculus	+	-	-
Melanoides tuberculata	+	-	+
Naids sp	+	+	+
Paleomonetes paldosus	+	+	+
Physa sayi	+	+	+
Polycentropus sp	+	+	+
Ranatra sp	-	-	+
Rhagovelia obesta	-	-	+
Spaniodoma sp	-	+	+
Sphaerium sp	-	+	+
Tubifex tubifex	-	+	+

From Table 4.9, it can be observed that *Anodonda cygneae*, *Hexagenia bilineata*, *Lethorus americanus, Naids sp, Paleomonetes paladosus, Physa sayi,* and *Polycentropus sp* were identified in the three sites of study. The observation implies that these species of benthic macro-invertebrate had tolerance to environmental factors in the three sites of study along Lake Victoria. Ngodhe *et al*. (2014) pointed out that *Anodonda cygneae* is a bioindicator for pollution and can tolerate a wide range of water quality parameters.

Also, Table 4.9 indicates that *Agrion splendens, Caenis moesta, Ceratopogonidae sp, Cleon simile, Corixa sp, Dolomedes*, *Gylia altitis*, *Hirudo medicinalis*, *Hydropsyche sp, Ilibius,* and *Melanoides tuberculata* were identified along Mbita beach east of the course way and Oluch Kimira river mouth whereas *Spaniodoma sp, Sphaerium sp* and *Tubifex tubifex* were found along Homa Bay sewage discharge point and Oluch Kimira river mouth. The result suggests that water quality along the different study sites influenced occurrence and distribution of benthic macro-invertebrates along Lake Victoria shoreline.

In addition, Table 4.9 reveals that *Coenagrion sp, Haemopis sp*, and *Lumbliculus* benthic macro invertebrate species were only identified along Mbita beach east of the course way while *Ranatra sp and Rhagovelia obesta* were found only along Oluch Kimira river mouth. The occurrence in isolated ecological locations indicates that water quality had effect on the occurrence and distribution of benthic macro-invertebrates species. Sandin (2003) noted that, in addition to physical variables, chemical variables of water quality had a large impact on the biological distribution of macro invertebrates. Similarly, Brraich and Kaur (2017) opined that distribution of benthic macro invertebrates is based on biological characteristics of organism and physico-chemical nature of the habitat. Therefore, it can be established that the occurrence and distribution of benthic Macro invertebrate species could be as a result of spatial variation in water quality in the sites of study and adaptability of benthic macro invertebrates to different ecological conditions. Jun *et al.* (2016) recommended that maintenance of ecological integrity and sustainability was an important step in conservation and enrichment of biodiversity and distribution in freshwater bodies.

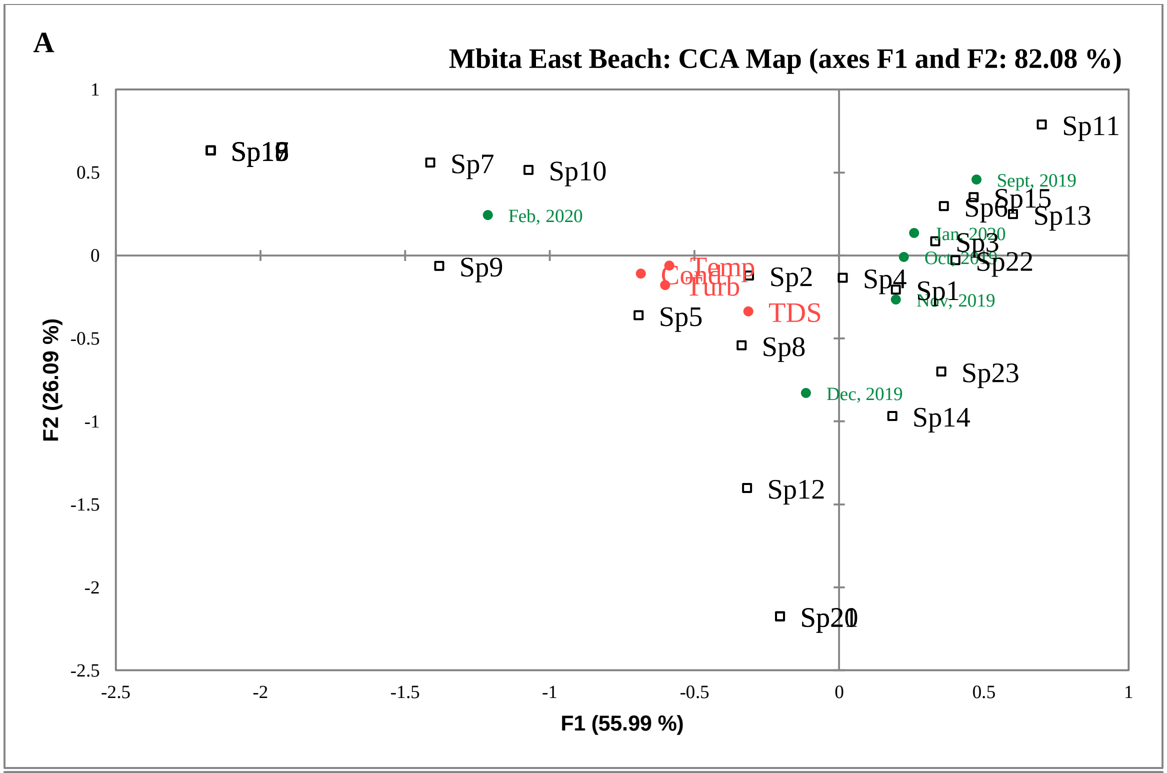
4.4 Effect of Water Quality on Benthic Macro Invertebrates

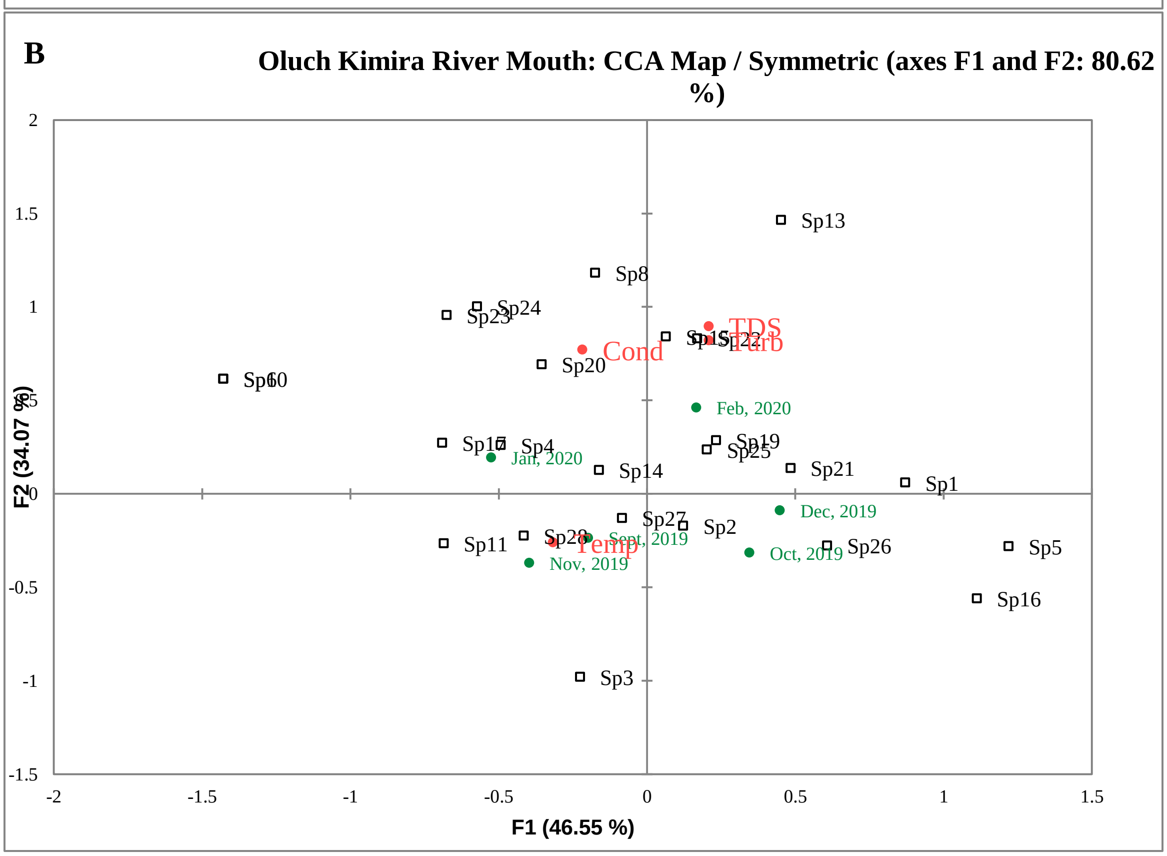
The objective sought to determine the effect of physico-chemical parameters and nutrients load on diversity, abundance and distribution of benthic macro invertebrate species along the shores of Lake Victoria.

To determine the effect, canonical correspondence analysis (CCA) was performed to explore the relations among the water quality variables ((temperature, pH, conductivity, dissolved oxygen (DO), total dissolved solids (TDS), oxidation-reduction potential (ORP), Secchi, and turbidity; major nutrients such as nitrates, nitrites, soluble reactive phosphorus (SRP), Silicon Dioxide (SiO_2), Ammonium (NH_4), total Nitrogen (TN), total phosphorus) and benthic macro invertebrate species abundance. The biplots are presented in Figures 4.5 to 4.8.

4.4.1 Physico-chemical and Benthic Macro Invertebrates

The Canonical Correspondence analysis, biplots, presented in Figure 4.5 (A, B, & C) and Figure 4.6 (C, D, & E) shows the relations between benthic macro invertebrates and physico-chemical parameters (temperature, pH, conductivity, dissolved oxygen (DO), total dissolved solids (TDS), oxidation-reduction potential (ORP), secchi, turbidity) during six months period of study along Oluch Kimira river mouth, Mbita beach east of the course way and Homa Bay sewage discharge point.


A
Mbita East Beach: CCA Map (axes F1 and F2: 82.08 %)
F1 (55.99 %)
F2 (26.09 %)
Sp11
Sp7
Sp10
Sp9
Sp2
Sp4
Sp1
Sp5
Sp8
Sp23
Sp14
Sp12
Sp15
Sp6
Sp13
Sp3
Sp22
Temp
Cond
Turb
TDS
Sept, 2019
Feb, 2020
Jan, 2020
Nov, 2019
Dec, 2019


B
Oluch Kimira River Mouth: CCA Map / Symmetric (axes F1 and F2: 80.62 %)
F1 (46.55 %)
F2 (34.07 %)
Sp13
Sp8
Sp24
Sp23
TDS
Turb
Cond
Sp20
Sp22
Feb, 2020
Sp19
Sp25
Sp4
Jan, 2020
Sp14
Sp21
Sp1
Dec, 2019
Sp27
Sp2
Sp28
Sept, 2019
Temp
Sp11
Nov, 2019
Oct, 2019
Sp26
Sp5
Sp16
Sp3

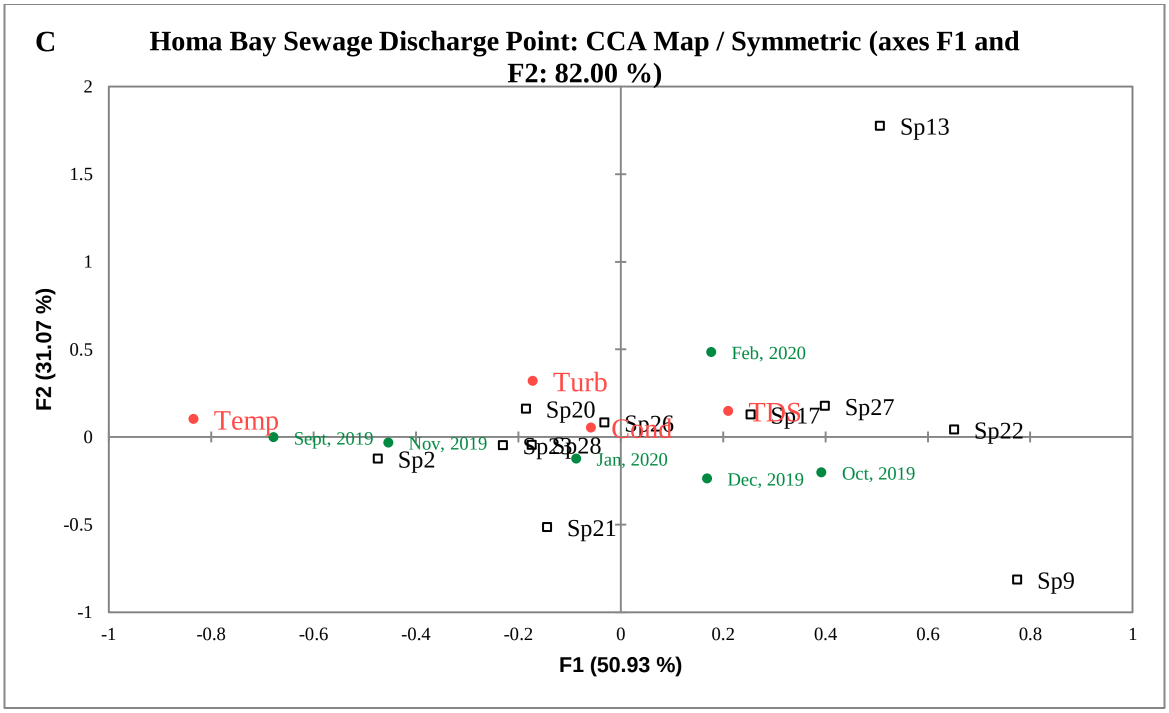
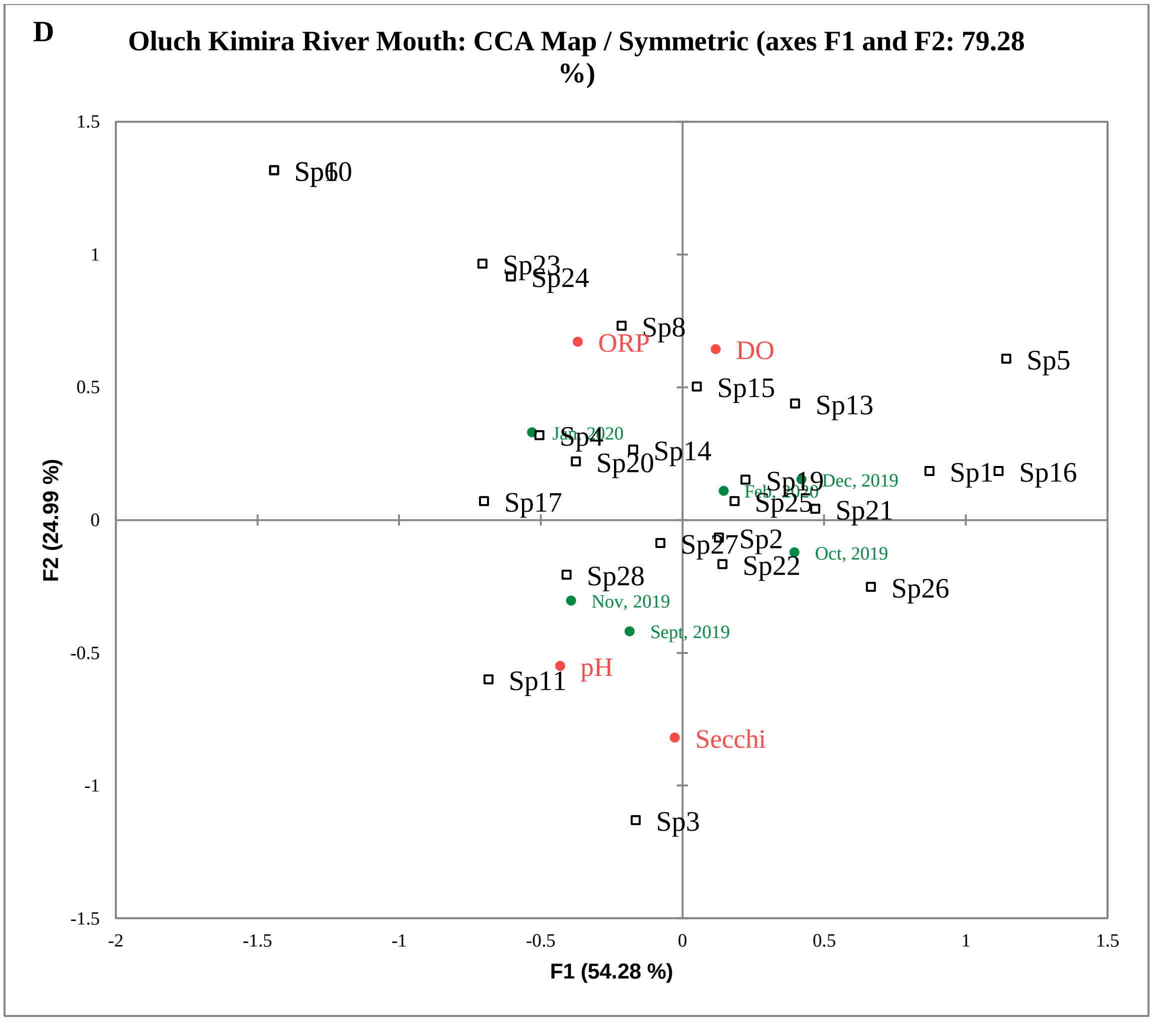


Figure 4.5: CCA for physico-chemical parameters and benthic macro invertebrates

Benthic macro invertebrate taxa (28): Sp1 = *Agrion Splenden*; Sp2= *Anodonta cygneae*; Sp3 = *Baetis*; Sp4 = *Caenis moesta*; Sp5 = *Ceratopogonidae sp.*; Sp6 = *Cloeon simile*; Sp7 = *Coenagrion* ; Sp8 = *Corixa*; Sp9 = *Corixids;* SP10 = *Dolomedes sp*; Sp11 = *Gylia altitis;* Sp12 = *Haemopis;* Sp13 = *Hexagenia bilineata;* Sp14 = *Hirudo medicinalis;* Sp15 = *Hydropsyche;* Sp16 = *Ilibius;* Sp17 = *Lethorus americanus;* Sp18 = *Lumbliculus;* Sp19 = *Melanoides tuberculata;* Sp20 = *Naids;* Sp21 = *Paleomonetes paladosus;* Sp22 = *Physa sayi;* Sp23 = *Polycentropus;* Sp24 = *Ranatra;* Sp25 = *Rhagovelia obesta;* Sp26 = *Spaniodoma;* Sp27 = *Sphaerium;* Sp28 = *Tubifex tubifex.* **Physico-chemical parameters**: Conductivity, Turbidity, Temperature and Total Dissolved Solids)

From the biplots, it can be observed that; electrical conductivity, total dissolved solids and turbidity of water correlated and exerted strong influence on the abundance of *Naids*, *Physa sayi*, *Hydropsyche sp*, and *Corixa sp*, along Oluch Kimira river mouth. In the same vein, *Corixa sp*, *Ceratopogonidae sp*, *Anadonta cygnea*, *Caenis moesta*, *Agrion splenden*, and *Corixids* associated with conductivity, total dissolved solids and turbidity along Mbita beach east of the course way and influenced the abundance of *Spaniodoma sp*, *Lethorus americanus*, *Sphaerium sp*, *Physa sayi*, and *Naids*, along Homa Bay sewage discharge point. The result suggests that *Naids* and *Physa sayi* species are sensitive to high levels of electrical conductivity, total dissolved solids and turbidity. Temperature in the study sites exerted greatest influence on *Anodonta cygnea*.

Figure 4.6 (D, E & F), illustrates relations between benthic macro invertebrate species and physico-chemical parameters including soluble reactive phosphorus, dissolved oxygen, pH and Secchi.



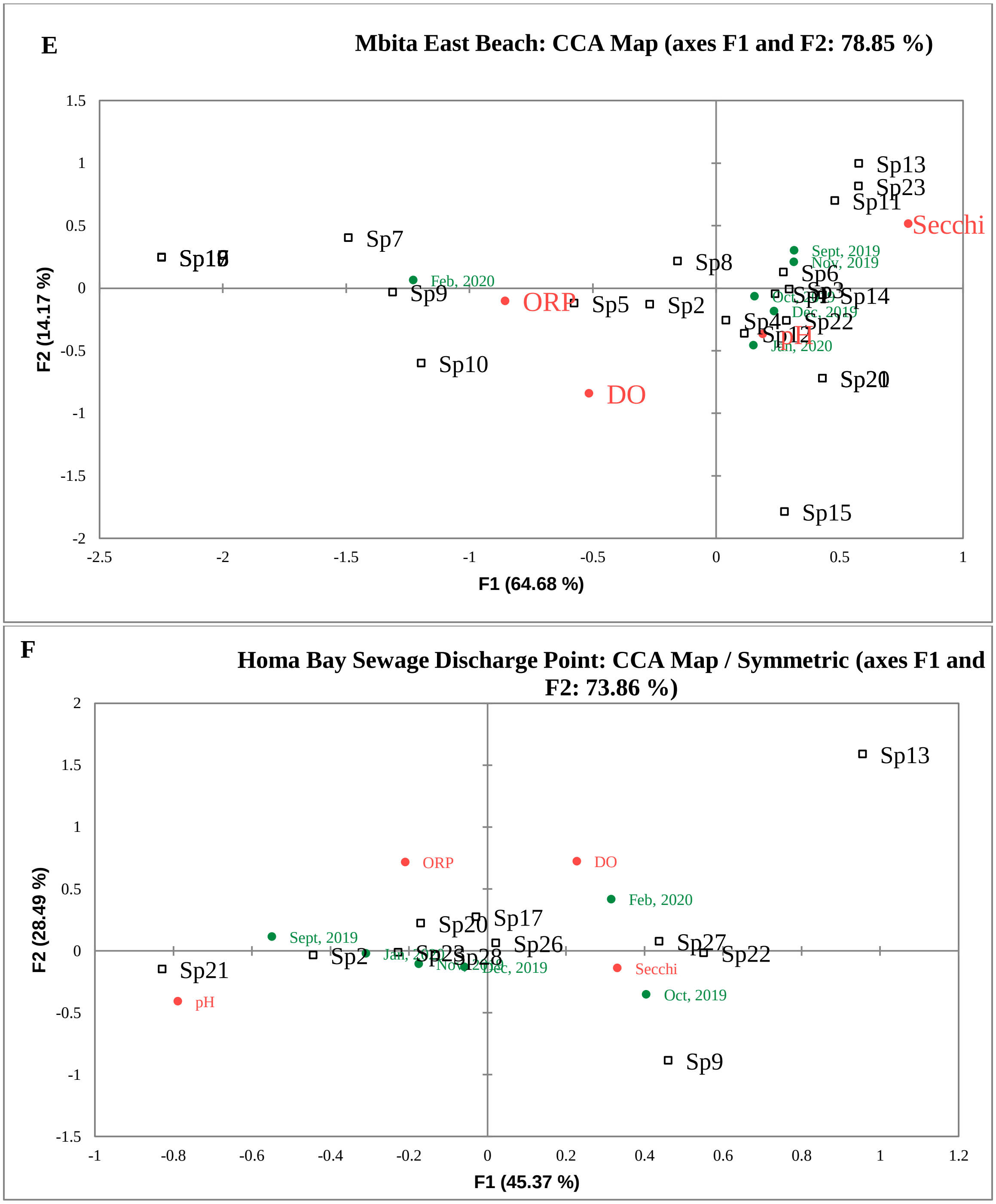


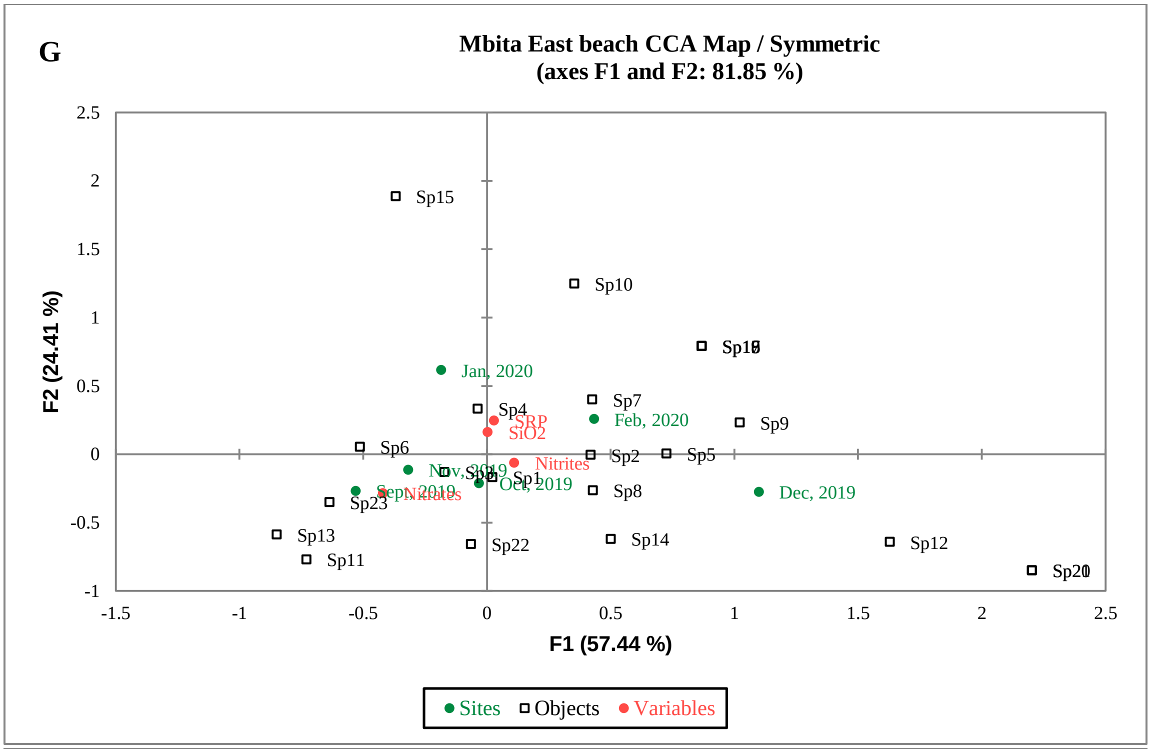
Figure 4.6: CCA for physico-chemical (DO, Secchi, pH & ORP) and benthic macro invertebrates

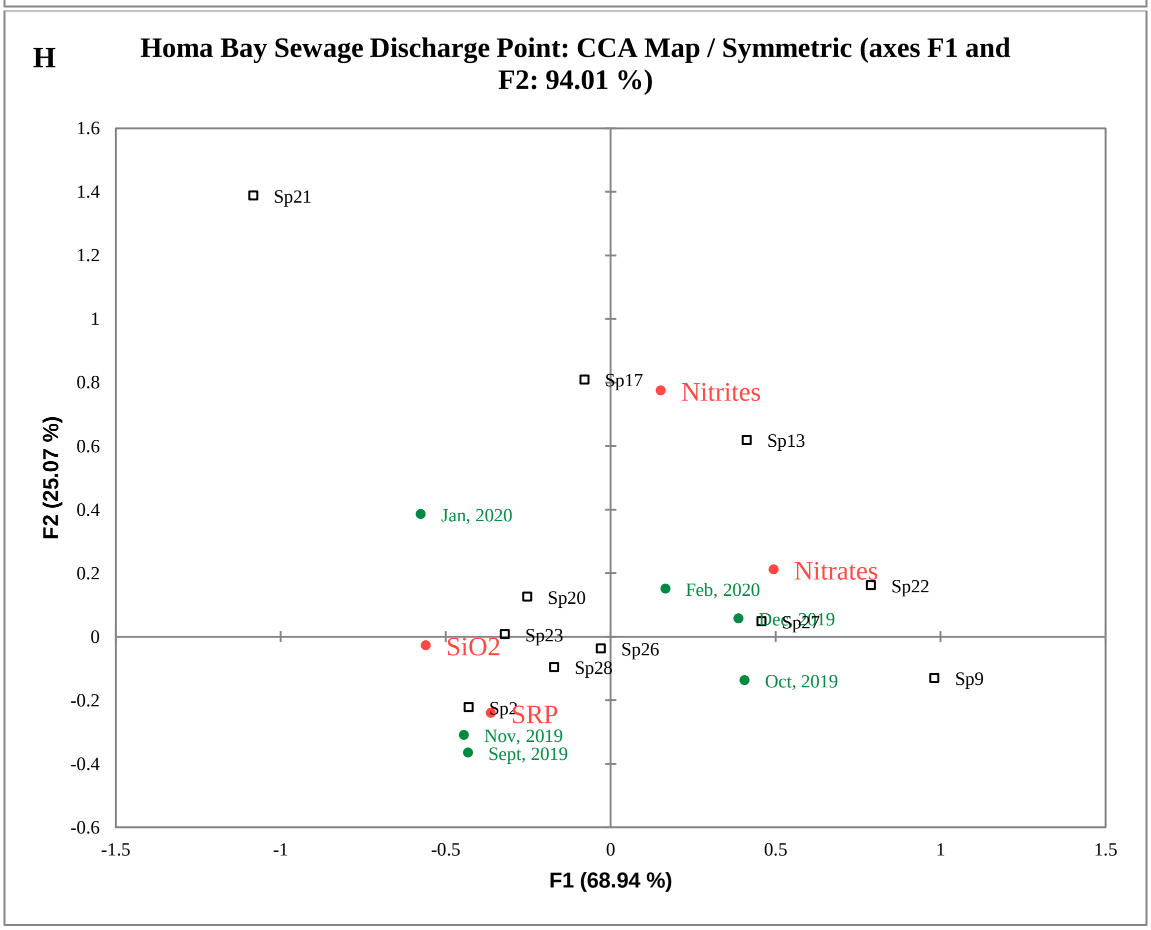
Benthic macro invertebrate taxa (28): Sp1 = *Agrion Splenden*; Sp2= *Anodonta cygneae*; Sp3 = *Baetis*; Sp4 = *Caenis moesta*; Sp5 = *Ceratopogonidae sp.*; Sp6 = *Cloeon simile*; Sp7 = *Coenagrion* ; Sp8 = *Corixa*; Sp9 = *Corixids;* SP10 = *Dolomedes sp*; Sp11 = *Gylia altitis;* Sp12 = *Haemopis;* Sp13 = *Hexagenia bilineata;* Sp14 = *Hirudo medicinalis;* Sp15 = *Hydropsyche;* Sp16 = *Ilibius;* Sp17 = *Lethorus americanus;* Sp18 = *Lumbliculus;* Sp19 = *Melanoides tuberculata;* Sp20 = *Naids;* Sp21 = *Paleomonetes paladosus;* Sp22 = *Physa sayi;* Sp23 = *Polycentropus;* Sp24 = *Ranatra;* Sp25 = *Rhagovelia obesta;* Sp26 = *Spaniodoma;* Sp27 = *Sphaerium;* Sp28 = *Tubifex tubifex.* **Physico-chemical parameters**: Secchi, Dissolved oxygen, pH and ORP)

The CCA maps in Figure 4.6 (D, E & F), shows that along Mbita beach east of the course way; Secchi influenced the abundance of *Hexagenia bilineata*, *Polycentropus,* and *Gylia altitis;* pH associated with *Physa sayi, Caenis moesta, Haemopis, Naids, Baetis, Hirudo medicinalis,* and *Cloeon simile*; Oxidation-reduction potential showed positive association with abundance of *Ceratopogonidae sp, Anadonta cygnea* and *Corixids;* while dissolved oxygen levels influenced abundance of *Dolomedes*. Along Oluch Kimira river mouth; secchi associated with *Baetis* and *Gylia altitis*; pH influenced abundance of *Tubifex tubifex* and *Gylia altitis*; oxidation-reduction potential exerted influence on abundance of *Corixa, Caenis moesta, Naids*, and *Hirudo medicinalis*; and dissolved oxygen associated with *Hydropsyche, Hexagenia bilineata, Corixa sp, Naids, and Hirudo medicinalis.* At Homa Bay sewage discharge point along the shores of Lake Victoria; secchi showed strong association with *Sphaerium* and *Physa sayi*; oxidation reduction potential influenced *Naids* and *Lethorus americanus*; and pH affected the abundance of *Paleomonetes paladosus* and *Anodonta cygnea.*

4.4.2 Nutrients and Benthic Macro Invertebrates along the Shores of Lake Victoria

Figure 4.7 (G, H & I) and Figure 4.8 (J, K & L) presents the result of canonical correspondence analysis on the relation between water nutrients (nitrates, nitrites, soluble reactive phosphorus (SRP), Silicon Dioxide (SiO_2), Ammonium (NH_4), total Nitrogen (TN), total phosphorus) and benthic macro-invertebrate along Mbita beach east of the course way, Oluch Kimira river mouth, and Homa Bay sewage discharge point.


G
Mbita East beach CCA Map / Symmetric
(axes F1 and F2: 81.85 %)
F2 (24.41 %)
F1 (57.44 %)
Sp15
Sp10
Jan, 2020
Sp4
SRP
SiO2
Sp7
Feb, 2020
Sp9
Sp6
Nitrites
Sp2
Sp5
Sp1
Oct, 2019
Sp8
Dec, 2019
Sp23
Sp13
Sp11
Sp22
Sp14
Sp12
Sites
Objects
Variables


H
Homa Bay Sewage Discharge Point: CCA Map / Symmetric (axes F1 and F2: 94.01 %)
F2 (25.07 %)
F1 (68.94 %)
Sp21
Sp17
Nitrites
Sp13
Jan, 2020
Nitrates
Sp22
Feb, 2020
Sp20
Sp27
Sp23
SiO2
Sp26
Sp28
Oct, 2019
Sp9
SRP
Nov, 2019
Sept, 2019

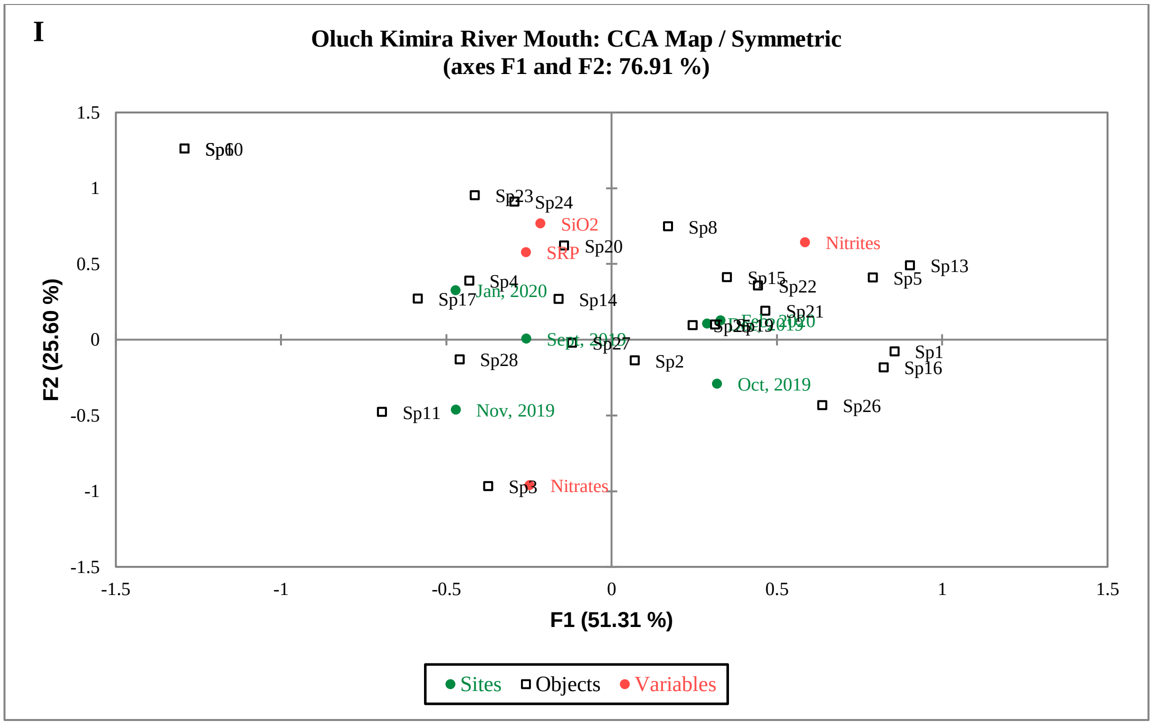


Figure 4.7: CCA for nutrients (nitrates, nitrites, SRP & SiO_2) and benthic macro invertebrates

Benthic macro invertebrate taxa (28): Sp1 = *Agrion Splenden*; Sp2= *Anodonta cygneae*; Sp3 = *Baetis*; Sp4 = *Caenis moesta*; Sp5 = *Ceratopogonidae sp.*; Sp6 = *Cloeon simile*; Sp7 = *Coenagrion* ; Sp8 = *Corixa*; Sp9 = *Corixids;* SP10 = *Dolomedes sp*; Sp11 = *Gylia altitis;* Sp12 = *Haemopis;* Sp13 = *Hexagenia bilineata;* Sp14 = *Hirudo medicinalis;* Sp15 = *Hydropsyche;* Sp16 = *Ilibius;* Sp17 = *Lethorus americanus;* Sp18 = *Lumbliculus;* Sp19 = *Melanoides tuberculata;* Sp20 = *Naids;* Sp21 = *Paleomonetes paladosus;* Sp22 = *Physa sayi;* Sp23 = *Polycentropus;* Sp24 = *Ranatra;* Sp25 = *Rhagovelia obesta;* Sp26 = *Spaniodoma;* Sp27 = *Sphaerium;* Sp28 = *Tubifex tubifex.* **Nutrients:** Nitrates, Nitrites, Soluble Reactive Phosphorus (SRP) and SiO_2

Figure 4.7 (G, H & I), reveals that the species; *Polycentropus*, *Naids*, *Ranatra*, associated with silica and soluble reactive phosphorus; *Centropogonidae*, *Hexagenia bilineata*, *Hydropsyche*, *Physa sayi*, and *Corixa* positive related with nitrites whereas *Baetis* associated with nitrates along Oluch Kimira river mouth. At Homa Bay sewage discharge point; *Anodonta cygnea*, *Tubufex tubifex*, *Spaniodoma*, *Naids*, and *Polycentropus* associated with soluble reactive phosphorus and silica; *Lethorus americanus* and *Hexagenia bilineata* related with nitrites while *Gylia altitis*, *Physa sayi* and *Hexagenia bilineata* associated with nitrates. Along Mbita beach east of the course way; the levels of soluble reactive phosphorus and silica strongly related to *Caenis moesta;* nitrates associated with *Polycentropus, Hexagenia bilineata, Gylia altitis, Cloeon simle, and Baetis;* and Nitrites associated with *Agrion splenden* and *Baetis*. The result indicates that the levels of silica and soluble reactive phosphorus influenced the abundance of *Naids* and *Polycentropus* whereas nitrates and nitrites levels exerted significant influence on abundance of *Hexagenia bilineata* and *Physa sayi* along Homa Bay sewage discharge point and Oluch Kimira river mouth. The finding concurs with Onwona Kwakwe *et al.* (2021) finding that *Physa sayi* sp., positively correlated with nitrate concentration.

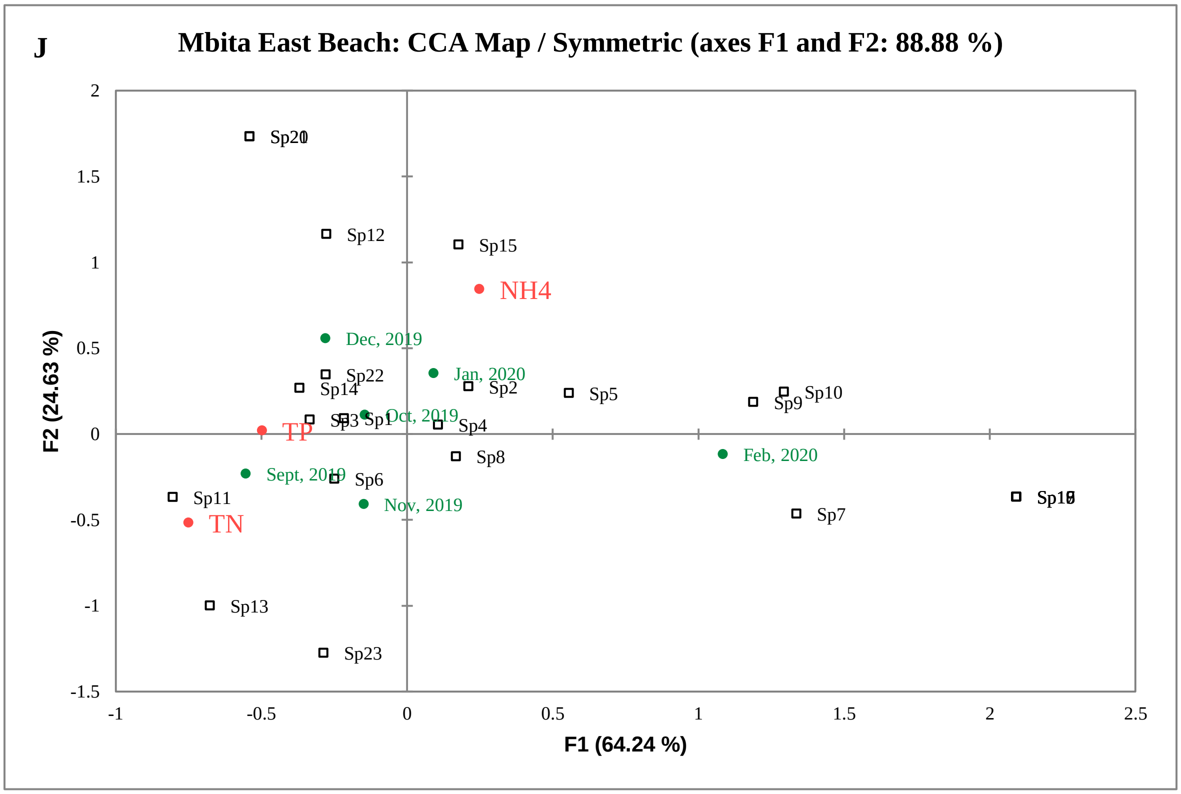


Figure 4.8: CCA for nutrients (TN, TP & NH_4) and benthic macro invertebrates

Benthic macro invertebrate taxa (28): Sp1 = *Agrion Splenden*; Sp2= *Anodonta cygneae*; Sp3 = *Baetis*; Sp4 = *Caenis moesta*; Sp5 = *Ceratopogonidae sp.*; Sp6 = *Cloeon simile*; Sp7 = *Coenagrion* ; Sp8 = *Corixa*; Sp9 = *Corixids;* SP10 = *Dolomedes sp*; Sp11 = *Gylia altitis;* Sp12 = *Haemopis;* Sp13 = *Hexagenia bilineata;* Sp14 = *Hirudo medicinalis;* Sp15 = *Hydropsyche;* Sp16 = *Ilibius;* Sp17 = *Lethorus americanus;* Sp18 = *Lumbliculus;* Sp19 = *Melanoides tuberculata;* Sp20 = *Naids;* Sp21 = *Paleomonetes paladosus;* Sp22 = *Physa sayi;* Sp23 = *Polycentropus;* Sp24 = *Ranatra;* Sp25 = *Rhagovelia obesta;* Sp26 = *Spaniodoma;* Sp27 = *Sphaerium;* Sp28 = *Tubifex tubifex.*
Nutrients: Total Nitrates (TN), Ammonia (NH_4), & Total Phosphorus (TP)

The biplots shows that, along Mbita beach east of the course way; *Hydropsyche*, *Haemopis*, *Anodonta cygnea,* and *Centropogonidae* associated with ammonia; *Baetis*, *Agrion splenden, Hirudo medicinalis, Physa sayi*, and *Cloeon simile* positive related with total phosphorus whereas *Gylia altitis*, *Cloeon simile, Hexagenia bilineata* and *Polycentropus* associated with total nitrates. At Homa Bay sewage discharge point, total nitrates and total phosphorus negatively related with benthic macro invertebrate species while ammonia influenced association with *Naids*, *Polycentropus* and *Tubifex tubifex*. Along Oluch Kimira river mouth, the levels of ammonia strongly influenced abundance of *Agrion splenden*, *Spaniodoma*, *Hydropsyche,* and *Melanoides tuberculata;* total nitrates associated with *Baetis* and *Gylia altitis, Hexagenia bilineata*, *Gylia altitis*, *Cloeon simle, and Baetis;* and nitrites associated with *Agrion splenden* and *Baetis.*

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

At Homa Bay sewage discharge point, the study established spatial and temporal variations in the lake water pH and temperature were highest along the shore at 8.4733 and 26.4817 respectively whereas nutrient load was moderate. Dissolved oxygen level of 5.0883 mg/L was the lowest value across the shores. On the other hand, along Mbita beach east of the course way, the study noted that the level of dissolved oxygen was the highest; average of 6.76 mg/L. pH level was moderate; an average of 8.035 with comparably the lowest nutrient loads. Nevertheless, along Oluch Kimira river mouth, dissolved oxygen was moderate, with high levels of thermal conductivity, total phosphorus, total nitrates, ammonia, silicate and turbidity.

The relatively higher species richness during the wet season compared to the dry season indicated that changes in rainfall and temperature influenced seasonal variability in benthic macro invertebrate diversity along the shores of Lake Victoria, in Homa Bay County, Kenya. Shannon Weiner diversity indices revealed that diversity of benthic macro invertebrates was relatively high along Mbita beach east of the course way and relatively low along the Homa Bay sewage discharge point. As regards to the abundance and distribution, the study established that along Mbita beach east of the course way the dominant taxa included *Cleon Simile*, *Agrion splendens*, *Anodonda cygneae, Baetis, and Caenis moesta* whereas along Homa Bay sewage discharge point *Spaniodoma, Sphaerium*, *Tubifex tubifex*, *Anadonda cygneae*, *Polycentropus and Naids*, and along

Oluch Kimira river mouth *Anodonta cygneae, Tubifex tubifex, Melanoides tuberculata, Paleomonetes paladosus*, *Caenis moesta*, and *Sphaerium* were dominant species. However, *Naids* and *Physa sayi* species had strong association to high levels of conductivity, total dissolved solids and turbidity; *Anadonta cygnea* associated strongly with temperature; soluble reactive phosphorus and silica influenced abundance of *Polycentropus*; and nitrates and nitrites levels exerted significant influence on abundance of *Hexagenia bilineata* along the shores of Lake Victoria.

5.2 Conclusion

From this study it can be concluded that there was significant variation in diversity of benthic macro-invertebrates along the shores of Lake Victoria, Homa Bay County. Similarly the benthic macro invertebrates varied in their abundance and distribution in the selected study sites along the shores in Homa Bay County. Further it is concluded that there was significant variation in water quality (physico-chemical) parameters along the lakeshore in Homa Bay County and variation in the water quality parameters significantly influence diversity, abundance and distribution of benthic macro-invertebrates. Benthic macro invertebrates diversity was relatively high along Mbita beach east of the course way with *cloeon simile*, *Agrion splendens*, *Anadonta cygnea*, *Baetis sp*, and *Caenis Moesta* being the most dominant species, while along Homa Bay sewage discharge point the dominant species included *Spaniodoma sp, Sphaerium sp, Tubifex tubifex*, *Anadonta Cygnae, Polycentropus* and *Naids*, and along Oluch Kimira river mouth the dominant species were; *Anadonta cygnea, Tubifex tubifex, Melanoides tuberculata, Paleomonetes paladosus, caenis moesta,* and *Sphaerium sp.* Finally, the study concludes that changes in selected physico-chemical parameters and nutrient loads concentration along Lake

Victoria shores influence the diversity, abundance and distribution of benthic macro invertebrates.

5.3 Recommendations

i. There is need for continuous monitoring of water quality along the shores of Lake Victoria in order to prevent any further degradation.
ii. The diversity, abundance and distribution of benthic macro invertebrates was low along the shores of Lake Victoria, therefore, there is need to regularly conduct public education and awareness on the significance of freshwater habitat in order to boost conservation of benthic macro invertebrates.
iii. Homa Bay sewage discharge point and Oluch-Kimira river mouth have relatively degraded water quality compared to Mbita beach east of the course way, therefore there is need to enhance legislative and regulatory policies in regard to environmental integrity.
iv. The national and county government should apply these findings into planning for future developmental activities along the shores of Lake Victoria.

5.4 Areas for further research

i. There is need for continued research to ascertain how benthic macro invertebrates' can be used as bio-indicators of water quality changes and pollution in the lake shores of Homa Bay County.
ii. There is need for more research to verify the extent of pollution in the entire Homa Bay County.
iii. There is need for a study on the potential use of buffering to minimize pollution loading into Lake Victoria shorelines in Homa Bay County.

REFERENCES

Abong'o, D. A., Wandiga, S. O., Jumba, I. O., Van den Brink, P. J., Naziriwo, B. B., Madadi, V. O., Wafula, G., Nkedi-Kizza A. P., & Henrik. (2015). *Occurrence, abundance and distribution of benthic macro-invertebrates in the Nyando River catchment, Kenya.* African Journal of Aquatic Science, 40(39).

Adams B. J., & Papa, F. (2010). Urban storm water management planning with analytical probabilistic models, Wiley, Toronto, Ontario, Canada.

Aganmwonyi, I., & Iriabgonse, F. E., C. (2015). Impact of Livestock Grazing on Abundance and Community Structure of Macro-invertebrate fauna of Ovia River, Edo State, Nigeria. J. Appl. Sci. Environ. Manage. Dec., 2015, Vol. 19(4).

Aina, O. A.. & Oyebamiji, O. F. (2011). Impact of Effluents on Water Quality and Benthic Macro-invertebrate Fauna of Awba Stream and Reservoir. J. Appl. Sci. Environ. Manage. March, 2011 Vol. 15 (1).

Aluoch, A. J. (2012). *Effects of Weir Installation on Water Quality and Macro-invertebrate Community Structure of Two Rivers in Lake Victoria Basin, Kenya.* A Master's Thesis Submitted in the School of Pure and Applied Sciences of Kenyatta University.

APHA (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd edition). Washington, D.C.: American Public Health Association.

Asenahabi, B. M. (2019). Basics of Research Design: A guide to selecting appropriate research design. *International Journal of Contemporary Applied Researches.* 6(5), 76-89. http://www.ijcar.net

Aston, R. J. (1973). Tubifids and Water Quality: *A review of Environmental Pollution*. 5(1), 1 - 10

Barbour, M. T., Gerritsen, J., Griffith, G. E., Frydenborg, R., McCarron, E., White, J. S., & Bastian, M. L. (1996). A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of North America Benthol. Soc*. 15 (2), 185–211.

Bernhardt, E. S., & Palmer, M. A (2006). Restoring streams in an urbanizing world. Freshwater Biology, 52: 738–751 doi:10.1111/j.1365-2427.2006.01718.

Bonada, N., Prat N., Resh V. H., & Statzner, B. (2006). Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. *Annual Review of Entomology*, 51:495-523.

Boyle T. P., & Fraleigh, H. D. (2003). Natural and anthropogenic factors affecting the structure of the structure of the benthic macroinvertebrate community in an effluent-dominated reach of the Santa Cruz River, AZ. Ecol. Ind. 3, 93–117.

Brraich, O. S., & Kaur, R. (2017). Temporal composition and distribution of benthic macro invertebrates in wetlands. *Current Science*, 112(1), 116-125. https:// www.jstor.org /stable/24911623.

Busulwa, H.S., & Bailey, R.G. (2004). Aspects of the physico-chemical environment of the Rwenzori Rivers, Uganda. *African Journal of Ecology* **42** (1): 87-92.

Camara, A. I., Tchakonte, S., Ajeagah, G. A., Tchatcho, N. L. N., Diomande, D., & Ngassam, P. (2015). Streams water quality and description of some aquatic species of Coleoptera and Hemiptera (Insecta) in Littoral Regionof Cameroon. *Biodiversity Journal*, 6(1), 27 – 40.

Carpenter, S. R., Benson, B. J., Biggs, R., Chipman, J. W., Foley, J.A., Golding, S. A., Hammer, R. B., Hanson, P. C., Johnhos, P. T. J., Kamarainen, A. M., Kratz, T. K., Lathrop, R. C., Mc-Mahon, K. D., Provencher, B., Rusak, J. A., Solomon, C. T., & Yuan, H. L. (2007): Understanding regional change: A comparison of two lake districts. *Bioscience* 57: 232-335.

Chandra, S., Vander Zanden, M. J., Heyvaert, A. C., Richards, B. C., Allen, B. C., & Goldman, C. R. (2005): The effects of cultural eutrophication on the coupling between pelagic primary producers and benthic consumers. *Limnol. Oceanogr.* 50: 1368-1376.

Chatzinikolaou, Y., Dakos, V., & Lazaridou, D. (2011). Longitudinal impacts of anthropogenic pressures on benthic macroinvertebrate assemblages in a large transboundary Mediterranean river during the low flow period. Acta hydrochimica et Hydrobiologica, 34: 453-463.

CIDP (2013-2017). Republic of Kenya: Homa Bay County Integrated Development Plan.

CIDP (2018-2022). Republic of Kenya: Homa Bay County Integrated Development Plan.

Davis, J., Horwitz, P., Norris, R., Chessman, B., McGuire, M., & Sommer, B. (2006). Are river bio-assessment methods using macro invertebrates applicable to wetlands? *Hydrobiologia* (2006) **572**:115–128

Devon, G., Sarah, M., & Sarah, S. (2015). Implications on Distribution and Abundance of Benthic Macro-invertebrates in the Maple River Based on Water Quality and Habitat Type. University of Michigan Biological Station.

Egertson, C. J., Kopaska, J. A., & Downing, J. A. (2003): A century of change in macrophyte abundance and composition in response to agricultural eutrophication. *Hydrobiologia* 524: 145-156.

EPA (2012). *Parameters of Water Quality Interpretation and Standards*. Ireland: Environmental Protection Agency.

EPA (2021). National Aquatic Resources Survey. Indicators: Benthic Macro invertebrates. Available online at: https://www.epa.gov/national-aquatic-resource-surveys/indicators-benthic-macroinvertebrates: Mountain studies institute.

EPA (2022). National Aquatic Resources Survey. Indicators: Dissolved Oxygen. Available online at: https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen.

European Commission (2008). *Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive).* Brussels: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040

Fakayode S. O. (2010). Impact Assessment of Industrial effluent on Water Quality of the Receiving Alaro River in Ibadan, Nigeria, AJEAM-RAGEE: 10:1-13.

Gonzales-Abraham, C. E., Radeloff, V. C., Hawbaker, T. J., Hammer, R.B., Stewart, S.I., & Clayton, M. K. (2007): Patterns of houses and habitat loss from 1937 to 1999 in northern Wisconsin. *Ecol. Appl.* 17: 2011-2023.

IOWA (2010). What in the world are Benthic Macroinvertebrates? Available online at: https://www.iihr.uiowa.edu/igs/publications/uploads/wfs.2010-07.pdf

Jeffries, M., & Mills, D. (1990). *Freshwater ecology: Principles and applications*. Belhaven Press

Jones, C., Palmer, R.M., Matkaluk, S., & Walters M. (2002). *Watershed Health Monitoring: Emerging Technologies*. CRC Press, Boca Raton.

Jun, Y. C., Kim, N. Y., Kim, S. H., Park, Y. S., Kong, D. S., & Hwang, S. J. (2016). Spatial distribution of benthic macro invertebrates assemblages in relation to environmental variables in Korean nationwide streams. Water, 8 (1), 27.

Kalff, J. (2002). *Limnology: inland water ecosystems*. Prentice Hall Inc. Upper Saddle River, New Jersey. 592pp.

Kasangaki, A., Chapman L. J., & Balirwa, J. (2008). Land use and the ecology of benthic macroinvertebrate assemblages of high-altitude rainforest streams in Uganda. Freshwatat. Ecol. 53: 681-697.

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 and Reservoirs: Research and Management 12:107-117.

Lake Victoria Environment Management Project (LVEMP) (2005). *Kenya National Water Quality Synthesis Report.*

Langdon, P., Ruiz, Z., Brodersen, K.P., & Foster, I. D. L. (2006): Assessing lake eutrophica-tion using chironomids: Understanding the nature of community response in different lake types. *Freshwater Biol.* 51: 562-577.

Leedy, P. D. & Ormod, J. E. (2005). Practical Research: Planning and Design. Prentice Hall, Upper Saddle River, NJ. Available online at: http://www.worldcat.org/title/practical-research-planning-and-design/oclc/53831701

Lung'ayia, H. B. O. (2012). Assessment of water quality using diatoms as bio-indicators in catchments of Lake Victoria, Kenya. PhD thesis, Vrije universitert Brussels. Faculty of science laboratory of general botany and nature management, Belgium.

Makoba, H., Shivoga, W., Muchiri, M., & Miller, S. N. (2008). *Use of benthic Macro-invertebrates as Indicators of Water Quality in River Njoro, Kenya.* Egerton University, Environmental Science Department.

Mary, J. F., & Macrina, T. Z. (2012). *Macro-invertebrate Composition, Diversity and Richness in Relation to the Water Quality Status of Mananga River, Cebu, Philippines.* Philippine Science Letters 5(2).

Masese, F. O., Muchiri, M., & Raburu, P. O. (2009) Macro invertebrate Assemblages as Biological indicators of Water Quality in the Moiben River, Kenya. African Journal of Aquatic Science 34:15-26.

Merritt, R. W., & Cummins, K. W. (1996). *An introduction to the aquatic insects of North America*. Kendall Hunt.

Minu, A., Routh, J., Machiwa, J. F., & Pamba, S. (2020). Spatial variation of nutrients and primary productivity in Rufiji Delta mangroves, Tanzania. African Journal of Marine Science. Available online at: https://doi.org/10.2989/1814232X.2020.1776391

Mokaya, S. K., Mathooko, J. M., & Leichtfried, M. (2012). Influence of anthropogenic activities of water quality of a tropical stream ecosystem. Afr. J. Ecol. 42:281-288.

Mugo, R., Waswa, R., Nyaga, J. W., Ndubi, A., Adams, E. C., & Flores-Anderson, A. I. (2020). Quantifying land use land cover changes in the Lake Victoria basin using satellite remote sensing: The trends and drivers between 1985 and 2014. Remote Sensing, 12 (17), 2829.

Muli, J. R. (1996). Environmental problems of Lake Victoria (East Africa): What the International Community can do. Lakes & Reservoirs: Research & Management, 2(1 – 2), 47-53

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

Ndiritu, G. G., Gichuki, N. N., Kaur, P., & Triest, L. (2003). Characterization of environmental gradients using physico-chemical measurements and diatom densities in Nairobi River, Kenya. *Aquat. Ecosyst. Health Manage*., **6**, 343-354.

Ngapula, G. W., & Kayanda, R. (2008). Benthic Macrofauna Community Composition, abundance and distribution in the Tanzanian and Ugandan Inshore and

Offshore waters of Lake Victoria. *African .Journal Aquatic Science,* 35(2) :185-192

Ngodhe, S. O., Raburu, P. O., & Achieng, A. (2014). *The impact of water quality on species diversity and richness of macro-invertebrates in small water bodies in Lake Victoria Basin, Kenya.* Journal of Ecology and the Natural Environment. Vol. 6(1).

Nolan, K. A., & Callahan, J. E. (2006). Beachcomber biology: The Shannon-Weiner Species Diversity Index. Pages 334-338, *in* Tested Studies for Laboratory Teaching, Volume 27 (M.A. O'Donnell, Editor). Proceedings of the 27th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 383 pages.

Ntiba, M. J, Kudoja, W. M., & Mukasa, C. T. (2010). Management issues in the Lake Victoria watershed. Lakes Reserv. Res. Manage. 6:211–216.

Odinga, J. A. (2015). Utilization of macro-invertebrate gathering to evaluate the natural integrity of Nyando Wetlands, Kenya. African Journal of Ecology and Ecosystems Vol. 2 (1).

Okungu, J., & Opango, P. (2005). Knowledge and Experiences gained from Managing. The Lake Victoria Ecosystem. Regional Secretariat, Lake Victoria Environmental Management Project (LVEMP). Dar es Salaam, Tanzania. 725pp.

Onwona Kwakye, M., Peng, F. J., Hogarh, J. N., & Van den Brink, P. J. (2021). Linking Macroinvertebrates and Physicochemical Parameters for Water Quality Assessment in the Lower Basin of the Volta River in Ghana. *Environmental*

Management, **68**, 928–936 (2021). https://doi.org/10.1007/s00267-021-01535-1

Opaa, B. O. (2003). Bio-assessment of constructed wetlands using macro invertebrates and nutrient removals by two macrophytes, Cyperus papyrus L. and Echinocloa pyramidalis L.., at Chemelil Sugar Company, Kenya. Unpublished Masters Thesis Moi University, Kenya. 118pp

Orwa, P. O., Omondi, R., Ojwang, W., & Mwanchi, J. (2015). *Diversity, composition and abundance of macro-invertebrates associated with water hyacinth mats in Lake Victoria, Kenya.* African Journal of Environmental Science and Technology 9(3).

Patang, F., Soegianto, A., & Hariyanto, S. (2018). Benthic macro invertebrates diversity as bio-indicator of water quality of some rivers in East Kalimantan, Indonesia. International Journal of Ecology

Peterson, G. D., Beard Jr, T. D., Beisner, B. E., Bennett, E.M., Carpenter, S.R., Cumming, G.S., Dent, C. L., & Havlicek, T. D. (2003): Assessing future ecosystems services: A case study of the Northern Highlands Lake District, Wisconsin. *Conserv. Ecol.* 7: 1-24.

Raburu, P. (2003). Water quality and the Status of Aquatic MicroInvertebrates and Ichthyofauna in River Nyando, Kenya. Unpublished Ph.D Thesis, Moi University, Kenya .313 p

Rader, B. R., Batzer, P. D., & Wissinger, S. A. (eds) (2001*).* Bioassessment and Management of North American Freshwater Wetlands. John Wiley & Sons, Inc, New York.

Ram, D. T., & Deep, N. S. (2013). *Evaluation of benthic macro-invertebrate assemblage for disturbance zonation in urban rivers using multivariate analysis: Implications for river management.* J. Earth Syst. Sci. 122, No. 4, August 2013.

Reese, V. A., & McDonald, J. (2012). *A Guide to Common Freshwater Invertebrates of North America*, *3rd edition*. Blacksburg: Woodward Publishing Company.

Renata, M. G. S., Kátia, G. F., Luis, A. P., & Giuliano, B. J. (2011). Influence of environmental factors on benthic macro-invertebrate communities of urban streams in Vereda habitats, Central Brazil. Acta Limnologica Brasiliensia 2011, Vol. 23(3).

Republic of Kenya (2007). *National Water Service Strategy.*

Rostgaard, S., & Jacobsen, D. (2005). Respiration rate of stream insects measured in *situ* along a large altitude range. *Hydrobiologia* **549**: 79-98.

Sandin, L. (2003). Benthic macro invertebrates in Swedish streams: Community structure, taxon richness, and environmental relations. Ecography, 26 (3), 269 – 282.

Sanyanga, R. A., & Hlanga, L. (2004): Limnology of Zimbabwe. In: *Limnology in developing countries* (Gopal, B. and Wetzel, R.G.), pp. 117-170. *International Scientific Publica-tions*, New Dehli.

Sarkar, S. K., Bhattacharya B., Debnath, S., Bandopathaya, G., & Giri, S. (2002). Heavy metals in biota from Sundarban Wetland Ecosystem, India: Implications to monitoring and environmental assessment. *Aquatic Ecosystem Health and Management* **5**(4): 467-472

Schmieder, K. (2010): European lake shores in danger - concepts for a sustainable develop-ment. *Limnologica* 34: 3-14.

Schnaiberg, J., Riera, J., Turner, M. G., & Voss, P. R. (2012): Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. *Environ. Manage.* 30: 24-34.

Shieh, S. A., & Yang, P. S. (2000). Community structure and functional organization of aquatic insects in an agricultural mountain of Taiwan. *Zool. Stud.*, **39**, 191-202.

Sly, P. G. (2011). The effects of land-use and cultural development on the Lake-Ontario eco-system since 1750. *Hydrobiologia* 213: 1-75.

Smith, D. G. (2001). Pennack's freshwater invertebrates of the United States (4th ed.). New York, NY: John Wiley & Sons, Inc.

Somero, G.N. (2010) The Physiology of Climate Change: How Potentials for Acclimatization and Genetic Adaptation Will Determine "Winners" and "Losers". Journal of Experimental Biology, 213, 912-920. https://doi.org/10.1242/jeb.037473

Steve, O. N., Phillip, O. R., & Alfred, A. (2014) .The impact of water quality on Species Diversity and richness of Macro invertebtates in Small Water bodies in Lake Victoria Basin, Kenya. *Journal of ecology and natural environment.* Vol. 6 (1). pp 32-41.

Suleiman, K., & Abdullahi, I. L. (2011). Biological assessment of water quality: A study of Challawa river water Kano, Nigeria. Bayero Journal of Pure and Applied Sciences, 4 (2), 121 – 127.

Tampo, L., Ouéda, A., Nuto, Y., Kaboré, I., Bawa, L. M., Djaneye-Boundjou, G., et al. (2015). Using physicochemicals variables and benthic macroinvertebrates for ecosystem health assessment of inland rivers of Togo. *Int. J. Inn. Appl. Stud*. 12, 961–976.

Teferi, M., Tsegazeabe H., Haileselasie,T., Asmelash, Haile, G. S., Genet, A., Solomon, A., Kiros, W., Solomon, T., Solomon, K., Gebru, E., & Hayal, L. B. (2013). Influence of water quality on the diversity and distribution of macro-invertebrates in highland stream, Northern Ethiopia. Scholarly Journal of Agricultural Science Vol. 2(2).

Tsegazeabe, H. H., & Mekonen, T. (2012). Influence of Water Quality on the Diversity and Distribution of Macro-Invertebrates in Hiwane Second Order Stream, Northern Ethiopia. Research Journal of Environmental and Earth Sciences 4(4).

UNDP (2006). *Water governance*: http://europeandcis.undp.org/WaterWiki/Water Governance.

UN-Habitat (2008). The State of The World's Cities 2008/2009, UN Habitat, Nairobi.

Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G.E., Matson, P. A., Schindler, D. W., Schlesinger, W. H., & Tilman, D. G. (2009). Human alteration of the global nitrogen cycle: Sources and consequences. *Ecol. Appl.* 7: 737-750.

Walz, N., Brüggemann, R., & Ostendorp, W. (2012): Die Seeufer, ein vergessenes Ökoton. *UWSF – Z. Umweltchem. Ökotox.* 14: 255-256.

Wibowo, D. N., & Santoso, S. S. (2017). *Short Communication: Benthic macro-invertebrate diversity as bio-monitoring of organic pollutions of river* *ecosystems in Central Java, Indonesia*. BIODIVERSITAS 18 (2), April 2017.

World Health Organization (2008). Guidelines for drinking-water quality, Vol.1, Recommendations, 3rd edn. (World Health Organization), Geneva. Switzerland.

World Health Organization (2017). Guidelines for drinking-water quality. Fourth edition. Geneva. Switzerland.

World Health Organization/UNICEF (2012). *Progress on Drinking Water and Sanitation* 2012. Retrieved on 15th Dec. 2017 from www.unep.org/geo

Xiao, Q., McPherson, E. G., Simpson, J. R., & Ustin, S. L. (2009). Hydrologic Processes at the Urban Residential Scale, Hydrological Processes, 21(16): 2174-2188.

Yakub, A. S. (2008). Effects of effluents on the water quality, plankton, and macro-invertebrates of the shore sediments and shore foliage of the Awba stream and reservoir, Ibadan, Nigeria. M.Sc. Thesis, University of Ibadan.

Yuan, L. L. (2004). Assigning macro invertebrate tolerance classifications using generalized additive models. *Fresh. Biol*. 49, 662–677. doi: 10.1111/j.1365-2427.2004.01206.x

APPENDIX I: Letter of Introduction

RONGO UNIVERSITY

OFFICE OF THE DEAN

SCHOOL OF GRADUATE STUDIES

Tel. 0771349741

P.O. Box 103 - 40404
RONGO

Our Ref: **MES/6001/2015**

Date: Tuesday, November 26, 2019

The Chief Executive Officer,
National Commission for Science, Technology & Innovation,
off Waiyaki Way, Upper Kabete,
P.O Box 30623-00100,
Nairobi-KENYA.

Dear Sir,

RE: RESEARCH PERMIT FOR MS. OWALO PATRICIA OKUNE-MES/6001/2015

We wish to inform you that the above person is a bona fide graduate student of Rongo University in the School of Agriculture Natural Resources and Environmental Studies pursuing a Master degree in Environmental Biology. She has been authorized by the University to undertake research titled; **"Influence of Water Quality on the Abundance of Benthic Macroinvertebrates along the Lake Victoria Shores in Homa-Bay County, Kenya."**

This is, therefore, to request the commission to issue her with a research permit to enable her proceed for field work.

Your assistance to her shall be highly appreciated.

Thank you.

Dr. Edward Anino
DEAN, SCHOOL OF GRADUATE STUDIES

RONGO UNIVERSITY
THE DEAN
26 NOV 2019
SCHOOL OF GRADUATE STUDIES
P. O. BOX 103 - 40404, RONGO

Copy to: Vice Chancellor
Deputy Vice Chancellor (Academic and Student Affairs).
Dean, School of Agriculture Natural Resources and Environmental Studies
HoD, Agronomy and Environmental Studies

APPENDIX II: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **865021**

Date of Issue: **16/December/2020**

RESEARCH LICENSE

This is to Certify that Ms.. PATRICIA OKUNE OWALO of Rongo University, has been licensed to conduct research in Homabay on the topic: INFLUENCE OF WATER QUALITY ON THE ABUNDANCE OF BENTHIC MACROINVERTEBRATES ALONG THE LAKE VICTORIA SHORES HOMA BAY COUNTY KENYA for the period ending : 16/December/2021.

License No: **NACOSTI/P/20/8213**

865021

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013

The Grant of Research Licenses is Guided by the Science, Technology and Innovation (Research Licensing) Regulations, 2014

CONDITIONS

1. The License is valid for the proposed research, location and specified period
2. The License any rights thereunder are non-transferable
3. The Licensee shall inform the relevant County Director of Education, County Commissioner and County Governor before commencement of the research
4. Excavation, filming and collection of specimens are subject to further necessary clearence from relevant Government Agencies
5. The License does not give authority to tranfer research materials
6. NACOSTI may monitor and evaluate the licensed research project
7. The Licensee shall submit one hard copy and upload a soft copy of their final report (thesis) within one year of completion of the research
8. NACOSTI reserves the right to modify the conditions of the License including cancellation without prior notice

National Commission for Science, Technology and Innovation
off Waiyaki Way, Upper Kabete,
P. O. Box 30623, 00100 Nairobi, KENYA
Land line: 020 4007000, 020 2241349, 020 3310571, 020 8001077
Mobile: 0713 788 787 / 0735 404 245
E-mail: dg@nacosti.go.ke / registry@nacosti.go.ke
Website: www.nacosti.go.ke

APPENDIX III: Kenya Marine and Fisheries Research Approval Letter

KENYA MARINE AND FISHERIES RESEARCH INSTITUTE

TELPHONE: KISUMU 2021461/020205697
E - mail: kmfkisumucentre@yahoo.com
When replying please quote
REF: KMF/KSM/INFO 9/VOL XX/
If calling or telephoning ask
For: Lucas Aluoch
please address your reply to
ASSISTANT/CENTRE DIRECTOR

KISUMU CENTRE
P.0. BOX 1881
KISUMU
KENYA

Patricia Okune Owalo
P.O. Box 103-40404
Rongo

Date: 26/06/2019

RE: STUDENT JOINING INSTRUCTION – Msc. Research Work

Reference is made to your letter received on 21st June,2019 in which you requested for the authority to use KMFRI personnel, equipment and the laboratory during your research work. This is to hereby inform you that your request has been approved, you will be required to pay a mandatory monthly bench fee of Ksh. 5000/-

You will also be expected to cater for the fuel for the institute vehicle and the allowances for the technical personnel during the field work. Make arrangement to report to the Principal Lab Technologist (PLT) for the logistics and the final budget for the whole activity.

Yours faithfully,

Lucas Aluoch

For Ag. DD (FWS)

KENYA MARINE & FISHERIES
RESEARCH INSTITUTE
KISUMU CENTRE
P. O. BOX 1881
KISUMU

APPENDIX IV: Research Authorization – Homa Bay County Director of Education

HARAMBEE

MINISTRY OF EDUCATION

STATE DEPARTMENT FOR EARLY LEARNING & BASIC EDUCATION

Telegrams: "SCHOOLING" Homa Bay
Telephone +
When replying please quote
cdehomabay@gmail.com

COUNTY DIRECTOR OF EDUCATION
HOMA BAY COUNTY
P.O BOX 710
HOMA BAY
DATE 21ST DECEMBER, 2020

REF: MOEST/CDE/HBC/ADM/11/VOL. III/7

Ms. PATRICIA OKUNE OWALO
RONGO UNIVERSITY

RE: RESEARCH AUTHORIZATION.

Following your application for authority to carry out research on "***Influence of water quality on the abundance of benthic macroinvertebrates along the lake Victoria shores, Homa Bay County,"*** I am pleased to inform you that you have been authorized to undertake research in Homa Bay County for the period ending **16th December, 2021.**

Kindly note that ,as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit a copy of the final research report to the County Director of Education Office after completion both the soft copy and hard copy.

Thank you in advance.

COUNTY DIRECTOR OF EDUCATION
HOMA BAY COUNTY
P O BOX 710-40300, HOMA BAY
Email: cdehomabay@gmail.com

Fred

MR. FREDRICK M. KIIRU
COUNTY DIRECTOR OF EDUCATION
Cc.

COUNTY COMMISSIONER
HOMA BAY COUNTY.

APPENDIX V: Research Authorization – Homa Bay County Government

REPUBLIC OF KENYA

HOMA BAY COUNTY GOVERNMENT

OFFICE OF THE GOVERNOR

Homa Bay County Headquarters
P.O Box 469-40300 Homa Bay - Kenya

E: governor@homabay.go.ke
www.homabay.go.ke

Our Ref: HBCG/COS/043/ 2020/12 (30)

17th December 2020

Patricia Okune Owalo
Department of Agronomy and Environmental Studies
RONGO UNIVERSITY
P.O Box 103 – 40404 Rongo, Kenya
E: patowalo@yahoo.com
Tel: 0723714083

RE: NO OBJECTION LETTER FOR UNDERTAKING RESEARCH PROJECT IN HOMA BAY COUNTY

This is to acknowledge receipt of your request for permission to carry out research along Lake Victoria Shores within Homa Bay County through the National Commission for Science, Technology and Innovation (NACOSTI) License No: **NACOSTI/P/20/8213**.

Homa Bay County Government has no objection to your academic research activity within Homa Bay County. However, upon completion of your research, you are expected to share your findings with the County Government for policy formulation and continuous service improvement to the public.

Best of luck in your research.

CHIEF OF STAFF
HOMA BAY COUNTY GOVERNMENT

Mr. Eliud Otieno Ochieng
CHIEF OF STAFF

APPENDIX VI: Authorization Letter – Ministry of Agriculture Homa Bay County

REPUBLIC OF KENYA

HOMA BAY COUNTY

OFFICE OF THE CHIEF OFFICER

AGRICULTURE, LIVESTOCK, FISHERIES & FOOD SECURITY & COOPERATIVES

REF;HBC/MOALF/CO/ADM3/VOL1/35

18/12/2020

TO WHOM IT MAY CONCERN

RE: AUTHORITY TO CONDUCT RESEARCH ALONG THE LONG THE LAKE VICTORIA SHORES HOMA BAY COUNTY

The bearer of this letter has been granted authority to carry out research related activities for the purpose of completion of her studies on the area of "The influence of water quality on abundance of benthic macro-invertebrates along the Lake Victoria shores, Homa Bay County".

The study will be carried out over the period of one year 2020/2021. It is required that on completion of this study, a copy of the report be given to this office.

We take this opportunity to wish her well in her undertakings.

CHIEF OFFICER
MINISTRY OF AGRICULTURE LIVESTOCK
& FISHERIES
HOME-BAY COUNTY GOVERNMENT
P.O. Box 469-40300, HOMA-BAY,-KENYA

SAMWEL OWIGO
CHIEF OFFICER,
AGRICULTURE, LIVESTOCK, FISHERIES & FOOD SECURITY & COOPERATIVES
HOMA BAY COUNTY

APPENDIX VII: Taxonomy of Bethic Macro Invertebrates

Order	Species
Decapoda	*Paleomonetes paladosus*
Diptera	*Spaniodoma sp*
Ephemeroptera	*Baetis sp*
Ephemeroptera	*Caenis moesta*
Ephemeroptera	*Cleon simile*
Ephemeroptera	*Hexagenia bilineata*
Haplotaxida	*Naids sp*
Haplotaxida	*Tubifex tubifex*
Hemiptera	*Corixa sp*
Hemiptera	*Corixids sp*
Hemiptera	*Lethorus americanus*
Hemiptera	*Rhagovelia obesta*
Hirudinea	*Haemopis sp*
Hirudinea	*Hirudo medicinalis*
Odonada	*Ceratopogonidae sp*
Prosobranchiata	*Gylia Altitis*
Pulmonata	*Melanoides tuberculata*
Pulmonata	*Physa sayi*
Trichoptera	*Hydropsyche sp*
Unionoida	*Anodonda cygneae*
Unionoida	*Polycentropus sp*
Veneroida	*Sphaerium sp*