# ECOSYSTEM INTEGRITY AND FISH POPULATION DYNAMICS OF RIVER AWACH KIBUON: TOWARDS MANAGEMENT OF LAKE VICTORIA BASIN

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I dedicate this work to my dear wife Loyce Atieno Ombok, lovely daughters Vanessa Adhiambo, Darlene Precious and Davina Peace and wonderful sons David Enock Ochieng' and Noel Blessing for their unrelenting and tireless support and encouragement during the entire study period.

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# ABSTRACT

Healthy rivers provide important ecosystem services and goods to the society. However, most medium-sized rivers worldwide are degraded by anthropogenic activities thereby reducing their usefulness. One such river is the 52-km long Awach Kibuon that drains the southern part of Lake Victoria Basin, Kenya. It provides water and fish to the riparian Gusii and Luo communities. However, its ecological health is threatened by poor anthropogenic practices in the basin. This study sought to determine its spatio-temporal ecosystem integrity and fish population dynamics based on water quality assessment, habitat characterization and fish community assessment. Eight monthly sampling surveys were carried out at 9 strategically picked sites along its channel. Purposive and random sampling designs were used to study river ecosystem integrity and fish population dynamics, respectively. Selected physico-chemical parameters were measured *in situ* using YSI Professional Plus multi-parameter water quality meter. Habitat quality assessment was conducted quantitatively using various tools. Fish samples for ecosystem integrity assessment were obtained by electro-fishing and from commercial catches for population dynamics studies. Fish population parameters (asymptotic length $L_\infty$, growth curvature $K$, growth performance index $\theta'$, exploitation rate $E$ and mortality rates $Z$, $M$ and $F$) were estimated by ELEFAN I routines in FISAT II Software Version 1.2.2. The study hypothesized that there are no significant spatio-temporal ecosystem integrity variations and no overexploitation of fish species in River Awach Kibuon. Spatio-temporal variations of physico-chemical parameters were tested using one-way ANOVA and two-sample t-test. Correlations between physico-chemical parameters and fish species abundance were determined by Canonical Correpondence Analysis (CCA). All physico-chemical parameters except pH varied significantly spatially ($\alpha < 0.05$) but not temporally ($\alpha > 0.05$). Most parameters conformed to natural longitudinal trends except turbidity, total dissolved solids (TDS) and nutrients whose levels indicated a river undergoing degradation. Habitat quality was poor upstream, moderate midstream and good at the river mouth. Four out of nine stations studied lacked ecosystem integrity characterized by poor habitat quality and low fish species diversity. All the four studied fish populations (*Oreochromis nioticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus*) in River Awach Kibuon are overexploited with exploitation rates that are greater than optimum sustainable exploitation rate ($E_{0.5}$) and maximum sustainable exploitation rate ($E_{\max}$). There was a strong significant positive association between river Habitat Quality Index (HQI) and Fish Index of Biotic integrity (FIBI) of fish communities in River Awach Kibuon (rs (39) = 0.97, p = .005). Canonical Correspondence Analysis (CCA) indicated that electrical conductivity, total dissolved solids (TDS) and surface water velocity significantly influenced the abundance of fish in River Awach Kibuon ($p < .05$).The study recommends restoration of natural riparian buffer vegetation, reduction of fishing pressure on all the four overexploited species and close monitoring of fishing activities in riverine fisheries by the State Department of Fisheries and Kenya Fisheries Service to ensure sustainable utilization.

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| | |
|---|---|
| ADB | African Development Bank |
| ANOVA | Analysis of Variance |
| BMU | Beach Management Unit |
| DO | Dissolved Oxygen |
| EGI | Empty Gut Index |
| ELEFAN | Electronic Length Frequency Analysis |
| EMCA | Environmental Management Coordination Act |
| FAO | Food and Agriculture Organization |
| FIBI | Fish Index of Biotic Integrity |
| GSI | Gonado-Somatic Index |
| HSI | Hepato-Somatic Index |
| IBI | Index of Biotic Integrity |
| ICLARM | International Center for Living Aquatic Resources |
| KMFRI | Kenya Marine and Fisheries Research Institute |
| LVB | Lake Victoria Basin |
| LVEMP | Lake Victoria Environmental Management Programme |
| LVFO | Lake Victoria Fisheries Organization |
| MoE | Ministry of Education |
| NTU | Nephelometric Turbidity Units |
| PP | Particulate Phosphorus |
| PPM | Parts Per Million |
| SE | Standard Error |
| SOPs | Standard Operating Procedures |
| SPSS | Statistical Package for Social Sciences |

| | |
|---|---|
| SRRs | Stock-recruitment relationships |
| TDS | Total Dissolved Solids |
| TL | Total Length |
| TP | Total Phosphorus |
| TN | Total Nitrogen |
| USEPA | Unites States Environmental Protection Agency |

# CHAPTER ONE

# INTRODUCTION

## 1.0 Background of the study

Rivers are dynamic chemical, physical and biological entities that traverse most of the earth's landscape draining unique land areas called watersheds or river basins (Meybeck et al., 1996). Healthy rivers are of great importance to society providing valuable goods and services including water, fish, recreation, hydroelectric power, transportation and navigation among others to humanity (Baron et al., 2003). However, most rivers worldwide are under great pressure emanating from both human activities and natural sources (Vörösmarty et al., 2010). Rivers are either degraded or are progressively being degraded mainly as a result of water abstraction for agricultural and industrial uses, damming for hydroelectric power generation and discharge of untreated or improperly treated domestic and industrial effluents giving rise to big losses of aquatic and riparian biodiversity and reduction in abundance (Jahnig et al., 2012). Additional sources of river degradation include; siltation and accumulation of nutrients from poor farming practices in the catchment areas, flow alterations, introduced species and channel modifications.

Ecosystem integrity may be defined as the system's capacity to maintain structure and ecosystem functions using processes and elements typical for its eco-region (Dorren et al., 2004). The ecological integrity of a river may be determined by evaluating the extent to which its chemical, physical and biological attributes conform to natural pristine conditions or the extent to which its waters can be used beneficially (Karr, 1981). The maintenance of a balanced community of organisms reflects the ecological integrity and the possible benefits that can be derived from an ecosystem (Karr, 1981). Ecological integrity can be assessed using chemical, physical and biological methods. The three methods of evaluation are considered important and complimentary to each other. However, biological assessment is highly valued and preferred because it integrates the condition of the river basin from tributaries to the mainstream river through evaluation of the response of aquatic assemblages. Historically, the monitoring of chemical and physical attributes of rivers is widespread but biological assessment based on biotic integrity is rare. However, biological assessment is increasing in North America and Europe but is still uncommon in most developing countries (Karr & Dudley, 1981; Aura et al., 2010; Abbasi & Abbasi, 2011).

### 1.0.1 Physico-chemical parameters

Assessment of physico-chemical parameters focuses only on the presence and concentrations of stressors but not their impacts on biota (Abbasi & Abbasi, 2011). The evaluation of ecosystem integrity of a river based on physico-chemical parameters is accomplished by measuring the concentrations of several key parameters such as total dissolved solids (TDS), turbidity, dissolved oxygen (DO), salinity, total nitrogen (TN), temperature, total phosphorus (TP) and electrical conductivity among others (Patil et al., 2012). Many parameters are measured *in situ* using a multi-parameter water quality meter while a few others such as nutrients are determined in the laboratory. The interpretation of river ecosystem integrity based on analyses of physico-chemical parameters should be limited to the actually measured parameters. This is because of the possible presence of a wide variety of artificial and natural chemicals in water making it almost impossible to measure all of them (Abbasi & Abbasi, 2011). Consequently, this stressor-based approach to river health assessment is characterized by limitations. The results of physico-chemical parameter analyses should therefore be complemented with those of habitat characterization and biological assessment.

### 1.0.2 Habitat characterization

Assessment of ecological integrity based on habitat characteristics focuses on availability of habitats and their condition but not their impacts on biota. Physical river habitats refer to any characteristic or combination of characteristics within or connected with the river that provides appropriate conditions for living and sustenance of biota (Kaufmann et al., 1999). Good habitats support many species and are found in areas which are least modified physically and are close to their natural state. According to Maddock (1999), the value of a habitat is determined by abundance and diversity of habitat features valuable to biota. The value of habitats is determined by the variety of physical structures and their unmodified natural condition (Raven et al., 1998).

In a river, the key habitats are riffles, pools and runs which determine the composition, distribution and abundance of riverine aquatic biota. Additional features such as in-stream and bank side vegetation also form part of the river habitat (Maddock, 1999). The riparian wetlands add to the complexity and value of habitat structures in a river ecosystem. The assessment of river physical habitat characteristics entails: counting of riffles, channel bends and pools; measuring width of natural riparian buffer vegetation, depth and width of the river channel; determining river bed substrate type; evaluation of land-use adjacent to the river, level of bank erosion and the extent of in-stream cover including macrophytes, debris made of wood and snags (Rogers, 2016).

### 1.0.3 Biological assessment

Biological assessment addresses the collective effects of all stressors, including degraded habitats and chemical pollution, which diminish biological diversity (Karr, 1991). It integrates the status of the whole river basin including tributaries and the mainstream river through assessment of the response of indigenous aquatic assemblages (Karr, 1991;

Barbour et al., 1999). Biological assessment is more robust and comprehensive relative to chemical and physical assessments (Karr, 1999).

Biological assessment of a river involves critical evaluation of the characteristics of its biological communities like species richness, trophic structure, species relative abundance, biomass, community structure or a composite index incorporating many parameters (Rosenberg & Resh, 1993). Biological assessment is important in evaluating degradation attributed to non-point pollution sources and non-chemical stressors such as physical and biological stressors. Biological assemblages integrate the impacts of all the stressful factors in the environment and therefore represent a broad estimate of their collective effects over time (Barbour et al., 1999). Historically, biological assessment of aquatic communities has been done by use of classical diversity indices such as Shannon-Wiener Index (H′), Simpson's Index (D) and Pielou's Evenness Index (J).

However, the relatively new Index of Biotic Integrity (IBI) introduced by James Karr in 1981 is increasingly being used. The IBI is highly preferred since it gives an overall outlook of biological, physical and chemical characteristics of any site in the river (Acuna et al., 2004; Aura et al., 2010). Developing an IBI involves comparison of environmental conditions at sampling sites with those of a chosen natural unmodified reference site in the same river or in unperturbed rivers of comparable size and habitat types located in the same ecoregion (Karr, 1981). A score of 1, 3, or 5 is given to every attribute or metric, depending on its level of deviation from the value expected at the reference site. Values that strongly deviate from it are scored (1), while those that moderately deviate, and those that approximate the reference value are scored (3) and (5), respectively. The final IBI value of each sampling site is attained by summing up the scores of all the metrics.

Other biological indices such as Empty Gut Index (EGI), Hepato-Somatic Index (HSI) and Gonado-Somatic Index (GSI) reflect the energy and food conditions prevailing in aquatic ecosystems. Empty Gut Index is the proportion of fish in a population with empty guts expressed as a percentage. EGI is used in fisheries to evaluate the availability of food to fish in their environment. Hepato-Somatic Index is the weight of the liver of an organism relative to the total weight of its body expressed as a proportion. It indicates the level of energy storage and recent feeding activity by the fish (Tyler & Dunn, 1976). Gonado-Somatic Index is the weight of the gonads relative to total fish body weight stated as a proportion. It depicts the nutritional condition and the spawning status of the fish population. GSI is also recognized as a specific indicator of maturity and periodicity of fish spawning (Kaur et al., 2018). Year-round GSI data helps in identification breeding season(s) in a year.

### 1.0.4 Fish population dynamics

The study of fish population dynamics is important in understanding fish population status hence contributes to informed decision making for effective management geared towards long-term sustainability (Quist, 2007; Carmago et al., 2015). Natural fish populations are constantly changing owing to varying environmental conditions and changing fishing pressures (McRae & Diana, 2005). Recruitment, growth and mortality rates are the main factors behind fish population dynamics (Ricker, 1975; Gulland, 1982; Sissenwine, 1984). Estimates of recruitment patterns, growth rates and mortality rates give an indication of what is responsible for the current fish population status and the changes that should be expected in the future (Pope et al., 2010). Fish populations are expected to increase in size if recruitment and growth rates exceed mortality losses and vice versa (Lazar, 2015).

Fish population parameters are determined by environmental factors and fish species life-history strategies (Silvestre & Garces, 2004). Fish species that live long with life spans longer than 15 years (K-strategists) tend to have high asymptotic length ($L\infty$), low natural mortality rate ($M$) and low curvature parameter ($K$). In contrast, fish species with short life spans of 5 years or less (r-strategists) are characterized by low asymptotic length ($L\infty$), high natural mortality rate ($M$) and high curvature parameter ($K$) (Sa-Oliveira et al., 2015). The determination of fish population parameters is based mainly on length, weight and age data of individual fish. Additional data that may be collected for comprehensive fish population studies include; fish distribution patterns, sex ratios, sexual maturity stages, weight of gonads and liver weight among others (Strange, 1996).

Recruits into a fishery refer to the number of young fish that survive long enough in spawning and nursery grounds to enter the fishing grounds or adult feeding grounds in a year. Recruitment results from multiple connected events beginning with release of mature gametes, fertilization, incubation, hatching, fry growth and survival, metamorphosis, growth and migration to the fishing grounds or adult feeding areas (Welcomme, 2001). Recruitment in fish populations is characterized by high variability from year to year (Gulland, 1982; Quist, 2007). It increases with increase in spawning stock sizes until a certain point after which it begins to decrease (Welcomme, 2001). The causes of high variability are unclear but climatic conditions or biotic factors like the spawning stock size are thought to be the key determinants of recruitment patterns in fish populations.

Growth in fish populations is measured in terms of increase in body size (length or weight) within a specified time period. Growth of tropical fish species is difficult to estimate based on seasonal and annual rings owing to lack of strong distinct seasons in the tropics unlike the temperate region (Sparre & Venema, 1998). Consequently, growth of tropical fish species is estimated by length-frequency analysis. Fish growth is described by the aid of the von Bertanlanffy growth model which is comprised of three important parameters; asymptotic length (*L*∞), growth curvature (*K*) and the 'birthday' parameter ($t_0$). These parameters differ for each species and may also vary for different populations of the same species. Short-lived fish species have bigger (*K*) values and can reach asymptotic length (*L*∞) within a year while long-lived species have small (*K*) values and reach asymptotic length after many years.

Mortality forms the negative aspect of fish population dynamics. Mortality in fish populations is partitioned into natural mortality rate (*M*) and fishing mortality rate (*F*). Natural mortality is attributed to diseases, spawning exhaustion, predation and old age among others (Yongo & Outa, 2016) while fishing mortality is attributed to deaths caused by fishing. Mortality in fish populations is easily estimated by tracking the outcome of a cohort or age-class (Sparre & Venema, 1998). In nature the mortality rates differ according to the age of the cohort. Young fish which are smaller in size experience higher natural mortality rate than big old fish. This is because they are prone to predation by various organisms and have lower fishing mortality rate because they escape through the meshes of most fishing nets and may not have migrated to the fishing grounds (Sparre and Venema, 1998). Conversely, old fish experience higher deaths from fishing than from natural causes because they are the main target of fishing but are less vulnerable to predation because of their big size.

Exploitation rate (*E*) is the fraction of total mortality rate (*Z*) that is attributed to fishing. This rate helps to assess the fishing status of the stock by determining the presence or absence of overfishing. The growth performance index (θ′) is used to obtain preliminary estimates of growth curvature (*K*) for populations or stocks lacking growth data. In open waters, environmental conditions may cause fish to grow fast toward a small size (high $K$, low $L\infty$), or slowly toward a large size (low $K$, high $L\infty$). Consequently, the growth performance index ($\theta'$) remains nearly constant in various populations of the same species (Pauly, 1994).

River Awach Kibuon, which was the site of this study, is a 52-km long river that flows into Lake Victoria at the Winam Gulf, Kenya. It originates from the Kisii Highlands, which are located 2100 meters above sea level close to Nyaramba Market in Nyamira County (Mwangi et al., 2015). The river traverses both Nyamira and Homa Bay Counties entering Lake Victoria near Kendu Bay town. It contributes to the water budget, sediment and nutrient loads and biodiversity of Lake Victoria (Okungu et al., 2005; Mwangi et al., 2012). It has not been studied comprehensively despite its importance to Lake Victoria and the riparian communities. The status of its biological communities, water quality and habitat quality remain largely unknown. This is probably due to the general perception that riverine fisheries in Kenya are not substantial, hence making minimal contribution to national annual fish production (Mwangi et al., 2012). It is therefore difficult at the moment to formulate policy and develop management plans and interventions that promote river ecosystem integrity and sustainable riverine fisheries.

## 1.1 Problem statement

Rivers all over the world are subjected to great pressures from both anthropogenic and natural sources. This leads to degradation and loss of ecosystem integrity. Consequently, the ecological benefits derived from such rivers are reduced or lost. Ongoing anthropogenic activities in the basin of River Awach Kibuon jeopardize its ecosystem integrity. Its physico-chemical parameters are threatened by poor farming practices in the catchment area which leads to soil erosion and subsequent siltation and sedimentation of the river through run-off. Additional sources of river contamination may include livestock grazing near the river bank and the practice of washing clothes in the river. Increased use of fertilizers in the riparian farmlands leads to leaching of nutrients which end up in the river with the potential of causing eutrophication, anoxia and general degradation of water quality. Rapidly increasing human population coupled with urbanization and industrialization also pose a threat to river water quality through discharge of raw effluents into the river. Habitat quality in rivers is being undermined by siltation and widespread deforestation and clearance of natural riparian buffer vegetation to pave way for farmlands. Biological communities in the river are threatened cumulatively by physical, chemical and biological stressors. These include chemical pollutants, degraded physical habitats and biological stressors which include parasites and pathogens. The exploited fish stocks in the river are constantly under pressure from excessive fishing effort, climate change, pollution and general aquatic environmental degradation.

## 1.2 Justification

Rivers that drain the Lake Victoria Basin including Awach Kibuon contribute substantially to the lake's water budget, sediment and nutrient loads and aquatic biodiversity (Okungu et al., 2005). High nutrient and sediment loads in these rivers may have adverse impacts on the ecological functioning of Lake Victoria. Rivers provide important goods and services such as water, fish, recreation, transportation and navigation to riparian communities which improve human welfare and quality of life (Barbour & Paul, 2010). They therefore need to be studied and managed appropriately to sustain their vital contributions to Lake Victoria and riparian human populations. Small and medium-sized water bodies dominate fresh water ecosystems worldwide and are probably the most threatened by degradation occasioned by adverse anthropogenic activities (Biggs et al., 2014; Oliveira et al., 2014) hence require informed management interventions. Riverine fisheries have been neglected in Kenya for a long time with respect to study and management efforts perhaps due to the assumption of minimal contribution to annual national fish production (Mwangi et al., 2012). Consequently, riverine fisheries are in danger of overexploitation and collapse and thus require urgent assessment to inform management and conservation planning for sustainability.

### 1.3 Significance of the study

This study determined the spatio-temporal ecological integrity of River Awach Kibuon through water quality assessment, habitat quality evaluation and fish community assessment. It also estimated a number of parameters on the population dynamics of the four leading commercially exploited fish species in the river. The information generated by ecosystem integrity assessment reveals the ecological status of different sections of the river and identifies negatively impacted areas. Such information is important for development of management plans and formulation of mitigative measures for river restoration and conservation. The dynamics of fish populations in the river were studied through the analysis of recruitment patterns, growth rates and mortality rates. The data generated can be used in the formulation of effective management strategies and measures for the long-term sustainability of fish stocks. The developed Fish Index of Biotic Integrity (FIBI) for River Awach Kibuon by the study is a vital tool to aquatic resource managers and conservationists in the river catchment and the whole Lake Victoria Basin eco-region as a benchmark.

### 1.4 Objectives

#### Main Objective

The study sought to ascertain the ecosystem integrity and fish population dynamics of River Awach Kibuon to generate useful information for sustainable management of Lake Victoria Basin.

**Specific Objectives**

1. Determine spatio-temporal physico-chemical parameters of River Awach Kibuon (velocity, DO, temperature, turbidity, conductivity, pH, TDS, TN and TP).
2. Characterize longitudinal habitats of River Awach Kibuon.
3. Establish spatio-temporal variations of fish community diversity indices (D, H' and J) in River Awach Kibuon.
4. Determine spatio-temporal Gonado-Somatic Indices, Hepato-Somatic Indices and Empty Gut Indices of Luambwa barb (*Enteromius cercops*) and Ripon barbel (*Labeobarbus altianalis*) populations in River Awach Kibuon.
5. Establish spatio-temporal Fish Indices of Biotic Integrity in River Awach Kibuon.
6. Estimate population parameters (recruitment patterns, growth parameters and mortality rates) and exploitation rates of *Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus* of River Awach Kibuon.
7. Evaluate correlations between physico-chemical parameters, habitat characteristics and fish community characteristics in River Awach Kibuon.

## 1.5 Hypotheses

1. There are no significant spatio-temporal differences in physico-chemical parameters in River Awach Kibuon.
2. There are no longitudinal differences in habitat characteristics in River Awach Kibuon.
3. There are no spatio-temporal differences in diversity indices (D, H' and J) of fish communities in River Awach Kibuon.

4. There are no spatio-temporal variations in GSI and HSI of *Enteromius cercops* and *Labeobarbus altianalis* in River Awach Kibuon.
5. There are no spatio-temporal differences in the FIBI in River Awach Kibuon.
6. The four main commercially exploited fish species at the mouth of River Awach Kibuon (*Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus*) are not overexploited ($E \leq E_{0.5}$).
7. Physico-chemical parameters, habitat characteristics and fish community characteristics are not significantly correlated in River Awach Kibuon.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews literature on riverine ecosystems focusing mainly on the ecological integrity of rivers based on physico-chemical parameters, habitat quality characteristics and biological characteristics of fish communities. It also reviews literature on fish population parameters and their importance to fisheries resource management and conservation. The physico-chemical parameters reviewed include river water surface velocity, electrical conductivity, temperature, turbidity, total dissolved solids, pH, total nitrogen, dissolved oxygen and total phosphorus.

The key river habitat characteristics covered include; river sinuosity, number of riffles, nature of bottom substrates, river bank profile, natural riparian vegetation width, river depth, river channel width, in-stream cover, dimension of pools and aesthetics of river reaches. Literature on important fish community attributes such as species richness, species evenness, abundance and composite diversity indices are also reviewed. These topics are reviewed with respect to their contribution to healthy and properly functioning riverine ecosystems and sustainable riverine fisheries.

The literature reviewed covers studies done on the global, regional and national scales. The study reviewed river ecosystem integrity studies conducted in America, Europe, Asia, Australia and Africa from 1972 to 2022. On the other hand, it also reviewed fish population dynamics studies conducted between 1984 and 2021 in America, Europe, Asia and Africa. This study also highlights a paradigm shift from classical biological indices such as D, H' and J to composite indices such as FIBI.

## 2.2 River Ecosystem Integrity

A river is a broad, unbroken natural stream of water that flows across land and empties into an ocean, a lake or another river. A river usually increases in size downstream due to convergence of tributaries (BBC, 2023). Rivers range in size from small to large with flow rates that also differ from swift and cascading in headwaters and slow in downstream backwaters of large rivers (Allan, 1995). Large rivers are formed by a number of tributaries and tend to become bigger downstream as more tributaries join in (Allan & Castillo, 2007). Typically, the water in a river is contained within a channel that is made up of the river bed and is bordered by the left and right banks (Lustig et al., 2020). However, in larger rivers, a greater floodplain frequently exists as a result of floodwaters overflowing the channel (Dunne & Aalto, 2013). In the lowlands near their mouths, rivers often have a more gradual slope with typically steeper slopes in the upstream reaches (Allan & Castillo, 2007).

The basis of river classification is often controversial and difficult but the size of the basin, length of the channel, hydrological attributes and geomorphological characteristics are often important factors (Tadaki et al., 2014). A river is frequently partitioned into three zones: the upper zone (crenon), the middle zone (rithron) and the lower zone (potamon) (Hawkes, 1975). River systems facilitate the gradual and steady movement of water, dissolved substances and particles of various sizes downstream through diverse drainage networks ranging from simple to highly complicated channels (Allan & Castillo, 2007). Rivers are not just channels transporting water, chemicals and sediments downstream but function as ecosystems with many complicated activities and interactions that occur among their abiotic and biotic components (Fisher & Likens, 1972).

A river ecosystem is comprised of the biotic component made of various biotic communities such as plankton, macrophytes, periphyton, macro-invertebrates and fish among others and the abiotic component which is the surrounding environment (Angelier, 2003; Orina, 2018). The two components form a self-sustaining system in which the non-living (abiotic) part provides favorable conditions for the existence and survival of the living part (biotic). Water for instance provides the medium in which the various forms of aquatic organisms live, thrive and survive. Substrates give organisms a surface and a home where they can attach, forage and complete most or all of their life cycles while also hiding from currents and predators (Allan & Castillo, 2007).

The biotic component of the ecosystem exists in trophic relationships where plants constitute the base of the trophic pyramid manufacturing organic matter through photosynthesis. Primary producers in rivers include algae, bryophytes (mosses and liverworts), vascular macrophytes and cyanobacteria (Lamberti et al., 2007). These plants are consumed by zooplankton, insects and fish which form higher trophic levels in the trophic pyramid. Birds and other animals that live close to such ecosystems eat fish. This encourages energy flow within the ecosystem and ensures sustainability.

When the ecosystem's structure, composition and function are unaltered, the integrity of the river ecosystem is achieved (Orina, 2018). The river can sustainably supply society with its goods and services if its ecosystem integrity is intact. Rivers that possess ecosystem integrity are of great benefit to society, supplying valuable goods and services. Such rivers are characterized by pristineness (natural undisturbed condition), nativeness (dominated by indigenous biota or species), diversity (have a variety of species that coexist) and resilience (ability to revive itself or bounce back after disturbance) (Rapport, 1998; Orina, 2018). A healthy ecosystem has "the capability of supporting and maintaining a balanced, integrated, adaptive, community of organisms having species composition, diversity, and functional organization comparable to that of natural habitats of the region" (Karr & Dudley, 1981).

On the other hand, unhealthy river ecosystems cannot sustainably supply vital goods and services to the society.

Both natural and man-made influences have an impact on the integrity of river ecosystems. Climate change influences ecosystem integrity of rivers through altered temperatures and precipitation levels, floods, droughts and outbreak of wildfires (Whitehead et al., 2009). In addition to altering temperatures, climate change also affects freshwater habitats by altering water flow patterns (Doll & Zhang, 2010). The composition, structure and function of biotic communities in rivers are greatly influenced by flow regimes (Poff & Zimmerman, 2010). Additionally, changes in river flow have an impact on other abiotic aspects of freshwater ecosystems that have an impact on the health of species, such as water quality, sediment transport and water temperature. Extreme natural pH can also be created locally by sulphur or soda spring seepage and volcanic gases (Allan, 1995). Freshwater ecosystems' water temperature, water quantity and quality are known to change in response to changes in precipitation and air temperature (Regier & Meisner, 1990). Although natural factors can adversely impact riverine ecosystems, their influence is not great because ecosystems have self-renewal capacity that ensures maintenance of biodiversity (Kleynhans & Louw, 2008).

The greatest threat to aquatic ecosystem integrity is posed by anthropogenic factors which are on the increase due to rapidly increasing human population (Allan & Castillo, 2007). Urbanization, industrialization and rapid human population increase pose serious threats to the health of freshwater ecosystems. Rivers, streams and wetlands are frequently used as trash disposal sites for solid garbage as well as receptacles for urban liquid effluents. Furthermore, water abstraction for domestic, industrial and agricultural purposes; damming for hydro-electric power generation; channelization and alteration of flow regimes compromise ecosystem integrity of rivers (Vörösmarty et al., 2010). Such human activities may negatively impact the composition, structure and functions of biotic communities.

Increased farming activities in the catchment areas, water abstraction for domestic and industrial use and increased human settlements can have adverse effects on riverine ecosystems (Blann et al., 2009). Farming entails clearance of trees and general change of natural vegetation cover. This leads to soil erosion and increased siltation and sedimentation of riverine systems. Modern agriculture is characterized by increased use of fertilizers and pesticides which ultimately end up in aquatic ecosystems through soil erosion (Yadav et al., 1997). This causes eutrophication in these systems leading to proliferation of aquatic weeds, hypoxia and general ecosystem degradation. River channelization and general alteration of natural river courses is also harmful to these ecosystems. Anthropogenic activities can therefore have great impacts on rivers impairing their integrity and greatly interfering with their biodiversity.

The medium-sized River Awach Kibuon located in the basin of Lake Victoria (Kenya), requires holistic investigation using chemical, physical and biological assessment methods since it is subjected to multiple degrading anthropogenic activities. The various sections of the river (upper, middle and lower) also differ with respect to flow rates, water volumes and anthropogenic pressures. There is clear knowledge gap on the ecological integrity of various sections of River Awach Kibuon which this study attempted to address through a purposive sampling research design.

### 2.3 Physico-chemical parameters

Water is a key component of the river ecosystem and its quality and quantity are essential for successful living of all biota in the ecosystem. Its quality is mainly assessed by measuring its physical and chemical attributes. Many water quality parameters can be measured or monitored as indicators of ecosystem health. However, the main parameters frequently monitored in aquatic ecosystems include velocity, temperature, turbidity, dissolved oxygen, pH, total dissolved solids, total nitrogen, total phosphorus and electrical conductivity (Karr & Dudley, 1981). These parameters have great influence on the presence, absence and distribution of aquatic biota.

The speed of water in any small area of the channel per unit time is referred to as river water velocity (Dodds, 2002). Water velocity presents both benefits and risks to aquatic dwellers. In one hand, it makes it easier to get resources to organisms and get waste out of them. On the other hand, it presents the risk of being swept away. If water velocity is very high, unattached and weakly attached organisms can easily be dislodged and swept downstream. River velocity is not uniformly distributed across the channel. Measurements of river velocity across the width of the river reveal that it is frequently higher in the middle and lowest near the sides and the river bed (Dodds, 2002).

Temperature is a key indicator of ecosystem health because temperature influences chemical, physical and biological processes within freshwater systems (Caissie, 2006). Temperature is one of the key determinants of the occurrence and distribution of aquatic biota. River water temperature is influenced by sunlight intensity and discharge of thermal effluents from industries (Ouma et al., 2016). The productivity of the whole river ecosystem as well as the growth rates, reproductive success and life cycles of ectothermic river residents are all impacted by temperature (Jones et al., 2017). Temperature determines the spatial distribution of living organisms since each organism has a defined temperature range within which it lives (Jones et al., 2017). The effects of temperature on aquatic creatures are widespread (Hutchison, 1975). Small fish experience significant physiological changes as a result of changes in the environment's temperature since their internal body temperatures are similar to those of the surrounding water (Crawshaw, 1979) and mortality is experienced rapidly exterior to the tolerance ranges. Thermal stress has been linked to the direct death of freshwater fish in their natural habitats (Tramer, 1978). All fishes can only survive in temperatures below 44 ºC because proteins are denatured at extremely high temperatures.

Turbidity is a measure of the relative clarity of a liquid**.** It is caused by the presence of suspended particles that scatter or absorb down-welling light (Grobbelaar, 2009)**.** When the presence of suspended particles becomes obvious in water, it is deemed turbid. Water turbidity may also be measured as the quantity of light scattered by the water's constituents when light is shone through it. Higher turbidity increases the intensity of scattered light (Allan & Castillo, 2007). Clay, silt, minute inorganic and organic materials, algae, dissolved colored organic compounds, plankton and other microscopic organisms are among the substances that commonly cause water turbidity (Davies-Colley & Smith, 2001). The measurement of turbidity is in nephelometric turbidity units (NTU) (USEPA, 1993; Allan & Castillo, 2007).

Many rivers exhibit a clear green colour and low turbidity levels of typically less than 10 NTU during base flow periods. When it rains, dirt and other debris from the land are washed into the river, giving it a murky brown hue that indicates greater turbidity values (Lin et al., 2011). Additionally, during high flows, water volumes and velocities are higher, which makes it easier to stir up and suspend debris from the stream bed resulting in increased turbidities (Dodds, 2002). High levels of particulate matter have an impact on river habitat quality, ecological productivity and light penetration. Contaminants, including metals and microorganisms can cling to particles thus enhancing the turbidity. Because of this, turbidity readings can be used as a sign of possible pollution in a body of water (Ongley, 1996).

Streams typically turn murky after rain. The increased sediment input from the land contributes to some of this turbidity, but it is also related to the higher water velocity, which can transport more materials from the channel (Garrad & Hey, 1995). In rivers, turbidity is not distributed uniformly. Near the bottom, the total concentration of suspended materials is higher (Irvine et al., 2011). The smallest particles, like clay, are suspended throughout the water column. When there is too much silt, delicate fish and invertebrate species cannot live. Silt turbidity can disrupt gaseous exchange and harm fish gills (Waters, 1995). High water turbidity can also impede light penetration and limit photosynthesis. High turbidity levels in water bodies like lakes, rivers and reservoirs can restrict the quantity of light reaching deeper depths, which can impede the growth of submerged aquatic plants and subsequently have an impact on animals that depend on them, such as fish. Additionally, the capacity of fish gills to take in dissolved oxygen might be impacted by high turbidity levels. Turbidity exceeding 100 NTU may lead to the loss of sensitive fish species (Schueler, 1997).

Dissolved oxygen is crucial for aquatic organisms' survival (Franklin, 2014). The concentration of DO in aquatic environments varies spatially and diurnally. Oxygen is mainly added into water through photosynthetic production and diffusion from the atmosphere (Gordon et al., 2004). In contrast, it is mainly consumed by aquatic organisms through respiration. The actual DO concentration in water is determined by the balance of photosynthesis and respiration, the amount of contact with the environment and transport processes (Dodds, 2002). Gaseous exchange between water bodies and the atmosphere keeps the concentration of dissolved oxygen at or near equilibrium which is governed by atmospheric partial pressure and temperature particularly in small and turbulent water bodies. High photosynthetic rates in highly productive waters can lead to oversaturated oxygen levels and large variations between day and night (Annisa et al., 2019). High organic matter content can easily deplete dissolved oxygen through the respiration of bacteria that decompose it.

DO levels can easily go below life sustaining levels and in such cases leading to death of organisms that cannot withstand low oxygen concentrations. Aquatic organisms have varying requirements for dissolved oxygen concentrations; hence it determines the distribution and abundance of aquatic organisms (Langseth et al., 2014). Even though many species of fish may survive short durations of anoxia, dissolved oxygen is essential for fish existence. While most fish stay away from hypoxic environments, some species have been shown to forage in potentially fatal low-oxygen situations when oxygen-rich waters are deficient in their prey (Rahel & Nutzman, 1994). In Missouri upland border streams, Smale and Rabeni (1995a, 1995b) demonstrated that fish distribution was significantly more impacted by oxygen tolerance than by temperature tolerance. Coble (1982) discovered that at locations along the Wisconsin River where the average summer dissolved oxygen level surpassed 5 parts per million, the diversity of fish species and various indicators of sport fish abundance were higher.

pH is a measure of the concentration of hydrogen ions in solution which is determined by the amount and strength of acid present. Acid rains, runoff from farms, industrial effluents, and emissions from fossil fuel all impact the pH of rivers (Dodds, 2002). Carbonic acid is the primary generator of hydrogen ions in natural waters (pH). In environments with high concentrations of decomposing plant matter, such as swamps, bogs and peat lands, organic acids also contribute to low pH levels. Due to both natural and man-made factors, the pH (acidity) of freshwaters can vary greatly (Khatri & Tyagi, 2015). Most species, including fish are affected by extreme pH values (< 5 and > 9). The effects of extreme pH values on biota range from reduced growth rates, failed reproduction in some species and death in some cases. In addition to out rightly harming fish, low pH can have a number of subtle impacts. Some fishes may experience a significant reduction in oogenesis (Ruby et al., 1977), reduced egg fertility or fry growth (Craig & Baksi, 1977), or low egg hatchability and growth (Ruby et al., 1977) at pH levels below about 6 (Menendez, 1976). Fromm (1980) reviewed a wide range of acid stress effects on freshwater fishes, highlighting the following as factors that cause fish to become extinct in acidic waters: reproductive failure due to failed calcium metabolism and lack of protein deposition in ova, damage to gill mucus and gill membranes, loss of salts and decreased hemoglobin's ability to carry oxygen.

Total dissolved solids are made up of a combination of small amounts of organic matter and inorganic salts in solution in water. The primary components include anions such carbonate ($CO_3^{-2}$), hydrogen carbonate ($HCO_3^-$), chloride ($Cl^-$), sulfate ($SO_4^{2-}$), and nitrate ($NO_3^-$) and cations such as magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$), sodium ($Na^+$) and potassium ($K^+$) (WHO, 2003). The average global concentration of TDS in freshwater bodies is roughly100 $mgL^{-1}$ (Allan, 1995). Because anthropogenic and natural sources vary greatly, so do the concentrations of TDS and specific constituent ions in the river.

TDS in rivers is mostly produced by sewage, urban and agricultural runoff and industrial wastewater (WHO, 2003). Depending on the solubilities of minerals in various geological locations, the TDS levels from natural sources can range from less than 30 mg $L^{-1}$ to as much as 6000 mg $L^{-1}$ (WHO/UNEP, 1989). Forty six (46) Canadian rivers that were monitored for water quality had average TDS levels of less than 500 mg $L^{-1}$ in 31 of the 46 rivers (Department of Fisheries and Environment Canada Report, 1977). High TDS concentrations exceeding 750 mg $L^{-1}$ negatively impact fertilization and hatching rates in coho and chum salmon. The embryo developmental time is also extended to epiboly and the eyed-egg stage. It has also been reported that growth and survival of aquatic invertebrates are negatively impacted by TDS concentrations exceeding 1500 mg $L^{-1}$ (Scannell & Jacobs, 2001).

Electrical conductivity is the capacity of water to transmit electric current or a measure of electrical conductance of water. Inorganic dissolved particles like sodium, magnesium, calcium, iron and aluminum cations or chloride, nitrate, sulfate and phosphate anions have a major impact on electrical conductivity in water (USEPA, 2012). The concentration of charged ions in solution and, to a lesser extent, ionic composition and temperature, determine differences in electrical conductivity (Allan, 1995). Due to the fact that high nutrient fluids have high electrical conductivity, it is possible to roughly connect system productivity with electrical conductivity as a predictor of total dissolved ions in water (Rusydi, 2018).

The geology of the region through which the water travels has a major impact on electrical conductivity in streams and rivers. Because granite is made up of more inert materials that do not ionize, streams and rivers that flow through granite bedrock tend to have lower conductivities than streams and rivers that flow through clay soils, which tend to have higher conductivities due to the presence of materials that ionize when washed into the water (Fondriest Environmental, 2014). A range of electrical conductivity between 150 and 500 µS $cm^{-1}$ has been found in inland freshwater streams sustaining healthy mixed fisheries in the United States, while values outside of this range may be hazardous to several fish and macro invertebrate species (USEPA, 2012).

Nutrients are important for the growth of plants in aquatic ecosystems. Plants form the base of the trophic pyramid and through photosynthesis manufacture organic matter which supports all secondary producers. In rivers, nutrient levels are mainly altered through anthropogenic activities such wastewater disposal, careless farming practices leading to erosion of soil and eutrophication (Okungu et al., 2005; Raburu et al., 2009). The productivity of riverine ecosystems can be described by the concentration of nutrients which can also accurately predict phytoplankton abundance and trophic status of lakes (Wetzel, 1983). The key nutrients in aquatic systems are nitrogen and phosphorus. Many experiments in aquatic systems have shown that phosphorus supply limits growth in freshwaters (Mesner & Geiger, 2005). However, some studies indicate that nitrogen has the effect and others indicate that both phosphorus and nitrogen are limiting factors. In fact, where nitrogen resources are artificially increased, phosphorus becomes limited and vice versa. Both do contribute to the significant issue of nutrient contamination or eutrophication.

Supplies of phosphorus in pristine freshwaters are relatively low because the element is very uncommon and is obtained primarily from slow rock weathering (Allan, 1995). Since it is difficult to separate all phosphorus compounds when analyzing water, they are typically categorized into operational groups such as soluble inorganic phosphorus, also known as soluble reactive phosphorus, soluble organic phosphorus, particulate phosphorus (PP), and total phosphorus (TP), which is the sum of all of these (Mesner & Geiger, 2005). TP is typically used as a measure of the total amount theoretically available in the water, whereas soluble inorganic phosphorus is a rough indicator of availability to living things. In pristine freshwater systems, nitrogen and phosphorus concentrations are quite low. They typically have 150 µg $L^{-1}$ of TN and 15 µg $L^{-1}$ of TP (Mueller & Helsel, 1996).

Anthropogenic actions invariably lead to increases in the levels of N and P reaching freshwaters, except in cases where they are devoted to minimizing problems caused by farming and waste disposal.

Knowledge gaps exist with respect to the current water quality condition of most rivers in the basin of Lake Victoria, including River Awach Kibuon. The few water quality investigations were carried out more than 15 years ago (Okungu & Opango, 1995; Okungu et al., 2005; Sangale et al., 2005). Damaging human activities in the catchment area have since increased due to quick increase in human population and urbanization thereby escalating stress upon the river. This study focused on selected water quality parameters of the river to help determine its present water quality status.

## 2.4 Habitat characterization

A habitat refers to any characteristic or combination of characteristics within or connected to an ecosystem which offers appropriate conditions for keeping and maintaining biota (Jowett, 1997). Good habitats support many species and are in most cases found in areas which are least modified physically and are close to their natural state. According to Maddock (1999), the quality of a habitat is determined by the occurrence of a variety of habitat features valuable to biota. The variety of the physical structures and their unaltered natural state may be the two main elements that affect habitat quality.

One of the five main causes of the degradation of aquatic resources is the modification or destruction of physical habitat structures by human actions (Karr et al., 1986; Karr, 1991). The habitat's ability to support aquatic communities is significantly influenced by in-stream and contiguous topographical features (Southwood, 1977; Plafkin et al., 1989; Barbour & Stribling, 1991). The condition and size of habitat that is available determine the make-up and composition of local biological assemblages. The most significant risks to biological diversity and the primary cause of recent species extinctions are generally acknowledged to be the destruction, modification and fragmentation of habitats (Helfman, 2007). Fish habitat is lost when water bodies get clogged with sediment, plants, or debris, or when they flood or dry out at the wrong time. In aquatic ecosystems, bottom trawling, channelization and dredging are other well-known habitat degraders (Helfman, 2007).

In a river, the key habitats are riffles, pools and runs which determine the composition, distribution and abundance of riverine aquatic biota. Additional features such as in-stream and bank-side vegetation also form part of the river habitat (Maddock, 1999). The riparian wetlands, which are linked to the rivers in cases where there are floodplains, add complexity and further value to the habitat structures in a river ecosystem. When a sampling site's physical habitat quality is comparable to that of a reference site, observable impacts can be attributed to either water quality variables (chemical contamination) or other stressors like pathogens (Barbour et al., 1999).

An assessment of habitat quality should be included in any final conclusions on the prevalence and severity of biological impairment to evaluate the extent to which habitat might be a limiting factor. As the surface on which many insects live and the structure near which many fishes find cover from currents or predators, the substrate of moving rivers exhibits significant spatial diversity (Pugsley & Hynes, 1986). The substrate type is also very important in fish reproduction where they provide surface for egg attachment and incubation. Habitat quality is critical to river ecosystem integrity and therefore need to be given adequate attention in river management and conservation plans.

### 2.5 Biological assessment

The biological status of a body of water is evaluated using biological surveys and other methods that directly quantify the local living organisms (USEPA, 2002). Finding out how effectively a body of water sustains aquatic life is the primary goal of biological assessments of aquatic communities. Biological assessment is preferred over physical and chemical assessments because it reflects the condition of overall ecological integrity of an ecosystem. Healthy biological communities in a water body imply healthy chemical and physical components of the same water body. Biological assessment has several advantages over physical and chemical analyses. It measures directly the impacts of all stressors (chemical, physical and biological) on the resident aquatic biota. Monitoring highly variable or diffuse sources of pollution, such as wet-weather discharges and storm-water runoff, can also be achieved by biological evaluation (USEPA, 1994). It is equally important in evaluating degradation attributed to non-point pollution sources and non-chemical stressors i.e., physical and biological stressors.

The interconnections between stressors that are biological, physical and chemical and their cumulative effects highlight the necessity to explicitly identify and evaluate the biota as indicators of actual water resource deficiencies (Fanelli et al., 2022). The effects of many stressors are integrated by biological assemblages. The structure and composition of biological assemblages therefore reflect the cumulative influence of all stressors over time. The native aquatic organisms react to the condition of the whole watershed comprised of tributaries and the main river (de Vries et al., 2019). Biological evaluation can also be used to determine the effectiveness of preventive and mitigative measures employed at specific degraded points in the ecosystem aimed at diminishing degradation attributed to diffuse pollution sources (Barbour et al., 1999).

A number of biological assemblages including plankton, periphyton, macro-invertebrates and fish may be used to evaluate ecosystem integrity of streams, rivers, lakes and reservoirs. The appropriate community is chosen based on the bio-monitoring situation at hand (Holt & Miller, 2010). Biological characteristics of living assemblages in water bodies are normally summarized into composite index values that depict their integrity status. A wide range of biotic indices exist which are utilized in evaluation of ecological integrity of water ecosystems. These incude diversity indices such as species richness, Shannon-Weiner Index (H′), Pielou’s Evenness Index (J), Simpson’s Index (D), Fish Index of Biotic Integrity (FIBI) and other biological indices including GSI, EGI and HSI.

### 2.5.1 Diversity indices

Diversity measures include species richness, H′, D and J. Diversity indices usually highlight the number of species present in an ecological community and their relative abundance. Species richness is a simple measure of diversity while D, H' and J are composite measures of diversity which integrate the number of species available in a community and their relative abundance (Li et al., 2010). Fish community diversity in a river is taken to be a true reflection of the ecological health of that aquatic environment. Consequently, the health of aquatic ecosystems can be measured and monitored overtime using diversity indices. Ecologically healthy aquatic ecosystems provide invaluable ecosystem services to society thus promote the welfare human populations (Baron et al., 2003).

#### 2.5.1.1 Species richness

Species richness is the total count of all species represented in an ecological community or ecosystem (Colwell, 2009). Species richness is simply the number of species in an ecological community and does not take into account their relative abundances. A biological community is deemed rich if species number is high (Li et al., 2010). Although species richness is a straightforward measure, it conveys little information of ecological importance since it does not reflect the abundance of the species counted. There may be high species richness and low diversity especially in cases where most species have low abundances.

#### 2.5.1.2 Species evenness - Pielou's Evenness Index (J)

Species evenness refers to the closeness of abundances of different species in an ecological community or ecosystem. It is a measure of diversity which quantifies numerical equality of the community (Morris et al., 2014). It quantifies and expresses the equitability of organisms while taking into account the relative abundance of each species. This metric asserts that diversity is high when species are evenly distributed among communities. Species evenness requires ecologists to be conversant with the relative abundances of all species in a given ecological community. In general, the more equally abundant the species in the ecosystem under consideration, the more diverse it is considered to be (Li et al., 2010). J is computed by dividing H′ by $H_{max}$ as shown in the equation below:

$$J = \frac{H'}{H_{max}} \quad (1)$$

Where H′ is the Shannon-Wiener Index and $H_{max}$ is the maximum possible diversity value of H′ computed as $H_{max} = \ln S$ where S = the total number of species. Equitability (evenness) values range between 0 and 1 with 0 depicting total lack of evenness and 1 representing complete evenness.

#### 2.5.1.3 Simpson's Index (D)

Simpson's Index (D) measures the likelihood that two individuals drawn at random from a sample will be of the same species (McCune & Grace, 2002). It is a metric for diversity that accounts for both the total number of species and the relative abundance of each species. Diversity rises along with species richness and evenness. The value of D is between 0 and

1, with 0 denoting no diversity and 1 denoting unlimited diversity (Barcelona Field Studies Centre, 2022).

#### 2.5.1.4 The Shannon-Wiener Index (H′)

Shannon-Wiener Index (H′) is a measure of diversity that incorporates species richness and relative abundances. The H′ measures the degree of uncertainty in identifying the species of a randomly selected individual from the sample (Morris et al., 2014). The value of H' typically ranges from 1.5 to 3.5 and seldom rises above 4.5. H' increases as both the richness and the evenness of the community increase (Siddique et al., 2016).

### 2.5.2 Other biological indices (GSI, HSI, and EGI)

Availability of food is among the key factors that contribute to thriving fish populations. Indices depicting biological characteristics of fish populations like Hepato-Somatic Index (HSI), Gonado-Somatic Index (GSI) and Empty Gut Index (EGI) give insight on the general condition of the environment in which fish lives. They also reflect the energy and food conditions prevailing in the aquatic ecosystems. The amount of energy available to fish is reflected in how they prioritize energy allocation. The determination of these biological fishery indices helps to establish the energy conditions prevailing in the environment (Rizzoa & Bazzolib, 2019). These indices have not been determined for fish species in River Awach Kibuon hence creating knowledge gaps that need to be filled. This study therefore determined these indices in order to bridge the existing knowledge gaps.

#### 2.5.2.1 Hepato-Somatic Index (HSI)

Hepato-Somatic Index (HSI) is the liver weight of an organism proportional to its total weight stated in form of a percentage. It indicates energy storage and recent feeding activity by the fish (Tyler & Dunn, 1976). If the fish obtain more energy than is needed for maintenance and growth, the surplus energy is stored as glycogen in the liver.

Consequently, a big relative liver size to the body weight indicates a well fed fish and an energy-rich environment and vice versa (Plante et al., 2005). Hepato-Somatic Index is therefore a reflection of the energy condition of the environment. It is easy to calculate but the fish must be sacrificed in order to remove and weigh the liver.

#### 2.5.2.2 Gonado-Somatic Index (GSI)

Gonado-Somatic Index (GSI) is the weight of gonads comparative to total weight, stated in the form of a percentage (Dadzie & Wangila, 1980). It expresses how energy is allocated to different uses by fish populations. The index depicts the nutritional condition and the spawning status of the fish population (Amtyaz et al., 2013). A fish population that is nutritionally limited and is out of the breeding season has small GSI values. Conversely, a fish population which is not nutritionally limited and is in the breeding season directs large amounts of energy toward gonad development and has relatively large GSI values (Tagarao et al., 2020). High GSI values are indicative of a fish population in good condition because reproduction is only allocated energy after the basic metabolic and somatic growth requirements have been met. GSI is also recognized as a specific indicator of maturity and periodicity of fish spawning (Kaur et al., 2018). Year-round GSI data help identify breeding season(s) in a year.

In total spawners, GSI peaks immediately before spawning and then drops as an increasing proportion of the population is made up of spent females. During the breeding season, there may be many GSI peaks in batch spawners (Welcomme, 2001). Peak GSI values range between less than 5% and 30% of total body weight depending on the species. These variations are mostly controlled by the seasonal pattern of egg development and spawning. Since batch spawners produce multiple batches of eggs during a season, total spawners frequently have higher GSI than batch spawners. GSI may range from 4% to 30% for multiple (batch) spawners, but it may be as high as 30% for total spawners (Wootton, 1990). Because it is affordable and simple to compute, GSI has been routinely utilized to assess reproduction timing (Lowerre-Barbieri et al., 2011). It gives information regarding maturation and seasonal patterns in gonad development since differences in yolk concentration at different oocyte stages primarily determine changes in GSI (Wallace & Selman, 1981; West, 1990).

#### 2.5.2.3 Empty Gut Index (EGI)

Empty Gut Index (EGI) is a representation of the proportion of fish in a population with empty guts relative to total population expressed as a percentage. EGI is used in fisheries to evaluate the availability of food to fish in their environment (Vinson & Angradi, 2011) and for comprehending daily feeding activity patterns (Cortes, 1997). If the proportion of fish with empty guts is big, then it is taken to mean a nutritionally poor or deficient environment (Arrington et al., 2002). However, it should be noted that EGI values may be influenced by the time of sampling and feeding habits of the fish being studied. For instance, a fish species that eats one big meal once a day may have different empty gut indices on the same day depending on the time of sampling.

### 2.5.3 Fish Index of Biotic Integrity (FIBI)

The ecological integrity of water bodies can also be evaluated by looking at the extent to which their chemical, physical and biological attributes conform to pristine natural conditions or the extent to which their waters can be used beneficially (Karr, 1981). According to Karr (1981), the possible benefits that can be realized from an ecosystem depends on its capacity to maintain a balanced biological community. Biological assessment of aquatic ecosystems using the IBI entails the characterization of biological communities at sampling sites and comparing with communities found in unmodified natural reference sites (Barbour et al., 1999). The selected appropriate community attributes (metrics) are scored with reference to conditions in unmodified pristine sites. The total metric scores of a particular site are summarized into a composite index value which reflects its integrity status.

Several biological communities including plankton, periphyton, macro-invertebrates and fish may be utilized in evaluation of ecosystem integrity of streams, rivers, lakes and reservoirs by means of the Index of Biotic Integrity (Li et al., 2010). The use of each biotic aquatic assemblage is accompanied by specific advantages. For instance, use of periphyton communities is advantageous in measuring short-term impacts owing to their short life spans and quick breeding rates (Barbour et al., 1999). They also exhibit vulnerability to some pollutants such as herbicides that might have no impact on other aquatic communities, or only impact them adversely at higher concentrations. Macro-invertebrate communities can provide insight into local conditions. They are especially suitable for determining site-specific effects since many benthic macro-invertebrates have restricted movements or are permanently attached. Many first and second order streams are rich in macro-invertebrates but poor in fish species.

The use of fish assemblages is accompanied by many advantages. Fish exhibit sensitivity to changes in a wide spectrum of environmental parameters. Fish communities are normally comprised of a collection of species belonging to different functional groups (piscivores, herbivores, insectivores, omnivores, carnivores and planktivores) with a tendency of incorporating impacts of lower levels in the trophic pyramid (Barbour et al., 1999). The identification of fish to species level is also comparatively easier (Karr, 1981). Because they have a relatively long lifespan and easily move about, fish are excellent indicators of long-term effects and general habitat conditions (Karr et al., 1986). With the exception of very contaminated environments, fish are common and can be found in most bodies of water (Oberdorff & Hughes, 1992). Fish is considered important in evaluating contamination since it is consumed by man and is at the apex of the aquatic food web (Barbour et al., 1999). Fish are also fairly simple to collect and identify down to the species level. Skilled fisheries specialists can sort and recognize majority of specimens in the field then release them back into the river uninjured. Environmental requirements of most fish species are reasonably well established. There also exists detailed information on the life histories of many fish species and their geographical distributions (Barbour et al., 1999).

IBI is highly preferred over other indices because it gives an all-round outlook of the biological, physical and chemical conditions of specific river locations (Acuna et al., 2004). The IBI has gained popularity because it provides the most integrative view of stream or river condition (Karr, 1999). Its popularity and acceptability may be attributed to its simplicity, relevance, quantitativeness, scientific justifiability, cost-friendliness and ease of use by natural resource managers (Aura et al., 2010). An effective multi-metric index such as IBI depends upon a suitable classification scheme, selection of appropriate characteristics (metrics), systematic sampling protocols and methodical procedures that extract pertinent biological patterns (Karr, 1999).

The selection of metrics that respond to varying levels of degrading actions in the watershed is important to the development of an IBI. Within the infinite range of measurable biological characteristics, only a small proportion varies systematically and reliably across a gradient of human influence. Measures in that small subset are potential metrics for an IBI. The common fish community attributes used as metrics include; species richness, abundance (total count of individuals), presence of intolerant species, percentage of tolerant species, presence of hybrids (Hubbs, 1961), proportion of individuals as omnivores, proportion of the community that is insectivorous cyprinids, presence of top carnivores and frequency of fish with tumors, deformities, parasites and other indicators of disease.

Choice of appropriate reference site(s) is vital to successful IBI development. The reference condition provides the framework for comparing results and identifying use impairment. Reference sites or conditions can be applied to an individual water body or others like it in the same region (Gibson et al., 1996). The two types of references used include those that are applicable to specific sites and those that are applicable to several water bodies in the same region. The former characteristically comprise measurements of conditions of natural unmodified sites on the river. In contrast, regional reference conditions are not site-specific and comprise measurements from a group of comparatively undegraded sites in a fairly homogeneous region with similar habitats (Barbour et al., 1999). Today, widespread adverse anthropogenic activities in rivers and their basins, makes it hard to locate natural undegraded sites usable as reference sites in the majority regions. As a result, least-disturbed areas of those available are increasingly being used to settle on the best reference conditions possible (Abbasi & Abbasi, 2011). In considerably changed water bodies through dredging and channelization, appropriate reference sites are generally unavailable (Gibson et al., 1996). Under these circumstances, simple ecological models and historical records are used to determine reference conditions.

The determination of integrity status of a river segment entails comparison of its environmental conditions with the characteristics of a chosen natural unmodified reference site in the same river or in unperturbed rivers of comparable size and habitat type located in a similar geographic area (Karr, 1981). A score of 1, 3 or 5 is given to each attribute or metric, depending on its level of deviation from the reference value. Those that strongly deviate are scored (1), moderate deviation (3), while values that approximate the reference condition are scored (5). According to Aura et al. (2010), a continuous scoring system is normally used for IBI. In this system, an attribute that declines with increasing degradation is scored as 1 for values below the $25^{th}$ percentile because they correspond to the utmost deviation from the reference condition. Values between the $25^{th}$ and $75^{th}$ percentiles that are below the reference site's value are given a rating of 3. Values that are above the $75^{th}$ percentile and roughly match those of reference sites are given a score of 5. On the other hand, attributes that increase with rising degradation, the rating is done the other way round (Karr & Chu, 1997a).

An alternative discrete rating system (trisection method) can be used and results compared with the continuous scoring system. In this scoring system (Barbour et al., 1999), all values of a metric from all sites are divided into three (trisected) for positive attributes that increase with improving conditions. Values that fall in the upper one-third are rated as 5, the ones in the middle-third are rated as 3 and those that fall within the lower one-third are rated as 1. According to Barbour et al. (1999), these three divisions should correspond to unimpaired, intermediate and impaired river conditions, respectively. On the other hand, for negative attributes that reduce with improving conditions, the values are again divided into three (trisected), but the scoring is reversed. The values within the upper one-third are rated as 1, while the ones in the middle-third are rated as 3 and the ones in the lower one-third are rated as 5.

The final IBI score of a sampling location is attained by adding up the ratings for all the metrics. The highest value of an IBI depends on the number of metrics used. If a total of nine metrics are used then the highest IBI value expected is 45. For qualitative evaluations of the final IBI scores, the highest value serves as a reference point for the inter-quartile ranges (Griffith et al., 2005). Metrics that pass the significant difference test are included in the final list used in developing an IBI (Aura et al., 2010; Raburu & Masese, 2012). This study developed a Fish Index of Biotic Integrity (FIBI) which is important in prioritizing areas for intervention along the stretch of the river. No such index exists for River Awach Kibuon and needed to be developed urgently to inform management and conservation planning especially in the face of increasing pressures in its catchment area (Mwangi et al., 2015). This study bridges this knowledge gap by developing a FIBI which will be used as a reference for management interventions in the whole basin.

## 2.6 Fish population dynamics

A fish population may be defined as a group of individuals of the same species that are separated from other groups in terms of space, genetics and demographic factors (Wells & Richmond, 1995). Natural fish populations are constantly changing in the face of varying environmental conditions and fishing pressures (McRae & Diana, 2005). Recruitment patterns, growth and mortality rates are the key factors behind fish population dynamics (Gulland, 1982; Sissenwine, 1984). Fish populations are expected to increase in size if recruitment and growth rates exceed mortality losses incurred within a specified time period. Recruits refer to the juvenile fish that survive the spawning and nursery grounds to enter the fishing grounds or adult feeding grounds in a year (Gebremedhin et al., 2021). Recruitment results from multiple connected events beginning with release of mature gametes, fertilization, incubation, hatching, fry growth and survival, metamorphosis, growth and migration to the fishing grounds or adult feeding areas (Welcomme, 2001). Recruitment in natural fish populations is characterized by high annual variability (Quist, 2007).

The stock-recruitment relationship, known as S-R relationship, associates the size of the fish stock, for one year, with the recruitment which results from the stock spawning normally during that year (Cadima, 2003). Recruitment generally increases with increasing stock size, but may start decreasing above a certain stock size (Welcomme, 2001). The causes of high variability are unclear but climatic conditions or biotic factors like the spawning stock size are thought to be the key determinants of recruitment patterns in fish populations (Sparre & Venema, 1998). The main difficulty in recruitment is to accurately predict the quantity of fish fry that will survive and develop to become juveniles in the following season (or become recruited into the fishery). An evaluation of time series data of recruitment for fourteen stocks of northwest Atlantic fish (Koslow & Diego, 1984) concluded that major physical factors such as El Nino, rather than local biological interactions such as competition and predation, determines to a large extent the recruitment to northwest Atlantic fisheries. Csirke (1980) showed a strong effect of sea conditions on the recruitment of Peruvian Anchovy.

Due to the high level of dispersion in graphs of recruitment plotted against stock size, it was formerly believed that the number of fish recruiting to a fishery each year was essentially independent of the size of the adult stock (Sparre & Venema, 1998). A variety of density-dependent functions have been developed in a bid to describe the relationship between stock and recruitment. Beverton-Holt and Ricker models are the most popularly used. According to the Beverton-Holt model, recruits grow in number as the size of the reproductively mature population grows up to a certain point. Beyond this point, the habitat simply cannot support any more recruits, hence their number remains constant even as the reproductively mature population grows (Sparre & Venema, 1998). Perfect compensation is the name given to this pattern. The Ricker model is different in that it predicts that when the population of reproductively mature individuals is big, instead of remaining constant, the number of recruits actually begins to decline. This condition is referred to as overcompensation (Cooper, 2006). A process known as depensation may begin when there is a small number of reproductively mature individuals. Depensation happens when net fecundity declines as the population that is reproductively mature declines. In other words, fewer recruits per adult enter the stock as the reproductively mature population shrinks. Fewer fish that are reproductively mature result in lower rates of fertilization since it is harder for fish to find mates, which ultimately results in fewer recruits (Cooper, 2006). Since the relationship between stock and recruitment is complex and involves many other factors, it remains the classic problem of fishery science. However, recognizing or comprehending the connection between stocks and recruitment is essential to preventing recruitment overfishing and stock collapse (Sparre & Venema, 1998).

The main objective of the study of growth is to determine how body size changes with age. Growth is measured in terms of increase in body size within a specified time period. Growth of individual fish in fish populations is described by the aid of the von Bertanlanffy growth model:

$$L_t = L_\infty \left\{ 1 - e^{\left(-K\,(t - t_0)\right)} \right\} \quad \textbf{(2)}$$

Where $L_t$ = predicted length at age $t$; $L_\infty$ = asymptotic length; $K$ = growth curvature and $t_0$ = the hypothetical age of fish at zero length. In higher latitudes (temperate climates), it is relatively easier to determine fish growth because individual fish are easily aged from annual rings on hard structures such as otoliths and scales. However, in the tropics, annual rings are not clear on scales and otoliths. The lack of strong distinct seasons in the tropics makes it hard to distinguish seasonal rings and annual rings on hard parts of tropical fish species (Sparre & Venema, 1998). Consequently, length-frequency analysis is used to estimate the age of tropical fish species. In length-frequency analysis, a large number of individual fish lengths taken from the fish population under study and deemed to be representative of it are separated into length groups and ultimately converted to age-groups. This conversion is possible because there is a known relationship between length and age (Sparre & Venema, 1998; Kilduff, 2009). The age-groups are assumed to represent cohorts. Several computerized techniques have been developed for accomplishing this task including the Battacharya method.

Growth parameters considered important in the study of fish populations include; $L_\infty$, $K$ and $t_0$ which are components of the von Bertanlanffy growth model. $L_\infty$ is the mean length of very old fish in a population; $K$, also known as the "curvature parameter," determines the rate at which a fish approaches its $L_\infty$; and $t_0$, also known as the "initial condition parameter," determines the moment at which the fish has zero length (Sparre & Venema, 1998). The $t_0$ has no biological meaning. Short-lived fish species have bigger $K$ values and can reach $L_\infty$ within a year while long-lived species have small $K$ values and reach $L_\infty$ after many years. Growth parameters are different for each species and might as well vary for various stocks of one species. Successive age-classes may also have different growth parameters in the same water body due to changing environmental conditions. Growth parameters may also differ for males and females of dimorphic species (Sparre & Venema, 1998).

The fish's metabolic rate and the growth parameter $K$ are connected. Compared to demersal species, pelagic fish are frequently more active and have a higher $K$ values. The metabolic rate depends on temperature as well; tropical fish have greater $K$ values than fish from colder waters. However, a link between *K* and $L_\infty$ obscures these relationships, causing small species to exhibit greater *K* values than large species at the same level of activity (Sparre & Venema, 1998). Through the use of graphical plots like the Gulland and Holt plot, Ford-Walford plot and von Bertalanffy plot, growth parameters can be estimated from length-at-age data (Sparre & Venema, 1998). There are a number of length-based techniques that can be used when fish cannot be aged, but lesser precision should be expected. The FAO-ICLARM FiSAT II program offers a number of length-based techniques (Gayanilo et al., 2005). These include the Battacharya and NORMSEP methods of separating modes believed to represent age classes. The *K* of the majority of fish species ranges from 0.1 to 1.0 per year.

Mortality in fish populations is partitioned into *F* and *M*. Natural mortality is caused by diseases, spawning exhaustion, predation, and old age while fishing mortality is attributed to deaths caused by fishing (Outa et al., 2020). The *M* is the instantaneous exponential rate at which fish in the population die from natural causes. Where there is fishing, the number of fish remaining in a population at time *t* can be estimated as:

$$\mathbf{N}_{\boldsymbol{t}} = \mathbf{N}_{\mathbf{0}} \boldsymbol{e}^{-\boldsymbol{Mt}} \qquad \textbf{(3)}$$

Where $N_0$ is the size of the population at the beginning, $N_t$ is the size of the population at time t and *M* is the instantaneous rate of natural mortality. If *M* is 1 per year, 63% of the population is expected to die every year from natural causes. *M* of 2 and 3 per year translates into death rates of 86% and 95%, respectively. Depending on the species' life history strategy, *M* might vary widely, although it is typically connected with the value of *K*. Based on data from Pauly (1980) and Beverton and Holt (1959), Kirkwood et al. (1994) found that *M*/*K* ratio is most frequently in the range of 1.5 to 2.5. When using the "per recruit" and yield/biomass models to establish reference points, *M* is crucial. In general, high *M* species should be fished harder than low *M* species because the maximum cohort biomass takes longer to build in high *M* species.

According to Sparre and Venema (1998), the easiest way to estimate mortality in a fish stock is to track the outcome of a cohort or age-class i.e., fish spawned around the same period. In nature the mortality rates differ according to the age of the cohort. Young fish which are smaller in size experience higher natural mortality rates than big old fish. This is because they are prone to predation by various organisms and have lower fishing mortality rates because they escape through the meshes of most fishing nets and may not have migrated to the fishing grounds (Sparre & Venema, 1998). Conversely, old fish experience higher *F* than *M*.

The best way to determine *M* is to use data on catch composition obtained from unexploited or lightly exploited fisheries. However, this opportunity is frequently lost since fishermen usually arrive before the scientists (Cadima, 2003). Consequently, Pauly's 1980 regression approach based on growth parameters *K* and $L_\infty$ as well as the ambient water temperature, is routinely used to predict *M*. Due to methodological limitations, *M* is frequently the most uncertain parameter in a stock assessment. Additionally, it is typically believed to be constant across all ages and years. This is very unlikely to be true given the varying abundances of predators, competitors and other cohorts of the same species, as well as the shifting conditions of the natural environment (Cadima, 2003).

*F* is the instantaneous exponential rate at which fish are removed from the population by fishing. The number fish remaining in a population at time *t* when both fishing and natural mortality are present, is estimated by the following equation:

$$\mathbf{N}_{t} = \mathbf{N}_{0} e^{-(\mathbf{F}+\mathbf{M})t} \quad \mathbf{(4)}$$

*Z* is comprised of both *F* and *M* (Kilduff, 2009). *F* is typically estimated by subtracting *M* from *Z*. There are many methods of estimating *F*. The first set of methods calculates an average *F* equilibrium or $F_{eq}$ for the year classes represented in the data set under the presumption that the stock is in an equilibrium state. The second major group makes several estimates of *F* for every year, as well as for every age group or size category. The methods that provide independent *F* estimates for each year are undoubtedly the most valuable for monitoring fishing mortality as a gauge of the current state of the fishery (Sparre & Venema, 1998). The simpler equilibrium methods are more likely to be used for data-limited fisheries that are perhaps only assessed every 2-3 years.

Where fish cannot be aged and only length frequency data are available as is the situation in the tropics, *Z* may be approximated using length converted catch curves and other comparable techniques. These techniques transform the length data into age-based forms from which annual mortality rates can be calculated using the von Bertalanffy growth parameters *K* and $L_\infty$. The length converted catch curve and the Beverton-Holt mean length methods are two of the six length-based methods available in FiSAT for estimating *Z* (Gayanilo et al., 2005). In order to apply these methods, the user must either estimate a minimum size above which fish are thought to be adequately represented in the sample or choose which points to include in the study.

Mortality rates can also be estimated from input data from random samples that effectively represent the exploited segment of the population. *Z* can be calculated by use of approximations of the count of fish in an age-class from two time periods, t1 and t2, at some stage in its exploited phase. Different researchers have developed various methods of estimating mortality rates. *Z*-equation which is based on length data (Beverton & Holt, 1966) serves as an illustration:

$$Z = K(L_\infty - L)/(L - L') \quad (5)$$

Where $L$ is the average length of fish of length $L'$ and longer, while $L'$ is "some length for which all fish of that length and longer are under full exploitation". It should be noted that $L'$ is the lower limit of the corresponding length interval (Sparre & Venema, 1998). $Z$ can also be estimated by a linearized catch curve which is a graphical representation of the logarithms of numbers caught plotted against age. The linearized catch curve is drawn from length composition data which makes use of the von Bertalanffy growth model to convert length into age. It is often called the "linearized length-converted catch curve" (Pauly, 1983a; Pauly, 1984a ; Pauly, 1984b).

Exploitation rate $E$ may be defined as the proportion of $Z$ that is attributed to fishing. It is computed by the following formula according to Gulland, 1971:

$$E = \frac{F}{Z} = \frac{F}{M+F} \quad (6)$$

This ratio aids in determining whether or not the stock has been overfished. The optimal value of $E$ ($E_{opt}$), according to Pauly (1983b), is thought to be close to 0.5. Gulland argues in favor of using $E$ = 0.5 as the ideal value for the exploitation rate, based on the idea that the sustainable yield is maximized when $F$ is equal to $M$. The growth performance index ($\theta'$) is computed by the following formula according to Pauly and Munro (1984):

$$\theta' = \log K + 2 \log L_\infty \quad (7)$$

Growth curves of fishes even of the same species and population can be very different and comparing them is indeed difficult (Pauly, 1991). The growth performance index $\theta'$ is an important parameter which is used to obtain preliminary approximations of $K$ parameter for stocks or species whose data for growth are unavailable. This is important for stock assessment to estimate $K$ from $L_\infty$ and also may be useful for assessment of growth performance potentials under various stresses of the environment such as different fish farming conditions (Mathews & Samuel, 1990; Gebremedhin et al., 2021). It expresses commonality between the growth patterns of different fishes (Pauly, 1981). Fish in open waters either grow slowly toward a large size (low $K$, high $L_\infty$) or swiftly toward a small size (high $K$, low $L_\infty$) depending on the environmental factors (such as temperature and the presence of predators). Because of this, the growth performance index of various populations of the same species is essentially constant (Pauly, 1994). Pauly discusses the causes of this nearly constant value of $\theta'$ which are ultimately related to how fish distribute the little oxygen diffusing through their gills (Pauly, 1981; Pauly, 1994).

The composition and structure of a fish population with respect to age-classes at any given time is an indication of what has happened to it before and what is expected to happen to it ahead. The dynamics of fish populations of River Awach Kibuon have not been investigated at all. This study determined the population dynamics (recruitment, growth, exploitation and mortality rates) of the main species of fish of River Awach Kibuon so as to bridge this glaring knowledge gap regarding fish population structures.

# CHAPTER THREE

# MATERIALS AND METHODS

## 2.7 Introduction

An overview of the research process and methodology is given in this chapter. Section 3.2 describes the study area and sampling stations; section 3.3 provides the sampling design; section 3.4 describes the sampling procedures for collection of physico-chemical parameters data, river habitat characteristics data, and fish community characteristics data; section 3.5 focuses on fish population parameters data collection methods; while section 3.6 summarizes the procedures and methods of data analysis.

## 2.8 Study area

This study was conducted on River Awach Kibuon, a medium-sized river that drains the southern part of Lake Victoria Basin (LVB), Kenya (Figure 1). River Awach Kibuon substantially influences the quality of water in the Kenyan portion of Lake Victoria through water discharge and deposition of sediments and pollutants. It also provides water to the surrounding riparian communities for livestock drinking, domestic and agricultural uses, and supports a small-scale commercial fishery especially at the river mouth (African Water Facility, 2008). The LVB is of great economic importance to its inhabitants; providing fish, water, recreation, transport and many other vital economic goods and services (Aura et al., 2013). The LVB that is located in Kenya contains numerous rivers that contribute about 45% of total yearly discharge to Lake Victoria (Twesigye et al., 2011).

River Awach Kibuon is one of the rivers in the Kenyan part of the LVB. Its catchment is characterized by a gradient of human disturbances. Most of the area practices subsistence farming which increases in intensity towards the river source (African Water Facility, 2008). The upper catchment area is densely populated (665 people per square kilometer) putting high pressure on land (Mwangi et al., 2015). It is also characterized by an equatorial climate with an average yearly rainfall ranging between 1,500 and 2,000 mm and easily eroded volcanic soils. The high pressure on land has led to widespread land degradation and riparian zone encroachment in the headwaters of the river. This is exacerbated by easily eroded volcanic soils, heavy rainfall, steep slopes and widespread poverty in the catchment area (African Water Facility, 2008). As a result of poor agricultural practices in the watershed, River Awach Kibuon has high sediment load content of 99 tons per square kilometer.

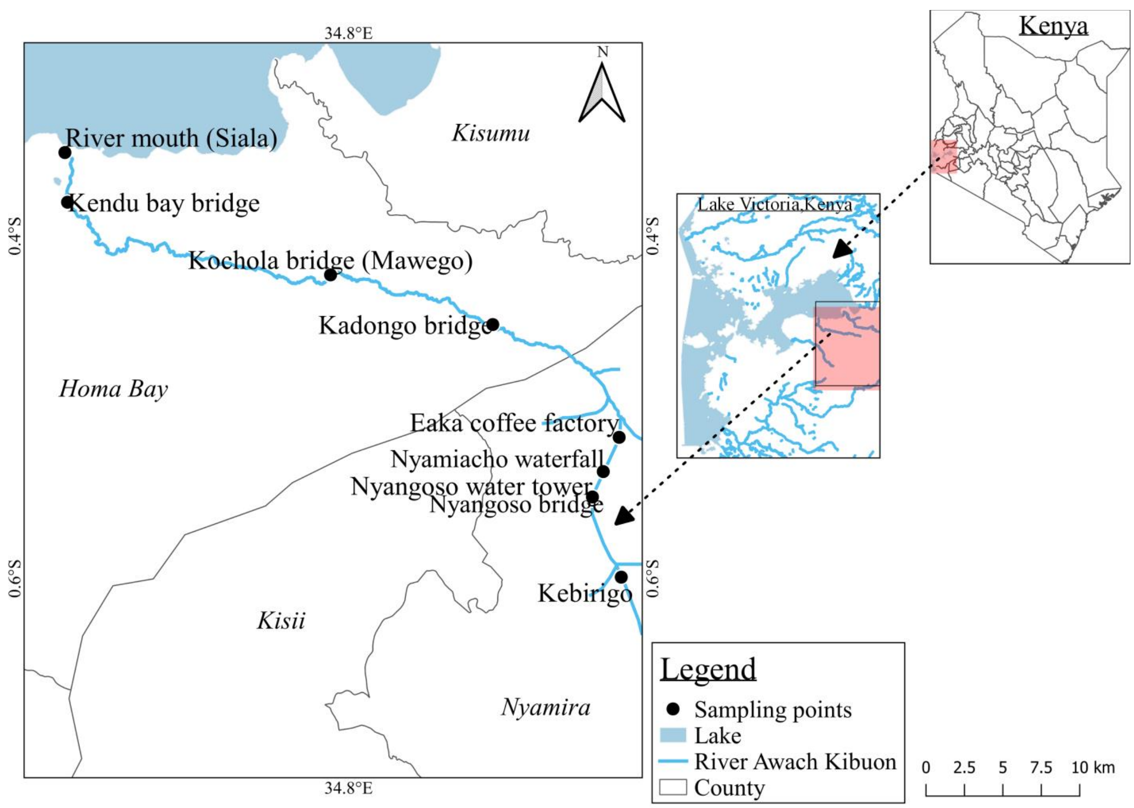


***Figure 1.*** **Map of River Awach Kibuon, Lake Victoria Basin, Kenya showing the nine (9) sampling stations**

### 2.8.1 Description of sampling stations

The sampling locations were chosen based on human activities taking place in various sections of the river and their possible effects on the fish populations along the river. In the upstream section which includes Kebirigo, Nyangoso Bridge, Nyangoso Water Tower, Nyamiacho Waterfall and Eaka Coffee Factory stations, the impacts of riparian zone encroachment, depleted natural riparian buffer vegetation, *Eucalyptus* trees, tea and coffee plantations and coffee factory on river fish communities were targeted. In the midstream section (Kadongo Bridge and Kochola Bridge stations), the effects of dispersed maize and sugarcane farming on fish communities were the subject of focus. The downstream section which comprises Kendu Bay Bridge and River mouth stations focused on the impacts of water abstraction for irrigation, subsistence maize and vegetable farming and extensive natural riparian vegetation on fish communities. Detailed description of each of the nine sampling stations is given below.

#### 2.8.1.1 Kebirigo sampling station

Kebirigo station is located near Kebirigo trading centre in Nyamira County at longitude $34.95946^0$ E and latitude $-0.59923^0$ S at a height of 1953 m above sea level. This was the uppermost station close to the source of Eaka River. The width of natural riparian buffer vegetation on the two banks of the river is narrow (< 5 m wide). The surrounding land is hilly and is predominantly used for *Eucalyptus* trees and tea plantations. The mean river channel width, water width and depth were 3.1 ± 0.25 m, 2.5 ± 0.23 m and 0.28 ± 0.04 m, respectively. Mean width of natural riparian buffer vegetation on the left and right river banks were 1.8 ± 0.9 m and 0.9 ± 0.16 m, respectively. Kebirigo sampling station has abundant riffles (> 5), stable bottom substrate and moderately stable banks. The area is developed (common setting) with dense human settlement and intense agricultural activities conducted up to the river bank. The observed water uses include livestock drinking and other domestic uses. It is characterized by low channel sinuosity with 3 moderately defined bends in 100 m river reach.

**Plate 1. Kebirigo sampling station**

#### 2.8.1.2 Nyangoso Bridge sampling station

Nyangoso Bridge sampling station is located in Nyangoso area in Nyamira County at longitude $34.94275^0$ E and latitude $-0.55417^0$ S at a height of 1846 m above sea level. The width of natural riparian buffer vegetation on the two banks of the river is narrow (< 5 m wide). Mean width of natural riparian buffer vegetation on the left and right river banks were 0.8 ± 0.11 m and 0.8 ± 0.16 m, respectively. *Eucalyptus* trees are planted almost to the river channel. The surrounding land is hilly and is predominantly used for *Eucalyptus* trees and tea plantations. The mean river channel width, water width and depth were 4.3 ± 0.23 m, 3.8 ± 0.21 m and 0.32 ± 0.02 m, respectively. The station had 2-4 riffles in 100 m stretch (common), moderately stable bottom substrate and moderately stable banks. The area in the immediate vicinity of the river is developed with dense human settlement and intense agricultural activities carried out up to the river bank. The observed water uses during sampling include livestock drinking, clothe washing and drawing for domestic purposes. The sampling reach is low in channel sinuosity with 3 moderately defined bends.

**Plate 2. Nyangoso Bridge sampling station**

#### 2.8.1.3 Nyangoso Water Tower sampling station

Nyangoso Water Tower sampling station is located about 50 m after Nyangoso Water Tower in Nyamira County at longitude 34.94261$^{0}$ E and latitude -0.55239$^{0}$ S at an altitude of 1838 m above sea level. The width of natural riparian buffer vegetation on both banks of the river is narrow (< 5 m wide). Mean width of natural riparian buffer vegetation on the left and right river banks were 1.2 ± 0.13 m and 2.1 ± 0.29 m, respectively. The surrounding landscape is hilly and is predominantly used for *Eucalyptus* trees and tea plantations. The mean river channel width, water width and depth were 6.0 ± 0.34 m, 5.4 ± 0.34 m and 0.42 ± 0.02 m, respectively. Nyangoso Water Tower sampling station had 2-4 riffles, stable bottom substrate and moderately stable banks. The area is developed with dense human settlement and intense agricultural activities conducted up to the river bank. The river water is used for washing clothes, livestock drinking and drawing for domestic purposes. The sampling station is characterized by moderate channel sinuosity having 1 well defined and 2 moderately defined bends.

**Plate 3. Nyangoso Water Tower sampling station**

#### 2.8.1.4 Nyamiacho Waterfall sampling station

Nyamiacho Waterfall sampling station is located near Nyamiacho SDA church in Nyamira County at longitude 34.94893$^{0}$ E and latitude -0.53756 $^{0}$ S at an altitude of 1779 m above sea level. The width of natural riparian buffer vegetation on the left bank is narrow (< 5 m wide) and that of the right bank is moderate (5 - 10 m wide). Mean width of natural vegetation on the left and right river banks were 4.0 ± 0.54 m and 5.5 ± 0.0.86 m, respectively. The land surrounding the river is hilly and is predominantly used for *Eucalyptus* trees and tea plantations. The mean river channel width, water width and depth were 7.4 ± 0.42 m, 6.8 ± 0.40 m and 0.54 ± 0.05 m, respectively. Nyamiacho Waterfall sampling station has 2-4 riffles, stable bottom substrate and stable banks. The area is developed with dense human settlement and intense agricultural activities. River water is used by livestock for drinking and is also drawn for use at home. The sampling station is characterized by low channel sinuosity with 2 moderately defined bends.

**Plate 4. Nyamiacho Waterfall sampling station**

### 2.8.1.5 Eaka Coffee Factory sampling station

Eaka Coffee Factory sampling station is located in Kioge area in Nyamira County at longitude 34.95822$^0$ E and latitude -0.51755$^0$ S at an altitude of 1667 m above sea level. The width of natural riparian buffer vegetation on both banks of the river is narrow (< 5 m wide). Mean width of natural riparian buffer vegetation on the left and right river banks were 1.2 ± 0.09 m and 0.8 ± 0.08 m, respectively. The surrounding landscape is hilly and is predominantly used for coffee and tea plantations and *Eucalyptus* trees. The mean river channel width, water width and depth were 5.2 ± 0.32 m, 4.6 ± 0.31 m and 0.48 ± 0.03 m, respectively. Eaka Coffee Factory sampling station is characterized by abundant riffles, moderately stable bottom substrate and unstable falling banks. The local area is developed with dense human settlement, intense agricultural activities and high pressure on land. The river water is used for clothe washing, coffee processing, livestock drinking, receptacle of factory effluents and other domestic uses. This sampling station had high channel sinuosity with 3 well defined and 2 moderately defined bends.

**Plate 5. Eaka Coffee Factory sampling station**

### 2.8.1.6 Kadongo Bridge sampling station

Kadongo Bridge sampling station is located in Kadongo area in Homa Bay County at longitude 34.88432$^0$ E and latitude -0.45169$^0$ S at an altitude of 1463 m above sea level. The width of natural riparian buffer vegetation on the left bank is extensive (> 20 m wide) while that of the right bank is narrow (< 5 m wide). Mean width of natural riparian vegetation on the left and right river banks were 20.4 ± 5.1 m and 2.9 ± 0.30 m, respectively. The land surrounding the river is gently sloping and is used for small-scale farming of various crops including sugar-cane, maize, beans and vegetables. There is also some land in the vicinity which is lying fallow under natural vegetation. The mean river channel width, water width and depth were 7.9 ± 0.67 m, 7.3 ± 0.66 m and 0.75 ± 0.05 m, respectively. Kadongo Bridge sampling station has 2-4 riffles (common) per 100 m river reach, moderately stable bottom substrate and moderately stable banks. The area in the immediate vicinity of the river is somehow developed (natural area) with a trading centre (Kadongo) and human settlements nearby. However, there are considerable portions of land lying fallow under natural vegetation. Agricultural activities are less intense and are carried out slightly away from the river banks. Observed river water uses include drinking by livestock and drawing for domestic uses. The sampling station is characterized by moderate channel sinuosity with 1 well defined and 2 moderately defined bends.

**Plate 6. Kadongo Bridge sampling station**

#### 2.8.1.7 Kochola Bridge sampling station

Kochola Bridge sampling station is located in Mawego area in Homa Bay County at longitude $34.78947^0$ E and latitude $-0.42267^0$ S at an altitude of 1293 m above sea level. Mean width of natural riparian buffer vegetation on the left and right river banks were 5.7 ± 0.99 m (wide) and 2.0 ± 0.13 m (narrow), respectively. The surrounding land is flat and gently sloping towards Lake Victoria and is used for small-scale agriculture of various crops including maize, beans and potatoes among others. Part of the land in the immediate vicinity of the river was lying fallow under natural vegetation. The mean river channel width, water width and depth were 13.7 ± 0.44 m, 12.9 ± 0.42 m and 0.60 ± 0.05 m, respectively. Kochola Bridge sampling station had 2-4 riffles per 100 m sampling reach, moderately unstable bottom substrate and moderately stable banks. The area is somehow developed (natural area) with human settlement and less intensive farming activities and plenty of fallow land. Drinking by livestock, clothe washing, bathing and drawing for domestic use were the observed human uses of the river. The sampling station has moderate channel sinuosity with 1 well defined and 3 moderately defined bends.

**Plate 7. Kochola Bridge sampling station**

### 2.8.1.8 Kendu Bay Bridge sampling station

Kendu Bay Bridge sampling station is located near Kendu Bay town at longitude $34.63571^0$E and latitude $-0.38023^0$ S at an altitude of 1148 m above sea level. The width of natural riparian buffer vegetation on left and right banks of the river is moderate (5 - 10 m wide). Mean width of natural vegetation on the left and right river banks were 8.8 ± 1.22 m and 5.8 ± 1.44 m, respectively. The surrounding land is gently sloping towards Lake Victoria and is covered by human settlements, natural vegetation, small-scale farming of maize, beans and potatoes among others. The mean river channel width, water width and depth were 15.3 ± 1.00 m, 14.6 ± 0.98 m, and 0.77 ± 0.07 m, respectively. Kendu Bay Bridge sampling station had abundant riffles (> 5), stable bottom substrate and moderately unstable banks. The area is developed with human settlement, a town in the vicinity and semi-intensive farming. Bathing, drinking by livestock, clothe washing and drawing for domestic use were the observed human uses of the river water. This sampling station had 2 well defined and 1 poorly defined bends.

**Plate 8. Kendu Bay Bridge sampling station**

### 2.8.1.9 River mouth sampling station

River mouth sampling station is located at longitude $34.63417^{0}$ E and latitude $-0.35122^{0}$ S at an altitude of 1136 m above sea level. The width of natural riparian buffer vegetation on the left bank of the river is extensive (> 20 m wide) while the right bank had wide (10 - 20 m wide) natural riparian buffer vegetation cover. Mean width of natural vegetation on the left and right river banks were 30.6 ± 4.6 m and 16.0 ± 3.58 m, respectively. The surrounding land is flat and swampy with a lot of papyrus and other trees. There is also horticultural farming of sugar cane, vegetables and fruits. The mean river channel width, water width and depth were 11.1 ± 0.78 m, 10.5 ± 0.76 m and 0.90 ± 0.08 m, respectively. River mouth sampling station has 1 riffle per 100 m river reach, unstable bottom substrate and moderately stable banks. The area is natural (wilderness) with dispersed human settlement and some farming activities. Sand harvesting, irrigation of horticultural crops, livestock drinking and drawing for domestic use were the observed human uses of the river. The sampling station had high channel sinuosity with 2 well defined and 2 moderately defined bends.

**Plate 9. River mouth sampling station**

## 2.9 Sampling design

Purposive sampling design was employed to bring out the effects of different anthropogenic activities along the longitudinal stretch of the river. The spatio-temporal sampling strategy was chosen to offer a reliable evaluation of the FIBI across a broad spectrum of human impact levels. For fish population dynamics studies, random samples of commercial fish catches landed at the River mouth station were collected monthly for the whole year 2020.

## 2.10 Sampling

Water, habitat and fish samples for river ecosystem integrity studies, were obtained monthly from strategically selected stations that were longitudinally chosen based on human activities along the river channel. All important river habitats i.e., pools, runs and riffles were covered during sampling. Water, habitat and fish sampling surveys were carried out monthly for eight months (four wet months, September to November 2019 and September 2020; and four dry months, December 2019, February, July and August 2020). These samples were collected in order to assess physico-chemical parameters, habitat characteristics and fish community characteristics and eventually determine the ecosystem integrity of different sections of the river. Fish length data were collected monthly from the

River mouth station for twelve months from January through December 2020 to establish population dynamics.

### 2.10.1 Physico-chemical parameters

Eight monthly sampling surveys were conducted across dry and wet seasons of the year. Each sampling trip took two (2) days in order to cover all the nine (9) sampling stations. Selected physico-chemical parameters, such as pH, total dissolved solids (TDS, mg $L^{-1}$), dissolved oxygen (DO, mg $L^{-1}$), temperature (ºC), electrical conductivity (µS $cm^{-1}$) and turbidity (NTU) were measured using standardized procedures for *in situ* data collection. Using a portable YSI Professional Plus multi-parameter meter at each station, these physico-chemical parameters were measured in accordance with APHA (2005) guidelines. In addition, triplicate water samples of 300 ml were collected directly from every sampling station, placed in a chilled cool box (4 ºC) and transferred to the laboratory within 48 hours for analysis of total phosphorous (TP, µg $L^{-1}$) and total nitrogen (TN, µg $L^{-1}$) utilizing the APHA (2005) recommended photometric techniques.

TN was determined through the oxidative conversion of all digestible nitrogen forms to nitrate and subsequent quantification of the nitrate. The persulfate technique was employed in this study. By oxidizing all nitrogenous substances to nitrate, it calculates the total nitrogen content. Organic and inorganic nitrogen are both converted to nitrate by alkaline oxidation at 100 °C to 110 °C. TN concentration was ascertained by analysis of the nitrate in the digestate. Cadmium reduction was used to determine nitrate concentration. Plotting the absorbances or peak heights of the nitrate calibration standards that were used during the digestion operation against their nitrogen concentrations allows one to determine the nitrate sample concentration by comparing the sample's absorbance or peak height with the standard curve.

Phosphorus analyses involved two main procedural steps; conversion of the target phosphorus form into dissolved orthophosphate and the colorimetric measurement of dissolved orthophosphate. A digestive method to measure total phosphorus must be able to properly oxidize organic matter in order to release phosphorus as orthophosphate since phosphorus can co-occur with organic matter. In this investigation, digestion was accomplished using the nitric acid-sulfuric acid technique. After digestion, liberated orthophosphate was determined using vanadomolybdophosphoric acid method which is most useful for routine analysis in the range of 1 to 20 mg $L^{-1}$. If phosphorus levels are between 0.01 and 6 mg $L^{-1}$, the ascorbic acid technique may be utilized.

**Plate 10. YSI Professional Plus multi-parameter water quality meter**

### 2.10.2 Habitat characterization

A quantitative approach to river habitat quality assessment was employed in this study since it enhances accuracy and precision in data collection (Kaufmann & Robinson, 1998). River depth was measured by a Meter Rule. Readings were taken from 3 points across the river transect. Mean river depth was later calculated. The bank to bank river channel width, water width within the river channel and the width of natural buffer vegetation on left and right river banks were measured using a 30 m tape measure and a string at an interval of 5 m along 20 m river stretch. The number of riffles and channel bends within the 100 m sampling reach were counted and recorded. River bed substrate type, in-stream cover, river bank erosion profile and aesthetic reach value were visually inspected and recorded. These characteristics were scored for each sampling station according to the criteria of Rogers (2016) presented in Table 1. The scores were added up to estimate the total Habitat Quality Index (HQI) score for each sampling location.

**Plate 11. Measuring habitat parameters in River Awach Kibuon**

**Table 1. Scoring criteria for physical river habitat characteristics (Rogers, 2016)**

| Habitat parameter | Scoring criteria | | | |
|---|---|---|---|---|
| **Available in stream cover** | **Abundant** | **Common** | **Rare** | **Absent** |
| **Score** | **4** | **3** | **2** | **1** |
| **Bottom substrate** | **Stable** > 50% gravel or larger substrate | **Moderately Stable** 30 – 50% gravel or larger substrate | **Moderately Unstable** 10 – 29.9% gravel or larger substrate | **Unstable** < 10% gravel or larger substrate |
| **Score** | **4** | **3** | **2** | **1** |
| **Dimension of largest pool** | **Large** Pool covers | **Moderate** Pool covers | **Small** Pool covers | **Absent** |
| **Score** | **4** | **3** | **2** | **1** |
| **Number of Riffles** | **Abundant** > 5 riffles | **Common** 2 – 4 riffles | **Rare** 1 riffle | **Absent** No riffles |
| **Score** | **4** | **3** | **2** | **1** |
| **Water level** | **High** < 5% of channel substrate is exposed | **Moderate** Water fills > 75% of the channel | **Low** Water fills 25 – 75% | **No Flow** Very little water in the channel |
| **Score** | **3** | **2** | **1** | **0** |
| **Channel sinuosity** | **High** ≥ 2 well-defined bends | **Moderate** 1 well-defined bend | **Low** < 3 moderately-defined | **None** Straight channel |
| **Score** | **3** | **2** | **1** | **0** |
| **Bank stability** | **Stable** | **Moderately Stable** | **Moderately Unstable** | **Unstable** |
| **Score** | **3** | **2** | **1** | **0** |
| **Riparian Buffer Vegetation** | **Extensive** Width of natural buffer is >20 meters | **Wide** Width of natural buffer is 10.1 – 20 meters | **Moderate** Width of natural buffer is 5 – 10 meters | **Narrow** Width of natural buffer is < 5 meters |
| **Score** | **3** | **2** | **1** | **0** |
| **Aesthetics of Reach** | **Wilderness** Outstanding natural beauty | **Natural Area** Trees or native vegetation | **Common Setting** area is developed | **Offensive** Cluttered; may be a dumping area |
| **Score** | **3** | **2** | **1** | **0** |
| **Total score** | **31** | **22** | **13** | **4** |

### 2.10.3 Biological assessment

Fish sampling surveys for river ecosystem integrity assessment were conducted monthly during wet (September, October and November) and dry (December, February, July and

August) seasons of the year in 2019 and 2020 using a backpack electro fishing apparatus (Plate 12) for rivers (Scot & Hall Jr., 1997; Lazorchak et al., 1998). A 50 m sampling reach covering all major local macro habitat types (pools, riffles and runs) was fished at every station for a period of 45 minutes (Griffith et al., 2005). The fish samples collected were deemed to be representative of the entire fish communities in each sampling site. The captured fish specimens were sorted and identified to species level, counted and measured for length and weight before being transferred to the laboratory for further analysis of stomach contents, gonads and livers within a 24-hour period (LVFO, 2007).

**Plate 12. Electro-fishing in River Awach Kibuon (Eaka Coffee Factory station)**

The collected fish samples were thereafter used to compute species richness and indices (D, H', J, GSI, HSI, EGI and FIBI). The various index values were in turn used to assign ecosystem integrity status to all the nine sampling stations along River Awach Kibuon.

#### 2.10.3.1 Diversity indices

##### 2.10.3.1.1 Species richness

Fish species richness per sampling station was determined by a simple count of the number of fish species caught (Lamb et al., 2008) from 45-minute electro-fishing in a 50-m river reach in each sampling station.

#### 2.10.3.1.2 Simpson's Index (D)

Simpson's Index (D) was computed by the equation given below according to Simpson (1949):

$$\boldsymbol{D} = \mathbf{1} - \left\{\frac{\sum \mathbf{n(n-1)}}{\mathbf{N(N-1)}}\right\} \qquad \textbf{(8)}$$

Where n = the total count of all organisms of a particular species and N = the total count of organisms of all species. The value of D falls within the range of 0 and 1 where 1 corresponds to infinite diversity and 0 represents no diversity.

#### 2.10.3.1.3 Shannon-Wiener Index (H′)

The Shannon-Wiener Index (H′) was calculated by means of the formula given below according to Margalef (1958):

$$\mathbf{H'} = -\sum \boldsymbol{pi} \ln \boldsymbol{pi} \qquad \textbf{(9)}$$

Where *pi* is the proportion of individuals belonging to the *i*th species in the dataset of interest.

#### 2.10.3.1.4 Pielou's Evenness Index (J)

Pielou's Evenness Index (J) was calculated by the following formula according to Pielou (1966):

$$\mathbf{J} = \frac{\mathbf{H'}}{\mathbf{H_{max}}} = \frac{\mathbf{H'}}{\mathbf{lnS}} \qquad \textbf{(10)}$$

Where $H_{max}$ = lnS and S = total number of species sampled. Hmax refers to maximum diversity possible. Evenness falls in the range of 0 to 1 with 1 corresponding to complete evenness and 0 representing total lack of evenness.

### 2.10.3.2 Other biological indices (GSI, HSI and EGI)

In the laboratory, the chilled fish specimens caught in the field were thawed, body cavity cut open, gonads and liver were removed and weighed to the nearest milligram (mg). The total fish body weight, gonads weight and liver weight, were then used to calculate GSI and HSI using the formulae given below according to Nunes et al. (2011):

$$\textbf{Hepato} - \textbf{Somatic Index}\ (\textbf{HSI}) = \left(\frac{\textbf{Liver weight}}{\textbf{Body weight}}\right) \times \textbf{100} \qquad \textbf{(11)}$$

$$\textbf{Gonado} - \textbf{Somatic Index}\ (\textbf{GSI}) = \left(\frac{\textbf{Gonad weight}}{\textbf{Body weight}}\right) \times \textbf{100} \qquad \textbf{(12)}$$

The fish stomachs were separated from the rest of the gut. Before the stomachs were opened up, qualifications were done classifying them as empty, ¼ full, ½ full, ¾ full, completely full according to the Standard Operating Procedures (SOPs) for collecting biological information from the fishes of Lake Victoria (LVFO, 2007) (Table 2).

**Table 2. Criteria used for the determination of stomach fullness index – LVFO SOPS**

| **Criteria** | **Fullness** | **Fullness index** |
|---|---|---|
| Stomach completely empty | Empty | 0 |
| Very little food present, stomach filled to less than a quarter when pressed from the anterior to distal end. | ¼ F | 1 |
| Half full stomach fills to about one half when pressed from the anterior to distal end. | ½ F | 2 |
| Stomach nearly full but wall not bulging, food fills about to three quarters when stomach is pressed from the anterior to distal end. | ¾ F | 3 |
| Stomach full distended with food from the anterior to distal end. | Full | 4 |

The EGI was then calculated using the formula below:

$$\textbf{Empty Gut Index}\ (\textbf{EGI}) = \left(\frac{\textbf{Fish with empty stomachs}}{\textbf{Total number of fish}}\right) \times \textbf{100} \qquad \textbf{(13)}$$

By use of a scalpel after mounting a surgical blade on it, the fish specimen was cut open at the belly gently exposing the gut and the gonads. The sex of the fish and gonad maturity stage were determined using the guidelines provided by Hopson (1972) (Table 3).

**Table 3. Maturity stages for fresh male and female fish**

| **Males** | **Females** |
|---|---|
| Immature: Testis appear a pair of thin transparent strands running longitudinally along the dorsal wall of the body cavity, sex's indistinguishable macroscopically. | 1 – Appearance like testis: Sexes indistinguishable microscopically |
| Early developing: Testis transparent grayish while occasionally pinkish narrow flattened. | 2 – Resting: Ovary grayish white or white of pinkish transparent, smooth and cylindrical, circular in transverse section eggs not visible microscopically, only slightly vascularized |
| Late developing: Testis semitransparent grayish white or pinkish, often well vascularized, more or less flattened in transverse section not milt | 3 – Early maturing: Ovary pinkish or reddish, semitransparent, pear shaped in section, eggs not visible microscopically, only slightly vascularized. |
| Mature/Resting: Testis opaque, whitish of pinkish often well vascularized, firm triangular in section, slight milt exudes from lumen when cut | 4 – Late maturing: Ovary pinkish or reddish with small opaque yolky ova clearly visible, pear shaped in section/ |
| Mature/ Ripe: Testis opaque, ivory white or pinkish, soft triangular in section. Lying in the longitudinal groove in ventral surface, copious milt when cut | 5 – Ripe: Ovary yellowish bulb opaque due to presence of large yolky ova clearly visible through superficial membrane, pear shaped section, large blood vessels on the surface |
| Ripe/ running: similar in appearance to stage 5 but milt running fully from vent when slightly external pressure applied to fish. | 6 – Running: Ova yellowish brown in color, oil globule present, slightly external pressure causes ripe ova to be extruded from the vent |
| | 7 – Spent – Ovaries loose and flabby containing torn follicular tissue rich in blood with a few residual stage 5 ova |

#### 2.10.3.3 Fish Index of Biotic Integrity (FIBI)

The methodology of river ecological integrity assessment using FIBI was divided into four sections; classification of streams and rivers, characterization of sampling stations, classification of captured fish and development of FIBI. Figure 2 is a summarized diagrammatic representation of steps leading to the development of a Fish Index of Biotic Integrity and spatio-temporal determination of ecological integrity of river Awach Kibuon, Lake Victoria Basin, Kenya.

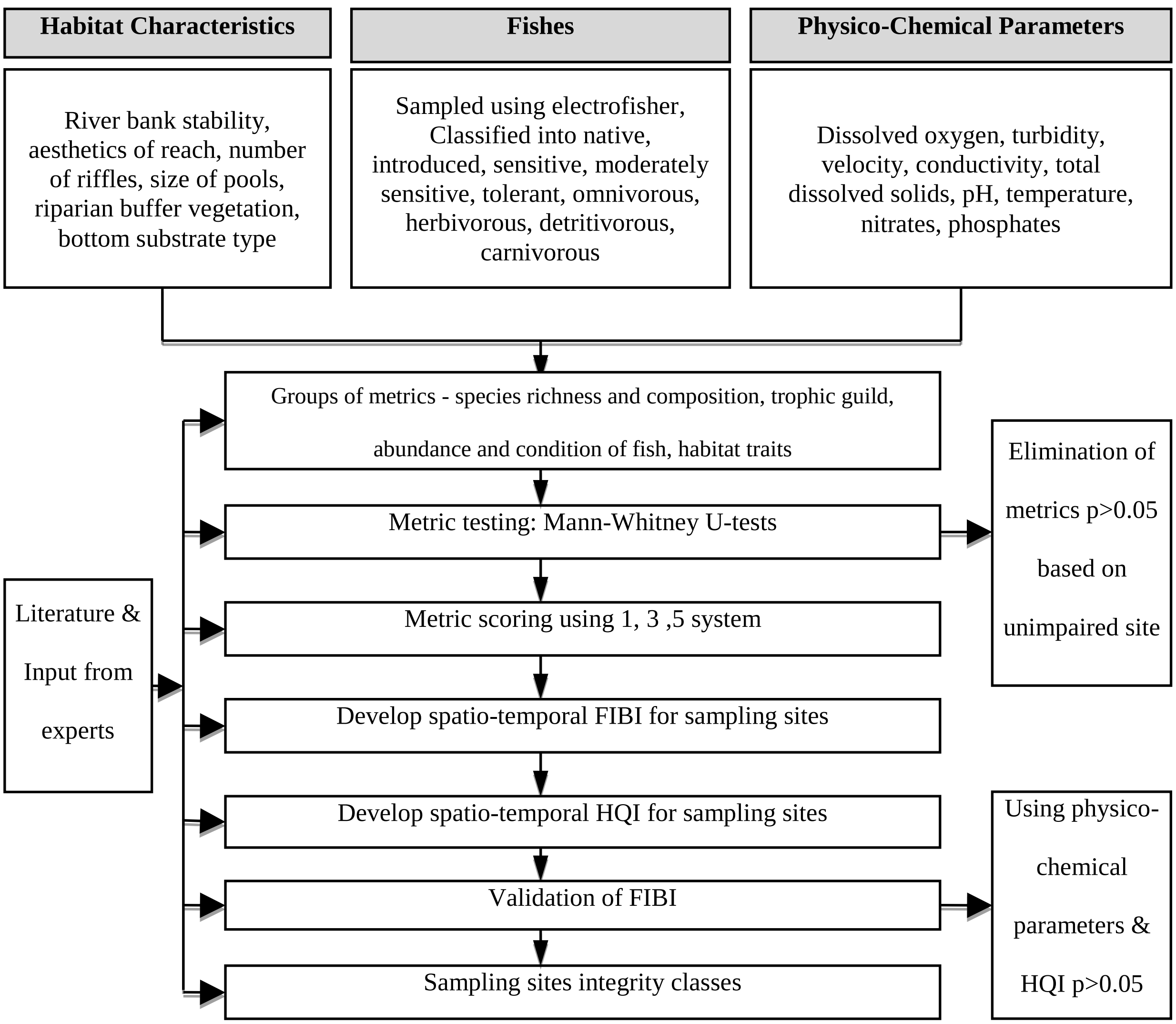


***Figure 2.*** **Diagrammatic representation of steps leading to the development of a Fish Index of Biotic Integrity and assignment of integrity classes in River Awach Kibuon (Adapted from Aura et al., 2017)**

#### 2.10.3.3.1 Classification of streams and rivers

For the purpose of this study, a simple classification scheme based on river length was used. According to this classification scheme; streams and rivers that are 1-45 km long are classified as small size, 46-102 km long rivers are classified as medium size, 103-1240 km long rivers are classified as large size, while rivers longer than 1240 km are classified as great rivers (Cushing & Allan, 2001).

#### 2.10.3.3.2 Characterization of sites

The sampling locations were chosen to reflect the effects of various degrees of anthropogenic activity on the fish populations along the whole length of the river. In the upper zone represented by Kebirigo, Nyangoso Bridge, Nyangoso Water Tower, Nyamiacho Waterfall and Eaka Coffee factory stations, the impacts of riparian zone encroachment, depleted natural riparian buffer vegetation, *Eucalyptus* trees and tea plantations and a coffee factory were targeted. In the midstream section (Kadongo Bridge and Kochola Bridge stations), the effects of scattered maize and sugarcane farming were the subject of focus. The downstream section (Kendu Bay Bridge and River mouth stations) focused on the impacts of water abstraction for irrigation, subsistence maize and vegetable farming and extensive natural riparian vegetation on fish communities.

The nine sampling stations were finally assigned any of the following four condition categories; unimpaired, intermediate, impaired and no-fish stations, depending on the width of natural riparian buffer vegetation, channel sinuosity, wilderness condition of the sampling reach, number of fish species caught and river habitat quality.

#### 2.10.3.3.3 Classification of captured fish species

To develop Fish Index of Biotic Integrity, the captured fish species were classified step by step into various groups. First, they were classified into trophic groups as herbivores, detritivores, insectivores and generalists as shown in Table 4 (Hocutt et al., 1994; Hay et al., 1996; Hugueny et al., 1996). Secondly, the fish species were classified based on origin as either native or introduced (exotic) according to electronic fish literature found in FishBase (Froese & Pauly, 2021). Finally, the captured fish species were classified according to their level of tolerance to environmental conditions as tolerant, moderately sensitive, or sensitive using existing literature on fish species of the LVB (Raburu & Masese, 2012).

**Table 4. Classification of fish communities encountered in River Awach Kibuon based on origin, tolerance and feeding characteristics**

| Family | Origin | Tolerance level | Trophic Guild | Reference |
|---|---|---|---|---|
| **Claridae** | | | | |
| *Clarias alluaudi* (Boulenger, 1906) | Native | Tolerant | Generalist | Raburu & Masese, 2012 |
| *Clarias theodorae* (Weber, 1897) | Native | M. sensitive | Insectivore | Hay et al. 1996 |
| *Clarias gariepinus* (Burchell, 1815) | Native | Tolerant | Generalist | Raburu & Masese, 2012 |
| **Mochokidae** | | | | |
| *Synodontis victoriae* (Boulenger, 1906) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |
| *Synodontis afrofischeri* (Hilhendorf, 1888) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |
| *Chiloglanis* sp. (Peters, 1868) | Native | M. sensitive | Detritivore | Raburu & Masese, 2012 |
| **Cyprinidae** | | | | |
| *Enteromius paludinosus* (Peters, 1852) | Native | M. sensitive | Insectivore | Corbet, 1961 |
| *Enteromius neumayeri* (Fischer, 1884) | Native | Sensitive | Variable | Raburu & Masese, 2012 |
| *Enteromius apleurogramma* (Boulenger, 1911) | Native | M. sensitive | Variable | Raburu & Masese, 2012 |
| *Enteromius jacksoni* (Gunther, 1889) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |
| *Enteromius nyanzae* (Whitehead) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |
| *Enteromius kerstenii* (Peters, 1968) | Native | M. sensitive | Insectivore | Hay et al., 1996 |
| *Enteromius cercops* (Whitehead) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |
| *Labeobarbus altianalis* (Boulenger, 1900) | Native | Sensitive | Variable | Raburu & Masese, 2012 |
| *Labeo victorianus* (Boulenger, 1901) | Native | M. sensitive | Insectivore | Corbet, 1961 |
| **Poiciliidae** | | | | |
| *Gambusia affinis* (Baird & Girard, 1853) | Introduced | M. sensitive | Insectivore | Graham, 2005 |
| **Cichlidae** | | | | |
| *Pseudocrenilabrus multicolor* (Schöller, 1903) | Native | M. sensitive | Detritivore | Raburu & Masese, 2012 |
| *Oreochromis leucostictus* (Trewavas, 1933) | Introduced | Tolerant | Herbivore | Raburu & Masese, 2012 |
| *Haplochromis* sp. (Hilgendorf, 1888) | Native | M. sensitive | Detritivore | Raburu & Masese, 2012 |
| **Mormyridae** | | | | |
| *Hippopotamyrus grahami* (Norman, 1928) | Native | M. sensitive | Insectivore | Corbet, 1961 |
| **Mastacembelidae** | | | | |
| *Mastacembelas frenatus* (Boulenger, 1901) | Native | M. sensitive | Insectivore | Raburu & Masese, 2012 |

*M. sensitive = moderately sensitive

### 2.10.3.3.4 FIBI development and validation

### Identification and selection of metrics

According to Karr (1981), metrics for FIBI development fall into three broad groups; species composition and richness metrics, trophic structure of the fish community metrics and abundance and condition of the fish metrics. A total of 26 potential metrics were identified based on characteristics of the fish caught and relevant literature (Table 5). They were then subjected to tests of systematic change along a gradient of human influence and independence before inclusion in the FIBI. The ability of potential metrics to separate unimpaired, intermediate and impaired sites was evaluated using Mann-Whitney U test (Mann & Whitney, 1947). The first 9 fish metrics in Table 6 were taken out of potential metrics when Mann-Whitney U tests revealed significant differences ($p < 0.05$) across site groups. The last 3 habitat metrics were identified based on clear variations between stations according to the scoring criteria in Table 5.

**Table 5. Potential metrics for inclusion in the Fish Index of Biotic Integrity**

| | Potential Metrics | |
|---|---|---|
| | **A. Species richness and composition metrics** | **Predicted response with increasing degradation** |
| 1 | Number of species | Decrease |
| 2 | Number of native species | Decrease |
| 3 | Number of *Enteromius* species | Decrease |
| 4 | Number of catfish species | Variable |
| 5 | Number of cichlid species | Decrease |
| 6 | Number of moderately sensitive species | Decrease |
| 7 | Number of tolerant species | Increase |
| 8 | Number of intolerant species | Decrease |
| 9 | Number of cichlid species | Decrease |
| 10 | Percent *Enteromius* species | Decrease |
| 11 | Percent clarid species | Variable |
| 12 | Percent cyprinid species | Decrease |
| 13 | Percent cyprinid individuals | Decrease |
| 14 | Percent tolerant species | Increase |
| 15 | Percent tolerant individuals | Increase |
| 16 | Percent intolerant species | Decrease |
| 17 | Percent *Enteromius* individuals | Decrease |
| 18 | Percent catfish individuals | Variable |
| 19 | Percent moderately sensitive species | Decrease |
| 20 | Percent of insectivorous species | Decrease |
| | **B. Trophic metrics** | |
| 21 | Number of insectivorous species | Decrease |
| 22 | Proportion as insectivores | Decrease |
| 23 | Proportion of individuals as omnivores | Increase |
| 24 | Percent insectivorous species | Decrease |
| 25 | Proportion as detritivores | Variable |
| | **C. Abundance and condition metrics** | |
| 26 | Number of individuals per 50 m river reaches | Decrease |

**Table 6. Twelve fish and habitat metrics used in the development of a Fish Index of Biotic Integrity (FIBI) based on the 1, 3, 5 scoring criteria in River Awach Kibuon**

| | Scoring Criteria | | |
|---|---|---|---|
| **Metric** | **1** | **3** | **5** |
| Number of native species | <2 | 2-5 | ≥6 |
| Number of cyprinid species | 0-1 | 2-3 | ≥4 |
| Number of insectivorous species | 1 | 2-3 | ≥4 |
| Number of moderately sensitive species | 1 | 2-4 | ≥5 |
| Number of fish per 50 m river reach | ≤50 | 51-75 | >75 |
| % *Enteromius* species | 0-33% | 34-67% | >67% |
| % Clarid species | >75% | 25-75% | 0-24% |
| % Tolerant species | >33% | 18-33% | 0-17% |
| Proportion of individuals as omnivores | >69% | 30-69% | 0-29% |
| Natural riparian buffer vegetation width | Narrow | Wide | Extensive |
| Aesthetics of reach | Cluttered | Common setting | Wilderness |
| Channel sinuosity | Low | Moderate | High |

The FIBI developed in this study consisted of 12 metrics (9 fish- and 3 habitat metrics) which successfully delineated the ecological integrity conditions of various sections of River Awach Kibuon. The 1st qualified metric is the number of native species which has been widely employed in Africa and around the world to develop Fish Indices of Biotic Integrity (Hocutt et al., 1994; Toham & Teugels, 1999; Morris et al., 2007; Raburu & Masese, 2012). This metric considers only indigenous species, leaving out introduced species which are understood to diminish the integrity of sites (Raburu & Masese, 2012). It is expected to decrease with increasing degradation. The 2nd qualified metric is the number of cyprinid species, which has been commonly used to develop FIBI in Africa (Hugueny et al., 1996; Raburu & Masese, 2012). The goal of this metric is to quantify the degree of degradation of submerged vegetation, which members of the cyprinid family often inhabit in Africa. It replaces the number of sunfish species metric of Karr (1981). Cyprinids are expected to decrease with increasing degradation.

The 3rd qualified metric is the number of insectivorous species which has been used before to develop FIBIs in the Lake Victoria region (Raburu & Masese, 2012). Because invertebrates process a large portion of organic materials in rivers, the insectivorous species metric is used to evaluate disturbances in secondary production (Zhu & Chang, 2008). Aquatic insects are responsive to pollution and general impairment of the environment and are expected to decline with increasing degradation along with insectivorous fish species. The 4th qualified metric is the number of moderately sensitive species, which has not been widely used in the past for FIBI development. However, it was included here because it clearly distinguished sampling stations according to their levels of degradation. It is expected to decrease with increasing degradation.

The 5th qualified metric is the number of fish individuals in 50 m river reaches which has been widely used in the development FIBIs around the world. It is a simple indicator of fish production, with low numbers observed in severely degraded ecosystems and waters with low nitrogen levels (Karr, 1981; Ganasan & Hughes, 1998). In general, it is expected that the number of fish caught decreases with degradation. However, this metric may at times not distinguish degraded and un-degraded sites clearly. This is exemplified by eutrophic water bodies which may have more individuals per unit length sampled than un-degraded sites.

The 6th qualified metric is % *Enteromius* species which is unique to this study but responded clearly to degradation gradient presented by the different sampling sites. Fish species of the new genus *Enteromius* (formerly Barbus), are mainly insectivorous fish sensitive or moderately sensitive to degradation. They are comparable to shiner species in North America. Percent *Enteromius* species metric is expected to decrease with increasing degradation.

The 7th selected metric is % clarid species which has also been used in the past to develop FIBIs. The dominance of clarids at a location is a sign of declining water quality and habitat conditions because they are thought to be tolerant of pollution and crowded conditions (Toham & Teugels, 1999; Raburu & Masese, 2012). In this study, 3 clarid species (*Clarias gariepinus*, *Clarias alluaudi* and *Clarias theodorae*) were encountered in various sampling sites. The percentage of clarid species is expected to increase with degradation.

The 8th qualified metric is percent tolerant species which has been widely used to develop fish indices of biotic integrity globally (Toham & Teugels, 1999; Zhu & Chang, 2008). The percentage of tolerant species is hypothesized to increase with degradation as intolerant species decrease and migrate. This metric responded well to degradation gradient presented by various sampling sites in this study. It is comparable to the "percent tolerant individuals" metric of Hughes and Oberdorff (1999). It distinguishes poor and intermediate water quality like the original percent green sunfish metric developed by Karr in 1981.

The 9th fish metric qualified for FIBI development in this study is the proportion of individuals as omnivores which is intended to measure the extent of environmental deterioration occurring as a result of the disruption of the food chain (Karr et al., 1986; Oberdorff & Hughes, 1992). This metric has been used frequently worldwide in FIBI development (Fausch et al., 1984; Oberdorff & Hughes, 1992; Hugueny et al., 1996; Toham & Teugels, 1999; Raburu & Masese, 2012). The proportion of omnivores is expected to increase with degradation as they thrive in degraded environmental conditions at the expense of food specialists (Hay et al., 1996).

**Reference conditions**

Due of the lack of pristine, untouched locations, reference sites were not used in this study to develop the scoring criteria. Instead, sites with varying levels of human involvement within the river were sampled in order to find clues regarding the condition of the resource (Raburu & Masese, 2012). This method is preferred when it is impossible to identify pristine conditions (Simon & Lyons, 1995) and expectations for each attribute are based on best observed values (Fausch et al., 1984; Oberdorff & Hughes, 1992; Karr & Chu, 1997b; Ganasan & Hughes, 1998; Kestemont et al., 2000).

**Metric scoring criteria and ecological integrity classes**

A 1-, 3-, 5-rating scheme, which is frequently used in FIBI development, was employed in this study (Oberdorff & Hughes, 1992; Aura et al., 2010). Box plots with median ($50^{th}$), $25^{th}$ and $75^{th}$ percentiles for each metric relative to the best observed values were used. By this scoring system for degradation, values within the $25^{th}$ percentile were scored as 1, values falling between the $25^{th}$ and $75^{th}$ percentiles were scored as 3, while values above the $75^{th}$ percentile were scored as 5. The rated metrics were then added up to obtain the final FIBI score. Sensitivity of FIBI to degradation was assessed by correlating metric values with Habitat Quality Index scores and physico-chemical parameters values using Spearman Rank Correlation Coefficient and Canonical Correspondence Analysis (CCA).

The maximum score of 45 served as a standard for the five-class scheme since a total of nine fish metrics were used, each with the highest value of five. Ecological integrity classes were defined based on the total FIBI scores at excellent, good, fair, poor, very poor and no-fish sites in relation to the habitat traits at respective sites (Table 33). Assignment of ecological integrity condition for the sampling sites was based on five-condition category classes of excellent, good, fair, poor and very poor developed by Karr et al. (1986) depending on whether the final FIBI score was within 41-45, 33-40, 24-32, 19-23 and 9-18, respectively. The sampling stations with no fish were assigned the sixth category of 0 score (Table 33).

## 2.11 Fish population dynamics

Total length data (TL, cm) of four fish species (*Synodontis victoriae, Oreochromis niloticus*, *Protopterus aethiopicus* and *Clarias gariepinus*) were collected monthly from January through December 2020. The fish samples were drawn from the catches of artisanal fishermen landed at Siala landing beach (River mouth station) to help monitor their recruitment patterns, growth rates, mortality rates and exploitation rates. Fish sampling was conducted for one day every mid-month for consistency and TL measured to the nearest centimeter using a 1-metre measuring board. To minimize errors associated with fishing gear selectivity, the current study sampled and analyzed catches from multi-mesh gillnets only.

At the end of the 12-month sampling period, a total of 1632 specimens of *Synodontis victoriae*, 1678 of *Oreochromis niloticus*, 655 of *Clarias gariepinus* and 477 of *Protopterus aethiopicus* had been measured. Length data of each fish species were first entered into Microsoft Excel (Microsoft Inc.) version 10. They were next grouped into length-classes with equal length intervals to meet the data requirements of the FAO ICLARM Stock Assessment Tools (FiSAT II) software. The electronic length frequency analysis I (ELEFAN I) in FiSAT II Software Version 1.2.2 was used to estimate the population parameters according to Gayanilo et al. (2005).

### 2.11.1 Recruitment patterns

To calculate the number of pulses each year and the relative strength of each pulse, the recruitment patterns routine in the FiSAT II software reconstructed recruitment pulses using a time series of length-frequency data. The length frequency data were backward-projected onto an arbitrary 1-year time scale, following a trajectory described by the von Bertalanffy growth function, to derive the recruitment patterns. Because the location parameter ($t_0$) is unknown, the months on the x-axis cannot be located exactly. Growth parameters ($L_\infty$) and ($K$) were used as inputs.

### 2.11.2 Growth and mortality rates

Estimates of the growth parameters $K$ yr$^{-1}$ and $L_\infty$ (cm) for each species were obtained using ELEFAN I routine in FiSAT II software according to Gayanilo et al. (2005) based on Equation 3 (the von Bertalanffy growth model - VBGF): $L_t = L_\infty$ (1 - exp (-$K$ ($t - t_0$))).

The total mortality ($Z$ yr$^{-1}$) was estimated using the length-converted catch curve method in ELEFAN I, using the final estimates of $L_\infty$ and $K$ and the length distribution data for the species as inputs according to Pauly (1984).

The natural mortality ($M$ yr$^{-1}$) was estimated with $K$ yr$^{-1}$, $L_\infty$ (cm) and T (mean annual habitat temperature (22.7 °C) in this case), according to Pauly's empirical formula (Pauly, 1980), as follows:

$$\mathbf{Ln}\ (\boldsymbol{M}) = -\mathbf{0.0152} - \mathbf{0.279}\ \mathbf{ln}\ (\boldsymbol{L_\infty}) + \mathbf{0.6543}\ \mathbf{ln}\ (\boldsymbol{K}) + \mathbf{0.4634}\ \mathbf{ln}\ (\mathbf{T}) \qquad \mathbf{(14)}$$

The fishing mortality ($F$ yr$^{-1}$) was calculated from the relationship:

$$\boldsymbol{F} = \boldsymbol{Z} - \boldsymbol{M} \qquad \mathbf{(15)}$$

Exploitation rate ($E$) was computed by Equation 1 according to Gulland (1971).

The growth performance index (θ′) was calculated according to Equation 7 (Pauly & Munro, 1984).

### 2.11.3 Beverton and Holt Y′/R and B′/R analyses

The Beverton and Holt (1966) model, as modified by Pauly and Soriano (1986), served as the basis for the relative yield-per-recruit model used. The option considering knife-edge selection was utilized, using probabilities of capture. $L_c/L_\infty$ and $M/K$ ratios were used as inputs. The relative yield-per-recruit ($Y'/R$) was computed by following equation:

$$\mathbf{Y'/R = EU^{\mathit{M/K}}} \left\{\frac{\mathbf{1-3U}}{\mathbf{(1+m)}} - \frac{\mathbf{3U^2}}{\mathbf{(1+2m)}} - \frac{\mathbf{U^3}}{\mathbf{(1+3m)}}\right\} \quad \textbf{(16)}$$

Where U = 1 - ($L_c/L_\infty$); m = (1-$E$)/($M$/$K$) = ($K$/$Z$); and $E = F/Z$

The relative biomass-per-recruit ($B'/R$) was estimated by the following equation:

$$\boldsymbol{B'/R} = \left(\frac{\boldsymbol{Y'/R}}{\boldsymbol{F}}\right) \quad \textbf{(17)}$$

Where B′/R = biomass per recruit, Y′/R = yield per recruit, $F$ = fishing mortality rate. Biological reference points, $E_{max}$, $E_{0.1}$ and $E_{0.5}$ were approximated using the first derivative of this function. $E_{max}$ is the exploitation rate at maximum sustainable yield (MSY), $E_{0.1}$ is the exploitation rate at maximum economic yield (MEY) and $E_{0.5}$ is the optimum exploitation rate. The probability of capture was attained from the backward extrapolation of the length-converted catch curve, according to Pauly et al. (1984). The selection parameters ($L_{25}$, $L_{50}$ and $L_{75}$) were estimated by FiSAT II using the logistic curve option which assumes symmetrical selection.

### 2.12 Data analysis

The quantitative data were first entered into Microsoft Excel (Microsoft Inc.) version 10 for proper arrangement. The arranged data for each objective were then transferred to Statistica, SPSS and FiSAT II softwares for further analysis. Data were analyzed using both descriptive and inferential statistics. For inferential statistics the level of significance was set at $\alpha = 0.05$. Quantitative data were subjected to normal distribution and homogeneity of variances tests before being subjected to one-way ANOVA and independent two-sample t-tests. Non-normally distributed data were first log-transformed before being subjected to further tests.

### 2.12.1 Physico-chemical parameters

The spatio-temporal variations of physico-chemical parameters of water were analyzed using STATISTICA Software version 7 (Statsoft Software Inc.). Spatial variations across the 9 sampling stations were tested using one-way analysis of variance while temporal difference between wet and dry seasons was tested using a two-sample t-test.

### 2.12.2 Habitat characteristics

The spatial differences of quantitative habitat characteristics such as mean river channel width and mean river depth were tested using one-way ANOVA while temporal variation between wet and dry seasons was tested using a two-sample t-test. Other river habitat characteristics such as natural riparian buffer vegetation width, bottom substrate type, number of riffles, river sinuosity, river bank stability, pool sizes and aesthetics of sampling reach, were scored according to the criteria of Rogers (2016) provided in Table 1.

### 2.12.3 Diversity indices

Descriptive statistics were used to evaluate spatio-temporal variations of diversity indices (Simpson's, Shannon-Weiner's, and Pielou's).

### 2.12.4 Other biological indices (GSI, HSI and EGI)

Descriptive statistics were used to assess spatio-temporal variations of GSI, HSI and EGI values of *Enteromius cercops* and *Labeobarbus altianalis* populations in the medium-sized River Awach Kibuon.

### 2.12.5 Fish Index of Biotic Integrity (FIBI)

The separation power of Mann-Whitney U test was used to test significant variations of metrics between impaired, intermediate and unimpaired stations. Assignment of ecological integrity condition was based on 5 condition category classes of excellent, good, fair, poor, and very poor according to Karr et al. (1986), depending on whether the final FIBI score was within 41-45, 33-40, 24-32, 19-23 and 9-18, respectively, whereas sampling stations with no fish were assigned the sixth category of 0 score (Table 40).

### 2.12.6 Population dynamics

The fish population dynamics data (length-frequency) were analyzed using FAO-ICLARM FiSAT II Software version 1.2.2. The electronic length frequency analysis I (ELEFAN I) in FiSAT II was used to estimate the population parameters ($L_\infty$, $K$, $Z$, $M$, $F$, $E$ & $\theta'$) according to Gayanilo et al. (2005).

### 2.12.7 Correlations between physico-chemical parameters, habitat characteristics and biological characteristics

The correlations between physico-chemical parameters and fish abundance determined by Canonical Correspondence Analysis (CCA) while the correlation between Habitat Quality Index and Fish Index of Biotic Integrity in River Awach Kibuon was determined by Spearman Rank Correlation Coefficient.

# CHAPTER FOUR

# RESULTS

## 4.1 Introduction

This chapter presents results of spatio-temporal physico-chemical parameters assessment, habitat quality characterization and biological assessment of fish communities in River Awach Kibuon. Biological assessment results are broken down into diversity indices, Fish Indices of Biotic Integrity and other biological indices such as GSI, HSI and EGI. The chapter also presents results on fish population dynamics of *Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus* of the same river. The population dynamics include growth parameters ($L_\infty$, $K$), growth performance index ($\theta'$), mortality rates ($Z$, $M$ & $F$), exploitation rate ($E$), recruitment patterns, yield per recruit (Y'/R) and biomass per recruit (B'/R) analyses.

## 4.2 Physico-chemical parameters

The physico-chemical parameters measured in River Awach Kibuon include surface water velocity, temperature, DO, turbidity, TDS, TN, TP, electrical conductivity and pH.

### 4.2.1 Velocity

The mean spatial surface water velocity ranged from 0.32 ± 0.02 m $s^{-1}$ at Kebirigo station to 1.23 ± 0.11 m $s^{-1}$ at Eaka Coffee Factory station with an overall river mean of 0.91 ± 0.05 m $s^{-1}$. The spatial pattern of mean surface water velocity in River Awach Kibuon is depicted in Figure 3. Surface water velocity was lowest near the source at Kebirigo, increased midstream, peaked at Eaka Coffee Factory then decreased towards the river mouth. One-way analysis of variance showed that mean spatial water surface velocity at the $p<.05$ level for the 9 stations in River Awach Kibuon varied significantly between sampling stations ($F$ (8, 63) = 8.45, $p$ = 0.00001). Comparisons of pairs using Tukey HSD post-hoc test revealed 3 overlapping homogeneous groups and showed significant variations between Kebirigo station and all other stations except River mouth station. River mouth station also varied significantly with Nyamiacho Waterfall, Eaka Coffee Factory, Kadongo Bridge, Kochola Bridge and Kendu Bay Bridge.

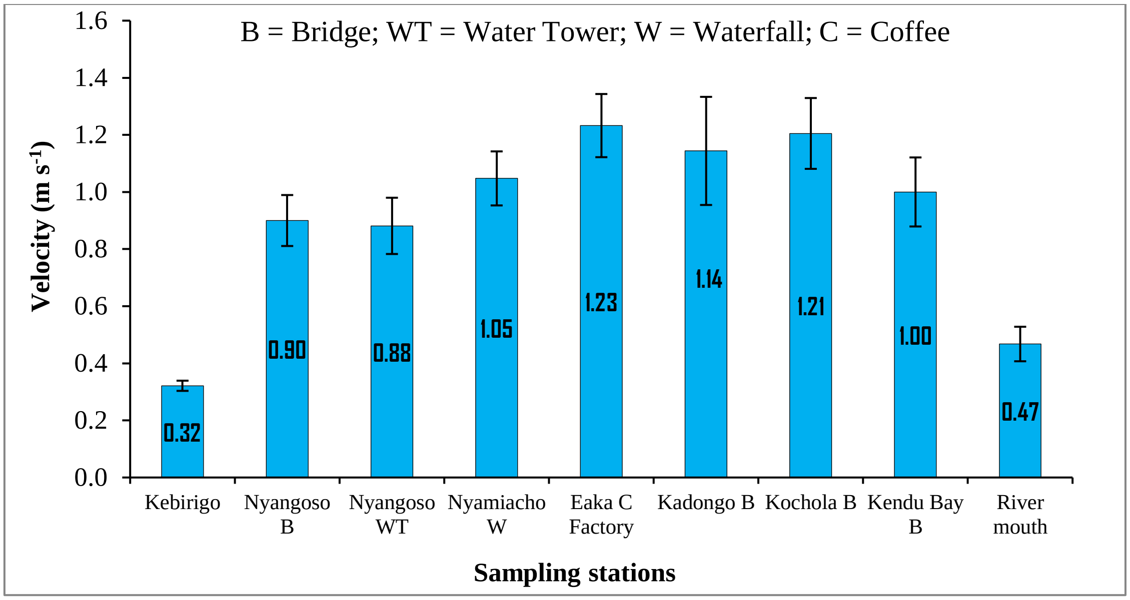


***Figure 3.*** **Mean (±SE) spatial surface water velocity variations in River Awach Kibuon**

The mean monthly river water velocity values during wet and dry seasons of the year are presented in Figure 4. During the wet season, surface water velocity ranged from 0.17 m $s^{-1}$ at the river mouth to 1.88 m $s^{-1}$ at Kadongo Bridge with an overall river mean of 0.97 m $s^{-1}$. During the dry season, it ranged from 0.29 m $s^{-1}$ at Kebirigo to 1.53 m $s^{-1}$ at Nyamiacho Waterfall with an overall river mean of 0.85 m $s^{-1}$. A two-sample t-test showed no significant temporal variation between wet and dry seasons; t (70) = 1.203, p = 0.233.

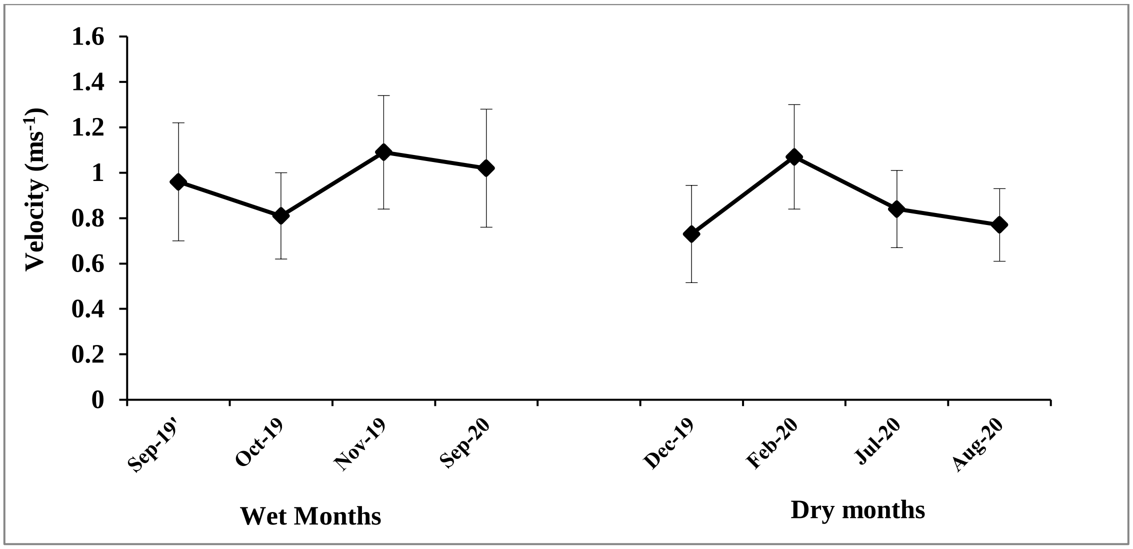


***Figure 4.*** **Mean (±SE) monthly surface water velocity variations in River Awach Kibuon**

### 4.2.2 Temperature

The mean spatial water temperature in River Awach Kibuon was lowest at Kebirigo station (18.1 $^{\circ}$C) and highest at River mouth station (22.7 $^{\circ}$C) with an overall river mean of 20.8 $^{\circ}$C. The longitudinal pattern of mean water temperature in River Awach Kibuon is presented in Figure 5.

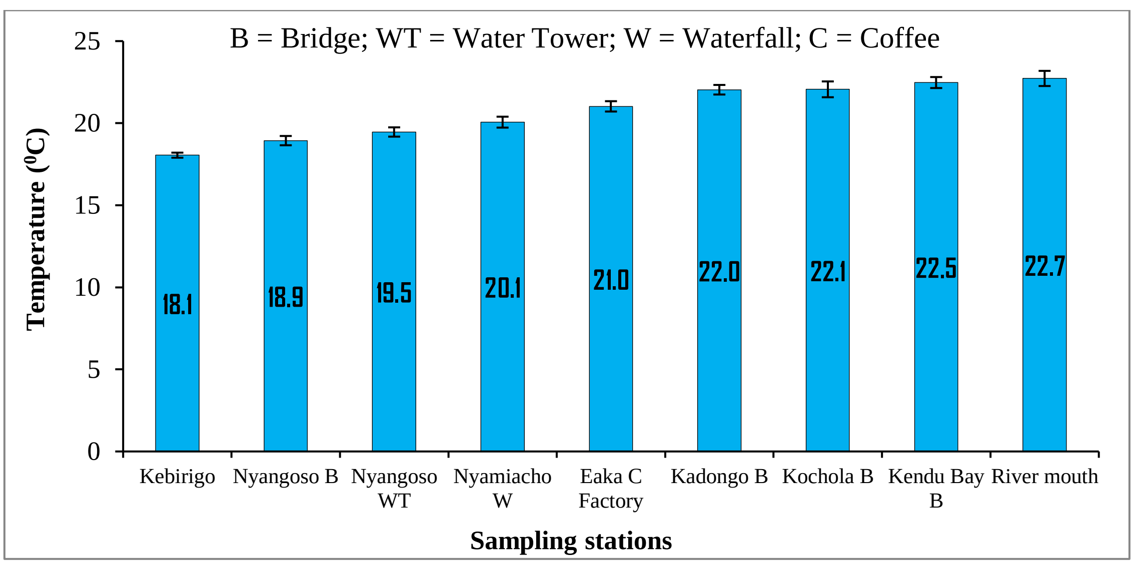


***Figure 5.*** **Mean (±SE) spatial temperature variations in River Awach Kibuon**

The mean spatial water temperature steadily increased downstream reaching the highest value at the River mouth station. One-way analysis of variance showed that mean spatial water temperature at the $p<.05$ level varied significantly between sampling stations ($F(8, 63) = 25.01$, $p = 0.00008$). Pair-wise comparisons using Tukey HSD post hoc test showed that Kebirigo, Nyangoso Bridge and Nyangoso Water Tower stations were homogeneous. Kadongo Bridge, Kochola Bridge, Kendu Bay Bridge and River mouth were also homogeneous. Nyamiacho Waterfall and Eaka coffee factory formed another homogeneous group. In general, midstream and downstream stations had significantly higher mean water temperature than the upstream stations.

The mean monthly river water temperatures during wet and dry seasons is presented in Figure 6. During the wet season, it ranged from 17.7 °C at Kebirigo to 24.8 °C at River mouth station with an overall river mean of 21.0 °C. During the dry season, it ranged from 17.5 $^{0}$C at Kebirigo to 23.5 $^{0}$C at Kadongo Bridge with an overall river mean of 20.5 °C (Figure 6).

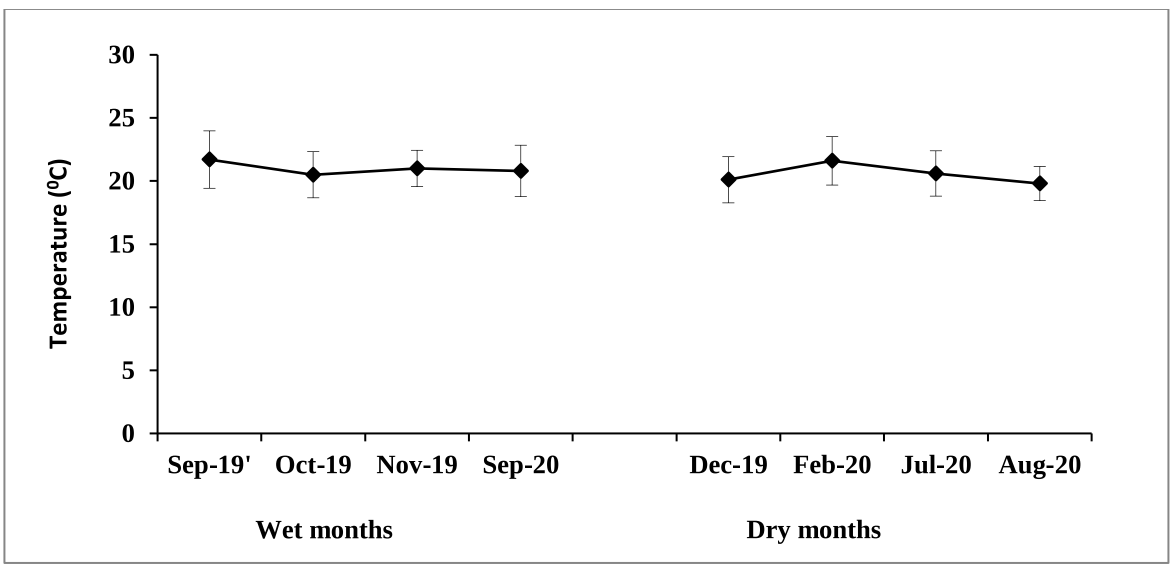


***Figure 6.*** **Mean (±SE) monthly temperature variations in River Awach Kibuon**

A two-sample t-test showed no significant temporal variation between wet and dry seasons in River Awach Kibuon; t (70) = 1.144, p = 0.256.

### 4.2.3 Dissolved oxygen (DO)

The mean longitudinal DO in River Awach Kibuon was lowest at River mouth station (6.91 mg $L^{-1}$) and highest at Nyangoso Bridge (7.57 mg $L^{-1}$) with an overall river mean of 7.31 mg $L^{-1}$. The spatial pattern of mean DO in River Awach Kibuon is presented in Figure 7. Mean spatial DO generally decreased downstream except at Kochola Bridge and Kendu Bay Bridge stations. One-way analysis of variance test showed that mean spatial dissolved oxygen at the $p<.05$ level varied significantly between sampling stations ($F (8, 63) = 2.27$, $p = 0.033$). Comparisons of various pairs using Tukey HSD post hoc test revealed 3 homogeneous groups and several significant variations. River mouth and Kadongo Bridge stations; Eaka Coffee Factory, Nyamiacho Waterfall, Kendu Bay Bridge and Kebirigo stations; Kochola Bridge, Nyangoso Bridge and Nyangoso Water Tower stations were homogeneous.

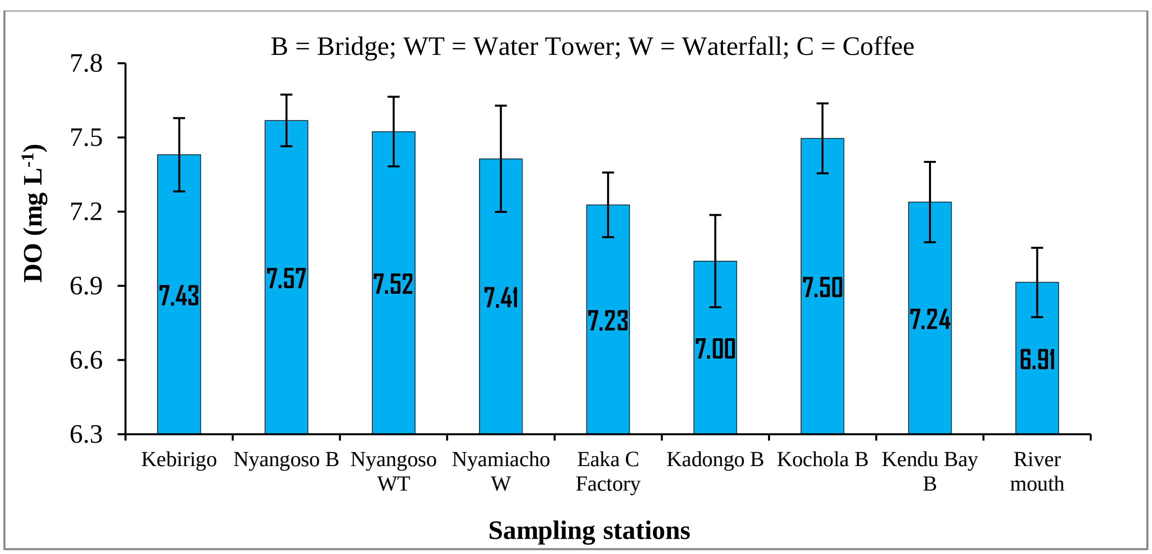


***Figure 7.*** **Mean (±SE) spatial dissolved oxygen variations in River Awach Kibuon**

The mean monthly river dissolved oxygen concentrations during wet and dry seasons is presented in Figure 8. During wet season, the lowest reading of 6.25 mg $L^{-1}$ was recorded at River mouth station while the highest reading of 8.17 mg $L^{-1}$ was recorded at Kochola Bridge station with an overall river mean of 7.39 mg $L^{-1}$. During the dry season, it ranged from 6.24 mg $L^{-1}$ at Kadongo Bridge station to 8.15 mg $L^{-1}$ at Nyamiacho Waterfall with an overall river mean of 7.24 mg $L^{-1}$. A two-sample t-test did not show any significant temporal variation between wet and dry seasons in River Awach Kibuon; t (70) = 1.323, p = 0.190.

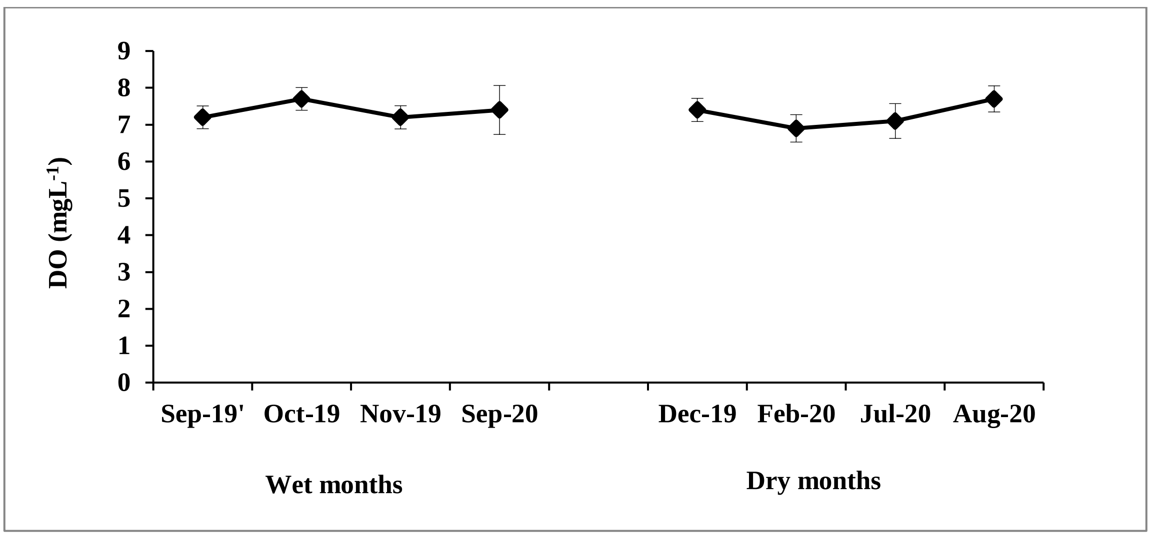


***Figure 8.*** **Mean (±SE) monthly dissolved oxygen concentrations in River Awach Kibuon**

### 4.2.4 pH

The mean spatial pH in River Awach Kibuon was lowest at River mouth station (7.42) and highest at Kebirigo station (7.98) with an overall river mean of 7.64. The spatial pattern of mean water pH in River Awach Kibuon is presented in Figure 9. Mean longitudinal pH did not show a clear pattern and was characterized by numerous fluctuations. One-way analysis of variance showed that mean spatial pH at the $p<.05$ level did not vary significantly between sampling stations (F (8, 63) = 0.67, p = 0.718).

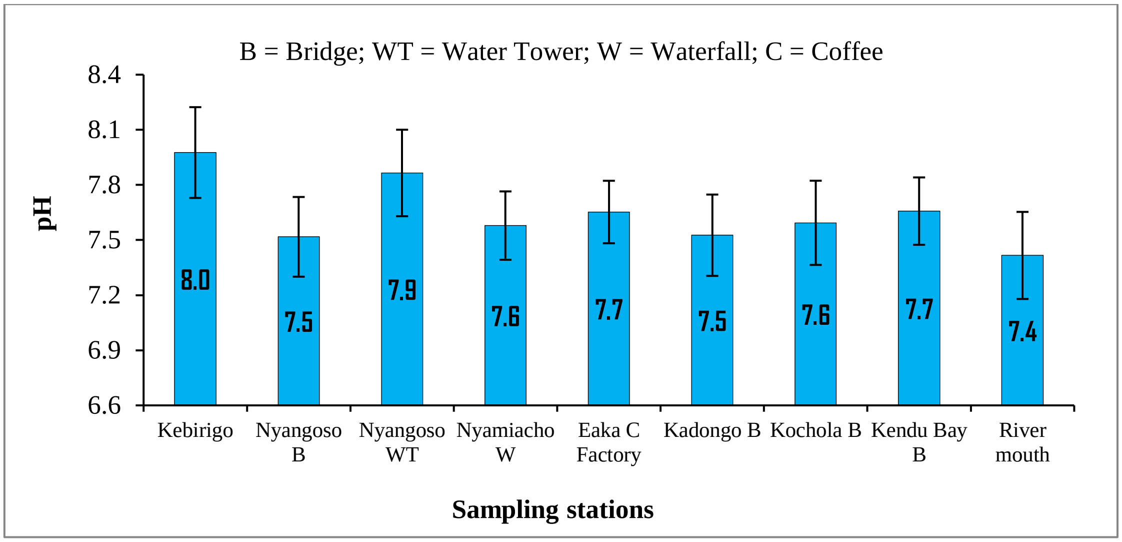


***Figure 9.*** **Mean (±SE) spatial pH variations in River Awach Kibuon**

The mean monthly pH variations during wet and dry seasons is presented in Figure 10. During the wet season, it ranged from 6.33 at Nyangoso Bridge to 8.75 at Nyangoso Water Tower with an overall mean of 7.39. During the dry season, it was lowest at River mouth station (7.01) and highest at Kebirigo station (8.72) with an overall river mean of 7.92.

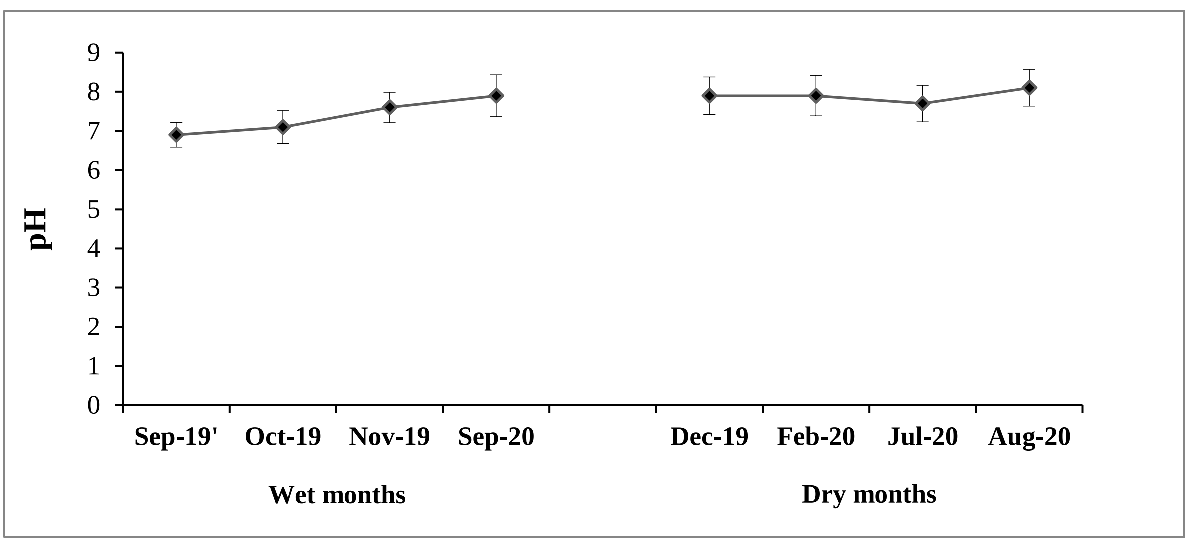


***Figure 10.*** **Mean (±SE) monthly pH variations in River Awach Kibuon**

On the other hand, a two-sample t-test showed significant temporal variation between wet and dry seasons in River Awach Kibuon; t (70) = -4.480, p = 0.0005.

### 4.2.5 Electrical conductivity

The mean spatial electrical conductivity in River Awach Kibuon ranged from 54.7 ± 0.83 µS $cm^{-1}$ at Nyangoso Water Tower station to 95.9 ± 0.72 µS $cm^{-1}$ at Kebirigo station with an overall river mean of 72.28 ± 16.9 µS $cm^{-1}$. The longitudinal pattern of mean water electrical conductivity in River Awach Kibuon is presented in Figure 11. Mean spatial electrical conductivity generally increased downstream except at Kebirigo station where it was highest. One-way analysis of variance showed that mean spatial electrical conductivity at the $p<.05$ level varied significantly between sampling stations ($F$ (8, 63) = 100.03, $p$ = 0.0002). Comparisons of different pairs using Tukey HSD post hoc test showed 4 homogeneous groups and several significant variations. Nyangoso Bridge, Nyangoso Water Tower, Nyamiacho Waterfall and Eaka Coffee Factory stations; Kadongo Bridge and Kochola Bridge; Kendu Bay Bridge and River mouth and Kebirigo and River mouth stations were homogeneous groups.

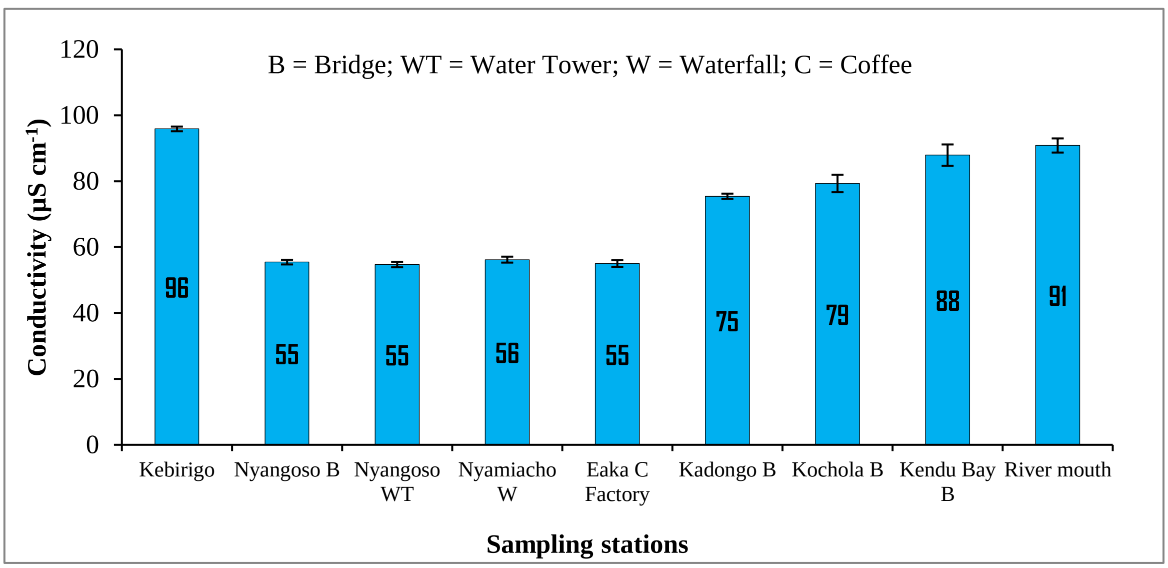


***Figure 11.*** **Mean (±SE) spatial electrical conductivity variations in River Awach Kibuon**

The mean river monthly electrical conductivity variations between wet and dry seasons is presented in Figure 12. During the wet season, it was lowest at Nyangoso Water Tower and

Nyamiacho Waterfall stations (53.3 µS cm$^{-1}$) and highest at Kendu Bay Bridge station (99.5 µS cm-1) with an overall river mean value of 71.5 µS cm$^{-1}$. During the dry season, it ranged from 50 µS cm$^{-1}$ at Nyangoso Water Tower station to 98.7 µS cm$^{-1}$ at Kebirigo station with an overall river mean value of 73.1 µS cm$^{-1}$. A two-sample t-test showed no significant temporal variation between wet and dry seasons in River Awach Kibuon; t (70) = 0.383, p = 0.703.

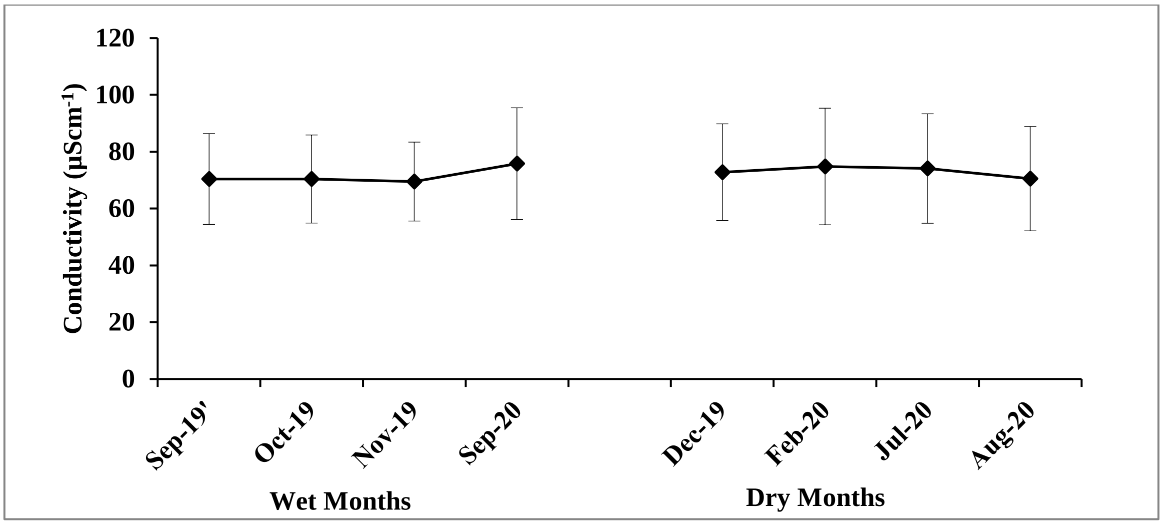


***Figure 12.*****Mean (±SE) monthly electrical conductivity variations in River Awach Kibuon**

### 4.2.6 Turbidity

The mean spatial turbidity in River Awach Kibuon ranged from 51 ± 2 NTU at Kebirigo station to 342 ± 41 NTU at River mouth station with an overall river mean of 201 ± 18 NTU. The longitudinal pattern of mean water turbidity in River Awach Kibuon is presented in Figure 13. Mean spatial water turbidity steadily increased downstream. One-way ANOVA showed that mean spatial turbidity at the $p<.05$ level varied significantly between sampling stations (F (8, 63) = 8.14, P = 0.005). Various pair-wise comparisons using Tukey HSD post hoc test showed numerous significant variations between stations and 4 homogeneous groups. The first 5 upstream stations were homogeneous. The remaining four midtream and downstream stations (Kadongo Bridge, Kochola Bridge, Kendu Bay Bridge and River mouth) were also homogeneous.

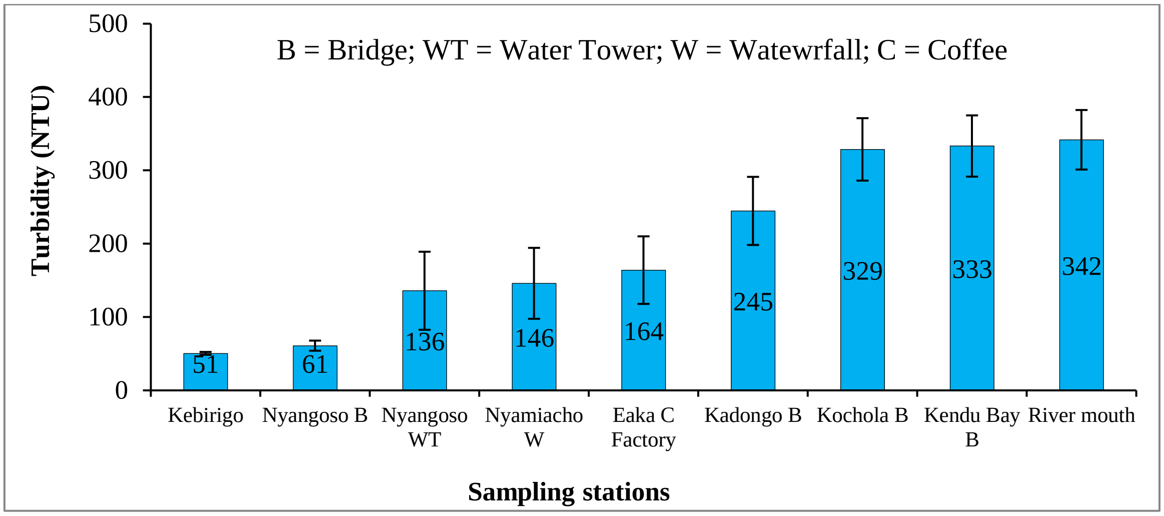


***Figure 13.*** **Mean (±SE) spatial turbidity variations in River Awach Kibuon**

The mean monthly turbidity variations between wet and dry seasons is presented in Figure 14. During the wet season, it was lowest at Kebirigo station (43 NTU) and highest at Nyangoso Water Tower station (487 NTU) with an overall river mean of 227 NTU. During the dry season, it ranged from 50 NTU at Nyamiacho Waterfall station to 468 NTU at Kadongo Bridge station with an overall river mean of 174 NTU. A two-sample t-test did not reveal significant temporal variation between wet and dry seasons in River Awach Kibuon; $t(70) = 1.480$, $p = 0.144$.

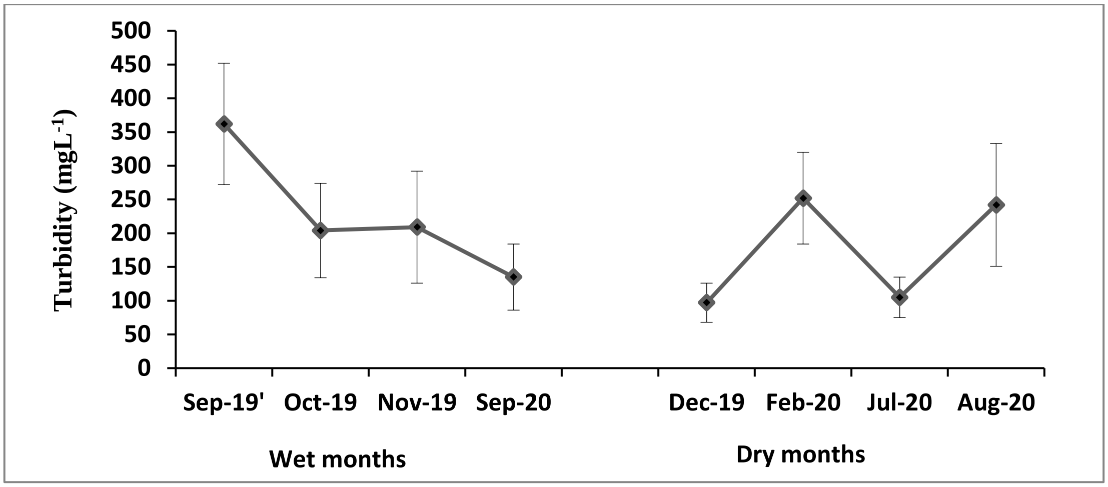


***Figure 14*. Mean (±SE) monthly turbidity variations in River Awach Kibuon**

### 4.2.7 Total dissolved solids (TDS)

The mean spatial TDS in River Awach Kibuon was lowest at Nyangoso Bridge station (42.2 ± 1.3 mg $L^{-1}$) and highest at Kebirigo station (73.9 ± 1.0 mg $L^{-1}$) with an overall river mean of 53.5 ± 1.4 mg $L^{-1}$. The spatial pattern of mean water turbidity in River Awach Kibuon is presented in Figure 15. Mean spatial TDS increased downstream but was highest in the first station upstream (Kebirigo). One-way analysis of variance showed that mean spatial turbidity at $p<.05$ level varied significantly between sampling stations ($F (8, 63) = 46.80$, $p = 0.0005$). Comparisons of various pairs using Tukey HSD post hoc test showed numerous significant variations between stations and 4 homogeneous groups. The first four upstream stations were homogeneous. Kadongo Bridge and Kochola Bridge; Kochola Bridge and Kendu Bay Bridge; and Kendu Bay Bridge and River mouth stations were also homogeneous.

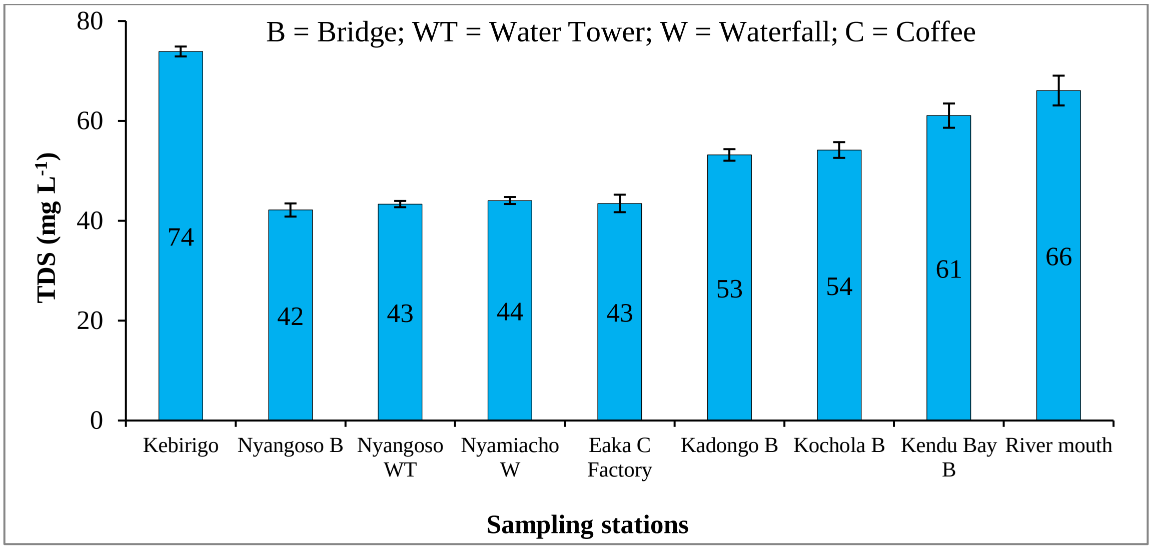


***Figure 15.*** **Mean (±SE) spatial total dissolved solids variations in River Awach Kibuon**

The mean monthly TDS variations between wet and dry seasons is presented in Figure 16. During the wet season, it ranged from 33.8 mg $L^{-1}$ at Nyangoso Bridge station to 81.9 mg $L^{-1}$ at River mouth station with an overall river mean of 52.8 mg $L^{-1}$. During the dry season, it was lowest at Nyamiacho Waterfall station (34.5 mg $L^{-1}$) and highest Kebirigo station (78.7 mg $L^{-1}$) with an overall river mean of 54.2 mg $L^{-1}$. A two-sample t-test did not show significant temporal variation between wet and dry seasons in the river; $t(70) = -0.524$, $p = 0.602$.

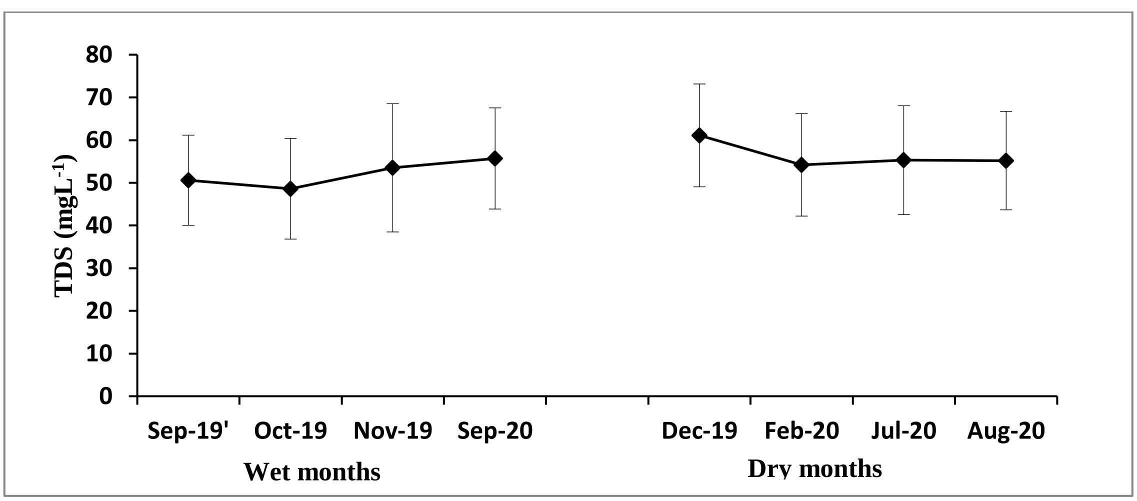


***Figure 16.*** **Mean (±SE) monthly total dissolved solids variations in River Awach Kibuon**

#### 4.2.8 Total nitrogen (TN)

The mean spatial TN in River Awach Kibuon ranged from 654 µg $L^{-1}$ at River mouth station to 1740 µg $L^{-1}$ at Kebirigo station with an overall mean of 1000 ± 81 µg $L^{-1}$. The spatial pattern of mean TN in River Awach Kibuon is presented in Figure 17. Mean spatial TN was highest upstream and steadily decreased downstream. One-way analysis of variance showed that mean spatial TN at the $p<.05$ level varied significantly among sampling stations ($F(8, 63) = 2.38$, $p = 0.026$). Comparisons of pairs using Tukey HSD post hoc test showed that Kebirigo station varied significantly with Kendu Bay and River mouth stations.

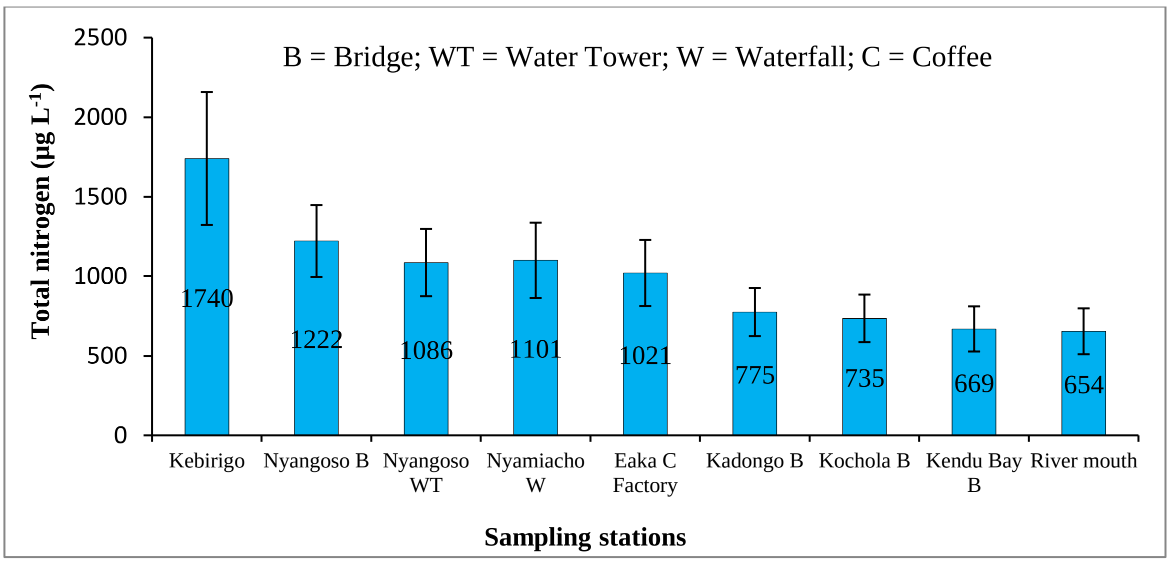


***Figure 17.*** **Mean (±SE) spatial total nitrogen variations in River Awach Kibuon**

The mean monthly TN variations between wet and dry seasons is presented in Figure 18. During the wet season, it ranged from 405 µg $L^{-1}$ at Kendu Bay Bridge station to 3465 µg $L^{-1}$ at Kebirigo station with an overall river mean of 1056 µg $L^{-1}$. During the dry season, it was lowest at Kendu Bay Bridge station (254 µg $L^{-1}$) and highest at Kebirigo station (3461 µg $L^{-1}$) with an overall river mean of 945 µg $L^{-1}$. A two-sample T-test did not show significant temporal variation between wet and dry seasons in River Awach Kibuon; t (70) = 0.688, p = 0.494.

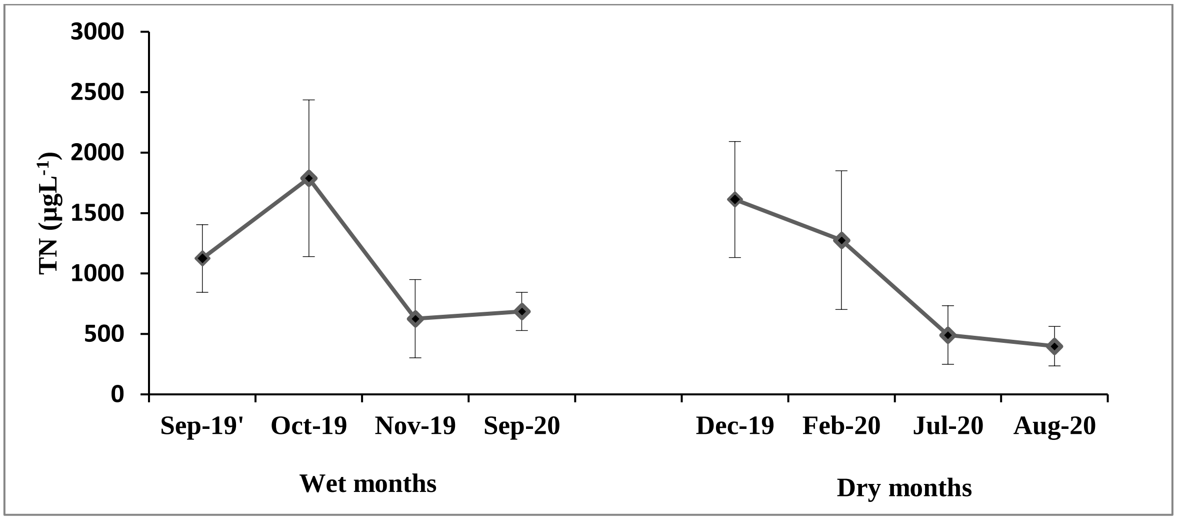


***Figure 18.*** **Mean (±SE) monthly total nitrogen variations in River Awach Kibuon**

### 4.2.9 Total phosphorus (TP)

The mean spatial TP in River Awach Kibuon was lowest at Nyangoso Bridge station (50 ± 7 µg $L^{-1}$) and highest at Kochola Bridge station (223 ± 35 µg $L^{-1}$) with an overall river mean of 125 ± 11 µg $L^{-1}$. The spatial pattern of mean TP in River Awach Kibuon is presented in Figure 19. Mean spatial total phosphorus increased downstream in the river reaching its highest value at the River mouth station. One-way ANOVA test showed that mean spatial total phosphorus at the $p<.05$ varied significantly among sampling stations (F (8, 63) = 5.68, p = 0.00002). Various pair-wise comparisons using Tukey HSD post hoc test showed numerous significant variations between stations and 4 overlapping homogeneous groups. The first 6 upstream and midstream stations were homogeneous. The last 5 midstream and downstream stations were equally homogeneous. Nyangoso Water Tower, Nyamiacho Waterfall, Eaka Coffee Factory, Kadongo Bridge and River mouth stations; and

Nyamiacho Waterfall, Eaka Coffee Factory, Kadongo Bridge, Kendu Bay Bridge, and River mouth stations were homogeneous.

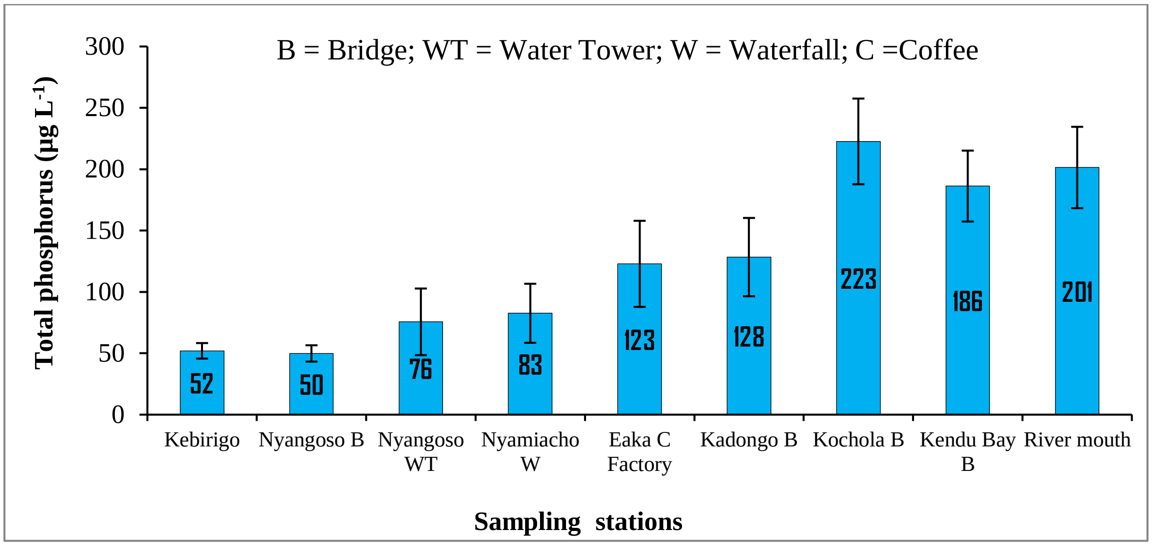


***Figure 19.*** **Mean (±SE) spatial total phosphorus variations in River Awach Kibuon**

The mean monthly total phosphorus variations between wet and dry seasons is presented in Figure 20. During the wet season, it ranged from 42 µg $L^{-1}$ at Nyangoso Bridge station to 285µg $L^{-1}$ at Eaka Coffee Factory station with an overall river mean of 119 µg $L^{-1}$. During the dry season, it ranged from 36 µg $L^{-1}$ at Kebirigo station to 386 µg $L^{-1}$ at River mouth station with an overall mean of 130 µg $L^{-1}$. A two-sample t-test did not show significant temporal variation between wet and dry seasons in the river; t (70) = -0.457, p = 0.649.

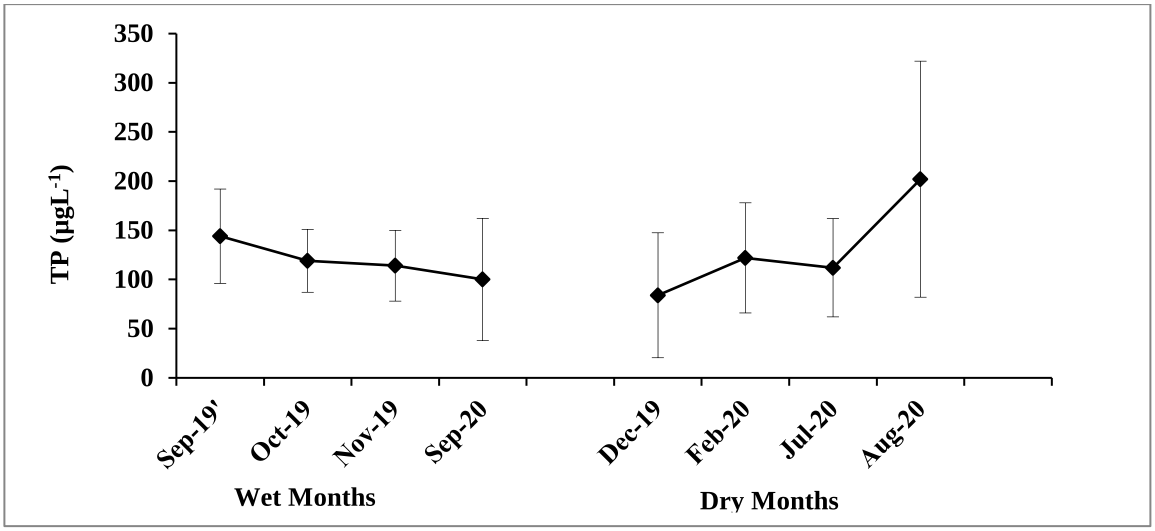


***Figure 20.*** **Mean (±SE) monthly total phoshphorus variations in River Awach Kibuon**

## 4.3 Habitat assessment

The results of river habitat assessment are summarized and presented in Table 14. The results of habitat assessment of River Awach Kibuon indicated that natural riparian buffer vegetation was narrow in all five upstream stations, increased and widened in mid-stream stations and became extensive at the River mouth station. Aesthetics of reach value was lowest in upstream stations (common setting), improved mid-stream (natural area) and reached highest value (wilderness) at River mouth station. Bottom substrate stability decreased downstream; stable upstream, moderately stable mid-stream and unstable downstream. Channel sinuosity generally increased downstream; low upstream, moderate mid-stream and high downstream. Riffles were most abundant in upstream stations, common in mid-stream stations, but were rare at the river mouth. River bank stability was variable but generally more unstable in upstream stations. The size of pools generally increased downstream.

**Table 7. Habitat Quality Metric Scores summed up as Habitat Quality Indices (HQI) for the nine sampling stations in River Awach Kibuon**

| Sampling Station / Parameter | Kebirigo | Nyangoso Bridge | Nyangoso Water Tower | Nyamiacho Waterfall | Eaka Coffee Factory | Kadongo Bridge | Kochola Bridge | Kendu Bay Bridge | River Mouth |
|---|---|---|---|---|---|---|---|---|---|
| In-stream cover | 3 | 1 | 3 | 3 | 2 | 4 | 4 | 2 | 4 |
| Riparian vegetation | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 3 |
| Bank stability | 0 | 2 | 2 | 3 | 0 | 2 | 2 | 1 | 2 |
| Channel sinuosity | 1 | 1 | 2 | 1 | 3 | 2 | 2 | 3 | 3 |
| Number of riffles | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 2 |
| Bottom substrate | 4 | 3 | 4 | 4 | 3 | 3 | 2 | 4 | 1 |
| Dimension of pools | 2 | 1 | 2 | 2 | 1 | 2 | 3 | 4 | 3 |
| Aesthetics of reach | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 3 |
| **Total** | **15** | **12** | **17** | **17** | **14** | **21** | **20** | **18** | **21** |

The main habitat characteristics (metrics) were scored according to the guidelines given in Table 1 and summed up to give a Habitat Quality Index (HQI) for each station (Table 7). Habitat Quality Indices of sampling stations generally increased downstream (Table 7). It ranged from 12 at Nyangoso Bridge station to 21 at Kadongo Bridge and River mouth stations, showing that the downstream stations had better habitat quality than the upstream stations. Kebirigo, Nyangoso Bridge and Eaka Coffee Factory stations have the lowest habitat quality (degraded) while Nyangoso Water Tower, Nyamiacho Waterfall and Kendu Bay Bridge stations have moderate habitat quality (moderately degraded). On the other hand, Kadongo Bridge, Kochola Bridge and River mouth stations have good habitat quality (undegraded).

Mean depth (m) in River Awach Kibuon ranged from 0.28 ± 0.02 m at Kebirigo station to 0.90 ± 0.1 m at River mouth station. River depth increased downstream conforming to expected longitudinal trends. Mean spatial river depth varied significantly spatially ($F$ (8, 63) = 12.03, $p$ = 0.005). In contrast, mean temporal river depth did not vary significantly between wet and dry seasons; $t$ (70) = 0.878, $p$ = 0357. Mean channel width (m) in River

Awach Kibuon was lowest upstream at Kebirigo (2.49 ± 0.2 m) and highest downstream at Kendu Bay Bridge station (14.6 ± 1.0 m). River width increased downstream and conformed to expected longitudinal trends. Mean spatial river width (m) varied significantly ($F (8, 63) = 32.18$, $p = 0.0005$). However, mean temporal river width did not vary significantly between wet and dry seasons; $t (70) = -0.449$, $p = 0.655$.

## 4.4 Biological assessment

### 4.4.1 Diversity indices

#### 4.4.1.1 Fish community characteristics

A total of 983 fish specimens were caught in River Awach Kibuon during the 8 months sampling period for river ecosystem integrity assessment (Table 8). There were a total of 21 species, 12 genera, 7 families and 6 orders represented in the catches. The family Cyprinidae and its genus *Enteromius* dominated the middle and lower reaches of the river. There was a total of 19 native species and 2 introduced (exotic) species. The fish data collected from the river were used to compute species richness and indices (D, H′, J, GSI, HSI, EGI and FIBI).

**Table 8. Checklist of fish species caught in River Awach Kibuon during the study**

| Order | Family | Genus | Species | Abundance |
|---|---|---|---|---|
| **Siluriformes** | Claridae | *Clarias* | *Clarias theodorae* | 29 |
| | Claridae | *Clarias* | *Clarias gariepinus* | 32 |
| | Claridae | *Clarias* | *Clarias alluaudi* | 2 |
| | Mochokidae | *Synodontis* | *Synodontis victoriae* | 1 |
| | Mochokidae | *Synodontis* | *Synodontis afrofischeri* | 1 |
| | Mochokidae | *Chiloglanis* | *Chiloglanis* sp. | 2 |
| **Cypriniformes** | Cyprinidae | *Enteromius* | *Enteromius paludinosus* | 1 |
| | Cyprinidae | *Enteromius* | *Enteromius neumayeri* | 34 |
| | Cyprinidae | *Enteromius* | *Enteromius apleurogramma* | 11 |
| | Cyprinidae | *Enteromius* | *Enteromius jacksoni* | 29 |
| | Cyprinidae | *Enteromius* | *Enteromius nyanzae* | 217 |
| | Cyprinidae | *Enteromius* | *Enteromius kerstenii* | 41 |
| | Cyprinidae | *Enteromius* | *Enteromius cercops* | 372 |
| | Cyprinidae | *Labeobarbus* | *Labeobarbus altianalis* | 97 |
| | Cyprinidae | *Labeo* | *Labeo victorianus* | 21 |
| **Perciformes** | Cichlidae | *Pseudocrenilabrus* | *Pseudocrenilabrus multicolor* | 48 |
| | Cichlidae | *Oreochromis* | *Oreochromis leucostictus* | 11 |
| | Cichlidae | *Haplochromis* | *Haplochromis* sp | 13 |
| **Cyprinodontiformes** | Poeciliidae | *Gambusia* | *Gambusia affinis* | 12 |
| **Synbranchiformes** | Mastacembelidae | *Mastacembelas* | *Mastacembelas frenatus* | 8 |
| **Osteoglossiformes** | Mormyridae | *Hippopotamyrus* | *Hippopotamyrus grahami* | 1 |
| **6 orders** | **7 families** | **12 genera** | **21 species** | **983** |

#### 4.4.1.2 Species richness

The spatial fish species richness in 9 sampling stations in River Awach Kibuon is presented in Table 9. A total of 21 fish species were encountered in the whole river. Spatial species richness ranged from 0 species at Kebirigo, Nyangoso Bridge, Nyangoso Water Tower and Nyamiacho Waterfall to 18 species at River mouth station. The spatial species richness increased downstream. River mouth station had the highest percentage of species richness of 86 % while the first 4 upstream stations had no fish.

**Table 9. Fish species richness in 9 sampling stations in River Awach Kibuon**

| Station | Number of species (richness) | (%) Species richness |
|---|---|---|
| Kebirigo | 0 | 0 |
| Nyangoso Bridge | 0 | 0 |
| Nyangoso Water Tower | 0 | 0 |
| Nyamiacho Waterfall | 0 | 0 |
| Eaka Coffee Factory | 2 | 10 |
| Kadongo Bridge | 9 | 43 |
| Kochola Bridge | 6 | 29 |
| Kendu Bay Bridge | 4 | 19 |
| River mouth | 18 | 86 |
| **Total** | **21** | |

Monthly fish species richness in River Awach Kibuon is presented in Figure 21. During the wet season species richness ranged from 6 species in November 2019 to 14 species in September 2019 with a median of 10 species. During the dry season species richness ranged from 9 species in December 2019 to 10 in February, July and August 2020 with a median of 11 fish species.

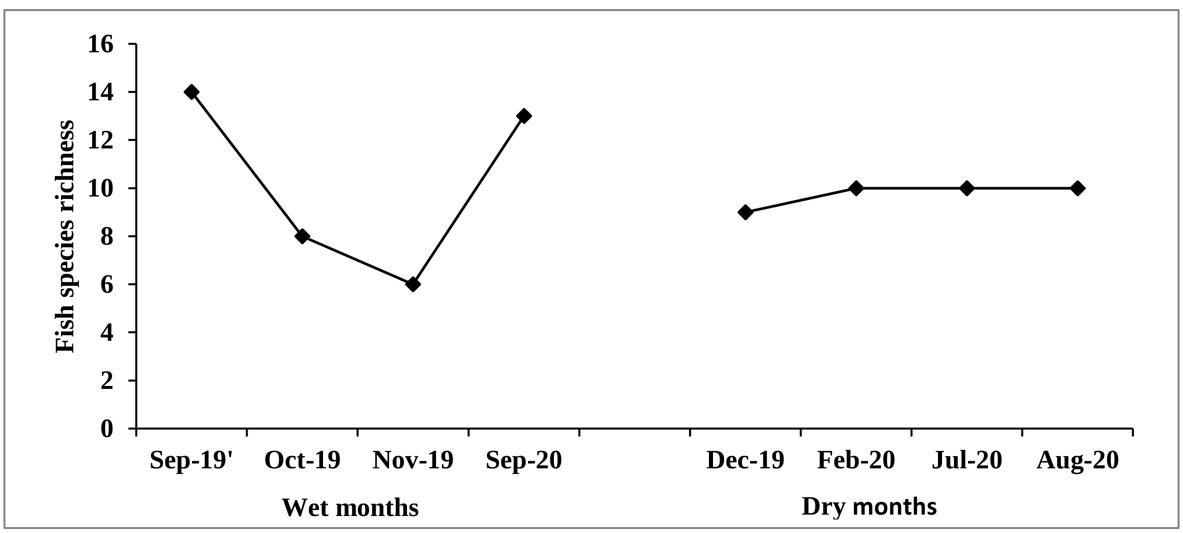


***Figure 21.*** **Monthly fish species richness in River Awach Kibuon**

#### 4.4.1.3 Species abundance

The total spatial fish abundance across the 9 samplings stations is presented in Table 10. Spatial fish abundance in River Awach Kibuon ranged from 0 in four upstream stations and 628 at the River mouth station. Eaka Coffee Factory, Kadongo Bridge, Kochola Bridge and Kendu Bay Bridge stations recorded 22, 149, 118 and 66 fish, respectively. Fish abundance in River Awach Kibuon generally increased downstream.

**Table 10. Fish abundance in 9 sampling stations in River Awach Kibuon**

| **Station** | **Number of fish caught (Abundance)** | **% Abundance** |
|---|---|---|
| Kebirigo | 0 | 0 |
| Nyangoso Bridge | 0 | 0 |
| Nyangoso Water Tower | 0 | 0 |
| Nyamiacho Waterfall | 0 | 0 |
| Eaka Coffee Factory | 22 | 2 |
| Kadongo Bridge | 149 | 15 |
| Kochola Bridge | 118 | 12 |
| Kendu Bay Bridge | 66 | 7 |
| River mouth | 628 | 64 |
| **Total** | **983** | **100** |

The temporal fish abundance in River Awach Kibuon is presented in Figure 22. During the wet season fish abundance ranged from 55 fish in September 2019 to 218 in September 2020 with a median of 66 fish. During the dry season fish abundance ranged from 33 fish in December 2019 to 247 in July 2020 with a median of 149 fish.

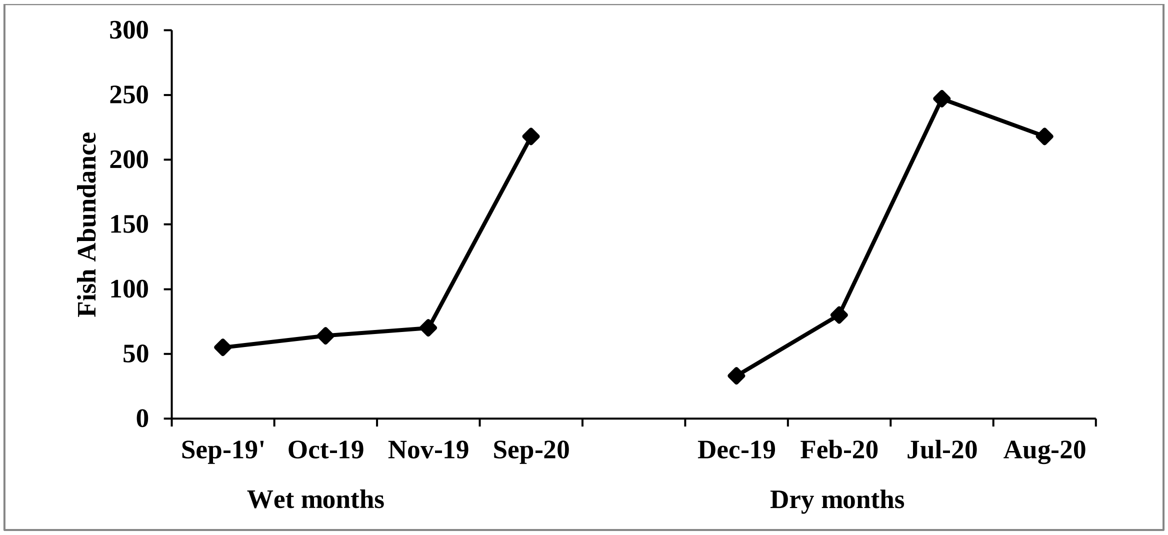


***Figure 22.*****Monthly fish abundance in River Awach Kibuon during wet and dry seasons**

The number of fish caught per species in River Awach Kibuon is presented in Table 11. The most numerically abundant fish species were *Enteromius cercops*, *Enteromius nyanzae* and *Labeobarbus altianalis* contributing 37.8%, 22.1% and 9.9% of total fish abundance, respectively. Seven species were rare and had a percentage abundance of less than 1%. These included *Mastacembelas frenatus*, *Enteromius paludinosus*, *Synodontis victoriae*, *Hippopotamyrus grahami*, *Clarias alluaudi*, *Chiloglanis* sp. and *Synodontis afrofischeri*. Majority of the species contributed between 1-5 % of total abundance.

**Table 11. Fish abundance per species in River Awach Kibuon**

| Fish species | Number caught | Relative abundance |
|---|---|---|
| *Enteromius cercops* | 372 | 37.8 |
| *Enteromius nyanzae* | 217 | 22.1 |
| *Labeobarbus altianalis* | 97 | 9.9 |
| *Pseudocrenilabrus multicolor* | 48 | 4.9 |
| *Enteromius kerstenii* | 41 | 4.2 |
| *Enteromius neumayeri* | 34 | 3.5 |
| *Clarias gariepinus* | 32 | 3.3 |
| *Clarias theodorae* | 29 | 3.0 |
| *Enteromius jacksoni* | 29 | 3.0 |
| *Labeo victorianus* | 21 | 2.1 |
| *Happlochromis* | 13 | 1.3 |
| *Gambusia affinis* | 12 | 1.2 |
| *Enteromius apleurogramma* | 11 | 1.1 |
| *Oreochromis leucostictus* | 11 | 1.1 |
| *Mastacembelas frenatus* | 8 | 0.8 |
| *Clarias alluaudi* | 2 | 0.2 |
| *Chiloglanis* sp. | 2 | 0.2 |
| *Synodontis victoriae* | 1 | 0.1 |
| *Synodontis afrofischeri* | 1 | 0.1 |
| *Enteromius paludinosus* | 1 | 0.1 |
| *Hippopotamyrus grahami* | 1 | 0.1 |
| **Total** | **983** | **100** |

#### 4.4.1.4 Spatial fish species distribution

The longitudinal distribution of fish species along River Awach Kibuon is presented in Table 12. The first four upstream stations (Kebirigo, Nyangoso Bridge, Nyangoso Water Tower and Nyamiacho Waterfall) had no fish. The fifth upstream station (Eaka Coffee Factory) had two clarid species (*Clarias gariepinus* and *Clarias theodorae*). The midstream stations (Kadongo Bridge and Kochola Bridge) recorded 9 fish species dominated by cyprinid and clarid species. Kendu Bay Bridge station recorded 4 cyprinid and clarid fish species whereas River mouth station recorded 18 fish species.

**Table 12. Spatial distribution of fish species at 9 sampling stations in River Awach Kibuon**

| Name of species | Kebirigo | Nyangoso Bridge | Nyangoso W Tower | Nyamiacho Waterfall | Eaka C Factory | Kadongo Bridge | Kochola Bridge | Kendu Bay Bridge | River Mouth |
|---|---|---|---|---|---|---|---|---|---|
| *Enteromius paludinosus* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Synodontis afrofischeri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Hippopotamyrus grahami* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Clarias alluaudi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Chiloglanis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Synodontis victoriae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Mastacembelas frenatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Enteromius apleurogramma* | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| *Oreochromis leucostictus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Gambusia affinis* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *Happlochromis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Labeo victorianus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Enteromius jacksoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Clarias theodorae* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| *Clarias gariepinus* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| *Enteromius neumayeri* | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| *Enteromius kerstenii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Pseudocrenilabrus multicolor* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Labeobarbus altianalis* | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| *Enteromius nyanzae* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *Enteromius cercops* | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| **Total** | **0** | **0** | **0** | **0** | **2** | **9** | **6** | **4** | **18** |

*Note*. 0 represents absence, 1 represents presence, C = coffee, W = water

#### 4.4.1.5 Simpson's Index (D)

The minimum, maximum and median spatial D values for 9 sampling stations in River Awach Kibuon are presented in Table 13. The median D ranged from 0 in all the 5 upstream stations to 0.61 at the River mouth station. Spatial median D increased downstream with exception of Kendu Bay Bridge.

**Table 13. Spatial minimum, maximum and median Simpson's Indices at 9 sampling stations in River Awach Kibuon**

| Station | Simpson's Index (D) | | |
|---|---|---|---|
| | Minimum | Maximum | Median |
| Kebirigo | 0 | 0 | 0 |
| Nyangoso Bridge | 0 | 0 | 0 |
| Nyangoso Water Tower | 0 | 0 | 0 |
| Nyamiacho Waterfall | 0 | 0 | 0 |
| Eaka Coffee Factory | 0 | 0 | 0 |
| Kadongo Bridge | 0 | 0.90 | 0.49 |
| Kochola Bridge | 0 | 0.78 | 0.56 |
| Kendu Bay Bridge | 0 | 0.69 | 0.51 |
| River mouth | 0.21 | 0.91 | 0.61 |

The temporal median D values in River Awach Kibuon are presented in Figure 23. During the wet season D values ranged from 0 to 0.91 with a median of 0.52 while in the dry season D ranged from 0 to 0.86 with a median of 0.52. The median D was similar during wet and dry seasons.

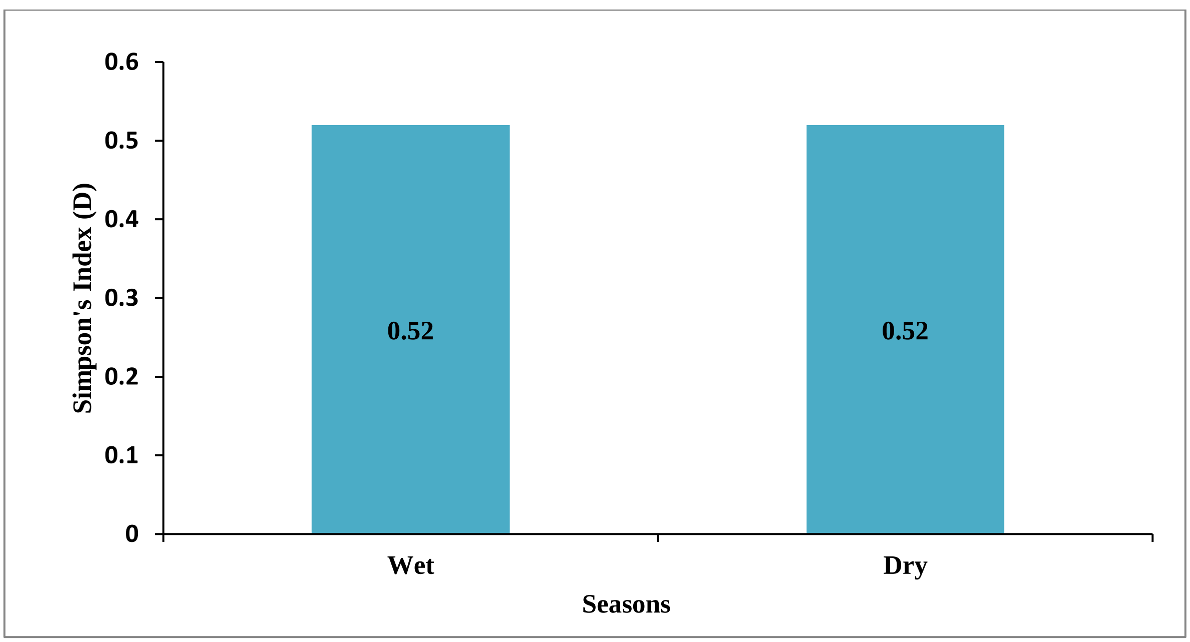


***Figure 23.*** **Temporal median Simpson's Index (D) values in River Awach Kibuon**

#### 4.4.1.6 Shannon-Weiner Index (H′)

The spatial minimum, maximum and median H′ for 9 sampling stations in River Awach Kibuon are presented in Table 14. It ranged from 0 at all the 5 upstream stations to 1.40 at the River mouth station. Spatial median H′ increased downstream with exception of Kendu Bay Bridge station.

**Table 14. Spatial minimum, maximum and median Shannon-Weiner Index (H') at 9 sampling stations in River Awach Kibuon**

| Station | Shannon-Wiener Index (H′) | | |
|---|---|---|---|
| | **Minimum** | **Maximum** | **Median** |
| Kebirigo | 0 | 0 | 0 |
| Nyangoso Bridge | 0 | 0 | 0 |
| Nyangoso Water Tower | 0 | 0 | 0 |
| Nyamiacho Waterfall | 0 | 0 | 0 |
| Eaka Coffee Factory | 0 | 0 | 0 |
| Kadongo Bridge | 0 | 1.55 | 0.68 |
| Kochola Bridge | 0.66 | 1.53 | 0.82 |
| Kendu Bay Bridge | 0 | 1.07 | 0.68 |
| River mouth | 0.52 | 2.03 | 1.40 |

The temporal median H′ values in River Awach Kibuon are presented in Figure 24. During the wet season, H′ ranged from 0 to 2.03 with a median of 0.74. During the dry season, H′ ranged from 0 to 1.75 with a median of 0.66. The median H' was slighty higher during wet season than dry season.

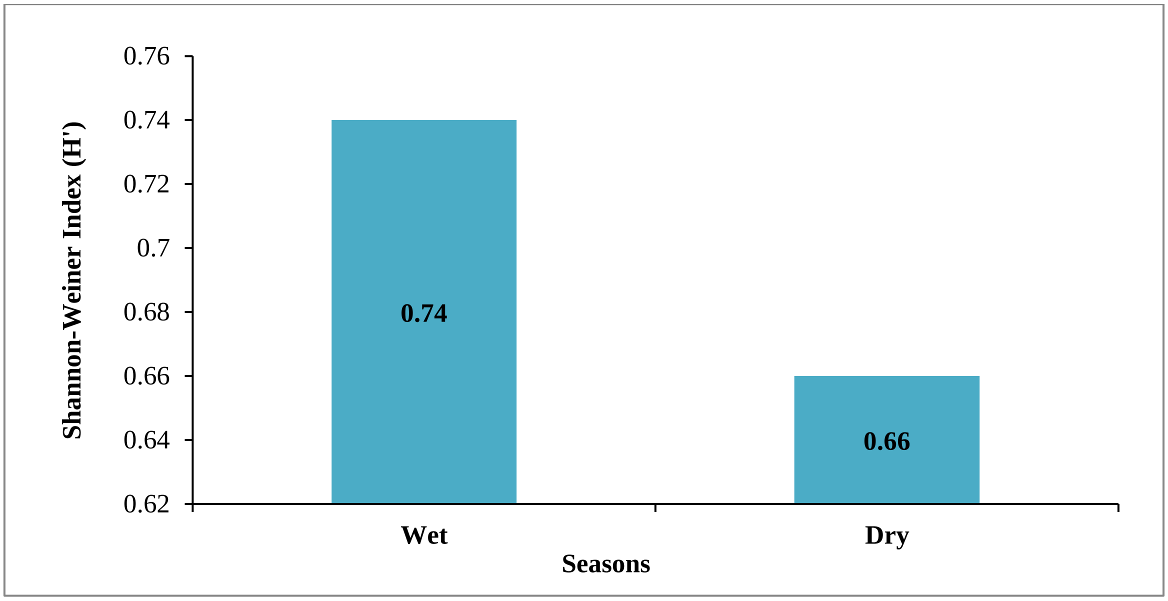


***Figure 24.*** **Temporal median Shannon-Weiner Indices in River Awach Kibuon**

#### 4.4.1.7 Pielou's Evenness Index (J)

The spatial median J for 9 sampling stations in River Awach Kibuon is presented in Table 15. It ranged from 0 at all the 5 upstream stations to 0.90 at Kochola Bridge station. The median J was highest midstream then decreased in both upstream and downstream directions.

**Table 15. Spatial minimum, maximum and median Pielou's Evenness Index (J) at 9 sampling stations in River Awach Kibuon**

| | Pielou's Evenness Index (J) | | |
|---|---|---|---|
| **Station** | Minimum | Maximum | Median |
| Kebirigo | 0 | 0 | 0 |
| Nyangoso Bridge | 0 | 0 | 0 |
| Nyangoso Water Tower | 0 | 0 | 0 |
| Nyamiacho Waterfall | 0 | 0 | 0 |
| Eaka Coffee Factory | 0 | 0 | 0 |
| Kadongo Bridge | 0 | 0.96 | 0.72 |
| Kochola Bridge | 0.60 | 1.46 | 0.90 |
| Kendu Bay Bridge | 0 | 0.98 | 0.75 |
| River mouth | 0.29 | 0.98 | 0.87 |

The temporal median J values in River Awach Kibuon are presented in Figure 25. During the wet season, J ranged from 0 to 1.0 with a median of 0.81. During the dry season, J ranged from 0 to 1.46 with a median of 0.67. The median J was higher during wet season than dry season.

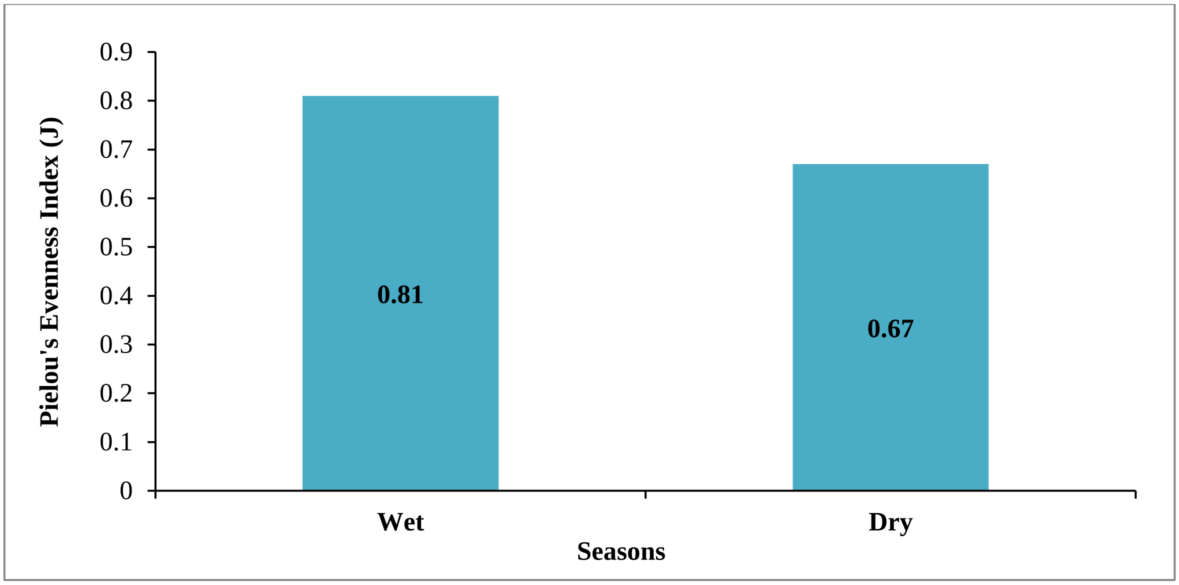


***Figure 25.*** **Temporal median Pielou's Evenness Index (J) values in River Awach Kibuon**

### 4.4.2 Other biological indices (GSI, HSI and EGI)

#### 4.4.2.1 Gonado-Somatic Index (GSI)

Gonado-Somatic Index is a reflection of the state of gonad development. The gonads (testis and ovaries) of *Enteromius cercops* and *Labeobarbus altianalis* were evaluated over a period of 8 months; 4 wet months (September, October, November 2019 and September 2020) and 4 dry months (December 2019 and February, July and August 2020).

#### 4.4.2.2 Gonado-Somatic Index of *Enteromius cercops*

The GSI results for *Enteromius cercops* based on sex of the fish in River Awach Kibuon are presented in Table 16. A total of 120 specimens were used to compute GSI of *Enteromius cercops* population in River Awach Kibuon. There were 74 male and 46 female specimens. The size range for males was from 0.11g to 237.6 g with a mean of 12.6 g. The size range for females was from 0.35-24.4 g with a mean of 4.5 g. The overall GSI values ranged from 0.5 to 15.1 with a median of 4.7. The male GSI values ranged from 0.5 to 6.5 with a median of 2.0 while the female GSI values ranged from 1.5 to 15.1 with a median of 9.5.

**Table 16. Gonado-Somatic Indices of *Enteromius cercops* in River Awach Kibuon**

| Sex | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Males | 74 | 0.11 – 137.6 | 12.6 | 0.5 – 6.5 | 2.0 |
| Females | 46 | 0.35 – 24.4 | 4.5 | 1.5 – 15.1 | 9.5 |
| Males and Females | 120 | 0.11 – 137.6 | 9.48 | 0.3 – 15.1 | 4.7 |

*Note*. GSI = Gonado-Somatic Index

The spatial GSI for *Enteromius cercops* in River Awach Kibuon is presented in Table 17. Kadongo Bridge and Kochola Bridge had the highest median GSI of 4.7 while River mouth had the lowest median GSI of 2.0. Median spatial GSI for *Enteromius cercops* decreased downstream from Kadongo.

**Table 17. Spatial median Gonado-Somatic Index variations of *Enteromius cercops* in River Awach Kibuon**

| Station | Number of specimens | Size range (g) | Mean fish size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Overall | 120 | 0.11 – 237.6 | 9.48 | 0.3 – 15.1 | 4.7 |
| Kadongo Bridge | 38 | 0.14 – 237.6 | 10.66 | 0.7 – 14.3 | 4.7 |
| Kochola Bridge | 52 | 0.77 – 211.8 | 12.67 | 0.5 – 10.3 | 4.7 |
| Kendu Bay Bridge | 12 | 1.21 – 24.37 | 4.27 | 0.5 – 13.3 | 2.6 |
| River mouth | 18 | 0.11 – 3.35 | 1.24 | 0.5 – 8.7 | 2.0 |

*Note*. GSI = Gonado-Somatic Index

Median temporal GSI in River Awach Kibuon is presented in Table 18. Season had a big effect on the GSI of *Enteromius cercops* in River Awach Kibuon. Median GSI values for wet and dry seasons were 2.7 and 4.7, respectively. Wet season had a bigger GSI range than the dry season. These findings conform to the expectation of higher GSI values for wet season than dry season. There was GSI synchronization with season.

**Table 18. Temporal median Gonado-Somatic Index variations of *Enteromius cercops* in River Awach Kibuon**

| Season | Number of specimens | Size range (g) | Mean fish size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Wet & dry | 120 | 0.11 – 237.6 | 9.48 | 0.5 - 15.1 | 4.7 |
| Wet | 47 | 0.11 – 131.95 | 7.87 | 0.5 - 15.1 | 2.7 |
| Dry | 73 | 0.30 – 237.6 | 10.52 | 0.5 - 10.3 | 4.7 |

*Note.* GSI = Gonado-Somatic Index

The GSI results of *Enteromius cercops* in River Awach Kibuon with respect to gonad stage is presented in Table 19. Mean GSI increased with advancement in gonad stage. The lowest median GSI (1.45) was observed at stage 2 (early maturing) of gonad development while the highest was observed at stage 5 (running) of gonad development (4.7).

**Table 19. The effects of gonad stage on Gonado-Somatic Index of *Enteromius cercops* in River Awach Kibuon**

| Gonad stage | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| All stages | 120 | 0.11 – 237.6 | 9.48 | 0.5 - 15.1 | 3.92 |
| Stage 2 – Early maturing | 14 | 0.37 – 37.6 | 8.91 | 0.9 - 12.8 | 1.45 |
| Stage 3 – Late maturing | 29 | 0.11 – 9.09 | 1.52 | 1.0  10.3 | 2.00 |
| Stage 4 - Ripe | 31 | 0.35 – 19.2 | 3.42 | 0.7 - 12.5 | 4.70 |
| Stage 5 - Running | 28 | 0.16 – 237.6 | 16.8 | 0.5 - 15.1 | 4.70 |
| Stage 6 - Spent | 18 | 1.53 – 211.8 | 21.9 | 0.7 - 13.3 | 3.30 |

*Note*. GSI = Gonado-Somatic Index

#### 4.4.2.3 Gonado-Somatic Index of *Labeobarbus altianalis*

The GSI results for *Labeobarbus altianalis* in River Awach Kibuon are presented in Table 20. A total of 51 specimens were used to compute GSI of *Labeobarbus altianalis* population in River Awach Kibuon. There were 37 male and 14 female specimens. The size range for males was from 0.7 - 848 g with a mean of 69.2 g. The size range for females was from 0.4 - 96.5 g for females with a mean of 32.8 g. The overall GSI values ranged from 0.3 to 8.8 with a median of 2.5. The male GSI values ranged from 0.3 to 7.3 while the female GSI values ranged from 1.6 to 8.8. As expected, females had a higher median GSI value (3.6) than males (1.1) since ovaries are heavier than testis.

**Table 20. Gonado-Somatic Indices of *Labeobarbus altianalis* in River Awach Kibuon**

| Sex | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Males | 37 | 0.7 - 848 | 69.2 | 0.3 - 7.3 | 1.1 |
| Females | 14 | 0.4 - 96.5 | 32.8 | 1.6 - 8.8 | 3.6 |
| Males and Females | 51 | 0.4 - 848 | 59.2 | 0.3 - 8.8 | 2.5 |

*Note*: GSI = Gonado-Somatic Index

The spatial GSI for *Labeobarbus altianalis* in River Awach Kibuon is presented in Table 21. Kadongo Bridge had the highest mean GSI of 6.1 while River mouth had the lowest median GSI of 0.4. Median spatial GSI for *Labeobarbus altianalis* decreased downstream from Kadongo.

**Table 21. Spatial median GSI values of *Labeobarbus altianalis* in River Awach Kibuon**

| Station | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Overall | 51 | 0.4 - 848 | 59.2 | 0.3 – 8.8 | 2.5 |
| Kadongo Bridge | 2 | 2.18 – 4.56 | 3.37 | 3.4 – 8.8 | 6.1 |
| Kochola Bridge | 27 | 0.4 - 848 | 78.4 | 0.6 – 7.3 | 3.9 |
| Kendu Bay Bridge | 18 | 10.23 – 96.5 | 39.44 | 0.3 – 3.7 | 0.6 |
| River mouth | 4 | 0.79 – 160 | 46.21 | 0.3 – 2.5 | 0.4 |

*Note.* GSI = Gonado-Somatic Index

Season had an effect on the GSI of *Labeobarbus altianalis* in River Awach Kibuon. The median GSI values for wet and dry seasons were 2.5 and 2.2, respectively (Table 22). This conforms to the expectation of a higher GSI value for wet season than dry season. There was GSI synchronization with season just as was observed in *Enteromius cercops*.

**Table 22. Median temporal GSI variations of *Labeobarbus altianalis* in River Awach Kibuon**

| Season | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| Wet & dry | 51 | 0.4 - 848 | 59.2 | 0.3 – 8.8 | 2.5 |
| Wet | 32 | 0.79 - 848 | 74.9 | 0.3 – 8.8 | 2.5 |
| Dry | 19 | 0.4 – 160 | 32.8 | 0.4 – 4.7 | 2.2 |

*Note*. GSI – Gonado-Somatic Index

The GSI results of *Labeobarbus altianalis* in River Awach Kibuon with respect to gonad stage is presented in Table 23. Mean GSI increased with advancement in gonad stage. The highest median GSI value was observed at stage 5 (running stage) of gonad development while the lowest median GSI value of 1.4 observed at stage stage 6 (spent) of gonad development.

**Table 23. The effects of gonad stage on GSI of *Labeobarbus altianalis* in River Awach Kibuon**

| Gonad stage | Number of specimens | Size range (g) | Mean size (g) | GSI Range | Median GSI |
|---|---|---|---|---|---|
| All stages | 51 | 0.4 - 848 | 59.2 | 0.3 – 8.8 | 2.5 |
| Stage 2 - Early maturing | 24 | 0.4 - 160 | 40.7 | 0.3 – 6.9 | 2.8 |
| Stage 3 - Late maturing | 10 | 0.7 – 160.3 | 40.7 | 0.3 – 4.3 | 3.0 |
| Stage 4 - Ripe | 2 | 2.18 – 48.1 | 25.1 | 3.4 – 5.0 | 4.2 |
| Stage 5 - Running | 10 | 1.11 - 848 | 152.96 | 0.3 – 8.8 | 4.3 |
| Stage 6 - Spent | 5 | 3.65 – 45.98 | 20.1 | 1.1 – 4.7 | 1.4 |

*Note*. GSI = Gonado-Somatic index

#### 4.4.2.4 Hepato-Somatic Index (HSI)

Hepato-Somatic index is the weight of the liver of an organism relative to its total body weight stated as a proportion. Two species, *Labeobarbus altianalis* and *Enteromius cercops,* were evaluated to determine their hepato-somatic indices.

#### 4.4.2.5 Hepato-Somatic Index (HSI) of *Enteromius cercops*

The HSI results for *Enteromius cercops* in River Awach Kibuon according to sex of the fish are presented in Table 24. A total of 120 specimens were used to compute HSI of *Enteromius cercops* population in River Awach Kibuon. There were 74 males and 46 females. The overall HSI values ranged from 0.1 to 7.3 with a median of 1.2. The male HSI values ranged from 0.1 to 4.3 while the female HSI values ranged from 0.1 to 7.3. The median HSI for males was 1.6 while the median HSI for females was 1.1. Sex of the fish made some difference in HSI values of *Enteromius cercops* in River Awach Kibuon.

**Table 24. Median Hepato-Somatic Indices of *Enteromius cercops* in River Awach Kibuon**

| Sex | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| Males | 74 | 0.11 - 137.6 | 12.6 | 0.1 - 4.3 | 1.6 |
| Females | 46 | 0.35 – 24.4 | 4.5 | 0.1 - 7.3 | 1.1 |
| Males and females | 120 | 0.11 – 137.6 | 9.48 | 0.1 - 7.3 | 1.2 |

*Note*. HSI = Hepto-Soamtic Index

The spatial HSI for *Enteromius cercops* in River Awach Kibuon is presented in Table 25. Kochola Bridge had fish with the highest median HSI of 1.8 while River mouth and Kadongo Bridge had the lowest median HSI values of 0.9 and 1.0, respectively. Median spatial HSI for *Enteromius cercops* did not show any discernible trend.

**Table 25. Spatial median variations of Hepato-Somatic Indices of *Enteromius cercops* in River Awach Kibuon**

| Sampling Station | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| All specimens | 120 | 0.11 - 237.6 | 9.48 | 0.1 - 7.3 | 1.2 |
| Kadongo Bridge | 38 | 0.14 - 237.6 | 10.66 | 0.1 - 4.5 | 1.0 |
| Kochola Bridge | 52 | 0.77 - 211.8 | 12.67 | 0.1 - 7.3 | 1.8 |
| Kendu Bay Bridge | 12 | 1.21 - 24.37 | 4.27 | 0.7 - 2.1 | 1.4 |
| River mouth | 18 | 0.11 - 3.35 | 1.24 | 0.1 - 2.4 | 0.9 |

*Note*. HSI = Hepato-Somatic Index

The median temporal HSI values for *Enteromius cercops* in River Awach Kibuon are presented in Table 26. Season impacted HSI of *Enteromius cercops* in River Awach Kibuon. Median HSI value for both wet season (1.8) was double that of the dry season (0.9). There was HSI synchronization with season.

**Table 26. Temporal median Hepato-Somatic Indices of *Enteromius cercops* in River Awach Kibuon**

| Season | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| Wet & dry | 120 | 0.11 - 237.6 | 9.48 | 0.1 - 7.3 | 1.2 |
| Wet | 73 | 0.7 - 237.6 | 16.36 | 0.1 - 3.7 | 1.8 |
| Dry | 47 | 0.11 - 8.51 | 2.12 | 0.1 - 4.6 | 0.9 |

*Note*. HSI = Hepato-Somatic Index

The HSI results for *Enteromius cercops* in River Awach Kibuon with respect to gonad stage is presented in Table 27. The median HSI did not change consistently with level of development of gonad stage. The lowest median HSI (0.9) was observed at stage 5 (running) of gonad development while the highest was observed at stages 2 (early maturing) and 6 (spent) of gonad development (1.8). The overall median HSI value was 1.2 indicating that stage of gonad development did not have much influence on HSI of *Enteromius cercops*.

**Table 27. The effects of gonad stage on Hepato-Somatic Indices of *Enteromius cercops* in River Awach Kibuon**

| Gonad stage | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| All stages | 120 | 0.11 – 237.6 | 9.48 | 0.1 – 7.3 | 1.2 |
| Stage 2 – Early maturing | 14 | 0.37 – 37.6 | 8.91 | 0.7 – 4.5 | 1.4 |
| Stage 3 – Late maturing | 29 | 0.11 – 9.09 | 1.52 | 0.1 – 4.5 | 1.8 |
| Stage 4 - Ripe | 31 | 0.35 – 19.2 | 3.42 | 0.1 – 4.6 | 1.1 |
| Stage 5 - Running | 28 | 0.16 – 237.6 | 16.8 | 0.1 – 7.3 | 0.9 |
| Stage 6 - Spent | 18 | 1.53 – 211.8 | 21.9 | 0.1 – 2.1 | 1.8 |

### 4.4.2.6 Hepato-Somatic Index (HSI) of *Labeobarbus altianalis*

The HSI results for *Labeobarbus altianalis* in River Awach Kibuon are presented in Table 28. A total of 51 specimens were used to compute HSI of *Labeobarbus altianalis* population in River Awach Kibuon. There were 37 male and 14 female specimens. The overall HSI values ranged from 0.1 to 2.5 with a median of 1.1. The male HSI values ranged from 0.1 to 2.5 with a median of 1.0 while the female HSI values ranged from 0.1 to 2.1 with a median of 1.5. Females had higher median HSI value (1.5) than males (1.0).

**Table 28. Median Hepato-Somatic Indices of *Labeobarbus altianalis* in River Awach Kibuon**

| Sex | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| Males | 37 | 0.7 - 848 | 69.2 | 0.1 – 2.5 | 1.0 |
| Females | 14 | 0.4 - 96.5 | 32.8 | 0.1 – 2.1 | 1.5 |
| Males and females | 51 | 0.4 - 848 | 59.2 | 0.1 – 2.5 | 1.1 |

*Note*. HSI = Hepato-Somatic Index

The spatial HSI values for *Labeobarbus altianalis* in River Awach Kibuon are presented in Table 29. Kochola Bridge had fish with the highest median HSI of 1.3 while Kadongo

Bridge had the lowest median HSI of 0.3. The median spatial HSI for *Labeobarbus altianalis* did not show any discernible trend.

**Table 29. Median spatial Hepto-Somatic Indices of *Labeobarbus altianalis* in River Awach Kibuon**

| Station | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| Overall | 51 | 0.4 - 848 | 59.2 | 0.1 – 2.5 | 1.1 |
| Kadongo Bridge | 2 | 2.18 – 4.56 | 3.37 | 0.1 – 0.5 | 0.3 |
| Kochola Bridge | 27 | 0.4 - 848 | 78.4 | 0.1 – 2.1 | 1.3 |
| Kendu Bay Bridge | 18 | 10.23 – 96.5 | 39.44 | 0.3 – 2.5 | 0.9 |
| River mouth | 4 | 0.79 – 160 | 46.21 | 0.6 -.1.3 | 1.2 |

Note. HSI = Hepato-Somatic Index

The median temporal HSI values for *Labeobarbus altianalis* in River Awach Kibuon are presented in Table 30. Season did not impact HSI of *Labeobarbus altianalis* in River Awach Kibuon. The median HSI values for wet and dry seasons were 1.2 and 1.1, respectively. There was no seasonal effect on HSI of *Labeobarbus altianalis* in River Awach Kibuon.

**Table 30. Temporal median Hepato-Somatic Indices of *Labeobarbus altianalis* in River Awach Kibuon**

| Season | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| Wet & dry | 120 | 0.4 - 848 | 59.2 | 0.1 – 2.5 | 1.1 |
| Wet | 73 | 0.4 – 160 | 32.8 | 0.5 – 2.1 | 1.2 |
| Dry | 47 | 0.79 - 848 | 74.9 | 0.1 – 2.5 | 1.1 |

*Note*. HSI = Hepato-Somatic Index

The HSI results of *Labeobarbus altianalis* in River Awach Kibuon with respect to gonad stage is presented in Table 31. The median HSI decreased with increase in stage of gonad development. The lowest median HSI (0.5) was observed at stage 6 (spent) of gonad development while the highest (1.4) was observed at stage 2 (early maturing) of gonad development.

**Table 31. The effects of gonad stage on Hepato-Somatic Indices of Labeobarbus altianalis in River Awach Kibuon**

| Gonad stage | Number of specimens | Size range (g) | Mean size (g) | HSI Range | Median HSI |
|---|---|---|---|---|---|
| All stages | 51 | 0.4 - 848 | 59.2 | 0.1 – 2.5 | 1.1 |
| Stage 2 - Early maturing | 24 | 0.4 – 140.3 | 40.7 | 0.6 – 2.1 | 1.4 |
| Stage 3 - Late maturing | 10 | 0.7 - 160 | 36.2 | 0.3 – 2.5 | 1.2 |
| Stage 4 - Ripe | 2 | 2.18 – 48.1 | 25.1 | 0.5 – 1.4 | 1.0 |
| Stage 5 - Running | 10 | 1.11 - 848 | 152.96 | 0.1 – 1.6 | 1.0 |
| Stage 6 - Spent | 5 | 3.65 – 45.98 | 20.1 | 0.4 – 1.4 | 0.5 |

*Note.* HSI = Hepato-Somatic Index

#### 4.4.2.7 Empty-gut index (EGI)

Empty Gut Index (EGI) is the proportion of fish in a population with empty guts expressed as a percentage. In River Awach Kibuon nine fish species (*Clarias gariepinus, Clarias theodorae*, *Enteromius cercops, Enteromius nyanzae*, *Enteromius jacksoni, Enteromius neumayeri, Labeobarbus altianalis, Oreochromis leucostictus* and *Enteromius kerstenii)* were assessed for the purpose of determining EGI. The EGI results for the 9 species are presented in Table 32.

**Table 32. Empty Gut Indices of 9 fish species in River Awach Kibuon**

| Species | No. of fish evaluated | Size range (g) | Mean size (g) | No. of fish with empty guts | No. of fish with food in the gut | Empty gut index (EGI) % |
|---|---|---|---|---|---|---|
| *Clarias gariepinus* | 27 | 1.3 - 958 | 100 | 5 | 22 | 19 |
| *Clarias theodorae* | 29 | 1.8 - 108 | 35 | 5 | 24 | 17 |
| *Enteromius cercops* | 122 | 0.1 - 9.1 | 2 | 2 | 120 | 2 |
| *Enteromius nyanzae* | 45 | 0.25 - 25.5 | 2.6 | 2 | 43 | 4 |
| *Enteromius jacksoni* | 16 | 1 - 20.5 | 8 | 1 | 15 | 6 |
| *Enteromius neumayeri* | 30 | 0.5 - 238 | 18 | 3 | 27 | 10 |
| *Labeobarbus altianalis* | 81 | 0.2 - 848 | 42 | 4 | 77 | 5 |
| *Oreochromis leucostictus* | 11 | 0.9 - 184 | 29.3 | 0 | 11 | 0 |
| *Enteromius kerstenii* | 20 | 0.3 - 28.4 | 2.6 | 2 | 18 | 10 |

The EGI of the nine fish species ranged from 0 to 19 %. *Clarias gariepinus* and *Clarias theodorae* had the highest percentages of empty guts at 19 % and 17 %, respectively. On the other hand, *Oreochromis leucostictus*, *Enteromius cercops*, *Enteromius nyanzae* and *Labeobarbus altianalis* had the lowest percentages of empty guts at 0 %, 2 %, 4 % and 5 %, respectively.

### 4.4.3 Fish Index of Biotic Integrity (FIBI)

The guidelines used for scoring and categorizing sampling stations into integrity classes are given in Table 33. The six integrity classes established for this study include; excellent (41-45), good (33 - 40), fair (24 - 32), poor (19-23), very poor (9-18), and no-fish (0).

**Table 33. Classification categories of total Fish Index of Biotic Integrity scores, their integrity classes and narrative description based on the riverine habitats in the study area**

| Total FIBI scores and integrity classes | Narrative description |
|---|---|
| Excellent, 41-45 | Extensive riparian natural-buffer vegetation (> 20 m), wilderness area (outstanding natural beauty), high channel sinuosity, > 4 cyprinid species, and ≥ 6 native species |
| Good, 33-40 | Wide riparian natural-buffer vegetation (10-20 m), natural area, moderate channel sinuosity, < 4 cyprinid species, and 3-5 native species |
| Fair, 24-32 | Moderate riparian natural-buffer vegetation (5-10 m), common setting area (developed), moderate channel sinuosity, & 2 cyprinid native species |
| Poor, 19-23 | Moderate riparian natural-buffer vegetation (5-10 m), common setting area (developed), moderate channel sinuosity, & 1 cyprinid native species |
| Very poor, 9-18 | Narrow riparian natural-buffer vegetation (< 5 m), offensive area (cluttered), low channel sinuosity, 0 cyprinid species, & 1 native species |
| No fish, 0 | Narrow riparian natural-buffer vegetation (< 5 m), offensive area (cluttered), low channel sinuosity, 0 cyprinid species, 0 native species, & 0 total species |

#### 4.4.3.1 Fish Index of Biotic Integrity (FIBI) scores and ecological integrity categories of sampling stations across seasons

The FIBI scores across sampling stations ranged from 0 to 43, showing no clear pattern downstream as shown in Table 32. The FIBI scores were lowest upstream, increased midstream decreased downstream and then reached its highest value at the river mouth. Seasonally, FIBI scores were the same between seasons at Eaka Coffee Factory and River mouth stations, higher during the wet season at Kadongo Bridge and Kendu Bay Bridge stations and lower during wet season at Kochola Bridge station. With regard to ecological integrity classes, only the River mouth fell in the excellent condition category with a FIBI score of 43 out of a possible total of 45. This station is deemed unimpaired and fairly undisturbed, being characterized by a huge papyrus swamp, extensive natural riparian-buffer vegetation (> 20 m) and 18 fish species. The midstream Kadongo Bridge and Kochola Bridge stations fell in the good ecological condition category (intermediate) with 36 and 34 FIBI scores, respectively. These stations are characterized by wide natural riparian buffer vegetation (10-20 m) and 6-9 fish species. Kendu Bay Bridge station fell in the fair condition category (impaired) with a FIBI score of 24, being characterized by wide natural riparian-buffer vegetation and 4 fish species. Eaka Coffee Factory station is deemed to be in poor condition category (impaired) with a FIBI score of 21, with narrow natural riparian-buffer vegetation (< 5 m) and 2 fish species. The first 4 upstream sampling stations (Kebirigo, Nyangoso Bridge, Nyangoso Water Tower and Nyamiacho Waterfall) are in the no-fish condition category with 0 FIBI scores and narrow riparian buffer vegetation (< 5 m) signifying impairment.

**Table 34. Spatio-temporal total Fish Index of Biotic Integrity scores ranging from 0 (no-fish) to 43 (excellent), as arrived at by summation of individual metric scores for each sampling station**

| Station | | Kebirigo | | Nyangoso Bridge | | Nyangoso W. Tower | | Nyamiacho Waterfall | | Eaka Coffee Factory | | Kadongo Bridge | | Kochola Bridge | | Kendu Bay Bridge | | River mouth | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Metric** | **Season** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** | **Wet** | **Dry** |
| No. of native species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | 3 | 3 | 5 | 3 | 1 | 5 | 5 |
| No. of cyprinid species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | 5 | 3 | 5 | 3 | 3 | 5 | 5 |
| No. of insectivorous species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 5 | 5 |
| No. of moderately sensitive species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 5 | 3 | 3 | 5 | 3 | 3 | 5 | 5 |
| No. of fish per 50 m river reach | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 |
| % *Enteromius* species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | 5 | 5 | 5 | 1 | 1 | 5 | 3 |
| % Clarid species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | 3 | 5 | 3 | 5 | 5 | 5 | 5 |
| % Tolerant species | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | 5 | 5 | 5 |
| Proportion as omnivores | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 3 | 3 | 3 | 3 | 1 | 1 | 5 | 5 |
| **FIBI Scores/season** | | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **21** | **21** | **39** | **33** | **31** | **37** | **25** | **23** | **43** | **43** |
| **FIBI Score/Station** | | **0** | | **0** | | **0** | | **0** | | **21** | | **36** | | **34** | | **24** | | **43** | |

### 4.5 Fish population dynamics

The population parameters of *Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus* from the mouth of River Awach Kibuon for the year 2020 were evaluated and the results are presented below.

#### 4.5.1 Nile tilapia (*Oreochromis niloticus*)

##### 4.5.1.1 Growth parameters ($L_\infty$ & $K$) and mortality rates ($Z$, $M$ & $F$)

The estimated asymptotic length ($L_\infty$), curvature parameter ($K$) and the growth performance index (θ′) for *Oreochromis niloticus* were 46.2 cm, 0.67 and 3.16, respectively. The length converted catch curve output from FiSAT Software showing $Z$, $M$, $F$ and $E$, is presented in Figure 26. $Z$ was 2.40, $M$ was 1.11 and $F$ was 1.30.

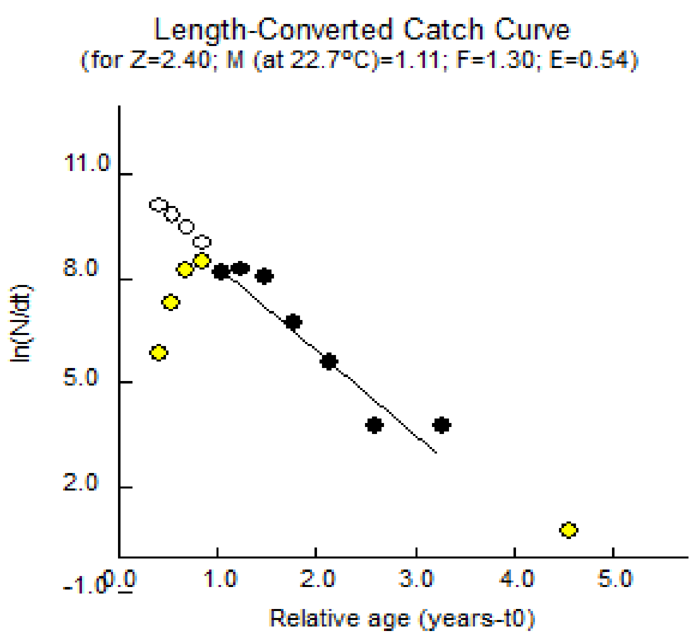


***Figure 26.*** **Length converted catch curve showing total mortality rate (*Z*), natural mortality rate (*M*), fishing mortality rate (*F*) and exploitation rate (*E*) of *Oreochromis niloticus* in River Awach Kibuon**

The growth curves of *Oreochromis niloticus* in River Awach Kibuon are presented in Figure 27.

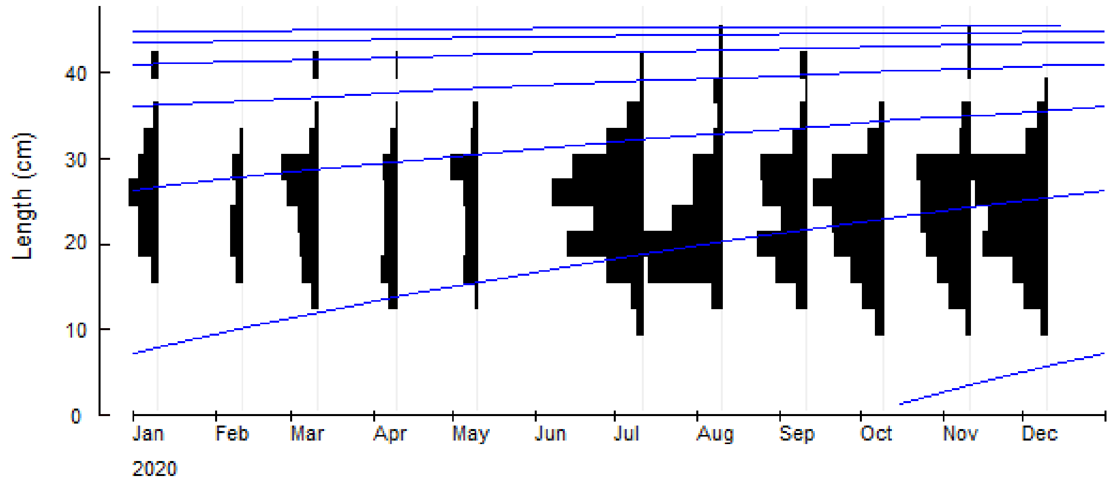


***Figure 27*. Growth curves of *Oreochromis niloticus* in River Awach Kibuon**

#### 4.5.1.2 Exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$)

The exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$) for *Oreochromis niloticus* stocks were 0.54, 0.40, 0.29 and 0.48, respectively. Since ($E$ = 0.54) is almost double the optimum sustainable exploitation rate ($E_{0.5}$ = 0.29) and higher than the maximum sustainable exploitation rate ($E_{\max}$ = 0.48), *Oreochromis niloticus* stocks in River Awach Kibuon are overexploited.

#### 4.5.1.3 Recruitment pattern

Recruitment patterns showing year-round and bi-modal annual pulses are illustrated in Figure 28. The length frequency data were backward-projected onto an arbitrary 1-year time scale, following a trajectory described by the von Bertalanffy growth function, to derive the recruitment patterns. Because the location parameter ($t_0$) is unknown, the months on the x-axis cannot be located exactly. The main recruitment pulse occurred in the first half of the year coinciding with long rainy season months of April-June while the second one occurred during the short rain months of September-October. The second recruitment pulse in the last quarter of the year was much weaker than the first pulse.

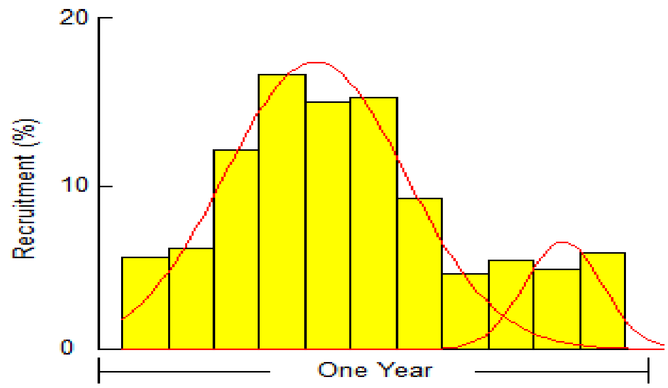


***Figure 28.*** **Estimated recruitment pattern of *Oreochromis niloticus* in River Awach Kibuon**

#### 4.5.1.4 Beverton and Holt relative yield and biomass per recruit models

The Beverton and Holt's relative yield-per-recruit and biomass-per-recruit model indices for sustainable yields for *Oreochromis niloticus* are illustrated in Figure 29. The model indices for *Oreochromis niloticus* were 0.29 for optimum sustainable yield ($E_{0.5}$), 0.48 for the maximum sustainable yield ($E_{max}$) and 0.40 for maximum economic yield ($E_{0.1}$).

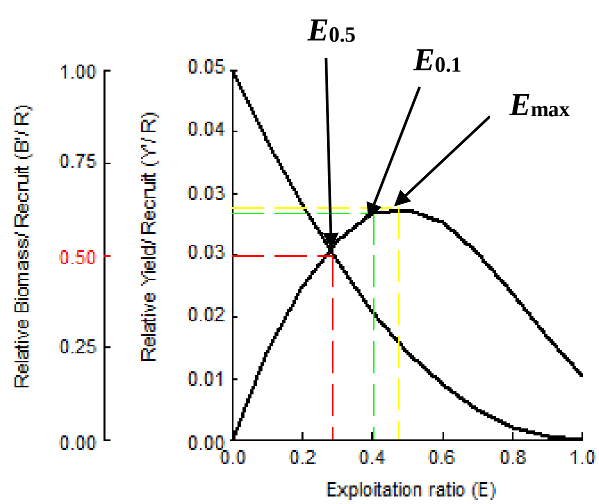


***Figure 29.*** **Beverton and Holt's relative yield per recruit and relative biomass per recruit models, showing levels of yield indices; $E_{0.5}$, $E_{0.1}$, and $E_{max}$ of *O. niloticus* population in River Awach Kibuon**

#### 4.5.1.5 Probability of capture

The probability of capture results for *Oreochromis niloticus* are illustrated in Figure 30. The results indicated that 25% of *Oreochromis niloticus* fish of 15.58 cm, 50% of the fish of 18.73 cm and 75% of fish of 21.54 cm TL would be retained upon encounter with the fishing gear. For *Oreochromis niloticus*, the predicted $L_c/L_\infty$ ratio based on the relationship between the length at initial capture ($L_c$) and the $L_\infty$ was 0.24. $L_c/L_\infty$ ratio of less than 0.5 is an indication of the presence of a percentage of juvenile fish in the landed catches of *Oreochromis niloticus*. The ratio of the *K* to the *M*, which determines how far a fish can grow before dying naturally, was 1.7. *M/K* values greater than 1.5 indicate that *M* exceeded *K* meaning that many fish would die before achieving their growth potential.

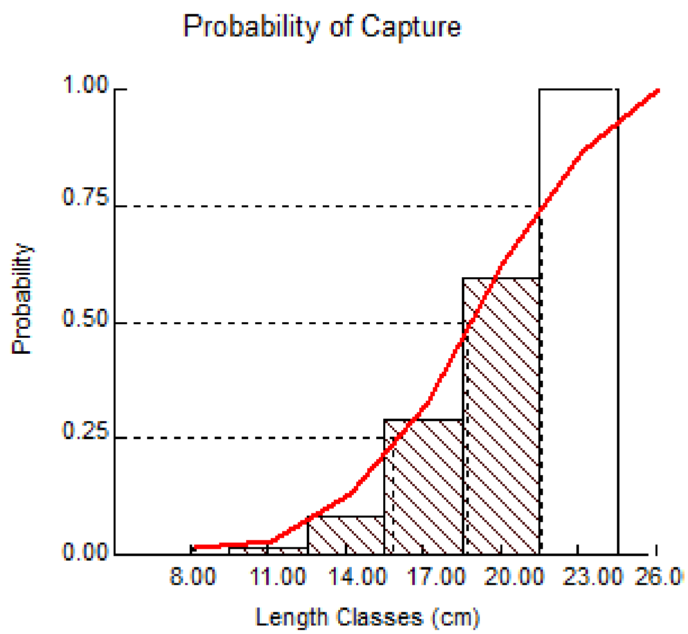


***Figure 30.* Logistic curves showing 25%, 50% and 75% probability of capture length (cm TL) of *Oreochromis niloticus* population in River Awach Kibuon**

### 4.5.2 Lake Victoria squeaker (*Synodontis victoriae*)

#### 4.5.2.1 Growth parameters ($L_\infty$ & $K$) and mortality rates ($Z$, $M$ & $F$)

The estimated $L_\infty$, $K$ and θ′ for *Synodontis victoriae* were 26.3 cm, 0.83 and 2.76, respectively. The length converted catch curve output from FiSAT Software showing *Z*, *M*, *F* and *E*, is presented in Figure 31. *Z* was 3.69, *M* was 1.49 and *F* was 2.20. The growth curves of *Synodontis victoriae* in River Awach Kibuon are presented in Figure 32.

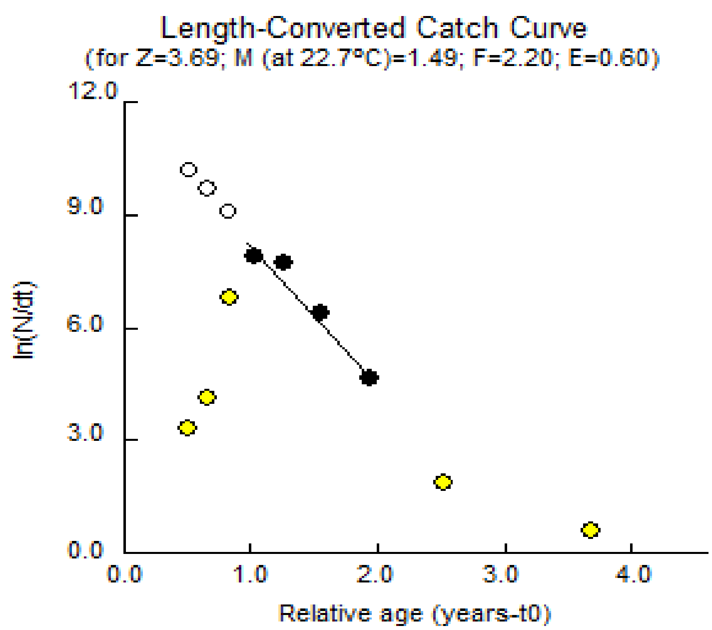


***Figure 31.*** **Length converted catch curve showing total mortality rate (*Z*), natural mortality rate (*M*), fishing mortality rate (*F*), and exploitation rate (*E)* of *Synodontis victoriae* in River Awach Kibuon**

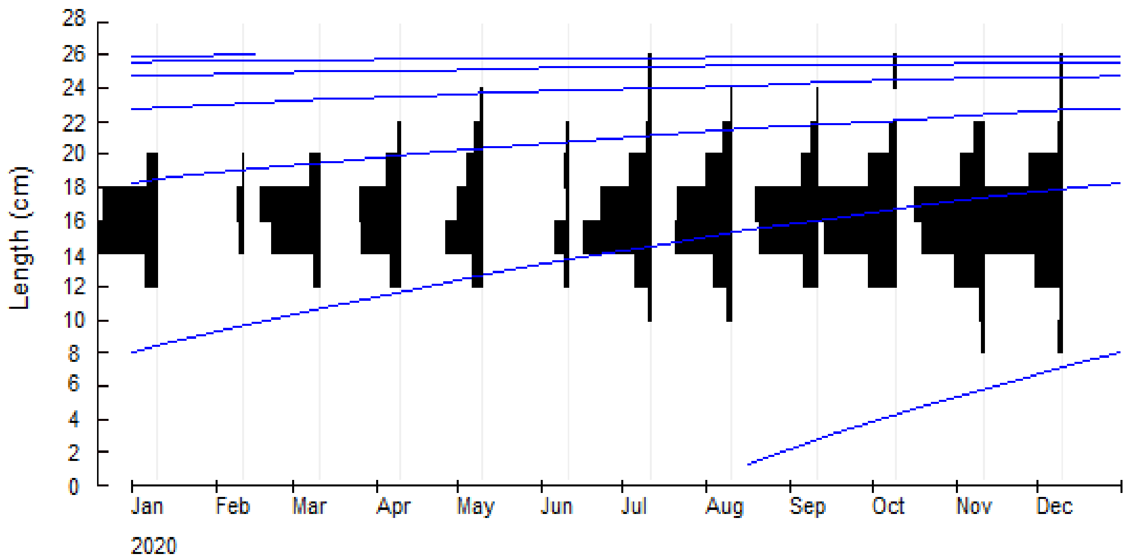


***Figure 32.*** **Growth curves of *Synodontis victoriae* in River Awach Kibuon**

#### 4.5.2.2 Exploitation rates (*E*, $E_{0.1}$, $E_{0.5}$ and $E_{max}$)

The exploitation rates (*E*, $E_{0.1}$, $E_{0.5}$ and $E_{max}$) for *Synodontis victoriae* stock were 0.60, 0.47, 0.32 and 0.56, respectively. Since ($E$ = 0.60) is almost double the optimum sustainable exploitation rate ($E_{0.5}$ = 0.32) and higher than the maximum sustainable exploitation rate ($E_{max}$ = 0.56), *Synodontis victoriae* stocks in the Awach Kibuon River are overexploited.

#### 4.5.2.3 Recruitment pattern

Recruitment patterns showing year-round and bi-modal annual pulses are illustrated in Figure 33. The length frequency data were backward-projected onto an arbitrary 1-year time scale following a trajectory described by the von Bertalanffy growth equation to derive the recruitment patterns. The months on the x-axis cannot be located exactly since the location parameter ($t_0$) is not known. The two recruitment pulses occurred in the first and second halves of the year coinciding with long rainy season months of April-June short rainy months of September-October. There was strong recruitment intensity almost throughout the year and the difference between first and second pulses was small.

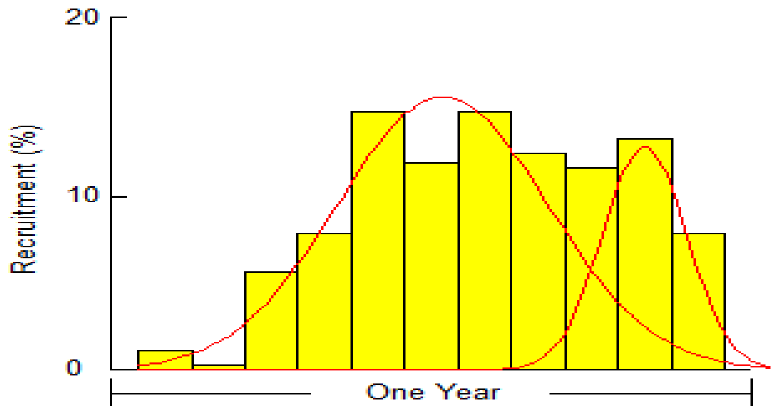


***Figure 33.* Estimated recruitment pattern of *Synodontis victoriae* in River Awach Kibuon**

#### 4.5.2.4 Beverton and Holt relative yield and biomass per recruit models

The Beverton and Holt's relative yield-per-recruit and biomass-per-recruit model indices for sustainable yields for *Synodontis victoriae* are illustrated in Figure 34. The model indices for *Synodontis victoriae* were 0.32 for optimum sustainable yield ($E_{0.5}$), 0.56 for the maximum sustainable yield ($E_{max}$) and 0.47 for maximum economic yield ($E_{0.1}$).

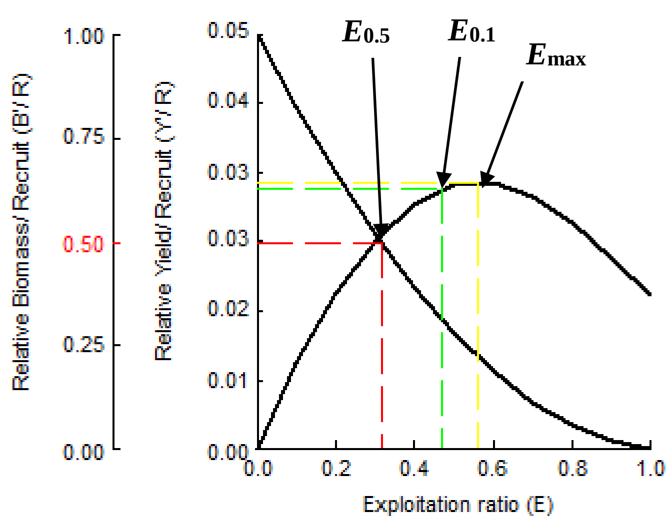


***Figure 34.* Beverton and Holt's relative yield per recruit and relative biomass per recruit models, showing levels of yield indices; $E_{0.5}$, $E_{0.1}$, and $E_{max}$ of *Synodontis victoriae* population in River Awach Kibuon**

#### 4.5.2.5 Probability of capture

The probability of capture results for *Synodontis victoriae* is illustrated in Figure 35. The results indicated that 25% *Synodontis victoriae* fish of 12.28 cm, 50% of the fish of 13.78 cm and 75% of the fish of 15.32 cm TL would be retained upon encounter with the fishing gear. The estimated $L_c/L_\infty$ ratio which uses the association between the length at first capture ($L_c$) and the $L_\infty$ was 0.34 for *Synodontis victoriae*. $L_c/L_\infty$ ratio of less than 0.5 indicates presence of many young fish in the landed catches of *Synodontis victoriae*. The ratio of *K* and *M* approximates the probability of a fish completing its potential growth before dying of natural mortality was 1.8 for *Synodontis victoriae*. *M/K* values greater than 1.5 signify that *M* exceeded *K* implying that many fish would die before achieving their potential growth.

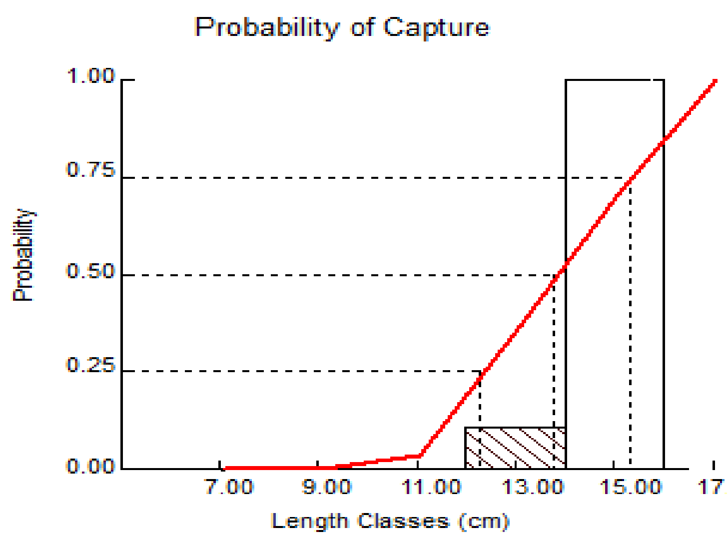


**Figure 35. Logistic curves showing 25%, 50%, and 75% probability of capture length (cm TL) of *Synodontis victoriae* population in River Awach Kibuon**

### 4.5.3 African catfish (*Clarias gariepinus*)

#### 4.5.3.1 Growth parameters ($L_\infty$ & $K$) and mortality rates ($Z$, $M$ & $F$)

The estimated $L_\infty$, $K$ and θ′ for *Clarias gariepinus* population in the medium-sized Awach Kibuon River were 92.9 cm, 0.70 and 3.78, respectively. The length converted catch curve output from FiSAT Software showing *Z*, *M*, *F* and *E*, is presented in Figure 36. *Z* was 1.97, *M* was 0.94 and *F* was 1.03. The growth curves of *Clarias gariepinus* in River Awach Kibuon are presented in Figure 37

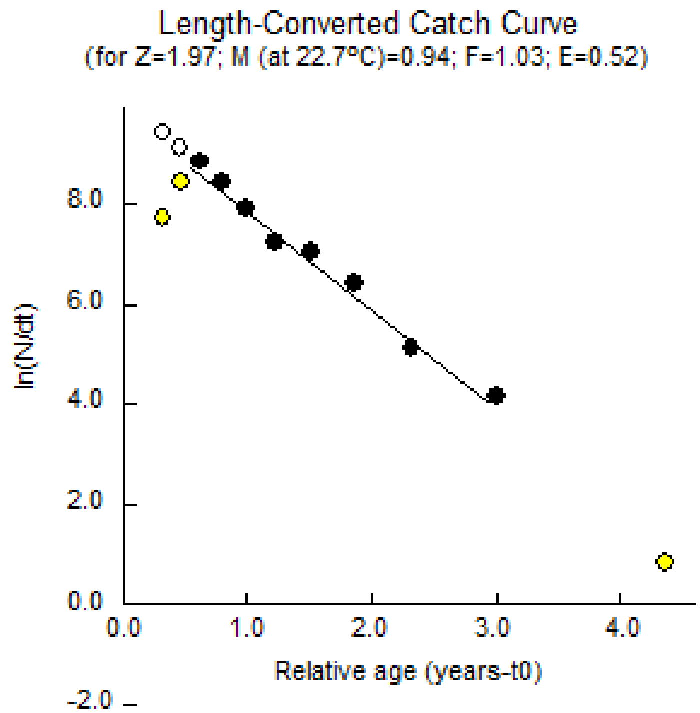


***Figure 36.*** **Length converted catch curve showing total mortality rate (*Z*), natural mortality rate (*M*), fishing mortality rate (*F*) and exploitation rate (*E*) of *Clarias gariepinus* population in Awach Kibuon River**

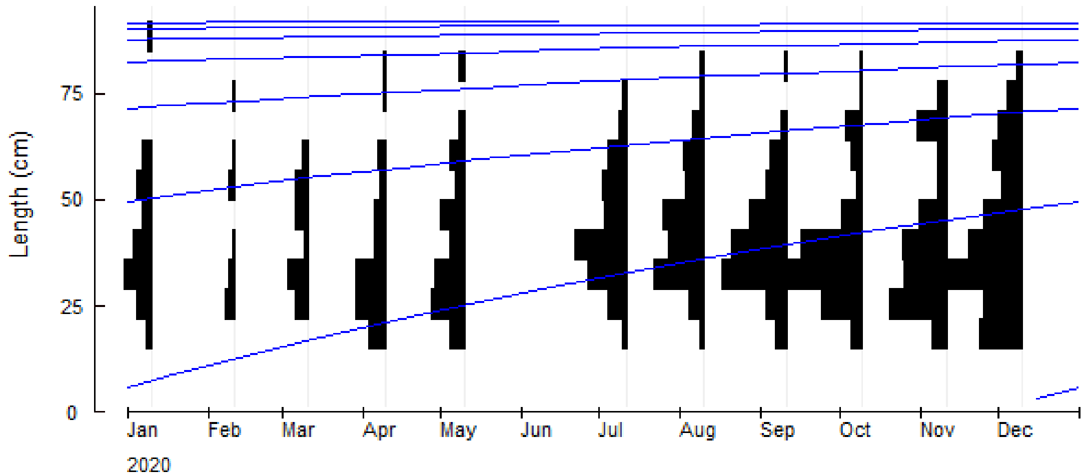


***Figure 37.*** **Growth curves of *Clarias gariepinus* in River Awach Kibuon**

#### 4.5.3.2 Exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$)

The exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$) for *Clarias gariepinus* stock in River Awach Kibuon were 0.52, 0.36, 0.29 and 0.46, respectively. Since the exploitation rate ($E$ = 0.52) is much higher than both the optimum sustainable yield ($E_{0.5}$ = 0.29) and the maximum sustainable yield ($E_{max}$ = 0.46), *Clarias gariepinus* stocks in River Awach Kibuon are overexploited.

#### 4.5.3.3 Recruitment pattern

Recruitment pattern showing year-round recruitment and one main annual pulse is illustrated in Figure 38. The length frequency data were backward-projected onto an arbitrary 1-year time scale, following a course described by the von Bertalanffy growth function to derive the recruitment patterns. Since the location parameter ($t_0$) is not known, the months on the x-axis cannot be located exactly. *Clarias gariepinus* exhibited strong recruitment intensity during the first half of the year peaking in the long rainy months of April-June. However, the second recruitment pulse was not very clear but occurred in the second half the year coinciding with short rainy months of September-October.

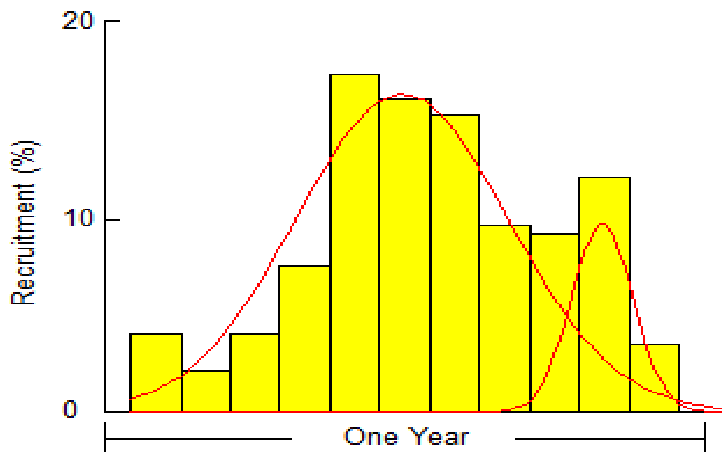


***Figure 38.*** **Estimated recruitment pattern of *Clarias gariepinus* in River Awach Kibuon**

#### 4.5.3.4 Beverton and Holt's relative yield and biomass per recruit models

The Beverton and Holt's relative yield-per-recruit and biomass-per-recruit model indices for sustainable yields for *Clarias gariepinus* are illustrated in Figure 39. The model indices for *Clarias gariepinus* were 0.29 for optimum sustainable yield ($E_{0.5}$), 0.46 for the maximum sustainable yield ($E_{max}$) and 0.36 for maximum economic yield ($E_{0.1}$).

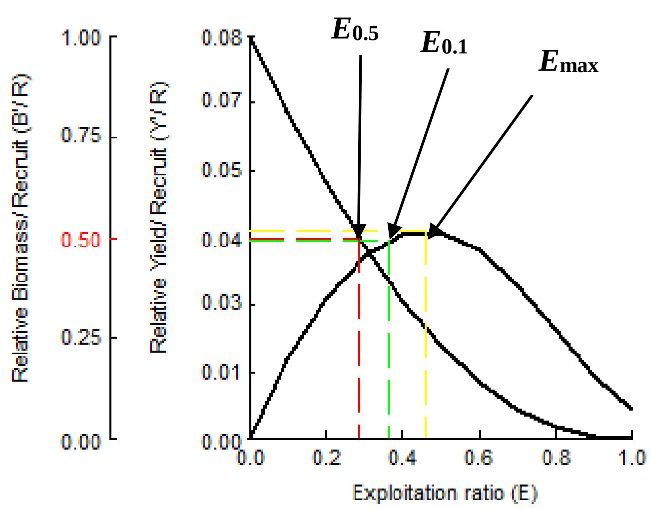


***Figure 39.*** **Beverton and Holt's relative yield per recruit and relative biomass per recruit models, showing levels of yield indices; $E_{0.5}$, $E_{0.1}$, and $E_{max}$ of *C. gariepinus* population in River Awach Kibuon**

#### 4.5.3.5 Probability of capture

The probability of capture results for *Clarias gariepinus* is illustrated in Figure 40. The results showed that 25% of *Clarias gariepinus* fish of 18.80 cm TL, 50% of the fish of 24.05 cm TL and 75% of all fish of 30.16 cm TL would be retained upon encounter with the fishing gear. The estimated $L_c/L_\infty$ ratio which uses the relationship between length at first capture ($L_c$) and the $L_\infty$ was 0.20 for *Clarias gariepinus*. $L_c/L_\infty$ ratio of more than 0.5 indicated low presence of juvenile fish in the landed catches of *Clarias gariepinus*. The ratio of the *K* and *M* which estimates the potential of a fish to complete its potential growth before dying of *M* was 1.3 for *C. gariepinus*. *M/K* values lower than 1.5 indicated that natural mortality rate did not exceed growth rate meaning that many fish would achieve their potential growth before they died.

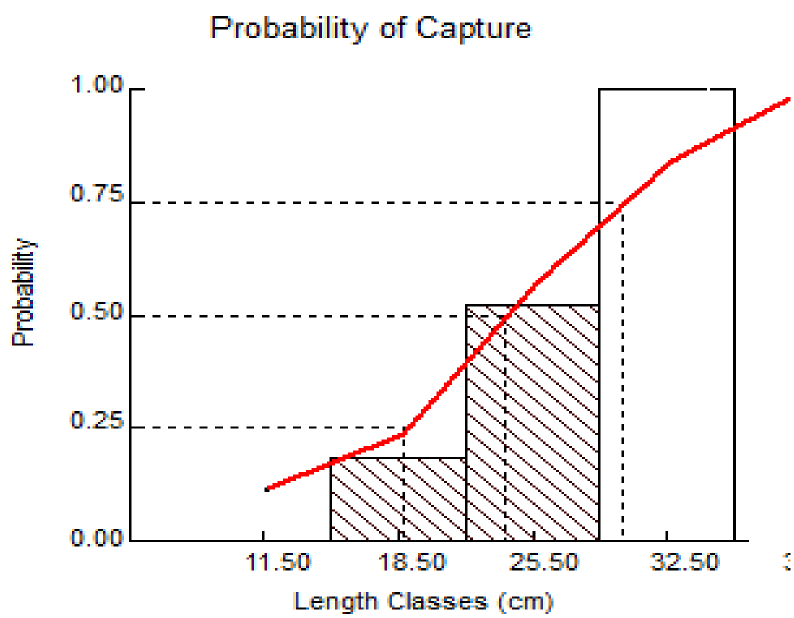


***Figure 40.*** **Logistic curves showing 25%, 50%, and 75% probability of capture length (cm TL) of *Clarias gariepinus* population of River Awach Kibuon**

### 4.5.4 African lungfish (*Protopterus aethiopicus*)

#### 4.5.4.1 Growth parameters ($L_\infty$ & *K*) and mortality rates (*Z*, *M* & *F*)

The estimated asymptotic length ($L_\infty$), curvature parameter (*K*) and the growth performance index (θ′) for *Protopterus aethiopicus* were 153.7 cm 1.1 and 4.42, respectively. The length converted catch curve output from FiSAT Software showing *Z*, *M*, *F* and *E*, is presented in Figure 41. *Z* was 3.22, *M* was 1.09 and *F* was 2.13. The growth curves of *Protopterus aethiopicus* in River Awach Kibuon are presented in Figure 42.

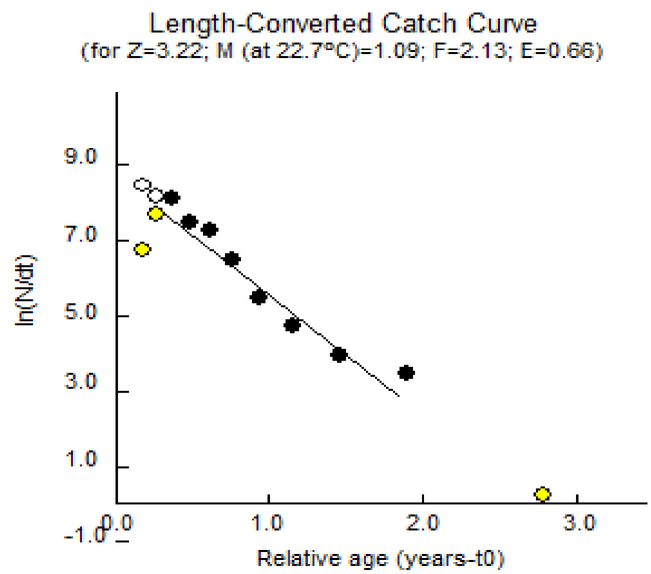


***Figure 41*. Length converted catch curve showing total mortality rate (*Z*), natural mortality rate (*M*), fishing mortality rate (*F*) and exploitation rate (*E*) of *Protopterus aethiopicus* in River Awach Kibuon**

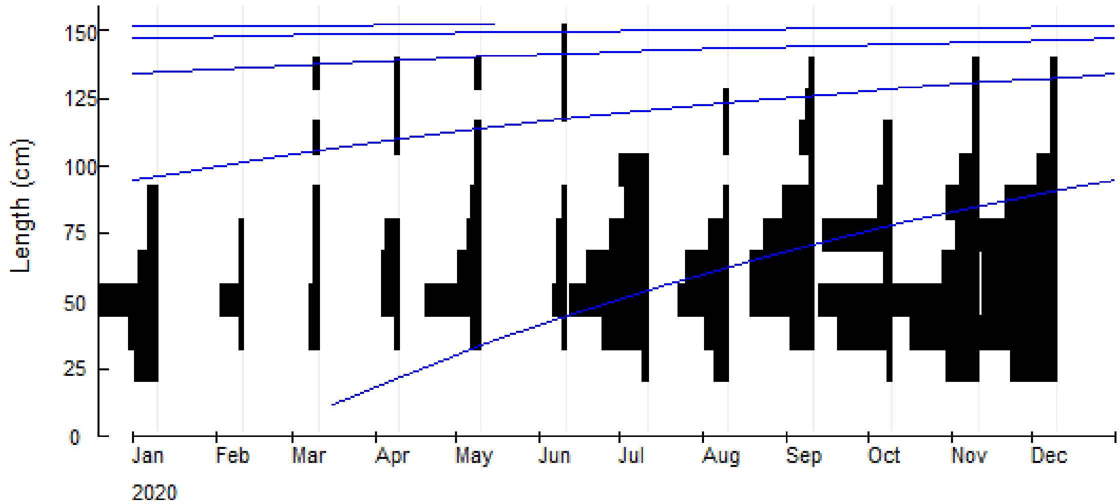


***Figure 42.*** **Growth curves of *Protopterus aethiopicus* in River Awach Kibuon**

#### 4.5.4.2 Exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$)

The exploitation rates ($E$, $E_{0.1}$, $E_{0.5}$ and $E_{max}$) for *Protopetrus aethiopicus* stock were 0.66, 0.35, 0.30 and 0.46, respectively. Since ($E$ = 0.66) is more than double the optimum sustainable exploitation rate ($E_{0.5}$ = 0.32) and much higher than maximum sustainable exploitation rate ($E_{max}$ = 0.53), *Protopterus aethiopicus* stocks in River Awach Kibuon are therefore severely overexploited.

#### 4.5.4.3 Recruitment pattern

Recruitment pattern showing year-round and bi-modal annual pulses are illustrated in Figure 43. The length frequency data were backward-projected onto an arbitrary 1-year time scale following a curve described by the von Bertalanffy growth equation to produce the recruitment patterns. The months on the x-axis cannot be located exactly because $t_0$ (the location parameter) is not known. Recruitment intensity was strong almost throughout the year. The bi-modal annual pulses were present but not very clear. Recruitment was low during the beginning and ending months of the year but strong during the middle months.

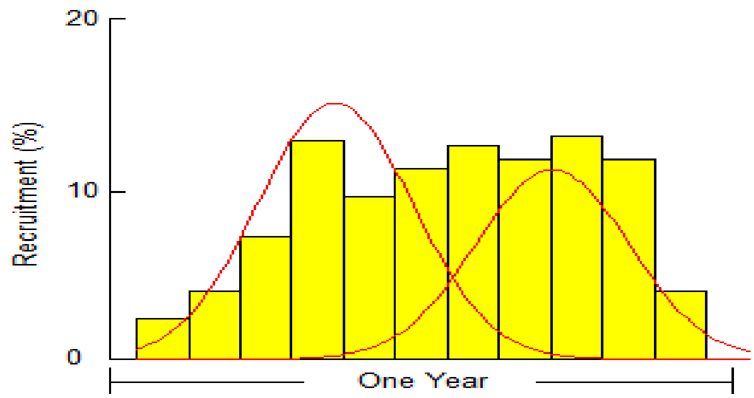


***Figure 43.*** **Estimated recruitment pattern for *Protopterus aethiopicus* in River Awach Kibuon**

#### 4.5.4.4 Beverton and Holt relative yield and biomass per recruit models

The Beverton and Holt's relative yield-per-recruit and biomass-per-recruit model indices for sustainable yields for *Protopterus aethiopicus* are illustrated in Figure 44. The model indices for *Protopterus aethiopicus* were 0.30 for optimum sustainable yield ($E_{0.5}$), 0.46 for the maximum sustainable yield ($E_{max}$) and 0.36 for maximum economic yield ($E_{0.1}$).

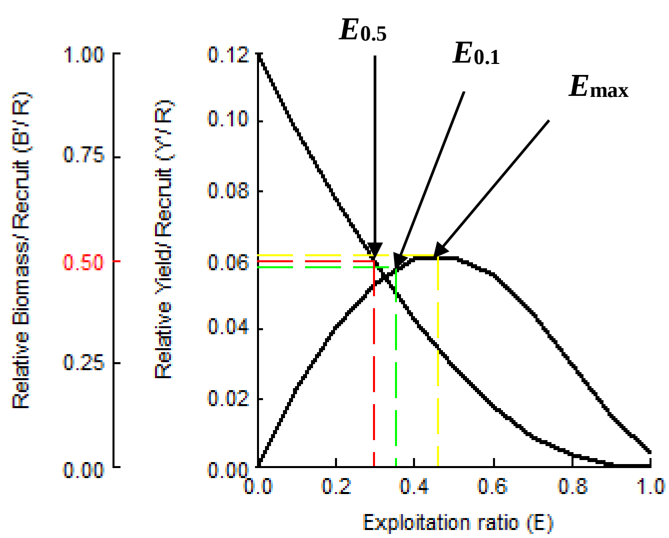


***Figure 44.*** **Beverton and Holt's relative yield per recruit and relative biomass per recruit models, showing levels of yield indices; $E_{0.5}$, $E_{0.1}$, and $E_{max}$ of *Protopterus aethiopicus* population in River Awach Kibuon**

#### 4.5.4.5 Probability of capture

The probability of capture results for *Protopterus aethiopicus* are illustrated in Figure 45. The results showed that 25% of *Protopterus aethiopicus* fish of 28.84 cm, 50% of fish of 49.82 cm, and 75% of fish of 74.8 cm would be retained upon encounter with the fishing gear. The estimated $L_c/L_\infty$ ratio using the relationship between the length at first capture ($L_c$) and the $L_\infty$ was 0.17 for *Protopterus aethiopicus*. $L_c/L_\infty$ ratio of less than 0.5 indicated high presence of juvenile fish in the landed catches of *Protopterus aethiopicus*. The ratio of the *K* and *M* which approximates the probability of a fish completing its potential growth before dying of *M* was 1.0 for *Protopterus aethiopicus*. *M/K* value lower than 1.5 indicated that *M* did not exceed *K* meaning that many fish would achieve their growth potential.

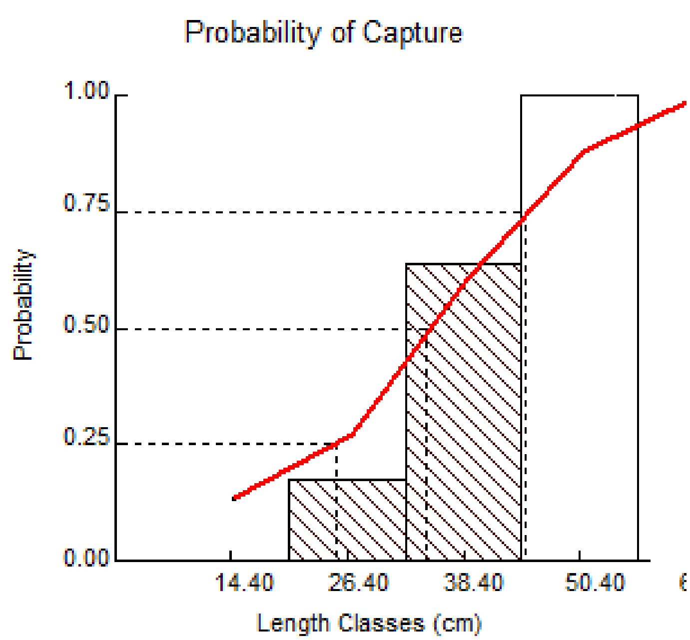


***Figure 45.*** **Logistic curves showing 25%, 50%, and 75% probability of capture length (cm TL) of *Protopterus aethiopicus* population in River Awach Kibuon**

### 4.6 Correlations between physico-chemical parameters, habitat characteristics and biological characteristics of fish of River Awach Kibuon

The Spearman Rank correlation indicated that there was a strong significant positive association between river Habitat Quality Index (HQI) and Fish Index of Biotic integrity (FIBI) of fish communities in River Awach Kibuon ($r_s (39) = 0.97$, $p = .005$). Canonical Correspondence Analysis (CCA) indicated that electrical conductivity, total dissolved solids (TDS) and surface water velocity significantly influenced the abundance of fish in River Awach Kibuon ($p < .05$). Turbidity and dissolved oxygen had notable significant influence on fish species abundance ($p < .1$). Nutrients, temperature and pH had little influence on fish abundance in River Awach Kibuon. Of the 5 sampling stations that had fish, Eaka Coffee Factory is strongly associated *Clarias theodorae*. Kadongo Bridge, Kochola Bridge and Kendu Bay Bridge stations are associated with high water velocity, high dissolved oxygen, high turbidity and a number of fish species including *Labeo victorianus*, *Labeobarbus altianalis*, *Enteromius cercops*, *Enteromius neumayeri* and *Enteromious apleurogramma*. The River mouth station is associated with high electrical conductivity, high total dissolved solids and high diversity of fish species. A Canonical Correspondence Analysis (CCA) biplot showing the association between water quality parameters, sampling stations and fish species abundance is presented in Figure 46.

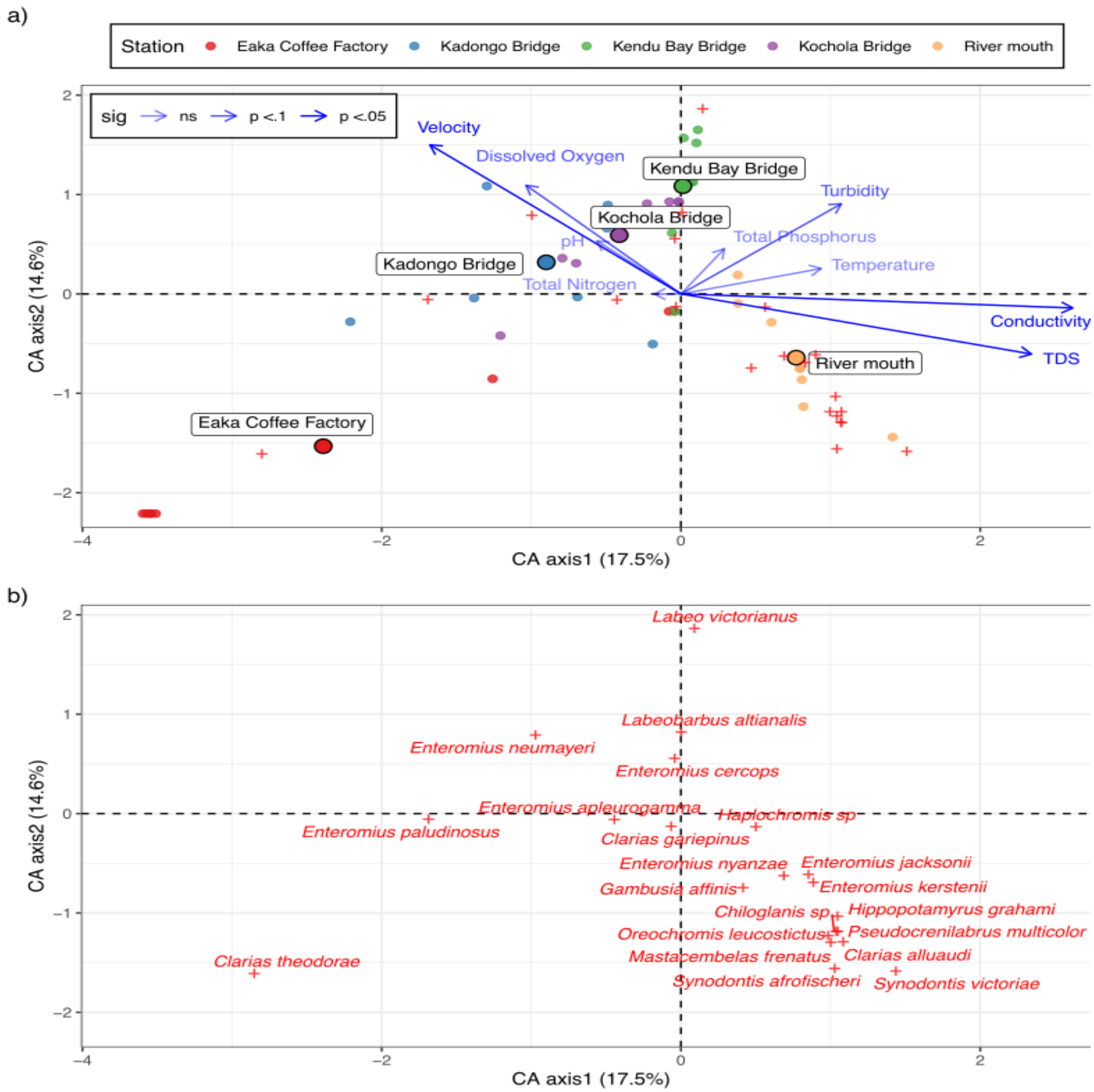


***Figure 46*: a) Canonical correspondence analysis biplot showing the influence of physico-chemical parameters (blue arrows) on fish species abundance at sampling stations (Eaka Coffee Factory, Kadongo Bridge, Kochola Bridge, Kendu Bay Bridge and River mouth) in River Awach Kibuon; and b) fish species distribution in River Awach Kibuon.**

# CHAPTER FIVE

# DISCUSSION

## 4.7 Introduction

This chapter discusses the results of the study as per the objectives and hypotheses. It begins by looking at the spatio-temporal water quality status of River Awach Kibuon and its implication on river ecological integrity. It also discusses spatial river habitat characteristics, spatio-temporal diversity indices (D, H' and J) of river fish communities, other biological indices of fish populations (Gonado-Somatic Index, Hepato-Somatic Index, and Empty Gut Index) and Fish Index of Biotic Integrity. The chapter also discusses population parameter estimates of the four leading commercial fish species landed at the mouth of River Awach Kibuon and their implication on the overall health of those fish stocks. It closes with a discussion on the correlations between physico-chemical parameters, habitat characteristics and fish community characteristics in the river.

## 4.8 Physico-chemical parameters

Water quality is one of the key components of ecological integrity of aquatic ecosystems such as rivers and lakes (Karr & Dudley, 1981). Key physico-chemical parameters such as temperature, pH and DO determine and define organisms which can live and survive in particular water bodies. Each organism has a defined range for each parameter within which it lives and thrives. Consequently, drastic changes in physico-chemical parameters can affect biotic integrity by causing direct mortality or changing species balance in the fish community through reduced reproductive rates or altered competitive ability (Karr & Dudley, 1981). In this study of River Awach Kibuon, temperature, velocity and turbidity exhibited natural longitudinal trends (Hynes, 1970). However, electrical conductivity, DO, TP, TN and TDS deviated from natural longitudinal trends probably due to the negative impacts of anthropogenic activities along the river catchment.

Velocity refers to the speed at which water flows along a channel. Various elements, including gradient, water volume, the shape of the river channel and the amount of friction produced by the riverbed, boulders and vegetation, affect velocity along the river's channel (Hayley, 2021). The water velocity pattern observed in River Awach Kibuon conforms to the natural pattern expected in most streams where velocity is usually greatest midstream and lower in upstream and downstream sections. The significant spatial variation of velocity along River Awach Kibuon may be attributed to the changing gradient along the length of the river. The river surface velocity range of 0.32 to 1.23 m $s^{-1}$ recorded in this study is characteristic of small rivers of this size.

Temperature in flowing waters is very important because it influences metabolic reactions in aquatic organisms and affects the capacity of water to hold oxygen (Lewis, 2008). In River Awach Kibuon, mean temperature was highest downstream and lowest upstream. The significant spatial temperature variations may be attributed to the differences in altitude between sampling stations ranging from 1953 m above sea level at Kebirigo to 1136 m above sea level at the River mouth and the different sampling times at various stations. At high altitude, low temperatures are expected while at low altitudes, relatively higher temperatures are expected. River Awach Kibuon waters conformed to this trend by being colder upstream at higher altitudes and warmer downstream at lower altitudes. The stations sampled in the morning hours had slightly lower temperatures than those sampled in the afternoon. The lack of significant temporal temperature variation may be attributed to the increasing similarity between dry and wet seasons probably due to climate change. The temperature range of 18-23 $^{\circ}$C recorded for this study is within what is expected for this region (Lewis, 2008) and is close to 17.8 – 24.6 °C reported by Orina et al. (2017) in River Kuja in the Lake Victoria Basin.

DO is a measure of how much oxygen is dissolved in the water, which is also the amount available to living aquatic organisms. The amount of DO in a stream or river is a reflection of its water quality and is a function of the rate of photosynthesis and diffusion from the atmosphere. Water that moves quickly, like that in rivers, typically has a higher concentration of dissolved oxygen than water that is still. Since all aquatic life utilizes DO in surface waters, measuring DO is often done to determine the health of the lakes and streams. The DO levels were high and fairly constant along the longitudinal stretch of River Awach Kibuon (6.91 - 7.57 mg $L^{-1}$) and across dry and wet seasons (7.24 and 7.39 mg $L^{-1}$), respectively. These DO levels are conducive and supportive of all forms of riverine biological diversity. The spatial significant DO variation may be attributed to temperature differences between different sections of the river and also to varying sampling times at the various sampling stations. Cold water has a higher capacity to hold oxygen thereby explaining the higher dissolved oxygen recorded upstream.

The high DO levels recorded along the whole stretch of the river may be explained by the constant state of motion of the river water constantly receiving atmospheric oxygen through diffusion. The time of sampling may have influenced DO levels in the river. Stations that were sampled during morning hours had slightly more DO levels than those sampled in the afternoon hours. The lack of seasonal variations may be explained by the fact that dry and wet seasons were not clearly distinguishable during the study period probably due to climate change. Dry seasons are no longer as dry as in the past years but occasional heavy rains occur during dry seasons. The DO levels recorded in this study (6.91 - 7.57 mg $L^{-1}$)

are higher than the 3.1 - 5.5 mg $L^{-1}$ reported by Ouma et al. (2016) and 4.1 - 5.5 mg $L^{-1}$ reported by Orina et al. (2017) in water quality studies of Lake Victoria beaches and River Kuja, respectively.

pH serves as a gauge for the water's relative levels of free hydrogen and hydroxyl ions. While water with more free hydroxyl ions is basic, water with more free hydrogen ions is acidic. The solubility and biological availability of chemical components including nutrients (phosphorus, nitrogen and carbon) and heavy metals (lead, copper, cadmium etc.) are determined by the pH of water. Mean spatial pH values in River Awach Kibuon were not significantly different implying absence of activities in the catchment that release pH reducing or increasing substances. However, the mean temporal pH values varied significantly with the wet season having 7.36 and dry season 7.24. Ouma et al. (2016) also found significant seasonal pH variations in Lake Victoria beaches albeit with higher values ranging from 6.8 to 8.9. Excessively low and high pH values can be harmful to the use of water. The pH range of 7.4 to 8.0 recorded in River Awach Kibuon falls within 6-9 range which is conducive for most aquatic life. pH values below 4 and above 11 are known to be fatal to some species of fish while values of 4-6 and 9-11 impede growth and result in failed reproduction. Low pH is also known to increase bioaccumulation of heavy metals like mercury in fish and toxicity of ammonia in water thereby endangering the lives of aquatic organisms (Scheuhammer & Graham, 1999).

Electrical conductivity is a measure of a material's capacity to conduct electric current. Electrical conductivity in River Awach Kibuon varied significantly spatially but was not significantly different temporally. With the exception of Kebirigo station, electrical conductivity in River Awach Kibuon generally increased downstream ranging from 55 to 96 µS $cm^{-1}$. The downstream increase is expected since the river increases in size downstream gathering more electrolytes from the increased number of tributaries. Lack of seasonal electrical conductivity differences in the river may be attributed to the increasing similarity of dry and wet seasons in the recent past. The findings of this study on electrical conductivity are close to 70 - 120 µS $cm^{-1}$ reported in River Kuja (Orina et al., 2017) but much lower than 420 - 753 µS $cm^{-1}$ reported by Ouma et al. (2016) in Lake Victoria, Kenya beaches. The relatively high electrical conductivity value observed at Kebirigo station may be attributed to metal works and oil leaks from vehicles washed near the river. In comparison to less disturbed streams, municipal areas usually have higher quantities of metals like zinc, copper, lead, chromium, cadmium and nickel. Industrial discharges are a factor in these high quantities, but non-point sources, including brake linings (which include nickel, chromium, lead and copper) and tires (which contain zinc, lead, chromium, copper and nickel), are a bigger contributor (Meyer, 2009).

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The higher the total suspended solids in the water, the higher the turbidity. The turbidity in River Awach Kibuon varied significantly spatially, increasing downstream. The downstream increase is the expected longitudinal trend since rivers become bigger downstream draining a bigger area with more tributaries joining with more sediments therefore ending up in the river. There was no significant temporal variation probably because the seasons are no longer clearly distinguishable. The turbidity values obtained in this study (51 to 342 NTU) were much lower than the 279 to 554 NTU reported by Ouma et al. (2016) in a study of water quality of landing beaches in the gulf of Lake Victoria, Kenya.

TDS is a measure of the total amount of both organic and inorganic compounds in a liquid. Minerals, salts and organic matter make up the majority of these solids, which can serve as a basic gauge of water quality. TDS is used to both indicate the visual qualities of drinking water and to indicate the overall presence of a wide range of chemical pollutants. TDS in River Awach Kibuon varied significantly spatially but not temporally. With the exception of Kebirigo station, TDS increased downstream ranging from 42 - 74 mg $L^{-1}$. The increase downstream is expected given the fact that as the river travels downstream, many tributaries join bringing in sediments from soil erosion in the surrounding farms. Lack of temporal TDS variation may be as a result of climate change which has made the seasons less distinguishable. The TDS findings of this study are closer to 60.7 - 135 mg $L^{-1}$ reported by Orina et al. (2020) in selected beaches in the gulf of Lake Victoria, Kenya but much lower than 208 - 407 mg $L^{-1}$ reported by Ouma et al. (2016) in the rural catchment areas of Lake Victoria Basin, Kenya.

Nutrients are chemical elements required for the development of plant and animal life. In healthy natural water bodies such as lakes and rivers, nutrients are needed for the growth of phytoplankton that forms the base of complex food webs supporting the entire aquatic ecosystems. The most prevalent nutrients in rivers and streams are nitrogen and phosphorus, which mostly come from precipitation, fertilizer application, effluents from sewage treatment plants and natural mineral dissolution from soil or geological formations (Mueller & Helsel, 1996). Total nitrogen (TN) in River Awach Kibuon varied significantly spatially but not temporally. TN generally decreased downstream ranging from 1740 ± 417 µg $L^{-1}$ at Kebirigo station (river source) to 654 ± 144 µg $L^{-1}$ at River mouth station. The findings of this study on TN compare favorably to 1002.9 to 1315.3 µg $L^{-1}$ reported by Orina et al. (2017) in a study of River Kuja. The significant spatial decrease downstream may be explained by the level of intensity of farming practiced along the longitudinal stretch of the river. The upper catchment is located in Nyamira County that predominantly practices intensive farming of tea and coffee characterized by increased use of fertilizers. In contrast, the lower catchment area is characterized by low intensity crop farming involving minimal use of fertilizers. Lack of temporal variations may be attributed to continuous agricultural activities in most of the catchment throughout the year. Stations located in the upper reaches of the river such as Kebirigo, Nyangoso Bridge, Nyangoso Water Tower and Nyamiacho Waterfall had comparable TN levels because of similarity in farming activities. In contrast, stations located in the middle and lower reaches of the river had lower TN levels attributable to less intense farming activities.

Phosphorus is one of the essential nutrients required in aquatic ecosystems to promote productivity and plant life but excess quantities in water can cause eutrophication. Phosphorus is a typical component of organic wastes in sewage and industrial effluents, manure and agricultural fertilizers (Mueller & Helsel, 1996). In this study, total phosphorous (TP) varied significantly spatially along the river but was not significantly different between seasons. TP generally increased downstream. TP in the river may originate from crop farms through the use of fertilizers in the catchment reaching the rivers through runoffs containing products of soil erosion or from the weathering of rocks in the drainage area (Mueller & Helsel, 1996). The downstream increase in total phosphorus levels can be attributed to accumulation as the river travels downstream. TP findings in this study (50 – 223 µg $L^{-1}$) compare favorably to 68.1 - 372.3 µg $L^{-1}$ reported by Orina et al. (2017) in River Kuja probably as a result of similarity in elevation, soil characteristics and agricultural activities.

In general, most physico-chemical parameters including DO, pH, electrical conductivity and temperature in River Awach Kibuon were within safe and conducive ranges for fish communities (Alabaster & Lloyd, 1982). However, turbidity, TDS and nutrient levels indicated a river in the process of degradation by sediments and eutrophication. It can therefore be presumed that physico-chemical parameters had moderate impact on the biotic integrity and overall ecosystem integrity of River Awach Kibuon.

### 4.9 Habitat assessment

The quality and diversity of physical river habitats is an important component of river ecological integrity and plays a big role in determining the diversity and abundance of fish and other biota found in the streams and rivers (Karr & Dudley, 1981). The low habitat quality recorded in the upper zone of the river may be attributed to the widespread riparian zone encroachment, habitat destruction and intense agricultural activities practiced in this part of the river catchment. In contrast, midstream and downstream stations had better habitat quality which may be attributed to wide and extensive natural riparian buffer vegetation and less intense agricultural activities in these areas. These findings underline the importance of physical habitat characteristics to the river ecosystem and the strong link between the river channel and its basin.

Mean depth in River Awach Kibuon varied only significantly spatially increasing downstream but not temporally. The spatial variations encountered conform to the general longitudinal trend. Most rivers are shallow at the source, increasing gradually in depth as they move downstream reaching their deepest points at the river mouth. Lack of seasonal variation in river depth may be attributed to climate change which has made the two seasons indistinguishable. The mean river channel width also varied significantly spatially but was not significantly different temporally. The downstream spatial increase in width is self explanatory since rivers become bigger downstream as tributaries join thereby increasing the volume of water and the width of the channel. The lack of temporal variation may again be attributed to climate change and reduced rains during wet seasons in the recent past.

Channel sinuosity defines the degree of meandering of a riverbed. In general, sinuosity is lowest in constrained mountain streams and largest in meandering gravel or sand-bedded streams. Channel sinuosity arises from flow hydraulic processes around channel bends in which secondary, across-channel circulation can increase meander wavelength and the migration of meanders across a floodplain (Leopold et al., 1964). In comparison to straighter channels, those with high sinuosity may have more and deeper pools near the peak of a meander curve. As a result, channel sinuosity is a crucial element of fish habitat, and habitat models could use the sinuosity parameter. Channel sinuosity increased downstream in River Awach Kibuon increasing the availability of habitats for biota. This probably explains the increased number of fish species downstream.

The term "river bed substrate" describes the kind of material that makes up the streambed. This varies greatly from fine sediment through gravel and stones of varying sizes to huge rocks and boulders. The geology of the region affects the kind of substrate in a river, but water velocity and nearby land usage can also influence this. In slower flowing areas, such as pools, the substrate is often finer, whereas faster flowing areas usually have coarser substrates. In River Awach Kibuon, bottom substrate stability decreased downstream with the average size of substrate material decreasing downstream, starting with huge rocks and boulders upstream, decreasing to cobbles and gravel, finally to silt and fine sand at the River mouth. This is in conformity with the expected longitudinal trends (Hynes, 1970).

In general, physical river habitat characteristics such as width of natural riparian buffer vegetation, channel sinuosity and general aesthetics of the river reaches correlated strongly with FIBI values obtained. The stations that had very narrow or non-existent natural buffer riparian vegetation had no fish while the ones that had wide and extensive natural buffer vegetation and wilderness outlook had the highest level of species diversity. This finding emphasizes the importance of river habitat to biological diversity and the overall river ecosystem integrity.

## 4.10 Biological assessment

### 4.10.1 Diversity indices

The diversity of fish species in a river is important in assessing its ecological integrity. Important criteria for assessing the stability and function of ecosystems include species richness and composition (Bibi & Ali, 2013). The results of this study indicate that River Awach Kibuon is characterized by varying longitudinal fish species diversity ranging from 0 in the first four upstream stations to a maximum of 18 species at the River mouth station. The same pattern is also reflected in the values of D, $H'$ and J. The 0 fish species diversity recorded in the upstream stations may be attributed to high level of anthropogenic activities in the catchment area such as riparian zone encroachment, intense agricultural activities resulting in river siltation, deforestation and general river habitat degradation. Discharge of effluents into the river may have negatively impacted river species diversity as demonstrated by low fish species diversity at Eaka Coffee Factory station where only two clarid fish species were encountered.

The midstream section of River Awach Kibuon had fairly good fish species diversity ranging from 6 to 9 species and moderate D and $H'$ values. This may be attributed to the fairly good habitat quality that characterizes this section of the river. Good habitat quality is exhibited in the form of wide natural riparian buffer vegetation (10-20 m), unmodified natural condition of the area and moderate channel sinuosity. The downstream section of the river had a mixture of low diversity at Kendu Bridge station and higher diversity at the

River mouth station. The relatively low diversity observed in Kendu Bay Bridge station may be attributed to sampling difficulties with an electro-fisher which is known to perform poorly in deep and wide rivers (Penczak & Jakubowksi, 1990). Kendu Bay Bridge station had the highest width with deep fast-moving water thereby rendering electro-fishing somehow ineffective. The habitat quality was fair owing to low in stream cover, wide natural riparian buffer vegetation, moderate channel sinuosity and high degree of naturalness of the area.

The River mouth station had the highest fish diversity characterized by 18 species, high channel sinuosity, extensive natural riparian buffer vegetation and the unmodified natural condition of the surrounding area. There was hardly any temporal effect on the diversity of fish communities in River Awach Kibuon. This may be attributed to the increasing similarity of the conventional wet and dry seasons in the recent past probably as a result of the effects of climate change. From the foregoing discourse, the fish diversity indices clearly revealed the ecological integrity status of different sections of River Awach Kibuon and by extension the negative impacts of anthropogenic activities on fish communities in the river. Naturally, fish biodiversity should generally increase downstream via natural increases in habitat diversity (Hynes, 1970) but in our study the pattern was disrupted probably by anthropogenic impacts. Kochola Bridge and Kendu Bay Bridge stations' diversity indices deviated from expected natural longitudinal trends.

#### 4.10.2 Other biological indices (GSI, HSI and EGI)

Fish population indices such as GSI, HSI and EGI generally indicate and reflect the condition of the environment in which fish live in terms of energy availability. In addition, GSI of a fish population also helps in determining breeding season(s) of the species studied. In this study, GSI values of *Enteromius cercops* and *Labeobarbus altianalis* varied with respect to the sex of the fish, season and the development stage of the gonad of the fish. These variations may be attributed to the differences in the structure and form of testis and ovaries. Female gonads (ovaries) are far bigger than male gonads (testis) because ova are far bigger in size than spermatozoa. Thus, GSI values of mature female fish are naturally far higher than those of mature males. The median GSI values of *Enteromius cercops* and *Labeobarbus altianalis* in River Awach Kibuon varied between different stages of gonad development increasing with increase in stage of gonad development. This conforms to the expected natural trend where gametes increase in weight as they grow resulting into bigger GSI values. There was also variation in median GSI values between wet and dry seasons for the two species. The GSI ranges of 0.5 to 15.1 and 0.3 to 8.8 obtained for *Enteromius cercops* and *Labeobarbus altianalis*, respectively are comparable to those obtained by other researchers working on the same subject area. Pimple and Kharat (2014) studied the GSI and fecundity of *Rohtee ogilbii* in Western Ghats of Maharashtra (India) and reported GSI value range of 3.6-11.8. Nunes et al. (2011) working with Atlantic sardine, *Sardina pilchardus*, obtained higher GSI values of 9.6-12.3 (December - February) and 0.3-0.9 (July-August).

The fish's stored energy is indicated by the HSI, which is also a reliable sign of recent feeding activity (Tyler & Dunns, 1976). Since it is important in the formation of vitellogenin, the precursor of the yolk, the liver is a crucial organ in fish reproduction (Lucifora et al., 2002). Both spatially and temporally, the HSI values for *Enteromius cercops* and *Labeobarbus altianalis* varied notably spatially implying that different parts of the river had varying food levels. The HSI values were almost the same for males and females in both species. Since liver weight is a reflection of the food situation in the environment, it can be presumed that food availability differed spatially and temporally in the river. In cases of enhanced food availability, excess energy taken by the fish is stored in the liver in the form of glycogen leading to big liver sizes and HSI values. In contrast, lean times result into low HSI values. The lack of HSI variations based on sex of the fish is understandable because unlike gonads, the liver size is approximately the same in the two sexes. The HSI range of 0.1 - 3.7 for *Enteromius cercops* and 0.5 - 2.1 for *Labeobarbus altianalis* obtained during wet season are comparable to values obtained by other researchers in similar studies. Zin et al. (2011) studied the HSI of *Channa orientalis* in Mandalay Region and reported HSI minimum mean values of 0.84 ± 0.30 for males in March and 1.08 ± 0.31 for females in July. The maximum mean HSI values of 1.46 ± 0.15 for males in December and 1.60 ± 0.24 for females were obtained in January.

The EGI values ranged between 0 - 19% across the 9 species studied. From these figures, it can be argued that the food availability in River Awach Kibuon is generally good (Vinson & Angradi, 2011). Fish of the genus *Enteromius* had very low EGI values. The feeding habits of the fish species may also explain why some stomachs might have been empty. The fish species that feed continuously on small meals are not likely to be found with empty stomachs regardless of sampling time. On the other hand, fish species that eat far between large meals are likely to be found with empty stomachs if sampling is done shortly before their eating time. Therefore, the EGI values may at times not indicate the true food situation in the environment since feeding habits and chosen fish sampling times may have a bearing on EGI values. In this study clarid species, *Clarias gariepinus* and *Clarias theodorae*, whose feeding habits fall between omnivores and carnivores had higher EGI values of 17 to 19%. The sampling time is likely to have influenced EGI values for these species since they have big stomachs and probably eat large meals far between. The cyprinid species, *L. altianalis, E. neumayeri, E. cercops, E. nyanzae, E. kerstenii,* and *E. jacksoni,* which lack true stomachs and eat small meals throughout, had relatively small EGI values implying that fish sampling time had little or no adverse effects.

### 4.10.3 Fish Index of Biotic Integrity (FIBI)

The Fish Index of Biotic Integrity (FIBI) scores in River Awach Kibuon fluctuated longitudinally. It was lowest upstream, increased midstream, decreased downstream, then increased to the highest value at the river mouth. The observed pattern illustrated a gradient of influence of human activities on the ecological integrity of the river basin from source to mouth. The low FIBI scores ranging from 0 - 21 out of a possible 45 in the headwater section of the river may be attributed to the negative impacts of anthropogenic activities such as widespread riparian zone encroachment, deforestation and poor farming practices that cause soil erosion and leaching of agrochemical residues. Although some headwaters of rivers are naturally fishless, studies of the longitudinal distribution of fish in rivers of the Lake Victoria Basin have revealed the presence of 1 or 2 small-bodied cyprinid and clarid fish species in headwaters (Raburu & Masese, 2012; Masese et al., 2020). Thus, the fishless condition in the first 4 upstream is not natural but consequences of anthropogenic activities that have caused impairment hence requiring restoration.

The midstream section had intermediate FIBI scores of 36 and 34, indicating moderate level of degradation. This may be attributed to wide natural riparian buffer vegetation, moderate habitat quality and the 6-9 fish species encountered in this section of the river. The midstream section is not as densely populated as the upstream section and the pressure on land is far less. The agricultural activities are less intense characterized by subsistence farming of maize, beans, sugar-cane and vegetables which are less damaging to the aquatic environment. The midstream section of the river is therefore moderately impaired requiring management measures to forestall further degradation.

The downstream section of the river had FIBI scores of 24 and 43 for Kendu Bay Bridge and River mouth stations signifying impairment and unimpairment, respectively. The low FIBI score of 24 recorded at Kendu Bay Bridge station which indicates impairment may be attributed to fair habitat quality evidenced by low in-stream cover and moderate riparian-buffer vegetation and the 4 fish species encountered. However, it is also possible that the electro fishing method used in this study may not have captured all the fish species present at this station as it had huge rocks, was wide, deep, rough and most difficult to sample (Penczak & Jakubowksi, 1990). The high FIBI score of 43 at River mouth station may be attributed to extensive natural riparian-buffer vegetation; good habitat quality and the 18 fish species encountered which indicate unimpaired condition. The extensive natural riparian-buffer vegetation is protective of the river and its habitats thereby enhancing its capacity to support increased number of fish species (Lowe-McConnell, 1975).

In general, the FIBI scores did not strictly conform to expected natural longitudinal trend of downstream increase. Anthropogenic variables such as pollution and habitat degradation can cause longitudinal biotic parameter changes in the river (Stanford & Ward, 2001). In unmodified natural conditions, fish species diversity is expected to increase downstream with the increase in stream order which is accompanied by increase in habitat diversity, pool development and habitat volume (Hynes, 1970; Lowe-McConnell, 1975). In River Awach Kibuon, fish species diversity fluctuated downstream with Kochola Bridge and Kendu Bay stations deviating from the expected natural trend indicating negative impacts of anthropogenic activities.

The FIBI scores and the ecological integrity classes assigned to different sections of River Awach Kibuon are indicative of a deteriorating environment under the influence of multiple cumulative human activities. This is likely to worsen with rapidly rising human population in the whole Lake Victoria Basin (Njiru et al., 2008). The challenge at hand is to reverse the current, dangerous trend by improving FIBI scores at the affected stations by restoring both water and habitat quality. This can be realized by reforestation of riparian zones which improves riverine ecological integrity (Kasangaki et al., 2008; Hughes & Vadas, 2021). The index developed herein, can be used by aquatic resource managers and scientists in this ecological region to monitor degradation levels and inform restorative efforts as it identified sources of impairment clearly.

The successful development of a FIBI in a medium-sized river in this study makes a strong case for their consideration in similar future endeavors. It is worth noting that a number of state- or basin-specific versions of the IBI have been successfully developed for small to medium-sized wadeable streams in the Midwestern United States (Seegert, 2000) as well as the use of large rivers around the world (Simon & Emery, 1995; Zhu & Chang, 2008; Aura et al., 2017) despite serious challenges. Notably, it is very difficult to obtain representative fish samples from large rivers because of size and depth (Penczak & Jakubowksi, 1990). This difficulty violates one of the fundamental assumptions of the IBI concept, which requires entire fish communities to be sampled without bias towards size or taxa (Karr, 1981; Karr et al., 1986). It is much easier to fulfill this assumption in small to medium-sized rivers to obtain credible ecological integrity assessment results. It is also very difficult to obtain good reference sites in large rivers as most of them have been dammed, channelized and/or dredged (Seegert, 2000). The use of small to medium-sized rivers in FIBI development is therefore vindicated by this study.

### 4.11 Fish population dynamics

The results of the current and previous studies indicate notable changes in population parameters of the four studied species over the last four decades in the Lake Victoria Basin and other water bodies in Kenya (Appendix 6). $L_\infty$ of *Oreochromis niloticus* ($L_\infty$ = 46.2 cm) in the current study is exactly the same to that reported by Yongo and Outa (2016) but smaller than 64.6 cm, 63.1 cm and 58.8 cm reported by Getabu (1992), Dache (1994) and Njiru et al. (2007), respectively in studies of Lake Victoria fish populations. $L_\infty$ of *Clarias gariepinus* ($L_\infty$ = 92.9 cm) is equally smaller than $L\infty$ = 114.3 cm reported by Macharia et al. (2017) in Lake Baringo. Similarly, $L_\infty$ of *Synodontis victoriae* ($L_\infty$ = 26.3 cm) is much smaller than 40.0 cm reported by Asila & Okemwa (1988) in Lake Victoria. These declines may be attributed to over-fishing and increasing habitat degradation within the Lake Victoria Basin (Sparre & Venema, 1998).

*K* for *Oreochromis niloticus* steadily increased from 0.25 $yr^{-1}$ (Getabu, 1992), to 0.35 $yr^{-1}$ (Dache, 1994), to 0.59 $yr^{-1}$ (Njiru et al., 2007) and to 0.67 $yr^{-1}$ in the current study. The same trend was also observed in growth studies of *Synodontis victoriae* and *Clarias gariepinus* populations in Lake Victoria (Asila & Okemwa, 1988) and Lake Baringo (Macharia et al., 2017), respectively. The high growth curvatures (*K*) imply fast growth rate and earlier attainment of $L_\infty$. The changes in $L_\infty$ and *K* indicate a decrease in average size of landed individuals of the four fish species over time. This may be attributed to stressful environments as a result of environmental degradation and overfishing (Sparre & Venema, 1998). This view is validated by reported widespread habitat/environmental degradation in Lake Victoria (Njiru et al., 2008).

*Z*, *M* and *F* have all increased over the last four decades in all the four fish species investigated and were higher in the river than in the lake populations. Increase in *F* in Lake Victoria Basin may be attributed to rapid increase in the fishing effort (Regional Frame Survey Report, 2014). Environmental degradation of the Lake Victoria Basin by pollution, invasive weeds, eutrophication and climate change (Njiru et al., 2008) may also be responsible for high mortality rates. Overcapacity of fishermen, fishing gears and fishing crafts is also a widespread challenge in the entire basin (Regional Frame Survey Report, 2014).

Exploitation rate (*E*) of 0.54 for *Oreochromis niloticus* is higher than 0.34 reported by Getabu (1992). Similarly the exploitation rate (*E*) of 0.52 for *Clarias gariepinus* is higher than 0.46 reported by Macharia et al. (2017) in Lake Baringo, Kenya. The higher (*E*) values may be attributed to increasing fishing pressure on the fish populations of Lake Victoria (Njiru et al., 2018). The yield-per-recruit model developed by Beverton and Holt provides the most accurate representation of how population characteristics affect biomass and yield (Beverton & Holt, 1966). At the reported mortality rates, the observed *E* of 0.54 for *Oreochromis niloticus* is much higher than the optimum exploitation rate $E_{0.5}$ of 0.29 and slightly higher $E_{0.1}$ of 0.40 (MEY) and $E_{max}$ of 0.48 (MSY). This implies that the *Oreochromis niloticus* population in River Awach Kibuon is overfished. Similarly, the *E* of *Synodontis victoriae* (0.60), *Clarias gariepinus* (0.52) and *Protopterus aethiopicus* (0.66) exceeded their maximum exploitation rates ($E_{\max}$) of (0.56, 0.46 and 0.46), respectively. The implication is that all the four main commercial fish species in River Awach Kibuon are overexploited.

Probability of capture information helps fisheries resource managers determine sustainable minimum fish sizes in a fishery and is indicative of the actual fish sizes caught in the fishing grounds by specific gears (Kindong et al., 2018). The results of this study indicate that $Lc/L\infty$ ratio was lower than 0.5 in all the four species indicating the presence of large quantities of juveniles in the catches of *Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus.* This may be attributed to fishing in breeding grounds or use of small-meshed fishing gears and possible occurrence of growth overfishing. Close monitoring of riverine fisheries in the Lake Victoria Basin is therefore recommended to reduce the prevalence of juveniles in the catches.

Recruitment patterns showed all year-round recruitment with bi-modal annual pulses for three species (*Synodontis victoriae*, *Oreochromis niloticus* and *Protopterus aethiopicus*) and one main pulse for *Clarias gariepinus* occurring during the months of May through June and September through October. The first pulse was usually more pronounced than the second and both recruitment pulses coincided with long and short rainy seasons of the year. These findings concur with Pauly's (1982) observations of two recruitment pulses occurring in tropical fish and short-lived species annually. These findings are comparable to those of Yongo et al. (2018) in a study of Nile perch populations in Lake Victoria.

### 4.12 Correlations between physico-chemical parameters, habitat characteristics and biological characteristics of fish communities in River Awach Kibuon

The results of Canonical Correspondence Analysis (CCA) indicated that several physico-chemical parameters influenced fish species abundance and diversity in River Awach Kibuon. Electrical conductivity, total dissolved solids (TDS) and velocity had strong influence while dissolved oxygen, turbidity and temperature had moderate influence. Nutrients and pH exerted little influence on fish abundance and diversity in the river. These results concur with the findings of Ghimire & Koju (2021), Wu et al. (2019) and Suvarnaraksha et al. (2012) who studied the relationship of fish species diversity and environmental variables in Kamala River (Nepal), Chisui River (China), and a tropical river in Ping-Wang River Basin (Thailand), respectively and reported strong correlation between fish species diversity and temperature, dissolved oxygen, channel velocity, electrical conductivity, TDS and nitrates. The physico-chemical parameter ranges observed in this study compare favourably to the findings of Ouma et al. (2016) and Orina et al. (2017) in similar water quality studies of Lake Victoria and River Kuja, respectively. The strong influence of water quality parameters on the diversity and abundance of fish communities in River Awach Kibuon demonstrates the importance of water quality to aquatic biota. Consequently, no effort should be spared in maintaining water quality for healthy and sustainable biotic communities.

FIBI had strong positive significant correlation with HQI. The strong significant correlation between habitat quality and biological characteristics is a clear demonstration of the importance of habitat quality to biological communities in the river. This finding is comparable to that of Gorman and Karr (1978) who reported a strong positive correlation between habitat diversity and fish species diversity with a correlation coefficient r value of 0.81. Habitat is a major determinant of aquatic community potential (Barbour & Stribling, 1991). Habitat provides suitable conditions for sustaining biota (Jowett, 1997). The strong significant correlation between habitat quality and biological characteristics in River Awach Kibuon should also be seen as a validation of the results obtained by both habitat assessment and biological assessment in determining it ecological integrity.

# CHAPTER SIX

# CONCLUSIONS AND RECOMMENNDATIONS

## 4.13 Introduction

This chapter highlights the conclusions drawn from the findings of the study and the recommendations made for mitigation. This chapter's findings and recommendations are arranged in accordance with the study's objectives. The conclusions are drawn with respect to the ecological integrity of River Awach Kibuon and exploitation status of the leading four commercial fish stocks exploited at the mouth of the river. Recommendations are made to correct negative trends and ensure long-term sustainability of natural aquatic and fisheries resources in River Awach Kibuon.

## 4.14 Conclusions

In light of the results of this study the following conclusions are made:

### Physico-chemical parameters

Water quality of the river is fairly good but with indications of beginning degradation especially with respect to turbidity, TDS and nutrients which may be attributed to deterioration of habitat characteristics and general degradation of the water catchment area. Most physico-chemical parameters significantly varied spatially but not temporally. Geographical location influenced water quality of River Awach Kibuon but season had little or no influence. Therefore, the hypothesis that spatio-temporal physico-chemical parameters did not vary significantly in River Awach Kibuon is rejected.

### Habitat characteristics

Habitat quality varied spatially along the length of the river. The upstream section had very narrow natural riparian buffer vegetation, hence require urgent mitigation. The midstream and downstream sections had fair and good habitat quality, respectively. Habitat quality markedly impacted fish community diversity and overall ecosystem integrity of River Awach Kibuon. Habitat quality varied spatially. Consequently, the hypothesis that habitat quality did not vary spatially is rejected.

**Diversity indices**

Diversity indices (D, H' and J) indicated a degraded river upstream, moderately degraded midstream and undegraded downstream at the river mouth. Diversity indices varied spatially but not temporally. Season did not significantly influence fish diversity indices while geographical location did. Consequently, the hypothesis that spatio-temporal fish diversity indices did not vary in River Awach Kibuon is rejected.

**Other biological indices (GSI, HSI, and EGI)**

The GSI, HSI and EGI values observed in this study indicated a river environment that has moderate to good supply of food. Geographical location and season had strong influence on GSI values but little influence on HSI values. As a result, the hypothesis that location and season did not have significant effect on biological indices in River Awach Kibuon is rejected.

**Fish Index of Biotic Integrity (FIBI)**

The longitudinal FIBI scores indicated a river that is impaired upstream with narrow riparian zones and absence of fish in all the first four samplings stations, intermediate midstream with 6-9 fish species and fairly unimpaired downstream at the river mouth with with extensive natural riparian beuffer vegetation and 18 fish species. FIBI varied spatially along the river but did not differ much temporally. Therefore, the hypothesis that spatio-temporal FIBI did not vary in River Awach Kibuon is rejected.

**Fish population dynamics**

All the four studied fish stocks (*Oreochromis niloticus*, *Synodontis victoriae*, *Clarias gariepinus* and *Protopterus aethiopicus*) in River Awach Kibuon are overexploited with exploitation rates higher than $E$ optimum ($E > E_{opt}$) and $E$ maximum ($E > E_{\max}$). Fish populations in the river exhibited year-round recruitment with bi-modal annual pulses that characterize tropical species. Consequently, the hypothesis that the four main species exploited at the mouth of River Awach Kibuon are not overexploited is rejected.

**Correlations between physico-chemical parameters, habitat characteristics and fish community characteristics**

Habitat Quality Index had strong positive significant correlation with Fish Index of Biotic Integrity. Conductivity, TDS and velocity also correlated significantly with fish abundance. Consequently, the hypothesis that physico-chemical parameters, habitat characteristics and fish community characteristics are not significantly correlated is rejected

## 4.15 Recommendations

In light of the results and conclusions of this study the following recommendations are made:

**Physico-chemical parameters**

The study recommends improvement of the the degraded river habitats in order to protect and preserve water quality of the river.

**Habitat characteristics**

The study recommends urgent restoration of natural riparian buffer vegetation in the entire upstream and midstream sections of the river. The Kenya Forest Service (KFS) should facilitate reforestation and protection of the river's riparian zones and ensure that national environmental laws and regulations like the Environmental Management and Coordination (EMCA) Act of 1999 are enforced to the letter.

**Diversity indices**

The study recommends improvement of the whole aquatic environment through better farming practices in the catchment area, riparian zones protection and possible re-stocking of the upstream zone with appropriate fish species in a bid to improve diversity indices.

**Other biological indices (GSI, HSI and EGI)**

The study recommends comprehensive river catchment management involving protection of riparian zones, prevention of soil erosion, restricted use of fertilizers and harmful chemicals in terrestrial farms in the basin in order to improve biological indices such as GSI, HSI and EGI and ensure healthy biotic communities.

**Fish Index of Biotic Integrity (FIBI)**

The study recommends the use of the developed FIBI in conjunction with HQI to monitor and manage the ecological integrity of River Awach Kibuon and other rivers in the Lake Victoria Basin, Kenya. It also recommends increased use of small to medium-sized water bodies in the development of FIBIs, as this is more convenient than use of large rivers that may require other assessment tools.

**Fish population dynamics**

The study recommends strict enforcement of fisheries legislation in riverine fisheries of the Lake Victoria Basin to ensure healthy and thriving fish populations. The study also recommends a reduction of fishing effort on all the four overexploited species to ensure long-term sustainability.

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# APPENDICES

## Appendix 1. Physico-chemical parameters data collection sheet

Date…………Station name………………Start time……………….......... End time……….

Longitude…………… Latitude……………. Observed stream use………………………….

Potential source of pollution if any…………………………………………………………...

| Parameter | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| pH | | | | |
| Temperature | | | | |
| Dissolved Oxygen (DO) | | | | |
| Total Dissolved Solids (TDS) | | | | |
| Conductivity | | | | |
| Total Nitrogen (TN) | | | | |
| Total Phosphorus (TP) | | | | |
| ORP | | | | |
| Distance taken by floater | | | | |
| Time taken by floater | | | | |
| Rate of water flow | | | | |
| Water level in channel | | | | |

**Appendix 2. Fish sampling for Fish Index of Biotic Integrity data collection sheet**

Date……………Station name……………………Start time…................End time…………

Longitude………………Latitude………………………Observed stream use……………..

Potential source of pollution if any………………………………………………………...

| Details of Fish Species Caught | | |
|---|---|---|
| Name of Species (Local and scientific) | No. of fish | No. of fish with lesions on the skin, parasites or any abnormality |
| | | |
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| | | |
| | | |
| | | |
| Any Other Relevant Information | | |

**Appendix 3. Population dynamics data collection form**

Assessment of fish catches at the river mouth - length frequency data

Date……………………………………… Time of the Day……………………………...

Name of species………………………………………………………………………………

GPS (Latitude) ………………………………Longitude…………………………………

Weather conditions……………………………………………………………………………

| No. | Total Length (cm) | Standard Length (cm) | Forked Length (cm) |
|---|---|---|---|
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## Appendix 4. River habitat characteristics data collection sheet

Date………………Station name…………………………Start time……………….................End time…………………………………

Longitude…………………………Latitude………………………Observed stream use…………………………………………………

Potential source of pollution if any……………………………………………………………………………………………..........

| Parameter | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| Channel width | | | | |
| Stream width | | | | |
| Stream depth | | | | |
| Width of natural vegetation on left side | | | | |
| Width of natural buffer vegetation on right side | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tick if available in river channel/ where appropriate | Trees | Snags | Wood debris | Holes | Macrophyte | Grass | Wilderness aesthetic | Natural aesthetic | Common aesthetic |
| | | | | | | | | | |
| | Clear water | Slightly turbid water | Turbid water | Stream bend with the stream reach/ channel sinuosity | Number well defined bends | Number of moderately defined bends | Number of poorly defined bends | No. of riffle: | |
| | | | | | | | | | |
| Water level in the river | High | Moderate | Low | No flow | Bank stability | Stable | Moderately stable | Moderately unstable | Unstable |
| | | | | | | | | | |
| Bottom substrate | Stable | Moderate stable | Moderatel y unstable | Unstable | Dimension of largest pool Score | Large | Moderate | Small | Absent |
| | | | | | | | | | |

**Appendix 5. Fish reproductive and feeding characteristics data collection sheet**

Date…………………………………………………………………………………………………………………………….

Sampling site name……………………………………………Standardized Fishing Time (1 Hour)……………………………………..

GPS (Latitude)……………………………….Longitude…………………………………………………………………………..

Species Name (Local and Scientific)………………………………………………………………………………………….

Weather conditions…………………………………………………………………………………………………………….

| No. | TL (cm) | FL (cm) | SL (cm) | Weight (g) | Sex (M/F) | Gonad wt (g) | Liver wt (g) | Gut fullness (0-4) | Types of food in stomach | Sexual maturity stage |
|---|---|---|---|---|---|---|---|---|---|---|
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| | | | | | | | | | | |

**Appendix 6. Population parameters of Oreochromis niloticus, Clarias gariepinus, Synodontis victoriae and Protopterus aethiopicus in River Awach Kibuon and Lake Victoria, Kenya from 1988-2021**

| ***Location and period*** | **Population parameters** | | | | | | | **Source** |
|---|---|---|---|---|---|---|---|---|
| ***Oreochromis niloticus*** | **L∞ (cm TL)** | ***K* (yr$^{-1}$)** | ***Z* (yr$^{-1}$)** | ***M* (yr$^{-1}$)** | ***F* (yr$^{-1}$)** | ***E = F/Z*** | **Ø'** | |
| Nyanza Gulf, Lake Victoria, Kenya, 1992 | 64.6 | 0.25 | 0.82 | 0.54 | 0.28 | 0.34 | 3.03 | Getabu (1992) |
| Nyanza Gulf, Lake Victoria, Kenya, 1994 | 63.1 | 0.35 | 1.71 | 0.72 | 0.99 | 0.58 | 3.14 | Dache (1994) |
| Nyanza Gulf of Lake Victoria, Kenya, 2007 | 58.8 | 0.59 | 2.12 | 1.00 | 1.12 | 0.48 | 3.31 | Njiru et al. (2007) |
| Lake Victoria, Kenya, 2014-2015 | 46.2 | 0.69 | 2.18 | 1.14 | 1.05 | 0.46 | 3.14 | Yongo & Outa (2016) |
| Mouth of River Awach Kibuon, LVB, Kenya, 2021 | 46.2 | 0.67 | 2.40 | 1.11 | 1.30 | 0.54 | 3.16 | Present study (2021) |
| ***Clarias gariepinus*** | | | | | | | | |
| Lake Baringo, Kenya | 114.3 | 0.37 | 1.14 | 0.61 | 0.53 | 0.46 | | Macharia et al. (2017) |
| Mouth of River Awach Kibuon, LVB, Kenya, 2021 | 92.9 | 0.70 | 1.97 | 0.94 | 1.03 | 0.52 | 3.78 | Present study (2021) |
| ***Synodontis victoriae*** | | | | | | | | |
| Lake Victoria, Kenya, 1988 | 40.0 | 0.24 | | | | | 2.6 | Asila & Okemwa (1988) |
| Mouth of River Awach Kibuon, LVB, Kenya, 2021 | 26.3 | 0.83 | 3.69 | 1.49 | 2.20 | 0.60 | 2.76 | Present study (2021) |
| ***Protopterus aethiopicus*** | | | | | | | | |
| Mouth of River Awach Kibuon, LVB, Kenya, 2021 | 153.7 | 1.10 | 3.22 | 1.09 | 2.13 | 0.66 | 4.42 | Present study (2021) |

**Appendix 7. Spatial water surface velocity range, mean, standard error and 95% confidence intervals in River Awach Kibuon**

| Parameter | Water surface velocity m $s^{-1}$ | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 0.22 – 0.38 | $0.32^{ab}$ | 0.02 | 0.28 | 0.36 |
| Nyangoso Bridge | 0.53 – 1.20 | $0.90^{bc}$ | 0.09 | 0.69 | 1.11 |
| Nyangoso Water Tower | 0.50 – 1.33 | $0.88^{c}$ | 0.10 | 0.65 | 1.11 |
| Nyamiacho Waterfall | 0.71 – 1.53 | $1.05^{c}$ | 0.09 | 0.82 | 1.27 |
| Eaka Coffee Factory | 0.79 – 1.67 | $1.23^{c}$ | 0.11 | 0.97 | 1.49 |
| Kadongo Bridge | 0.60 – 2.00 | $1.14^{c}$ | 0.19 | 0.70 | 1.59 |
| Kochola Bridge | 0.77 – 1.90 | $1.21^{c}$ | 0.12 | 0.91 | 1.50 |
| Kendu Bay Bridge | 0.58 – 1.40 | $1.00^{c}$ | 0.12 | 0.71 | 1.29 |
| River mouth | 0.17 – 0.71 | $0.47^{ab}$ | 0.06 | 0.32 | 0.61 |

***Note.* SE = Standard Error; CI = Confidence Interval; Supercripts a, b and c indicate homogeneous groups of stations in terms of surface river velocity.**

**Appendix 8. Longitudinal water temperature range, mean, standard error and 95% confidence intervals in River Awach Kibuon**

| Parameter | Temperature ($^{0}$C) | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 17.5 -18.7 | $18.1^{a}$ | 0.2 | 17.7 | 18.4 |
| Nyangoso Bridge | 18.3 - 19.6 | $18.9^{ab}$ | 0.3 | 18.3 | 19.6 |
| Nyangoso Water Tower | 18.8 - 20.1 | $19.5^{ab}$ | 0.3 | 18.8 | 20.1 |
| Nyamiacho Waterfall | 19.3 - 20.8 | $20.1^{bc}$ | 0.3 | 19.3 | 20.8 |
| Eaka Coffee Factory | 20.3 - 21.8 | $21.0^{cd}$ | 0.3 | 20.3 | 21.8 |
| Kadongo Bridge | 21.3 - 22.7 | $22.0^{de}$ | 0.3 | 21.3 | 22.7 |
| Kochola Bridge | 20.9 - 23.2 | $22.1^{de}$ | 0.5 | 20.9 | 23.2 |
| Kendu Bay Bridge | 21.7 - 23.3 | $22.5^{de}$ | 0.3 | 21.7 | 23.3 |
| River mouth | 21.6 - 23.8 | $22.7^{e}$ | 0.5 | 21.6 | 23.8 |

***Note*. SE = Standard Error, CI = Confidence Interval, Superscripts a, b, c, d and e show homogeneous groups of stations in terms of temperature.**

**Appendix 9. The spatial DO range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| Parameter | Dissolved Oxygen (mg $L^{-1}$) | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 6.60 -7.93 | 7.43[ab] | 0.15 | 7.08 | 7.78 |
| Nyangoso Bridge | 6.98 – 7.89 | 7.57[a] | 0.10 | 7.32 | 7.82 |
| Nyangoso Water Tower | 7.06 – 8.05 | 7.52[a] | 0.14 | 7.19 | 7.86 |
| Nyamiacho Waterfall | 6.53 – 8.15 | 7.41[ab] | 0.21 | 6.91 | 7.92 |
| Eaka Coffee Factory | 6.69 – 7.75 | 7.23[abc] | 0.13 | 6.92 | 7.54 |
| Kadongo Bridge | 6.24 – 7.84 | 7.00[bc] | 0.19 | 6.56 | 7.44 |
| Kochola Bridge | 6.96 – 8.17 | 7.50[a] | 0.14 | 7.16 | 7.83 |
| Kendu Bay Bridge | 6.50 – 7.72 | 7.24[abc] | 0.16 | 6.85 | 7.62 |
| River mouth | 6.25 – 7.50 | 6.91[c] | 0.14 | 6.58 | 7.25 |

***Note.* SE = Standard Error, CI = Confidence Interval, Superscripts a, b and c depict homogeneous groups of stations with respect to temperature**

**Appendix 10. The spatial pH range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| Parameter | pH | | | | |
|---|---|---|---|---|---|
| **Sampling Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 6.53 – 8.72 | 7.98 | 0.25 | 7.39 | 8.56 |
| Nyangoso Bridge | 6.33 – 8.26 | 7.52 | 0.22 | 7.00 | 8.03 |
| Nyangoso Water Tower | 6.71 – 8.75 | 7.87 | 0.24 | 7.31 | 8.42 |
| Nyamiacho Waterfall | 6.74 – 8.20 | 7.58 | 0.19 | 7.14 | 8.02 |
| Eaka Coffee Factory | 6.87 – 8.22 | 7.65 | 0.17 | 7.25 | 8.05 |
| Kadongo Bridge | 6.78 – 8.56 | 7.53 | 0.22 | 7.00 | 8.05 |
| Kochola Bridge | 6.71 – 8.56 | 7.59 | 0.23 | 7.05 | 8.14 |
| Kendu Bay Bridge | 6.71 – 8.41 | 7.66 | 0.18 | 7.22 | 8.09 |
| River mouth | 6.47 – 8.61 | 7.42 | 0.24 | 6.86 | 7.98 |

***Note.* SE = Standard Error, CI = Confidence Intervals**

**Appendix 11. The spatial electrical conductivity range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| | Electrical Conductivity (µS $cm^{-1}$) | | | | |
|---|---|---|---|---|---|
| **Sampling Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 92.3 – 98.7 | $95.9^{a}$ | 0.7 | 94.2 | 97.5 |
| Nyangoso Bridge | 53.7 – 59.3 | $55.4^{d}$ | 0.7 | 53.7 | 57.1 |
| Nyangoso Water Tower | 50.0 – 57.5 | $54.7^{d}$ | 0.8 | 52.7 | 56.7 |
| Nyamiacho Waterfall | 51.4 – 59.3 | $56.2^{d}$ | 0.9 | 54.1 | 58.3 |
| Eaka Coffee Factory | 50.8 – 58.6 | $55.0^{d}$ | 1.0 | 52.5 | 57.4 |
| Kadongo Bridge | 72.4 – 77.9 | $75.4^{c}$ | 0.8 | 73.5 | 77.3 |
| Kochola Bridge | 69.1 – 88.3 | $79.3^{c}$ | 2.7 | 73.0 | 85.6 |
| Kendu Bay Bridge | 72.3 – 99.5 | $87.9^{b}$ | 9.2 | 80.2 | 95.6 |
| River mouth | 81.9 – 98.4 | $90.8^{ab}$ | 2.1 | 85.8 | 95.9 |

***Note.*** **SE= Standard Error, CI = Confidence Interval, Superscripts a, b, c and d show homogeneous groups of station with respect to electrical conductivity**

**Appendix 12. The spatial turbidity range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| | Turbidity (NTU) | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 43 - 59 | $51^{a}$ | 2 | 46 | 55 |
| Nyangoso Bridge | 45 - 105 | $61^{a}$ | 7 | 45 | 77 |
| Nyangoso Water Tower | 53 - 487 | $136^{ac}$ | 53 | 10 | 262 |
| Nyamiacho Waterfall | 50 - 461 | $146^{acd}$ | 48 | 32 | 260 |
| Eaka Coffee Factory | 55 - 443 | $164^{abcd}$ | 46 | 55 | 273 |
| Kadongo Bridge | 101 - 468 | $245^{bcd}$ | 46 | 135 | 355 |
| Kochola Bridge | 148 - 450 | $329^{bd}$ | 43 | 228 | 429 |
| Kendu Bay Bridge | 168 - 471 | $333^{b}$ | 42 | 235 | 432 |
| River mouth | 173 - 472 | $342^{b}$ | 41 | 246 | 438 |

***Note*. SE = Standard Error, CI = Confidence Interval, Superscripts a, b, c and d show homogeneous groups of stations in terms of turbidity**

**Appendix 13. The spatial TDS range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| | Total Dissolved Solids (TDS) mg $L^{-1}$ | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 69.6 – 78.7 | $73.9^{a}$ | 1.0 | 71.6 | 76.3 |
| Nyangoso Bridge | 33.8 – 47.1 | $42.2^{b}$ | 1.3 | 39.0 | 45.3 |
| Nyangoso Water Tower | 41.2 – 47.1 | $43.4^{b}$ | 0.6 | 41.9 | 44.8 |
| Nyamiacho Waterfall | 41.2 – 47.7 | $44.1^{b}$ | 0.7 | 42.4 | 45.7 |
| Eaka Coffee Factory | 34.5 – 49.1 | $43.5^{b}$ | 1.8 | 39.3 | 47.6 |
| Kadongo Bridge | 50.7 – 60.7 | $53.2^{c}$ | 1.2 | 50.4 | 55.9 |
| Kochola Bridge | 46.8 – 59.8 | $54.2^{cd}$ | 1.6 | 50.4 | 57.9 |
| Kendu Bay Bridge | 50.1 – 71.4 | $61.1^{de}$ | 2.4 | 55.3 | 66.8 |
| River mouth | 56.7 – 81.9 | $66.1^{de}$ | 3.0 | 59.0 | 73.1 |

***Note*. SE = Standard Error, CI = Confidence Interval, Superscripts, a, b, c and d showing homogeneous groups of stations with respect to turbidity**

**Appendix 14. The spatial TN range, mean, standard error, and 95% confidence intervals per station in River Awach Kibuon**

| | Total Nitrogen (TN) µg $L^{-1}$ | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 505 - 3465 | $1740^{a}$ | 417 | 753 | 2727 |
| Nyangoso Bridge | 598 - 2291 | $1222^{ab}$ | 225 | 690 | 1753 |
| Nyangoso Water Tower | 445 - 1986 | $1086^{ab}$ | 212 | 585 | 1587 |
| Nyamiacho Waterfall | 369 - 2030 | $1101^{ab}$ | 236 | 542 | 1660 |
| Eaka Coffee Factory | 350 - 1784 | $1021^{ab}$ | 208 | 528 | 1513 |
| Kadongo Bridge | 347 - 1566 | $775^{ab}$ | 152 | 417 | 1134 |
| Kochola Bridge | 260 - 1593 | $735^{ab}$ | 150 | 381 | 1090 |
| Kendu Bay Bridge | 254 - 1459 | $669^{b}$ | 142 | 334 | 1004 |
| River mouth | 274 - 1304 | $654^{b}$ | 144 | 312 | 995 |

***Note*. SE = Standard Error, CI = Confidence Interval, Superscripts and b show homogeneous groups of stations in terms of total nitrogen**

**Appendix 15. The spatial TP range, mean, standard error and 95% confidence intervals of 9 sampling stations in River Awach Kibuon**

| | Total Phosphorus (TP) µg $L^{-1}$ | | | | |
|---|---|---|---|---|---|
| **Station** | **Range** | **Mean** | **SE** | **-95% CI** | **+95% CI** |
| Kebirigo | 36 - 89 | $52^{a}$ | 6 | 37 | 67 |
| Nyangoso Bridge | 40 - 96 | $50^{a}$ | 7 | 34 | 66 |
| Nyangoso Water Tower | 39 - 265 | $76^{ab}$ | 27 | 11 | 140 |
| Nyamiacho Waterfall | 43 - 246 | $83^{abc}$ | 24 | 26 | 139 |
| Eaka Coffee Factory | 43 - 285 | $123^{abcd}$ | 35 | 40 | 206 |
| Kadongo Bridge | 69 - 346 | $128^{abcd}$ | 32 | 53 | 204 |
| Kochola Bridge | 90 - 356 | $223^{d}$ | 35 | 140 | 305 |
| Kendu Bay Bridge | 92 – 313 | $186^{bcd}$ | 29 | 118 | 255 |
| River mouth | 96 - 386 | $201^{cd}$ | 33 | 123 | 280 |

***Note.*** **SE = Standard Error, CI = Confidence Interval, Superscript a, b, c and d show homogeneous groups of stations with respect total phosphorus**

**Appendix 16. Letter requesting for research permit**

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**National Council for Science, Technology and Innovation (NACOSTI)**
**Utalii House, 8th Floor, Uhuru Highway**
**P. O. Box 30623 – 00100**
**NAIROBI - KENYA.**

Dear Sir/Madam

**RE: OSURE GEORGE OWITI, REG. NO: DAN16/00001/18**

The above mentioned is a student of Kisii University currently pursuing a Doctorate of Philosophy (PhD) degree in Fisheries in the Faculty of Agriculture and Natural Resource Management. The topic of his research is, **"Fish population dynamics and intergrity indecies of River Awach Kibuon: Towards ecosystem health management of Lake Victoria basin, Kenya".**

We are kindly requesting for assistance in acquiring a research permit to enable him carry out the research.

Thank you.

for Prof. Anakalo Shitandi, PhD
**Registrar, Research and Extension**

KISII UNIVERSITY
29 MAY 2019
REGISTRAR RESEARCH & EXTENSION

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ECOSYSTEM INTEGRITY AND FISH POPULATION DYNAMICS OF RIVER AWACH KIBUON: TOWARDS MANAGEMENT OF LAKE VICTORIA BASIN

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