ASSESSMENT OF ECOSYSTEM INTEGRITY BASED ON HABITAT QUALITY AND FISH INDICES OF RIVER KATHITA AND ASSOCIATED DAMS IN UPPER TANA BASIN, KENYA.

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DECLARATIONS

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I declare that this thesis is my original work and has not been presented for a degree in any other University or any other award.

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DEDICATION

The greatest mentor is the one who inspires just as the greatest architect is the one who builds. Thus I dedicate this work to my dear mother, Severina Kabaka and other family members for their inspiration and support throughout my studies.

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ABSTRACT

Riverine environments have been threatened by human activities leading to alteration of their biogeochemistry, necessitating an assessment of their ecosystem integrity. River Kathita, in Eastern Kenya, drains into Indian Ocean through River Tana. It is exposed to a variety of anthropogenic activities that affect its habitat quality and integrity. There is limited information on its biota and habitat. This study is therefore designed to bridge this gap and relate how various human activities alter its integrity. A study on assessment of habitat quality and fish index of biotic integrity was conducted on Kathita River and associated dams area in upper Tana basin. Sampling was done for six months (March - August 2020) at eleven stations. Physical-chemical parameters were measured using a YSI multiparameter meter. Total phosphates and nitrates were estimated using the method described in APHA 2014. Nine habitat metrics were assessed and used to develop habitat quality index. Fish samples were collected using an electrofisher, identified to species level and categorized as exotic, indigenous, rheophilic, tolerant or intolerant. Fish diversity was estimated using Shannon-Weiner, Simpson, evenness and species richness indices. Data analysis was done using SPSS and MINITAB versions 22 and 14 respectively. 1133 fish constituting 20 species were caught. *Labeobarbus oxhyrinchus* was most dominant (24%) while *Schilbe intermedius* was least (0. 1%). HQI was highest at S1 (21.00 ± 0.730) and lowest at S3 (12.17 ± 0.307). All estimated FIBI were rated ‘below good’, S7 (35.33 ± 2.716, S10 (27.00 ± 1.125). Results from HQI and FIBI shown that the environmental quality of the upper Tana River is degraded. Habitat quality, integrity and biodiversity indices were estimated here for the first time. They form a basis for monitoring environmental quality and integrity in subsequent assessment hence the information will be useful in formulating the environmental conservation and management.

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LIST OF ABBREVIATIONS AND ACRONYMS

DO - Dissolved Oxygen

PH - Potential Hydrogen

HQI - Habitat Quality Index

ANOVA - Analysis of Variance

°C - Degree Celsius

FIBI - Fish-based Index of Biological Integrity

Fig - Figure

IBI - Index of Biotic Integrity

SPSS - Statistical Package for Social Sciences

TN - Total Nitrogen

TP - Total Phosphorus

TDS - Total Dissolved Solids

EC - Electrical Conductivity

RBP - Rapid Bio-assessment Protocols

QHEI - Qualitative Habitat Evaluation Index

MIWB - Modified Index of Well Being

WHO - World Health Organization

APHA - American Public Health Association

a.s.l - above sea level

WFD – Water Framework Directives

Ltd - Limited

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Ecosystem integrity of a river is its capacity to maintain structure and ecosystem functions using processes and features of its ecoregion. It is attained when the structure and function of the ecosystem are unperturbed. In such a state, the river can provide its ecological services and function sustainably (Roseman & Debruyne, 2015; Orina, Albert, Reuben, & Emmy, 2018; Li, Zhang, Lu, Zhao, & Zhu, 2021). The use of conventional methods that used physical-chemical parameters are not reliable for evaluating ecological status of surface waters (Hunting ER, de Jong S & Vijver MG. 2017). Thus for example, the water framework directives (WFD) in Europe recommends the use of biological quality elements that include fish to assess the ecological integrity of aquatic ecosystems (Breine, Ergo, & Bergh, 2018). The choice of fish as indicators of ecological integrity on spatial and long term time scale is due to a number of attributes such as their high mobility, long life span and representation in a broad range of trophic levels (Karr, 1981).

Studies in Europe and Asia have demonstrated that fish based indices that include fish community structure and physical and chemical parameters provide strong basis for evaluating the effects of anthropogenic activities on aquatic ecosystem. For example, earlier fish based indices were developed in Europe, Asia, New Zealand, Canada and Africa. Further fish-based indices in Asia have been developed in Pakistan, China, Taiwan and Iran (Breine et al., 2018).

In Kenya, Raburu and Masese (2010) have FIBI for Rivers Sondu, Nzoia and Yala. Orina et al. (2018) also published a fish-based index of biotic integrity for River Kuja that drains into Lake Victoria in South-West Kenya.

Riverine ecosystems provide numerous benefits to man and the environment including water, fish, medicine, construction materials, habitat, recreation, sacred sites, nutrient cycling, soil formation and integrity (Opperman, Jeff, et al., & WWF, 2018). The benefits promote acquisition of good quality resources that promote the well-being of man. However, these resources are threatened with overexploitation by humans.

United Nations report of 2015 explains that man's population is growing drastically with the current world population being more than 7.4 billion projected to reach 8.5 billion by 2030 (United Nations news center, 2015). This will consequently pose an increased demand on resources from terrestrial and aquatic habitats. This demand has resulted in increased agricultural land and settlements which has promoted cutting down of riparian vegetation and modification of rivers. Such anthropogenic activities negatively impact on the riverine resources through pollution and degradation. Although floods and landslides degrade riverine ecosystems, they do not greatly affect them because the ecosystems have self-renewal attribute (Kleynhans & Louw, 2008). There is therefore a need to understand the effect of various anthropogenic activities on riverine ecosystems.

Comprehensive knowledge on riverine ecosystems is essential for formulating appropriate policies for management and conservation. Different methods have been used to assess the quality and integrity of riverine ecosystems. One of the methods is the use of physical-chemical characteristics to estimate the habitat quality index of riverine habitats, an approach which is expensive and time consuming (Raburu & Masese, 2010). Another method involves the use of geomorphic features and some biological attributes influencing habitat structure and energy input to assess habitat quality. Lastly, the method of biomonitoring biomonitoring uses of living organisms as bio indicators of habitat quality and integrity. Some of the organisms which have been used include macroinvertebrates (Aura, 2008), macrophytes, bryophyte and recently fish (Li, Zheng & Liu, 2010). This study therefore has the purpose of assessing the habitat quality and ecosystem integrity of River Kathita and the associated dams area in the upper Tana basin using habitat quality index and fish index of biotic integrity.

1.2 Statement of the problem

River Kathita, in Eastern Kenya flows via agricultural lands, urban and industrial areas from where there is a possibility of being polluted. Tharaka-Nithi and Meru Counties get water, fish and other natural resources such as construction materials from its wetland. However, it is facing challenges due to pollution coming from towns like (Kithaku, Meru and Marimanti), abstraction and damming, destruction of riparian riverine zones, and catchment areas and shrines, prohibited fishing for example use of chemicals and neglect to cultural ecological regulations which were used to conserve and govern their utilization of riverine resources. The major tributaries of R. Kathita include: Gakuuru, Thingithu, Thanantu, Mariara, and others. Before the 1990s, this river was rich in biodiversity that included fish, macrophytes, trees, hippopotamus and different types of birds. Its water volume was always high. By now, the status of this river in terms of biodiversity richness and integrity has been greatly affected - a situation that requires quick intervention. Additionally, there is little information on the river's levels of pollution, biota and habitat quality. Inadequate knowledge on this river's biota and habitat quality may hinder its uses and effective management. This study attempted to assess the ecosystem integrity of the river based on habitat quality index and fish index of biotic integrity, to obtain information which can be used for management and conservation of the river and the associated four dams stretch in the upper Tana basin.

1.3 Justification

There are few baseline investigations of the ecosystem integrity of the upper Tana basin in which River Kathita and a series of dams are situated. Further, there are few ecological studies on the community structure of biotic communities inhabiting the river. Studies on habitat quality and biotic integrity are useful since they provide information that can be used to formulate management advice for habitat conservation.

The following study was therefore carried out to assess the ecosystem integrity of Kathita River and the associated four dams stretch in the upper Tana basin using habitat quality and fish index of biotic integrity, fish diversity, distribution and occurrence. The information will be useful for the river's hydrology, biodiversity and habitat quality.

1.4 Objectives

1.4.1 General Objective

The overall objective of this study was to assess the ecosystem integrity of River Kathita and associated four dams stretch in the upper Tana basin based on habitat quality index and fish index of biotic integrity.

1.4.2 Specific objectives

1. To determine spatial and temporal variation in physical and chemical parameters - pH, temperature, total dissolved solids, dissolved oxygen, conductivity, total phosphorus and total nitrogen concentration in River Kathita and associated four dams stretch in upper Tana basin.
2. To assess spatial and temporal variation of HQI in River Kathita in the upper Tana basin.
3. To assess the spatial and temporal variation of FIBI in River Kathita and the four dams stretch in the upper Tana basin.
4. To determine the relationship between physical and chemical parameters and abundance of fish in River Kathita and the four dams stretch in the upper Tana basin.

1.5 Hypothesis of the study

1. There was no significant spatial and temporal variation of selected physical and chemical parameters in River Kathita and the associated four dams stretch in the upper Tana basin.
2. There was no significant spatial and temporal variation of habitat quality index in River Kathita.
3. There were no significant spatial and temporal variances of the fish-based index of biotic integrity in River Kathita and the associated four dams in the upper Tana basin.
4. There was no significant relationship between physical-chemical parameters and abundance of fish in River Kathita and the associated four dams stretch in the upper Tana basin.

1.6 Scope of the study

The scope of the study involves the development of a habitat quality index and a fish index of biotic integrity of Kathita River and associated four dams stretch in the upper Tana basin of Mt. Kenya. The two indices were then used to assess the ecosystem integrity of the respective habitat. The study therefore collected data on the metrics used to estimate the indices namely: for estimating habitat quality and: for estimating fish index of biotic integrity. Further, the study correlated the physical and chemical parameters with spatial and temporal distribution of fish along River Kathita and the associated constructed dams in the upper Tana basin.

1.7 Limitations and delimitations of the study

A preliminary survey of River Kathita and the associated four dams stretch in upper Tana basin revealed that some parts of this ecosystem could not be assessed for sampling due to complex terrain problems such as very steep slopes and water falls and lack of access roads and pathways in certain sections of the river. This affected the distribution of the sampling points. There were difficulties in identifying juvenile stages of eight species of the genus

Labeobarbus inhabiting habitats of the upper Tana basin which are very similar and difficult to tell apart. However, these limitations were overcome by requesting the inhabitants of these areas to guide and direct us to the sites. The juveniles were not included in data analysis since their sexes could not be identified.

1.8 Assumptions of the study

The study assumed that the ecosystem in the upper Tana basin was stable and was in dynamic equilibrium that the habitat quality and integrity of the ecosystem was consistent throughout the area that was to be investigated and that the fish communities were in good relationship with the physical and chemical structure of the riverine environment.

1.9 Operational definition of terms

Ecosystem integrity - It is the system's capacity to maintain structure and ecosystem functions using processes and elements characteristic for its ecoregion.

Biodiversity - The variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.

Nativeness – Refers to the degree of which biota of a habitat are indigenous.

Habitat – This is an ecological area occupied by living organisms.

Pristineness – Refers to the ability of a habitat to be in its natural state and provide adequate resources sustainably as it has been doing since times immemorial.

Diversity - This is the state of having diverse components that coexist.

Resilience - It explains that a changed ecosystem has the ability to resuscitate itself.

Ecoregion - an area defined in terms of its natural features and surroundings.

Species richness – It is the total number of species known in a sample.

Evenness – Refers to the measure of how different the abundances of the species in a community are from each other.

Simpson index: It is a weighted arithmetic mean of proportional abundance and measures the probability that two individuals randomly selected from a sample belongs to the same species.

Shannon-Weiner index: Measures the degree of uncertainty of forecasting the species of a random sample is related to the diversity of a community.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter contains River Tana ecosystem, River Tana Fisheries resources, River Kathita fisheries, physical-chemical parameters, habitat quality indices, fish-based index of biotic integrity, values governing the evaluation of riverine ecosystem integrity, riverine ecosystem integrity evaluation, biological parameters, diversity indices and river integrity evaluation challenges.

2.2 The Tana River ecosystem

Th and drains the eastern and southern slopes of the Aberdares and Mt. Kenya respectively. From its source, it covers a distance of 1014 km to discharge its waters into the Indian Ocean at the Ungwana bay near Malindi town in the north coast of Kenya. Most of the upper Tana basin is forested and has many tributaries such as Kathita, Thika, Sagana, Thingithu, Thuci that converge to form River Tana (Aura, R., Mulanda, C., Kimani, E., Musa, S., Kundu, R., & Njiru, J. M., 2017).

Close to its upper and middle reaches, a lot of developmental activities have taken place since independence occasioned by the ever expanding population in the central Kenya region. These include the development of agriculture for example cultivation of coffee, tea, tobacco, maize, potatoes and pyrethrum; rapid growth of urban centers such as Nyeri, Meru, Marimanti, Embu and Kivaa. This growth in agriculture and urbanization is associated with discharges of respective effluents which negatively impact the water quality and biodiversity in the Tana River basin. It traverses most of the Kenyan agro-climatic zones. In Mt. Kenya and Aberdares, it traverses the cold and humid zone 1-9, to VI 1—1 (very arid and very hot) over much of the lower Tana (Campbell, Coe, Saunders, & Hills, 1980). The river Tana basin lies within the tropics in Kenya south of the equator and its climate is influenced by the monsoon winds originating from the south east of Indian Ocean, whose climate is further influenced by the large scale pressure systems of western Indian Ocean (Munga, Kimani, Ruwa, & Vanreusel, 2016)

2.2.1 River Tana fisheries Resources.

River Tana fisheries resources are one of the least studied in Kenya. The river has received little ecological attention. This is partly due to inaccessibility of this region due to poor communication infrastructure, lack of development incentives, lack of fish eating culture and poor knowledge on existence and types of fish resources in the river (Campbell, K., C. Coe, and M. Saunders, 1980). All earlier studies on River Tana fisheries were conducted by researchers from the east African freshwater fisheries research organization from early 1900 up to early 1970s (Campbell et al., 1980). The studies chiefly emphasized on the taxonomy, distribution and general few feeding ecology of fish. There were few attempts to assess the fishery potential of the river especially at the lower reaches (Mann, 1967, 1969; Whitehead, 1959; Campbell et al., 1980; Copley, 1941). Jumbe (1997) also assessed the status of the Tana River dam fisheries twenty years after dam construction (middle reaches) while Van Someren (1952) studied the biology of Trout in Kenya (upper reaches of River Tana).

The river supports a rich diversity of aquatic species as well as many important fisheries for the local communities constituting of 16 families, which include: Mochokidae, Protopteridae, Claroteidae, Schilbeidae, Cichlidae, Alestiidae, Amphiliidae, Anguillidae, Aplocheilidae, Poeciliidae, Bagridae, Salmonidae, Gobiidae, Clariidae, Mormmyridae and Cyprinidae (Table 1). In this region, fish is the second most important source of animal protein (Mwaniki, 2007). Its species diversity includes 41 native species, three introduced species namely: Guppy, *Poecilia reticulata* (Peters, 1859), Million fish, *Gambusia affins* (Baird & Girard, 1853) and

Sea trout, *Salmo trutta trutta* (Linnaeus, 1758) and two endemic species – Feathered-barbelled squeaker, *Synodontis manni* (De Vos, 2001) and Mnanzini nothobranch, *Nothobranchius willerti* (Wildekamp, 1992) (Froese & Pauly 2021). The latter two species occur naturally only in the Tana River basin hence there is a need to conserve them. Despite this, knowledge on their biology is lacking (Froese & Pauly 2021, table 1). The highest biodiversity of fish was found in ox-bow lakes Shakababo and Moa by earlier researchers (Mwaniki, 2007).

Table 1. Fish species of River Tana.

Species	**Family**	**Habitat**	**Length (cm)**	**Trophic level**	**Status**
Alestes affinis	Alestiidae	pelagic	14 TL	3.1	native
Amphilius uranoscopus	Amphiliidae	demersal	20 TL	2.9	native
Anguilla bicolor bicolor	Anguillidae	demersal	100 TL	3.6	native
Anguilla mossambica	Anguillidae	demersal	150 TL	3.3	native
Anguilla nebulosi labiata	Anguillidae	demersal	121 TL	3.8	native
Labeobarbus rhinoceros	Cyprinidae	benthopelegic	42 TL	3.0	native
Enteromius neumayeri	Cyprinidae	benthopelagic	15 TL	3.0	native
Labeobarbus oxyrhynchus	Cyprinidae	benthopelagic	49 TL	3.3	native
Enteromius paludinosus	Cyprinidae	benthopelagic	19 TL	2.8	native
Enteromius zanzibaricus	Cyprinidae	benthopelagic	10 TL	3.0	native
Chiloglanis brevibarbis	Mochokidae	benthopelagic	6 TL	3.1	native
Clarias gariepinus	Clariidae	benthopelagic	170 TL	4.4	native
Clarias liocephalus	Clariidae	demersal	32 TL	3.3	native
Clarotes laticeps	Bagridae	demersal	98 TL	3.1	native
Gambusia affinis	Poeciliidae	benthopelagic	7 TL	3.2	introduced
Garra dembeensis	Cyprinidae	benthopelagic	14 TL	2.0	native
Glossogobius giuris	Gobiidae	demersal	61 TL	4.3	native
Labeo cylindricus	Cyprinidae	benthopelagic	49 TL	2.0	native
Labeo gregorii	Cyprinidae	benthopelagic	13 TL	3.0	native
Labeo mesops	Cyprinidae	benthopelagic	39 TL	2.0	native
Marcusenius macrolepidotus	Mormyridae	demersal	32 TL	3.2	native

Mormyrus kannume	Mormyridae	demersal	122 TL	3.2	native
Neobola kinondo	Cyprinidae	benthopelagic	10 TL	2.8	native
Nothobranchius jubbi	Aplocheilidae	benthopelagic	6 TL	3.2	native
Nothobranchius microlepis	Aplocheilidae	benthopelagic	70 TL	3.5	native
Nothobranchius patrizii	Aplocheilidae	benthopelagic	5 TL	3.1	native
Nothobranchius willerti	Aplocheilidae	benthopelagic	4 TL	3.3	endemic
Oreochromis spilurus percivali	Cichlidae	benthopelagic	16 TL	2.4	native
Oreochromis spilurus spilurus	Cichlidae	benthopelagic	24 TL	2.6	native
Pantanodon stuhlmanni	Poeciliidae	benthopelagic	5 TL	3.2	native
Parailia somalensis	Schilbeidae	demersal	7 TL	3.2	native
Petrocephalus catostoma	Mormyridae	demersal	17 TL	3.4	native
Protopterus amphibius	Protopteridae	demersal	45 TL	3.2	native
Salmo trutta trutta	Salmonidae	pelagic	171 TL	3.2	introduced
Poecilia reticulata	Poeciliidae	benthopelagic	7 TL	3.7	introduced
Schilbe intermedius	Schilbeidae	pelagic	61 TL	3.3	native
Schilbe mystus	Schilbeidae	demersal	40 TL	3.0	native
Synodontis manni	Mochokidae	demersal	27 TL	2.6	endemic
Synodontis serpentis	Mochokidae	benthopelagic	13 TL	2.6	native
Synodontis zanzibaricus	Mochokidae	benthopelagic	14 TL	2.6	native

Source: (Froese & Pauly 2021).

The fishery resources contain some of the largest species in Kenya with sizes ranging from 20 – 171 cm TL. Some of the largest fishes found in the river include: (Sea trout), *S. trutta trutta* (Linnaeus, 1758), (Common catfish), *Clarias gariepinus* (Burchell, 1822), (African mottled eel) *Anguila nebulosa labiata* (Peters, 1852), (African longfin eel), *Anguila mossambica* (Peters, 1852), (Shortfin eel), *Anguila bicolor bicolor* (McClelland, 1844), (Widehead catfish), *Clarotes laticeps* (Rüpell, 1829),(Elephant-snout fish), *Mormmyrus kannume* (Forsskåll, 1775), all of which attain during their lifetime sizes of above 95 cm TL (Froese & Pauly 2021), table 1 above. The biology and stock sizes of most of these species are poorly documented apart from their initial taxonomic findings.

The dominant fish species being exploited include: (Gregori's labeo), *Labeo gregorii (*Günther, 1894), (Sabaki tilapia), *Oreochromis spilurus spilurus* (Günther 1894), (Tana lungfish), *P. affins annectens* (Owen, 1839) and (Silver catfish), *Schilbe intermedius* (Rüpell, 1832). However, few studies have been conducted on the appropriate gears e.g. mesh sizes for use in catching these species, a factor that can lead to the overfishing of fish in Tana River basin.

So far, the type of gears used for fishing include gillnets, with mesh size from 1.5-3.5 inches, traditional traps and 7-9 inch hooks (Mwaniki, 2007). Therefore, there is need to conduct gear selectivity studies to come up with recommendation of suitable mesh size regulations for sustainable exploitation of fish.

Towards the lower Tana basin, is a floodplain which constitutes series of ox-bow lakes. These provides to the local community a rich subsistence fishery which constitute of: *L. gregorii, O. spilurus spilurus* and *S. intermedius* (Mwaniki, 2007).

This indicate that the fishery in the lower Tana basin is multispecies and faces the challenges posed by multigear fishing which often leads to overfishing of the smaller bodied fish species.

Only in the lower Tana basin and its estuary has a subsistence fishery that has attracted scientific research and management hence most of the published information has focused on this area (Munga et al., 2016; Campbell et al., 1980; Whitehead, 1959; Aura et al., 2017).

Besides the fishery resources, the Tana River basin has a rich diversity of aquatic fauna such as crocodiles, hippopotamus, monitor lizards, unidentified frog species, numerous bird species (geese, African jacana, fish eagles, gray and goliath Herons, yellow-billed stork, hamerkop, malachite and pied kingfisher). All these organisms together with fish comprise a complex aquatic and terrestrial food web of the Tana River basin. For example, fish eagles, kingfishers, herons and hamerkops are the top predators in the food web constituting of fish and other aquatic organisms. Other top fish predators include crocodiles and monitor lizards (Mwaniki, 2007).

2.2.2 Effects of agricultural activities on water quality and aquatic life in the Tana River basin.

The government of Kenya is planning to have various projects in River Tana basin which will have various impacts to its fisheries as well the communities inhabiting these areas. These projects include: Mumias Sugar Project that will use 40,000 hectares of the lower Tana River chiefly to grow sugarcane (Mwaniki, 2007), construction of High Grand Falls Dam at Kibuuka waterfalls (confluence of Rivers Tana and Kathita) in middle reaches of Tana River which is set to irrigate 250,000 hectares of land and produce over 7,000 megawatts of electricity (Kamadi, 2019), The Million Acre initiative which will irrigate half million acres of land for maize production and 200,000 acres for sugarcane farming and the mega Lamu Port South Sudan Ethiopia Transport (LAPSSET. Fish are sensitive to changes in water quality, effluent from sugar factories as well as from other agricultural activities have been shown to change the physiochemical characteristics of the water that they are pumped into. The effluent could also affect fish physiological aspects such as growth, reproduction and feeding and survival of fish embryos and larvae. The overall effect of agricultural activities in Tana basin will result in reduction in suitable fish habitats including genetic diversity (Okungu & Opango, 2005; Wetland Consulting Service Ltd, 2014). Researchers and environmental conservationists have warned that these agricultural activities which among others will involve the construction of roads, barrages and conversion of ox bow lakes and swamps into agricultural land will negatively impact on the environmental quality, the subsistence and sometimes commercial fishery of lakes shakababo and Moa and fish diversity. The Ox-bow lakes and swamps in the lower Tana flood plain provide an important link for fish which migrate between them and the upper Tana River basin to breed and later return back for feeding grounds in the area. Some of the important fish species in Upper Tana River basin such as *L. gregorii* are known to breed within the Ox-bow lakes hence conversion of habitat in Tana River basin into agricultural land will further affect stock sizes, breeding and feeding grounds of riverine fishes (Mwaniki, 2007).

2.3 River Kathita Fisheries

Kathita River is one of the major main rivers in Tharaka Constituency and whole of Tharaka-Nithi and Meru Counties. The 120 km long permanent river, flows from the top of Mt. Kenya and joins Tana River at Kibuuka waterfalls, a place where there are plans to construct 'The High Grand Falls Dam' (Roue, Cesard, Adou, & Oteng, 2015; Kamadi, 2019). This river joins River Tana below the dams area. Its catchment area is about 1620km² with high rainfall (750-1500mm mm per year) and even snow melt at the sources. The water in Kathita river is of excellent quality for irrigation. The electrical conductivity (EC) (25°C) = 0.15 mill mhoscm^{-2} (Nkondi irrigation project feasibility study, 1989).

Fishing is done mostly by local young and middle-aged men using local gears like gill nets, handlines and traps. These gears are scarce and are inefficient in catching fish. The river is permanent and fishing is done all the year round. Some of the fish species caught include: *C. gariepinus, A. nebulosa labiata*, *Labeobarbus tanensis L. gregorii* and *O. spilurus spilurus*. All these species are native except *C. gariepinus* which was introduced into this river.

Before 1990s, there were no tilapia species along this river but currently there is a change in that it's now one of the main fish species caught (Kinyua, (pers.com). During dry seasons, fishermen sometimes used prohibited chemicals and herbs for fishing. This highly affected the ecosystem of the river and its resources. In addition to home consumption, fish is also sold locally hence source of income. Some of the studies that have been done in other rivers and streams in Mt. Kenya region include: Monitoring water and habitat quality in six rivers draining the Mt. Kenya and Aberdare catchment (M'Erimba, Mathooko, Karanja, & Mbaka, 2014), Effect of anthropogenic activities and Seasonal Variation on Water Quality of Nkenye (Chikuu) Stream in Chuka (Ombaka, Gichumbi, Mukono & Kibaara, 2013), Analysis of Physical-chemical and Bacteriological attributes of Water Samples from Irigu River Meru South (Ombaka, & Gichumbi, 2012) and effects of anthropogenic activities on water quality in River Rupingazi, Embu County (Bonareri, 2017).

2.4 Values governing the evaluation of riverine ecosystem integrity.

Evaluation of ecosystem integrity of a river is done using four main values which include: Pristiness, diversity, nativeness and resilience. Nativeness is the degree of which biota of a habitat are native. If the abundance of native species is high then the ecological status is also high (Clayton & Edwards, 2006). This concept is reinforced by the value of pristineness which shows when and where a habitat is uninterrupted. According to this concept, a habitat in its natural state is able to provide adequate resources sustainably. It does not rely heavily on the use of biota than structural functionality and physical-chemical parameters. The third value is diversity. It is the state of having diverse components that coexist. The components can be ecosystem, habitat, plants or animals within a community. It is when an ecosystem is unimpaired or minimally disturbed that its diversity is attained. The last value is the ecosystem resilience, which explains that a changed ecosystem has the ability to resuscitate itself. According to Dubos in 1981, an ecosystem is never dead but can resuscitate itself if all pollutants are stopped to be discharged into a river or a lake (Orina et al., 2018).These values supplement each other during the evaluation of riverine integrity.

2.5 Riverine ecosystem integrity evaluation.

The various goods and services provided by rivers can be used as parameters for evaluation. If quantified, these goods and services can estimate the extent of deviance from normalcy. The deviation results from overexploitation of rivers and its catchment. Prolonged exploitation damages the quality of riverine ecosystem and reach to a point that it can’t function nor provide the goods and services. It becomes very expensive and even impossible to restore an ecosystem Once its health has been compromised. Regular evaluation of rivers is therefore necessary to avoid such situations (Orina et al., 2018). Assessment of rivers has been made possible by use of biotic and abiotic factors present in an ecosystem. There are various methods that are used to evaluate the river ecosystems (Raburu & Masese, 2010). Conventionally, evaluation depended on physical-chemical characteristics of water but later, new ecological considerations were made to evaluate how the habitat and biota can be used. Living organisms are more effective to use in assessment due to their ability to spell out the environmental condition. They tend to migrate, hibernate or aestivate on exposer to negative conditions which can lead to death if prolonged. Physical-chemical characteristics of water, habitat quality and living organisms are the three methods usually applied in river evaluation.

2.5.1 Physical-chemical Parameters.

Water is the major resource in river ecosystem and thus its assessment can represent the quality of ecosystems. Its assessment is based on its physical and chemical properties. Physical examination involves assessment of water temperature, light, turbidity and total dissolved solids among others. Temperature is one of the important factors that influence the occurrence of aquatic living organisms. Water temperature in rivers rises due to direct exposure to sunlight, thermal pollution from industries or high concentration of suspended solids that absorb solar energy. This increase can lead to changes in distribution and abundance of living organisms.

Light is another important factor. It is the main driving source of energy in primary production. The amount of light reaching the river ecosystem can be affected by the shedding effect of the riparian vegetation. Similarly, its penetration in water column depends on turbidity which is affected by total suspended solid arising from catchments. Turbidity affects the distribution and abundance of producers and consumers in a riverine ecosystem (Van de Haterd & Ter Heerdt, 2007).

The chemical parameters used to assess water include dissolved oxygen concentration (DO), nutrient concentration and pH, TDS, conductivity, alkalinity, temperatures among others. These parameters are important to the aquatic biotic community. The latter like terrestrial animal uses oxygen for respiration. Oxygen in water column is introduced by the autotrophs during photosynthesis or infusion from the atmosphere. Its concentration can decrease due to thermal pollution, decomposition or increased respiration rate in rivers. The DO concentration in rivers affects distribution and abundance of living organisms. Nutrient concentration is another parameter that influences the occurrence of primary producers and consequently the consumers. Nutrients alterations in water column are due to human activities like agriculture, urbanization and sewage input (Raburu, 2003; Okungu & Opango, 2005). Increased nutrient concentration alters food web components (Biggs et al., 2000) and faunal distribution in an aquatic ecosystem. pH as a chemical parameter influences the occurrence, distribution and abundance of different living organisms in rivers. Water pH is influenced by acid rains, agricultural runoff, industrial discharge and fossil fuel emission (Fundamentals of environmental measurement, 2016). Low water pH often results to physical damage of living organism and increases the solubility of minerals.

The quality of water in rivers is a key concern in the world since it is used for drinking, domestic purposes, irrigation and support of aquatic life. Its assessment has been done in R. Jamuna (Uddin, Alam, Mobina & Miah, 2014) and R. Surma (Alam, Islam, Muyen, Mamun & Islam, 2007). These studies revealed that water quality is influenced by industrial wastes, municipal sewage and agricultural runoff. These activities have also been reported by Raburu, (2003), Okungu & Opango (2005) and Mutunga, Zulu & De Souza (2012) in Kenya. These threaten the pristineness of inland water bodies like Lake Victoria and its basin by promoting nutrient enrichment, erosion and sedimentation (Okungu & Opanga, 2005; WRMA & JICA, 2014).

Graham (1929) and Greenwood (1974) also reported that water quality of Lake Victoria has been changing since 1920. Such changes have led to frequent cases of algal bloom, water hyacinth infestation and increased water turbidity (Karani, 2005). Most of these impacts come from the adjoining rivers draining into the lake. Studies on water quality have been conducted in River Kuja with key emphasis on land use (Via et aqua, 1975; Ongwenyi, Johnson & James, 1993; Kathumo, Gachene, Gicheru & Kariuki, 2012), soil science (Wielemaker & Boxem, 1982), suspended sediment loading (Kiragu, 2009) and flood management (WRMA & JICA, 2014).

This method of assessment is limited in its application. This is because it is expensive and lacks a single index that combines multiple water quality parameters (Kwak & Freeman, 2010). The latter is due to different uses of water hence difficult to generate a single index that could satisfy all the set standards.

2.5.2 Habitat quality parameters.

Living organisms lives in an ecological area referred to as a habitat which comprises of the earth's surface structure and living component that impact the structure and energy input into the niche. Water habitats are homes to aquatic living organisms and also provide surface for breeding and spawning, the services that are only available in natural and minimally troubled areas (Orina et al., 2018). Ecologists have formulated protocols used to evaluate rivers' habitats in order to promote sustainability of their resources hence helping in determining the nature and degree of abiotic limitations on biotic communities. Knowledge on habitats is important since they support the lotic ecosystem dynamics and ecological organization that dictates the biotic structure of the river (Maddock, 1999).

The state of the stream and riparian habitat integrity determines its condition (Kleynhans, 1997). Its assessment concentrates on the variety of flow conditions, extent of erosion, substrates content and amount of woody debris among other factors upon which stream biotic community structure is put up. In evaluation, either qualitative or quantitative criteria or both can be applied. Qualitative habitat evaluation is done visually whereby the selected attributes are estimated in the field and rated as per the defined procedure. This method can be executed rapidly and does not require specialized personnel hence advantageous.

The commonly used qualitative habitat indices are: Qualitative Habitat Evaluation Index (QHEI) (Rankin, 1989) USEPA Rapid Bio-assessment Protocols (RBP) (Plafkin, Barbour, Porter, Gross & Hughes, 1989) and Riparian, Channel and Environmental Inventory (RCE) (Petersen, 1992). After applying these criteria in streams of North Dakota and northwestern Minnesota, it was found out that the indices highly correlate with each other. While QHEI and RBP emphasizes on channel geomorphology, RCE stresses on riparian zones variable. The study shown that RBP is the most subjective as compared to the other indices.

When using these indices, some habitat features are over emphasized while others are diminished. The indices did not predict on the fish community structures in those streams (Stauffer & Goldstein, 1997). Due to biasness, the use of qualitative method occasionally fails to provide the objectivity of the study (Poole, Frissell & Raph, 1997). According to Hannaford and Resh (1995), the survey team should be trained to reduce the variability in observation and recording. A better approach of quantifying habitat attributes has also been applied to increase accuracy and precision.

Quantitative habitat evaluation which involves measurement of stream variables uses additional equipment and resources relative to the visual based approach hence promoting accuracy, precision and relevancy to the objectives of the study (Kaufmann & Robinson, 1998).

Few quantitative protocols have been described by Platts, Megahan and Minshall (1983), Wang, Simonson and Lyons (1996), Kaufmann, Levine, Robinson, Seeliger and Peck (1999) and Roper, Kershner, Archer, Henderson and Bouwes (2002). Some of the limitations facing this method include inconsistence in application and training, lack of repeatability and resolutions that promotes detection of ecosystem change (Roper, Kershner, Archer, Henderson & Bouwes, 2002).

Habitat evaluation considers water availability, geomorphic features and flow patterns. The attributes assessed include: status of river bank, riparian zone and watershed characteristics of rivers (Binns & Eiserman, 1979; Kondolf, 2000). These characteristics are rated, scored and summed up to determine the HQI. Barbour and Stribling (1994), M-DEQ (1997), Bain, Hughes and Arend (1999), Barbour, Gerritsen, Snyder and Stribling (1999), Kaufmann et al. (1999) and Rogers (2016) have applied diverse characteristics and scoring criteria with modifications in assessing habitat quality index and this has increased the probability to ascribe objectivity of the studies.

Several rivers and streams of United States have been assessed to reveal how man activities influence aquatic habitat and water hydrology (American Rivers, 2003; Somerville & Pruitt, 2004; Paul et al.,2003). Raburu and Masese (2010) also evaluated the integrity of River Nzoia, Nyando and Sondu-Miriu using USEPA RBP in Lake Victoria, Kenya. Due to difficulties in quantification of some metrics used, this method has not been very successful in all streams (Somerville & Pruitt, 2004). The technique therefore remains questionable when applied and it is not widely used. (Poole et al.,1997).

2.5.3 Biological Parameters.

Evaluation of the ecosystem integrity of both aquatic and terrestrial ecosystems have involved the use of plant and animal communities (Karr & Chutter, 1999). Birds, macrophytes and pryophytes have also been used in different ecosystems (Orina et al., 2018; Roche et al., 2010; Ojija, Gebrehiwot & Kilimba, 2017; Staniszewski et al., 2006). Living organisms are referred to use in evaluating ecosystem integrity due to their advantage as they have preference to a particular habitat. Their abundance, diversity and distribution tend to change once the habitat is altered.

Fish has been recommended in assessment of ecological integrity of aquatic ecosystems (Breine et al., 2018). The choice of fish as indicators of ecological integrity on spatial and long term time scale is due to a number of attributes such as their high mobility, long life span and representation in a broad range of trophic levels (Breine et al., 2018). Studies in Europe and Asia have demonstrated that fish based indices that include fish community structure and physical and chemical parameters provide strong basis for evaluating the effects of anthropogenic activities on aquatic ecosystem (Breine et al., 2018). It has been applied in different water bodies (Wilton, TMLD & WQASESD, 2004; Walsh et al., 2015; Biohabitats and Century engineering, 2016).

Diversity indices and fish-based index of biotic integrity are the two biotic indices mostly used.

2.5.3.1 Diversity indices.

The quantitative measure of the number of species present in a community and how individual species are distributed among the groups represented is referred to as the diversity index. Riverine fish species' abundance and diversity is important in interpreting the health status of the aquatic environment. If an aquatic environment is healthy, its users can obtain adequate and sustainable resources. There is therefore a need for regular assessment of diversity indices in water bodies.

Conventionally, diversity was thought to consist of richness and evenness, whereby fish richness is the number of various fish species present in an aquatic habitat. When the number of species is high, species richness within that aquatic ecosystem is said to be highly diverse. This is not always the case since a community can have multiple of species whereby some exist as a single entity or low abundance than others. Such ecosystem is considered as low diversity evenness. To bridge this gap, Species evenness was introduced by integrating abundance in evaluating the variety of a particular species. It measures and expresses how equitable organisms are, considering the proportional abundance of individual species. As per this index, the variety is high when the species are fairly distributed within sampling point. Simpson and Shannon-Wiener diversity indices are the new approaches formulated that integrates richness and equitability. Simpson index measures the possibility of two individuals randomly selected from a sample belonging to the same species. Its values ranges from 0 to 1, whereby 0 shows high diversity while 1 shows no diversity. the probability that two individuals randomly selected from a sample will belong to the same species. Shannon-Wiener index measures the degree of uncertainty of forecasting that the species of a random sample is related to the variety of a community. Shannon-Weiner values ranges from 0 to 5 with 0 showing no diversity. (Kiernan, 2021).

Biotic and abiotic factors: stream water level, urbanization, habitat alteration, climate change, competition and predation influences the diversity and distribution of riverine fish assemblage (Paul & Meyer, 2001); Shervette et al., 2007; Paller, Labatos, Lontoc, Matalog & Ocampo, 2011). Studies on fish diversity have been carried out in rivers Tayabas (Paller, Corpuz & Ocampo, 2013), Mahanadi (Kumar, Charan & Kumar, 2013) and Panjkora (Ahmad, Saeed, Khan & Akhtar, 2014) to show the status of those rivers. In Kenyan rivers, few studies have been carried out for estimation of the fish community structure indices. This has been done in Rivers Ragati-Sagana-Tana (Okeyo, 2003) and Awach Seme and Kisian (Mwangi, Ombogo, Amadi, Baker, & Mugalu, 2012). These research studies shown that under proper management, river ecosystems can deliver health and abundant resources.

2.5.3.2 Fish-based index of biotic integrity.

The initial comprehensive multimetric index practical to evaluate biotic condition in moving waters was the index of biotic integrity (Karr 1981) – FIBI. The index detects degradation of living systems, identifies management actions that can halt or reverse degradation, diagnoses the likely sources of degradation, monitors living systems to find out if management efforts to restore degraded sites are succeeding when used correctly. Its basis was established in a project in Allen County, Indiana, that began in 1973, soon after passage of the 1972 Clean Water Act (PL 92-500).

In Fish-based index of biotic integrity, different fish characteristics are used to estimate the ecosystem integrity. Karr developed this method in small streams of united states of America (Karr, 1981); Karr, Fausch, Angermeier, Yant & Schlosser, 1986). This was done by combining fish metrics to develop an index of biotic integrity (IBI) which is also referred to as fish-based index of biotic integrity (FIBI). Since fishes can infer the condition of the habitat, water quality and biological interaction, they are suitable as bio monitors.

Evaluation of running waters has progressed from the use of biometric indices to combination of multiple community descriptors and multivariate methods. Since 1980s, the last two have been used (Oliveira & Cortes, 2006). Due to the ability of fish to interact with its environment for survival and existence, researchers have capitalized on them. Fish-based index of biotic integrity integrates several fish knowledge on assemblage, trophic level, origin and function into a single ecologically based index which can give a clear correlation with land use and physical habitat variables. Its application is simple and cost-effective. This method has been applied in lakes (Reavie et al., 2008) and rivers (Lyons, 1992; Breine et al., 2004; Hering et al., 2006). Nevertheless, few studies have been carried out in the trophics. In Kenya, such studies involve the change of ichthynofauna (Kibaara, 1981; Mwangi et al., 2012) within Lake Victoria basin. Raburu and Masese (2010) developed FIBI for rivers Nzoia, Nyando and Sondu-Miriu and underlined various human activities that impact the riverine ecosystem.

2.6 River Integrity Evaluation Challenges.

It is vital to have a point of reference when evaluating the integrity of an ecosystem and this point should give data or status of a pristine habitat. The major shortcoming for the evaluation methods described above is absence of reference point since man activities have largely troubled most environments. The probability of having control experiment zone has lessened by continuous degradation. Various ecosystems have used different methods to establish reference points. Paleo-ecologists have used sediments and soil as a scoring method to come up with the reference point in New Zealand fresh waters but the method is very expensive and time consuming. Hence, Stoddard, Larsen, Hawkins, Johnson and Norris (2006) purposed to use minimally troubled area with the best attainable historical condition to counter this challenge. It is important to augment water quality attributes in the evaluation to know the causes of impairment within the particular habitat since the physical habitat structure sometimes might give a wrong prediction on the biological components within the reference point. That is why it is important to augment water quality characteristics in the assessment to know the causes of impairment within the particular habitat (Somerville & Pruitt, 2004).

Accurate observation and recording during the assessment is also limited by lack of training. Therefore, consistent integrated training procedure within a particular region is necessary and their application to relevant research bodies to promote proper evaluation of ecosystems. Similarly, it is necessary to regularly assess the riverine ecosystems for proper management and recovery plans (Roper, Kershner, Archer, Henderson & Bouwes, 2002).

CHAPTER THREE

3.0 METHODOLOGY

3.1 introduction

This chapter contains the study area, research design, sampling and data collection procedure and data analysis.

3.2 The study area

River Kathita, located between longitudes 037°.56990´E and 038°.00236´E and latitudes 00°.01329´N and 00°.26667´S is in eastern part of Kenya and has a basin with an altitude ranging from 472 – 1982 meters above sea level. Its catchment area is approximately 1620km² with high rainfall (750 – 1500mm per year) and even snow melt at the sources (Nkondi irrigation project feasibility study, 1989) which ensures continuous flow of water in all seasons. From the source in Mt. Kenya around Ithangune and Rutundu hills, the 120 Km long river (Recha, Makokha, & Shisanya, 2017) flows in a north-easterly direction, easterly through thick equatorial rainforests towards Meru town, and in a south easterly direction through Tharaka Nithi County (Tharaka constituency) after which it joins River Tana at Kibuuka waterfalls (Fig. 3.1). It is northernmost of the Mt Kenya tributaries of the Tana river. The river is unlike many other rivers finding their source in Kenyan moorland as it is formed by the melting glaciers on the peaks of Mt Kenya hence making its water very cold. The minimum flow ever recorded is 2.2 m^3sec^{-1} while the highest is 640 m^3/sec^{-1} (Nkondi irrigation project feasibility study, 1989). The topography is flat to slightly undulating, gently sloping from west (altitude 860 m) to east (altitude 730 m a. s. l) (Nkondi irrigation project feasibility study, 1989).

Temperatures are generally hot (29°C - 36°C) but can rise to as high as 40°C during certain periods (Recha, Makokha & Shisanya, 2017). Rainfall experienced is bimodal pattern with annual rainfall averaging between 500-800mm per year though it is slightly higher in the upper Mt. Kenya region (around Meru town). Rainy seasons have varying amount of rainfall whose effectiveness also differ (from March to May, and from October to December). The upper part of River Kathita (Meru County) region is densely populated unlike the lower part (Tharaka constituency) which is scarcely populated.

Both natural and planted vegetation is present. It consists of trees like: Mulberry fig (*Ficus sycomorus* L.), Tamarind (*Tamaridus indica* L.1753), Mexican-white cedar *(Cupressus lusitanica* Mill.*)*, Patula pine *(Pinus patula* Schiede ex schltdl. & Cham)*,* African baobab (*Adansonia digitate* L.), Natal fig (*Ficus natalensis* Hochst), Neem tree (*Azadirachta indica* A. Juss., 1830) and Mango tree *(Mangifera indica* L*.*) (Quattrocchi, 2012), grass and shrubs. Farming, livestock keeping, fishing and apiculture are the main economic activities in the area. Crops grown include: Tea, vegetables, coffee, pyrethrum, bananas, maize, peas, cowpeas, millet, sorghum, groundnuts and green grams.

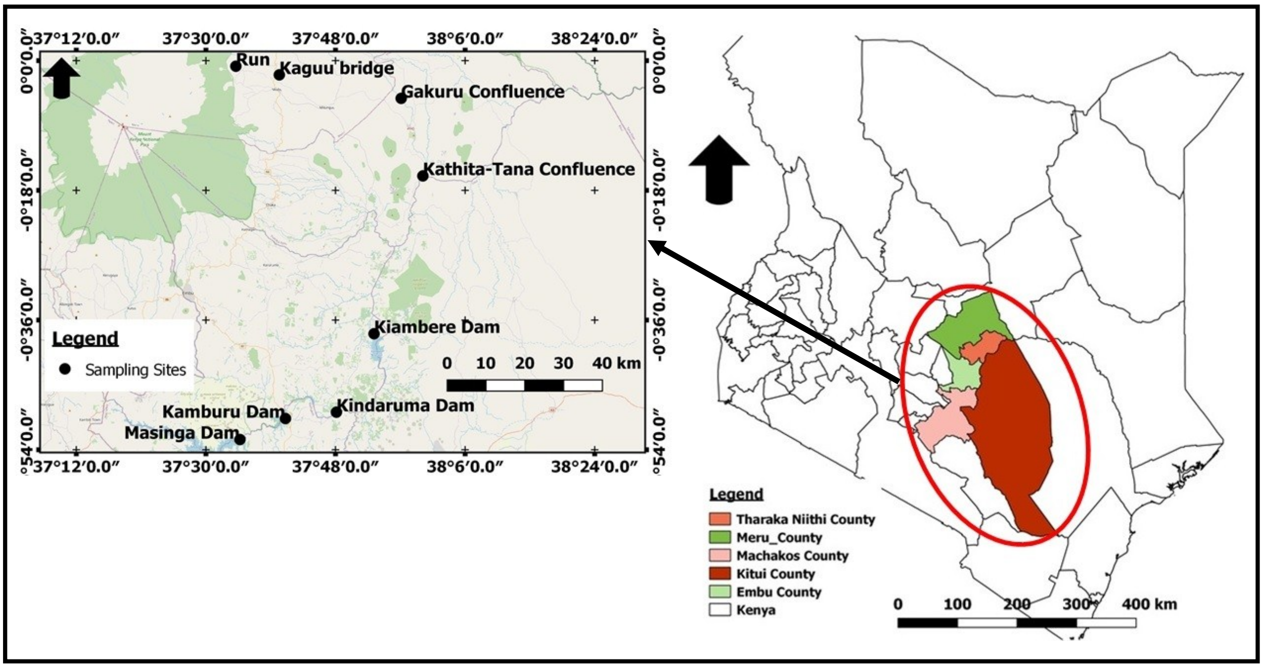

Figure 3.1: Map showing sampling sites along Rivers Kathita and Tana, Mt. Kenya region

The following characteristics were noted for the selected sampling stations after the conduction of a preliminary survey.

3.2.1 Mung'enya upstream run, R. Kathita (S1)

The station is in the upper reaches of River Kathita past Kithaku market from Meru town with coordinates 037°.56990´E and 00°.01329´N and an altitude of 1941 meters a. s. l. It is in Mung'enya village, Kathiranga sub-location in Meru County, a place commonly known as Githongo. The area is very cold and forested. Close to the site is a bridge across the river known as Kathiranga which joins the two adjacent communities. The riparian vegetation cover on either side of the river banks is a stretch of about 200 meters after which there is agricultural plantations of tea, maize, vegetables and napier grass. The vegetation in the area is both natural (95%) and planted (5%). The terrain of the land is gently sloping. Boulders dominated the bottom substrate while the instream cover constituted of wood debris, snags and macrophytes. The average water depth, width and flowrate were 0.44 m, 10.72 m and 0.614 m^3s^{-1} respectively. The maximum and minimum depth recorded were 0.53 m and 0.35 m respectively while that for width and flowrate were 11.79 m, 9.17 m and 1.2 ms^{2-1}, 0.4 m^3s^{-1} respectively. Agriculture is the major economic activities practiced (Fig.3.2).

Figure 3.1: Photos showing Mung'enya upstream run (S1), River Kathita

3.2.2 Mung'enya upstream reservoir, R. Kathita (S2)

The station is just above S1, located on coordinates 037°.56956´E and 00°.01300´N with an altitude of 1982 meters above sea level. It had similar characteristics in terms of riparian vegetation, economic activities and the topography with S1 described above. The bottom substrate was dominated by mud and fine silt. Instream cover constituted of wood debris, snags and macrophytes. The average water depth, width and flowrate recorded was 0.62 m, 9.57 m and 0.27 m/s^2 respectively. The maximum and minimum depth recorded were 0.82 m and 0.52 m respectively while that for width and flowrate were 11.79 m, 9.17 m and 0.5 m^3s^{-1}, 0.2 m^3s^{-1} respectively. This station together with S1 were used as reference point because they were minimally disturbed and met the threshold for physical habitat, biodiversity and land use as compared to others (Fig.3.3).

Figure 2.3: Photos showing Mung'enya upstream reservoir (S2), River Kathita

3.2.3 Kaguu bridge station, R. Kathita (S3)

The station is named after the bridge found here called 'Kaguu bridge'. It is located below Meru town on the coordinates 037°.6694´E and 00°.03290´N and an altitude of 1448 meters a. s. l. This station is in Mwiiteria sub-location, Ntima East ward in Meru County. It is a construction site and also a quarry.

The station had boulders as the main substrate while the instream cover comprised of plant and wood debris. Vegetation is both natural and artificial whereby natural vegetation consists of trees and shrubs and it is approximately 30%. Planted vegetation approximates 70% and it is mainly eucalyptus. It extends to about 5 meters on one side while on the other side, it has been encroached through agriculture up to the river bank leading to moderate river bank erosion. The terrain of the land is ragged. The river at this station had an average water depth, width and flowrate of 1.34 m, 3.95 m and 0.62 m^3s^{-1} respectively. The maximum and minimum depth recorded were 1.58 m and 1.21 m respectively while that for width and flowrate were 5.24 m, 1.3 m and 1.16 ms^{-2}, 0.31 m^3s^{-1} respectively. There is farming in the area, evidenced by banana plantations. Other human activities practiced were collection of concrete, bathing and collection of water for domestic use (Fig.3.4).

Figure 3.3: Photos showing Kaguu bridge (S3), R. Kathita)

3.2.4 Matangige station, R. Kathita (S4)

Matangige station is in Matangige village, Tharaka constituency, the point just before the confluence of River Gakuuru and River Kathita. It is located on coordinates 037°.95131´E and 00°.08782´N with an altitude of 701 meters a. s. l. Natural vegetation dominates the area (98%) and composed of trees, weeds and shrubs while planted vegetation (Neem trees and Napier grass) was estimated to be 2%. River banks are unstable and eroded and have a riparian vegetation which extended to about 20 meters from the bank. The terrain of the land is gently sloping with loamy soil. The instream cover constituted of macrophyte, wood debris and holes at banks. Its bottom substrate had a mix of sand, mud and boulders. The average water depth, width and flowrate was 1.14 m, 20.31 m and 0.43 m^3s^{-1} respectively. The maximum and minimum depth recorded were 1.41 m and 0.77 m respectively while that for width and flowrate were 28.0 m, 17.03 m and 0.86 m^3s^{-1}, 0.23 m^3s^{-1} respectively.

The major activities at this site include subsistence farming, fishing and livestock keeping. (Fig.3.5).

Figure 3.4: Photos showing Matangige station (S4) in Matangige village, R. Kathita.

3.2.5 River Kathita – Gakuuru confluence (S5)

This station is also in Matangige village in Tharaka constituency. It is where River Gakuuru joins River Kathita. Its coordinates are 037°.95209′E and 00°.08734′N and has an altitude of 701 meters above sea level. The vegetation type, land use activities and topography is similar to that of S4 described above. The instream cover constituted of macrophyte, wood debris and holes at banks while the bottom substrate had a mix of sand, mud and boulders. The average water depth, width and flowrate recorded was 1.61 m, 26.1 m and 0.39 m^3s^{-1} respectively. The maximum and minimum depth recorded were 2.01 m and 1.33 m respectively while that for width and flowrate were 30.33 m, 19.65 m and 0.76 m^3s^{-1}, 0.25 m^3s^{-1} respectively (Fig.3.6).

Figure 3.5: Photos showing River Kathita – Gakuuru Confluence (S5)

3.2.6 Mwerera station, R. Kathita (S6)

This station is in the old stage of the river and characterized by widened river channel with slow moving waters before joining River Tana. It is in Mwerera village, Gituma sub-location which is the lower parts of Tharaka-Nithi County. Its coordinates are 038°.00247´E and 00°.26589´S and has an altitude of 484 meters a. s. l.

Only natural scanty vegetation is present and constitutes of a few trees (acacias, baobabs, psycamores etc.) and shrubs. River banks are highly eroded and have very little riparian vegetation which starts about 5m from the river bank. The land terrain is ragged and rocky. The average water depth, width and flowrate of 0.54 m, 76.0 m and 0.56 m^3s^{-1} respectively were recorded. The maximum and minimum depth recorded were 1.04 m and 0.27 m respectively while that for width and flowrate were 80.0 m, 70.0 m and 1.01 m^3s^{-1}, 0.28 m^3s^{-1} respectively. Main activities around this site were bathing, livestock watering and fishing. Substrate type was boulders, sand and fine silt while instream cover was wood debris and macrophytes (Fig.3.7).

Figure 3.6: Photos showing Mwerera station (S6) in Mwerera village, R. Kathita

3.2.7 River Kathita – Tana confluence station (S7)

This is the last station in River Kathita and the point where it joins River Tana.it is in Mwerera village, Gituma sub-location, the lower parts of Tharaka-Nithi County. Its coordinates are 038°.00236′E and 00°.26667′S and an altitude of 472 meters a. s. l. Only natural scanty vegetation is present and constitutes of a few trees (acacias, baobabs, psycamores etc.) and shrubs. River banks are highly eroded and have very little riparian vegetation which starts about 5 m from the river bank. The land terrain is ragged and rocky.

The river at this station had an average water depth, width and flowrate of 1.02 m, 95.33 m and 1.12 m^3s^{-1} respectively. The maximum and minimum depth recorded were 1.5m and 0.60 m respectively while that for width and flowrate were 120.0 m, 15.0 m and 1.75 m^3s^{-1}, 0.85 m^3s^{-1} respectively.

Main activities around this site were bathing, livestock watering and fishing. Substrate type was boulders, sand and fine silt while instream cover was wood debris and macrophytes (Fig.3.8).

Figure 3.7: Photos showing River Kathita – Tana confluence (S7), R. Kathita

3.2.8 Kamburu dam station (S8), R. Tana

S8 is found in the border of Embu and Machakos counties. It is found on the coordinates 0.8291°S 37.6679°E It has an average depth of 52 meters and a total length of 730 meters. The dam has a total capacity of 123,000,000 m³. Sampling was done in Kisumu ndogo beach.

The area has only natural vegetation consisting of acacia, sycamore trees and shrubs among others. The land topography is gently sloping with sandy soil. Riparian vegetation is present and extends to more than 20 meters. There is human settlement near the dam constituting local fishermen around the beach (Fig.3.9).

Figure 3.8: Photos showing Kisumu ndogo beach, Kamburu dam station (S8)

3.2.9 Kiambere dam station (S9), R. Tana

S9 is found in the border of Embu and Kitui Counties. it is found on the coordinates 00°48´38´´S 37°48´46´´E. It has an average depth of 110 meters and a total length of 1000 meters. It has a total capacity of 585,000,000 m³. Sampling sites were in Spill-way beach.

The area has only natural vegetation consisting of acacias, baobabs, sycamore trees among others. The land terrain is ragged with sandy-rocky soil. Substrate type was boulders, muddy sandy and debris. There is settlement around the beach which compose mainly of Luo’s who carry out fishing in the area.

Fishing is the main activity here. It is done using gill nets, traps and long lines. The type of fish caught include tilapia, common carp and mudfish. There is no growing of crops around the dam except grazing of livestock. The dam is the main source of water for domestic use by the local community (Fig.3.10).

Figure 3.9: Photos showing spill-way beach station (S9) at Kiambere dam, R. Tana

3.2.10 Kindaruma dam station, R. Tana (S10)

S10 is found in the border of Embu and Machakos Counties, it is found on the coordinates 00°48´38´´S 37°48´46´´E. It has a n average depth of 24 m and a total length of 549 m. It has a total capacity of 18,300,000 m^3 and a surface area of 10 km^2.

The type of vegetation around the dam is both natural and artificial. Natural vegetation was approximated to be 80% while planted type was 20%. Natural vegetation comprised of acacias, sycamore trees among others. The land terrain was ragged with laterite and clay soils. There was thick riparian vegetation extending to more than 20 meters. Hanging trees on water in river banks were observed. Substrate type was boulders, muddy, sand and debris (Fig.3.11).

Figure 3.10: Photos showing Kindaruma dam station, (S10)

There is minimal agriculture carried out around the dam, where crops like vegetables and maize are grown. Livestock (cows and sheep) also come to graze around the dam. Fishing is done during morning hours by local people using gill nets and boats. The type of fish caught include catfish, tilapias and common carp. The dam has hostile aquatic animals like hippos and crocodiles. Water birds were also seen swimming in the dam.

3.2.11 Masinga dam station (S11), R. Tana

This dam is the largest of all dams. It bounders Embu and Machakos Counties with the coordinates 00°53´21´´S 37°35´40´´E. Sampling stations were on the part belonging to Embu County. It has an average depth of 60 meters and a total length of 2200 meters. It has a total capacity of 1,560,000,000 m³. It has a surface area of 120 km

The type of vegetation found was both planted and natural vegetation. Planted vegetation was dominant and approximates 70% which consists of blue gams and a few grevilleas. Natural vegetation approximates 30%, consisting of acacias, sycamore trees among others. The topography of the land is gently sloping with loamy soil. The type of substrate varied from place to place. Some parts had boulders, small rocks, muddy, sand and debris (Fig.3.12).

Figure 3.11: Showing Masinga dam station, (S11)

The Geographical positioning system (Garmin Ltd) was used to take positions for sampling sites and their altitude and they are presented in table 3.2.

Table 3.2: GPS positions of sampling sites in the upper Tana River basin

No.	Station	Altitude m (a.s.l)	Longitudes	Latitudes
S1.	Mung'enya – run	1941	37.56936	0.01297
S2.	Mung'enya – reservoir	1982	37.56947	0.01294
S3.	Kaguu bridge	1448	37.66994	0.03290
S4	Matangige	701	37.95131	0.08782
S5.	Kathita-Gakuuru confluence	701	37.95209	0.08734
S6.	Mwerera	484	38.00243	0.26590
S7.	Kathita-Tana confluence	472	38.00236	0.26668
S8.	Kamburu	1016	37.6679	0.8291
S9.	Kiambere	706	37.4846	0.4838
S10.	Kindaruma	789	37.4846	0.4838
S11.	Masinga	1062	37.3540	0.5321

The most upstream sampling point was at S2 on River Kathita tributary while the rest of sampling sites were along the river profile with the last one situated in S9 on the River Tana downstream.

3.3 Research design

The study mainly involved field work and laboratory analysis whereby sampling was conducted once monthly from March to August 2020 (March to May – wet season, June to August – Dry season) to collect data for use in assessing ecosystem integrity of River Kathita and the four associated dams stretch in upper Tana basin. There were eleven sampling sites (S1-S11), of which seven (S1-S7) were on River Kathita and four (S8-S11) were in the associated constructed dams stretch in the upper Tana basin (Fig. 1). The dams include S8, S9, S10 and S11.

The data collected include: physical and chemical parameters: (temperature, DO, TDS, conductivity, pH, and nutrients – TP and TN), metrics for estimating the habitat quality index (available instream cover, bottom substrate, dimension of largest pool, number of riffles, water level, channel sinuosity, bank stability, riparian buffer vegetation and aesthetic of reach), metrics for estimating fish based index of biotic integrity (FIBI) (Number of native species, number of intolerant species, number of rheophilic species, percentage of benthic species, percentage of tolerant individual, percentage of cyprinidae individual, percentage of detrivores individual, percentage of carnivores individual, percentage of omnivores individual, number of individual per 50m of sampling, number of exotic species and modified index of well-being and fish distribution and abundance.

3.4 Sampling and data collection procedure

3.4.1 Physical and Chemical Parameters

Multiparameter meter (YSI professional plus series model) was used for *in-situ* measurement of water pH, temperature (°C), dissolved oxygen (mgL^{-1}), conductivity and total dissolved solids (mgL^{-1}). Triplicates water samples were collected from the river in 500 ml plastic bottles which had been cleaned and rinsed with double distilled water at every sampling site. The bottles were labeled using a masking tape, kept in a cooler box containing ice and then taken to the laboratory for the analysis of nutrients TN and TP concentrations within 72 hours using the method described in APHA 2014.

3.4.2 Fish sampling

An electrofisher (Samus 1000) and a battery of 12 volts producing a current of 75A were used to catch fish. However, in dams associated with River Kathita, local fishermen were used to catch fish using gill nets of mesh size 3.5, 4 and 4.5 inches. Fishing was carried out during the day and the time recorded. The fish samples were sorted, counted and identified to species level using the identification keys by Witte and Van Densen (1995). An electronic weighing balance, Asca Cm-121 (1200g × 0.1g) and Salter model 180 (top pan balance) were used to measure weights of small and big fish respectively. The total length to the nearest 0.1 cm was measured using a one-meter measuring board. Further classification of species as either indigenous or exotic was done using earlier literature materials of fish species in Lake Victoria basin (Onchumba & Manyala, 1992; Witte & Van Densen, 1995; Mboya et al. (2005) & Froese & Pauly 2021).

The samples were further categorized into either tolerant or intolerant according to Froese & Pauly (2021), Hugueny, Camara, Samara & Magassouba (1996), Toham & Teugels (1999) and Raburu & Masese (2010).

Fish species diversity was estimated using the information recorded regarding the number of species, biomass and abundance (Krebs, 1999; Magurran, 2004). At each station, fish were sorted into species and number of individuals counted and recorded to get abundance. Percentage fish species composition was calculated by taking the number of specimens of particular species (n) divide by the total number of fish counted (N) multiply by 100. Fish biomass was obtained by weighing all fish catches at each sampling site and then summing up.

3.4.3 Estimation of fish biodiversity indices

Shannon-Weiner, Simpson, Species evenness and species richness diversity indices were computed using the following formulae;

i) Shannon-wiener's diversity index formula (Shannon & Wiener, 1949);

$$H = -\sum_{i=I}^{S} p_i \text{In}(p_i)$$

ii) Evenness index (Pielou, 1966);

$$E_H = {}^{\text{H}}/_{\text{InS}}$$

iii) Simpson index of diversity;

Simpson index of diversity = 1-D

$$D = \sum_{i=1}^{s} Pi^2$$

Simpson index of diversity = 1-D

iv) Margalef's Richness Index (d) (Margalef, 1958);

$$d = \frac{(S-1)}{In\ N}$$

Pi: The proportion of individuals calculated as abundance of individual species divided by total number of individuals in the community sampled.

In: The natural log

Σ: The sum of all calculation

S: The number of species

H: The Shannon index of diversity

D: Simpson index.

3.4.4 Fish index of biotic integrity (FIBI)

The methodology utilizes three major metrics constituting of twelve sub metrics in computing FIBI (Table 3). The first set of metrics are within species richness and composition: Number of native species, number of intolerant species, number of rheophilic species, percentage of benthic species, percentage of tolerant individual and the percentage of Cyprinidae individual. This category helps to evaluate the level of pollution that has been subjected to the aquatic environments.

The second category of metrics fall under trophic guild: percentage of detrivores, percentage of carnivores, percentage of Omnivores. The third set of metrics involves fish species abundance and condition factor: Number of individual per 50m of sampling, number of exotic species, modified index of well-being.

The scoring criteria of the metrics for use in estimating FIBI are presented in table 3.3.

The criteria described by (Karr, 1981; Raburu & Masese, 2010) was used to score the above three categories.

Table 3.3: FIBI metrics and its scoring criteria

Category	**Metric**	**Scoring criteria**		
		1 **(worst)**	**3**	**5 (best)**
Species richness and composition	Number of native species	< 3	3 - 5	≥ 6
	Number of intolerant species	< 3	3 - 5	≥6
	Number of rheophilic species	0	1	>1
	Percentage of benthic species	< 7.5	7.5 – 15	>15
	Percentage of tolerant individual	>20	10 – 20	< 10
	Percentage of Cyprinidae individual	< 40	40 - 80	>80
Trophic metric	Percentage of detrivores individual	< 7.5	7.5 – 15	≥ 15
	Percentage of carnivores individual	< 1	1 – 4.4	≥ 4.5
	Percentage of carnivores individual	>45	20 – 45	< 20
Abundance and condition	Number of individual per 50 m of sampling	< 25	25 – 50	> 50
	Number of exotic species	≥ 2	1	0
	Modified index of well-being	< 1.25	1.25 – 2.50	≥ 2.50

In table 3 above, the percentage proportion of an individual species was estimated using the formula;

$$\% = \frac{\text{No. of individual fish population}}{\text{total No. of fish in a community}} \times 100$$

The condition factor that evaluated the health status of fish was estimated using the formula:

$$\mathbf{MIWB} = 0.5ln\mathbf{N} + 0.5ln\mathbf{B} + HN + HB$$

Where;

ln – Natural log, **N**- Number of fish individuals caught per unit distance sampled**, B**- Biomass of fish individuals caught per unit distance excluding tolerant and exotic species, **HN, HB** – Shannon-Wiener diversity index based on fish numbers and biomass respectively.

Each metric was scored and a summation computed and the sites then interpreted as excellent, good, fair, poor or very poor depending on whether it was within the range of 50-60, 40-49, 30-39, 20-29 and <20 respectively.

3.4.5 Habitat quality evaluation

The habitat quality index was estimated using the methodology described in Rodgers (2016). The method uses 9 metrics in estimating HQI namely: Available instream cover, bottom substrate, dimension of largest pool, number of riffles, water level, channel sinuosity, bank stability, riparian buffer vegetation and aesthetics of reach.

A long stick and a tape measure were used to take river depth by taking readings from three points along the river and an average estimate value for stream depth was calculated. A stick of length 2.62 meters was used to estimate the width of the river channel by holding it across the river channel from the river bank and then estimating the number of times the stick will fit into the channel. The natural buffer vegetation was visually estimated. Physical counting was done to get the number of riffles and channel sinuosity while river bed substrate, bank erosion profile, aesthetic of reach and instream cover - snags, woody debris, holes at the banks and macrophytes were visually examined and recorded. Where the depth was great and the bottom of the river could not be seen, a bottom graph was used to collect benthic material which was then used to categorize the nature of the bottom. The scoring criteria for the metrics used in estimating HQI are presented in table 3.4.

Table 3.4 : Habitat characteristics scoring criteria

Habitat parameter	**Scoring criteria**			
Available instream cover	**Abundant** >50% of substrate that favors colonization and fish cover, virtuous mix of several stable cover types such as snags, wood debris, holes in the bank, macrophytes	**Common** 30 – 50% of substrate supports firm habitat; sufficient habitat for maintenance of populations; may be limited in the number of various habitat types.	**Rare** 10 – 29.9% of substrate ropes firm habitat; habitat accessibility less than desirable; substrate frequently troubled or removed.	**Absent** < 10% of substrate supports firm habitat; absence of habitat is obvious; substrate unstable or absent.
Score	**4**	**3**	**2**	**1**
Bottom substrate	**Stable** >50% gravel or larger substrate ; gravel, sarsens; dominant substrate type is grit or larger	**Moderately Stable** 30 – 50% gravel or larger substrate; prevailing substrate type is mix of grit with some finer sediments.	**Moderately Unstable** 10 – 29.9% grit or bigger substrate; prevailing substrate type is finer than gravel, but may still be a mix of sizes.	**Unstable** < 10% grit or bigger substrate; substrate is uniform sand, silt, clay, or bedrock.
Score	**4**	**3**	**2**	**1**
Dimension of largest pool	**Large** Pool occupies more than 50% of the channel width; maximum depth is >1 meter	**Moderate** Pool occupies roughly 50% or slightly less of the channel width; maximum depth is 0.5 – 1 meter	**Small** Pool occupies roughly 25% of the channel width; maximum depth is < 0.5 meter	**Absent** Pools are absent, only shallow auxiliary pockets.
Score	**4**	**3**	**2**	**1**
Number of Riffles To be reckoned, riffles must extend > 50% the width of the channel and be at least as long as the channel width	**Abundant** >5 riffles	**Common** 2 – 4 riffles	**Rare** 1 riffle	**Absent** No riffles
Score				

	4	**3**	**2**	**1**
Water level	**High** Water reaches the base of both lower banks; <5% of channel substrate is uncovered.	**Moderate** Water fills > 75% of the channel; or < 25% of channel substrate is uncovered.	**Low** Water fills 25-75% of the existing channel or riffle substrates are mostly exposed..	**No flow** Very little water in the channel and mostly extant in standing pools, or stream is dry.
Score	**3**	**2**	**1**	**0**
Channel sinuosity	**High** ≥ 2 well-defined bends with deep outside areas -cut banks and shallow inside areas-point bars present	**Moderate** 1 well defined bend or ≥ 3 moderately-defined bends existing.	**Low** < 3 moderately-defined bends or only poorly-defined bends existing.	**None** Straight channel; might be channelized
Score	**3**	**2**	**1**	**0**
Bank stability	**Stable** Little proof (<10%) of erosion or bank letdown; bank angles average <30°	**Moderately Stable** Some proof (10 – 29.9%) of erosion or bank letdown; small areas of erosion mostly healed over, bank angles average 30 – 39.9°	**Moderately Unstable** Proof of erosion or bank letdown is common (30 – 50%); high possibility of erosion during flooding; bank angles average 40 - 60°	**Unstable** Large and frequent proof (> 50%) of erosion or bank letdown; raw areas recurrent along steep banks; bank angles average > 60°
Score	**3**	**2**	**1**	**0**
Riparian Buffer Vegetation	**Extensive** Width of natural buffer is greater than 20 meters.	**Wide** Width of natural buffer is 10.1 to 20 meters	**Moderate** Width of natural buffer is 5 to 10 meters	**Narrow** Width of natural buffer is less than 5 meters
Score	**3**	**2**	**1**	**0**
Aesthetics of Reach	**Wilderness** Exceptional natural beauty; usually wooded or unpastured area; no apparent indications of anthropogenic activity.	**Natural Area** Trees or native flora is common; some development evident - from fields, pastures, natural dwellings little proof of human activity	**Common Setting** Not offensive; area is developed, but uncluttered such as in an urban park.	**Offensive** Stream does not augment the aesthetics of the area; cluttered; highly developed; may be a dumping area
Score	**3**	**2**	**1**	**0**
Total score				

The total HQI for every station was obtained by summing up the rated scores and then characterized as exceptional, high, intermediate, limited and or minimal integrity index for 26 – 31, 20 – 25, 14 – 19, 8 – 13, < 7, respectively.

3.5 Data analysis, techniques and presentation

Physical and chemical parameters, fish and habitat integrity index data was entered in Microsoft excel sheet. Means, standard error, minimum and maximum value were obtained from descriptive statistics and are presented in tables and graphs. The means were subjected to Analysis of Variance (2-way ANOVA) using SPSS software version 22 to undertake post hoc analyzes where there were significant variations of all variables evaluated ($p < 0.05$). In cases where there were significant variations, Tukey test was carried out to obtain the actual pair of stations and months with significant differences. The data was presented using graphs and tables.

Pearson correlation was used to compute correlation analysis to determine relationship between different variables estimated.

CHAPTER FOUR

4.0 RESULTS, ANALYSES AND INTERPRETATION

4.1 Introduction

This chapter contain results for spatial and temporal variation of physical-chemical parameters, habitat quality index variation, fish community structure, spatial and temporal distribution of fish, fish biodiversity indices, fish based index of biotic integrity and correlation analysis between physical-chemical parameters and fish abundance.

4.2 Spatial and temporal variation of physical-chemical parameters

4.2.1 Temperature variation

The highest mean temperature was recorded at S9 (26.58 ±0.543°C) while the lowest was recorded at S1 (12.85 ± 0.0.345°C). There was increasing trend in mean temperatures downstream (Fig.4.1).

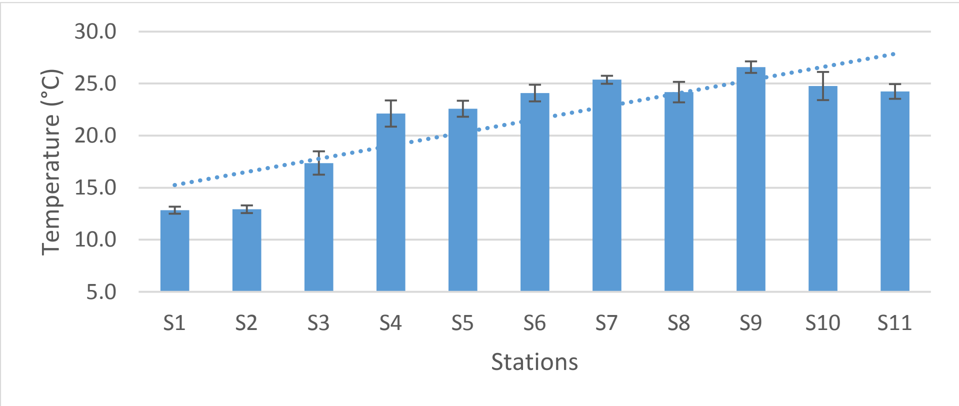

Figure 4.1: Mean temperature ± (SE) at different sampling stations

There was a significant variation in mean temperatures between stations, F (10, 178) = 108.35, *p* = 0.000. S4 was lower by between 0.677 and 5.899, 2.362 and 6.618, 0.001 and 4.257 than that of S7, S9, S10 and S11 respectively. S4 was also higher by between 2.619 and 6.875, 7.035 and 11.291, 7.11 and 11.367 than that of S3, S2 and S1 respectively. S6 was higher by between

4.640 and 8.896, 9.056 and 13.312, 9.132 and 13.387 than that of S3, S2 and S1 respectively. It was also lower by between 0.342 and 4.597 than that of S9. S5 was lower by between 0.173 and 5.386, 1.858 and 6.114 than that of S7 and S9 respectively. It was higher by between 3.123 and 7.379, 7.53 and 11.795, 7.615 and 11.871 than that of S3, S2 and S1 respectively. S7 was higher by between 5.424 and 10.637, 9.841 and 15.053, 9.916 and 15.128 than that of S3, S2 and S1 respectively. S3 was lower by between 4.682 and 8.937, 7.109 and 11.365, 5.098 and 9.354, 4.748 and 9.004 than that of S8, S9, S10 and S11 respectively but higher by between 2.288 and 6.544, 2.364 and 6.620 than that of S2 and S1 respectively. S8 was lower by between 0.300 and 4.556 than that of S9 but higher by between 9.098 and 13.353, 9.173 and 13.429 than that of S2 and S1 respectively. S9 was higher by between 11.525 and 15.781, 11.601 and 15.857, 0.233 and 4.489 than that of S2, S1 and S11 respectively. S10 was higher by between 9.514 and 13.770, 9.590 and 13.846 than that of S2 and S1 respectively. S2 was lower by between 9.164 and 13.420 that that of S11. S1 was lower by between 9.240 and 13.496 than that of S11.

Mean temperatures ranged from 20.32 ± 1.31°C in July to 24.17 ± 1.9°C in March 2020 on a temporal scale. These results shown that there was a general decreasing trend (Fig.4.2).

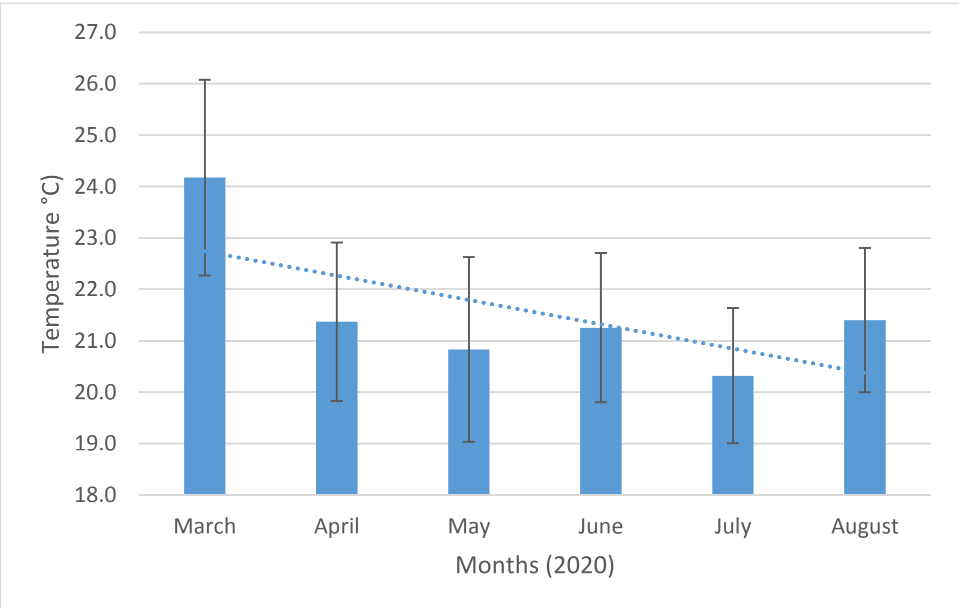

Figure 4.2: Mean temperature ± (SE) in different sampling months

ANOVA shown that there were no significant differences between the months.

4.2.2 Dissolved oxygen concentration variation

S9 recorded the lowest mean DO value (6.64 ± 0.458 mgL^{-1}) whereas the highest was recorded at S2 (9.3 ± .065mgL^{-1}). The mean values shown a general decreasing trend downstream (Fig.4.3).

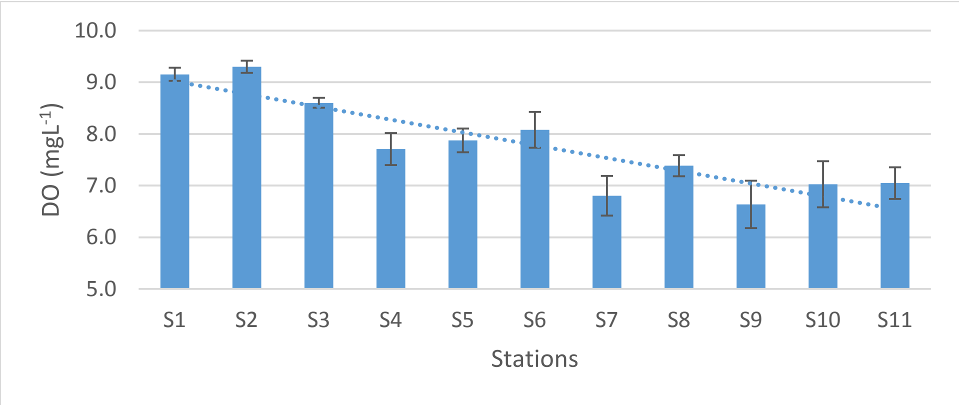

Figure 4.3: Mean Dissolved Oxygen ± (SE) at different sampling stations

There was a significant variation between stations as shown by ANOVA. F (10, 178) = 32.37, $p = 0.000$. S4 (S4) was higher by between 0.022 and 1.80, 0.361 and 1.814 than that of S7 and S9 respectively. However, it was lower by between 0.189 and 1.641, 0.863 and 2.315, 0.715 and 2.168 than that of S3, S2 and S1 respectively. S6 was higher by between 0.395 and 2.174, 0.734 and 2.186, 0.323 and 1.776 than that of S7, S9 and that of S10 respectively. S5 was higher by between 0.205 and 1.985, 0.544 and 1.997, 0.134 and 1.586, 0.114 and 1.567 than that of S7, S9, S10 and S11 respectively but lower by between 0.005 and 1.458, 0.679 and 2.132, 0.5320 and 1.985 than that of S3, S2 and S1 respectively. S7 was lower by between 0.937 and 2.716, 1.611 and 2.390, 1.464 and 3.243 than that of S3, S2 and S1 respectively. S3 was higher by between 0.503 and 1.956, 1.276 and 2.729, 0.865 and 2.318, 0.846 and 2.299 than that of S8, S9, S10 and S11 respectively. S8 was higher by between 0.047 and 1.5 than that of S9 and lower by between 1.177 and 2.630, 1.03 and 2.482 than that of S2 and S1 respectively. S9 was lower by between 1.95 and 3.402, 1.803 and 3.255, than that of S2 and S1 respectively. S10 dam was lower by berween 1.539 and 2.992, 1.392 and 2.845, than that of S2 and S1 respectively. S2 was higher byb between 1.520 and 2.972 than that of S11 whereas S1 was higher by between 1.373 and 2.825 than that of S11.

July 2020 had the lowest mean DO concentration of 7.03 ±0.324mgL^{-1} while March 2020 had the highest mean value (8.67 ± 0.1 mgL^{-1}). There was a general decreasing trend during the sampled months (Fig.4.4).

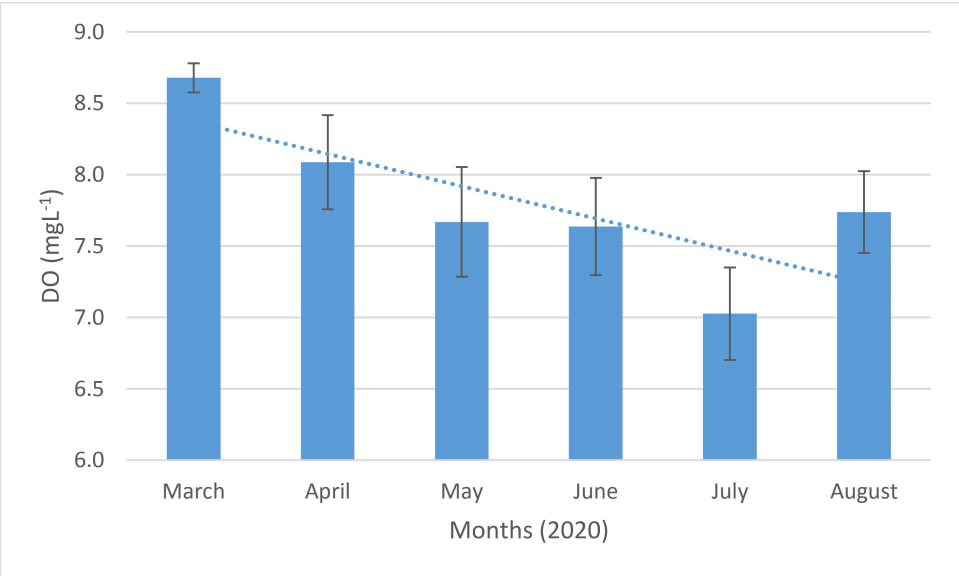

Figure 4.4: Mean Dissolved Oxygen ± (SE) in different sampling months.

ANOVA revealed that there was a significant variation, F (5, 183) = 7.11, p = 0.000, between months. August was lower by between 0.177 and 1.705, July was lower by between 0.635 and 2. 314 and June was by between 0.268 and 1.796 than that of March respectively. March was higher by between 0.254 and 1.760, 0.296 and 1.767, 0687 and 2.158, 0.206 and 1.676 than that of May, June, July and August respectively.

4.2.3 Total dissolved solids variation

S2 recorded the lowest mean TDS while the highest mean value at S4 with 51.56 ± 4.73 mgL^{-1} and 120.23 ± 11.37 mgL^{-1} respectively. There was moderate increasing trend down the sampling stations (Fig.4.5).

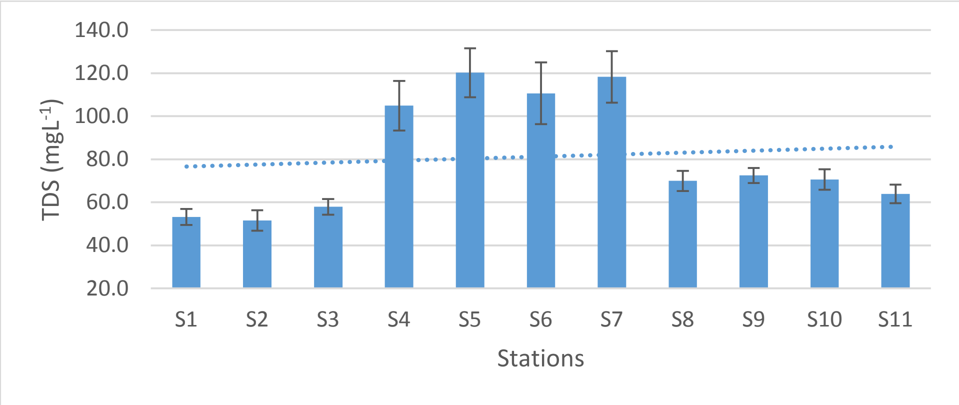

Figure 4.5: Mean TDS ± (SE) at different sampling stations

ANOVA revealed a statistical significance variation between stations, F (10, 178) = 36.86, *p* = 0.000. S4 was higher by between 27.75 and 66.25, 15.68 and 54.18, 12.99 and 51.49, 15.02 and 53.52, 34.06 and 72.56, 32.44 and 70.94, 21.70 and 60.20 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S6 was higher by between 33.53 and 72.03, 21.46 and 59.96, 18.77 and 57.27, 20.80 and 59.30, 39.84 and 78.35, 38.22 and 76.72, 27.48 and 65.99 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S7 was higher by between 36.84 and 84.00, 24.77 and 71.93, 22.08 and 69.24, 24.11 and 71.27, 43.15 and 90.31, 41.53 and 88.69, 30.79 and 77.95 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S9 was higher by between 1.82 and 40.32, 0.20 and 38.70 than that of S2 and S1 respectively.

Temporally, the mean TDS ranged from 60.97 ± 6.78mgL^{-1} to 99.38 ± 10.56 mgL^{-1} in March and August respectively (Fig.4.6)

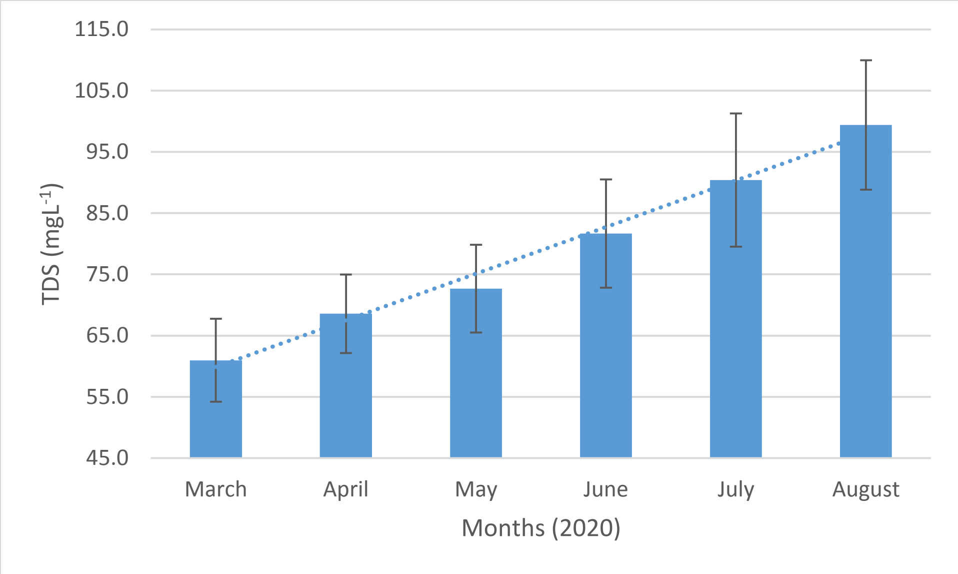

Figure 4.6: Mean TDS ± (SE) in different sampling months

ANOVA shown a significant variation between months, F (5, 183) = 8.53, p = 0.000. March was lower by between 0.68 and 40.71, 9.34 and 49.38, 18.42 and 58.46 than that that of June, July and August respectively. April was lower by between 1.77 and 41.81, 10.85 and 50.89 than that of July and August respectively. May was lower by between 6.75 and 46.79 than that of August.

4.2.4 pH variation

S2 recorded the lowest mean pH with a value of 7.580 ± 0.295 while S4 recorded the highest (8.3 ± 0.1533). There was a slight increasing trend in mean pH down the sampling stations (Fig.4.7).

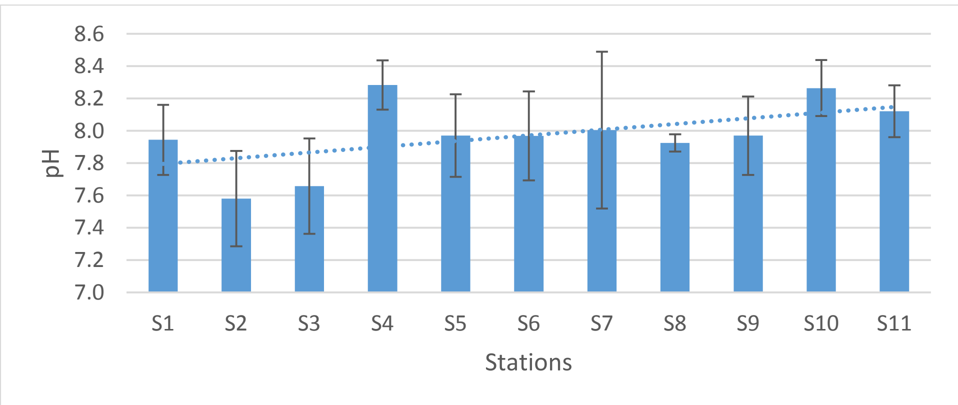

Figure 4.7: Mean pH ± (SE) at different sampling stations

There was no significant variation between stations as shown by ANOVA.

Temporally, the mean pH ranged from 6.750 ± 0.0500 during the month of March 2020 to 8.11 ± 0.165, the month of August 2020. There was an increasing trend in mean pH during the sampled months (Fig.4.8).

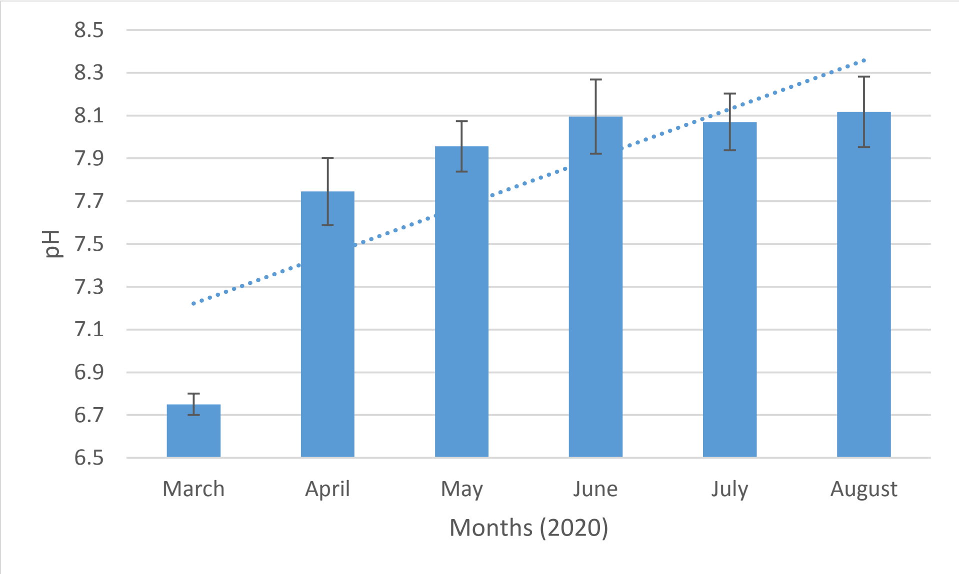

Figure 4.8: Mean pH ± (SE) in different sampling months

A significant statistical variation was observed between months, $F(5, 183) = 4.69$, $p = 0.000$. March was lower by between 0.0842 and 0.8490, 0.0618 and 0.8266, 0.1058 and 0.8705 than that of June, July and August respectively.

4.2.5 Total nitrogen concentration variation

The mean total nitrogen concentration ranged from 103.1 ± 18.02 μgL^{-1} at S11 dam to 353.10 ± 70.3 μgL^{-1} at S4. There was a moderate decreasing trend in mean total nitrogen concentration in the sampled stations (Fig.4.9).

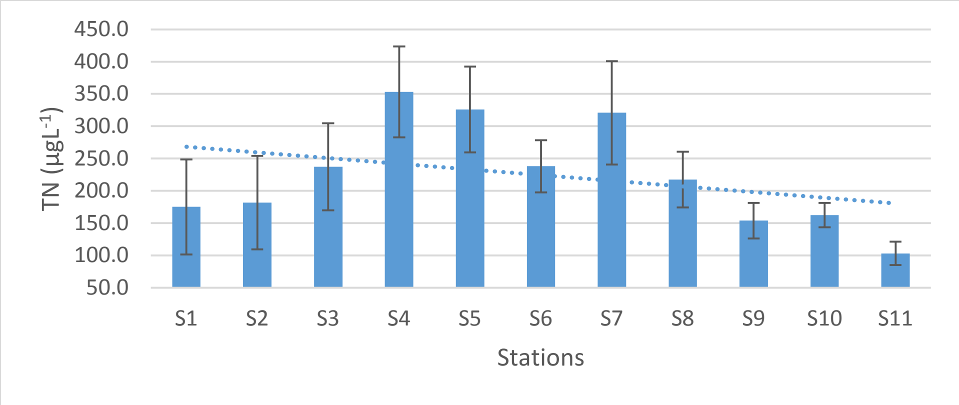

Figure 4.9: Mean Total Nitrogen ± (SE) at different sampling stations

There was significant variation in mean total nitrogen between stations, F (10, 178) = 7.29, *p* = 0.000. S4 was higher by between 29.8 and 294.2, 3.5 and 267.8, 67.1 and 331.5, 58.6 and 323.0, 41.2 and 305.6, 45.8 and 310.2, 117.8 and 382.2 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S5 was higher by between 2.7 and 267.1, 40.0 and 304.4, 31.5 and 295.9, 14.1 and 278.5, 18.7 and 283.1, 90.7 and 355 than that of S3, S9, S10, S2, S1 and S11 respectively. S7 was higher by between 5.0 and 328.8, 55.7 and 379.5 than that of S9 and S11 respectively.

Temporally, the lowest mean TN was recorded in May 2020 (118.64 ± 13.97 μgL^{-1}) while the highest mean TN (358.84 ± 68.7 μgL^{-1}) was recorded in March 2020. The means shown a decreasing trend (Fig.4.10).

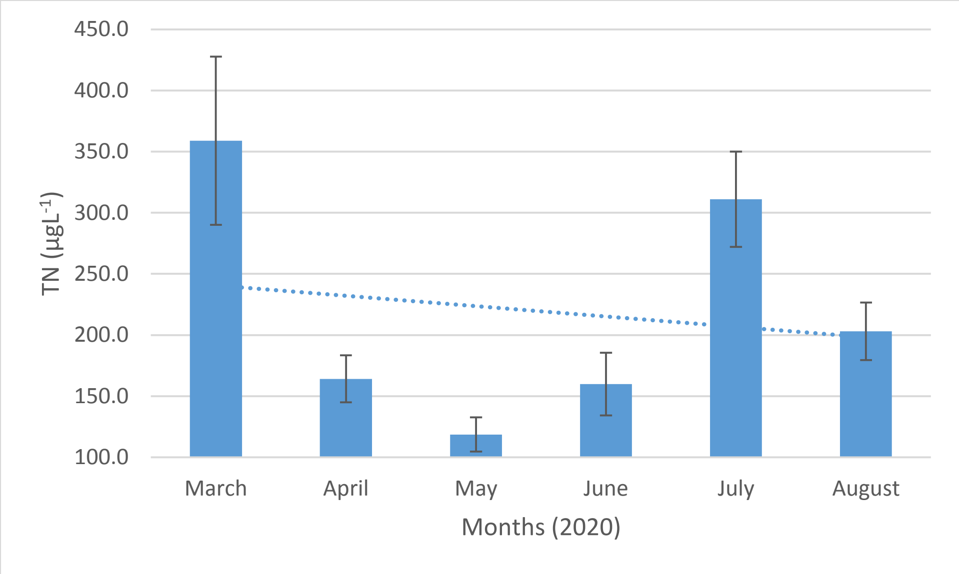

Figure 4.10: Mean Total Nitrogen ± (SE) in different sampling months

ANOVA revealed that mean total nitrogen concentration varied significantly, F (5,183) = 18.47, *P* = 0.000, between months. March was higher by between 107.7 and 280.3, 153.9 and 326.5, 114.6 and 283.2, 71.4 and 240.0 than that of April, May, June, and August respectively. April was lower by between 36.9 and 205.5 than that of July. May was lower by between 83.0 and 251.6, 0.2 and 168.8 than that of July and August respectively. June was lower by between 43.6 and 208.3 than that of July. July was higher by between 0.6 and 165.1 than that of August.

4.2.6 Total phosphorus concentration variation

Average total phosphorus ranged from 37.94 ± 7.89 μgL^{-1} at S11 to 98.50 ± 20.54 μgL^{-1} at S5. There was no general trend in mean total phosphorus concentration in sampling stations (Fig.4.11).

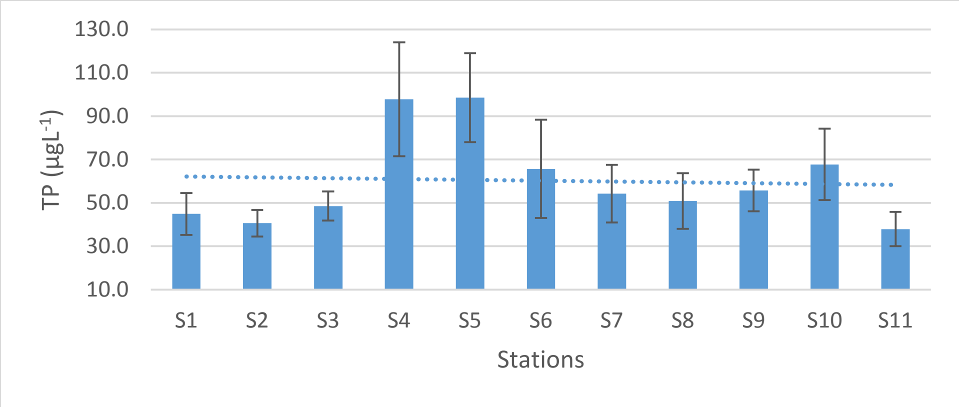

Figure 4.11: Mean Total Phosphorus ± (SE) at different sampling stations

There was no significant variation between the stations.

Temporally, the month of March had the lowest mean TP concentration of 22.99 ± 5.13 µgL^{-1} while April had the highest mean value of 105.10 ± 22.1 µgL^{-1} (Fig.4.12).

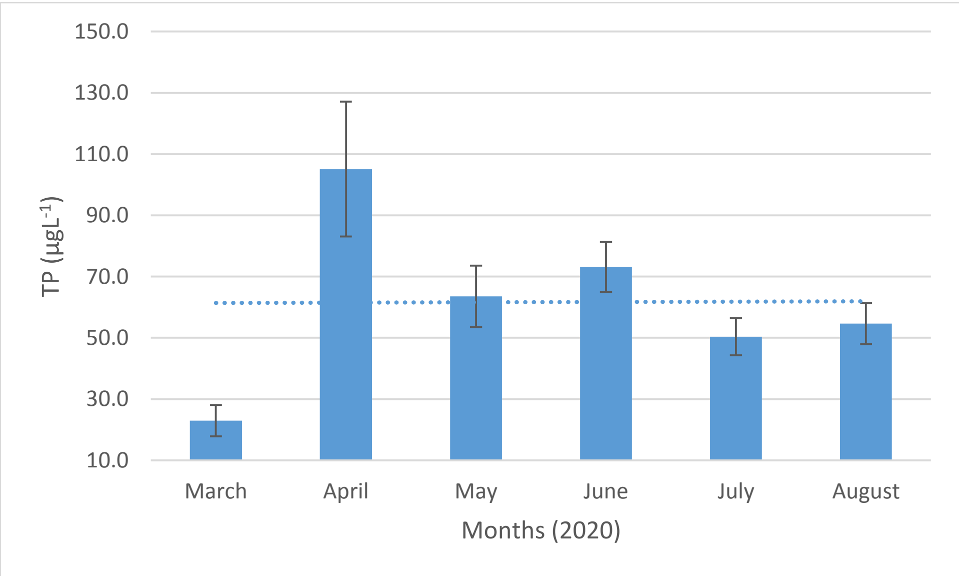

Figure 4.12: Mean Total Phosphorus ± (SE) in different sampling months

ANOVA shown that there was a significant difference between months, F (5, 183) = 8.55, p = 0.000. March was lower by between 23.55 and 76.93 than that of April. April was higher by between 8.46 and 61.84, 22.24 and 74.39, 17.99 and 70.15 than that of May, July and August respectively.

4.2.7 Electrical conductivity variation

S2 recorded the lowest mean electrical conductivity (65.13 ± 4.42 μScm^{-1}) whereas the highest (182.27 ± 18.0 μScm^{-1}) was found at S6. There was a general increasing trend in mean electrical conductivity downstream (Fig.4.13).

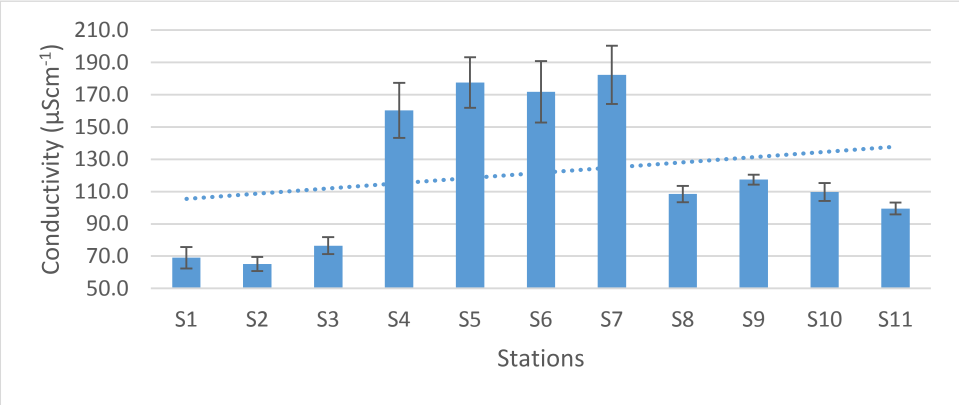

Figure 4.13: Mean Electrical conductivity ± (SE) at different sampling stations

The stations had significant variation as shown by ANOVA, F (10, 178) = 55.51, p = 0.000. S4 was higher by between 57.79 and 109.87, 25.77 and 77.84, 16.90 and 68.98, 24.56 and 76.64, 69.14 and 121.22, 65.21 and 117.28, 34.85 and 86.93 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S6 was higher by between 69.24 and 121.31, 37.22 and 89.22, 28.35 and 80.43,36.01 and 88.08, 80.59 and 132.66, 76.65 and 128.73, 46.30 and 98.38 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S5 was higher by between 75.09 and 127.16, 43.06 and 95.14, 34.20 and 86.27, 41.86 and 93.93, 86.43 and 138.51, 82.50 and 134.57, 52.15 and 104.22 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S7 was higher by between 73.88 and 137.66, 41.85 and 105.63, 32.99 and 96.77, 40.65 and 104.43, 85.23 and 149.00, 81.29 and 145.07, 50.94 and 114.72 than that of S3, S8, S9, S10, S2, S1 and S11 respectively. S3 station was lower by between 5.99 and 58.06, 14.83 and 66.93, 7.19 and 59.27 than that of S8, S9 and S10 respectively. S8 was higher by between 17.33 and 69.41, 13.40 and 65.47 than that of S2 and S1 respectively. S9 was higher by between 26.20 and 78.27, 22.26 and 74.34

than that of S1 and S2 respectively. S10 was higher by between 18.54 and 70.62, 14.61 and 66.68 than that of S2 and S1 respectively. S2 was lower by between 8.25 and 60.32 than that of S11 while S1 was lower by between 4.31 and 56.39 than that of S11.

On a temporal scale, mean electrical conductivity varied from 99.39 ± 11.4 μScm^{-1} in April 2020 to 144.91 ± 17.62 μScm^{-1} in August 2020. There was a general increasing trend in mean electrical conductivity in sampled months (Fig.4.14).

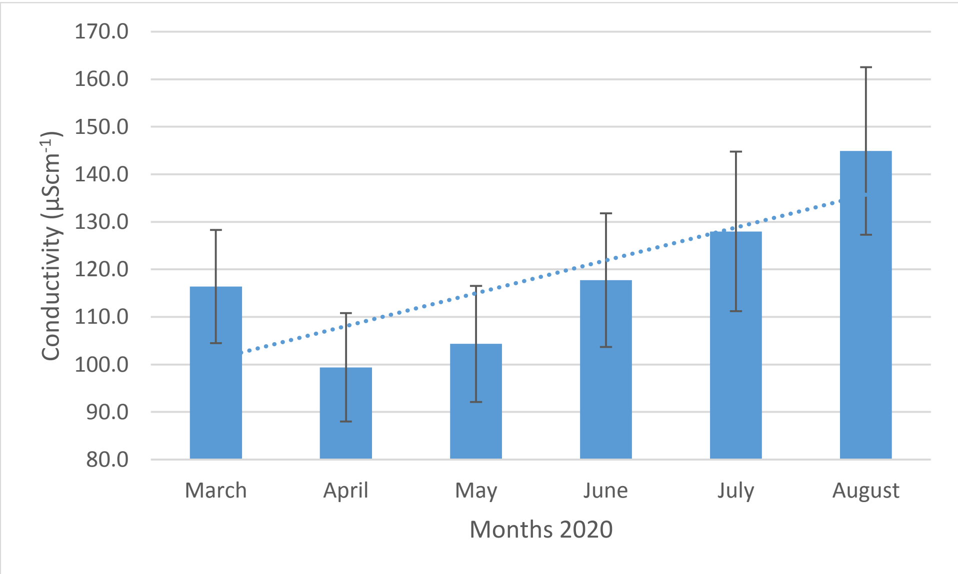

Figure 4.14: Mean Electrical conductivity ± (SE) in different sampling months

ANOVA shown that there was no significant difference between months.

4.3 Habitat quality index variation

The HQI ranged from 12.17 ± 0.307 at S3 to 21.00 ± 0.730 at S1. (4.1).

Table 4.1: Mean HQI ± (SE) values at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S1	18	23	21.00	0.730
S2	11	20	16.83	1.302
S3	11	13	12.17	0.307
S4	13	15	13.83	0.307
S5	12	15	13.83	0.477
S6	10	18	12.50	1.176
S7	16	21	17.83	0.703
Total	10	23	15.43	0.546

The index exhibited a decreasing trend downstream (Table 4.1). ANOVA shown that there was significant variation of habitat quality index between sampled stations, $F (6, 119) = 46.45$, $P = 0.000$. S4 was lower by 1.593 and 6.047, 0.953 and 5.047, 5.286 and 9.381, than that of S7, S2 and S1 respectively. S6 was lower by between 3.286 and 7.381, 2.286 and 6.381, 6.619 and 10.714, than that of S7, S2 and S1 respectively. S5 was lower by between 1.953 and 6.047, 0.953 and 5.047, 3.286 and 9.381, than that of S7, S2 and S1 respectively. S7 station was higher by between 3.619 and 7.714 and lower by between 1.286 and 5.381 than that of S3 and S1 respectively. S3 was lower by between 2.619 and 6.714, 6.953 and 11.047, than that of S2 and S1 respectively. S2 was lower by between 2.286 and 6.381 than that of S1.

Temporally, the mean habitat quality index ranged from 14.143 ± 0.9368 in May 2020 to 17.429 ± 1.5865 in April 2020. (Table 6).

Table 4.2: Mean HQI ± (SE) in different sampling months

Month (2020)	Mean	Minimum	Maximum	Std. Error of Mean
March	16.000	12.0	22.0	1.4310
April	17.429	12.0	23.0	1.5865
May	14.143	11.0	18.0	.9368
June	15.571	10.0	22.0	1.5408
July	14.857	11.0	21.0	1.3875
August	14.571	11.0	20.0	1.1518
Total	15.429	10.0	23.0	.5465

No significant variation was realized between months.

4.4 Fish community characteristics

4.4.1 Fish community structure

A total of 1133 fish specimen were caught, belonging to 10 families constituting of 20 species. Family Cyprinidae had the highest (8) number of species followed by Cichlidae with 4, Mochokidae with 2 species while Alestidae, Mormyridae, Schilbeidae, Bagridae, Anguilidae, Poeciliidae, and Claridae had a single species each. Of the total number of fish species, 16 were tolerant and six intolerant to pollution and adverse environmental condition. 11 fish species were omnivores, 7 carnivores and 2 both herbivores and detrivores. 16 species were native while the rest (4) were exotic (Table 4.3).

Table 4.3: Fish species classification as per the taxa, status, tolerance and trophic guild

Family	Common name	Scientific name	Status	Tolerance level	Trophic guild
Alestidae	Redfin robber	*Brycinus affinis* (Günther, 1894)	Native	Tolerant	Omnivore
Anguillidae	African mottled eel	*A. nebulosa labiata* (Peters, 1852)	Native	Intolerant	Carnivore
Bagridae	Sudan catfish	*Bargrus docmak* (Forskåll, 1775)	Native	Intolerant	Omnivore
Cichlidae	Mozambique tilapia	*O. mossambicus* (Peters, 1852)	Exotic	Tolerant	Omnivore
	Sabaki tilapia	*O. spilurus niger* (Günther, 1894)	Native	Tolerant	Omnivore
	Redbelly tilapia	*Coptodon zilli* (Gervais, 1848)	Exotic	Tolerant	Herbivore
	Redbreast tilapia	*Coptodon rendalii* (Boulenger, 1897)	Exotic	Tolerant	Herbivore
Claridae	Common catfish	*Clarias gariepinus* (Burchell,1822)	Native	Tolerant	Carnivore
Cyprinidae	Gregori's labeo	*Labeo gregorii* (Günther, 1894)	Native	Tolerant	Herbivore
	Zanzibar barb	*Enteromius zanzibaricus* (Peters, 1868)	Exotic	Tolerant	Carnivore
	Straightfin barb	*Enteromius paludinosus* (Peters, 1852)	Native	Tolerant	Omnivore
	Pangani barb	*Labeo oxyrhynchus* (Pfeffer, 1889)	Native	Intolerant	Omnivore
	East-African redfinned barb	*Enteromius apleurogramma* (Boulenger, 1911)	Native	Tolerant	Carnivore
Mochokidae	Redeye labeo	*Labeo cylindricus* (Peters, 1852)	Native	Intolerant	Omnivore
	Common carp	*Cyprinus carpio* (Linnaeus 1758)	Native	Tolerant	Omnivore
	Short barbelled suckermouth	*Chiloglanis brevibarbis* (Boulenger, 1902)	Native	Tolerant	Detrivore
	Tana squeaker	*Synondotis serpentis* (Whitehead, 1962)	Native	Tolerant	Omnivore
Mormyridae	Elephant-snout fish	*Mormyrus kannume* (Forskåll, 1775)	Native	Intolerant	Carnivore
Poeciliidae	Million fish	*Lebistes reticulatus* (Peters, 1859)	Native	Tolerant	Carnivore
Schilbeidae	Silver catfish	*Schilbe intermedius* (Rüpell, 1832)	Native	Tolerant	Omnivore

L. oxyrhynchus was the most dominant fish species with a percentage composition of 21.2% followed by *O. spilurus niger* (19.7%) and *O. mossambicus* (17.4%) in that order. Seven fish species had a percentage composition of more than 3% while the majority (16 species) had a composition of less than 3%. The fish species with the highest percentage of occurrence was *C. gariepinus* with 63.9% followed by *O. spilurus niger* with 58.3%, *C. carpio* with 52.8%, *L. oxyrhynchus* with 52.8%, *O. mossambicus* with 47.2%, *L. gregorii* with 25% and *C. rendalii* with 19.4%. Three fish species occurred thrice, five fish species occurred twice while some other five fish species occurred once (Table 8).

Table 4.4: Percentage occurrence and composition of fish species in River Kathita and the associated constructed dams stretch in the upper Tana basin

Species	*Occurrence*	*% Occurrence*	*Abundance*	*% composition*
Oreochromis mossambicus	17	47.2	197	*17.39*
Oreochromis spilurus	21	58.3	223	19.68
Coptodon zilli	2	5.6	16	1.41
Coptodon rendalii	7	19.4	33	2.91
Labeo gregorii	9	25.0	66	5.83
Enteromius zanzibaricus	2	5.6	38	3.35
Enteromius paludinosus	1	2.8	20	1.77
Labeo oxyrhynchus	19	52.8	271	23.92
Enteromius apleurogramma	1	2.8	3	0.26
Bricynus affinis	2	5.6	9	0.79
Cyprinus carpio	19	52.8	79	6.97
Clarias gariepinus	23	63.9	114	10.1
Lebistes reticulatus	1	2.8	1	0.18
Chiloglanis brevibarbis	3	8.3	10	0.88
Anguila nebulosa labiata	3	8.3	22	1.94
Bargrus docmak	3	8.3	8	0.71
Labeo cylindricus	2	5.6	13	1.15
Schilbe intermedius	1	2.8	1	0.1
Mormyrus kannume	2	5.6	7	0.62
Synodontis serpentis	1	2.8	2	0.2
N			1133	100.00

4.4.2 Spatial and temporal distribution of fish

The spatial distribution of fish in Kathita River and the associated dams stretch in upper Tana basin is presented in table 4.5.

Table 4.5: Distribution of fish species along the sampling stations

Fish species	S5	S7	S8	S9	S10	S11
O. mossambicus	0	0	70	62	62	3
O. spilurus	7	25	56	36	87	12
Coptodon zilli	0	0	0	0	2	14
Coptodon rendalii	0	0	13	0	5	15
Labeo gregorii	2	54	0	10	0	0
E. zanzibaricus	0	0	0	0	0	38
E. paludinosus	0	0	0	0	0	20
Labeo oxyrhynchus	106	154	0	6	4	1
E. apleurogramma	0	0	0	0	0	3
Bricynus affinis	0	9	0	0	0	0
Cyprinus carpio	0	0	28	14	18	19
Clarias gariepinus	0	3	45	26	12	28
Lebistes reticulatus	1	0	0	0	0	0
Chiloglanis brevibarbis	3	7	0	0	0	0
A. nebulosa labiata	22	0	0	0	0	0
Bargrus docmak	0	8	0	0	0	0
Labeo cylindricus	0	13	0	0	0	0
Schilbe intermedius	0	1	0	0	0	0
Mormyrus kannume	0	7	0	0	0	0
Synodontis serpentis	0	2	0	0	0	0
Total	141	283	212	154	190	153

The tilapia species dominated stations S8 to S11 which are the dams. Labeobarbus species dominated the River Kathita as well as *A. nebulosa labiata.* More fish species were found at S7 followed by S11 while S8 had the lowest number of fish species.

The mean number of fish caught per sampling station for all species combined is presented in table 9. S7 had the highest mean fish catch of 46.00 ± 5.961 per hour while S5 had the lowest (23.6 ± 7.306 per hour) (Table 4.6).

Table 4.6: Mean fish abundance ± (SE) in different stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	0	49	23.67	7.306
S7	18	61	46.00	5.961
S8	12	80	35.33	10.022
S9	19	39	25.67	2.871
S10	0	103	32.83	17.850
S11	6	78	25.50	11.348
Total	0	103	31.50	4.131

ANOVA shown that there was no significant variation of fish abundance in different sampling stations hence no spatial trend.

Temporally, the highest mean fish abundance was recorded in April 2020 (38.83 ± 14.242) while the least (21.17 ± 8.179) was recorded in July 2020 (Table 4.7).

Table 4.7: Mean fish abundance ± (SE) in different months

Month (2020)	Minimum	Maximum	Mean	Std. Error of Mean
March	4	78	34.50	12.088
April	6	103	38.83	14.242
May	8	80	38.33	12.167
June	0	49	26.00	8.903
July	0	47	21.17	8.179
August	19	52	30.17	4.881
Total	0	103	31.50	4.131

There was no significant variation in mean fish abundance for the sampled months.

4.4.3 Fish biodiversity indices

4.4.3.1 Spatial trend for mean diversity indices

The mean fish Shannon-Weiner diversity indices are presented in table 4.8.

S5 and S7 had the lowest (0.534 ± 0.171) and highest (1.21 ± 0.27) means for Shannon-Wiener index respectively.

Table 4.8: Mean Shannon-Weiner diversity index ± (SE) at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	0.0000	1.2544	.534369	.1705754
S7	.2270	1.7476	1.211136	.2696213
S8	1.0027	1.4735	1.208067	.0694861
S9	.8387	1.5464	1.196391	.1251001
S10	0.0000	1.2642	.614594	.2749664
S11	0.0000	1.6426	1.026809	.2412083
Total	0.0000	1.7476	.965228	.0916916

The values obtained shows that the abundance constitutes of more than one species since they are not close to zero. The diversity was high at S7 and low at S5.

Analysis of Variance revealed that there was no significant variation among the sampled stations.

The mean fish Simpson diversity indices are presented in table 13.

S5 and S7 had the lowest (0.320 ± 0.93) and highest (0.659 ± 0.269) mean Simpson index, respectively.

Table 4.9: Mean Simpson index at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	0.0000	.6622	.320385	.0929665
S7	.1128	.8148	.580843	.1230758
S8	.5828	.7500	.658637	.0268527
S9	.3884	.7380	.606667	.0583711
S10	0.0000	.6925	.318622	.1432252
S11	0.0000	.7771	.548161	.1156563
Total	0.0000	.8148	.505553	.0446902

The values obtained shown that the stations had a moderate diversity of species.

ANOVA shown that there was no spatial significant difference in sampled stations.

The mean fish evenness diversity index is presented in Table 4.10.

The lowest evenness index (0.390 ± 0.177) was recorded at S10 dam while the highest (0.896 ± 0.52) was recorded at S8 dam.

Table 4.10: Mean evenness index at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	0.0000	.8631	.599210	.1367223
S7	.3274	.9711	.734607	.1067304
S8	.7386	1.0849	.896150	.0515193
S9	.5211	.9023	.759238	.0605554
S10	0.0000	.9119	.390189	.1772491
S11	0.0000	.9980	.729760	.1491808
Total	0.0000	1.0849	.684859	.0534176

The community of species in S8 was perfectly even while that for the other stations was almost perfectly even.

ANOVA shown that the means did not vary significantly on spatial scale for the sampled stations.

The mean fish species richness indices are presented in Table 4.11.

Species richness ranged from 2.17 ± 0.654 at S5 to 5.17 ± 1.046 at S7.

Table 4.11: Mean species richness at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	0	5	2.17	.654
S7	2	8	5.17	1.046
S8	3	5	4.00	.365
S9	4	6	4.83	.307
S10	0	6	3.17	1.046
S11	1	7	4.00	.931
Total	0	8	3.89	.342

S7 had more species compared to other stations. S5 had lowest number of species.

Means did not show any significant variation for the sampled stations.

4.4.3.2 Temporal trend for mean diversity indices

The temporal variation for biodiversity indices is presented in Table 4.12.

March 2020 recorded the lowest mean Shannon-Weiner index (0.767 ± 0.224) whereas the highest (1.202 ± 0.1262) was recorded in August 2020. Mean evenness index was lowest (0.599 ± 0.139) in March 2020 and highest (0.858 ± 0.361) in August 2020. Simpson index ranged from 0.405 ± 0.109 in March 2020 to 0.648 ± 0.503 in August 2020. Mean species richness index varied from 3.00 ± 1.265 in July 2020 to 4.50 ± 0.764 in May 2020.

Table 4.12: Mean values ± (SE) for diversity indices in different sampling months

Month (2020)		richness	SIMPSON	SHANNON	EVENNESS
March 2020	Mean	4.00	.4049	.7671	.5992
	Std. Error of Mean	.730	.109	.2237	.1386
April 2020	Mean	3.67	.4865	.9153	.7157
	Std. Error of Mean	.615	.0932	.1827	.0897
May 2020	Mean	4.50	.5726	1.1374	.6899
	Std. Error of Mean	.764	.1192	.2481	.1418
June 2020	Mean	3.83	.4801	.9292	.6132
	Std. Error of Mean	1.108	.1331	.2702	.1434
July 2020	Mean	3.00	.4409	.8403	.6333
	Std. Error of Mean	1.265	.1443	.3004	.2033
August 2020	Mean	4.33	.6481	1.202	.8576
	Std. Error of Mean	.558	.0503	.1262	.0361
Total	Mean	3.89	.5056	.9652	.6848
	Std. Error of Mean	.342	.0447	.0917	.0534

There was no trend for the above indices. ANOVA also revealed that there was no significant variation between the months.

4.4.4 Fish-based index of biotic integrity (FIBI)

The spatial distribution fish index of biotic integrity in different sampling sites is presented in table 17.

The mean FIBI recorded was lowest at S10 (27.00 ± 1.125) while the highest was at S7 (35.33 ± 2.716) The general mean was 29.89 ± 0.820.

Table 4.13: Mean FIBI ± (SE) at different sampling stations

Station	Minimum	Maximum	Mean	Std. Error of Mean
S5	24	38	30.33	2.603
S7	28	46	35.33	2.716
S8	26	30	28.00	.516
S9	26	32	29.67	.803
S10	24	30	27.00	1.125
S11	24	36	29.00	1.844
Total	24	46	29.89	.820

Significant differences between stations was revealed by ANOVA, F (7.136) = 7.56, P= 0.000. S4 was lower by between 1.798 and 11.535 than that of both S7 and S6. S6 was higher by between 2.132 and 11.868, 0.465 and 10.202, 3.132 and 12.868, 1.132 and 10.868, than that of S8, S9, S10 and S11 respectively. S7 was higher by between 2.132 and 11.868, 0.465 and 10.202, 3.132 and 12.868, 1.132 and 10.868 than that of S8, S9, S10 and S11 respectively.

On temporal scale, the lowest FIBI mean (29.00 ±1.983) was recorded in April 2020 while the highest (31.33 ± 3.412) was recorded in June 2020 (Table 4.14).

Table 4.14: Mean FIBI ±(SE) in different sampling months

Month (2020)	Minimum	Maximum	Mean	Std. Error of Mean
March	24	36	29.67	1.745
April	24	38	29.00	1.983
May	26	34	30.33	1.308
June	24	46	31.33	3.412
July	24	40	29.33	2.404
August	26	34	29.67	1.202
Total	24	46	29.89	.820

Temporally, ANOVA revealed that there was no significant variation.

4.5 Correlation analysis between physical-chemical parameters and fish abundance

Pearson correlation analysis between physical-chemical parameters and fish abundance is presented in Table 4.15. Temperature had a significant negative correlation with TDS, TN and TP. TDS had a significant positive correlation with conductivity and TN but had a significant negative correlation with temperature. Conductivity had a significant positive correlation with temperature, TDS, TN. TN had a significant negative correlation with temperature and a significant positive correlation with TDS and conductivity. TP had a significant negative correlation with temperature.

Table 4.15: Correlation analysis for physical-chemical parameters and fish abundance using Pearson correlation method.

		Temp(◦C)	DO(mgL¯¹)	TDS(mgL¯¹)	Cond(µScm¯¹)	pH	TN(µgL¯¹)	TP(µgL¯¹)	abundance
Temp(◦C)	Pearson Correlation	1	.202	-.343*	-.131	-.240	-.301*	-.358*	.166
	Sig. (2-tailed)		.183	.021	.389	.113	.044	.016	.275
	N	45	45	45	45	45	45	45	45
DO(mgL¯¹)	Pearson Correlation	.202	1	.018	.161	.041	.171	.027	.162
	Sig. (2-tailed)	.183		.908	.292	.788	.263	.860	.289
	N	45	45	45	45	45	45	45	45
TDS(mgL¯¹)	Pearson Correlation	-.343*	.018	1	.958**	-.139	.475**	.193	.064
	Sig. (2-tailed)	.021	.908		.000	.363	.001	.205	.676
	N	45	45	45	45	45	45	45	45
Cond(µScm¯¹)	Pearson Correlation	-.131	.161	.958**	1	-.200	.534**	.070	.091
	Sig. (2-tailed)	.389	.292	.000		.188	.000	.649	.551
	N	45	45	45	45	45	45	45	45
pH	Pearson Correlation	-.240	.041	-.139	-.200	1	.075	.214	-.108
	Sig. (2-tailed)	.113	.788	.363	.188		.626	.158	.478
	N	45	45	45	45	45	45	45	45
TN(µgL¯¹)	Pearson Correlation	-.301*	.171	.475**	.534**	.075	1	-.090	-.185

	Sig. (2-tailed)	.044	.263	.001	.000	.626		.555	.223
	N	45	45	45	45	45	45	45	45
TP(μgL^{-1})	Pearson Correlation	-.358*	.027	.193	.070	.214	-.090	1	.084
	Sig. (2-tailed)	.016	.860	.205	.649	.158	.555		.581
	N	45	45	45	45	45	45	45	45
abundance	Pearson Correlation	.166	.162	.064	.091	-.108	-.185	.084	1
	Sig. (2-tailed)	.275	.289	.676	.551	.478	.223	.581	
	N	45	45	45	45	45	45	45	45

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

**. Correlation is significant at the 0.01 level (2-tailed).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

This chapter presents discussion on physical-chemical parameters, habitat quality characteristics, fish community structure, fish biodiversity indices and fish based index of biotic integrity.

5.2 Physical-chemical parameters

One of the crucial factors that influences physiological activity of organisms is the water temperature. Stream morphology, soil hydrology, riparian vegetation, climate and human activities are known to influence water temperature (Independent Multidisciplinary Science Team, 2000). In this study, S1 recorded the lowest mean temperature. This could be the case because the station was in the upper most part of the river which is very close to its source - Mt. Kenya. Water at this point mostly results from the melting ice hence having very low temperatures. The area is also highly forested, a condition which can also result into low temperatures. The significant changes of water temperature among the stations could be due to various activities adjacent to each sampling point, time of sampling and altitude. Stations in low altitude areas had high temperatures compared to those in high altitude areas. According to Independent Multidisciplinary Science Team 2000, activities like change of land use, urbanization and discharge of heated effluents have been reported to change the water temperatures. Agriculture and establishment of urban centers leads to removal of riparian vegetation thereby exposing the rivers' surface to the sun leading to increased water temperatures in the river.

Agricultural activities, clearing of vegetation and discharge of heated effluents in Meru town and municipal wastes from Marimanti town probably increased water temperatures downstream. S6 recorded the highest temperatures. In this area, the width of the river channel was big, water speed was low and water depth low. This could have resulted to the high temperatures recorded due to increased residence time of flow. In addition, the semi-arid conditions of the area could also contribute to high temperatures. The slight drop in water temperature at station S7 could have been caused by the mixing of the water from the two rivers with different temperatures. Water temperature influences the abundance, occurrence and migration trend of aquatic animals. Chaurasia & Tiwari, (2012) reported that if temperatures rise beyond or falls much below the optimum (20-29 °C) for tropical fish species, then it leads to fish deaths.

There were also significance differences in DO concentration amongst sampling sites. Low concentrations at S6 and S7 can be attributed to effluents from Marimanti town and increased temperatures. S4 and S5 having low DO concentrations could be due to effluents from factories, decomposition of organic substances and nutrients from agricultural activities, sewage and industries from Meru town, and high temperatures in the region. It has been reported that effluents from factories cause a reduction in dissolved oxygen concentration (Turinayo, 2013; Chaurasia & Tiwari, 2011) and Sultana et al., 2017). Rabalais, (2002); Zaimes, (2002); Sahu & Chaudhari, (2015) had associated reduced dissolved oxygen in water bodies to decomposition of organic substances and nutrients. Consequently, low dissolved oxygen in the last four stations was probably due to increased water temperatures, degraded water quality or accumulation of nutrients and pollutants. Temporally, DO generally had a decreasing trend except for the month of August. Consecutive decrease in rainfall from wet season (March-May) to dry season (June to August can be attribute to the decreased DO by decreasing the diffusion rate of oxygen in water and increased the water temperature. There are no agricultural activities in the month of August since it is a dry period. This could have resulted to the slight increase in DO due to decreased organic substances and nutrients in water. Nonetheless, the river's mean DO range (7.27 mgL^{-1} – 9.2 mgL^{-1}) was at a level that is not injurious to water life (Chapman, 1966).

Total dissolved solids and electrical conductivity were highest at S7, S5 and S4. Accumulation of wastes matter from agricultural activities especially along the river course, high water temperatures, low flow of the river as well as urban runoff could have caused the high amounts. Priti and Khan (2011) shown that wastes and pollutants comes from the urban centers and agricultural land. Bayram, Onsoy, Bulut and Akichi (2013) has also reported high TDS where water temperatures are high and low flow of the river. In this study, TDS and electrical conductivity were probably changed by prohibited discharge sewer lines, industries and fertilizer utilization. Wastes matter illegally disposed into the river from Marimanti town probably contributed to high values of TDS and electrical conductivity downstream.

The mean pH levels were generally oscillating near neutral and within a range that favours aquatic life (6.5 – 9.0) and safe for drinking (6.5 – 8.5) (Sharma, Bora & Shukla, 2013; WHO, 2017). The changes in pH could be due to agricultural chemicals, industrial effluents discharge and rain water. According to Kumar (2014), presence of alkaline and acidic chemicals used in the manufacturing process have been shown to cause alterations in the pH of water. Studies in India (Yadav, Jyoti & Renu, 2014), Uganda (Turinayo, 2013) and Kenya (Akali, Nyongesa, Neyole & Miima 2011) have reported the above observation. There are many industries along River Kathita especially around Meru region. Such include: Tea factories (Githongo tea factory, Kiegoi tea factory, Njeru industries limited) and use of agricultural chemicals that discharge basic effluents into the river at Meru and Marimanti towns could have resulted to the elevated pH at S1, S4 and S7. For the dams, increased pH levels could be attributed by effluents discharges from nearby town like Embu, Kivaa market and agricultural farms especially around

S11 and S10. Rainy months experienced reduced pH levels compared to dry months. Since rain water is moderately acidic, it could therefore attribute to the reduced pH levels. Once they were introduced into the river, they lower the pH levels. Equally, Kanda, Nyamadzawo and Gatosa (2015) found that rains can lead to pollution from molasses which were acidic in nature. Therefore, the study demonstrated that the river did not have extreme changes that can exert stress or detrimental to aquatic life.

The levels of TN and TP were generally average in all the sampled stations. The two middle stations (S4 and S5) recorded the highest levels as compared to other stations. More agricultural activities in these areas involving the use of agricultural chemicals could attribute to the high levels has reported by Orina et al., (2018). Upstream stations (S1 and S2) were well forested hence macrophytes had the potential to absorb these nutrients. This explains why these stations recorded low values. Surface runoff from urban areas and industrial discharge can also cause increased nutrient loading and other contaminants within rivers as it has been previously reported (Kanda et al. 2015; Orina et al. 2018) in different ecosystems. Manure or organic wastes (Isa, 2015) can also cause excess nitrogen concentration. In this river, TN was much elevated than phosphorus concentration and this similar observation was made by Withers, Neal, Jarvie & Doody (2014) explaining that high TN is recorded where rivers drain from agricultural areas. Temporally, the rainy season had high nutrient concentration than dry months. This can be due to increased nutrient loading. Similar results have been reported in Pampean (Carlos, Alijandra, Carlos & Alicia, 2007) and Samborombón Bay (Schenone, Volpedo, Fernández & Cirelli, 2007).

5.3 Habitat quality characteristics

According to the calculated HQI in this study, six out of seven stations were graded as below good. The change of physical nature of riverine ecosystem could have attributed to the observed significant variation. Raven et al., (1998) reported that the change of nature within a catchment and between catchment can be enhanced by agriculture, roads, urbanization and mining among others. Stations like S4, S5 and S6 had low integrity indices due to agricultural activities, water abstraction and livestock watering. There was minimal riparian vegetation and missing in some stations hence impacted on the river's habitat hence it can be responsible for the significant changes in physical-chemical parameters among sampling sites. Vegetation helps in reducing speed of wind, enhance bank stability and accumulation of organic matter in the river. This reduced downstream leading to the erosion of banks, substrate covered with sediments and changing of the river channel and hence promoting impairment of the river's habitat (USEPA, 2000). Studies by (Raburu & Masese, 2010; M'Erimba et al., (2014) reported similar results in rivers Nzoia, Sondu-Miriu, Nyando and streams in Mount Kenya region respectively.

The significant spatial variation of HQI downstream was majorly due to the above described anthropogenic activities along the river. ANOVA analysis of HQI categorized Stations like S5, S7, S3 and S4 in the same group due to the fact that agriculture was the main man activity around the sampling site. In this study, the research findings were similar to that from other studies that have been conducted in Kenyan rivers - Kuja, Nzoia, Sondu-Miriu, and Nyando and other streams elsewhere. For comparison purposes with others results obtained from similar studies, the HQI values were converted to percentages. Results for this study were within the same range as for those from other studies that have been conducted elsewhere (Table 5.1).

Table 5.1: Comparison of HQI in this study and that of other streams

Author	Habitat	Range(%)	Comments
This study	River Kathita	32.26 – 74.2	From severely degraded to partially degraded.
Orina et al., 2018	River Kuja (Kegati to River mouth as from November 2016 to August 2017)	35.5 – 77.4	From severely degraded to partially degraded.
Raburu and Masese 2010	Lake Victoria basin (R. Nzoia, Nyando and Sondu-Miriu in Feb, March and July 2004)	22 – 60.5	From severely degraded to degraded.
Biohabitat And Century Engineering, 2016	Anne Arundel county (Magothy, Seven and Salamanders – 2015	61.31 – 98.01	From degraded to minimally degraded sites.
Paul et al., 2003	Maryland wadable streams (piedmont class, coastal plain and Highland class from 1994 – 2000)	15.43 – 99.35	From severely degraded to minimally degraded sites.
Diana, Allan and Diana, 2006	Southern Michigan (Huron and Raisin basin from 1999 –2000)	33.3 – 79.3	From severely degraded to partially degraded.

Temporally, the index was relatively stable over the sampled months. Nevertheless, there was a slight increase of the index in the first three months and attributed to the growth of autotrophs (uses light energy to manufacture food) since the months were characterized with rains. Consequently, the index was stable over a short period of time. Nevertheless, the most disturbed sites were easily observed and measured. Johnson et al., (2001) and Roper et al., (2002) also affirmed that short time sampling revealed a stable integrity index.

5.4 Fish based parameters

5.4.1 Fish community structure

The results revealed that the river and the associated dams waterfronts a number of fish species. S1, S2, and S3 had no fish caught. This was ascribed to extreme cold temperatures (10°C - 14°C) experienced in the area and poor habitat conditions respectively especially at S3. The poor conditions were caused by fast running waters, cold temperatures due to cold water originating from melting ice from the nearby peak of Mt. Kenya, water abstraction and degraded river banks. Low temperatures between (10°C to 12°C) have been reported to influence fish distribution and abundance in a study by Todd & Joseph, (2003) in Tomales bay, California.

The abundance and occurrence of fish species was high downstream than midstream and upstream. A study by Orina et al., (2018) in River Kuja found that the fish species abundance and occurrence was high midstream than upstream and downstream. The difference with this study either could be due to the fact that the last station in River Kathita was its confluence with River Tana hence providing a better environment for fish in terms of food availability, breeding grounds and favorable temperatures. River Kathita was characterized with high abundance of native fish species and some exotic species only occurring at its confluence with River Tana. The associated dams of River Tana had most of the exotic species. According to the findings of this study, fish community structure changed downstream which could possibly be due to the changes in food availability, availability of good habitats for breeding and substrate structure. USEPA, (2016) reported that Changes in water and habitat quality promote the loss of sensitive species while the tolerant and invasive species tend to dominate hence explaining why the alien fish species tend to occur and dominate downstream as compared to midstream and upstream.

Temporally, some fish species: *E. paludinosus, E. apleurograma, L. reticulatus*, *C. zilli*, and *C. brevibarbis* occurred only during rainy season most of which are migratory fish. Griffin & Ojeda, (1992); Paller et al., (2013) reported that fish migrate to spawning during rainy season resulting to an increased biodiversity.

5.4.2 Fish biodiversity indices

Fish diversity is helpful in explaining the environmental health condition of the river and some features of particular fish species such as habitat preference and resistance to environment specific stress. Bibi & Ali, (2013) reported that species richness and composition are vital parameters for ecosystem stability and function. River Kathita and associated dams have diverse communities of fish. Simpson, evenness, and Shannon-Weiner diversity indices shown that the diversity was found to be higher downstream as compared to upstream. Even though the upstream areas have low species diversity indices, it is still a vital ecosystem niche for some riverine fauna communities. Agricultural activities, eroded banks and open access to livestock have been connected to lower diversity indices. Such activities were evidenced at S5, S7, S11 and S10. Both livestock and crop farming could lead to fecal deposition, urine and trampling of sediments which have been reported by Orina et al., 2018 to directly affect the quality of rivers and hence fish diversity. Species richness was higher downstream than midstream and upstream. This was probably contributed by presence of a stable and a more functional habitat created after the confluence between the two rivers. This area was also a breeding ground for many fish species hence increasing the species richness than in midstream and upstream.

The results also demonstrated that the river and the associated dams waterfronts some sensitive fish species (*C. carpio* and *O. mossambicus*) which have been listed in the IUCN red list (IUCN Red List Version, 2020-2, Froese and Pauly 2021). The presence of these species within the rivers shows that under proper management, respective habitats in the river can be conserved and act as a refugia for vulnerable fish species.

Temporally, results for fish diversity indices revealed a general increasing trend except for species richness. Changing seasons did not have a greater impact on fish diversity in River Kathita and the associated dams since there was no significant variation between months. However, abundance of fish caught was high during the wet months (March 2020 to August 2020), which was probably due to increased DO concentration and existence of migratory species during those months for breeding purposes upstream. Generally, the results suggested that urban land use, agricultural activities and industries had a large effect on fish biota in River Kathita and the associated dams.

5.4.3 Fish-based index of biotic integrity

The integrity of the habitat surrounding all the six stations sampled for fish was below good as shown by the fish-based index of biotic integrity. Two of these stations are in River Kathita and have been rated as poor habitats using HQI. As land use practices increased, the FIBI decreased. This was revealed in the habitats at S5 and S10 dam which had the lowest FIBI in their categories. Raburu and Masese (2010) studies for rivers Nyando, Sondu-Miriu and Nzoia within Lake Victoria basin revealed that land use activities influence the integrity of rivers and the lake at large. Factors identified to be responsible for lowering the river's integrity are: Intense urbanization, high population densities, mining, and agricultural activities. The indices for this study were within the same range as other related studies. This was probably because of similar activities carried out in these ecosystems. The table below (Table 5.2) presents comparative research studies within a converted range of a scale 0 to 5.

Table 5.2: Comparison of FIBI in this study and that of other rivers and streams

AUTHOR	FIBI area research	RANGE (0-5)	COMMENTS
This study	River Kathita (from the catchment to the confluence with R. Tana) and associated dams as from March 2020 to August 2020.	2 – 3.8	Very poor to fair
Orina et al.,2018	River Kuja (Kegati – river mouth as from November 2016 t0 August 2017).	1.7 – 4.5	Very poor to good.
Biohabitat and Century Engineering, 2016	Anne Arundel county (Magothy, Sevem and salamanders – 2015)	1.67 – 3.67	Very poor to fair
Raburu and Masese, 2010	Lake Victoria basin (R. Nzoia, Nyando and Sondu-Miriu – Feb, March and July 2004)	1.7 – 4.6	Very poor to good.
Diana et al., 2006	Southern Michigan (Huron and Raisin basin from 1999 – 2000)	0.25 – 3.85	Very poor to fair
Paul et al., 2003	Maryland wadable streams (piedmont class, Coastal plain and Highland class from 1994 – 2000)	1.00 – 5.00	Very poor to good

Few studies have been carried out on development of habitat quality and fish based assessment tools in Lake Victoria basin and in Kenya. For formulation of regulations that can be used to reestablish and conserve degraded ecosystem, data on habitat integrity is essential. River's ecological integrity need to be maintained and restored for it to be beneficial in supplying sufficient resources. According to Sara & Kagan (2014); UNEP, (2016), pristine aquatic ecosystem provides sustainable intrinsic values and benefit to human communities. Korsgaard (2006) reported that anthropogenic activities impact the biological condition within rivers by changing flow regime, water quality, physical habitat structure and interactions among species (USEPA, 2016). Natural vegetation and soil conditions have also been reported to be altered (Mutie, Mate, Home, Gawain & Gathenya, 2006; Stolhlgren, 2008). This consequently leads to increased water temperature, erosion, siltation and general habitat degradation (Mbaka, 2010) and (Stevens & Council, 2008) respectively. This disrupt fish biota negatively because of lowered water quality (Okungu & Opango, 2005; Wetland Consulting Service Ltd, 2014), use of prohibited gears and overfishing (Cadwalladr, 1965; Ogutu-Ohwayo, 1990; Mboya et al. 2005; Njiru et al. 2006; Njiru, Kazungu, Ngugi, Gichuki, & Muhoozi, 2008). Raburu, Masese & Mulanda, (2009) found that through modification, the condition of habitat is depurated. Such findings were seen at the sampled dams of River Tana where some species were only present in certain dams and absent in others. Some of the fish species in S11 (Masinga) were absent in other dams downstream. This probably was caused by obstruction of migratory fish species reducing fish diversity and abundance downstream. Equally, earlier studies ((LVEMP, 1999; Baliriwa et al., 2003; Aloo, Ojwang, Omondi, Njiru & Oyugi, 2013) reported that introduced biota in Lake Victoria basin caused a serious ecological and economic loss. Miller and Williams, (1989) also reported that introduction of non-native fish species contributes to extinction. This means the rivers' biota is also at stake due to presence of introduced fish species like *Clarias gariepinus* and many human activities that affect the rivers condition.

The information presented in this thesis form a basis for tracking changes in ecosystem integrity of River Kathita and the associated dams. It therefore makes it possible to institute necessary conservation measures for restoration, conservation and management

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter contains conclusions for the study and recommendations.

6.2 Conclusions

Assessment of the habitat quality of River Kathita based on HQI shows that it ranged from poor to good and its degradation decreased downstream up to and including dams associated area while the habitat integrity of the associated dams area as demonstrated by fish indices of biotic integrity was found to be 'below good'. Almost all fish caught in R. Kathita were native while those in dams were exotic. Examples of native species were *L. oxhyrinchus, L. cylindricus, A. nebulosa labiata* and *L. gregorii* while examples of introduced species are *C. gariepinus, C. rendalii* and *C. zilii*. The biodiversity of fish species in upper Tana were high as indicated by the biodiversity indices. There was enrichment of the surface water sources in R. Kathita and dams area with phosphates and nitrates, an undesirable situation which leads to eutrophication. This was due to leaching of fertilizers within the upper Tana River basin. Physical-chemical parameters did not influence abundance of fish in the study area.

6.3 Recommendations

There are very few studies that have been carried out in Mt. Kenya region though it is rich in aquatic ecosystems rich in biodiversity of various species. I therefore recommend more studies to be carried out since a single or short term study cannot provide enough data that can help to relate the fish structure dynamics and river changes system. Activities that can improve and maintain integrity of rivers such as afforestation and reforestation need to be adopted to promote sustainability of river resources.

REFERENCES

Ahmad, L., Saeed, K., Khan, S., & Akhtar, N. (2014). Icthyofaunal Diversity of River Panjkora Upper Dir Khyber Pakhtunkhwa Pakistan. *The Journal of Zoology Studies, 1*(6):27-32.

Akali, N., Nyongesa, N., Neyole, E., & Miima, J. (2011). Effluent discharge by Mumias Sugar Company in Kenya: an empirical investigation of the pollution of River Nzoia. Sacha. *Journal of Environmental Studies, 1*(1), 1-30.

Alam, J. B., Islam, M. R., Muyen, Z., Mamun, M., & Islam, S. (2007). Water quality parameters along rivers. *Int. J. Environ. Sci. Tech., 4* (1), 159-167.

Aloo, P., Ojwang, W., Omondi, R., Njiru, J., & Oyugi, D. (2013). A review of the impacts of invasive aquatic weeds on the biodiversity of some tropical water bodies with special reference to Lake Victoria (Kenya). *Biodiversity Journal, 4*(4), 471-482.

American Rivers. (2003). Defending the Clean Water Act: Resources, web site: http://www.amrivers.org/waterquality/streammiles.htmhttp://www.amrivers.org/waterquality/streammiles.htm on 23rd October 2020.

APHA. (2014). Standard methods for the examination of water and wastewater (21st ed.), American Public Health Association, Washington DC, American Water Works., p. 1325.

Aura, M. C. (2008). *Macroinvertabrate Index of Biotic Integrity for assessing the water quality of Rivers Kipkaren and Sociani, Nzoia River Basin, Kenya*. Kenya Msc. Thesis Moi University.

Aura, R., Mulanda, C., Kimani, E., Musa, S., Kundu, R., & Njiru, J. M. (2017). Ecohydrology & Hydrobiology Spatio-temporal macroinvertebrate multi-index of biotic integrity (MMiBI) for a coastal river basin : a case study of. *Integrative Medicine Research*, *17*(2), 113–124. https://doi.org/10.1016/j.ecohyd.2016.10.001

Bain, M. B., Hughes, T. C., & Arend K. K. (1999). Trends in methods for assessing freshwater habitats. *Fisheries, 24*(4), 6-21.

Baird, S. F. and C. F. Girard, (1853). Descriptions of new species of fishes collected by Mr. John H. Clark, on the U. S. and Mexican Boundary Survey, under Lt. Col. Jas. D. Graham. Proceedings of the Academy of Natural Sciences of Philadelphia v. 6: 387 390.

Balirwa, J. S., Chapman, C. A., Chapman, L. J., Cowx, I. G., Geheb, K., Kaufman, L … Witte, F. (2003). Biodiversity and fishery sustainability in the Lake Victoria basin: An unexpected marriage? *Bioscience, 53*, 703–715.

Barbour, M. T. & Stribling, J. B. (1994). A technique for assessing the stream habitat structure. Pg 156 - 178 in Proc. of riparian ecosystem of the humid US: Function, values and management. National Association of Conservation Districts, Washington, D.C. March 15-18, 1993, Atlanta, Georgia.

Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). *Rapid Bioassessment Protocols for use in wadeable streams and rivers. Periphyton, benthic macroinvertebrates and fish* (2nd ed.). EPA 841- B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. Retrieved from http://www.epa.gov/owow/monitoring/rbp/download.html on 3rd February 2021.

Bayram, A., Onsoy, H., Bulut, V. N., & Akinci, G. (2013). Influences of urban waters on the stream water quality: A case study from Gumushane Province, Turkey. *Environmental Monitoring and Assessment, 185*:1285-1303.

Bibi, F., & Ali, Z. (2013). Measurement of diversity indices of avian communities at Taunsa Barrage Wildlife Sanctuary, Pakistan. *The Journal of Animal & Plant Science, 23*(2), 469-474.

Biggs, B. J. F., Francoeur, S. N., Huryn, A. D., Young R., Arbuckle, C. J., & Townsend, C. R. (2000). Trophic cascades in streams: effects of nutrient enrichment on autotrophic and consumer benthic communities under two different fish predation regimes. *Canadian Journal of Fisheries and Aquatic Sciences, 57*, 1380–1394.

Binns, N. A., & Eiserman, F. M. (1979). Quantification fluvial trout habitat in Wyoming.

Transactions of the American Fisheries Society, 108, 215–228.

Biohabitat and Century Engineering Inc. (2016). Biological condition summary 2016 spring and summer indices periods. Targeted watershed sites Anne Arundel County, Maryland. Association/Water Environment Federation.

Bonareri, S.P. (2017). Effects of Human Activities on Water Quality of Rupingazi River, Embu County, Kenya. Msc. Thesis. Kenyatta University.

Brabec, K., & Szoszkiewicz, K. (2006). Macrophytes and diatoms — major results and conclusions from the STAR project. *Hydrobiologia, 566*, 175–178.

Breine, J., Simoens, I., Goethals, P., Quataert, P., Ercken, D., Liefferinghe, C. V., & Belpaire1, C. (2004). A fish-based index of biotic integrity for upstream brooks in Flanders (Belgium). *Hydrobiologia, 522*, 133–148.

Breine, J., Ergo, M. B., & Bergh, E. Van Den. (2018). A technical guide to develop a statistically valid fish-based index in compliance with the water framework directive : an evaluation for Turkish freshwaters, 303–319. https://doi.org/10.1007/s40071-018-0209-2

Burchell, W. J. (1822). Travels in the interior of southern Africa. 2 vols. London. v. 1: i-xi + 1-582 + 1-4, 1 Map.; v. 2: 1-648. [Fishes in v. 1: 280, 284, 425, 445.]

Cadwallard, A. (1965). The decline of *Labeo victorianus* (Boulenger), (Pisces: Cyprinadae) fishery of Lake victoria and associated deterioration in some indigenous fishing methods in the Nzoia river, Kenya. *East African Agriculture and Forestry Journal, 30,* 249-256.

Campbell, K., C. Coe, and M. Saunders, (1980). A survey of the Tana River at Kora and a checklist of the fishes of Tana River, In C. Coe and M. Collins (eds.), Kora research Project.

Clay, C. N., (1984). New Reservoirs in Africa 1980-2000, CIFA Occas. Pap. No. 11: 23p, FAO, Rome-Italy.

Carlos, M., Aljandra, V. V., Carlos, O., & Alicia, C. (2007). Water quality index as an tool for river assessment in agricultural area in the Pampean plains of Argentina. *Journal of Urban and Environmental Engineering, 1*(1), 18–22.

Chapman, D., (1996). *Water Quality Assessments: A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*. Second Edition. UNESCO/WHO/UNEP. University Press, Cambridge. 626p

Chaurasia, N. K., & Tiwari, R. K. (2011). Effect of industrial effluents and waste on physicochemical parameters of River Rapati. *Advances in Applied Science Research, 2*(5), 207-211.

Chaurasia, N. K., & Tiwari, R. K. (2012). Physico-chemical characteristics of sugar factory and distillery effluents. *Annals of Biological Research*, *3*(9), 4406-4408.

Clayton, J., & Edwards, T. (2006). Aquatic plants as environmental indicators of ecological condition in New Zealand lakes. *Hydrobiologia, 570*, 147–151.

Copley, H. (1941) A short account of the freshwater fishes of Kenya. *Journal of East Africa Natural History and Society*, 16, No. 1(70), pp. 1-24

Daily, G. C., Susan, A., Paul R. E., Larry G., Jane L., Pamela A. M., … Woodwell, G. M. (1997). Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. *Issues in Ecology 2.* Springs.

De Vos, L. D. G. (2001). *Synodontis manni* (Teleostei: Mochokidae), a new catfish from the Lower Tana River, Kenya. Ichthyological Exploration of Freshwaters v. 12 (no. 1): 41-50.

Dubois, (1981). The whooing earth. EPA Journal.

Orina, O. N., Albert, G., Reuben, O., & Emmy, S. (2018). Ecosystem integrity of River Kuja based on habitat and fish biotic indices. *Journal of Tropical Hydrobiology and Fisheries. 01*(1), 7–13. Fausch, K. D., J. Lyons, P. L. Angermeier, and J. R. Karr. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium 8:123-144.

Fausch, K. D., J. R. Karr, and P. R. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. Transactions American Fisheries Society 113:39-55.

Froese, R. and D. Pauly. Editors. (2021). Fishbase. World wide Web electronic publication. www.fishbase.org, version (06/2021).

Fundamentals of environmental measurement (2016). pH of water. Retrieved from https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ on 26/11/2018.

Graham, M. (1929). *The Victoria Nyanza and its fisheries. A report on the fishing surveys of Lake Victoria (1927-28*). London, Crown Agents Colonies.

Greenwood, P. H., (1974). The cichlid fishes of Lake Victoria, East Africa: The biology and evolution of a species flock. *Bulletin of the British Museum of Natural History (Zoology), 6*, 1–134.

Griffin, J. E., & Ojeda, S. R. (1992). *Textbook of endocrine physiology* (2nd ed.). New York, Oxford University Press.

Haines-Young, R., & Chopping, N. (1996). Quantifying landscape structure: a review of landscape indices and their application to forested landscape. *Progress in Physical Geography, 20*(4), 418-445.

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

Hering, D., Johnson, R. K., Kramm, S., Schmutz, S., Szoszkiewicz, K., & Verdonschot, P. F. M. (2006). Assessment of European streams with diatoms, macrophytes, macroinvertebrates and fish: a comparative metric-based analysis of organism response to stress. *Freshwater Biology 51*, 1757–1785.

Hopkins, T.E., Cech, J.J. The Influence of Environmental Variables on the Distribution and Abundance of Three Elasmobranchs in Tomales Bay, California. *Environmental Biology of Fishes* 66**,** 279–291 (2003). https://doi.org/10.1023/A:1023907121605

Hugueny, B., Camara, S., Samaura, B. A., & Magassouba, M. (1996). Applying an index of biotic integrity based on fish communities in a West African River. *Hydrobiologia 331*, 71-78.

Hunting ER, de Jong S, Vijver MG (2017). Assessment of monitoring tools and strategies safeguarding aquatic ecosystems within the European water framework directive. CML-rapport 192. Leiden University, Institute of Environmental Sciences, Conservation Biology, Leiden.

Independent Multidisciplinary Science Team. (2000). Influences of human activity on stream temperatures and existence of cold-water fish in streams with elevated temperature. Report of a Workshop: Technical Report 2000-2 on the Oregon Plan for Salmon and

Watersheds. Oregon: Oregon Watershed Enhancement Board, Salem. pp 2-18.

Isa, Z. (2015). Assessment of spatial and temporal distribution of some physiochemical parameters of ground water quality of Birnin Gwari, North West of Nigeria. *International Journal of Technology Enhancements and Emerging Engineering Research, 3*, (10), 4352.

Jumbe, J. J., (1997). The status of the Tana River dam fisheries twenty years after dam construction, In K. Remane. African Inland Fisheries, Aquaculture and the environment, Fishing News Books, pp.175-384.

IUCN, (2020). The IUCN Red List of Threatened Species. Version 2020-2.

Johnson, D. H., Pimman, N., Wilder, E., Silver, J. A., Plotnikoff, R. W., Mason, B. C. … Barreti, C. (2001). *Inventory and monitoring of Salmon habitat in the Pacific Northwest: directory and synthesis of protocols for management/ research and volunteers in Washington, Oregon, Idaho, Montana and British Columbia*. Washington department of fish and Wildlife, Oympia, Wa. 212 pp.

Kamadi, J. (2019). Tana River basin under threat. Retrieved from https://scienceafrica.co.ke/development-tana-river-basin-under-threat/ on 22/07/2021.

Kanda, A., Nyamadzawo, G., & Gotosa1, J. (2015). Characterisation of Distillery Molasses Stillage and Assessment of Water Quality of a River Running through a Sugar Cane Plantation in Southern Zimbabwe. *Journal of Scientific Research & Reports, 6*(1), 1-12.

Karani, P. W. (2005). Status of water quality monitoring in the Kenyan portion of Lake Victoria Basin. Nile Basin Initiative and Nile Trans-boundary Environmental Action Project, 2005. Nile Basin National, Water Quality Monitoring Baseline Study Report for Kenia *(PDF) LIMNOLOGY OF THE RIVER NILE*. Available from: https://www.researchgate.net/publication/268015997_LIMNOLOGY_OF_THE_RIER_NILE [accessed Aug 09 2018].

Karr, J. R. (1981). Assessment of biotic integrity using fish communities. Fisheries **6**(6):21-27.

Karr, J. R., Fausch, K. D., Angermeier, P. L., Yant, P. R., & Schlosser, I. J. (1986). Assessing Biological Integrity in Running Waters: A Method and Its Rationale. *Illinois Natural History Survey Special Publication 5*. Champaign, Illinois.

Karr, J. R., & Chu E. W. (1999). Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington D.C.

Kathumo, V. M., Gachene, C. K. K., Gicheru, P. T., & Kariuki, P. C. (2012). Effect of land Use and climate change on hydrological processes in the River Kuja catchment Kenya. *East African Agriculture and Forestry Journal, 78*(1), 23-31.

Kaufmann, P. R., & Robison. E. G. (1998). Physical Habitat Characterization, Section 7. In J. M. Lazorchak et al. (eds). EMAP- *Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Wadeable Streams*. Washington, D.C, USEPA, EPA/620/R-94/004F.

Kaufmann, P. R., P. Levine, Robison, E. G., Seeliger, C., & Peck. D. V. (1999). *Quantifying Physical Habitat in Streams*. Washington, D.C, USEPA, EPA/620/R-99/003.

Kibaara, D. (1981). Endangered fish species of Kenya's inland waters with emphasis on *Labeo spp.* Proceedings of the workshop of the Kenya Marine and Fisheries Institute July 13-19, 1981.

Kiernan, D. (2021). *Natural Resources Biometrics.* Suny college of environmental science and forestry. Retrieved from https://LibreTexts.org on 06/07/2021.

Kleynhans, R. (1997). Genetic variation in *Lachenalia bulbifera*. S. A, Msc Thesis, University of the Orange free States.

Kleynhans, C. J., & Louw, M. D. (2008). River reach demarcation, delineation and suitability. In:Department of Water Affairs and Forestry 2008. *Comprehensive Reserve Determination study for selected water resources (rivers, groundwater and wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Resource Unit Delineation*. Report No. 26/8/3/10/12/006. Pretoria, Department of Water Affairs and Forestry.

Kondolf, G. M. (2000). Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals. *Restoration Ecology, 8*(1), 48-56.

Korsgaard, L. (2006). Environmental flows in integrated water resources management: linking flows, service and values. Denmark, PhD thesis, institute of environment and resources, Technical University of Denmark. Pp 1-40.

Krebs, C.J. (1999) Ecological Methodology. 2nd Edition, Benjamin Cummings, Menlo Park, pp 620.

Kumar, S. T., Charan, G. B., & Kumar, S.S. (2013). Review of the research on the Fish Diversity in the River Mahanadi and Identifying the Probable Potential Ornamental fishes among them with reference to Threats and Conservation Measures. *Research Journal of Animal, Veterinary and Fishery Sciences, 1*(3), 16-24.

Kumar, V. (2014). Sugar mill effluent utilization in the cultivation of maize (*Zea mays l*) in two seasons. *Journal of Waste Management, 2014*, 1-12.

Kwak, T. J., & Freeman, M. C. (2010). Assessment and management of ecological. In W. A. Hubert & M. C. Quist (Eds), *Inland fisheries management in North America, integrity* (3rd ed. pp. 353–394). Maryland , American Fisheries Society, Bethesda.

Li, L., Zheng, B., & Liu, L. (2010). Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. *Procedia, 2*, 1510- 1524.

Li, P., Zhang, Y., Lu, W., Zhao, M., & Zhu, M. (2021). Identification of Priority Conservation Areas for Protected Rivers Based on Ecosystem Integrity and Authenticity : A Case Study of the Qingzhu River , Southwest China.

Linnaeus, C. (1758). Systema Naturae, Ed. X. (Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Tomus I. Editio decima, reformata.) Holmiae. v. 1: i-ii + 1-824 [Nantes and Pisces in Tom. 1, pp. 230-338; a few species on later pages. Date fixed by ICZN, Code Article 3. Pictures of available Linnaean type specimens is at www.linnean-online.org/]

LVEMP. (1995). Lake Victoria environmental management project document. Government of Kenya, Uganda and United Republic of Tanzania.

Lyons, J. (1992). Using the index of biotic integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. General Technical Report NC-149. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station. Downloaded from https://www.nrs.fs.fed.us/pubs/gtr/gtr_nc149.pdf. On 26/11/2018.

Maddock, I. (1999). The importance of physical habitat assessment for evaluating river health, *Freshwater Biology, 41*, 373-391.

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Scientific Ltd, Oxford, Retrieved from, https: //www2.ib.unicamp.br/profs/Thomas /NE002_2011/maio10 /Magurran%202004 %20c2-4.pdf on 26/11/ 2018. Pp 18-130.

Mann, M. J. (1967). A preliminary Report on a Survey of the Fisheries of the Tana River, Kenya. Survey of the Irrigation potential of the Lower Tana River Basin, volume 7, Appendix M — Infrastructure and Secondary Development, Food and Agriculture Organization of the United Nations, Acres International, Canada, and International Land Development Consultants N. V., The Netherlands, Anex M—III p. 1-23.

Mann, M. J. (1969). A,brief report on a survey of the fish and fisheries of the Tana river, with speoial reference to the probable.~ffects of the proposed barrages,.

Manyala, J.O., C.O. Nyawade and C.O. Rabour, 1992. The dagaa (Rastrineobola argentea, Pellegrin) fishery in the Kenyan waters of Lake Victoria; a national review and proposal for future research. In P. Mannini, (ed.) The Lake Victoria Dagaa (Rastrineobola argentea). Report of the first meeting of the working group on Lake Victoria Rastrineobola argentea, 9–11 December, 1992, Kisumu, Kenya. UNDP/FAO Regional Project for Inland Fisheries Planning (IFIP) RAF/87/099-TD/38/92: 18–35.

Margalef, R. (1958) Information Theory in Ecology. General Systems, 3, 36-71.

Mbaka, J. G. (2010). *Impacts of canopy cover variations and organic matter dynamics on benthic invertebrate community along Njoro River, Kenya*. Kenya: MSc. Thesis, Egerton. Pp 97.

Mboya, D., Manyala, J. O., & Ngugi, C. C. (2005). Fish introductions and their impact on the biodiversity and fisheries of Lake Victoria. In Knowledge and Experiences gained from Managing Lake Victoria Ecosystem. In Mallya G. A., Katagira F .F., Kang'oha G., Mbwana S. B., Katunzi E. F., Wambede J. T., Azza N., Wakwabi E., Njoka S. W. Kusewa M., Busulwa H. (Eds). Kujabasinal Secretariat, Lake Victoria Environmental

Management Project (LVEMP). Pp 529-551.

McClelland, J. (1844). Apodal fishes of Bengal. Calcutta Journal of Natural History v. 5 (no. 18): 151-226, Pls. 5-14. [Date of 5 July 1844 from Fowler (MS), but perhaps incorrect; usually cited as 1845 in recent literature.

M'Erimba, C. M., Mathooko, J. M., Karanja, H. T., & Mbaka, J. G. (2014). Monitoring water and habitat quality in six rivers draining the Mt. Kenya and Aberdare catchment using macroinvertebrates and qualitative habitat scoring. *Egerton Journal of Science. & Technol*ogy.14, 81-104.

M-DEQ (Michigan Department of Environmental Quality), (1997). Qualitative biological and habitat survey protocols for wadeable streams and rivers, water bureau policy and procedures rev 2002 pp 1-53.

Miller, R. R., Williams, J. D., & Williams, J. E. (1989). Extinctions of North America fishes during the past century. *Fisheries, 14*, 22-38.

M. Roue, N. Cesard, Y. C. Adou Yao and A Oteng-Yaboah (2015). Knowing our lands and reources. UNESCO., 30-39.

Munga, C. N., Kimani, E., Ruwa, R. K., & Vanreusel, A. (2016). Species Composition of Fisheries Resources of the Tana and Sabaki Estuaries in the Malindi-Ungwana Bay, Kenya, 27–38. https://doi.org/10.1007/978-3-319-25370-1

Mutie, M., Mate, B., Home, P., Gawain, H., & Gathenya, J., (2006). Evaluating land use change effect on river flow using USGS geospatial stream flow model on Mara river basin Kenya, Center for Remote Sensing of Land Surface, Bonn, pp 28-30.

Mutunga, C., Zulu, E., & De Souza, R-M. (2012). Population Dynamics, Climate Change, and Sustainable Development in Africa Washington, DC and Nairobi: Population Action International (PAI) and African Institute for Development Policy (AFIDEP). Pp 4-44.

Mwangi, M. B., Ombogo, A. M., Amadi, J., Baker, N., & Mugalu, D. (2012). Fish species composition and diversity of small riverine ecosystem in Lake Victoria basin, Kenya. *International Journal of Science and Technology, 2*(9), 675-680.

Mwaniki, N. (2007). Tana River Fisheries - Kenya Sugar Project EIA Report. Retrieved fromhttps://repository.cuk.ac.ke/bitstream/handle/123456789/153/ENVIRONMENTAL%20IMPACT%20ASSESSMENT.pdf?sequence=1&isAllowed=y.

Niebuhr, C. (1775). Descriptiones animalium avium, amphibiorum, piscium, insectorum, vermium; quae in itinere orientali observavit Petrus Forskål. Post mortem auctoris edidit Carsten Niebuhr. Hauniae. 1-20 + i-xxxiv + 1-164, map.

Njiru, M., Kazungu, j., Ngugi, C. C., Gichuki, J., & Muhoozi, L. (2008). An overview of the current status of Lake Victoria fishery: Opportunities, challenges and management strategies. *Lakes & Reservoirs: Research and Management, 13*, 1–12.

Njiru, M., Nzungi, P., Getabu, A., Wakwabi, E., Othina, A., Jembe, T., & Wekesa, S. (2006). Are fisheries management, measures in Lake Victoria successful? The case of Nile perch and Nile tilapia fishery. *African Journal of Ecology, 45*, 315-323.

Nkondi Irrigation project feasibility study, (1989). Natural Resources Consultants Ltd. Nairobi, Kenya.

Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization, (2017). License: CC BY-NC-SA 3.0 IGO.

Ochumba, P. B. O., & Manyala, J. O. (1992). Distribution of fishes along the Sondu- Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield.

Ogutu-Ohwayo, R. (1990). The decline of native fishes of Lake Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile Perch, *Lates niloticus* and *Nile tilapia*, *Oreochromis niloticus*. *Environmental biology of fishes, 27*, 81-96.

Ojija, F., Mesfin, G., & Neema, K. (2017). Assessing ecosystem integrity and macroinvertebrates community structure: Towards conservation of small streams in Tanzania. *International Journal of Scientific and Technology Research, 6* (02).

Okeyo, D. O. (2003). Riverine fishes of Kenya: the current status on the diversity and distribution in the Ragati-Sagana-Tana Riverws drainage system. *Disco. Innov., 15*(1/2).

Okungu, J., & Opango, P. (2005). Pollution load into Lake Victoria from the Kenyan catchment. In knowledge and experiences gained from managing Lake Victoria ecosystem. Dares Salaam: Regional: Secretariat, Lake Victoria Environmental Management Project (LVEMP), 90-108.

Oliveira, S.V., & Cortes, R.M.V. (2006). Environmental indicators of ecological integrity and their development for running waters in northern Portugal. *Limnetica, 25*, 479–498.

Ombaka, O; Gichumbi, JM (2012). Investigation of Physicochemical and Bacteriological Characteristics of Water Samples from Irigu River Meru South, Kenya. *International Journal of Scientific & Engineering Research,*3(11) ISSN 2229-5518

Ombaka, O., Gichumbi, J.M., Mukono, S.T. and Kibara, D (2013). Effect of Human Activities and Seasonal Variation on Water Quality of Nkenye (Chikuu) Stream in Chuka, Kenya. *International Journal of Modern Chemistry,* 4(1): 50-65

Ongwenyi, S. G., Johnson U. K., & Nyagaga, J. M. (1993). Impact of hydrobiologycal and land use processes on quality of water in the Gucha catchment, Southwestern Kenya. *Hydrological of the warm humid regions*; proceedings of the Yokohama Symposium, July 1993, IAHS Publ. No. 216.

Opperman, Jeff, et al. & WWF (2018). Valuing Rivers. *How the diverse benefits of healthy rivers underpin economies?* WWF, 2018.

Owen, R. (1839). On a new species of the genus *Lepidosiren* of Fitzinger and Natterer. Proceedings of the Linnean Society of London 1839 [v. 1]: 27-32

Paller, V. G., Labatos, B. V., Lontoc, B. M., Matalog, O. E., & Ocampo, P. P. (2011). Freshwater fish fauna in watersheds of Mt. Makiling Forest Reserve, Laguna, Philippines. *Phillipine Journal of science, 140*(2). 195-206.

Paller, V. G., Corpus, M. N. C., & Ocampo P. P. (2013). Diversity and distribution of freshwater fish assemblages in Tayabas River, Quezon (Phillipines). *Phillipines journal of science*, 142(1), 55-67.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscapes. *Annual Rev Ecol System*, *32*,333-365.

Paul, M. J., Stribling, J. B., Klauda R. J., Kazyak, P. F., Southerland, M. T., & Roth, N. E. (2003). A Physical Habitat Index for Freshwater Wadeable Streams in Maryland Final report. Maryland Department of Natural Resources Tawes State Office Building. 580

Peters, W. (C. H.), (1852). Diagnosen von neuen Flussfischen aus Mossambique. Monatsberichte der Königlichen Preussischen Akademie der Wissenschaften zu Berlin 1852: 275-276, 681-685.

Peters, W. (C. H.), (1859). Eine neue vom Herrn Jagor im atlantischen Meere gefangene Art der Gattung *Leptocephalus*, und über einige andere neue Fische des Zoologischen Museums. Monatsberichte der Königlichen Preussischen Akademie der Wissenschaften zu Berlin 1859: 411-413. [Published in 1859 (see Bauer et al. 1995:22

Petersen, R. C. (1992). The RCE: A Riparian, Channel, and Environmental Inventory for small streams in the agricultural landscape. *Freshwater Biology, 27*, 295-306.

Taylor Avenue Annapolis, Maryland 21401. Pp 1-1 – 3-21.

Pielou, E. C., (1996). The relation between evenness and diversity. Wiley, New York.

Plafkin, J. L., Barbour, M. T., Porter, K. D., Gross, S. K., & Hughes, R. M. (1989). *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish*. EPA 440-4-89-001, Washington, D.C, USEPA Office of Water Regulations and Standards.

Platts, W. S., Megahan, W. F., & Minshall, G. W. (1983). Methods for Evaluating Stream, Riparian, and Biotic Conditions. USDA Forest Service Intermountain Forest and Range Experiment Station, General Technical Report INT-138, Ogden, UT. Pp 70.

Poole, G. C., Frissell, C.A., & Ralph, S.C. (1997). In-stream habitat unit classification: Inadequacies for monitoring and some consequences for management. *Journal of the American Water Resources Association, 33*(4), 879-896.

Priti, S., & Khan, I. A. (2011). Ground water quality assessment of Dhankawadi ward of Pune by using GIS. *International Journal of Geomatics and Geosciences*, 2(2), 688-703.

Quattrocchi U. (2012). *CRC World Dictionary of Medicinal and Poisonous Plants: Common Names, Scientific Names, Eponyms, Synonyms, and Etymology*. Boca Raton, Louisiana: CRC Press, Taylor & Francis Group. pp. 3667 3668. ISBN 9781420080445.

Rabalais, N. N. (2002). Nitrogen in aquatic ecosystems. *Ambio. 31*(2), 102-112.

Raburu, P. O., Masese, F. O., & Mulanda, C. A. (2009). Macro-invertabrates index of biotic integrity (M-IBI) for monitoring rivers in the upper catchment of Lake Victoria Basin, Kenya. *Aquatic Ecosystem Health and Management, 12*(2), 197-205.

Raburu, P. O. (2003). *Water quality and the status of aquatic macroinvertebrates and ichthyofauna in River Nyando, Kenya*. Kenya, PhD thesis, Moi University.

Raburu, P. O., & Masese, F. O. (2010). Development of a Fish-Based Index of Biotic Integrity (FIBI) for Monitoring Riverine Ecosystems in the Lake Victoria Drainage Basin, Kenya.

Rankin, E. T. (1989). *The qualitative habitat evaluation index (QHEI): Rationale, methods, and applications*. Columbus, Ohio EPA, Division of Surface Water.Ecological assessment *River Res. Applic. 28*, 23–38.

Raven, P. J., Holmes, N. T., Dawson, F. H., Fox, P. J., Evarard, M., Fozzard, I. R., & Rouen, K.J. (1998). *River habitat quality: the physical character of river and streams in the UK and Isle of Man*. River habitat survey, Report No. 2 U.K., Environment Agency, Bristol.Pp 3-28.

Reavie, E. D., Kireta, A. R., Kingston, J. C., Sgro, G. V., Danz, N. P., Axler, R. P., & Hollenhorst, T. P. (2008). Comparison of simple and multimetric diatom-based indices in Great Lakes

Recha, C. W., Makokha, G. L., & Shisanya, C. A. (2017). Climate variability and causes : from the perspective of the Tharaka people of eastern Kenya. *Geoscience Letters*, 4–11. https://doi.org/10.1186/s40562-017-0088-1

Roche, J., Godinho, C., Rabaca, J. E., Frochot, B., Faivre, B., Mendes, A. & Paula, C. D. (2010). Birds as bio-indicators and as tools to evaluate restoration measures, Proceedings 7th European Conference on Ecological Restoration, Avignon, France, 23-27/08/2010. Pp 14.

Rogers, A. (2016). Habitat Quality Index metrics and Calculations; Water Quality Program Texas Parks and Wildlife Department TCEQ Biological Monitoring Training. Pp 179.

Roper, B. B., Kershner, J. L., Archer, E., Henderson, R., & Bouwes, N. (2002). An evaluation of physical stream habitat attributes used to monitor streams. *Journal of the American Water Resources Association, 38*(6), 1637-1646.

Roseman, E. F., & Debruyne, R. L. (2015). The renaissance of ecosystem integrity in North American large rivers, 1–3. https://doi.org/10.1111/rec.12175

Rüppell, W. P. E. S. (1829). Beschreibung und Abbildung mehrerer neuer Fische, im Nil entdeckt. Brönner, Frankfurt am Main. 1829: 1-12, Pls. 1-3.

Rüppell, W. P. E. S. (1832). Fortsetzung der Beschreibung und Abbildung mehrerer neuer Fische, im Nil entdeckt. Brönner, Frankfurt am Main. 1-14, Pls. 1-3.

Sahu, P. O., & Chaudhari, P. K. (2015). The characteristics, effects and treatment of wastewater in sugarcane industry. *Water quality exposure and health, 7*(3), 435-444.

Sara, V., & Kagan, J. (2014). Assessing ecological integrity across jurisdictions and scale.

http://www.defenders.org/publication/eco-integrity-measures-across-jurisdictions-andscales. Pp 1-44.

Schenone, N., Volpedo, A. V., Fernández, & Cirelli, A. (2007). Trace metal contents in water and sediments in Samborombón Bay wetland, Argentina. *Wetland ecology and manag., 15*, 303-310.

Shannon, C.E. & Weaver, W. (1949). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Sharma, A., Bora, C. R., & Shukla, V. (2013). Evaluation of seasonal changes in physicochemical and bacteriological characteristics of water from the Narmada River (India) using multivariate analysis. *Natural Resources Research, 22*(4), 283-296.

Shervette, V. R., Aguirre, W. E., Blacio, E., Cevallos, R., Gonzalezm, M., Pozo, F., & Gelwick, F. (2007). Fish communities of the disturbed mangrove wetland and an adjacent tidal river in Palmar, Ecuador. *Estuarine Coast Shelf Science, 72*(1-2). 115-128.

Somerville, D. E., & Pruitt, B.A. (2004). Physical Stream Assessment: A Review of Selected

Protocols for Use in the Clean Water Act Section 404 Program. September 2004, Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division (Order No. 3W-0503- NATX). Washington, D.C., 213 pp. Document No. EPA 843-S-12-002.

Stauffer, J. C., & Goldstein, R. M. (1997). Comparison of three qualitative habitat indices and their applicability to prairie streams. *North American Journal of Fisheries Management, 17*, 348-361.

Stevens, C., & Council, T. (2008). A fish-based Index of biological integrity for assessing river condition in Central Alberta. Technical Report, T. 2008-001, Canada, Alberta.

Stohlgren, T. (2008). Forest legacies, climate change, altered disturbances regimes, invasive species and water, Fort Collins, Colorado, United States. *Unasylva. 229*, 44-49

Sultana, S., Ahmed, A. N., Sultana, S., Biswas, P. K., Saha, B., & Alam, S. (2017). Assessment on water quality of waste water in sugar industry and its impact on environment. *open access library journal, 4,* 1-11.

Staniszewski, R., Szoszkiewicz, K., Zbierska, J., Lesny, J., Jusik, S., & Clarke, R. T. (2006). Assessment of sources of uncertainty in macrophyte surveys and the consequences for river classification. *Hydrobiologia, 566*, 235–246.

Stoddard, J. L., Larsen, D. P., Hawkins, C. P., Johnson, R. K., & Norris, R. H. (2006). Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications, 16*, 1267–1276.

Szoszkiewicz, K., Ferreira, T., Korte, T., Baattrup-Pedersen, A., Davy-Bowker, J., & O'Hare, M. (2006). European river plant communities: the importance of organic pollution and the usefulness of existing macrophytemetrics. *Hydrobiologia, 566*, 211–234.

Tafangenyasha, C., & Dzinomwa, T. (2005). Land use impacts on river quality in Lowveld sand river system insouth-east Zimbabwe. *Land use and water resource research, 5*, 3.1-3.10.

Toham, A. K., & Teugels, G. G. (1999). First data on an Index of Biotic Integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. *Hydrobiologia, 397*, 29–38.

Turinayo, Y. K. (2013). *Impact of wastewater effluents from a sugar industry and molasses based distillery on water quality of River Musamya in Lugazi, Uganda*. Uganda, Msc. Thesis, Makerere University. Pp 2-76.

Uddin, M. N., Alam, M. S., Mobin, M. N., & Miah, M. A. (2014). An Assessment of the River Water Quality Parameters: A case of Jamuna River. *J. Environ. Sci. & Natural Resources, 7*(1), 249 – 256.

UNEP. (2016). A Snapshot of the World's Water Quality: Towards a global assessment. Nairobi, Kenya, United Nations Environment Programme, 162pp.

United Nations (2015). Population 2030. *Demographic challenges and opportunities for sustainable development planning.* Newyork, 2015.

USEPA. (2000). *The Quality of Our Nation's Waters.* Washington, DC, United States Environmental Protection Agency, Office of Water, EPA 841/S/00/001. Pp. 9-33.

USEPA. (2016). *A practitioner's guide to the biological condition gradient: A framework to describe incremental change in aquatic ecosystem*. Washington, DC, EPA-842-R-16-001.U S Environmental Protection Agency. Pp 7-30.

Van de Haterd, R. J. W. & G. N. J. Ter Heerdt, 2007. Potential for the development of submerged macro- phytes in eutrophicated shallow peaty lakes after restoration measures. *Hydrobiologia 584*: 277–290.

van Someren, V. D. (1952). The Biology of Trout in Kenya Colony. Government printer Nairobi.

VIA ET AQUA. (1975). Migori – Kihancha regional master plan on water and land utilization summary report volume I, prepared for the Ministry of Water Development. Isric Library K E 75. 13.

Wakwabi, E. O., Balirwa, J., & Ntiba, J. M. (2013). Aquatic biodiversity of Lake Victoria basin. In Eric Odada, D. Olago and W. Ochola (eds.). Environmental Development: An Ecosystem Assessment of Lake Victoria Basin Environmental and Socio Economic Status, Trends. Pp 77-109.

Walsh, B., Costanzo, S. D., Dennison, W. C., Campbell, J. P., Lehman, M., Nortrup, M., … Petersen, P. (2015). *Natural resource condition assessment for Prince William Forest Park: National Capital Region*. Natural Resource Report NPS/PRWI/NRR—2015/1051. Colorado, National Park Service, Fort Collins. Retrieved from http://science.nature.nps.gov/im/units/ncrn/index.cfm on 25th Nov 2018. Pp. 104.

Wang, L., Simonson, T. D., & Lyons, J. (1996). Accuracy and precision of selected stream habitat estimates. *North American Journal of Fisheries Management, 16*, 340-347.

Wetland Consulting Services (Pty) Ltd. (2014). Specialist Assessment: Aquatic Ecosystems

Lonmin Platinum, Marikana Mine.

Whitehead, P. J. P. (1959). Notes on a collection of fishes from the Tana river below Garisa, Kenya. *Journal of the East Africa Natural History Society,* 23 (4):167-171

WHO. (2017). UN-Water Glaas Trach Fin Initiative: Tracking financing to sanitation, hygiene and drinking-water at the national level. Guidance document summary for decision-makers. Geneva Switzerland, (Author), pp 3-19.

Wielemaker, W. G., & Boxem H. W. (1982). Kenya soil survey - soils of Kisii area. Kenya. *Agricultural Research Report* (Versl. landbk. Onderz.) 922.

Wildekamp, R. H. (1992). A new *Nothobranchius* (Cyprinodontiformes: Aplocheilidae) from the Kenyan coastal plains, with a redefinition of the subgenus *Aphyobranchius*. Ichthyological Exploration of Freshwaters v. 3 (no. 2): 187-192.

Withers, P. J. A., Neal, C., Jarvie, H. P., & Doody, G. D. (2014). Agriculture and eutrophication: Where do we go from here? *Sustainability, 6*, 5853-5875.

Witte, F., & Van Densen, W. L. T. (1995). *Fish stock and fisheries of Lake Victoria*. In a handbook for field observations. Cardigan (UK), Samara publishing limited.

WRMA, & JICA. (2014). Gucha-Migori river basin integrated flood management plan. Retrieved from http://open_jicareport.jica.go.jp/pdf/1000018470_03.pdf (On 24th Nov 2018, 11.49 pm).

Yadav, A., Jyoti, R., & Renu, D. (2014). Physico-chemical analysis of treated and untreated effluents from sugar industry. *Journal of Environment and Human, 1*(2), 2373-8332.

Zaimes, G. N. & Schultz, R. C. (2002). Phosphorus in agricultural watersheds: A literature review. Iowa State University, Iowa, pp 24- 60.

APPENDICES

[redacted]

Number of indigenous species	Number of exotic species	No. fish species caught	No of total individuals caught
Any other information			

APPENDIX II: DESCRIPTIVE STATISTICS FOR SPATIAL VARIATION

Station		Temp(◦C)	DO(mgL $^{-1}$)	TDS(mgL $^{-1}$)	Cond(µScm $^{-1}$)	pH	TN(µgL $^{-1}$)	TP(µgL $^{-1}$)	HQI	FIBI	abundance	richness	SIMPSON	SHANNON	EVENNESS
Mung'enya run	Mean	12.84833	9.1533	53.2250	69.033	7.9440	175.088	44.928	21.00	0.0	0.00	0.00	.000	.000	.000
	Minimum	11.400	8.80	40.95	48.7	7.35	64.421	23.286	18	0	0	0	.000	.000	.000
	Maximum	13.900	9.51	65.65	94.0	8.57	533.895	87.571	23	0	0	0	.000	.000	.000
	Std. Error of Mean	.344678	.12932	3.76189	6.5861	.21738	73.767	9.675	.730	0.0	0.000	0.000	.000	.000	.000
Mung'enya pool	Mean	12.93333	9.2983	51.5583	65.133	7.5800	181.579	40.638	16.83	0.0	0.00	0.00	.000	.000	.000
	Minimum	11.400	8.80	36.00	48.8	6.70	67.579	24.429	11	0	0	0	.000	.000	.000
	Maximum	14.200	9.53	65.65	77.9	8.57	457.579	59.000	20	0	0	0	.000	.000	.000
	Std. Error of Mean	.375648	.11943	4.72894	4.4177	.29483	72.318	6.147	1.302	0.0	0.000	0.000	.000	.000	.000
Kaguu bridge	Mean	17.36667	8.6017	57.8917	76.517	7.6567	237.046	48.513	12.17	0.0	.17	.17	.000	.000	.000
	Minimum	12.900	8.20	48.00	58.2	6.80	89.684	33.286	11	0	0	0	.000	.000	.000
	Maximum	20.700	8.87	71.50	97.2	8.71	520.700	79.000	13	0	1	1	.000	.000	.000
	Std. Error of Mean	1.115248	.09414	3.60311	5.3076	.29565	67.453	6.720	.307	0.0	.167	.167	.000	.000	.000

B-K-G conf	Mean	22.116 67	7.7067	104.8917	160.317	8.28 40	353.103	97.761	13.8 3	28.3 3	23.67	2.17	.320	.534	.599
	Minimu m	16.500	6.60	67.60	86.1	7.76	190.737	41.900	13	24	0	0	.000	.000	.000
	Maxim um	25.500	8.70	144.75	212.4	8.59	612.300	219.000	15	37	49	5	.662	1.254	.863
	Std. Error of Mean	1.2520 43	.30739	11.54875	17.0419	.153 32	70.297	26.278	.307	2.45 9	7.306	.654	.093	.171	.137
K-G conf	Mean	22.588 33	7.8717	120.2250	177.600	7.97 00	326.005	98.501	13.8 3	30.3 3	23.67	2.17	.320	.534	.599
	Minimu m	20.030	7.30	82.55	121.7	7.17	174.947	36.100	12	24	0	0	.000	.000	.000
	Maxim um	25.700	8.60	156.00	229.0	8.66	623.400	173.286	15	38	49	5	.662	1.254	.863
	Std. Error of Mean	.76581 3	.22954	11.37023	15.6648	.255 48	66.483	20.543	.477	2.59 1	7.306	.654	.093	.171	.137
B-K-T conf	Mean	24.083 33	8.0800	110.6700	171.783	7.96 80	238.104	65.643	12.5 0	35.0 0	46.00	5.17	.581	1.211	.735
	Minimu m	20.900	6.71	72.00	122.1	7.14	159.158	.000	10	28	18	2	.113	.227	.327
	Maxim um	25.800	9.30	154.70	234.1	8.64	414.947	155.000	18	45	61	8	.815	1.748	.971
	Std. Error of Mean	.80557 1	.34634	14.31528	19.0985	.275 13	40.300	22.633	1.17 6	2.60 8	5.961	1.046	.123	.270	.107
K-T conf	Mean	25.366 67	6.8033	118.3000	182.267	8.00 33	320.737	54.238	17.8 3	35.0 0	46.00	5.17	.581	1.211	.735
	Minimu m	24.600	6.04	102.05	154.9	7.19	187.579	37.571	16	28	18	2	.113	.227	.327
	Maxim um	25.900	7.26	141.70	216.3	8.87	463.895	80.429	21	46	61	8	.815	1.748	.971
	Std. Error of Mean	.39299 4	.38412	11.99128	18.0354	.485 71	79.922	13.257	.703	2.80 5	5.961	1.046	.123	.270	.107
Kambur u dam	Mean	24.183 33	7.3867	69.9483	108.517	7.92 40	217.517	50.873		28.0 0	35.33	4.00	.659	1.208	.896

	Minimum	22.200	6.80	56.67	92.4	7.80	108.100	.000		26	12	3	.583	1.003	.739
	Maximum	28.700	8.00	86.50	126.4	8.10	389.700	86.900		30	80	5	.750	1.474	1.085
	Std. Error of Mean	.976189	.20537	4.65896	5.0421	.05344	43.160	12.903		.516	10.022	.365	.027	.069	.052
Kiambere dam	Mean	26.58333	6.6350	72.4717	117.417	7.9700	153.783	55.708		29.67	25.67	4.83	.607	1.196	.759
	Minimum	25.400	5.60	57.70	110.4	7.30	99.200	21.150		26	19	4	.388	.839	.521
	Maximum	29.200	8.78	83.20	130.7	8.61	247.600	80.400		32	39	6	.738	1.546	.902
	Std. Error of Mean	.543088	.45840	3.53846	3.0375	.24302	27.586	9.567		.803	2.871	.307	.058	.125	.061
Kindaruma dam	Mean	24.75500	7.0267	70.6033	109.733	8.2640	162.317	67.707		27.00	32.83	3.17	.319	.615	.390
	Minimum	22.400	5.96	58.67	89.9	7.70	115.500	9.000		24	0	0	.000	.000	.000
	Maximum	31.130	8.59	86.45	126.4	8.60	236.500	119.700		30	103	6	.693	1.264	.912
	Std. Error of Mean	1.354951	.44518	4.71719	5.6249	.17348	18.852	16.437		1.125	17.850	1.046	.143	.275	.177
Masinga dam	Mean	24.23333	7.0483	63.9250	99.433	8.1220	103.095	37.937		29.00	25.50	4.00	.548	1.027	.730
	Minimum	22.400	6.37	44.70	88.7	7.70	38.600	19.000		24	6	1	.000	.000	.000
	Maximum	26.900	8.51	73.10	112.8	8.51	168.100	69.000		36	78	7	.777	1.643	.998
	Std. Error of Mean	.706478	.30819	4.25397	3.6618	.16057	18.016	7.895		1.844	11.348	.931	.116	.241	.149
Total	Mean	21.36905	7.8295	79.4819	118.725	7.9575	220.427	60.828	15.43	28.61	23.53	2.80	.358	.685	.495
	Minimum	11.400	5.60	36.00	48.7	6.70	38.600	.000	10	23	0	0	.000	.000	.000

	Maximum	31.130	9.53	156.00	234.1	8.87	623.400	219.000	23	46	103	8	.815	1.748	1.085
	Std. Error of Mean	.645874	.13801	3.82610	5.9946	.07291	18.012	5.092	.546	.667	3.031	.309	.039	.079	.050

APPENDIX III: DESCRIPTIVE STATISTICS FOR TEMPORAL VARIATION

Month		Temp(◦C)	DO(mg L^{-1})	TDS(mg L^{-1})	Cond(µSc m^{-1})	pH	TN(µg L^{-1})	TP(µg L^{-1})	HQI	FIBI	abundance	richness	SIMPSON	SHANNON	EVENNESS
March 2020	Mean	24.1730	8.6780	60.9740	116.400	6.7500	358.83740	22.98930	17.8571429	27.8181818	25.1818182	2.7272727	0.2810605	0.5201499	0.4466885
	Minimum	13.90	8.00	36.00	70.0	6.70	38.60000	0.00000	14.0000000	23.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	31.13	9.30	110.00	183.0	6.80	623.40000	41.90000	23.0000000	36.0000000	78.0000000	7.0000000	0.7771203	1.6425778	0.9127332
	Std. Error of Mean	1.90145	.10164	6.77967	11.8801	.05000	68.72864	5.13276	1.3875050	1.2271044	8.7050854	0.6337609	0.0794501	0.1561657	0.1148842
April 2020	Mean	21.3690	8.0880	68.5670	99.390	7.7450	164.18596	105.10317	19.2857143	28.2727273	28.8181818	2.3636364	0.3053941	0.5661257	0.4868685
	Minimum	13.39	6.40	40.95	48.7	7.12	90.70000	31.85714	15.0000000	24.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	26.40	9.52	102.70	152.7	8.66	291.78947	219.00000	25.0000000	38.0000000	103.0000000	6.0000000	0.7187500	1.3208883	0.9528195
	Std. Error of Mean	1.53948	.32978	6.40076	11.3991	.15738	19.12366	22.05107	1.5843624	1.5141209	9.3680484	0.5919571	0.0839600	0.1599396	0.1109171
May 2020	Mean	20.8300	7.6690	72.6650	104.340	7.9560	118.63526	63.53324	19.1428571	28.2727273	25.2727273	3.4545455	0.4466263	0.8926499	0.5354798
	Minimum	11.40	6.20	49.40	56.3	7.48	64.42105	24.42857	15.0000000	24.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	26.00	9.53	120.90	179.7	8.64	193.89474	110.42857	25.0000000	34.0000000	80.0000000	6.0000000	0.8148148	1.7399668	0.9710940
	Std. Error of Mean	1.79512	.38469	7.16381	12.2083	.11787	13.96649	10.03393	1.5950604	1.2511152	8.2330718	0.7904387	0.1087912	0.2225235	0.1299156
June 2020	Mean	39.4364	7.6373	81.6682	117.755	8.0945	159.90445	73.19870	18.2857143	30.8181818	23.0000000	3.0000000	0.3451107	0.6833369	0.4440887
	Minimum	12.60	5.60	55.25	65.0	7.27	88.10526	41.85714	14.0000000	23.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

	Maximum	223.50	9.51	136.20	193.0	8.87	326.52632	136.14286	24.0000000	46.0000000	49.0000000	8.0000000	0.7656250	1.6588092	0.9155385
	Std. Error of Mean	18.46203	.34125	8.84758	14.0508	.17365	25.73445	8.17044	1.7142857	2.5648611	6.9543969	0.9244163	0.1049970	0.2146102	0.1170355
July 2020	Mean	20.4482	7.0336	93.1227	132.482	7.8836	310.97641	50.36827	18.4285714	31.3636364	20.0909091	2.3636364	0.3112004	0.6172320	0.4218413
	Minimum	12.90	5.96	61.10	72.4	6.47	108.63000	30.33333	14.0000000	23.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	25.40	9.31	154.70	219.3	8.57	509.68421	96.14000	24.0000000	46.0000000	47.0000000	8.0000000	0.7777275	1.7475752	1.0848662
	Std. Error of Mean	1.34706	.32397	10.50229	16.3852	.18858	38.93088	6.02927	1.6741329	2.4909754	6.5177444	0.9748914	0.1100010	0.2297564	0.1476001
August 2020	Mean	21.4000	7.7373	99.3773	144.909	8.1173	203.12392	54.63065	17.1428571	28.0000000	23.0909091	2.9090909	0.4567228	0.8315256	0.6339267
	Minimum	12.90	6.05	65.65	77.6	7.14	72.31579	19.48000	13.0000000	24.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	26.20	9.12	156.00	234.1	8.71	320.21053	87.57143	23.0000000	34.0000000	52.0000000	6.0000000	0.7379973	1.4522313	0.9644620
	Std. Error of Mean	1.40402	.28772	10.56103	17.6241	.16503	23.54764	6.68773	1.5800629	1.1361818	5.6043077	0.6668044	0.0951989	0.1830383	0.1245595
Total	Mean	24.7278	7.7911	79.9668	119.808	7.9193	220.42666	60.82787	18.3571429	29.0909091	24.2424242	2.8030303	0.3576858	0.6851700	0.4948156
	Minimum	11.40	5.60	36.00	48.7	6.47	38.60000	0.00000	13.0000000	23.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	Maximum	223.50	9.53	156.00	234.1	8.87	623.40000	219.00000	25.0000000	46.0000000	103.0000000	8.0000000	0.8148148	1.7475752	1.0848662
	Std. Error of Mean	3.26776	.13671	3.81925	5.9579	.07686	18.01204	5.09162	0.6198623	0.7279717	3.0292329	0.3085568	0.0393045	0.0789162	0.0497444