INFLUENCE OF PHYSICO-CHEMICAL PARAMETERS AND SEDIMENT CHARACTERISTICS ON BENTHIC MACROINVERTEBRATE COMMUNITY DYNAMICS IN ISIUKHU RIVER, KENYA

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DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a research thesis entitled **“Influence of Physico-Chemical Parameters and Sediment Characteristics on Benthic Macroinvertebrate Community Dynamics in Isiukhu River, Kenya”**

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DEDICATION

This work is dedicated to my lovely parents (Mzungu Dume Kadzenga and Mbodza Mzungu Kadzenga) and the entire Mzungu’s family for their financial and moral support throughout the academic journey. May the Almighty God Bless them.

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ABSTRACT

Physico-chemical and sediments are critical aquatic habitat resources for macroinvertebrates. Macro-habitats are altered through oxygen and food availability alteration. Distribution of macroinvertebrates in responses to physico-chemical characteristics and sediments are less understood in rivers. However, influence the abundance and distribution of macroinvertebrates. Physico-chemical and sediments data; and how this influence macroinvertebrate is key to understanding their dynamics in Isiukhu River. This study evaluated the physico-chemical parameters and substrate characteristics on the abundance, diversity and spatial distribution of macroinvertebrates in Isiukhu River. Specifically, the study (i) determined physico-chemical parameters along the river (ii) quantified the sediment grain size along river (iii) analysed abundance and spatial distribution of macroinvertebrates, and (iv) evaluated the relationship between physico-chemical parameters, substrate characteristics and macroinvertebrate distribution and composition along river. The study was conducted between March 2018 and March 2019. Samples were taken from three zones that were divided into 10 sampling sites; Upstream (Ichina 1, Ivakale 2, Kimangeti 3 and Senyende 4); midstream (Shirere 5, Rosterman 6 and Mwibatsilo 7); downstream (Shibeye 8, Mutono 9 and Ekero 10). Temperature, dissolved oxygen, pH, salinity, percentage saturation oxygen, conductivity and turbidity were measured on site using Hydro Lab. H_2O sample were taken for Total Suspended solids, Nitrates and phosphates determination in the laboratory. Sediments were collected using shovel and Ekman Dredge sampler while benthic macroinvertebrates were collect using a Kick-Net. Macroinvertebrates were preserved in 70% alcohol and transported to the lab for identification. Dried sediment samples were separated using a Retsch Sieve Shaker with from 0.063 to 15mm mesh sizes, weight of each fraction was measured and recorded. SPSS version 23 was used to calculate the mean values of physico-chemicals and GRADISTAT 9.1 to sediment grain sizes. Diversity and eveness were calculated using Shannon diversity index. Temperature, conductivity, turbidity, salinity, pH and Oxidation Reduction Potential from the upstream to downstream. The upstream sediments were very coarse gravelly; the downstream sediments are very fine sand indicating that the sediments get finer downstream of Isiukhu River. Rosterman had the highest mean sediment grain size (9.97 mm), and Senyende (0.56 mm) had the least. Upstream sampling sites were dominated by Vellidae, Gyrinidae, Gerridae and Notonectidae, midstream sites were dominated by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Belostomatidae and the downstream by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Dictynidae. A total of 637 individual of macroinvertebrates were collected from upstream sites, midstream had 248 individuals while the downstream had 108 individuals. Highest mean abundance (100±9.2) was recorded at Kimangeti (upstream) while the least at Mutono (11±0.7) downstream. H= 2.2177 was greater at Kimangeti (upstream) while lowest at Ekero (1.2012) downstream. Physico-chemical and sediment accounted for 54.8% and 28.7% respectively of variability of macroinvertebrates. Study shows that physico-chemical and sediments influences macroinvertebrates abundance and diversity in Isiukhu River.

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ABBREVIATIONS AND ACRONYMS

GOK	Government of Kenya
SPC	Specific conductivity
ORP	Oxidation-reduction potential
TDS	Total dissolved solids
GRADISTAT	Grain size distribution and statistical package
PCA	Principal Component Analysis
CCA	Canonical Correspondence Analysis
GF/F	Glass fibre filter
DO	Dissolved oxygen
TSS	Total suspended solids
ANOVA	One Way of Analysis of Variance
APHA	American Public Health Association
MMUST	Masinde Muliro University of Science and Technology
NTU	Nephelometric Turbidity Units
PSS	Practical Salinity Scale
PAST	Paleontological Statistics Software
WHO	World Health Organization
CEWERM	Centre of Excellence for Water and Environmental Resources Management (MMUST)
WARMA	Water Resources Management Authority
WRUAs	Water Resources User’s Associations

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Rivers and streams provide important environmental goods and services (Wanderi *et al.,* 2022). The ecological traits of these rivers and streams that include biodiversity and abundance of aquatic fauna and flora are largely dependent on water quality (Mzungu *et al.,* 2022). Anthropogenic activities within their outreaches are stressing river and stream quality threatening the existence of these flora and fauna (Piano *et al.,* 2020; Carrasco-Badajoz *et al.,* 2022). In addition, anthropogenic activities such as harvesting of sand, water extraction and agricultural activities are a threat to watersheds that serve as sources of the lotic ecosystems, (Shivoga *et al.,* 2007).

Benthic fauna in rivers is impacted by biotic and abiotic characteristics that operates at spatial and temporal scales (Kaboré *et al.,* 2016). Bottom grains of a stream provide essential habitat for macroinvertebrate (Zinabu *et al.,* 2019). The stream bed sediments affect aquatic macroinvertebrates directly or indirectly by altering their habitats, food availability or oxygen circulation (Harrison *et al.,* 2007). Movement of a river across different landscapes alter stream/river flow, altering the water's physico-chemical parameters while in transit (Tavzes *et al.,* 2006).

Normally, rivers pass through a gradient of land uses from their headwater sources to downstream (Wanderi *et al.,* 2022). Their physico-chemical qualities change dramatically downstream as they pass through various land uses, which affects the riverine biota, including the distribution of macroinvertebrates and fish communities (Turyahabwe *et al.*, 2022). Upstream waters influence the biochemical characteristics of rivers and streams thereby playing a vital role in determining composition and distribution of macroinvertebrate (Shivoga *et al.*, 2007; Lubanga, 2021). The upstream, is the point of greatest convergence of the terrestrial and fluvial realms, are thought to be the sites of greatest catchment impacts on river conditions (Wilkes *et al.*, 2017). The physico-chemical characteristics of entire river, however, are significantly influenced by the contribution of watershed and upstream, particularly with regard to the transfer and transportation of nutrients and related elements (Wanderi *et al.*, 2022).

The role of spatial ecosystem heterogeneity in shaping the colonization of rivers by faunal communities as stream/river flows across the landscape has been and continues to be a key concern (e.g. Kaboré *et al.*, 2016); Wilkes *et al.*, 2017; Zinabu *et al.*, 2019; Dallas & Rivers-Moore, 2022; Mzungu *et al.*, 2022; Raphahlelo *et al.*, 2022). Tropical rivers show spatial, periodic, and foreseeable instabilities resulting from downpours and droughts (Barichivich *et al.*, 2018). Seasonal variations in rainfall dynamics exert evolutionary pressures that affect communities of organisms and their biological traits (Raphahlelo *et al.*, 2022; Wang *et al.*, 2022). Pronounced seasonal differences in rainfall result in high variability in flow regimes of most tropical rivers, which are important determinants of their abiotic and biotic characteristics (Feigl *et al.*, 2021; Dallas & Rivers-Moore, 2022; Mzungu *et al.*, 2022). Rapid population growth, farming and transformation of forests into farmlands has occasioned high turbidity and dominance of fine sediments giving streams a characteristic brown colour (Graça *et al.,* 2015). Variations in the health of rivers, particularly from weathering and sand deposition, as well as water contamination, are directly linked to land use changes within most watersheds of Kenya (Lubanga, 2021). Heavy downpours lead to a large amount of suspended matter and high sediment loads, some of which scours accumulated material on the streambed and movement of substrata (Shivoga, 2001).

Habitat degradation and pollution are the main threats to global freshwater biodiversity (Dudgeon, 2006). Destruction of vegetation within a stream watershed directly impacts the substrate characteristics of the affected river channel (Wanderi *et al.*, 2022). Human land use practices accelerate sedimentation, which negatively impacts stream dwelling macroinvertebrate communities. A universal issue is the impact of river and stream pollution on human health (Mzungu *et al.,* 2022). The principal contaminants in many tropical streams are fertilizers, in particular, nitrates and phosphates (Kibichii *et al.,* 2007). The acceptable limits for nitrate and phosphate in surface water are 50 mg/L and 5 mg/L, respectively, as per World Health Organization (WHO) guidelines (WHO, 2021).

Many studies have identified habitat/environment as the most crucial factors in the structuring of biological communities (Lubanga, 2021). Many studies have shown that change in substrate and flow regimes determines the stability and complexity of habitats in lotic systems and thus affect the dynamic of macroinvertebrate communities. (Kibichii *et al.,* 2007; Shivoga *et al.,* 2007; Onyando *et al.,* 2013; Sitati *et al.,* 2021; Greig *et al.,* 2022; Mzungu *et al.*, 2022).

Sediment characteristics and environmental factors have a notable effect on the composition, diversity and abundance of aquatic macroinvertebrate assemblages (Raphahlelo *et al.,* 2022). Grain size variation cause environmental changes that alter the taxonomic composition, species richness, diversity and abundances (Masese & Raburu, 2017; Akamagwuna *et al.,* 2019). Sediments influence macroinvertebrate assemblage composition and are influenced by physical disturbances in streams (Akamagwuna *et al.*, 2019; Raphahlelo *et al.,* 2022). Fine sediments from erosion deposition have been shown to be significant in determining macroinvertebrate abundance and species composition along river courses (Jones *et al.,* 2012). Several land uses in watershed have occasioned excess supply of silts and sand to water regime, such that the heaping of fine sediment to numerous streams at present, far surpasses the pre-industrial levels (Shimba & Jonah, 2016; Dallas & Rivers-Moore, 2022). Alarm about the effects of such high fine sediments accumulation have on the aquatic ecosystem have resulted to prepositions that fine deposits are among the damaging pollutants (Akamagwuna *et al.,* 2019). Damage to respiratory and feeding organs, abrasion of soft-sensitive tissues, habitat quality adjustment, and changes in food availability and quality are some of the ways in which these affect aquatic macroinvertebrates (Jones *et al.,* 2012; Akamagwuna *et al.,* 2019; Blettler *et al.,* 2019; Sitati *et al.,* 2021). This is even more aggravated in developing countries where the rapid increase in population has led to unplanned settlement along river courses and unsustainable farming on stream/river banks.

Isiukhu is tropical river, that serves as a reliable source of freshwater, supports a very rich floral and faunal biodiversity and is exposed to extreme flow events associated with high variability in rainfall patterns (Onyando *et al.,* 2016; Matindu, 2020). The river drains a broad gradient of land uses, including farmlands (mostly sugarcane growing along the upstream and mixed farming along the downstream), forested areas inside the Kakamega Forest, and peri-urban areas within the Kakamega Municipality (Onyando *et al.*, 2013; Onyando *et al.*, 2016). This results in longitudinal variations of habitats in various sections of the watercourse, which become even much distinctive due to influence from anthropogenic activities such as agricultural, urbanization, mining and human settlement. These factors make Isiukhu River suitable for stream ecological studies of varied habitats supporting macroinvertebrate species (Matindu, 2020; Oremo *et al.,* 2020). However, the taxonomic diversity and data on the composition of freshwater organism remain less understood in many developing countries (Boyero *et al.*, 2009), particularly in tropical regions, where these environments hold many of the global macroinvertebrate species (Dudgeon, 2006). The knowledge gap calls for management strategies and conservation approaches that are specifically tailored to tropical lotic ecosystems (Wantzen *et al.*, 2006). Knowledge of the responses of benthic communities to changes in physico-chemical parameters, substrate characteristics and extreme flow events is necessary in management and conservation programs of lotic ecosystems, particularly in tropical areas where the streams are rapidly affected by increasing anthropogenic influences.

In addition, identification of suitable method for monitoring lotic watercourses from sediments pollution in the tropics have been a subject of concern for many aquatic ecologists (Akamagwuna *et al.,* 2019; Sitati *et al.,* 2021; Greig *et al.,* 2022). Studies on the relationship between abundance and distribution of macroinvertebrates, as well as physico-chemical factors and substrate features, are many in temperate regions (Mzungu *et al.,* 2022). However, such studies are limited in tropical area particularly in Africa (Shivoga *et al.,* 2007; Onyando *et al.,* 2016; Masese & Raburu, 2017; Oremo *et al.,* 2020; Lubanga, 2021).

Urbanization, agriculture, mining and sand harvesting, which cause a significant amount of bank erosion, are disrupting many tropical rivers. This is the situation with Isiukhu watercourse, which flows through the Kakamega forest in the upstream, Kakamega town in the midstream and agricultural activities in the downstream, hence displaying distinct environment condition that provide habitat for macroinvertebrate.

This study, analysed the dynamics of the benthic macroinvertebrate communities in the Isiukhu River in relation to the physico-chemical properties and sediment grain sizes. It was anticipated that the study would shed light on how the taxonomic diversity and composition of stream macroinvertebrates in the three reaches of the river are influenced by physico-chemical and substrate characteristics.

1.2 Statement of the Problem

Lotic ecosystems are the most challenged ecosystems because of human-induced disruptions caused by development programs that impair macroinvertebrate and fish habitats (e.g., Dudgeon, 2006; Turyahabwe *et al.*, 2022). Macroinvertebrate are widely used as bio indicators globally because of their of their apparent sensitivity to water quality deterioration, including physico-chemical water quality change, sediment pressure, their functional and structural diversity, their abundance in all aquatic habitats and a well-established taxonomy (Akamagwuna *et al.,* 2019). Different macroinvertebrates families possess traits that enable them to adapt to local environmental conditions. Thus analysing the abundance, composition and distribution of them, can give an indication of environmental impairment (Shivoga *et al.,* 2007). The traits of any macroinvertebrate organism detect its relationship with the surrounding and can provide a mechanistic approach into taxon environment interactions (Akamagwuna *et al.*, 2019). In Kenya, the aspect of employing macroinvertebrate to detect rivers and streams health status is still limited. In the Isiukhu River, the main water quality stressors are physico-chemical parameters variation and sedimentation(Onyando *et al.,* 2013). Sedimentation is caused by erosion from poorly farmed lands, bank sand harvesting and mining. This provides an opportunity to employ macroinvertebrates abundance to detect impact of the two stressors (physico-chemical parameters and sediment grain size).

There is scant information on the impact of physico-chemical factors and substrate characteristics on the diversity and spatial distribution of macroinvertebrates. Moreover, the impact of allochthonous input on substrate characteristics and how they influence diversity and distribution of the macroinvertebrates is poorly understood.

The few studies that have been done on River Isiukhu have paid attention to the influence of land use on nutrient regime and macroinvertebrates distribution (Onyando *et al.*, 2013) while Oremo *et al.* (2020) studied heavy metals in stream macroinvertebrates. However, the influence of substrate characteristics and physico-chemical parameters on benthic macroinvertebrates abundance and distribution are scant. Furthermore, many studies on biomonitoring that have been carried out in many tropical rivers like Isiukhu have focused on effects of pollutants on macroinvertebrates (Azrina *et al.*, 2005; Shivoga *et al.,* 2007; Lubanga, 2021; Mzungu *et al.,* 2022). Besides, substrate characteristics have been reported to have extreme effects to macroinvertebrates, healthy and survival of streams (Harrison *et al.,* 2007; Akamagwuna *et al.*, 2019). While many benthic invertebrates have been shown to be associated with coarse sediments environment or have been shown to favour certain velocity ranges (Wellnitz *et al.*, 2001), there are no studies to-date, on the impacts of velocity on the structure of macroinvertebrate communities in Isiukhu River.

This study analysed the impacts of physico-chemical and sediment grain size characteristics on benthic macroinvertebrates community dynamics in Isiukhu River, Kenya.

1.3. Justification of the Study

The determination of the influences of physico-chemical parameters and sediment grain size and their influence on the distribution of macroinvertebrates along the stream will provide a better understanding of how human activities affects the river. Environmental stress and particularly fine sediments accumulation are among the greatest threats facing the lotic systems (Ibemenuga & Inyang, 2008). Isiukhu River is subjected to extreme human interference due to the high population, overdependence and rapid urbanization. It is important to see how these changes impact physico-chemical water parameters and substrate characteristics and ultimately the distribution and abundance of macroinvertebrates some of which are bio indicators of river health (Wanderi *et al.,* 2022).

Given that macroinvertebrates have been broadly employed as bioindicators of the health of aquatic ecosystems due to their responsiveness to water quality impairment, including sediment stress there is need to determine their relationship with sediments grain size for purposes of conserving the river. The fact that Isiukhu river traverses different land uses also present a unique situation suitable for tropical ecological studies of spatial macroinvertebrates distribution in relation to the habitats or biotopes and how it is influenced by physico-chemical and substrate characteristics (Verberk *et al.,* 2013).

The gradient of land uses in watershed is closely correlated with many physico-chemical water quality in lotic systems (Shivoga *et al.,* 2007). For instance, there is consensus that catchment within urban areas tend to have higher concentrations of pollutants and nutrients (Mzungu *et al.,* 2022). Similarly, conductivity and fine sediment accumulation in streams and rivers increased with the proportion of farm lands (Masese *et al.,* 2017). Since, Isiukhu River traverses the different land uses, it gives the reason for this study to investigate whether abundance and distribution of macroinvertebrate communities was being determined by physico-chemical parameters and sediment grain sizes.

1.4. Study Objectives

1.4.1 Main Objective

To assess the influence of physico-chemical parameters and sediment grain size on dynamics of benthic macroinvertebrates communities in Isiukhu River, Kakamega County, western Kenya.

1.4.2 Specific objectives

1. To determine the physico-chemical parameters along the course of Isiukhu River.
2. To quantify the substrate characteristics (sediment grain size) along Isiukhu River.
3. To analyse abundance and spatial distribution of macroinvertebrates along Isiukhu River.
4. To evaluate the relationship between physico-chemical parameters, substrate characteristics and macroinvertebrate distribution and composition along Isiukhu River.

1.5 Hypotheses

1. There is no significant difference between physico-chemical parameters at sampling sites in the upstream, midstream and downstream reaches of Isiukhu River.
2. There is no significant difference between sediment grain size at the upstream, midstream and downstream reaches of Isiukhu River.
3. There is no significant difference in the distribution and abundance of macroinvertebrates between the upstream, midstream and downstream reaches of Isiukhu River.
4. There is no relationship between physico-chemical parameters, substrate characteristics and macroinvertebrate distribution and composition at the upstream, midstream and downstream reaches of Isiukhu River.

1.6 Significance of the study

The findings of the study will be important to different people, government and non-governmental organizations, county governments and national government, national and international agencies, communities and to all stakeholders involved in environmental conservation programmes. Knowledge generated by this study will offer an opportunity for the Isiukhu River advocacy protection groups and communities push for changes in the river management and conservation. Additionally, it can be used by different environmental activists to push for efforts aimed to promote restoration of biodiversity and ecological integrity of lotic systems around Africa. Data obtained from this study can be used to formulate policies and plans that will be eventually be used in conserving and maintaining the Isiukhu River watershed. The results generated from this will add knowledge, that can be referred by researchers, students, government officials and environmentalists in designing studies and conservation strategies. Data from this study will significant in seeking to identify the effects of variations in land use practices on sediment characteristics as a predictor of macroinvertebrate abundance. This can be utilized as a physical pollution indicator inside the Isiukhu River watershed for upcoming monitoring, such as establishing water quality and fine sediment status sufficient to support essential biological processes.

Results of this study will be useful to the adjacent communities, as it will highlight how their activities impact the river, which will give the community an opportunity to be involved in sustainable utilization of stream. Furthermore, data from this study will provide biological records required to make well-informed decisions on the management of Isiukhu water catchment by ministry of water and irrigation, WARMA and Water Resources Users Associations (WRUAs). Lastly, the knowledge on distribution and responses of benthic communities to changes in substrate characteristics and physico-chemical parameters is necessary for a management and conservation program of lotic ecosystems, particularly in streams that are being rapidly degraded by increasing anthropogenic influences like Isiukhu River.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discusses physico-chemical parameters, sediments grain size characteristics, macroinvertebrates and the relationship of physico-chemical and sediments grain size characteristics on the distribution and abundance of macroinvertebrates. It details what has fidnigns by scholars and experts on physico-chemical parameters, distribution of macroinvertebrates and the contribution of physico-chemical parameters and sediments grain size on the abundance, distribution and taxon richness of macroinvertebrates. This chapter is critical in identification of knowledge gaps and providing clues on best ways to fill them.

2.2 Effects of physico-chemical parameters on stream macroinvertebrate distribution

Macroinvertebrates live within a certain range of temperatures, (Hynes, 1975). In aquatic ecosystems temperature is intimately related to latitude, altitude, and seasons (Sripanya *et al.,* 2022). Temperature in aquatic ecosystem can be altered by both physical and natural factors. It influences the solubility and composition of hydro-components and this largely can change the quality of water and habitat characteristics of freshwater streams (Turyahabwe *et al.,* 2020). Because aquatic macroinvertebrates play a crucial function in the aquatic ecosystem and serve as a sign of a stream's health, changes in habitat characteristics have a direct impact on them (Andem *et al.,* 2022). Temperature elevation can be harmful to macroinvertebrates (Mzungu *et al.*, 2022). Numerous aquatic ecosystem studies have found a link between feeding rates and metabolism and temperature (Kaboré *et al.,* 2016; Purcell *et al.,* 2017) Some studies in temperate regions have shown that temperature is the single most important variable affecting habitat characteristics (Masese & Raburu, 2017). Communities and populations of macroinvertebrates exhibit significant location variability associated with changes, resulting in variations of community assemblages in some reaches (M'Erimba *et al.,* 2014; Mathers *et al.*, 2023). Each group of macro invertebrates survive in a specific range of temperature.

Temperature in rivers tend to elevate from upstream to downstream under ideal situation, this brings dynamic in macroinvertebrates colonization (Mathers *et al.*, 2023). However, human activities within the watershed largely contribute in the erodibility and sedimentation of stream and rivers. Persistence of these processes can cause reduction in depth, which will lead to a rise in temperature and thus affect the macroinvertebrate composition (Wotton & Warren, 2007). Unexpected increase in temperature due to extreme weather conditions like drought have been reported to have negative effect on specific stages of insects such as the eggs, larva and nymph (Hynes, 1975; Harrison *et al.*, 2007). The changes in substrate characteristics along the river regimes also can alter the temperature of stream biotopes. This has been suspected to influence colonization of macroinvertebrates in streams (Bonada & Resh, 2013). Few studies have emphasised on the influence of substrate characteristics on macroinvertebrates composition and colonization yet it has been found to affect many factors such as turbidity, dissolved oxygen concentration and temperature which highly determine the colonization and composition of macroinvertebrates in many biotopes (Hynes, 1970; Wanderi *et al.,* 2022). Despite the role of temperature as an influential aspect in colonization and composition of macroinvertebrates in freshwater ecosystems, many ecological studies have ignored it (Mathers *et al.,* 2023).

pH is among the basic water parameters that greatly affects stream macroinvertebrates. The highest species diversity is found at the pH range of 4-9 and it decreases at the pH below 4 and above 9 (Turyahabwe *et al.,* 2022). Sudden changes in pH can stress or kill them (Ibemenuga & Inyang, 2006). The photosynthetic depletion of CO_2 and the evaporative concentration of bicarbonate might result in higher pH levels than 10 (Carrasco-Badajoz *et al.,* 2022). On the other hand, very low pH below 4.5 results from acid rain and cation exchange. In this case, the carbon dioxide cycle has little influence on the biological species varieties, and frequently, ionic aluminum has hazardous biological effects (Talling, 2010). Different benthic macroinvertebrates have different degrees of resistance to acidity (Turyahabwe *et al.,* 2020). It is because of this character that they are being employed in the determination of water quality in lotic systems (Lubanga, 2021). Land use practices within the watershed bring sediments of different salts composition which alter the pH of the stream (Oremo *et al.,* 2020). Depending on the other physico-chemical parameters, low pH values accompanied by open waters tend to favour high biodiversity and colonization rates (Mzungu *et al.,* 2022). pH is affected by agricultural land use and acidic precipitation, it has major impacts on colonization, assemblages and distribution of macroinvertebrates. However, very few studies have worked at the relationship between land use and precipitation, how they influence substrate distribution and their effects on macroinvertebrate assemblages (Stubauer *et al.,* 2010). Rivers and streams normally traverse different geographical and ecological zones (Wanderi *et al.,* 2022). Hence, it's more likely to be subjected to various land use practices such as agricultural, municipality, forested areas etc, and all these can alter the pH which largely alter assemblage and distribution of fauna (Zampella *et al.,* 2007).

Phosphorus and nitrogen, the two very significant soil constituents, are used to control crop yields and soil fertility. For crop plants, nitrogen is the most important element, and plant productivity is closely tied to its availability (Oremo *et al.,* 2020). Nitrates could enter the aquatic habitat from urban waste and agricultural operations (Lubanga, 2021). Phosphorus, a crucial component and necessary for enhanced agricultural productivity to support our food sources, is present in the majority of fertilizers (Wang, 2022). A significant amount of phosphorus from fertilizers, reaches the aquatic ecosystem through runoff. Additionally, the effluent from washing detergents contains phosphates. Algal blooms caused by excessive nitrogen availability in the aquatic habitat, affects less tolerant aquatic organisms (Oremo *et al.,* 2022). Additional nutrients can affect water quality when surface runoff pushes water and topsoils into water regimes (Mzungu *et al.,* 2022). Excessive levels of nitrates, phosphates and pathogens in contaminated water can have an effect on the variety and composition of macroinvertebrates in lotic systems (Jones *et al.,* 2012; Shimba & Jonah, 2016). By determining the availability of food, these variables have bearing on the population and distribution of macroinvertebrates in stream ecosystems.

Worldwide the decline in aquatic habitats has been linked to increasing land use practices (Mzungu *et al.,* 2022). Many lotic ecosystems in tropical areas are facing several challenges among them habitat loss, habitat lost and decline, resulting to population decrease (Raphahlelo *et al.,* 2022). Due to pollution from agricultural areas and other human activities that change the habitats and nutrients, rivers in Kenya are degrading, which is resulting in a decline in the variety and richness of macroinvertebrates (M'Erimba *et al.,* 2014). Benthic macroinvertebrates provide us with the understanding of how variation in aquatic habitat conditions affect aquatic macroinvertebrates (Raphahlelo *et al.,* 2022). Their distribution also is influenced by the interactions among habitat characteristics, physico-chemical variables human activities (Zampella *et al.,* 2007). Changes in physico-chemical parameters can significantly affect the distribution of benthic macroinvertebrates (Kibichii *et al.,* 2007). Due of their sensitivity to environmental disruptions, macroinvertebrate abundance and diversity have been utilized in several studies to identify changes in the environment (Akamagwuna *et al.,* 2019; Mzungu *et al.,* 2022). Consequently, macroinvertebrates composition can be used to detect habitat alterations.

Many streams and rivers in Kenya are threatened by fast growing human population that results to overdependence of the freshwater resources (Oremo *et al.,* 2020). Many studies have shown that increasing pollution from deforestation, urban development, sand harvesting and farming causing a decline in both the quantity and quality of water (Collier, 1995; Shivoga *et al.,* 2007; Akamagwuna *et al.,* 2019; Mzungu *et al.,* 2022; Wanderi *et al.,* 2022). For the adjacent communities, the river provides drinking water and supplies water for irrigation. However, to date, very few studies have looked at the effects of human activities on physico-chemical parameters and how these impact the fauna. The objective of the current study was to determine the physico-chemical parameters and their effect on distribution and abundance of macroinvertebrates in the Isiukhu River.

2.2.1 Effect of Land Use on physico-chemical Characteristics of Rivers

Lotic ecosystems sentinels conditions in the watershed and riparian zones (Onyando *et al.,* 2013). As a result of the influence of the watershed on streams and rivers (Hynes, 1975), several studies have assessed the effects of physico-chemical conditions at the watershed. The upstream reach of rivers is assumed to have a stronger influence especially in transfer of nutrients in the river than other reaches (Wanderi *et al.,* 2022). Human activities that range from forested areas, agricultural land, municipal areas and mining affects the water quality and ecological conditions of the rivers at different scales (Raphahlelo *et al.,* 2022). Land use gradient in the watershed change the composition of rivers mostly through changes in dynamics of erosional processes, nutrients run-off as well as ecosystem processes such as nutrients cycles, photosynthesis and composition of fauna (Wanderi *et al.,* 2022). Many studies have found a correlation between land uses on water physico-chemical parameters (Andem *et al.*, 2022; Mzungu *et al.,* 2022). Vegetation and municipal land uses have greater consequences for water quality during the rainy season, making urban land use the most important factor controlling water quality variation (Wanderi *et al.,* 2022). Therefore, changes in flow levels throughout an area can combine with land use and other human activities to impact physico-chemical factors, which in turn affect macroinvertebrate composition (Shivoga *et al.,* 2007). Therefore, in order to create sustainable management plans, it is imperative to comprehend patterns and variations in average water quality across large spatial(Fang *et al.,* 2010; Mzungu *et al.,* 2022).

Studies on the spatial dynamics of physico-chemical parameters in Isiukhu River are very limited (Onyando *et al.,* 2013; Oremo *et al.,* 2020; Matindu, 2020). Nevertheless, variation in physico-chemical water quality can happen at different spatial scales. Rivers and streams have been shown to have distinct physico-chemical conditions (e.g. temperature, DO, turbidity, PH, saturated oxygen percentage, TSS etc.) from upstream to downstream (Vannote *et al.,* 1980; Tallaksen & Van Lanen, 2004) and different spatial patterns have been observed in African rivers (e.g., Kuemmerlen, 2015; Lubanga, 2021; Mzungu *et al.,* 2022; Raphahlelo *et al.,* 2022; Sabha *et. al.,* 2022).

Kakamega County has experienced a lot of land use changes as a result of rapid human population growth. People have expanded their agricultural lands and some established settlements within the watershed. Towns such as Kakamega at the midstream and Mumias at the downstream have graown rapidly. Given that the Isiukhu river has been impacted by the various land uses in the catchment, the hypothesized upstream to downstream gradient (Vannote *et al.,* 1980) may not apply to this lotic system.

The characteristics of the Isiukhu River offer interesting situations for comprehending the interplay between physico-chemical factors influencing water quality in rivers and their impact on the distribution, abundance and composition of macroinvertebrate. The results of this research will contribute to the understanding of the response of water quality to land use gradients at various spatial scales.

2.3 Effects of Substrate Characteristics on Macroinvertebrates Distribution

Rivers and streams vary spatially in response to river flow regime, primary production and sediment accumulation (Ibemenuga & Inyang, 2008; Akamagwuna *et al.,* 2019). Macroinvertebrates for a long time have been used as biological end-points for stream restoration and conservation because they are substrate sensitive (Raphahlelo *et al.,* 2022). In riverine ecosystems, bottom material features are an essential part of the physical habitat. This is because the sediments form a fundamental constituent of the substrate upon which benthic fauna locomote, rest, shelter, and forage. They define the slope and roughness effects that bring hydrological stress which benthic fauna must tolerate (Brysiewicz *et al.,* 2022). Stream sediments can originate from outside the river channel from colluvium processes or from alluvial process within the channel itself. The supply of sediments from outside the channel is extremely variable and is reliant on erodibility of the soil, land use practices and geographical features (Rutherford & Mackay, 1986; Wood and Armitage, 1997). Sediment grain sizes determine the channel structure of streams. Different land uses have impacts on the supply of sediments to the watercourse (Rosenfeld *et al.,* 2010; Pullanikkatil *et al.,* 2015). Spatial variation in sediment characteristics produce macroinvertebrate responses in various ways. For instance, size variation determines the hiding and structural properties of macroinvertebrates (Raphahlelo *et al.,* 2022). Stable sediment is preferred by most macroinvertebrates because they represent undisturbed ecosystem while unstable sediments show disturbed environments (Newcombe & MacDonald, 1991; Hynes, 1975).

Fine sediments are a major contributor to the deterioration of river ecosystems and ecological processes (Akamagwuna *et al.*, 2019; Ntloko *et al.*, 2021). Sediments can alter the viability of the substrate for several taxa, enhance macroinvertebrate grifts, and change breathing and foraging habits (Harrison *et. al.*, 2007; Akamagwuna *et al.*, 2019). Macroinvertebrates communities show strong variability, which is linked with their voltinism, which results from changes in composition and colonization across land use gradients (Mathers *et al.*, 2023). The spatial variation of macroinvertebrate may explain river health (Mzungu *et al.*, 2022). However, few researches have taken into account the possible effect of spatial variability in sediment grain sizes on their study conclusions, despite the well acknowledged spatial dynamism of substrate typical of riverine systems, with the majority of sampling being done exclusively on a seasonal basis (Akamagwuna *et al.*, 2019). This is suspected to have ecological repercursions that may pose significant implications for management of fine sediment pressures, the flow regime, or wider conservation plans (Vannote *et al.*, 1980). Ormerod (1987) found that using a combination of spatial scale and seasonal sampling techniques was the best way to characterize aquatic diversity.

It is widely acknowledged that fine sediments play a critical role as environmental filters in forming the communities of aquatic macroinvertebrates (Akamagwuna *et al.*, 2019; Mathers *et al.*, 2023). Even though lotic ecosystems naturally include fine sediments, the amount of fine material loaded in these ecosystems now is significantly higher than it was in the past. The current severe fine sediment inputs are predicted to intensify in the future due to changes in climate-induced runoff regimes and the intensification of agricultural practices in response to the world's expanding demand for food production (Wanderi *et al.,* 2022). By comprehending the role fine sediment deposits play in maintaining functional and taxonomic biodiversity, future environmental monitoring initiatives will be strengthened. Though most riverine biomonitoring and evaluation methods are currently developed and applied at the microhabitat level (Ormerod, 1987), fine sediment dynamics are probably going to show greater relationships with instream populations across all habitat scales (Brysiewicz et al., 2022).

Little has been documented on the influence of physico-chemical parameters on functional macroinvertebrate communities (Mathers *et al.,* 2023), it is widely acknowledged that substrate composition may play major roles in controlling the structure of macroinvertebrate communities (Akamagwuna *et al.,* 2019). It is of interest that there is little information on the relationships between macroinvertebrate communities and habitat charateristics, as well as how they change geographically. It has been demonstrated that macroinvertebrates can be used to monitor lotic systems for potential effects of fine sediment and other environmental conditions on the ecosystems' natural functioning (Mzungu *et al.,* 2022). Knowledge of the processes in lotic ecosystems can help identify the ways in which ecosystem functioning may be impacted by environmental changes. Functional measures have been used recently to address a variety of environmental stresses, such as changes in flow regime (Hynes, 1975) and excessive fine sedimentation (Mathers *et al.,* 2023).

Nonetheless, it has been demonstrated that habitat structure can mitigate the ecological consequences of stresses while populations residing in various habitat units may respond differently to stream interventions such as river restoration techniques (Mwakisunga *et al.*, 2020). Expanding our knowledge on the functional communities occupying various habitat units throughout time will make it easier to identify the possible impacts of both natural and man-made stresses on ecosystem functioning. This study sought assess macroinvertebrate abundance and diversity in three reaches of Isiukhu River on the basis of the substrate (gravel, sand, and silt).

2.4 Abundance and Spatial Distribution of Macroinvertebrates

Macroinvertebrates include the insects (stoneflies, mayflies, caddis flies, beetles, bugs, true flies and dragonflies), crustaceans (such as isopods, amphipods and crayfishes), molluscs, (e.g., Snails, bivalves), annelids (e.g., leeches, worms), and surface (e.g. tricladida), (Griffiths, 1999; Boyero *et al.*, 2011). Macroinvertebrates tends to differ in assemblages, composition, diversity and colonization in different biotopes such as pools and riffles (Hauer & Resh, 2017). Farming practices, laundry, hydrological activities, and sunbathing can change the physiochemical characteristics of watercourses, affecting the abundance of macroinvertebrates as well as the status of the water (Ojija & Laizer, 2016). Drought has a significant impact on physico-chemical parameters and produces alterations in the taxonomical and functional organization of biota (Bonada & Resh, 2013; Brysiewicz *et al.*, 2022). Aquatic ecosystem supports high biodiversity, they include both plants and animals which share the same resources. The physiological responses of each particular group of macroinvertebrates can be examined on the basis of specific pollutants (Runck, 2007). The impacts of contaminants on the population assemblages can be done through studying their life-cycles (Diepens *et al.*, 2014). This makes it possible to know the health streams and habitat deterioration in landscape. The abundance, taxonomic richness and evenness of macroinvertebrates assemblages is reliable and cheapest way which has been used to examine water quality for decades (Carter *et al.,* 2017).

River ecosystems depend heavily on macroinvertebrates (Rezende *et al.,* 2014). They are seen as the basis of a stable ecosystem (Brysiewicz *et al.,* 2022) and constitute a significant portion of freshwater ecosystems due to their function in the food webs (Carrasco-Badajoz *et al.,* 2022). It is crucial to employ benthic macroinvertebrates to assess how natural and human-caused factors affect the ecological health of streams. Numerous pressures caused by human activity frequently affect aquatic ecosystems, interfering with the behaviour of aquatic animals (Mzungu *et al.,* 2022).

Urban development according to M'Erimba *et al.* (2014) often results in a shift in the major land use from natural vegetation to built environment with mpervious surface, which increases surface runoff (Hawkins et al., 1982; Mwakisunga *et al.,* 2020; Sabha *et al.,* 2022). Agricultural activities might impact macroinvertebrate populations in different ways (Hynes, 1975), sedimentation and run-off of pollutants. When industrial effluent flows into into a river, it can significantly raise the pollution level of heavy metals, leading to deposition and enrichment of heavy metals, which are harmful to benthic macroinvertebrates (M'Erimba *et al.,* 2014). In addition to anthropogenic activity, macroinvertebrate populations are impacted by natural events. Numerous research investigations have demonstrated that during the dry season, a reduction in water flow results in a drop in water surface area and a series of events in physico-chemical variables that impact macroinvertebrate survival (Jones *et al.,* 2012; Carrasco-Badajoz *et al.,* 2022). Floods are a significant natural disturbance that often results in pulse disruptions in macroinvertebrates (Rezende *et al.,* 2014). Rapid velocity in the flood stream scours the streambed, transport debris and snags, and alter the channel itself (Boyero *et al.,* 2009; Shilla & Shilla, 2012), redistributing substrate materials and changing the mix of benthic macroinvertebrate species.

According to Jones *et al.* (2012) and Akamagwuna *et al.* (2019), fine sediment loads can affect aquatic organisms and their microhabitats by causing harm to their feeding and breathing organs, abrading soft-sensitive tissues, changing the quality of their habitat, and changing the quantity and quality of their food. These consequences might show up as a decline in biodiversity and a general deterioration of the health of the ecosystem as a whole, which would be detrimental to the structure and function of the ecosystem (Hart, 1992; Mesa *et al.,* 2013). Aquatic macroinvertebrates have been used as bioindicators to track the impact of increased fine sediment loads on freshwater ecosystems (Musonge *et al.*, 2020).

Many studies have revealed ways in which anthropogenic and natural features affect macroinvertebrate assemblages' responses to ecological variables (Rezende *et al.,* 2014). Nevertheless, despite the recent rise in research in other regions, there is scant information on tropical rivers in Africa and Latin America (Carrasco-Badajoz *et al.,* 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the area of study, research design, data collection, in-situ measurements of physico-chemical variables, sediments sampling, macroinvertebrates sampling, laboratory processing, analysis of samples and data analysis.

3.2 Study area

The study was conducted along Isiukhu River in Kakamega County, Kenya. Isiukhu River which originates from the Kakamega forest is a tributary of River Nzoia, that flows into Lake Victoria which is the second biggest freshwater lake in the world (Onyando *et al.,* 2016). Kakamega county lies between latitudes 0° 07′03″ N and 0° 15′ N and longitudes 34° 32′East and 34° 57′East (figure 1). The County has varying topography with altitudes ranging from 1250 m to 2000 m above sea level (Oremo *et al.,* 2020). Upstream, the river traverses the Kakamega tropical rainforest that borders the Nandi Escarpment in the east and Vihiga County in the west and north (Tsingalia & Kassily, 2009). The Nandi Escarpment catchment marks eastern border rising to the general elevation of 1,600 to 2,000 m (Wanyonyi *et al.,* 2021).

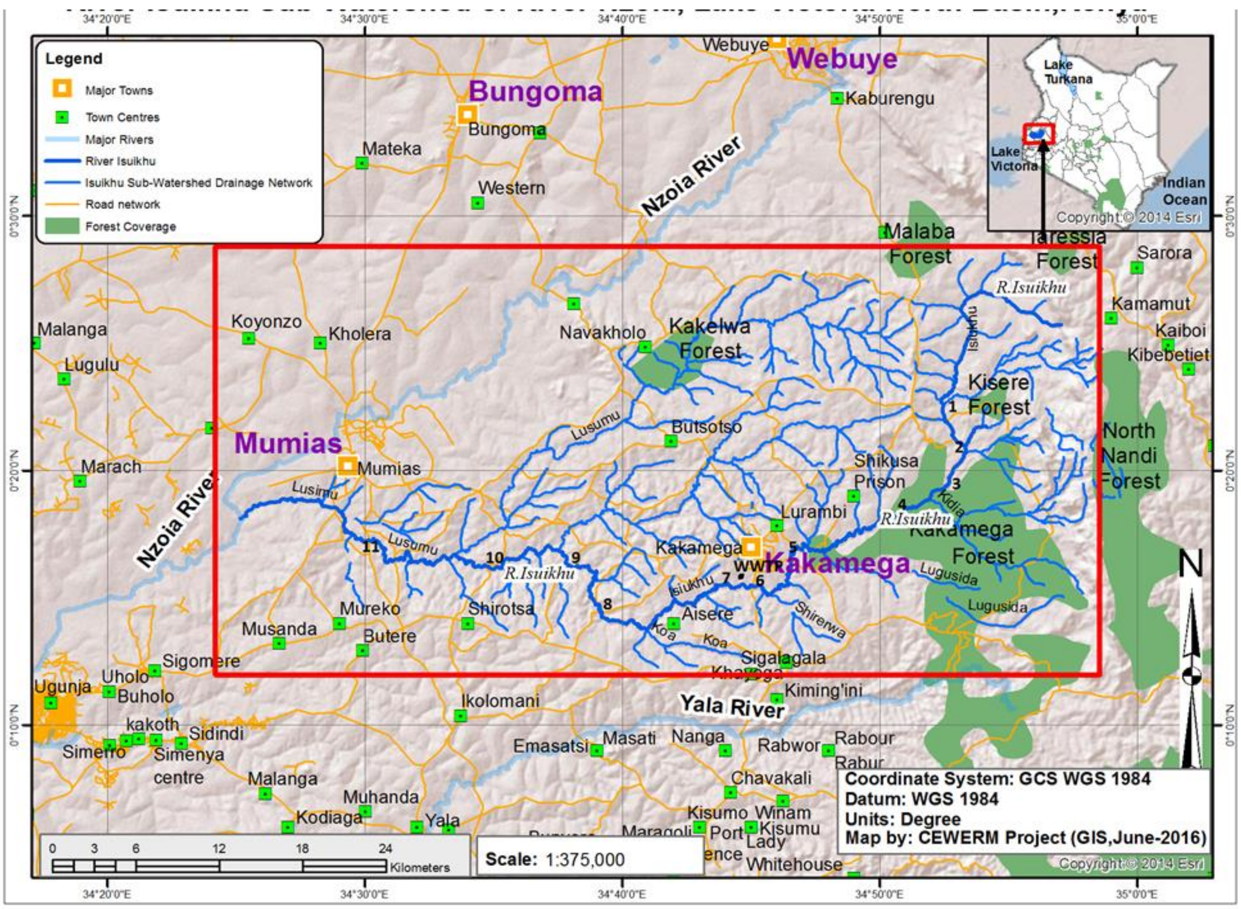

Figure 1: Isiukhu River sub-watershed of River Nzoia Catchment in Lake Victoria Basin.

There are two distinct rainy seasons in Kakamega County: the long and short rains. The short rains start in July and last in October, with a peak in August, whereas the long rains run from March to June, peaking in May (Solomon *et al.*, 2007). The driest months are December to February. The County's typical annual rainfall ranges from 1600 mm to 2100 mm with high humidity. The northern and southern regions receive 1000 mm and 2400 mm of rain annually, respectively (Wanyonyi *et al.*, 2021). Kakamega has an average maximum temperature range of 28 to 32 °C and a minimum of 11 to 13°C. Low temperatures are usually recorded at night and very high during the day (Solomon *et al.*, 2007).

The high amounts of rainfall in Kakamega makes the land prone to erosion and reduces agricultural output in the county (Wanyonyi *et al.*, 2021). In this county 70% of the land is covered with maize and the main cash crop is sugarcane with traces of tea grown on a small scale (Tsingalia & Kassily, 2009). Livestock keeping is practiced in the county.

The Isiukhu River originates from the Nandi Escarpment (at an altitude of 1,700 to 2,000 m above sea level). It traverses different land uses, including sugarcane plantations, forested areas, township and mixed farmlands. In the upstream, it drains an area comprised of sugarcane plantations and Kakamega tropical rainforest, while the midstream and downstream comprises the Kakamega urban centre and mixed farmlands (Onyando *et al.*, 2016).

Table 1: Show the characteristics of all the 10 sampling sites. Sampling sites varied from the forested upstream, urban and municipality at midstream and agricultural activities downstream

S/N	Site	Description of the study site	Land use type	GPS position, Obtained using GPS device
1.	Ichina (U)	-Found upstream- The river is narrow with a width of about 5m -It is more of a pool and there no vegetation covers on the surface. -Mainly composed of large pebbles. -water is clear with high velocity.	Land use practices at this site include sand harvesting, grazing, sugarcane farming, maize, cassava plantation and natural forest	0° 16′ 45″ N 34° 41′ 17″ E
2.	Ivakale (U)	Found upstream width of about 7m Found at upstream of the river and the water and has very high velocity. Surrounded by a wetland, with reeds and other swampy grasses.	Sugarcane and maize plantation, grazing is the main activity since it’s surrounded by a wetland with a lot of grasses, Within the Kakamega forest.	0° 26′ 35″ N 34° 53′ 24″ E
3.	Kimangeti (U)	Found at the upstream of the river Has width of about 10m.Water is clear with a high velocity, sometimes it floods and form a swampy region. Vegetation at this point is mainly a forest and some area is cover with grasses.	Human activities- water harvesting, mixed farming and natural forest	0° 28′ 1″ N 34° 52′ 31″ E

4.	Senyende (U)	Found at the upstream, has a width of about 25m Water is clear with a high velocity The vegetation is mainly guava trees and other indigenous species within the forest.	Human activities- the main activity in this region is sand harvesting, maize farming sugarcane plantation. and natural forest	0° 22′ 4″ N 34° 52′ 31″ E
5.	Shirere (M)	Found at the midstream of the river. Water is moving at a moderate velocity. The place is rocky and the water flows with high turbulence.	Composed of both natural and planted forest of eucalyptus, some parts are covered with nappier grass.	0° 15′ 17″ N 34° 44′ 59″E
6.	Rosterman(M)	Found at the midstream of the river Water is not much clear and the move at a moderate velocity The water normally floods and it is more of a swampy of grass	Land uses Napier and maize farming, mining of gold.	0° 15′ 19″ N 34° 43′ 38″E
7.	Mwibatsilo(M)	Found at the midstream of the river. Water is much clear and it moves at a moderate velocity. Sometimes it floods and form pools of water	Land use- maize, sugarcane and sand harvesting.	0° 14′ 31″ N 34° 39′ 8″ E

		Vegetation around this place is mainly planted forest of eucalyptus with a bit grasses.		
8.	Shibeye (D)	Found at the downstream The water is not clear	Land use- sugarcane plantation, manmade forest, sand harvesting and construction	0°16′6″ N 34°37′ 53″ E
9.	Mutono (D)	Found at the downstream High turbidity, riffles and turbulence	Land use- sugarcane plantation, maize farming, grasses	0°16′ 20″ N 34°35′ 29″ E
10.	Ekero (D)	Found at the downstream High turbidity, riffles and turbulence	Land use- sugarcane, beans, maize and cassava farming, sand harvesting, grazing.	0° 17′ 5″ N 34° 30′ 6″ E

3.3 Research Design

The study was conducted using a stratified randomized design. For this study, we marked out ten sampling sites within three reaches based on their accessibility, land uses and landscape gradient (Figure 1). On the basis of various land use types in three layers: upstream, midstream, and downstream of the Isiukhu River, ten sampling sites were chosen. The sampling sites were as follows: Upstream (1. Ichina, 2. Ivakale, 3. Kimangeti and 4. Senyende); midstream (5. Shirere, 6. Rosterman and 7. Mwibatsilo); downstream (8. Shibeye, 9. Mutono and 10. Ekero). Among these sampling sites, the Savona sampling site was not included due to accessibility. The river flows through the three strata: upstream, midstream, and downstream. The upstream was the least disturbed while the midstream comprises of urban centre (Kakamega town) and agriculture was the main activity downstream. These sites were chosen based on human activities along the river banks, such as sand gathering, animal keeping, and farmland, as well as municipal wastewater flow into the river and accessibility. For each stratum, sampling sites were designated at randomly. Routine sampling of sediments and macroinvertebrate was done twice a month in the first and last week of the month from March 2018 to March 2019. On each of the sampling occasion, physico-chemical variables were recorded at every sampling point.

3.4 *In situ* measurement of physiochemical variables

Measurement of water physico-chemical variables was done for a period of 12 months from March 2018 to March 2019. On each sampling occasion physico-chemical variables including temperature, dissolved oxygen concentation and saturation, pH, salinity, percentage saturation oxygen, conductivity and turbidity were measured using a Hydrolab Quanta Multi-Probe Meter (Quanta Sonde Model). All the readings were taken at average of 0.5 m.

Water velocity was measured using a Digital Water Velocity Meter (Model OTT MF Pro) at 60% water depth along across-section of the stream.

Additionally, 500 ml of water samples for phosphate and nitrate analyses were also collected in duplicate in high-density plastic bottles that had been acid-washed. These samples were then kept in a cooler box with ice packs until they were taken to the chemistry lab at Masinde Muliro University of Science and Technology for analysis.

3.4.1 TSS samples collection

The total suspended solids were determined in the field by filtering water samples via Whatman Glass Fibre Filters (GF/F) with 0.42mm thickness, 0.45 μm pore size, and 47mm diameter. Water samples were collected from sites, and 100 ml of water being at each station. The ten Fibre Glass filters were then packed in aluminum envelopes and placed in a cool box before being transferred to the Masinde Muliro University of Science and Technology Zoology laboratory for analysis.

3.4.2 Measurement of stream and habitat variables

Site description was done for each sampling site by measuring stream width, depth, flow velocity and determination of the land uses practices. The width of each sampling site was measured using a measuring tape. A meter rule was used to measure the river's depth. Similarly, a mechanical flow meter was used to measure velocity at random within the designated reach (General Oceanics; 2030 Flow meter, Miami, Florida).

3.5 Sediment sampling

Simultaneous with physico-chemical parameters sediments and macroinvertebrates, sediments were collected using the disturbance techniques. To ensure that sediment samples accurately represent the locations from which macroinvertebrates were obtained, three replicate samples were collected at each sampling location each time, with macroinvertebrates from riffles and pools. Benthic sediments were collected using a small shovel and an Ekman Dredge sampler. The Ekman Dredge sampler grabber that was used to collect the benthic sediment had a capacity of 3.5 litters and a dimension of 152 x 152 x 152 millimetres and it's entirely made from inert stainless steel. It had overlapping flaps that prevent any loss of the samples. The Ekman Dredge is link with a rod of 1.5-meter length and a drop-weight system that enables the samples to be taken at various depths. While in operation the thin hinging flaps open when lowered, spring loaded close when a drop-weight is dropped. It was used to collect the sediments in soft sediments especially at the middle stream and parts of the lower stream. The upstream had mostly hard substrate that prevent the use of Ekman Dredge sampler. However, the water was shallow and a stainless shovel of 12 inches was employed.

An open-ended polythene bag (height 70 cm, diameter 40 cm) was carefully interspersed in an undisturbed stretch of stream bed to collect samples of the suspended fine sediments down to a depth of 15 cm. Subsequently, a 20-cm-long wooden stick was used to agitate the water column strongly for approximately two minutes, avoiding contact with the benthic surfaces, in order to elevate fine silt on the surface of the stream bed. The suspended fine sediments were then collected quickly from within the cylinder into a 250 ml hard polythene bag. One sediment sample was taken from every sampling site. The samples were kept in polythen bags and transported to the MMUST zoology laboratory for size determination analysis.

Duplicate benthic sediments were collected from every sampling site put in a 1 kg plastic bags, packed in a lager bag and transported to the laboratory for analysis. They were oven-dried for one day and the dried sediment samples were placed in the uppermost Retsch Sieve. The shaker was then turned on to sieve the sediments mechanically for 30 minutes. The sediments that remained on each sieve and pan were sampled and weighted using a digital balance having an accurateness of 0.0001 g.

3.6 Macroinvertebrate sampling

A kick-net Sampler was used to simultaneous collect physico-chemical parameters, sediments and macroinvertebrates. The Kick-net has 25 cm by 25 cm opening of 100 µm mesh net and 1 metre adjustable handle. A representative stretch of around 100 meters was chosen at each sampling site that featured stream biotopes (riffles, edge waters and pools). To reduce the effects of physical disturbance and consequently macroinvertebrate drift, sampling was carried out from the downstream to the upstream. At each sampling site, triplicate points were chosen for sampling the benthic macroinvertebrates using a kick-sampler. The sampling involved a three-minute kick/sweep sample using a standard 1 mm mesh size hand-net. The net was positioned against the water current and the sample went through the opening. This method was adopted from Dickens & Graham (2002). On the other hand, swimming macroinvertebrates species were collected using plankton sweep nets with 100 µm mesh size which encloses an area of 0.0284 m^2. The sampler had a rectangular opening covered with a 100-µm mesh net at the front for allowing water to flow through it and a conical collecting mesh-net at the back with a detachable collecting bottle at the end. The sampler was placed in flowing water with the front opening facing upstream. The top 10 cm of substrate enclosed by the sampler was physically agitated by hand to dislodge animals which drift downstream into the conical net and the collecting bottle. Nektons (swimming) and pleustons, (surface-dwelling) macroinvertebrates were collected using plankton net of mesh size of 250 µm which was repeatedly used in sweeping the water surface especially where water was calm.

Macroinvertebrates were collected from various habitats and biotopes (riffles, edge waters, and pools) at the 10 sampling sites. In all the sampling sites thet macroinvertebrate collection was done for 20 -25 minutes.

The nets were then inverted and the contents transferred into a 250 ml specimen bottle and preserved with 50 ml of 70% ethanol. The bottles were sealed, labelled and transported to Masinde Muliro University of Science, Zoology laboratory for identification.

3.7 Laboratory Processing and Analysis of Samples

The macroinvertebrates were identified in the field to the family level using an Invertebrate Field Guide Handbook (Gerber & Gabriel 2002) and a magnifying glass. However, macroinvertebrates that could not be identified in the field were preserved in70% ethanol placed in a 250 ml specimen plastic bottle and transported to the laboratory for further identification. using a a Leica Stereo Microscope (Model SZ61-TR).

In the lab the preserved faunal samples were washed through 100 μm and 250 μm mesh-size sieves.

Sediment grain size was determined according to (Dickens and Graham, 2002). Sediment samples were wet sieved for 15 minutes using a Retsch Sieve Shaker with sieves ranging from 0.063 to 15 mm mesh size. Wet sieving method was considered because it represents separation of cumulative classes that have stability to physical dis-aggregation in water, a condition considered favorable for protecting sediments structures with time. It is the most widely used approach for researching macroinvertebrate communities in sediment formations, and it entails immersing sediments in water for several minutes to break down aggregates (Akamagwuna *et al.,* 2019).

The sediments samples were spread in aluminium foil and dried in the lab for 4-5 days. The dry-sieving technique was adapted from Blaud *et al.,* (2017). Fresh dried sediment samples were then placed on top of a nest of sieves (10 mm and above, 5.6 mm-10 mm, 2.8 mm – 5.6 mm, 1.25 mm – 2.8 mm, 500 μm – 1.25 mm and 62 μm – 500 μm) arranged in a shaker. To give sediments of these specific fractions, the shaker was then turn on and allow to run for 30 minutes per sample.

3.7.1 Nitrates Analysis from Water Samples

The sodium salicylate method (APHA, 1998) was used to quantify NO_3. Using a nylon 45 micro filter, a 20 ml water sample was filtered using this method and combined with 1 ml of freshly prepared sodium salicylate solution in a conical flask. After that, the bottles were put in an oven to dry at a temperature of 95 °C. By adding 1 ml of strong sulphuric acid and carefully swirling the bottles while they were still hot, the residues were quantitatively dissolved. Then 40 ml of distilled water were added and mixed together. Finally, 7 ml of potassium sodium hydroxide tartrate solution was added and stirred and the absorbance at 420 nm was measured.

3.7.2 Phosphate Analysis in Water Samples

The Molybdate technique was used to measure PO_4^{-3} (APHA, 1998). A measured 25 ml of the water sample were put into a conical flask for this method, and 1 ml of concentrated H_2SO_4 and 5 ml of concentrated HNO_3 were added. To get rid of the HNO_3, the sample was broken down until the solution was colourless. After cooling the flask, 20 ml of distilled water and 1 drop of phenolphthalein indicator were added and mixed. A drop of 1M NaOH was added to the sample solution acquired a faint pink tinge. To eliminate the turbidity of the particles, a 0.45µm membrane filter was used to filter the neutralized solution. After filtering, the material was put into a 100 ml volumetric flask and filled with distilled water to the mark. The molybdate colorimetric test (a mixed reagent was made and 8 ml of it was obtained and applied to 25 ml of the sample) was used to measure the P content of the digested sample. Using UV spectroscopy at a wavelength of 880 nm, samples were analysed.

3.8 Data Analysis

The mean and standard deviation of the following variables were calculated using the Statistical Package for the Social Sciences (SPSS) version 23: temperature, dissolved oxygen, pH, salinity, % saturation of oxygen, conductivity, ORP, turbidity, nitrates and phosphates. The software was used to determine the trends in physico-chemical changes from upstream to downstream and their influence on macroinvertebrates. Data normalcy was checked using the Kolmogrov-Smirnov normalcy test prior to analysis.

One-way ANOVA was used to analyze the significant difference in physico-chemical variables. Pearson correlation was used to correlate mean grain size to the mean abundance and taxon richness. Sediments analysis was done using GRADISTAT version 9.1which provides important clues on the sediment attribution, transportation history and depositional conditions (Blott & Pye, 2001)). Four categories were used to categorize the sediment grain sizes: (a) average size; (b) size distribution (sorting); (c) symmetry or preferential spread (skewness) to one side of the average; and (d) degree of concentration of the grains in relation to the average (kurtosis). The software also was able to categorize the sediments in each sampling site into the different classes ranging from gravel to fine silt sand.

The average abundance (individual/dm^2) and comparative abundance of macroinvertebrate samples were also calculated for each site.

Diversity and eveness were determined, using the Shannon diversity index (H′), calculated as:

$H' = -\Sigma pi\ Lnpi$ (Shannon & Weaver, 1949), where pi = the proportion of the i^{th} taxon; and Σ = the summation of all values from the first to the i^{th} taxon encountered.

Shannon Evenness Index, was Calculated as:

$E = H'/Hmax$, where H' = Shannon diversity index for the sample; Hmax = maximum possible diversity for a collection of N individuals in a sample. Hmax was calculated as $Hmax = \log s$; where S is the number of species identified (Shannon & Weaver, 1949).

And Dominance (J') was calculated on the basis of evenness:

(J) as: $J' = 1 - E$ (Brower *et al.,* 1990), and was estimated for each sample at a site.

All analyses of diversities, richness and evenness were performed using PAST software (Version 3.21) and figures were created in PAST multivariate clustering and MS Excel (2016).

To reduce the dimensionality of the physico-chemical and sampling sites in the three reaches, Principal Component Analysis (PCA) was used to summarize variation in physico-chemical parameters in the sampling sites across the upstream, midstream and downstream reaches, it was calculated using XLSTAT (Version 4.1).

Canonical correspondence analysis (CCA) was used to examine the relationship between macroinvertebrate abundance and composition, water quality variables and nutrients across the reaches within the varied land uses practices.

Detrended correspondence analysis (DCA), was used to check for dataset linearity prior to applying CCA to taxonomic datasets (Lubanga, 2021). As a result, CCA was declared appropriate for the analysis.

The mean similarities of macroinvertebrates families between the sampling sites in the upstream, midstream and downstream were compared using two-way nested Analysis of Similarities (ANOSIM), with replicate land uses nested spatially. ANOSIM compares the average of ranked differences within groups to the average of ranked differences between groups. An R value near "0" indicates a consistent distribution of high and low ranks both within and between groups, whereas an R value close to "1.0" indicates group dissimilarity.

To determine the main macroinvertebrates families in the ten sampling sites attributed to changes in land uses, physico-chemical parameters and fine sediment accumulation. A Similarity Percentage Analysis (SIMPER) was employed. Each family's percentage contribution to the overall dissimilarity between site categories was calculated. SIMPER is a strictly paired analysis comparing two-factor levels (Clarke & Warwick, 2001), and comparisons were done in this instance between pristine upstream, disturbed municipality and mining midstream, and agriculturally disturbed downstream.

3.8.1 Water Velocity Determination

To calculate discharge, the flow meter readings were first converted to velocities at each vertical using the manufacturer's flow meter counts conversion formula.

Discharge (Q) was then calculated as:

$$Q = w_1 D_1 v_1 + w_2 D_2 v_2 \ldots w_n D_n v_n \text{ ....} (1)$$

Where w is the width in metres, D is the depth of the vertical in metres, v is the average velocity at each vertical ($m.s^{-1}$) and Q is the discharge in $m^3.s^{-1}$ Wetzel (2001).

3.8.2 Determination of Total Suspended Solids

Fibre Glass filters (GF/F) containing the total suspended particulate matter were dried in an oven (BINDER) at 105 ^{o}C for 1 hour to constant weight and Total Suspended Solids was determined using the equation below:

$TSS\ (mg/L) = \frac{A-B}{V} X\ 10^6$ (Onyando *et al*. 2016)

Where:

A= Weight of filter (g) + residue

B= Weight of pre- dried filter without residue (g)

V= Volume of water filtered (ml)

CHAPTER FOUR

RESULTS

4.1 Introduction

This Chapter presents detailed analyses of the physico-chemical, sediment grain size characteristics, macroinvertebrates distribution and abundance at the sampling sites along Isiukhu River.

4.2 Spatial Variation in Physico-chemical Parameters along Isiukhu River

Results in table 2 show the mean variation in physico-chemical parameters of water in Isiukhu River from upstream to downstream. There was a general increase in temperature, conductivity, turbidity, salinity, pH and oxidation-reduction potential (ORP) from the upstream to downstream. Conversely, there was a slight reduction in dissolved oxygen, percentage oxygen saturation and velocity downstream as the river traversed different land uses.

Table 2: Spatial variation of physiochemical parameters (mean± standard deviation) along Isiukhu River during the study period

Sites/Parameters	**Ichina**	**Ivakale**	**Kimangeti**	**Senyende**	**Shirere**	**Rosterman**	**Mwibatsilo**	**Shibeye**	**Mutono**	**Ekero**
Temperature (^{0}C)	19.94±0.30	20.20±0.35	20.72 ± 0.75	20.55±0.61	20.74±18.84	20.78±1.85	21.24±2.16	21.6 ± 2.29	22.15 ±1.85	22.86 ± 1.8
Conductivity (µS/cm)	71.66 ± 4	54.14±24.73	57.86 ± 22.95	83.71 ± 24.05	96.86 ± 56.50	67.57 ± 30.29	90.05 ± 27.11	92.43 ± 30.06	90.71 ± 31.04	91.71 ± 31.84
Salinity (pss)	0.044 ± 0.008	0.032 ± 0.005	0.039 ± 0.011	0.045 ± 0.013	0.043 ± 0.01	0.043 ± 0.014	0.046 ± 0.011	0.039 ± 0.016	0.049 ± 0.012	0.049 ± 0.016
Turbidity (NTU)	96.08 ± 59.53	147.79± 111.84	132.5 ± 56.61	251.68± 280.17	472.86± 581.05	463.87± 540.43	351.13± 364.76	502.74 ± 69	529.85 ± 637.90	624.62 ± 548.46
pH range	6.72 - 9.5	6.65 - 9.81	6.96 - 9.54	7.18 - 9.66	7.02 - 9.54	7.16 - 9.71	7.33 - 9.7	6.67 - 9.73	6.63 - 9.5	6.68 - 9.48
Dissolved oxygen (mg/L)	7.0 ± 3.06	8.21 ± 5.04	9.13 ± 5.5	8.53 ± 5.3	7.42 ± 4.7	7.38 ± 5.4	7.05 ± 4.33	7.65 ± 4.11	7.01 ± 6.03	7.93 ±4.85
Oxygen saturation (%)	75.0 ± 31.97	58.73±38.64	73.78 ± 37.51	75.73 ± 38.95	77.31 ± 39.64	80.84 ± 36.31	79.42 ± 37.3	80.29 ± 34.4	83.88 ± 42.45	85.33 ± 44.33
ORP (mV)	306.81± 43.57	296 ± 115.80	309.24± 27.19	277.24± 43.77	322.81 ± 55.15	327.81 ± 38	327.19 ± 37.35	334.57 ± 38.56	337.69 ± 32.85	340.9 ± 32.28
Velocity (m/s)	0.41± 0.39	0.303 ± 0.322	0.165 ± 0.16	0.166 ± 0.20	0.291 ± 0.28	0.17 ± 0.2	0.31± 0.3	0.29 ± 0.27	0.248 ± 0.23	0.208 ± 0.19
Depth (m)	0.03 ± 0.02	0.042 ± 0.02	0.11 ± 0.2	0.051 ± 0.03	0.0409 ± 0.026	0.063 ± 0.037	0.076 ± 0.039	0.066 ± 0.04	0.161 ± 0.22	0.154 ± 0.115
TSS (mg/L)	302.14 ± 74.71	137.86 ± 43.96	110.71 ± 36.90	221.43 ± 71.22	370 ± 43.11	429.29 ± 30.88	366.43 ± 47.50	349.29 ± 43.34	415 ± 48.90	525.71 ± 76.94

4.2.1 Temperature

There was a general increase in temperature from upstream to downstream of Isiukhu River during the study (Figure 2). The highest temperature (22.86 ± 1.8 ºC) was observed at Ekero downstream while the lowest mean temperature (19.94±0.30 ºC) was recorded at Ichina sampling site upstream. Observed temperatures were withing the recommended WHO guidelines (WHO, 2011).

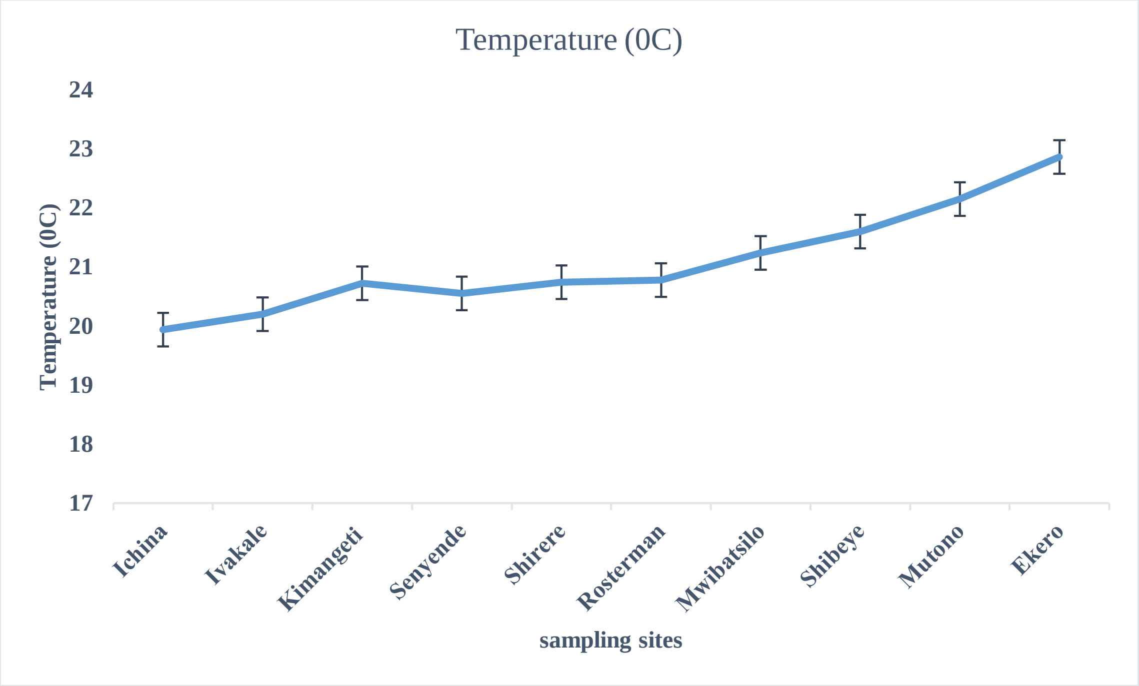

Figure 2: Mean temperature trend along the Isiukhu River

4.2.2. Electrical Conductivity

The mean conductivity was highest at Shirere (96.86 ± 56.50 µS/cm) sampling site in the midstream while the lowest at Ivakale (54.14±24.73) upstream (Figure 3). The downstream sampling sites of Shibeye, Mutono and Ekero recorded conductivity values of above 90 µS/cm indicating reducing conductivity downstream. In all the sampling sites conductivity values were within the WHO recommended limits.

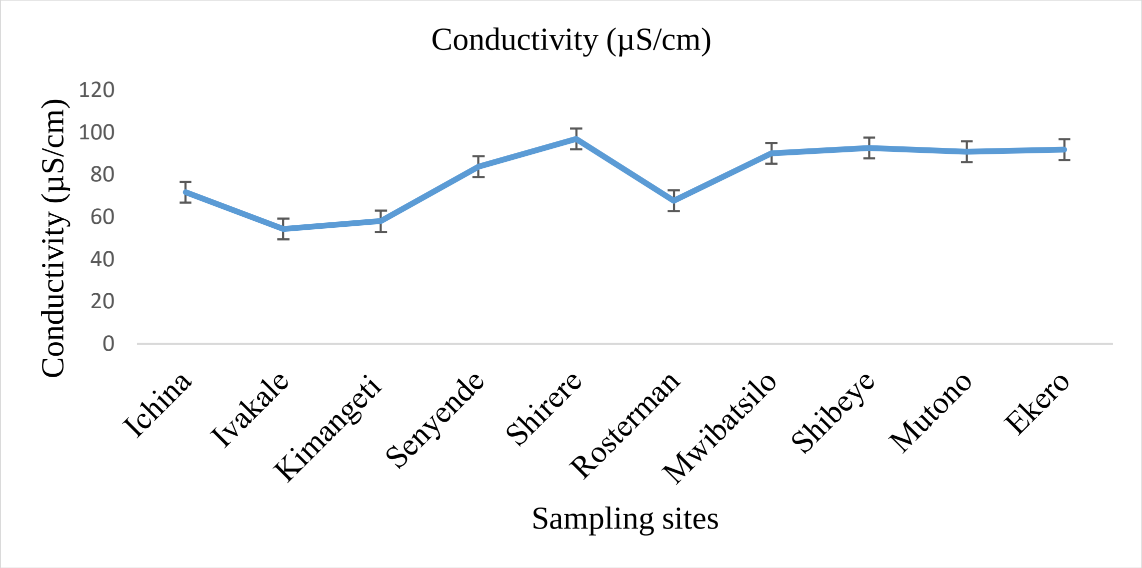

Figure 3: Mean Conductivity trend along the Isiukhu River

4.2.3. Salinity

Salinity did show a clear trend; however, the highest mean salinity was recorded at the downstream sites. The sampling sites of Mutono and Ekero had mean salinity values of 0.049 ± 0.02 pss and 0.049 ± 0.01pss respectively while the lowest was at Ivakale site (0.032 ± 0.005 pss) in the upstream (Figure 4).

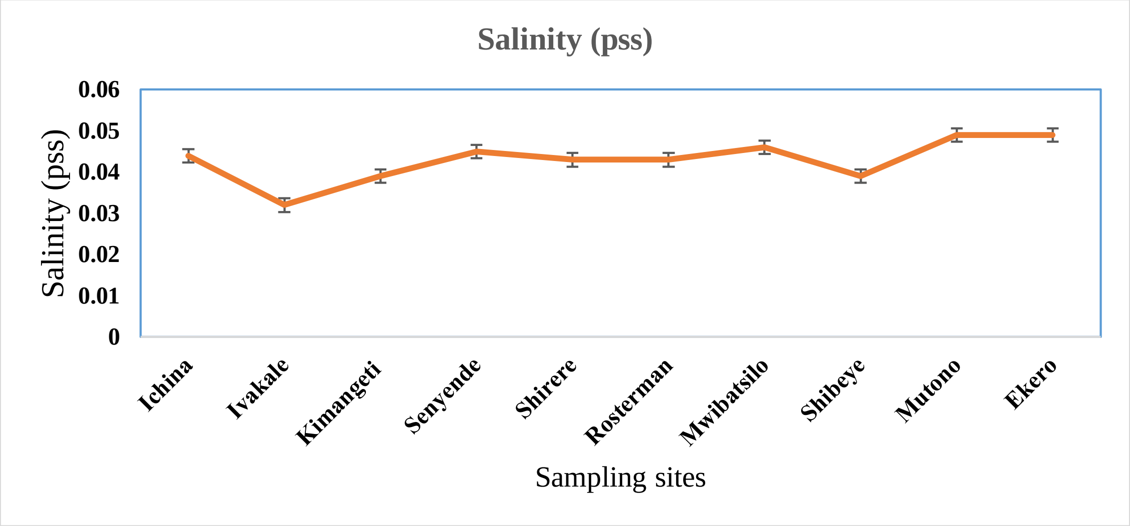

Figure 4: Mean Salinity trend along the Isiukhu River

4.2.3. Turbidity

Turbidity increased downstream. The highest turbidity was measured at Ekero site (624.62 ± 548.46 NTU) at the downstream and the lowest (96.08 ± 59.53 NTU) at Ichina sampling site in the upstream Figure 5).

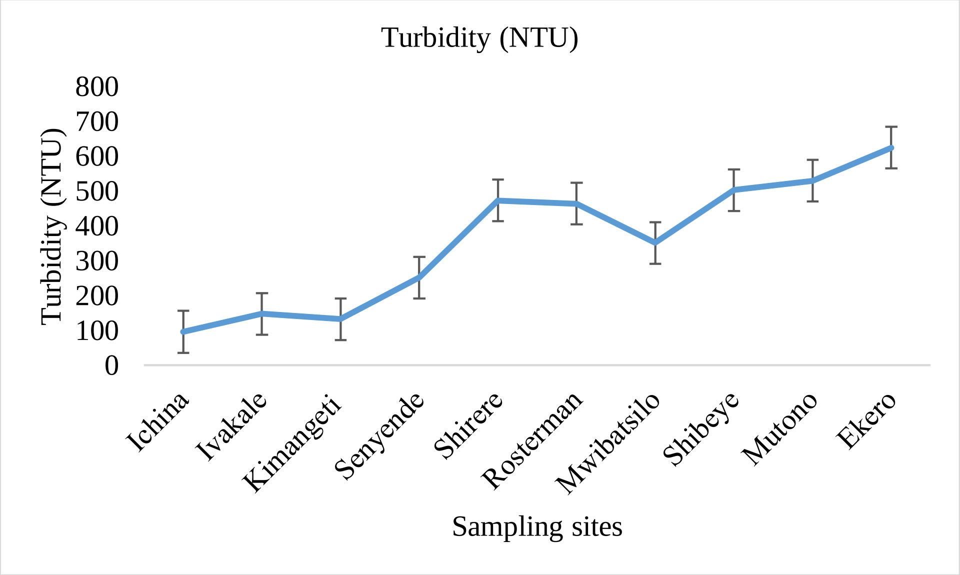

Figure 5: Mean Turbidity trend along the Isiukhu River

4.2.4. pH

The mean pH showed a slight increase from upstream to downstream of the river. The pH ranged from 7.84 at Ichina sampling site in the upstream to 8.29 at Mwibatsilo in the downstream (Figure 6). The highest pH range was recorded at Mwibatsilo (7.33–9.7) sampling site in the downstream while the lowest was recorded at Ichina (6.72 – 9.5) in the upstream. The mean pH at the upstream sites of Ichina, Ivakale ranged between 6.72–6.96, at the midstream sites it ranged between 7.05–7.42 while downstream sites it ranged between 6.63–6.68. All the pH values were within the WHO (2011) recommended limits.

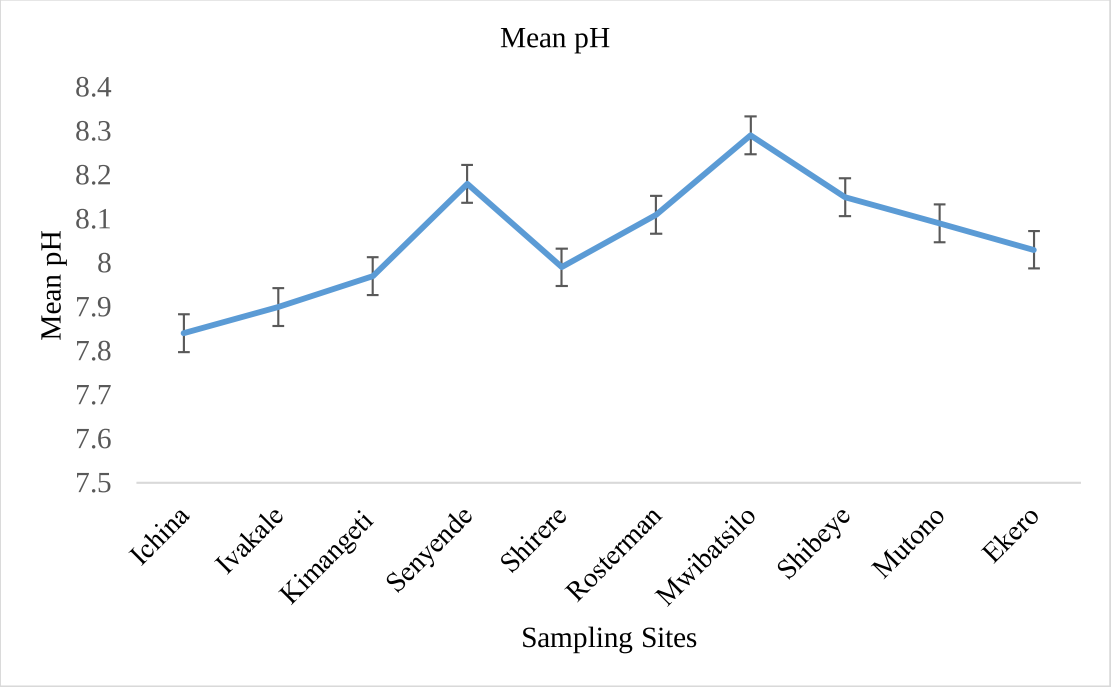

Figure 6: Mean pH trend along the Isiukhu River

4.2.5. Dissolved oxygen

The highest mean dissolved oxygen (9.13±5.5 mg/L) was recorded at Kimangeti sampling site in the upstream while the lowest was recorded at Ichina (7.0 ± 3.06 mg/L) in the upstream and Mutono (7.01) in the downstream (Table 2).

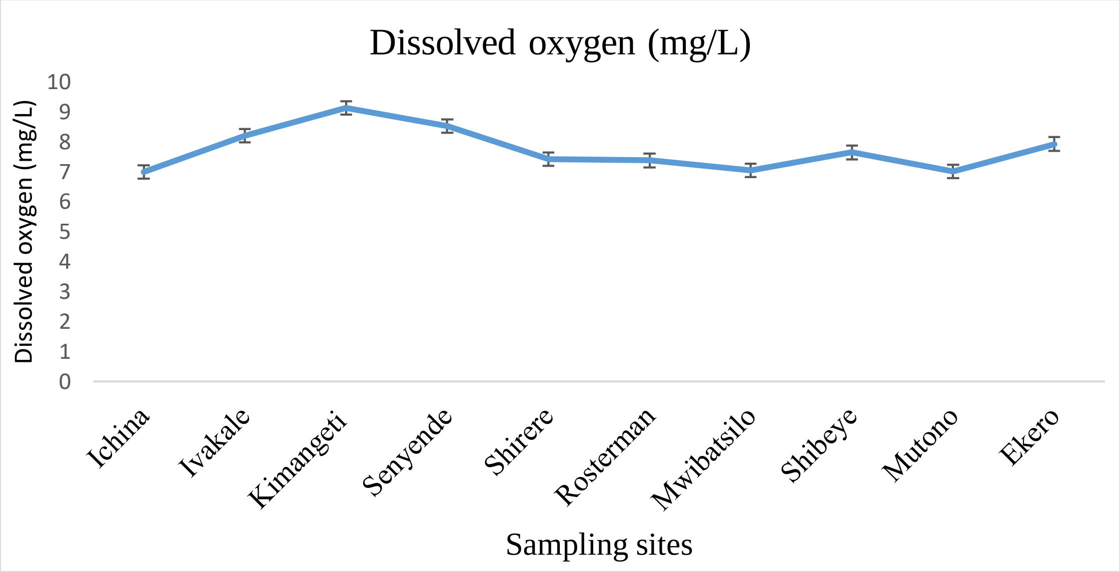

Figure7: Mean Dissolved oxygen trend along the Isiukhu River

4.2.6. Total Suspended Solids

There was a general increase in TSS from the upstream to the downstream. The highest TSS was recorded in Ekero (525.71±76.94) in the downstream while the lowest was recorded in the unpstream site of Kimangeti (110.71±36.90; Figure 8).

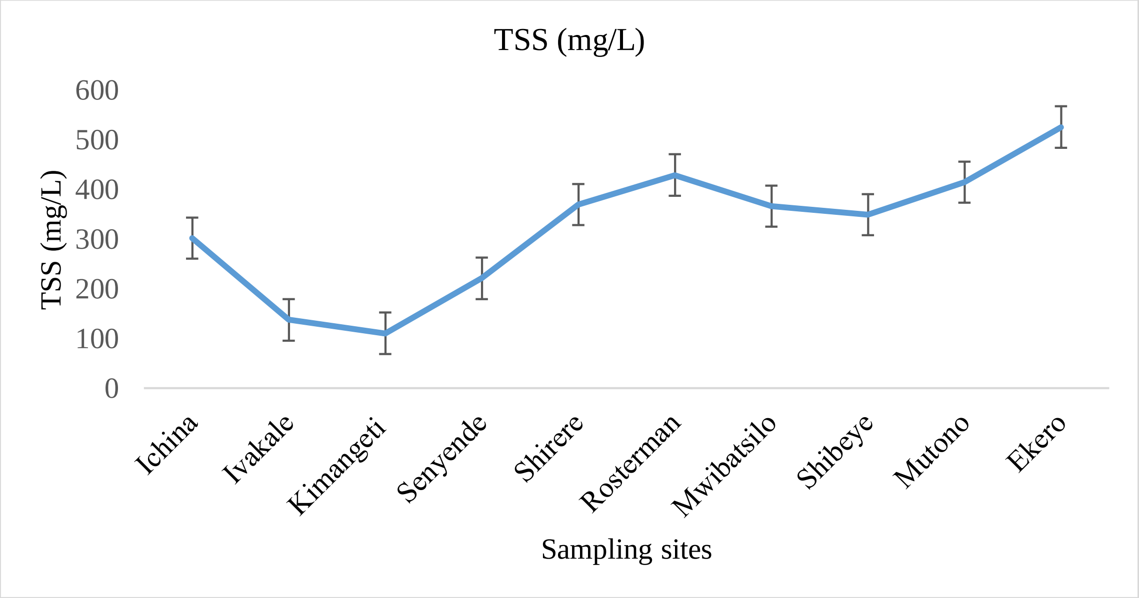

Figure 8: Mean TSS (mg/L) trend along the Isiukhu River

4.2.7 Nitrate and Phosphates

Trend in nitrates concentrations in river water ranged between 0.076±0.014mg/l at Ichina in the upstream to 0.98±0.032mg/L at Rosterman in midstream (Figure 8). The coefficient of variation result showed that nitrate concentration in water varied significantly (0.32–1.25) within all the 10 sampling sites studied (Table 3). Isiukhu River 's water nitrate concentrations were below the acceptable limits receommended by NEMA (2006).

Phosphate concentration in river water samples ranged from 1.13±0.046 mg/L in Ichina to 3.05 ± 0.27 mg/L in the Ekero (Table 3). The coefficient of variation results revealed that phosphate concentration varied significantly (0.59-0.33) across all sampling sites analysed. Phosphate concentrations in Isiukhu River water were higher that than the allowable maximum by WHO (2021) for drinking water in all sampling sites analysed.

Table 3: Concentration of phosphates and nitrates (Mean ± Standard error values) in water of Isiukhu River, Kenya

Nutrients	Sites	Ichina	Ivakale	Kimangeti	Senyende	Shirere	Rosterman	Mwibatsilo	Shibeye	Mutono	Ekero
nitrates (mg/L)	Mean± standard error	0.076± 0.014	0.131± 095	0.254± 0.117	0.67±0.148	0.184± 0.075	0.98±0.032	0.104± 0.034	0.152± 0.02	0.116± 0.036	0.089± 0.027
	CV	0.32	1.25	0.79	0.39	0.7	0.86	0.57	0.23	0.53	0.52
Phosphates (mg/L)	Mean± standard error	1.13±0.046	1.64 ± 0.178	1.68 ± 0.25	1.99 ± 0.034	2.02 ± 0.48	2.49 ± 0.31	2.67 ± 0.28	2.84 ± 0.40	2.95 ± 0.38	3.05 ± 0.27
	CV	1.23	0.97	0.83	1.33	0.59	0.92	0.98	0.85	0.9	1.07

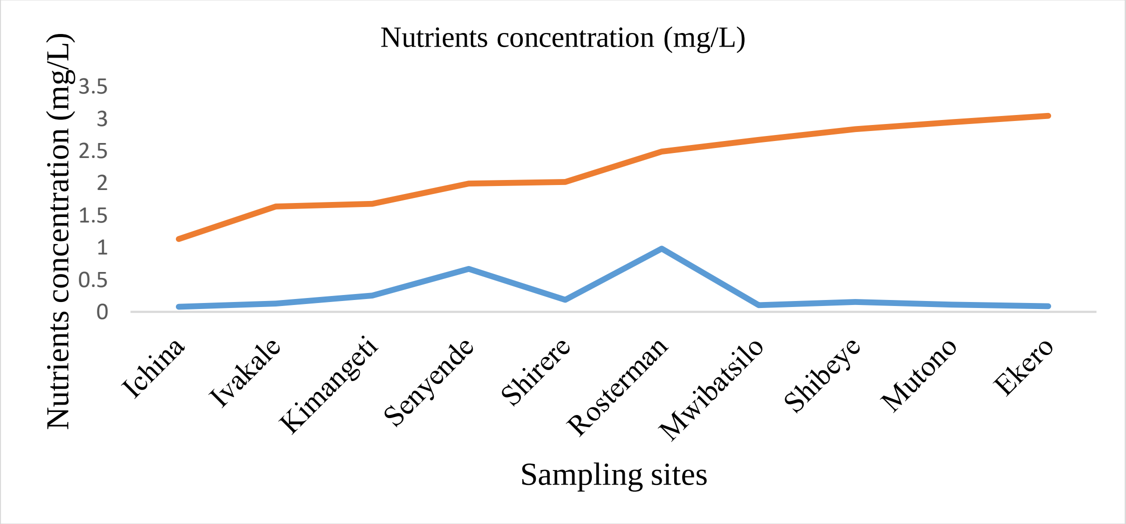

Figure 9: Phosphates and nitrates concentration in Isiukhu River water

The similarities among physico-chemical water quality and sampling sites variables in the river are summarized in figure 10. In this PCA plot, the F1 axis explained 47.06% of the similarity in total data, while PCA F2 axis explained only 21.34% of the total variance in water physico-chemical among sites. Rosterman at the midstream and Mutono at the downstream were associated with higher levels of temperature, turbidity, pH, phosphates and DO% than the other sites. Ekero (in the downstream), Shibeye (in the downstream), Mwibatsilo (in the midstream) and Shirere (in the midstream) were associated with higher ORP, TSS, salinity and SPC. The upstream sampling sites of Kimangeti and Senyende were associated with high levels of nitrates and dissolved oxygen while Ichina and Ivakale were associated with high velocity (Figure 10).

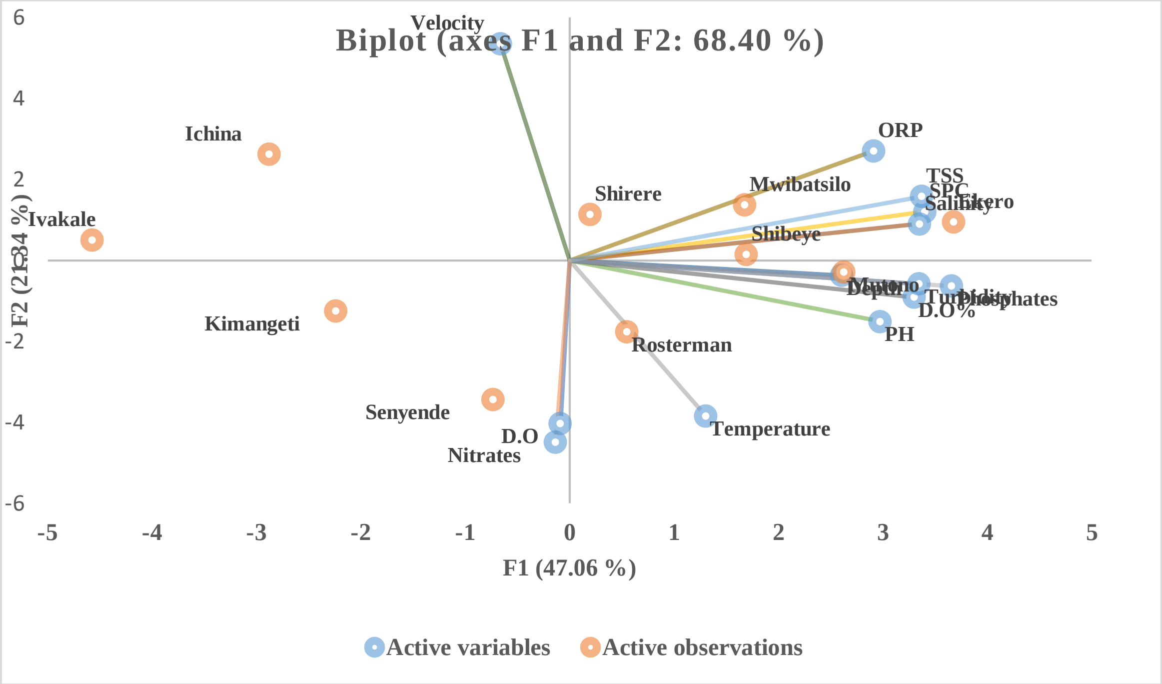

Figure 10: Principal component analysis of physico-chemical parameters and nutrients in the Isiukhu River, Kenya (In all the sampling sites n = 10).

Phosphates levels were higher than nitrates in all the sampling sites from the upstream to downstream (Figure 11). Both of them varied significantly across the sampling sites (P >0.05). Ekero sampling site at the downstream recorded level of phosphates 3.05 ± 0.27 mg/L in while Rosterman sampling site at the midstream recorded highest level of nitrates 0.98±0.032mg/L.

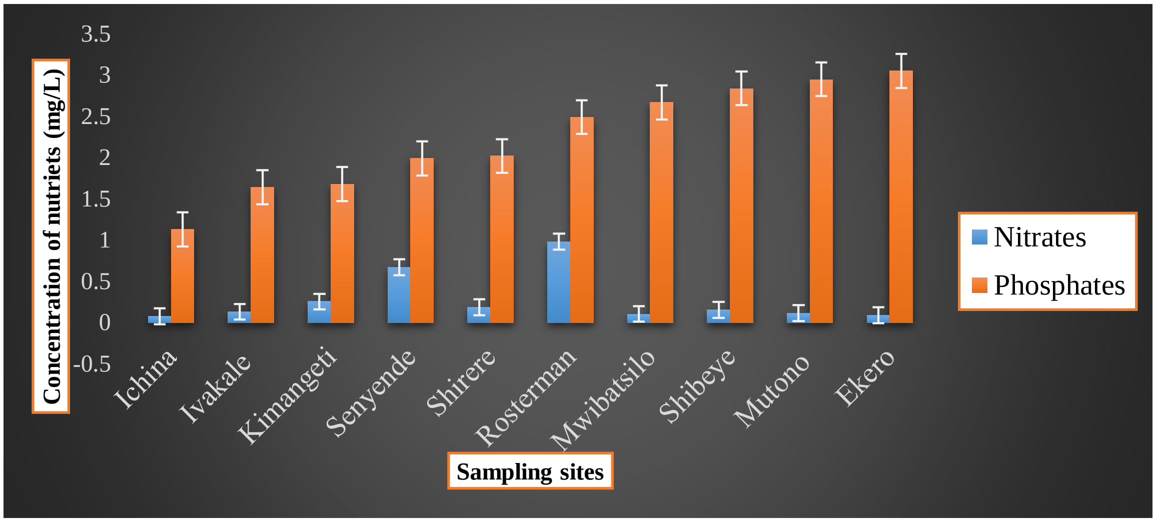

Figure 11: Variation in nitrates and phosphates concentration in the ten sampling in the Isiukhu River, Kenya within the upstream, midstream and downstream reaches during the study period. Error bar represent standard error.

Results of Pearson correlation coefficient (r) among physico-chemical parameters showed some significant relationship with each other at p <0.05 as shown in table 4. The results showed a positive significant relationship between Specific conductivity and salinity (r = 0.724), SPC and DO% (r = 0.750), SPC and turbidity (r = 0.811), SPC and TSS (0.737), SPC and Phosphates (0.675), pH and salinity (r = 0.648), pH and turbidity (r = 0.659), pH and phosphates (r = 0.814), depth and salinity (r = 0.705), depth and phosphates (r= 0.661), salinity and DO% (r = 0.722), salinity and TSS (0.699), salinity and phosphates (r = 0.688), DO% and turbidity (r = 0.682), DO% and TSS (r = 0.722), DO% and phosphates (r = 0.639), ORP and TSS (r = 0.783), ORP and phosphates (r = 0.697), turbidity and TSS (r = 0.708), turbidity and phosphates (r = 0.844) and TSS and phosphates (0.728). A negatively correlation was observed between DO and velocity (r = -0.632) and velocity and nitrates (-0.680) (Table 4).

Table 4: Pearson correlation coefficient (r) between physico-chemical parameters in all sampling sites in Isiukhu River, Kenya

Variables	**Temperature**	**SPC**	**D.O**	**PH**	**Depth**	**Salinity**	**D.O%**	**ORP**	**Turbidity**	**Velocity**	**TSS**	**Nitrates**	**Phosphates**
Temperature	**1**												
SPC	0.31	**1**											
D.O	0.18	-0.21	**1**										
PH	0.45	0.52	-0.04	**1**									
Depth	0.20	0.40	0.29	0.35	**1**								
Salinity	0.25	**0.72**	-0.19	**0.65**	**0.71**	**1**							
D.O%	0.33	**0.75**	0.13	0.55	0.44	**0.72**	**1**						
ORP	-0.36	0.60	-0.14	0.35	0.57	060	0.53	**1**					
Turbidity	0.38	**0.81**	0.05	**0.66**	0.33	0.45	**0.68**	0.58	**1**				
Velocity	-0.54	0.09	**-0.63**	-0.32	-0.31	-0.03	-0.22	0.19	-0.17	**1**			
TSS	0.07	**0.77**	-0.30	0.48	0.44	**0.70**	**0.72**	**0.78**	**0.71**	0.122	**1**		
Nitrates	0.33	-0.2	0.34	0.18	-0.26	-0.22	0.22	-0.31	0.07	**-0.68**	0.01	**1**	
Phosphates	0.30	**0.68**	0.13	**0.81**	**0.66**	**0.69**	**0.64**	**0**	**0.84**	-0.253	**0.73**	0.003	**1**

Values in bold are different from 0 with a significance level alpha=0.05

4.2 Sediment Grain size characteristics

Results in table 5 show percentage sediment grain size composition, sample types, textural groups and sediment types from upstream at Ichina sampling site to downstream at Ekero in Isiukhu River. The highest percentage of sediment grain size at all sampling sites consist of gravel, sand, mud and clay.

Sediments in Isiukhu River were characterised as polymodal and extremely poorly sorted in the upstream and downstream but trimodal and extremely poorly sorted in the midstream. The upstream to downstream had poorly-sorted sediments with varying grains sizes indicating that the sediments have not undergone much transport. Whereas the upstream sediments (at Ichina, Ivakale and Kimangeti sampling sites) are fine gravelly mud and very coarse gravelly mud, the downstream sediments (at Shibeye, Mutono and Ekero) were very coarse gravelly muddy very fine sand and very fine gravelly clayey very fine sand indicating that the sediments get finer (i.e., mainly clay silt and sand) moving from upstream to downstream of Isiukhu River.

Table 5: Percentage sediment grain size composition, textural groups and sediment types along Isiukhu River, Kenya

Sediments/Site	**Ichina**	**Ivakale**	**Kimangeti**	**Senyende**	**Shirere**	**Rosterman**	**Mwibatsilo**	**Shibeye**	**Mutono**	**Ekero**
Gravel	28.7	27.9	28.1	5.3	12.3	34.7	36.6	32.9	22.0	27.4
Sand	32.0	31.9	46.9	53.7	69.2	54.4	43.5	46.4	39.0	50.0
Mud	39.3	40.2	25.0	40.9	18.5	10.9	19.9	20.7	38.9	22.7
V. Coarse Gravel	3.9	14.3	0.4	0.1	2.5	18.2	4.7	3.2	7.3	5.5
Coarse Gravel	9.9	3.8	0.3	1.0	3.1	7.0	7.4	7.1	5.1	3.0
Medium Gravel	1.3	2.2	0.2	0.2	2.0	0.9	7.0	3.8	0.8	1.2
Fine Gravel	11.1	5.0	26.2	1.6	2.4	4.1	9.5	10.0	6.1	2.0
V. Fine Gravel	2.5	2.6	1.0	2.4	2.4	4.4	8.0	8.7	2.6	15.6
V. Coarse Sand	7.2	7.6	11.2	0.9	1.8	2.2	8.7	8.4	4.9	1.5
Coarse Sand	1.2	4.6	1.9	2.0	2.0	10.9	5.3	6.2	2.1	6.7
Medium Sand	7.2	0.8	1.3	2.4	9.4	1.8	7.0	7.1	4.7	4.7
Fine Sand	2.6	2.2	19.1	4.4	26.1	19.2	11.7	11.6	2.2	1.7
Very Fine Sand	13.9	16.8	13.3	44.0	29.9	20.3	10.8	13.1	25.1	35.4
V. Coarse Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Coarse Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Medium Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Fine Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Very Fine Silt	3.4	3.3	2.0	3.5	1.6	0.9	1.7	1.6	3.3	0.0
Clay	22.3	23.8	14.8	23.5	10.7	6.4	11.4	12.5	22.6	22.6
Sample Type	Polymodal, Extremely	Polymodal, Extremely	Trimodal, Extremel	Unimodal, Very Poorly Sorted	Trimodal, Very	Polymodal, Extremel	Polymodal, Extremely	Polymodal, Extremel	Polymodal, Extremely Poorly Sorted	Trimodal, Extremely Poorly Sorted

Sediment Textural Groups	Poorly Sorted Gravelly Mud	Poorly Sorted Gravelly Mud	y Poorly Sorted Gravelly Muddy Sand	Gravelly Muddy Sand	Poorly Sorted Gravelly Muddy Sand	y Poorly Sorted Muddy Sandy Gravel	Poorly Sorted Muddy Sandy Gravel	y Poorly Sorted Muddy Sandy Gravel	Gravelly Muddy Sand	Gravelly Muddy Sand
Sediment Type	Fine Gravelly Mud	Very Coarse Gravelly Mud	Fine Gravelly Muddy Fine Sand	Very Fine Gravelly Muddy Very Fine Sand	Coarse Gravelly Muddy Very Fine Sand	Muddy Sandy Very Coarse Gravel	Muddy Sandy Fine Gravel	Muddy Sandy Fine Gravel	Very Coarse Gravelly Muddy Very Fine Sand	Very Fine Gravelly Clayey Very Fine Sand

Table 6 results show spatial distribution of mean grain size, sorting coefficient, skewness and kurtosis of sediments along the river. Rosterman sampling site in the midstream had the highest mean sediment grain size (9.97 mm), followed by Ivakale, upstream (7.69 mm) and the least grain size of 0.56 mm was recorded at Senyende in the midstream.

The sorting coefficient ranged from 2.97φ at Senyende site (upstream) to 20.27φ at Rosterman in the midstream. The skewness of sediment samples was high and ranged from 6.59 at Rosterman in midstream to 158 at Senyende sampling site upstream of the river.

The calculated high kurtosis means more of the variance is as a result of infrequent extreme deviations in sediment grain size distribution in the river hence the extremely very poor sorting of sediments in Isiukhu River during the study.

Table 6: Spatial distribution of mean grain size, sorting coefficient, skewness and kurtosis of sediments along Isiukhu River, Kenya during the study period

	Sediment Grain Size Parameters			
Sampling Sites	**Mean Grain Size) (mm)**	**Sorting Coefficient (φ)**	**Skewness**	**Kurtosis**
Ichina	4.93	11.55	3.60	18.45
Ivakale	7.69	18.32	2.66	9.10
Kimangeti	2.02	3.97	8.34	125.60
Senyende	0.56	2.97	10.60	158.10
Shirere	2.34	9.33	6.13	44.83
Rosterman	9.97	20.27	2.16	6.59
Mwibatsilo	5.51	12.03	3.68	18.73
Shibeye	4.46	10.53	4.20	24.35
Mutono	4.91	14.01	3.66	16.55
Ekero	3.83	12.29	4.60	24.85

4.3 Spatial Variation of Macroinvertebrate Taxa in Isiukhu River

Table 7 shows the spatial variation in percentage relative abundance of families of macroinvertebrates identified in sampling sites along Isiukhu River. A total of 993 individual macroinvertebrates in 21 families were identified from all the 10 sampling sites. The macroinvertebrate families were dominated by Veliidae (Water striders), Gerridae (Water striders), Notonectidae (Backswimmers) and Heptagenidae (Mayflies). The families were not evenly distributed in all sampling sites in the river. The upstream sampling sites were mainly dominated by Vellidae, Gyrinidae, Gerridae and Notonectidae families, the midstream sites were dominated by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Belostomatidae families and the downstream sites of Shibeye, Mutono and Ekero by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Dictynidae

Table 7: Spatial variation in percentage relative abundance of families of macroinvertebrates identified in sampling sites along Isiukhu River, Kenya (Total number of individual macroinvertebrates collected 993 consisting of 21 families)

	Sampling Sites									
Macroinvertebrate Families	**Ichina**	**Ivakale**	**Kimangeti**	**Senyende**	**Shirere**	**Rosterman**	**Mwimbatsilo**	**Shibeye**	**Mutono**	**Ekero**
Veliidae	29	12	29	31	49	23	24	14	0	10
Gyrinidae	4	13	0	0	0	5	6	0	9	0
Gerridae	12	12	0	1	0	3	15	0	18	65
Notonectidae	40	17	34	21	5	15	9	14	0	10
Cybaeidae	1	0	0	1	3	15	3	33	9	5
Heptagenidae	1	28	17	27	27	15	6	10	18	0
Chironomidae	3	0	0	0	0	0	0	0	0	0
Aeshnidae	3	0	7	0	0	0	0	0	0	0
Belostomatidae	7	3	1	15	11	18	21	0	0	0
Psepheridae	0	0	0	0	0	0	0	0	9	0
Neritidae	0	3	0	0	0	0	9	0	9	0
Perlidea	0	1	0	2	0	0	0	0	0	0
Naucoridae	0	1	0	0	0	0	0	5	0	0
Reduviidae	0	1	1	0	0	0	0	0	0	0
Oligonueriidae	0	3	3	1	3	5	0	10	0	0
Calopterigidae	0	3	2	0	0	0	0	0	0	0
Coenagrionidae	0	1	3	0	0	0	0	0	0	0
Hydrophilidae	0	0	1	0	0	0	3	0	0	0
Dictynidae	0	0	2	0	3	0	0	10	18	10
Elmidae	0	0	0	0	0	0	0	5	0	0
Gomphidae	0	0	0	0	0	0	0	0	9	0

The other macroinvertebrates families were moderately represented across sampling sites. Notonectidae was the dominant family and accounted for largest percentage (35%) of all the families. followed by Veliidae (33%), Gyrinidae (15%) and Gerridae (11%) (Figure 12). The families Elmidae, Perlidea, Chironomidae and Aeshnidae were the smallest and accounted for 1%.

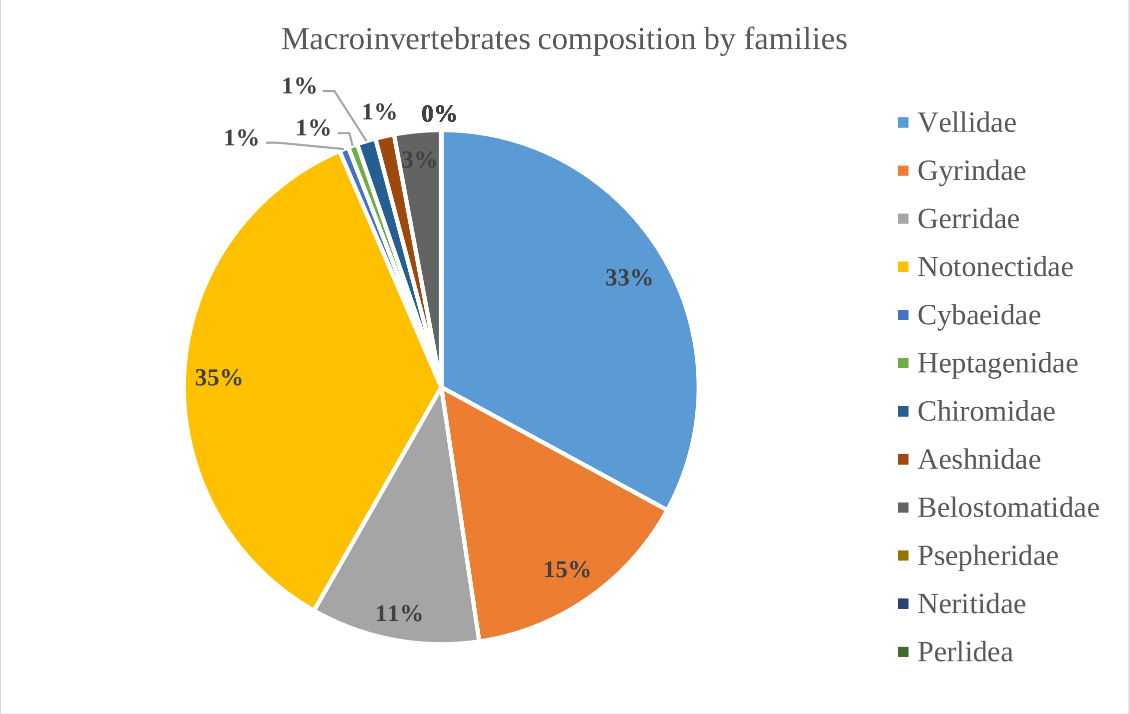

Figure 12: Percentage composition of macroinvertebrates families collected in Isiukhu River during the study period.

Most of the macroinvertebrates collected and identified were at Ichina (18%), followed by Ivakele (17%). The lowest abundance of macroinvertebrates was at Shibeye and Ekero (4%) and Mutono (3%) (Figure 13).

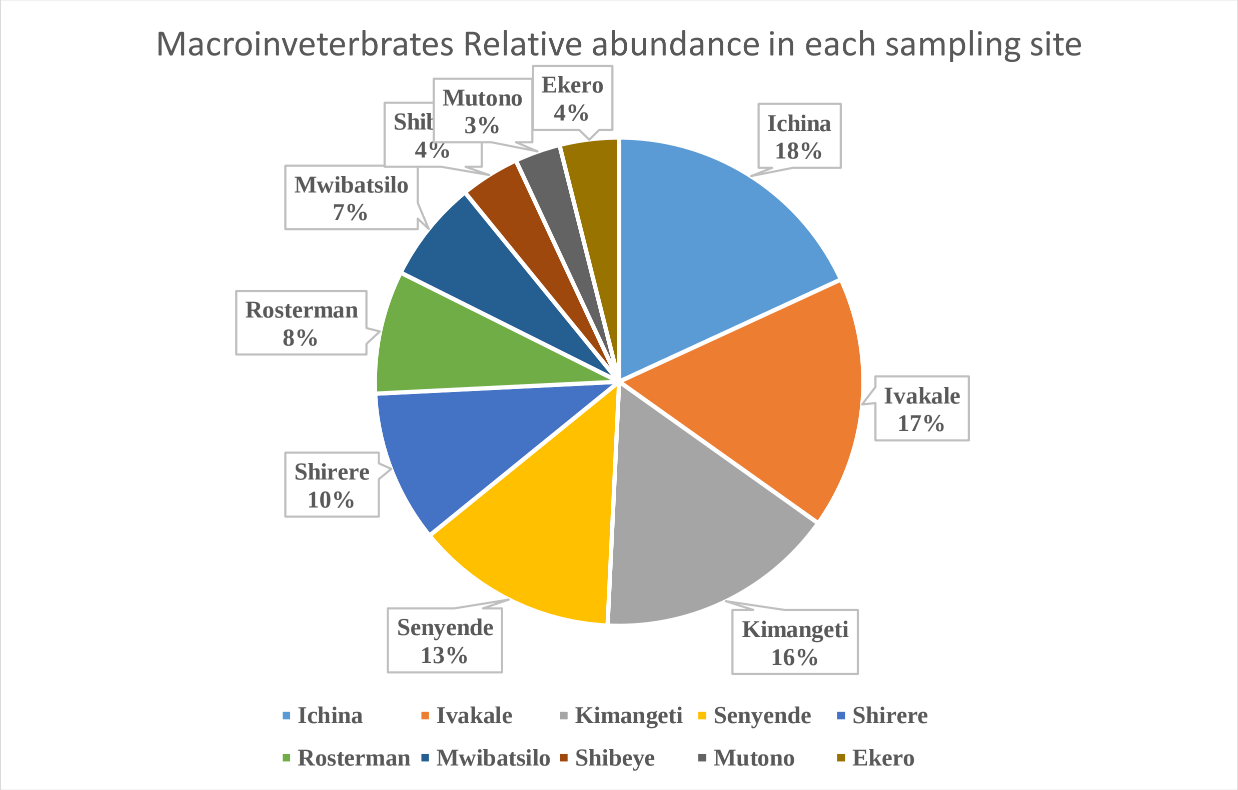

Figure 13: Relative abundance of macroinvertebrates families collected at each sampling site in Isiukhu River during the study period.

Results in Table 8 show the spatial variation in mean abundance, diversity and taxon richness of macroinvertebrates. There was a general decrease in macroinvertebrates mean abundance, number of taxa and taxon richness from upstream to downstream sampling sites in the river. The highest mean abundance of macroinvertebrates (100±9.2 individuals) was recorded in the upstream at Kimangeti followed by Senyende (91±8.4) and Ivakale (90 ±6.3), while the least was at Mutono (11±0.7) in the downstream (Table 8).

Diversity was high at the undisturbed upstream sites and lower at the disturbed midstream and downstream sites. The Shannon diversity index of 2.218 was greater at the Kimangeti site in the upstream but lowest at the Ekero site in the downstream. The Shannon evenness followed the same pattern as the Shannon diversity index with the highest value (0.865) and the lowest value (0.670) at the Ekero site in the downstream. However, dominance index showed a completely different trend with highest value at Ekero (0.3296) in the downstream while lowest value at Rosterman (0.1354) in the midstream (Table 8).

Table 8: Spatial variation in abundance (mean ± standard deviation, n = 21), Diversity indices and taxon richness of macroinvertebrates in the Isiukhu River, Kenya

SITES	**Ichina**	**Ivakale**	**Kimangeti**	**Senyende**	**Shirere**	**Rosterman**	**Mwibatsilo**	**Shibeye**	**Mutono**	**Ekero**
Individuals	180	166	158	133	100	81	67	39	30	39
Taxon Richness	10	14	11	8	7	8	10	8	8	5
Mean Abundance	75 ±7.4	90 ±6.3	100±9.2	91±8.4	37±4.1	39±2.8	34±2.3	21±1.7	11±0.7	20±2.7
Shannon Diversity Index (H)	1.6517	2.0263	2.2177	1.7184	1.388	1.8253	1.7735	1.7545	1.7275	1.2012
Shannon Evenness(J)	0.7173	0.74825	0.8646	0.7463	0.632	0.8307	0.7396	0.762	0.7862	0.67
Dominance (1-J′)	0.2827	0.25175	0.1354	0.2537	0.367	0.1693	0.2604	0.238	0.2138	0.32

Results in Table 9 show top-ranked SIMPER results in the composition of macroinvertebrates families mean abundance between ten sampling sites in the upstream, midstream and downstream. ANOSIM revealed significant differences in distribution, abundance and composition of macroinvertebrates among sampling sites in the upstream, midstream and downstream of Isiukhu River (R-statistic =0.883, *P*<0.0001). These finding suggest a dissimilarity between macroinvertebrates groups. SIMPER's comparisons of macroinvertebrates family abundance between ten sampling sites distributed in the upstream, midstream and downstream reaches identified Veliidae (21.88%), Gyrinidae (16.41%), Notonectidae (15.87%) Heptagenidae (8.502%), and Gerridae (6.529%), as the major families contributing the greatest dissimilarity between the sampling sites with higher abundance in the upstream sites of Ichina, Ivakale, Kimangeti and Senyende (Table 9). The families of Elmidae (0.2336%), Psepheridae (0.2505%), Chironomidae (0.2531%) and Naucoridae (0.3347%) were identified with the lowest dissimilarity between the ten sampling sites, with their abundance in the downstream sampling sites of Ekero, Mutono and Shibeye.

Table 9. Top-ranked SIMPER results in the composition of macroinvertebrates families mean abundance among ten sampling sites in the upstream, midstream and downstream in Isiukhu River

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean Ichina	Mean Ivakale	Mean Kimangeti	Mean Senyende	Mean Shirere	Mean Rosterman	Mean Mwibatsilo	Mean Shibeye	Mean Mutono	Mean Ekero
Vellidae	13.85	21.88	21.88	28	27	14.5	24	14	10	15	7.5	0	1
Gyrindae	10.38	16.41	38.29	12.5	18	10	10	25	6	6	0	5	0
Notonectidae	10.04	15.87	54.16	30	7.5	17	9.5	1	3	1.5	1.5	0	10
Heptagenidae	5.38	8.50	62.67	0.5	10	8.5	12.5	5	3	1	1	1	0
Cybaeidae	5.23	8.27	70.94	0.5	0	0	0.5	0.5	12.5	0.5	5.5	5	0.5
Gerridae	4.13	6.53	77.47	9	5	0	0.5	0	0.5	2.5	0	1	6.5
Belostomatidae	3.12	4.93	82.39	2.5	1.5	0.5	8.5	2	3.5	3.5	0	0	0
Dictynidae	2.22	3.51	85.9	0	0	8.5	0	1	0	0	0.5	1	1.5
Halobatinae	1.72	2.71	88.61	5	2.5	2.5	1	1	1	0.5	0.5	0.5	0.5
Coenagrionidae	1.01	1.59	90.21	0	5	1.5	0	0	0	0	0	0	0
Reduviidae	0.99	1.57	91.78	0	0.5	5	0	0	0	0	0	0	0
Oligonueriidae	0.91	1.44	93.22	0	1.5	1.5	0.5	0.5	1	0	1	0	0
Hydrophilidae	0.89	1.40	94.62	0	0	5	0	0	0	0.5	0	0	0
Neritidae a	0.69	1.10	95.72	0	1.5	0	0	0	0	1.5	0	0.5	0
Aeshnidae	0.69	1.09	96.81	1	0	3.5	0	0	0	0	0	0	0
Gomphidae	0.43	0.68	97.49	0	0	0	0	0	0	0	1	0.5	0
Calopterigidae	0.37	0.58	98.07	0	1.5	1	0	0	0	0	0	0	0
Perlidea	0.24	0.38	98.45	0	0.5	0	1	0	0	0	0	0	0
Avenae	0.23	0.36	98.81	0	0	0	0	0	0	1	0	0	0
Naucoridae	0.21	0.33	99.15	0	0.5	0	0	0	0	0	0.5	0	0
Chiromidae	0.16	0.25	99.40	1	0	0	0	0	0	0	0	0	0
Psepheridae	0.16	0.25	99.65	0	0	0	0	0	0	0	0	0.5	0
Elmidae	0.15	0.23	99.88	0	0	0	0	0	0	0	0.5	0	0

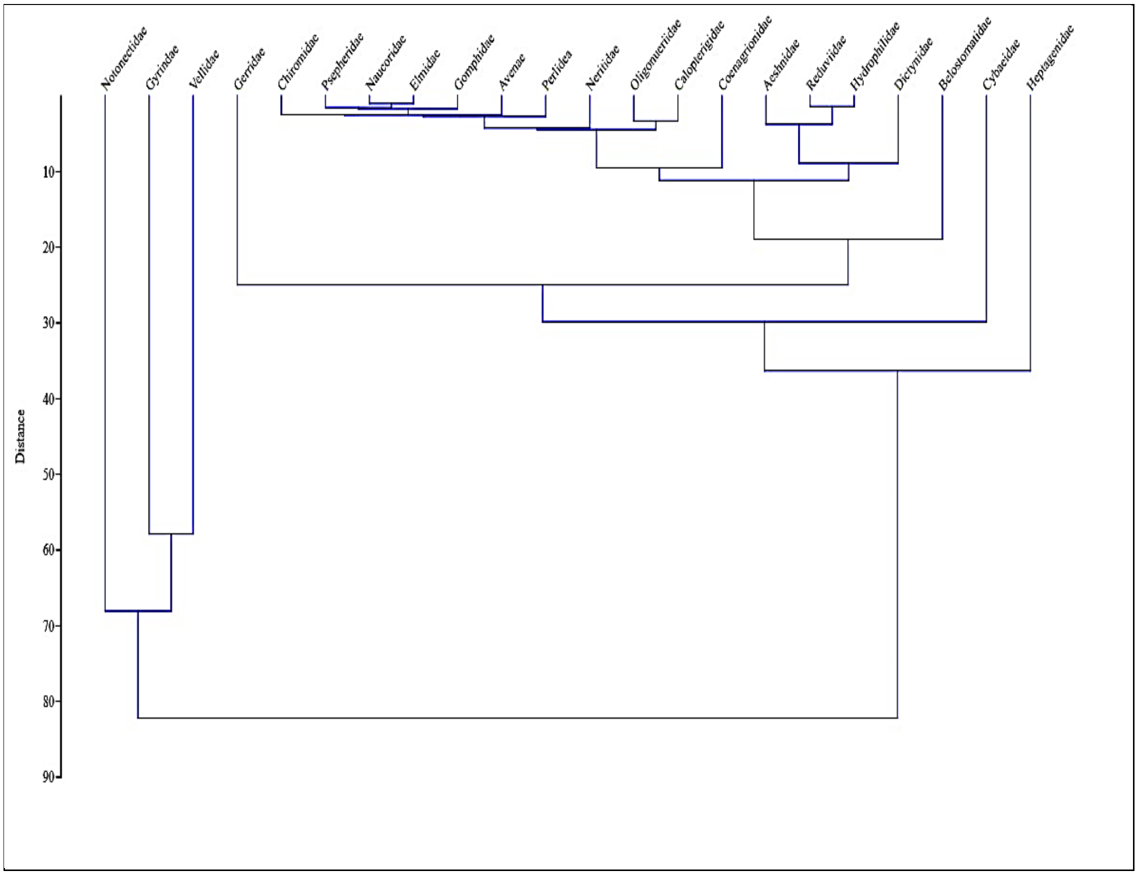

Figure 14: Dendrogram showing similarity in distribution of different families at each sampling site in Isiukhu River during the study period.

4.4 Relationship between physico-chemical parameters, Substrate Characteristics and Macroinvertebrate Abundance

Results in table 10 show correlation between physico-chemical parameters and macroinvertebrates families. The family Vellidae showed a strong positive correlation with percent dissolved Oxygen (r=0.702) but negative correlation with depth (r=-0.832), salinity (r=-0.693), ORP (r=-0.827), Turbidity (r=-0.707), TSS (r=-0.705) and phosphates (r=-0.880). Gyrindae positively correlated with pH (r=0.684) but negatively correlated with phosphates (r=-0.686). Gerridae positively correlated with DO (r=0.726) and velocity (r=0.643). Family Notonectidae negatively correlated with turbidity (r=-0.686) and phosphates (r=-0.730). Heptagenidae showed strong negative correlations with salinity (r=0.639), ORP (r=0.837) and TSS (r=0.784). Chironomidae positively correlated with velocity (r=0.664) while Belostomatidae negatively correlated with ORP (r=-0.694). Psepheridae positively correlated with depth (r=0.634). Family Perlidea showed a strong positively correlation with temperature (r=0.697) while strongly negatively correlated with ORP (r=-0.846). Oligonueriidae negatively correlated with SPC (r=-0.691), salinity (r=-0.772) and TSS (r=-0.673). Calopterigidae negatively correlated with SPC (-0.787), salinity (r=-0.631), DO% (r=-0.884) and TSS (r=-0.766), Coenagrionidae on the other hand showed a strong negative correlation with SPC (r=0.736), salinity (r=-0.692), DO% (r=-0.937) and TSS (r=-0.656). Cybaeidae was the only macroinvertebrate family that had a significant positive correlation with nitrates (r=0.652).

Table 10: Pearson Correlation coefficients between physico-chemical parameters and macroinvertebrates families in Isiukhu River during the study period

Variables	Temperature	SPC	D.O	PH	Depth	Salinity	D.O%	ORP	Turbidity	Velocity	TSS	Nitrates	Phosphates
Vellidae	-0.093	-0.628	-0.289	-0.539	**-0.832**	**-0.693**	**0.702**	**-0.827**	**-0.707**	0.288	**-0.705**	0.064	**-0.880**
Gyrinidae	-0.334	-0.264	0.028	**0.684**	-0.554	-0.575	-0.535	-0.410	-0.470	0.217	-0.453	-0.059	**-0.686**
Gerridae	-0.234	-0.162	**0.726**	-0.377	-0.080	0.000	-0.361	-0.002	-0.385	**0.643**	0.108	-0.429	-0.324
Notonectidae	-0.151	-0.449	0.346	-0.613	-0.234	-0.228	-0.303	-0.391	**-0.686**	0.289	-0.366	-0.155	**-0.730**
Cybaeidae	-0.093	0.000	0.381	0.292	0.055	0.039	0.470	0.337	0.348	-0.299	0.422	**0.652**	0.408
Heptagenidae	0.355	-0.541	0.397	-0.296	-0.361	**-0.639**	-0.558	**-0.837**	-0.401	-0.506	**-0.784**	0.356	-0.503
Chironomidae	-0.312	-0.207	-0.486	-0.548	-0.363	-0.111	-0.101	-0.182	-0.509	**0.664**	-0.055	-0.231	-0.605
Aeshnidae	-0.263	-0.468	0.245	-0.367	0.102	-0.142	-0.188	-0.196	-0.579	-0.229	-0.577	-0.090	-0.475
Belostomatidae	0.514	-0.118	-0.150	0.146	-0.575	-0.166	-0.028	**-0.694**	-0.151	-0.250	-0.200	0.615	-0.301
Psepheridae	0.083	0.207	0.505	0.095	**0.634**	0.444	0.329	0.255	0.083	-0.030	0.246	-0.185	0.381
Neritidae	-0.241	-0.261	-0.234	0.188	-0.121	-0.056	-0.571	-0.096	-0.260	0.308	-0.224	-0.325	0.022
Perlidea	**0.697**	-0.291	0.159	-0.047	-0.344	-0.416	-0.370	**-0.846**	-0.161	-0.348	-0.485	0.350	-0.284
Naucoridae	-0.186	-0.310	0.131	-0.108	-0.278	-0.583	-0.489	-0.078	0.098	0.247	-0.317	-0.233	-0.005
Reduviidae	-0.204	-0.478	0.390	-0.255	0.178	-0.179	-0.253	-0.181	-0.482	-0.405	-0.620	-0.042	-0.342
Oligonueriidae	-0.244	**-0.691**	0.509	-0.302	-0.297	**-0.772**	-0.537	-0.325	-0.275	-0.384	**-0.673**	0.288	-0.324
Calopterigidae	-0.338	**-0.787**	0.234	-0.471	-0.136	**-0.651**	**-0.884**	-0.385	-0.616	-0.083	**-0.766**	-0.162	-0.468
Coenagrionidae	-0.316	**-0.736**	0.124	-0.453	-0.227	**-0.692**	**-0.937**	-0.381	-0.534	0.060	**-0.656**	-0.173	-0.416
Hydrophilidae	-0.185	-0.395	0.340	-0.154	0.200	-0.067	-0.159	-0.134	-0.437	-0.400	-0.558	-0.045	-0.285
Dictynidae	-0.169	-0.289	0.418	-0.205	0.327	-0.027	-0.079	-0.028	-0.339	-0.421	-0.469	-0.096	-0.213
Avenae	-0.079	0.207	-0.486	0.610	-0.078	0.444	0.036	0.130	0.038	0.230	0.117	-0.199	0.230
Elmidae	0.019	0.207	0.165	0.250	-0.078	-0.111	0.247	0.237	0.540	0.143	0.071	-0.143	0.322
Gomphidae	0.057	0.291	0.391	0.278	0.224	0.104	0.386	0.342	0.545	0.120	0.182	-0.221	0.480

Values in bold are were significant at alpha=0.05

Results in table 11 show correlation between physico-chemical parameters and mean macroinvertebrates abundance. Dissolved oxygen (p=0.006) was the only variables which correlated positively with macroinvertebrate abundance. There was an insignificant negative correlation between macroinvertebrate abundance and temperature (p=-0162), SPC (p=-0.348), depth (p=-0.198), salinity (p= -0.214), % O_2 (p=-0.147), ORP (p=-0.331), turbidity (p=-0.377) and velocity (p=-0.024).

Table 11: Pearson correlation coefficients (r) between physico-chemical water quality variables and macroinvertebrate abundance in Isiukhu River during the study

					P values					
Parameters	**Temp**	**SPC**	**DO**	**pH**	**Depth**	**Salinity**	**% O_2**	**ORP**	**Turbidity**	**Velocity**
Macroinvertebrate abundance	-0.162	-0.348**	0.006	0.051	-0.198	-0.214	-0.147	-0.331**	-0.377**	-0.024

** Significant at $p< 0.01$ *significant at $p<0.05$

Results in table 12 show the summary of regression model (R^2) of the impacts of physico-chemical parameters on macroinvertebrate abundance. Results show that physico-chemical parameters accounted for 54.8% of spatial variation of macroinvertebrates abundance.

Table 12: Summary of regression model (R^2) of the relationship between selected physico-chemical parameters and macroinvertebrate abundance along Isiukhu River

Model Summary

					Change Statistics				
Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	0.740^a	0.548	0.471	23.3715	0.548	7.148	10	59	000

a. Predictors: (Constant), Velocity, Depth, Temperature, Salinity, ORP, D.O%, SPC, Turbidity, D.O, pH

Results in table 13 show that temperature, SPC, pH, depth, salinity, percentage oxygen saturation (% O_2), ORP, turbidity and velocity had negative effect on the macroinvertebrates abundance. Percentage oxygen saturation had a positive effect on the macroinvertebrate, indicating that the higher the oxygen, the higher the macroinvertebrate abundance. The physico-chemical parameters which had statistically significant effect on the macroinvertebrates were SPC (p=0.011), percentage oxygen saturation (p=0.024), ORP (p=0.001) and turbidity (p=0.001).

Table 13: Estimated regression coefficients of physico-chemical parameters against macroinvertebrates in Isiukhu River, Kenya

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		β	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	271.005	65.020		4.168	0.000	140.901	401.109
	Temperature	-.426	.496	-0.081	-0.859	0.394	-1.418	0.566
	SPC	-293.535	112.031	-0.295	-2.620	0.011	-517.709	-69.361
	DO	0.262	1.222	0.038	0.214	0.831	-2.184	2.708
	pH	-6.894	6.522	-0.226	-1.057	0.295	-19.944	6.156
	Depth	-12.079	27.450	-0.040	-0.440	0.662	-67.006	42.848
	Salinity	-360.619	312.867	-0.135	-1.153	0.254	-986.665	265.426
	Oxygen %	-0.406	0.176	-0.460	-2.311	0.024	-0.758	-0.054
	ORP	-0.211	0.063	-0.345	-3.347	0.001	-0.337	-0.085
	Turbidity	-0.039	0.009	-0.525	-4.419	0.000	-0.056	-0.021
	Velocity	-17.727	14.936	-0.142	-1.187	0.240	-47.613	12.160

a. Dependent Variable: macroinvertebrate abundance

Results in table 14 show the Anova for physico-chemical parameters and the macroinvertebrates. The macroinvertebrates families Veliidae (0.321), Gyrinidae (0.611), Gerridae (0.831), Notonectidae (0.121), Cybaeidae (0.823), Heptageniidae (0.207), Chironomidae (0.487), Aeshnidae (0.791), Belostomatidae (0.695), Pcepheridae (0.143), Neritidae (0.275), Perlidea (0.779), Naucoridae (0.925), Reduviidae (0.632), Oligonueriidae (0.969), Calopterigidae (0.443), Coenagrionidae (0.861), Hydrophilidae (0.264), Dictynidae (0.360), Elmidae (0.939) and Gomphidae (0.143) did not appear to be entirely influenced by physico-chemical parameters. Values had the same letter ^{b}, this mean that there were no significant differences in the in influence between macroinvertebrates and physico-chemical parameters.

Table 14: Analysis of Variance for physico-chemical water quality and macroinvertebrates abundance along Isiukhu River (n=9, $p \leq 0.05$)

Macroinvertebrates Regression	**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Vellidae	1666.391	8	208.299	5.409	0.321^b
Gyrinidae	172.231	8	21.529	1.205	0.611^b
Gerridae	2709.855	8	338.732	0.437	0.831^b
Notonectidae	1386.234	8	173.279	40.621	0.121^b
Cybaeidae	745.338	8	93.167	0.455	0.823^b
Heptagenidae	987.788	8	123.474	13.551	0.207^b
Chironomidae	7.651	8	0.956	2.131	0.487^b
Aeshnidae	38.924	8	4.866	0.536	0.791^b
Belostomatidae	515.130	8	64.391	0.833	0.695^b
Psepheridae	72.588	8	9.073	29.045	0.143^b
Neritidae	124.835	8	15.604	7.556	0.275^b
Perlidea	3.359	8	0.420	0.567	0.779^b
Naucoridae	14.699	8	1.837	0.239	0.925^b
Reduviidae	1.437	8	0.180	1.100	0.632^b
Oligonueriidae	48.973	8	6.122	0.147	0.969^b
Calopterigidae	10.029	8	1.254	2.662	0.443^b
Coenagrionidae	6.279	8	0.785	0.370	0.861^b
Hydrophilidae	8.274	8	1.034	8.193	0.264^b
Dictynidae	342.001	8	42.750	4.233	0.360^b
Elmidae	14.107	8	1.763	0.210	0.939^b
Gomphidae	72.588	8	9.073	29.045	0.143^b

Canonical correspondence analysis (CCA) of macroinvertebrates families with selected water quality parameters and sampling sites displayed distinct separations (Figure 14). The physico-chemical parameters correlated with specific macroinvertebrate families under different sites at the upstream, midstream and downstream. The first component explained 37.78% of the total variation in the dataset while the second component accounted for 30.34%. There was a distinct association of Veliidae and Belostomatidae families in Mwibatsilo, Shirere and Rosterman with high temperature, TSS and pH. Oligonueriidae, Cybaeidae, Elmidae, Psepheridae and Gomphidae were associated with high depth, ORP and DO at the sampling sites of Shibeye and Mutono in the downstream **(**Figure 15**)**

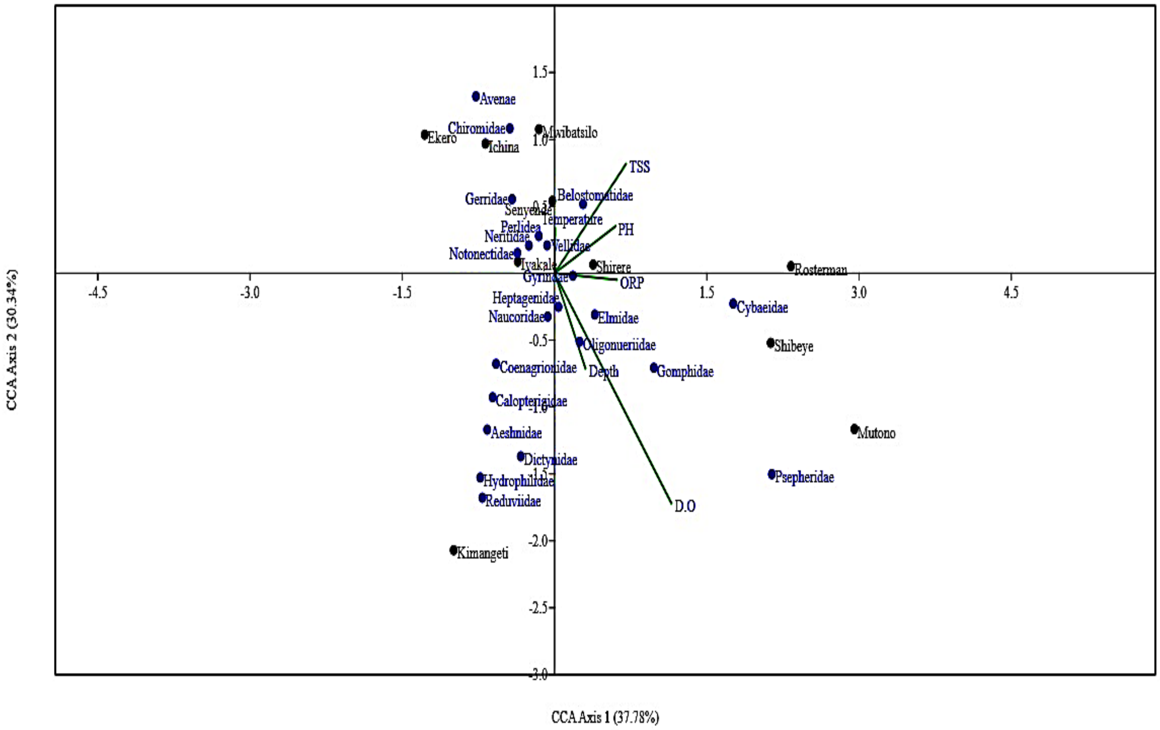

Figure 15: Canonical Correspondence Analysis (CCA) triplot on the association between water quality parameters, sampling sites and macroinvertebrates families in the Isiukhu River, Kenya.

The canonical correspondence analysis (CCA) ordination of macroinvertebrates families with selected water quality parameters displayed distinct separations. The first components explained 31.7% of the total variation in the dataset while the second component accounted for 24.62% (Figure 16). There was an association of Elmidae, Gomphidae, Naucoridae, Cybaeidae and Oligonueriidae with high levels of turbidity, DO%, phosphates, nitrates and SPC at the sampling sites of Rosterman, Shibeye and Mutono. Belostomatidae, Gerridae, Neritidae and Avenae correlated positively with high velocity at the sampling sites of Ivakale, Shirere, Senyende and Mwibatsilo.

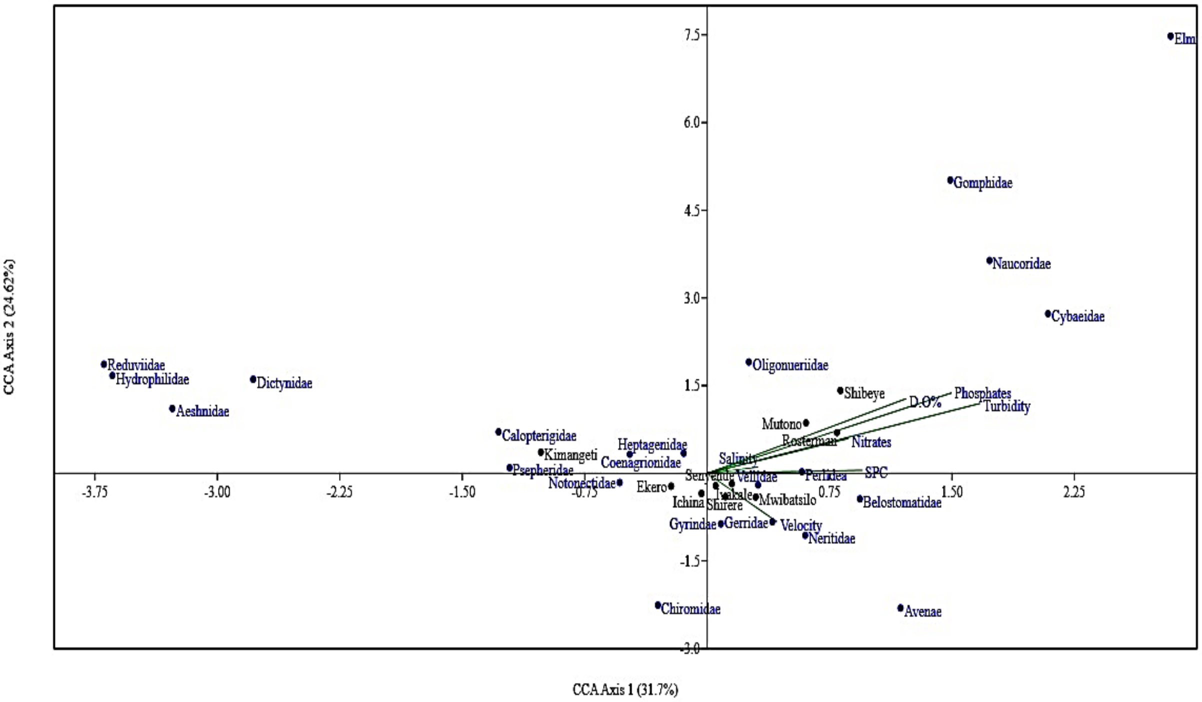

Figure 16: Canonical Correspondence Analysis (CCA) triplot on the association between water quality parameters, nutrients concentration and macroinvertebrates families in the Isiukhu River, Kenya.

4.4.2 Relationship between Substrate Characteristics and Macroinvertebrate Distribution

Results in table 15 show correlation of the mean sediments grain size, mean abundance and taxon richness. The mean abundance and taxon richness showed an insignificant statistical negative correlation of (r=-0.191) and (r=-0.396) respectively.

Table 15: Pearson Correlation (r) and their associated significance levels for comparisons of the Mean sediments grain size against Mean Abundance and Taxon Richness

Parameters		Mean Abundance	Taxon Richness
Mean sediments	Pearson Correlation	-0.191*	-0.396*
	Coefficients	0.076	-1.16
	Sig. (2-tailed)	0.597	0.257
	N	10	

Significant at $^{*}p \geq 0.05$

Results in table 16 show the summary of the impact of mean sediments grain size on the mean abundance and taxon richness using the regression model (R^2). It is clear that mean sediment grain size accounted for 28.7% of spatial variability of macroinvertebrates abundance.

Table 16: Results of Regression analysis (R^2) of Mean sediments grain size against Mean Abundance and Taxon Richness of Isiukhu River

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.536[a]	0.287	0.083	2.672

a. Predictors: (Constant), Mean Abundance, Taxon Richness

b. Dependent Variable: Mean sediments

Table 17 shows the Anova of mean sediments grain size to the mean abundance and taxon richness. The results show that, the significance of mean sediments grain size to mean abundance and taxon richness was statistically insignificant ($F_{(2,7)}$ =1.409, p=0.306).

Table 17: F- value and its statistical significance for one-way ANOVA of the mean sediments grain size and mean abundance and Taxon Richness

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	20.119	2	10.060	1.409	0.306[b]
1	Residual	49.981	7	7.140		
	Total	70.100	9			

a. Dependent Variable: Mean sediments

b. Predictors: (Constant), Mean Abundance, Taxon Richness

Results in table 18 show regression analysis (R^2) of sediments grain size on number of taxa, taxon richness, Shannon diversity index of Isiukhu River. The results show that taxon richness (20.137 %) was influenced by sediment grain size distribution, followed by Shannon diversity index (3.914 %).

Table 18: Results of Regression analysis (R^2) of sediments grain size against number of taxa, taxon richness and Shannon diversity index of Isiukhu River

	sediment grain size	
Parameters	R Square	P value
No. of Taxa	0.083329	0.41858
Taxon Richness	0.20137	0.19331
Shannon Diversity Index (H)	0.03914	0.58377

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1. Discussion

This section provides a critical discussion of the findings of this study. It explains and evaluates the findings, display how it connect to literature review and research objectives and make an argument in support the overall conclusion of the study on the influence of physico-chemical and substrate characteristics on benthic macroinvertebrates community dynamics.

5.1.1 Spatial variation in physico-chemical Parameters along Isiukhu River

This study set to determine the physico-chemical parameters along the course of Isiukhu River. There was a general increased temperature, conductivity, turbidity, salinity, pH, oxidation-reduction potential (*ORP*), nitrates and phosphates from upstream to downstream. As the river passed through diverse land uses, there was a modest decrease in dissolved oxygen, percentage oxygen saturation, and velocity downstream. The values of conductivity, temperature, turbidity and TSS reported in this research are higher than those was reported by Onyando *et al.*, (2013. In this study higher values of temperature, conductivity, turbidity, pH range and TSS were recorded in the urban, midstream and mixed farming at the midstream and downstream. These finding clearly show that land use practices alter physico-chemical parameters (Onyando *et al.,* 2013, 2016). Human activities such as farming using fertilizer increases increased H+ that have been shown to decrease pH values in rivers in the tropics (Oremo *et al.,* 2020).

The findings of this study also conform with other studies from other tropical rivers. For example, the increasing temperature from upstream had similar pattern with what was reported by Musonge *et al.*, (2020) in Alpine rivers of the Rwenzori Mountain in Uganda. Baytut & Gonulol, (2016) observed that temperature was higher at the mouth of Kızılırmak River in the Black Sea than its catchments. Mondal & Bhat, (2021), in a similar study in Central and Eastern India streams observed that physico-chemical parameters especially temperature increased downstream. From these findings, it is evidently that the forest at the upstream moderates' water temperature. This concurs with findings by Kasangaki *et al.*, (2008) in extreme-altitude Ugandan tropical forest rivers which revealed that vegetation ecosystems were dominated by lower stream temperatures. The abundance of macroinvertebrates in many rivers are dependent on temperature and somewhat alteration of the average temperature may alter the macroinvertebrates of the lotic systems (Omoigberale & Ogbeibu 2010).

The approximately pH values recorded during the investigation period were within the acceptable range (6.5-9) which is appropriate for water living organisms (APHA-AWWA, 1998). The pH in this study exhibited a slight upsurge from upstream to downstream of the river. This slight increase in pH downstream, can be attributed to the instream organic matter decomposition and some anthropogenic activities such as the mining of gold. This concurs with findings from a similar study on Piracicaba River Basin (Daniel *et al.*, 2002), in which high organic decomposition and mining activities led to saturation of carbon dioxide beyond the aquatic photosynthetic need, which led to rise in water pH. The elevated pH at the downstream can also be attributed to the intake and decomposition of organic matters in the zone, along with the degree of disequilibrium of hydrogen ions inflow from surface run-offs from the upper streams during the rains. This is concurring with findings by Umar *et al.,* (2018), in Dadin Kowa in Nigeria. They reported higher variation of pH at the downstream of Dadin Kowa river, which was due to influx and run-offs from upstream and midstream. Variation in pH may have direct effects for the health of the water living creatures since most of their metabolic processes are pH dependant (Suleiman & Abdullahi, 2017).

The highest mean dissolved oxygen (9.13 ± 5.5 mg/L) was recorded at Kimangeti sampling site at the upstream while the lowest was recorded at Mutono (7.0 ± 3.06 mg/L) at the downstream. This might be linked to the statistic that the river has not undergone much deterioration compared to other tropical rivers like River Njoro that entirely composed of agricultural activities within its riparian (Shivoga *et al.,* 2007). Extreme values of dissolved oxygen have been detected in other tropical streams that are less impacted by human activities. For example, Obot *et al.,* (2014) reported higher dissolved oxygen of 7.0mg/l in a study conducted in Uyo, Nigeria. The findings of the Uyo River were because of heavily covered riparian that minimises human impact to the river. The midstream and downstream of Isiukhu River also receive discharges from agricultural and municipal activities. This is concurring with similar study by Makumbe *et al.,* (2022) in the Sanyati Basin, Zimbabwe who found that domestic wastes and agricultural run-offs fertilized water bodies leading to high colonization by flora and anaerobic microbes that lead higher dissolve oxygen in the water column.

The maximum ORP was recorded at Ekero sampling site downstream while the lowest was at Senyende upstream. Higher ORP values imply high biological/biochemical oxygen demand to decompose organic matter in water. It also implies that microbial organisms that decompose dead tissues and pollutants can operate more effectively. The higher ORP downstream can be attributed to agricultural activities and midstream runoff from the township, which encourage microbial activities. This particular finding concurs with that by Mwanake *et al.,* (2019) who found that land use was more important in determining ORP and nitrogen concentration in the upstream of Mara River. A study Poulton &Allert (2012) at the Lower Missouri River, observed an increase in ORP downstream of the river despite the fact that it was highly polluted. This suggests that higher ORP, which indicates higher oxygen concentration, does not mean the lotic ecosystem is healthy.

The highest turbidity during the study was recorded at the Ekero (624 ± 546.46) sampling site upstream while the lowest was at Ichina (96.08 ± 59.53) upstream of Isiukhu River. Both organic and inorganic components can cause turbidity in lotic systems. These results are in agreement with the findings from similar research by Eneji *et al.,* (2012) who found that turbidity levels elevated downwards in several streams of Benue River. The Isiukhu River's turbidity is linked to human activities like washing, bathing, and irrigation, that are mostly at midstream and downstream.

The downstream sampling sites of Shibeye, Mutono and Ekero recorded conductivity values of above 90 µS/cm indicating the river has low conductivity through its course. Conductivity reveals the ions present in the water, which are often brought about by salt intrusion and leaching. Conductivity is a crucial physico-chemical characteristic for identifying salinity related concerns. The observed values are lower than most tropical rivers. For instance, in a study by Usman *et al.* (2014) at the upper Awash River in Ethiopia recorded a higher conductivity ranging from 327.67 to 492.87 S/cm and Lubanga, 2021), recorded higher conductivity of more than 100 µS/cm at Mara River. The low conductivity throughout the course of Isiukhu River may be due to the fact that the river flows through a granite bedrock which is made out of less reactive components that do not ionize once washed in water. These findings are in agreement with the EPA (2011) report which attributed high conductivity with rock composition of the rivers and extirpation concentration of ions. These results are also in agreement with the findings by Masese *et al.*, (2014) who found that the entire river regimes tended to have low and stable specific conductance irrespective of the local anomalies in the reaches, due to rock composition.

There was an increase in TSS values from upstream forested sites to high levels in disturbed mining, municipal and agricultural sites at the midstream and downstream. The trend can be atrributed to run-offs from agriculture and municipal activities and sedimentation caused by mining, sand harvesting and grazing. This is consistent with a study by Kibichii *et al.* (2007) who found that the high level of TSS in River Njoro resulted from land use practices such as crop farming and grazing. Similarly, the higher values of TSS can linked to draining sites from erosion of uncovered banks as reported by Lubanga, (2021) in a study at the Mara River Basin.

Nutrient concentrations were substantially higher at all of the sites examined. This indicates that the reaches of the Isiukhu River are contaminated by residues from agricultural activities, mining activities, and municipal inputs. Spatial variations in nutrient are highly associated with agricultural activities such as crop farming in parts of the midstream and downstream and grazing in the upper reach of the Isiukhu River watershed. A study by Kibichii *et al.,* (2007) examined land use gradient in the upstream of River Njoro watershed dominated by agricultural activities. The found an elevated nitrate at the agricultural sites which agrees with the findings of this study.

High phosphate levels found at the downstream can be linked to run-offs from the upper reaches. Unlike the upstream, agricultural land and mining sites at the midstream and downstream are prone to erosion due to lessened surface roughness and organic compounds concentration (Wetzel 2001). They are normally nutrient-rich as a result of artificial fertilization to boost crop yields and this contribute to nutrients concentration within the water column. A study by Mzungu *et al.,* (2022) on the Omubhira stream within the catchment of Isiukhu River found that landscape of the stream watershed impacted the degree of weathering and consequent nutrient discharge to the river flows. This probably explains why the downstream had a higher concentration of phosphates.

5.1.2 Substrate Characteristics

Results show that the sediments of the river from upstream to downstream were poorly-sorted with varying grains sizes indicating that the sediments had been deposited fairly near to the source area. Whereas the upper stream sediments are fine gravelly mud and very coarse gravelly mud, the downstream sediments are very coarse gravelly muddy very fine sand and very fine gravelly clayey very fine sand indicating that the sediments get finer (i.e., mainly clay silt and sand) moving from upstream to downstream of Isiukhu River. The extremely very poor sorting of sediments along the river can be explained by the computed high kurtosis, which indicates that a greater proportion of the variation is due to uncommon extreme deviations in sediment grain size distribution. The sediment grain size distributions are more concentrated and the frequency curves for particle size are sharper and narrower than those for the normal distribution. This can be attributed to the land uses practices along the riparian stream and the run-offs which generate fine sediments at the downstream. These findings are in agreement with those of M'Erimba *et al.,* (2014) in two Kenyan Tropical Rift Valley streams (Njoro and Ellegirini stream) in which they observed that sediments grain size distribution and composition in the water course was determined by anthropogenic activities. The reaches where agricultural activities were rampant had finer sediments compared to the other reaches. This may have resulted in the run-off of fine sediments to the stream. Comparable observation was made by Agboola *et al.,* (2019) in the rivers of Kwa Zulu-Natal, South Africa who found that parts of the rivers which lie within sugarcane plantation had finer sediments compared to the other reaches.

The sediments distribution pattern that shows finer sediments accumulation at the downstream can be attributed to the anthropogenic activities in the downstream and upstream of the river (Wang *et al.,* 2009).

These findings suggest that the river is composed of a mixture of sediments and grain size with the upstream composed of very coarse gravels while the downstream is composed of very fine gravelly clayey and sand. This concurs with observations from the Lower Mekong River that revealed that sediment grain size distribution was determined by the activities along the stream (Bravard *et al.,* 2014). Another factor which could be associated with the findings is the nature of the grain sizes, for example silt and clay travels as a wash load while sand travel as bedload during rise of floods Koehnken (2012a). This concurs with a similar by Zinabu *et al.,* (2019), who observed that down streams of Borkena and Awash Rivers had finer sediments due to run-offs.

The source of supply, the mode of transportation, and the land use practices all have an impact on the average size of sediments (Ramamohanarao *et al.* 2003).

Sorting Coefficient (φ) is expressed by sorting of sediments and it expresses the oscillations in the velocity variations of the depositing agent (Sahu, 1964). The observed sorting variance is related to differences in water turbulence and the variable depositing current (Angusamy & Rajamanickam 2006). The upstream had coarse gravelly while the downstream had finer sediments, which is consistent with a study by Anithamary *et al.,* (2011). Findings of this study also show a clear disparity of sorting coefficient which is high at the mining sampling locations of the midstream, this is because of continuous accumulation of fine sediments in unpredictable quantities. This agrees with the finding by Nilanjana *et al.,* (2016) who observed that mining sites had high sorting values at the River Kangsabati, West Bengal.

5.1.3 The spatial distribution and abundance of macroinvertebrates

Results showed that the upstream sampling sites were dominated by Vellidae, Gyrinidae, Gerridae and Notonectidae families, the midstream sites of Shirere, Rosterman and Mwibatsilo were dominated by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Belostomatidae families and the lowland sites of Shibeye, Mutono and Ekero by Vellidae, Gerridae, Notonectidae, Cybaeidae, Heptagenidae and Dictynidae. Results on the findings of the number of families differs from thopse by Onyando *et al.*, (2013). The family Tubificidae, Talitridae, Simulidae, Corixidae, Planorbidae and Physidae were not found in this study though they were observed by Onyando *et al.*, (2013). This might be explained by differences in data gathering techniques and the intensity of sampling. The decrease in diversity and abundance can may be be explained by the fact that water quality has deteriorated since the study by Onyando *et al.*, (2016) as a result of increased human population and intensive changes in land uses practices (Oremo *et al.*, 2019).

The decrease in abundance of macroinvertebrates upstream to downstream suggests that macroinvertebrates seem to respond to water quality deterioration and changes in substrate characteristics. For instance, Kimangeti in the upstream had the highest mean abundance, whereas Mutono in the downstream had the lowest. Similarly, the highest taxa richness was observed at upstream sampling sites of Senyende followed by Kimangeti while the least was at Mutono downstream.

The physico-chemical parameters particularly dissolved oxygen, temperature and sediments grain size together with biotic factors such food availability and land use/cover parameters have been reported to be responsible for determining macroinvertebrate distribution (Lamouroux *et al.* 2004).

It is known that riverbank flora with larger vegetation surfaces are associated with high macroinvertebrate populations (Shimba & Jonah, 2016). Similar studies by Heino & Peckarsky (2014) and Tonkin *et al*. (2016) found higher mean abundance, and taxon richness of macroinvertebrates in upstream sheltered sites than in exposed locations of the downstream. The high abundance and diversity at the upstream could also be attributed to the habitat heterogeneity due to stable physico-chemical parameters and larger sediments composition that attract high diversity (Masese & Raburu, 2017). Numerous studies have found a wide distribution of macroinvertebrates families in places with high large gravel (Harrison *et al.,* 2007; Masese *et al.,* 2017; Akamagwuna *et al.*, 2019; Raphahlelo *et al.*, 2022). The low diversity at the downstream sites of Ekero, Mutono and Rosterman could well be linked to habitat disruptions induced by gold extraction, load sediments run-offs and crop farming. The high abundance of Heptagenidae which belongs to the order Ephemeroptera at the upstream sites of Isiukhu River may be as a result of excess nutrients and the fact that this family is commonly linked with high water quality levels (Armitage *et al.* 1983; Azrina *et al.* 2006; Ghani *et al.* 2016). The presence of Dictynidae, Elmidae and Gomphidae at Shibeye, Mutono and Ekero is an indicator that the downstream water quality is poor. These families can survive in habitats that are disturbed and fluctuated due to their exceptional structural organization (Masese *et al.* 2014a). They are also excellent invaders of fine sediments and disturbed environments.

The many activities in the catchment region, such as gold extraction, municipal operations, residential waste disposal, grazing, and fertilizer waste, usually have an impact on water quality and habitat accessibility, which has an impact on the composition of macroinvertebrates (Masese & Raburu, 2017). As the environment is disturbed, the population of sensitive taxa usually decreases while the population of more tolerant taxa increases, and thus the ecosystems become more homogeneous (Lubanga, 2021).

Shannon diversity index, and evenness was higher at the upstream compared to the midstream and downstream. The diversity and evenness indices at each sampling site appeared to represent the water quality standards. High species diversity at the upstream sites was associated with less disturbances while a lower diversity at downstream was signified by environmental contamination and fine sediments accumulation due to increasing anthropogenic activities, such as gold mining, sand harvesting and agriculture activities (Akamagwuna *et al.,* 2019). Gold mining and sand harvesting eliminates benthic macroinvertebrates (López-López *et al.*, 2009; Masese & Raburu, 2017). These findings are in agreement with those from a study in Finland by Heino & Peckarsky (2014) who found that macroinvertebrates assemblage decreased with increase human activities along the river. The high abundance and diversity in these sites were characterized by relatively higher DO and lower TDS, temperature, turbidity and salinity as compared to midstream and downstream sites. These agrees with findings by Akamagwuna *et al.,* (2019) in Tsitsa River and its Tributaries where they observed that undisturbed parts of the river had high abundance of macroinvertebrates than downstream because of favourable physico-chemical parameters and sediments grain size. The upper stream macroinvertebrates respond in environmental changes at small spatial scale, for example in forested area, farmland and in microhabitats e.g., riffles. These environments determine food availability and shelter, for example forested region along the river encourage colonization of cryptogams which provide food to the macroinvertebrates. Masese *et al.* (2009a), they found that macroinvertebrates abundance was high in riffles and other microhabitats at the headwaters. The nature of the microhabitats in Isiukhu River also determined the distribution of the macroinvertebrates, for examples the upper region is composed of coarse sediments than the down region which had larger sediments, thus harbouring high densities of shredding macroinvertebrates e.g., veliidae and Notonectidae than downstream. The same trends were reported by Haapala *et al.,* (2003) in Merenoja and Rutajoki streams. This study reveal that, there is variation of macroinvertebrates in the upper stream within small spatial scale and there is widely variation of macroinvertebrates assemblage downstream, reflecting the wider variance in environmental factors.

5.1.4 Relationship between physico-chemical parameters and Macroinvertebrates Distribution

The results of correction showed that macroinvertebrates families correlate with physico-chemical parameters in differently. Onyando *et al.,* (2013) found out that macroinvertebrates correlated with specific physico-chemical parameters differently and they attributed it to shifts in land use patterns along the stream that largely altered the physico-chemical parameters. The regression analysis on the other hand showed that physico-chemical parameters influence the distribution, abundance and diversity of macroinvertebrates by 54.8%. which means that macroinvertebrates colonization is also influenced by other factors like sediment grain size distribution in a stream regime. Macroinvertebrates are sensitive to variation in physico-chemical parameters that influence water quality (Onyando *et al.,* 2013). Some physico-chemical parameters like temperature correlated with many of the macroinvertebrate's families. This agrees with a similar study by Eze & Chigbu, (2015) in Iyi Okai stream where they found that while physico-chemical parameters were the main drivers of macroinvertebrates colonization, they were other factors such as microbiological parameters, sediments grain size and hydrological factors that influence distribution. Ude (2012) reported that in Ebonyi River dissolved oxygen was the parameters with greater influence macroinvertebrates distribution. Dieter *et al.,* (1996), observed that macroinvertebrate taxa are sensitive to physico-chemical parameters, sediments grain sizes and chemical properties of aquatic ecosystems. The macroinvertebrate composition is influenced by physico-chemical parameters resulting from changes in land uses practices of the riparian area (Idowu *et al.,* 2012). A noticeable parameter in this study was depth which increased from upstream to downstream and which resulted in low abundance and diversity of macroinvertebrates at the downstream. This is consistent with findings by Baumgärtner *et al.,* (2008) where the patterns of macroinvertebrate community varied in Calabar River, partly as a result of species shifts, but essentially as a result of differing dominance structures, sediments composition and land use practices.

The higher taxa richness and diversity in the upstream sampling sites can be explained by minimal disturbance of river bed and favourable physico-chemical parameters within the reach. Bhawsar & Vyas, (2022) reported similar findings from their study in Barna Basin of the Narmada River. They observed that stream reaches with high vegetation cover had high abundance of macroinvertebrates due to favourable temperature and dissolved oxygen. Mwakisunga *et al.* (2020) also found that physico-chemical parameters and grain sizes distribution influenced macroinvertebrates at the Dares salaam harbour channel.

5.1.5 Relationship between substrate characteristics and macroinvertebrates distribution

The mean sediments grain size distribution correlated negatively and insignificantly with the mean abundance (r=-0.191) and taxon richness (r=-0.396). In addition, the mean sediments grain size influenced the spatial variability of macroinvertebrates, in terms of the mean abundance and taxon richness by 28.7%. This could be explained by pointing out that macroinvertebrate's distribution is not only affected by sediments but also by other factors such as physico-chemical and hydrological and abiotic factors (Griffiths, 1999). The upstream sediments are fine gravelly mud and very coarse gravelly mud; the downstream sediments are very finely sand indicating that the sediments get finer moving from upstream to downstream. The high abundance and diversity observed in the upstream in the less disturbed Kakamega forest sampling sites and the minimum abundance and diversity observed in the downstream sampling sites implies that fine sediments which were observed in the downstream may have been as a result of land use activities that define the river macroinvertebrates distributio (Parés *et al.,* 2018). The observed pattern of sediments distribution which determined macroinvertebrates diversity and abundance followed some predicted responses in a similar study by Akamagwuna *et al.,* (2019) where they observed that macroinvertebrates aligned themselves according to sediments distribution. Buendia *et al.*, (2013) reported similar findings in Isabena River, Central Pyrenees where they found that macroinvertebrates abundance and diversity decrease with increase in fine sediments loading. Raphahlelo *et al.,* (2022) reported that, certain reaches of exceedingly fine sediment have been known to be uninhabitable by many macroinvertebrate families due to a lack of sufficient oxygen and a sluggish colonization process. The combination of these impacts could explain the low abundance and diversity at the lower stream (Harrison *et al.*, 2007). Decrease in i attachment places from upstream to lower stream concur with the findings by Wilkes *et al.* (2017), who reported that some macroinvertebrates families need places for attachment making them sensitive to every stress caused by fine sediments. Majority of the macroinvertebrates families at the downstream are suspected to reside at the surface (Onyando *et al.*, 2013). The results are in tandem with findings by Murphy *et al.* (2017), where different locomotive macroinvertebrates families react to fine sediments pressure. Wilkes *et al.* (2017) also found that benthic macroinvertebrates were limited when it comes to evasion from increased sediment accumulation. Higher fine sediments accumulation in rivers and streams have been reported to impact the nature of foraging and trophic depletion of macroinvertebrates (Masese *et al.* 2014a). For instance, Ibemenuga & Inyang, (2008) investigated macroinvertebrates feeding habitats in Ogbei stream of Nigeria, and observed that filter feeding showed a notable decrease in high fine sediment stream reaches.

Results of this study clearly show that, fine sediments accumulation in the downstream of the river may be a major cause of the low macroinvertebrates abundance (Harrison *et al.*, 2007; Akamagwuna *et al.,* 2019). This is backed up by the finding that macroinvertebrates that feed through shredding like Heptageniidae, exhibit high response to fine sediments accumulation (Buendia *et al.*, 2013, 2014). Studies by Hoy (2001) in Oregon rural and urban found that the lower stream had a lot of fine sediments which affected macroinvertebrates colonization. The fine sediments also offer large surface area to be colonised by biofilms whose microbial communities transform organic matter into a state that is available to consumers in the bed sediments (Zhou *et al.,* 2017). Nevertheless, depending on the geological sources of sediments, fine grain size particles as observed in the midstream and downstream, most likely have softening effect on the coarse granite sandy sediments and hence provide advantageous habitats for burrowing invertebrates (e.g. chironomids). This explains why high abundance of Chironomidae, Elmidae and Hydrophilidae were found in the downstream.

The grain size affects the availability and stability of certain environmental conditions like oxygen and organic matter content thus affecting the composition of macroinvertebrates along the stream regime. This concurs with a study in Mara River Basin by Lubanga, (2021) which showed that most benthic organisms had high densities on coarse gravel bottoms with high oxygen circulation and nutrients content, while low densities occurred on sandy unstable grounds near the shore with low oxygen circulation and nutrients content. Schoen *et al.* (2013) also showed that many invertebrate taxa were most abundant in coarse sediments and that at sites where oxygen concentrations, this affirm the study results since the macroinvertebrates families occupying the upper reaches are highly subjective to sediments grain size.

These findings imply that while creating biomonitoring tools, it is important to consider the ability of macroinvertebrate assemblage establishment in fine sediments stress. It will give a comprehensive indicator of impacts of land uses practices within the riparian zones. In summary, assessing the impacts of sediments grain size to abundance, diversity and distribution of macroinvertebrates in river and stream regime is very crucial.

5.2 CONCLUSION

There was an overall trend of increase in temperature, conductivity, turbidity, salinity, pH and oxidation-reduction potential (*ORP*) from the upstream to downstream in Isiukhu River while there was a slight reduction in dissolved oxygen, percentage oxygen saturation and velocity downstream as the river passed through the land uses in the Isiukhu River Watershed.

The upstream sediments (at Ichina, Ivakale and Kimangeti sampling sites) were fine gravelly mud and very coarse gravelly mud, the downstream sediments (at Shibeye, Mutono and Ekero) were very coarse gravelly muddy, very fine sand and very fine gravelly clayey, very fine sand indicating that the sediments get finer (i.e., mainly clay silt and sand) moving from upstream to downstream of the Isiukhu River.

The undisturbed upstream was dominated by Veliidae, Gyrinidae, Gerridae, Notonectidae, Cybaeidae and Heptagenidae macroinvertebrates families, the midstream was dominated Veliidae, Notonectidae, Cybaeidae, Heptagenidae and Belostomatidae the downstream was dominated by Gerridae, Dictynidae, Elmidae and Gomphidae pointing to changes in physico-chemical parameters and substrate characteristics along the river regime.

The physico-chemical parameters correlated differently with specific macroinvertebrates families leading to differences in their abundance and distribution.

5.3 RECOMMENDATIONS

The study recommends that vegetation cover and riparian areas along the Isiukhu River should be protected for the conservation of the river’s fauna because of the findings that physico-chemical parameters that are generated by land use practices, highly affect the spatial distribution of macroinvertebrates.

The study also recommends that activities such as sand harvesting and mining should be regulated since the contribute in accumulation of fine sediment in the river, which affect the distribution, colonization and abundance of macroinvertebrates.

It is recommending that organic that organic farming practices in the downstream, reduction of manucipal wastewater discharge into Isiukhu in township areas be reduced through better waste management, upgrading of sewage treatment works, stopping illegal sand harvesting and using upgraded environmental methods of gold mining at the midstream to avoid affecting the macroinvertebrates abundance, composition, colonization and diversity

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APPENDICES

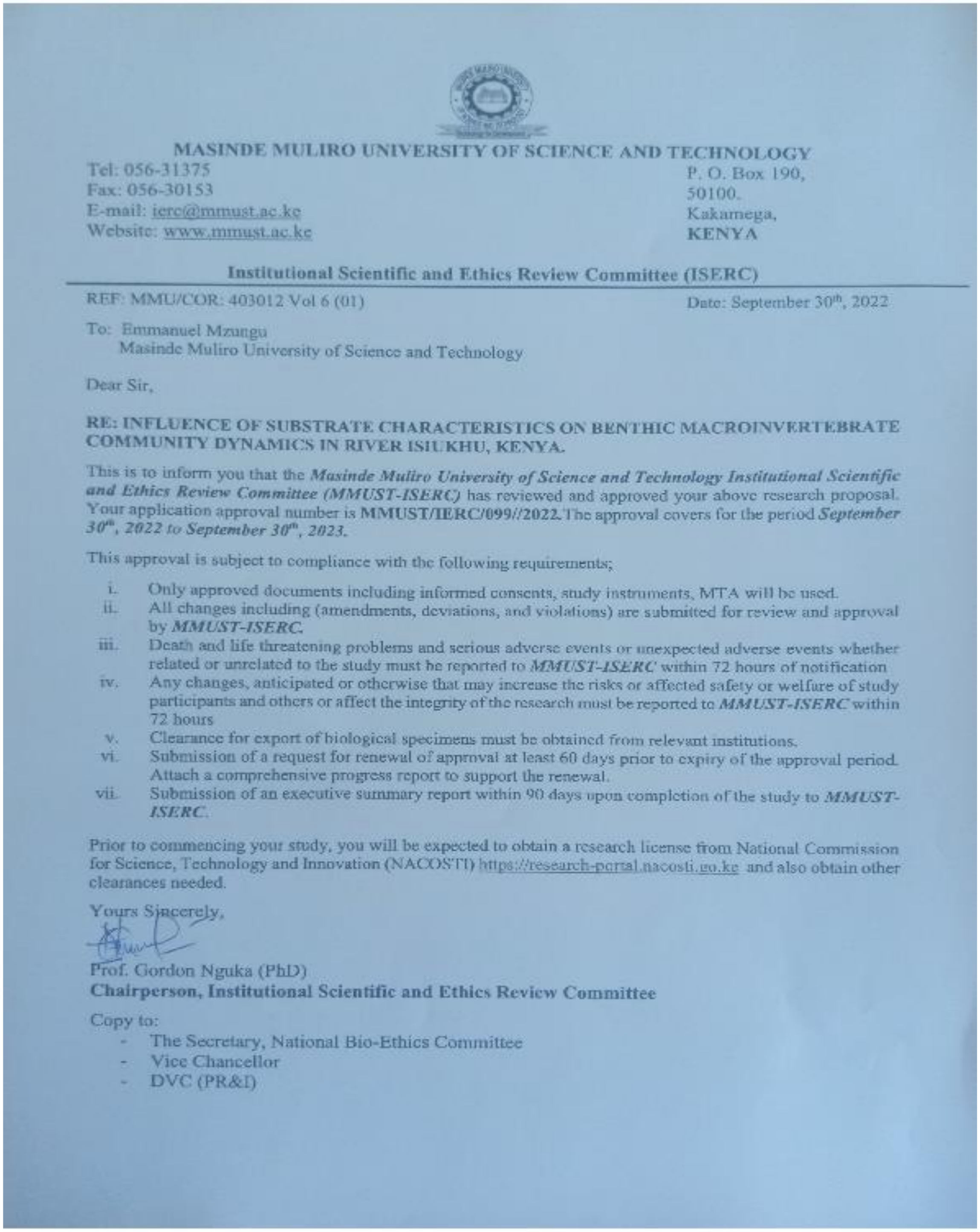
Appendix 1: Sampling sites of Senyende, Kimangeti (upstream) and Shibeye (downstream).

Appendix 2: Physico-chemical parameters measuring in the Ivakale at the upstream of River Isiukhu.

Appendix 3: A picture of sample Macroinvertebrates species from the field (May fly Ephemeroptera)

Appendix 4: Ekman Dredge Sampler for sediment sampling

Appendix 5: Letter of study approval from Instititutional Scientific Review Committee(MMUST-ISERC)



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P. O. Box 190,
50100.
Kakamega,
KENYA

Institutional Scientific and Ethics Review Committee (ISERC)

REF: MMU/COR: 403012 Vol 6 (01)

Date: September 30th, 2022

To: Emmanuel Mzungu
Masinde Muliro University of Science and Technology

Dear Sir,

RE: INFLUENCE OF SUBSTRATE CHARACTERISTICS ON BENTHIC MACROINVERTEBRATE COMMUNITY DYNAMICS IN RIVER ISIUKHU, KENYA.

This is to inform you that the ***Masinde Muliro University of Science and Technology Institutional Scientific and Ethics Review Committee (MMUST-ISERC)*** has reviewed and approved your above research proposal. Your application approval number is **MMUST/IERC/099//2022.** The approval covers for the period ***September 30th, 2022** to **September 30th, 2023.***

This approval is subject to compliance with the following requirements;

i. Only approved documents including informed consents, study instruments, MTA will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***MMUST-ISERC.***
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***MMUST-ISERC*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***MMUST-ISERC*** within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***MMUST-ISERC.***

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://research-portal.nacosti.go.ke and also obtain other clearances needed.

Yours Sincerely,

Prof. Gordon Nguka (PhD)
Chairperson, Institutional Scientific and Ethics Review Committee

Copy to:
- The Secretary, National Bio-Ethics Committee
- Vice Chancellor
- DVC (PR&I)

Appendix 6: Certificate of study approval from NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **824954**

Date of Issue: **01/July/2022**

RESEARCH LICENSE

This is to Certify that Mr.. Emmanuel Mzungu Mzungu of Masinde Muliro University of Science and Technology, has been licensed to conduct research in Kakamega on the topic: INFLUENCE OF PHYSICOCHEMICAL AND SEDIMENT GRAIN SIZE CHARACTERISTICS ON BENTHIC MACROINVERTEBRATES COMMUNITY DYNAMICS IN RIVER ISIUKHU, KENYA for the period ending : 01/July/2023.

License No: **NACOSTI/P/22/18545**

824954
Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

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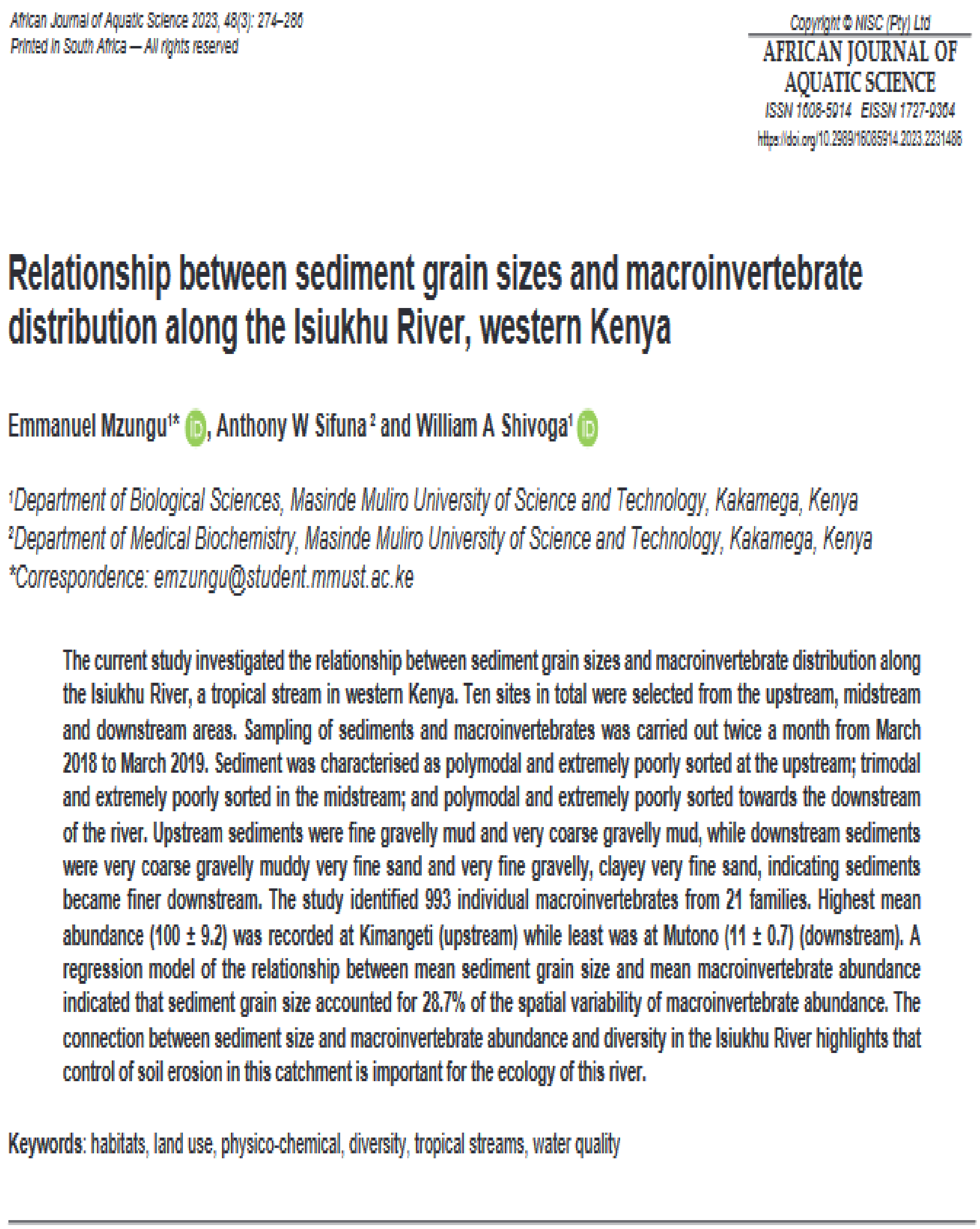
Appendix 7: Publication



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Relationship between sediment grain sizes and macroinvertebrate distribution along the Isiukhu River, western Kenya

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The current study investigated the relationship between sediment grain sizes and macroinvertebrate distribution along the Isiukhu River, a tropical stream in western Kenya. Ten sites in total were selected from the upstream, midstream and downstream areas. Sampling of sediments and macroinvertebrates was carried out twice a month from March 2018 to March 2019. Sediment was characterised as polymodal and extremely poorly sorted at the upstream; trimodal and extremely poorly sorted in the midstream; and polymodal and extremely poorly sorted towards the downstream of the river. Upstream sediments were fine gravelly mud and very coarse gravelly mud, while downstream sediments were very coarse gravelly muddy very fine sand and very fine gravelly, clayey very fine sand, indicating sediments became finer downstream. The study identified 993 individual macroinvertebrates from 21 families. Highest mean abundance (100 ± 9.2) was recorded at Kimangeti (upstream) while least was at Mutono (11 ± 0.7) (downstream). A regression model of the relationship between mean sediment grain size and mean macroinvertebrate abundance indicated that sediment grain size accounted for 28.7% of the spatial variability of macroinvertebrate abundance. The connection between sediment size and macroinvertebrate abundance and diversity in the Isiukhu River highlights that control of soil erosion in this catchment is important for the ecology of this river.

Keywords: habitats, land use, physico-chemical, diversity, tropical streams, water quality