PHYSICOCHEMICAL WATER QUALITY AND BENTHIC MACROINVERTEBRATES OF RIVERS IN IKPE COMMUNITY, EDO STATE

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External Examiner	**Date**

DEDICATION

This project is dedicated to God Almighty who gave me the strength to carry out my research and for the sound health He gave to me all through this period.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometry
ANOVA	Analysis of Variance
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
Ca^{2+}	Calcium
CF	Contamination Factor
Cl^{-}	Chloride
Cu^{2+}	Copper
DMR	Duncan Multiple Range
DO	Dissolved Oxygen
DCA	Detrended Correspondence Analysis
EC	Electrical Conductivity
EF	Enrichment Factor
FMEnv	Federal Ministry of Environment
Mg^{2+}	Magnesium
Na^{2+}	Sodium
NO_2	Nitrite
NO_3	Nitrate
$NH_4^{-}N$	Ammonium Nitrogen
NTU	Nephelometric Turbidity Unit
PCA	Principal Components Analysis
PLI	Pollution Load Index
RDA	Redundancy Analysis
CCA	Canonical Correspondence Analysis

SO_4^{2-}	Sulphate
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WHO	World Health organization
WQI	Water Quality Index
Zn	Zinc

ABSTRACT

Freshwater ecosystems face significant threats from environmental stressors, particularly in regions where rivers serve as primary resources for diverse communities. In the Ikpe Community of Edo State, Nigeria, assessing the impact of these stressors on water quality and aquatic biodiversity is critical for ecological health. This study aimed to evaluate seasonal and spatial variations in water quality, analyse the composition, abundance, and diversity of macroinvertebrate taxa, and adopt a benthic macroinvertebrate-based multimetric index for assessing the biological integrity of these freshwater systems.

Water quality parameters (temperature, pH, depth, flow rate, and chemical concentrations) were measured at sampling stations along the Orhionmwon, Irogbe, and Okhuaihe Rivers across two wet and dry seasons (07:30–09:00 hrs). Sediment samples were collected using a composite sampling method, and benthic macroinvertebrates were preserved in formalin for laboratory identification. Physicochemical parameters followed APHA (2017) protocols, while heavy metals were analysed via Atomic Absorption Spectrophotometry (AAS). Pollution indices (Enrichment Factor, Pollution Load Index) assessed sediment contamination, and diversity metrics (Shannon-Wiener, Simpson) evaluated ecological health. Statistical tests (Mann-Whitney U, Kruskal-Wallis) analysed macroinvertebrate differences, while Redundancy Analysis (RDA) and Detrended Correspondence Analysis (DCA) examined correlations with environmental variables.

Results showed significant seasonal and spatial variations in water quality, with parameters like electrical conductivity, transparency, and river width differing significantly across stations ($p<0.01$). Although most parameters were within Federal Ministry of Environment (FME) guidelines, some, such as turbidity, exceeded recommended levels in specific areas. Principal Component Analysis (PCA) results highlighted key parameters like Phosphate, Sulphate, Turbidity, Electrical Conductivity and Chloride which significantly influence water quality. Sediment samples revealed seasonal variations influenced by runoff, vegetation with correlations among elements such as iron, nitrate, and chromium. Pollution indices, including the Enrichment Factor (EF), Pollution Load Index (PLI), and Geoaccumulation Index (Igeo), which were employed to evaluate metal contamination, showed that contamination was generally low, with some stations experiencing mild pollution. The ecological risk assessment indicated low potential ecological risk, though elevated metal levels could pose long-term risks to macroinvertebrate health. Additionally, the Water Quality Index (WQI) values ranged from 9.35 (Okhuaihe 1, Reference Station) to 16.53 (Okhuaihe 2, Impacted Station), with all stations classified as "Excellent" based on WQI values less than 50. Macroinvertebrate taxa showed varying sensitivities, with Ephemeroptera and Diptera reacting sensitively to environmental changes, while resilient taxa like Haplotaxida and Coleoptera adapted to impacted conditions. Flow rate, turbidity, and habitat variability influenced species preferences, with sediment-tolerant species flourishing in higher turbidity areas. Multimetric indices were adopted using abundance of Decapoda, Trichoptera, Ephemeroptera, Odonata-Coleoptera, Fliers alongside Taxa evenness, indicating good river quality and further highlighted that environmental factors such as pH, electrical conductivity, and nutrient levels shaped the macroinvertebrate composition, abundance, and diversity across rivers. Rivers like Orhionmwon and Okhuaihe 2 were identified as priority areas for conservation due to marked ecological changes. The study highlighted that environmental factors helped to shape the macroinvertebrate distribution and abundance, using statistical tools for ecosystem health assessment and conservation.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Streams and rivers are particularly vulnerable in tropical locations where vast forested areas are converted to crops and grazing fields (Boyero *et al*., 2009). The capacity of freshwater ecosystems to uphold their natural hydrological processes and biological dynamics, along with their role in providing clean and reliable water sources, has been compromised due to deteriorating conditions in their surrounding catchment areas (MEA, 2005; UN-Water, 2011). The gradual decline in the quality of freshwater resources underscores the pressing necessity to develop accurate tools, methodologies, and approaches for assessing the impacts of human-induced activities on these ecosystems to ensure prompt and targeted management interventions, facilitating appropriate strategies for restoration and mitigation (Edegbene *et al*., 2019).

In addition to health and food, access to clean and drinkable water is a fundamental human necessity. This supports the UN Sustainable Development Goal 6, which aims to provide everyone access to clean water and sanitary facilities by 2030. The objective is to boost safe water use and reuse globally by minimising pollution, eliminating dumping, and lowering the discharge of chemical compounds and materials into the water (WHO, 2019; UNEP, 2021). Despite its significance, the quality of readily accessible drinking water is frequently lowered because of demands placed on it by an expanding population, increased agricultural output, the discovery and mining of natural resources, urbanisation, and industrialisation (Naeem *et al*., 2013; Li and Wu, 2019). The ongoing contamination of water resources by manmade activity has cumulative effects on humanity, including issues from climate change, rivers drying up, and wetlands being reclaimed. Consuming water polluted by biological or chemical agents might pose substantial health concerns to the public since water quality affects health. Worldwide, an estimated 2.3 billion people are thought to be infected with water-borne illnesses (Ahmed *et al*., 2020), and yearly, polluted drinking water causes 485,000 deaths from diarrhoea (WHO, 2019). According to the World Health Organisation (WHO), water pollution globally causes 20% of cancers and 70% of other disorders (WHO, 2022).

The biotic and physical deterioration of river ecosystems has been aided by several uses of river ecosystems, including laundry, irrigation, hydropower generation, as well as activities in rivers' catchments such as unregulated land use, landscape alteration (Nyenje *et al*. 2010; PACN 2010; Kujawa and Glińska-Lewczuk 2011). A major source of water pollution in Nigeria is the discharges of untreated and inadequately treated municipal and industrial effluents into rivers. These discharges have caused severe ecological alteration of water resources in Nigeria (e.g. Arimoro and Ikomi 2008).

Many organisms survive in freshwater settings, although physical factors have proven to be practical barriers for some creatures. Most times, several populations of different species will coexist as a community. It goes without saying that the environment of organisms living in a freshwater ecosystem includes a variety of factors such as temperature, transparency, depth, and chemical composition. According to Farah *et al*., (2002), water bodies such as rivers are important freshwater sources vulnerable to pollution by various activities, such as domestic and industrial use, which impact their physical and chemical parameters affecting the overall quality of the water body. They are regularly used as dumping grounds for untreated waste from homes and industries, thus leaving them very unfit for usage when desired. Numerous studies in Nigeria have identified anthropogenic activities as an easy source of water pollution (Akintola and Nyamah, 1978; Ayoade and Oyebande, 1983; Ayoade, 1988, Obasi and Balogun, 2001; Ovrawah and Hymore, 2001).

The evaluation of water quality serves not only to determine its suitability for human consumption but also to assess its appropriateness for agricultural, industrial, recreational, and commercial purposes, as well as its capacity to support aquatic ecosystems. As municipal, industrial, and agricultural wastewater enters water bodies, it introduces biological and chemical contaminants, including heavy metals (Adekanmbi and Falodun, 2015). As vital water sources, rivers play crucial roles in drinking water supply, recreational and sporting activities such as water sports and fishing, all of which have implications for human well-being (Shanbehzadeh *et al*., 2014). Elevated levels of pollutants within river systems lead to a reduction in Dissolved Oxygen (DO) levels and an increase in parameters like Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) (Kaur and Verma, 2014). These physicochemical traits significantly influence aquatic life, impacting various ecological processes.

In Nigeria, key parameters used for assessing water quality encompass temperature, pH, conductivity, biochemical oxygen demand, dissolved oxygen, chemical oxygen demand, turbidity, phosphate, nitrate, sulphate, ammonia, and heavy metals (Arimoro *et al*., 2007). These physicochemical indicators have been observed to catalyse biochemical reactions within water systems. Fluctuations in their concentrations indicate of shifts in the water ecosystems condition; the outcome of such changes is a compromise in the suitability of the water for beneficial purposes (Igbinosa *et al*., 2012).

Most rivers in Nigeria, predominantly in urban and semi-urban cities, are now used to dispose both solid and liquid wastes. These high-polluting activities are now threatening the sustainability and functionality of freshwater ecosystems in Nigeria (Arimoro 2009; Arimoro and Oganah 2010), and the Rivers in Ikpe community, where this study was undertaken is no exception.

Macroinvertebrates exhibit foreseeable reactions to human disturbance, can be readily distinguished in laboratory settings, typically have lifespans exceeding a year, and lack the extensive mobility that fish possess. Due to their inability to elude contamination, macroinvertebrates can amalgamate the impacts of the stressors they are exposed to, over time and in conjunction. As a result, macroinvertebrate communities remain within aquatic systems for a duration that enables them to mirror the enduring consequences of pollutants. Nonetheless, this duration is sufficiently short to enable responses to comparatively sudden alterations in water quality. Unlike fish, these populations remain relatively motionless, subjecting them continuously to the elements of the water surface they inhabit. Consequently, due to their restricted mobility and relative incapacity to relocate from unfavourable conditions, the origins of chronic pollution sources can often be deduced by comparing the communities of these organisms. The responses of each macroinvertebrate to disruptions in their surroundings lead to quantifiable and frequently predictable changes in the abundance and composition at the community level (EPA, 2016).

Compared to other faunitic groups, macroinvertebrates offer several advantages as indicators of river health. First, they have a worldwide distribution with species that are differentially sensitive to changes in environmental conditions including nutrient enrichment—a major outcome of wastewater effluent discharges (Li *et al*., 2010; Arimoro, 2011; Odume *et al*., 2012). Second, in Sub-Saharan Africa, there is a growing interest in using macroinvertebrates to assess river health (Arimoro *et al*., 2008b; Masese *et al*., 2009; Arimoro, 2009; Wolmarans *et al*., 2014). Third, because macroinvertebrates can easily be sampled with inexpensive equipment, they are an ideal group of organisms for monitoring river health in developing countries where the availability of finance often impedes such studies. Fourth, sub-lethal responses of macroinvertebrates have been used as early warning signals of deteriorating water quality (Masese *et al*., 2009; Odume *et al*., 2012).

Macroinvertebrate communities represent an important fraction of stream biodiversity and their assemblage composition and richness correlate strongly with environmental change at each level (Strayer, 2006). For example, an increase in sediment loading and deposition by anthropogenic disturbance can bury macroinvertebrates and their habitats and cause the loss of species in streams (Connolly and Pearson, 2007). Benthic macroinvertebrates fluctuate in response to natural and human-induced disturbances and are therefore good indicators of environmental health (Muralidharan *et al*., 2010).

Aquatic sediments can act as both a sink and a source of pollutants and are formed from the deposition of particles and colloids (David *et. al.,* 2003). Certain pollutants are concentrated in the sediments because industrial, domestic and agricultural wastes are continuously being discharged into our aquatic systems. Such pollutants can endanger public health when unified in the food chain or released into the overlying waters that serve as drinking water supplies. Heavy metals from the forgoing can constitute a serious health hazard. Metals having densities five times greater than water are known as heavy metals (Garbarino *et al.*, 1995). The aquatic system receives many heavy metals from unregulated sewage, industrial effluent, a constituent of pesticides used in arable land and runoff from hinterlands (Tarq *et al.*, 1991). Heavy metals are transported as either dissolved species in water or as an integral part of suspended sediments and they may be volatilized to the atmosphere or stored in the river sediments.

1.2 Statement of Problem

One of the most recent problems in developing countries like Nigeria is the shortage of clean water, particularly in rural communities that rely on rivers as their main source of domestic water supply. The deteriorating quality of water threatens sustainable living in these communities, therefore, giving a reason for worry (Omoigberale *et al*., 2013). Sadly, rivers are being polluted by indiscriminate dumping of sewage, waste from industries, agricultural waste and other human activities, which in turn, affect the physical and chemical characteristics of these water bodies (Nkwoji *et al*., 2010).

Orhionmwon River, Irogbe River and Okhuaihe River (at Ikpe community) are important fishing sites in Edo state and are currently impaired by human activities such as waste deposits, bathing, farming, indiscriminate defecation, laundry, large-scale sand dredging and agricultural runoffs from neighbouring farmlands, where the application of fertilizers is a common practice. Ikpe Waterside community, where these rivers are located is variously under-developed when compared to other villages in Edo State because it lacks the basic amenities of proper health facility, pipe borne water and toilet facilities. So, they defecate into the river water in their backyard thereby posing serious health hazards to the consumers of raw water in the communities settling along the riverbank. The rivers are in the tropics with a mean annual temperature of 30.2 °C, relative humidity of 61% and annual rainfall ranging between 1200 mm and 1300 mm (Edegbene *et al*., 2015). The availability of clean and safe supply of drinking water is a requirement for sustainable growth and development. Thus, the quality of water influences the well-being of any population that uses it. Hence, an examination of water for physical and chemical characteristics is essential for public health studies (Chinedu *et al*., 2011).

Aquatic biota are reliable indicators of the impact of human-induced activities on freshwater ecosystems because they reside in the system, integrating the combined effects of physical, chemical and biological stressors (Shull *et al*., 2019). Of the different aquatic biota, macroinvertebrates are commonly used for assessing the effects of the ecological state of water bodies (Rosenberg and Resh, 1993; Bonada *et al*., 2006; Odume *et al*., 2012); deterioration and a variety of biological monitoring (biomonitoring) approaches have been developed based on them, e.g. single biotic index, multivariate and multimetrics (Bonada *et al.*, 2006).

A multimetric index for assessing the biological integrity of benthic macroinvertebrate communities has not yet been established, as no documented research or published studies have previously been conducted within these study sites at Ikpe Community.

1.3 Justification for the Study

Anthropogenic influences in this region include industrialisation, religious (including fetish) activities, expansion of agricultural and grazing activities. Rivers in these locations are of importance to inhabitants along its stretch, since it is a source of domestic water supply, recreational activities and irrigation for farming. Various human activities on the environment have resulted in unprecedented accumulation of physical constituents and trace metals in various matrixes of the ecosystem (Institute of Environmental Conservation and Research, 2000). The aquatic ecosystem which has been envisaged by many as a universal receptacle is not an exception to this menace (Ezenwa, 2013). Anthropogenic perturbations leading to ecological impairment emphasize the importance of this research, given the absence of documented evidence on their influence on the physicochemical properties and benthic macroinvertebrate structure and diversity of these river systems.

Water quality monitoring in Nigeria relies chiefly on the analysis of physicochemical variables and basic analysis of biotic distribution in relation to pollution gradient (Arimoro and Ikomi, 2009; Arimoro *et al.*, 2015; Edegbene *et al.*, 2015; Edegbene, 2018). However, physicochemical analysis alone as a means of monitoring water quality conditions has been criticized because it cannot give an all-inclusive picture of the state of water bodies. Once more, physicochemical analysis is not cost-effective unlike the macroinvertebrate sample collection and analysis; it requires a lot of analytical skills and finances to carry out such analysis. (Edegbene *et al.*, 2019). In instances where physicochemical analysis is complemented with biotic analysis, such analyses have not yielded the needed results because they are not directly linked to management. Consequently, the development of a multimetric index for these three Rivers in Ikpe community, Edo state, Nigeria is sacrosanct currently. The relevance of the multimetric index is premised on the observation that, despite its extensive global application in aquatic ecosystem assessment, no documented multimetric index presently exists for the water bodies in Ikpe Community. Addressing this gap is thus essential to establishing a baseline for evaluating biological integrity in the area.

In recent years, numerous methods have been developed to assess the ecological condition of freshwater ecosystems. Because of the low costs, fast field deployment, and use of various metrics at different levels in the biological hierarchy, multi-metric indices (MMIs) have been extensively used to measure ecosystem conditions (Baptista *et al*., 2007; De Bikuña *et al*., 2015; Ntislidou *et al*., 2018; Lu *et al*., 2019).

The advantages of using aquatic invertebrates for Multimetric Indices include;

1. aquatic life stages that respond to a broad range of environmental conditions,
2. being relatively immobile and
3. living in close contact with bottom sediments and the water column (Bonada *et al*., 2006; Mereta *et al*., 2013).

Thus, aquatic invertebrates have been widely used in MMIs, because they meet many of the criteria that characterise the efficacy of this bio-monitoring tool (De Bikuña *et al*., 2015; Ntislidou *et al*., 2018; Fierro *et al*., 2018).

In the field of biology, MMIs designed to evaluate and signal the health of ecosystems, like the Index of Biological Integrity (IBI) introduced by Karr in 1981, and the Vegetation Index of Biological Integrity (VIBI) developed by Mack in 2004, have been extensively employed to gauge the impact of human activity on natural environments. This is accomplished by combining measures of the biological community that exhibit notable responsiveness to changes in one or more of the physical or chemical attributes that are influenced by human actions or disruptions (Karr and Chu, 1997). The observed measurements, often compiled into "metrics" such as species abundances, growth forms, diversity, and conservation significance, tend to encompass multiple levels of causative hierarchy, potentially diluting the signal of the underlying factor one aims to detect. MMIs effectively streamline this causal hierarchy and exploit the independent data encapsulated within these metrics to generate a singular index that mirrors disturbances of human origin (Karr and Chu, 1997).

This methodology is particularly advantageous in the context of resource management, where the primary interest frequently centres on understanding how human activities disrupt biological communities. This proves challenging given the intricate web of connections linking human interference to the quantifiable biological metrics, compounded by the obscurity surrounding mediating factors. Nevertheless, managers bear the responsibility of evaluating the impact of human-induced disturbances on systems, allotting resources to counteract these impacts, and gauging the outcomes of these remedial endeavours. MMIs prove valuable in this scenario, providing a quantitative means to gauge the effects of disturbances even when causal processes remain uncertain. Additionally, MMIs can serve as a foundation for constructing causal models (Riseng *et al*., 2006).

1.4 Aim and Objectives

The study was aimed at evaluating the water quality and macroinvertebrate indices of three Rivers in Ikpe community, Edo State, Nigeria.

The objectives of the study were to;

i. determine the water quality and its seasonal and spatial variation.
ii. determine the macroinvertebrate composition, abundance and diversity
iii. determine the seasonal and spatial variation of the macroinvertebrate’s fauna

iv. adopt a multimetric index for accessing the biological integrity of macroinvertebrate communities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Physico-chemical Parameters in Surface Water

Water quality assessment is frequently based on the monitoring of the physical, chemical and biological parameters, owing to natural occurrences and anthropogenic activities; with the aim of developing strategies for the protection of freshwater resources from pollution (Al-Harbi *et al.* 2006).

The acidity level of water, as indicated by its pH, plays a crucial role in determining how corrosive it can be. Several factors can alter the pH of water. Gupta *et al.* (2009) found a positive correlation between pH, electrical conductance, and total alkalinity. In their study, they observed a reduced rate of photosynthetic activity and an increase in the assimilation of carbon dioxide and bicarbonates, which ultimately led to a rise in pH. Additionally, low oxygen levels coincided with high temperatures during the summer months. The higher pH values observed suggest that changes in physico-chemical conditions have a greater impact on the carbon dioxide and carbonate-bicarbonate equilibrium, as noted by Karanth (1987).

To evaluate the quality condition of the rivers, Kaizer and Osakwe (2010) looked at the physico-chemical features and heavy metal concentrations in water samples from five river systems (the Ase, Agbarho, Ethiope, Ekakpamre, and Afiesere rivers) in the central region of Delta State, Nigeria. The watersheds selected for the study were uniformly distributed and had equivalent geology, climate, soil, and plant composition. Studies on water samples obtained from the rivers revealed that their physico-chemical properties varied substantially. According to a comparison of the heavy metal level in the various samples with recommended international criteria like WHO (1993), the rivers were not significantly contaminated and are thus suitable for residential and industrial usage.

In the Nworie inland River in Imo State, Nigeria, Ubuoh *et al.* (2023) examined the impact of human activities on water chemistry and the corresponding ecological risk from January 2020 to December 2022. The results of the physicochemical tracers showed that the water was hard (Ca^{2+}), somewhat acidic, and had high amounts of phosphorus, $CaCO_3$, and dissolved oxygen—all of which were over WHO critical criteria. Critical worldwide limits for heavy metals including Cd^{2+}, Cr^{2+}, Fe^{2+}, Ni^{2+}, and Pb^{2+} were exceeded. $Pb^{2+} > Fe^{2+} > Cu^{2+} > Zn^{2+} > Cd^{2+} > Cr^{2+} > Ni^{2+}$ were the metals in Nworie Inland River that were in decreasing quantity, indicating an increase in human activity such as dumping of organic waste into the river through time. There were, respectively, positive and negative connections between physico-chemical tracers and components in water resulting from intricate human activities. Due to agricultural operations and vehicle flows, PCA was considerably loaded with $CaCO_3$, COD, DO, Ca, PO_4, Cu, Fe, and Zn in PC1. In PC_2, was loaded with SO_4 and significantly loaded with NO_3, causing nutrient enrichment and eutrophication because of the disposal of organic waste in the river and the use of fertilizer. Cl and Na were only slightly overloaded in PC_3. Cadmium's contamination factor (Cf) was high whereas those of other heavy metals were low, in the following order: Cd^{2+}, Pb^{2+}, Cu^{2+}, Fe^{2+}, Zn^{2+}, Ni^{2+}, and Cr^{2+}. Both the pollutant load (PLI) and the degree of contamination were moderately measured. Lower River (LR), Upper River (UR), and Middle River (MR) are in order of the degree of contamination. In decreasing order, the ecological risk factor were: Cd^{2+}, Pb^{2+}, Cu^{2+}, Fe^{2+}, Zn^{2+}, Ni^{2+}, and Cr^{2+}, with a moderate risk index. The self-purification capabilities of a moving river or stream may be usually credited with the moderate to low contamination and ecological risk determined in this study, which helps to minimize pollution load and related risk. However, the high cadmium concentrations could be associated with rising urban activities and would pose a deleterious effect to the lives of the people and the ecosystem.

An analysis of changes in the physicochemical properties of surface water following dredging operations in the Otamiri and Nworie Rivers in Imo State, Nigeria, was carried out by Iwuoha and Osuji (2012). The purpose was to assess the environmental repercussions of dredging on water quality. The results of the ten-month post-dredging monitoring period indicated a slight enhancement in water quality. Parameters such as pH, dissolved oxygen (DO), and total suspended solids (TSS) exhibited positive changes, whereas biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_5), turbidity, total hardness, acidity, alkalinity, and electrical conductivity experienced decreases, converging toward levels comparable to those prior to the dredging operation. The researchers concluded that the influence of dredging on water quality is confined to specific locations and is relatively short-term in nature.

In the Nigerian state of Rivers, which is home to the Etche ethnic group, the river that passes through the settlements of Imeh, Edegelem, and Chokocho was the subject of a study conducted by Onyegeme *et al.* (2018). The laboratory findings of the chosen physico-chemical parameters, when compared to the WHO standard, revealed that all the chosen physico-chemical parameters, except for pH, were within the range allowed by the WHO in both the wet and dry seasons. During the rainy season, pH values of 5.00±0.00, 5.40±0.40, and 5.40±0.30 were recorded for Imeh, Edegelem, and Chokocho, respectively. In contrast, during the dry season, the pH values were 5.83±0.01, 5.56±0.01, and 5.90±0.01 for Imeh, Edegelem, and Chokocho, respectively. These findings indicate that the river exhibits an acidic nature, likely due to the accumulation of organic waste. This acidity results from the decomposition of organic matter by aerobic microbes, which generates carbon dioxide as a byproduct. This carbon dioxide then dissolves in water, forming carbonic acid and thereby increasing the water's acidity, as explained by Keith (2003). Consequently, the acidic conditions in the Otamiri-Oche River pose a potential threat to its native species. Additionally, it's noteworthy that magnesium hardness exceeded the permissible limit set by the World Health Organization (WHO) only during the rainy season.

The concentrations of turbidity, TSS, and DO according to Umunnakwe and Johnson's (2013) preliminary investigation of some physico-chemical parameters and water quality of the Imo River, Nigeria, showed that the river was not fit for drinking without treatment; and the river cannot support aquatic life sufficiently. They claimed that activity at the nearby paper mills, cosmetic manufacturers, and other businesses as well as urban runoff were responsible for polluting the river. In 2013, Gideon *et al.* conducted research on the Okura River, Kogi State, Nigeria's physico-chemical properties. The World Health Organization (WHO, 2011) and Standard Organization of Nigeria (SON, 2007) drinking water criteria were followed, and they concluded that the concentration of physical and chemical parameters in the river was within acceptable levels. Based on the concentrations of the physico-chemical parameters, this renders River Okura drinkable, while the presence of anions such nitrate and sulfate showed some quantities of undesirable compounds in the river.

Hydrobiological studies of the Benin River were carried out at Koko by Fregene (1978) and reported the river had an acidic quality. Ayayi and Osibanjo (1981), Fufeyin (1987), and Egborge *et al.* (1986) also supported this acidity. Egborge *et al.* (1986) examined two stations along the stretch in a study at the upper stages of the Benin River and its tributary, the Jamieson River, to determine the contamination potential by N.E.P.A. (National Electric Power Authority) thermal power station at Ogorode, which uses the water of the Benin River for cooling. Having observed a greater temperature at Benin River than in Jamieson River, they identified a risk for thermal pollution. While dissolved oxygen, phosphate, nitrates, and silicate were often lower in Benin River, the concentration of iron, potassium, sodium, calcium, and magnesium were generally greater. They deduced that the examined stretch was oligotrophic in nature from the different values for physical and chemical parameters that were found.

Water samples from ten (10) streams at various locations throughout Ado-Ekiti and its surrounds in Ekiti State, Southwestern Nigeria, were taken for a study on specific streams conducted by Siyanbola *et al*. (2013). The samples' physicochemical characteristics were assessed. The parameters assessed in the water samples taken from the streams were clearly within the bounds of the restrictions of the World Health Organization (WHO, 2011) based on the findings of the analysis of the streams in Ado-Ekiti. The samples did not contain any iron or lead. As a result, most of the streams could be used for personal needs including drinking, cooking, bathing, and washing. The lack of industry in Ado-Ekiti and its surroundings may be the cause of these outcomes, although as the town grows, the environment may progressively improve. Therefore, it was crucial that the streams under study be routinely checked.

In order to ascertain the pollution levels and other physical and chemical characteristics of Ubeji Creek in Warri, Uzoekwe and Oghosanine (2011) assessed the creek. They found that parameters such as pH, dissolved oxygen, biochemical oxygen demand, and chemical oxygen demand fell within the acceptable limits established by the World Health Organisation (WHO, 2011) for surface water. Additionally, the concentrations of heavy metals in the creek were below the levels known to cause harmful effects and remained within regulatory standards. Anyanwu (2012) carried out a study on the physicochemical characteristics and trace metal content of Ogba River in Benin City, Nigeria. Among the twenty-six parameters examined, there were notable differences in BOD_5 (Biochemical Oxygen Demand over 5 days), depth, flow velocity, sulphate, phosphate, nitrate, and sodium levels among different sampling locations. Furthermore, they observed that thirteen of these parameters displayed distinct seasonal variations.

For six months, from March to August 2011, Edegbene *et al.* (2012) examined the physical and chemical properties of the Atakpo River in Nigeria's Niger Delta. Along the river's path, three specified stations were picked to connect with the locations of diverse human activities. The river was rapidly degrading, which might be linked to the fermentation of cassava and other human activities taking place in the river, which had a detrimental effect on the water quality of the river. Due to this, immediate action was required to improve the river's rapidly declining condition.

In Nigeria's Cross River State and Bakassi, Akpa Yafe River's physical and chemical features were investigated by Udofia *et al.* in 2014. According to the results, even though the majority of the water parameters were within the range considered acceptable by the Federal Ministry of the Environment (FMENV) and the WHO, the DO was low and the Lead readings were higher than the allowed limit. This suggested that pollution posed a threat to the Akpa Yafe River.

An analysis of the risks and financial effects of improper wastewater treatment and regulation in the community was carried out in 2014 by Odigie. As a concrete example, the study examined the Ikpoba River in Benin City, Nigeria. The findings revealed that the substantial economic operations occurring along the Ikpoba River's banks played a major role in the extensive pollution affecting the river. These operations encompassed various industrial and commercial activities within the city, such as car washing, rug cleaning, livestock trading, slaughterhouses, and waste disposal from markets.

The physical and chemical properties of water samples collected from the Itaogbolu region in Ondo State, Nigeria, were examined in a study by Adefemi and Awokunmi (2010). They found that the electrical conductivity of the water ranged from 300 to 11500µSc/cm. The study also provided data on several other parameters: pH levels ranged from 6.59 to 7.68, temperatures ranged from 21.10 to 27.10°C, chloride concentrations were between 78.10 and 156.20mg/l, total hardness ranged from 130 to 298mg/l, sulphate concentrations were between 82.50 and 97.00mg/l, total dissolved solids (TDS) ranged from 0.00 to 0.2mg/l, and alkalinity varied from 0.92 to 2.45mg/l.

In the Niger Delta, Effiong *et al*. (2021) carried out research on the seasonal and regional fluctuation in water quality indicators of a humid tropical river. All the parameters analysed varied across stations, which was attributed to the levels of habitation within each station and proximity to land. All the measures, except for temperature, did not, however, exhibit any discernible spatial variation. TSS and transparency both show a substantial difference in the examined parameters. There are human-mediated influences on the river system, as evidenced by the fact that TSS, TDS, EC, and alkalinity levels for portable water exceeded WHO-permitted limits. According to studies, the Mbo River's measurements indicated low-moderate-high pollution levels, indicating an ecology that was unsettled.

On the other hand, Agbaire and Obi (2009) looked at how the characteristics of water from the Ethiope River near Abraka were impacted by seasonal variations. The study found that during the wet season, the water had a conductivity of 81.7µS/cm, a temperature of 27.73°C, a pH level of 6.82, a TDS of 0.2mg/l, total suspended solids (TSS) measuring 16.21mg/l, dissolved oxygen (DO) content of 16.80mg/l, and a biochemical oxygen demand (BOD) of 4.5mg/l. During the dry season, the water's conductivity was 87.2µS/cm, temperature was 29.150°C, mean pH was 6.82, TDS was 0.34mg/l, TSS was 15.21mg/l, DO was 17.45mg/l, and BOD was 4.38mg/l.

The water quality of the Ethiope River, which is in Nigeria's Niger Delta coast, was evaluated by Aisien *et al*. (2010). The results of their investigation demonstrated that the river's quality exhibited variations from one location to another along its course. The water collected from different stations, labelled as A, B, C, D, E, F, and G, was categorized as having "Fairly Good," "Fair," "Poor," and "Bad" quality at stations A and G, B and F, D and E, and C, respectively. This observation highlighted that the water quality within the Ethiope River was contingent on the specific collection point. Moreover, the study found that as the river flowed downstream, the water quality gradually decreased. However, the water quality at station G indicated that the river possessed a noteworthy self-purification capability. This meant that despite the pollution affecting the river, the water quality remained satisfactory at this station. This phenomenon of self-purification was also noted by Rim-Rukeh in 2006 for the Orogodo River. In a separate study, Aluyi *et al* (2003) examined several physical and chemical parameters in the River Ethiope. During the sampling period, the recorded water temperature ranged from 25.5 to 27°C, while the dissolved oxygen (DO) levels varied from 4.1 to 7.8 mg/l. The biochemical oxygen demand (BOD_5) values ranged between 0.4 and 4.2 mg/l, chemical oxygen demand (COD) between 18 and 68 mg/l, and total solids from 3.0 to 6.6 mg/l. Additionally, concentrations of total hardness, calcium, phosphate, magnesium, and iron, which were within the range of 0.0 to 2.2 mg/l, as well as sulphate, generally exhibited low levels.

The low densities of populations of pollution-tolerant macroinvertebrate groups, the declining water quality, and the physico-chemical conditions of the water during the dry season months all indicated organic pollution stress caused by decomposing household waste and inorganic fertilizer that irrigation systems washed into the stream, according to Emere and Nasiru (2009), who studied macroinvertebrates as indicators of the water quality of an urbanized stream in Kaduna State.

The number of benthic macroinvertebrate species and their relationship to physico-chemical parameters were studied by Shailendra *et al*. (2013). They found that there were 42 species of benthic macro-invertebrates' fauna, which were divided into five classes, five families, and three (3) phyla, including Oligochaeta, crustacea, Hexapoda, Gastropoda, and Pelecypoda. They also noted that the percentage composition of mollusc and arthropod species was 47% and 35.57%, respectively, with annelid species having a percentage composition of 17.35% and occurring least. All benthic macroinvertebrates (phylum Annelida, oligochaeta), arthropods (crustacea, hexapoda), mollusks (gastropoda, pelecypoda), and temperature all exhibited positive correlations with transparency and nitrate, as well as positive correlations with Annelids and Arthropods and total hardness. All benthic macro-invertebrates (phylum Annelida, oligochaeta, arthropods, crustacea, and hexapods), mollusca, gastropoda, and pelecypoda, showed negative correlations with pH, D.O., B.O.D., alkalinity, chloride, and phosphate, while temperature showed negative correlations with arthropods. Molluscs and overall hardness on the other hand had a negative relationship.

An assessment of the macroinvertebrate community and water quality of a rural river in Southeast Nigeria, in relation to anthropogenic activities was carried by Anyanwu *et al.*, (2021). Uncontrolled sand mining was the main human activity in the river. Results indicated that biochemical oxygen demand, dissolved oxygen, and pH were outside of permissible ranges. There were 346 macroinvertebrate specimens documented, representing 12 species and 3 taxonomic groupings. The community structure indicated disruption, and the macroinvertebrates were primarily pollution-tolerant species like *Halipus* sp. larvae and *Chironomus* sp. larvae. Canonical correspondence analysis revealed that the first canonical axis, with an eigen value of 0.042, accounted for approximately 80% of the variance. While Axis 2 exhibited a significant positive correlation with Araneae affected by phosphate and BOD, Axis 1 had a substantial positive association with Hemiptera and Diptera which was explained by temperature and BOD. Temperature-influenced station 2 exhibited a significant positive correlation with axis 1, while pH, TDS, and EC-influenced station 1 had a substantial negative association. Axis 2 and Station 3, which were impacted by phosphate and BOD, were strongly positively correlated.

In a similar vein, Anyanwu *et al*. (2019) investigated the macroinvertebrate fauna living in a Southeast Nigerian River that receives an effluent discharge with the goal of determining how different human activities impact the community structure of these organisms. The research identified twenty different taxa belonging to five taxonomic groups, totalling 119 macroinvertebrate individuals. Among these, non-biting midges of the Chironomus species were the most abundant, comprising 39.5% of the total. Regarding their spatial distribution, station 2 had the highest number of macroinvertebrates with 57 individuals, followed by stations 3 and 2, which had 37 and 25 individuals, respectively. Most of these macroinvertebrates were species that could tolerate adverse environmental conditions, making up 75% of the population. The diversity indices, including the Shannon-Wiener index (ranging from 1.717 to 1.923), Margalef Species Richness (ranging from 2.769 to 2.968), and Evenness index (ranging from 0.4285 to 0.6843), indicated a lower number of species and suggested environmental degradation due to human impacts. Both the physicochemical parameters and the composition of the macroinvertebrate communities indicated that the river was negatively affected by effluent discharge and other human activities. Specifically, station 1 appeared to be polluted due to cumulative impacts based on physicochemical parameters, while station 2 was impacted by effluent discharge according to the macroinvertebrate assemblages.

Three different locations were used by Ayanwu *et al*. (2022) to evaluate the water quality of a rural river in Southeast Nigeria in relation to human activity. Uncontrolled sand mining was the main human activity in the river. While some of the biochemical oxygen demand measurements were over the permitted range, they noticed that pH and dissolved oxygen levels were below acceptable limits. The study found that the water quality was not negatively impacted by the impacts of the season, sand mining, and other activities.

The impact of industrial activities on water quality of Omoku Creek, Rivers State of Nigeria was investigated by Ewa *et al.* (2011). This was done by examining the physico-chemical and organic parameters of water samples of the creek to determine the quality and extent of pollution. It was reported that Omoku creek, by virtue of its quality status, had detrimental effects on aquatic lives, as the mean levels of parameters like turbidity, temperature, BOD and DO exceed FEPA'S permissible limits for surface water. High content of TSS suggests that wastes were being added to the water from other sources such as the dumpsites within the catchment apart from the industrial effluents.

Heavy metals are inorganic elements required for plant growth in very minute quantities, toxic and poisonous in relatively high concentrations, biologically undegradable but, easily assimilated and are bioaccumulated in the protoplasm of aquatic organisms (Egborge, 1994). Obasohan *et al.* (2006) reported that the heavy metals in the environment may accumulate to acutely toxic levels without visible signs.

Seventy-two (72) Nigerian rivers, streams, and waterways in Southern Nigeria were the subject of a study by Asonye *et al.* (2007) that examined their physico-chemical properties and heavy metal profiles. The turbidity, conductivity, and pH of all the samples were higher than World Health Organisation (WHO) and European Economic Community (ECC) Standards. Profiles of the heavy metals showed Pb, Cd, Cr, Zn and Mn levels in some of the samples being above the guidelines of WHO and EEC. Similarly, in Ishiagu, Ebonyi state, Nigeria, Ude *et al*. (2012) examined the physicochemical characteristics and heavy metal level of several water sources located within two kilometres of a quarry site. It was observed that all physico-chemical parameters and heavy metals investigated were all above the World

Health Organization (WHO) permissible limits for drinking water at the quarry site and one kilometre from the quarry site. Total hardness, chloride and fluoride were above the WHO permissible limits at the quarry site. A higher concentration above WHO specification, were also observed in phosphate and conductivity in all the samples. The metals (Aluminium, Cadmium, Iron, Zinc, Lead, Calcium and Magnesium) occurred above WHO permissible limits for drinking water in all the samples but, lead was not detected in the sample collected two kilometres away from the quarry site. Sodium, potassium, manganese and copper were above the WHO permissible limits in samples collected from the quarry site.

In the Nigerian Delta state, surface water samples from the Warri River were studied by Wogu and Okaka (2011). They used an Atomic Absorption Spectrophotometer (AAS) to quantitatively analyse the concentrations of nine heavy metals: Cadmium, Chromium, Copper, Iron, Lead, Manganese, Nickel, Vanadium, and Zinc. The heavy metals were ranked in decreasing concentration order as follows: Iron (Fe) > Manganese (Mn) > Zinc (Zn) > Copper (Cu) > Nickel (Ni) > Vanadium (V) > Chromium (Cr) > Cadmium (Cd) > Lead (Pb). Among these, Iron had the highest average concentration at 1.9304 mg/l, while Lead showed the lowest mean concentration at 0.0001 mg/l. It's worth noting that the Warri River received pollutants from various sources including industries, agriculture, and households. The elevated Iron concentration was attributed to the discharge of effluents from the Iron and steel industry located at Aladja. The study's findings indicated that Cadmium, Chromium, Manganese, and Nickel had maximum values that exceeded the limits recommended by the Environmental Protection Agency (EPA) in 2003, the World Health Organization (WHO) in 2003, and the Standard Organisation of Nigeria (SON) in 2007.

A study on the physical and chemical properties of the Ossiomo River in Edo State was carried out by Ikhuoriah and Oronsaye (2016). They examined various factors such as total solids, calcium, magnesium, chloride, phosphate, nitrate, and sulfate. These factors displayed notable variations in different seasons, with statistically significant differences ($p<0.05$). However, the remaining parameters exhibited no substantial alterations ($p<0.05$). The researchers concluded that despite the negative impact of human activities on station 2, the measured values remained within acceptable limits.

2.2 Water Quality Index and Principal Component Analysis

Examining the condition of drinking water quality through an empirical approach has the potential to furnish scientific evidence that can inform decision-making processes aimed at safeguarding and overseeing water quality. In cases where prompt action is necessary, this approach becomes imperative. To accomplish this, it is essential to employ robust water quality assessment methods and pollution models to yield dependable outcomes and bolster confidence in managerial decisions. Various strategies for assessing water quality have been developed and put into practice by researchers (Tian and Wu, 2019; Su *et al.*, 2019; Li and Wu, 2019). For instance, Fathi *et al.* (2018) employed a multivariate approach along with the Water Quality Index (WQI) to appraise water quality in Iran's Baheshtabad River. In a similar vein, Fatoba *et al.* (2016) conducted a potential ecological risk assessment to gauge water quality and ecological risks in Kokori and Kolo Creek, with NPI analysis identifying Cd, Ni, and Cr as the primary contributors to pollution. Furthermore, Owamah *et al.* (2020) also utilized the Water Quality Index (WQI) to assess the groundwater status in the Emevor community located in Nigeria's Niger Delta region.

To assess water quality using the Water Quality Index (WQI) and pollution models, Sam *et al.* (2023) examined the physicochemical properties of drinking water in selected communities—Okerenkoko, Kurutie, and Oporoza—located in the Gbaramatu Kingdom within the Niger Delta region of Nigeria. Twelve carefully chosen areas throughout the three towns were tested for nitrate, chromium, cadmium, copper, lead, aluminum, pH, total hardness, total dissolved solids, cyanide, and residual chlorine. The examined water samples' WQI findings showed that they were unfit for consumption, with a mean pH of 8.11±0.32, above the crucial WQI value of 100. The main causes of the decline in water quality were nickel concentrations between 0.014 and 0.176 mg/L and residual chlorine levels between 11.6 and 7407 mg/L, both of which were over the WHO-recommended limits of 0.02 and 0.25, respectively. Although groundwater's organoleptic qualities were superior to those of surface and rainwater, the geo-accumulation index revealed that the region's water sources range from mildly to severely polluted with Ni and Cd.

A water pollution index was used in a study by Umunnakwe and Nnaji (2015) to assess the effects of different factors on the pollution levels of the Nworie River. Their analysis showed that certain factors, specifically turbidity and total suspended solids, exceeded the established standards for surface water. Additionally, the levels of iron exceeded the recommended limits for sediment. The dissolved oxygen level measured at 5.7mg/l indicated the river's ability to support aquatic life. The study computed pollution indices, revealing that the organic parameters had an index of 0.42, while the inorganic parameters had an index of 0.34. Comparatively, during the river dredging in 2010, the organic parameters had a higher index of 0.48, while the inorganic parameters had an index of 0.30. For sediments, the organic variables scored 0.08, and the inorganic variables scored 0.02. During the 2010 dredging, the organic parameter index for sediments increased to 0.13, while the index for inorganic variables rose to 0.053. These pollution indices strongly indicated that organic waste pollution was more pronounced during the dredging of the Nworie River.

To determine if the Otamiri and Oramiriukwa Rivers (2010) were suitable for public usage, Amadi *et al* used the Water Quality Index (WQI). The overall WQI score for the collected samples was 174.49. This elevated WQI value was primarily due to significant concentrations of conductivity, color, total solids, turbidity, total coliform, iron, manganese, COD, BOD, and nitrate, which can be attributed to human activities along the riverbanks. Comparing these findings to the Nigerian Standard for Drinking Water Quality (NSDWQ) permissible limits revealed that the rivers were contaminated, rendering the water unsafe for domestic consumption and necessitating treatment.

The composition of the benthic macroinvertebrate communities in a stream in southern Nigeria was studied by Keke *et al.* (2021). They examined how these communities were influenced by both the physical and chemical characteristics of the water and sediment, particularly in areas affected by human activities. To analyse their data, the researchers used two statistical techniques: Principal Component Analysis (PCA) and Canonical Corresponding Analysis (CCA). These methods allowed them to make sense of a dataset containing 33 different water quality measurements. Furthermore, the researchers pinpointed the key physicochemical factors that played a significant role in shaping the macroinvertebrate communities. They also examined the connection between these crucial factors and the types of macroinvertebrates present. The results obtained from PCA and CCA highlighted that the presence of heavy metals in the sediment was the most influential factor contributing to the variability in benthic macroinvertebrate communities. The CCA results were particularly insightful, as they revealed a strong link between the characteristics of the species present in the stream and the environmental conditions. Specifically, the stream's sediments were found to be contaminated with heavy metals from industries that had relocated from the nearby areas, impacting both the water and sediment quality, as well as the structure of the benthic communities at the affected site. This impact was evident through the dominance of species that could tolerate high levels of organic pollution and heavy metals. Due to rapid urbanisation, the researchers observed a gradient of human-induced impacts that led to higher concentrations of heavy metals and nutrients at different sites along the stream. This was reflected in the prevalence of pollution-tolerant species, particularly from the Oligochaete and Diptera groups, at Sites 2, 3, and 4. The study offered valuable insights into the extent of chemical pollution caused by urbanization in a developing world context. The researchers' use of advanced statistical techniques and comprehensive water quality measurements provided a solid foundation for understanding the effects of anthropogenic stressors on aquatic ecosystems.

To document the selected physicochemical composition of various study sites within the Falcorp mangrove swamp ecosystem in Ijala, Warri, Delta State, Odigie and Olomukoro (2020) collected surface water samples from multiple locations. The differences between Stations 1, 2, 3, 4, and 5 for pH, Temperature, Electrical conductivity, DO, BOD_5, TSS, Turbidity, Chloride, Salinity, Sulphate, Nitrate, Hardness, Ca, Ma, Zn, Cd, and Pb were not statistically significant ($P>0.05$). For the following parameters: TDS, Bi-carbonate, Phosphate, Fe, and Cu, there were significant differences ($P<0.05$) across the 5 stations. Apart from pH, the mean concentrations of most of the physical and chemical parameters in the surface water fell below the permissible WHO thresholds for portable water. At stations 1, 2, 3, 4, and 5, the water quality index (WQI) varied from 8.45 to 24.9, 8.31 to 23.95, 8.36 to 16.26, 8.24 to 10.11, and 8.43 to 23.58, respectively. With Eigenvalues 1 (PC1-PC6) and > 1 (PC7-PC22), the principal component analysis (PCA) of the data sets produced 35 variables under 22 components. In contrast to the negative association between DO, BOD_5, PO_4, NO_3, Fe, Zn, Cu, and Pb, there was a positive link between pH, water temperature, TDS, EC, TSS, TDS, TDS, turbidity, Cl, HCO_3, salinity, SO_4, hardness, Ca, Mg, and Cd. They noted that despite the numerous human activities taking place inside the estuarine habitat's watershed, the results of the measured concentration levels were low.

The water quality of the Okhuaihe River, Edo State, Nigeria was investigated by Egun and Ogiesoba-Eguakun (2016) from February to June to determine its suitability for drinking and other domestic purposes. Water samples collected from three stations were tested for fifteen physico-chemical parameters using standard analytical procedures. Biochemical oxygen demand and sodium were significantly different across the three stations. Except for calcium and iron, all other parameters were within the permissible limits recommended by the Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organisation (WHO). Water Quality Index (WQI) values ranged from 9.17 to 10.40, indicating excellent water quality which is suitable for drinking and domestic usage.

The effectiveness of the Pollution Tolerance Index (PTI) and Water Quality Index (WQI) as instruments for evaluating and managing rivers was investigated by Odigie (2019). The study was carried out on the Obueniyomo River to investigate the impact of human activities on both the river and its aquatic organisms. Three specific locations were chosen for analysis: upstream, mid-stream, and downstream. The data collected from these three sites underwent both statistical and biodiversity analyses. The data related to water quality were evaluated using the Weighted Arithmetic Index, while the Pollution Tolerance Index focused on pollution-sensitive groups. The primary benthic group identified was Chironomidae, constituting 20.99%, 18.47%, and 16.65% of the benthic community at the upstream, mid-stream, and downstream stations respectively. The findings from the Water Quality Index calculations for all three stations exceeded the benchmark value of 100. However, the Pollution Tolerance Index values recorded at these stations remained below 10, aligning with the Water Quality Index results. This alignment indicated the presence of pollution in the water, rendering it unsuitable for both human consumption and the survival of aquatic life.

The water quality features of the Okhuaihe River were evaluated by Ogbeibu and Ogiesoba-Eguakun (2019). Several parameters were found to be above the established standards, such as colour, Biological Oxygen Demand, Iron, Cadmium, and Lead; however, most of the parameters fell within the acceptable ranges set by the Federal Ministry of Environment and the World Health Organisation for safe drinking water and domestic use. Notably, nitrite, biological oxygen demand, water temperature, cadmium, and total hydrocarbon content exhibited significant variations ($p < 0.01$), and sodium showed a statistically significant difference ($p < 0.05$) between different monitoring stations. Based on the results obtained from the Duncan Multiple Range Test, station 3 stood out as a key contributor to differences in biological oxygen demand, nitrite, sodium, cadmium, and total hydrocarbon content, while station 4 was identified as the primary factor influencing water temperature. In contrast, the other measured parameters did not significantly differ among the stations ($p > 0.05$). The calculated Water Quality Index (WQI) for each station was 17.01 (Station 1), 13.29 (Station 2), 14.54 (Station 3), and 13.24 (Station 4). These readings fell within the acceptable range for high-quality drinking water (<50), indicating that the Okhuaihe River water is suitable for consumption by humans, aquatic life, and various household purposes. Principal Component Analysis (PCA) results revealed four main factors that impacted the river's water quality. These factors, with Eigen values exceeding 1, collectively explained 83.802% of the total variance. The study concluded that residents can confidently utilize water from the Okhuaihe River for domestic activities without concerns about its safety or quality.

The macroinvertebrate community and the pollution tolerance index (PTI) in the Edion and Omodo Rivers in the Agbede wetlands were studied by Olomukoro and Abdul-Rahman (2014). The prevalent groups, based on the percentage of their density occurrence, were Ephemeroptera (45.4%), followed by Diptera (24.7%) and Decapoda (24.03%). The PTI values for stations 2, 3, and 4 were notably low, suggesting diminished water quality at these locations. This was associated with the dominance of organisms such as Odonata (both Zygoptera and Anisoptera), Oligochaeta, and Chironomids, among others. Ephemeroptera displayed a relatively high diversity, showcasing families like Leptophlebiidae, Baetidae, and Ephemiridae, along with six distinct species including *Adenophleboides* sp., *Baetis* sp., *Centroptillum* sp., *Cloeon* sp., *Cloeon bellum*, and *Ephemeralla ignita*. These species' abundance indicated favorable water quality, likely attributed to their habitat preferences and available food sources. An interesting finding was that certain insects, like Ephemeroptera, displayed a preference for sluggish water environments adorned with macrophytes, which supported their ecological needs.

Similarly, the state and variety of the benthic fauna community in the Udu-Ughievwen wetlands were also surveyed by Olumukoro and Abdul-Rahman (2014) during a six-month period. A total of twelve taxonomic groups were recorded and the dominance of Ephemeroptera in most of the sites indicated a healthy nature or sound environmental quality of the entire Udu-Ughievwen wetlands. The study revealed that wetlands are populated by rather different assortments of macrobenthic invertebrates.

An investigation of the water quality index (WQI) and bacteriological qualities of Ossiomo river, Orhionmwon Local Government Area, Edo State, Nigeria was carried out by Odigie *et al.*, (2022). The Water Quality Index in this study ranged from 275.75 to 394.01 mg/l (upstream and downstream) for various sample locations during the various time periods. The midstream and downstream samples were rated as unsuitable for drinking while the upstream sample was given a very low rating for water quality. This could have been because of anthropogenic activities such as the direct dumping of waste, industrial contaminants, and agricultural runoffs into the receiving water body. According to Singh and Hussian (2016) and Rofhiwa *et al.* (2021), the water quality index rating of the examined samples suggested that the water samples from the Ossiomo River were not safe for human consumption.

To evaluate the Osse River's water quality index in Edo State, Nigeria, Ekhator *et al.* (2015) conducted research. The results revealed that the five stations' mean water quality index (WQI) values for the Osse River ranged from 89.676 41 to 550.678 182, with the greatest WQI values recorded during the wet seasons because of floods, human activities, and intrusion from the sea. Poor water stations 1 and 2 were categorized as well as good water stations 3, terrible water stations 4, and unfit for drinking station 5. Without adequate treatment, it was determined that Osse River was unfit for human consumption. But there are other things you can do with it.

The Ebonyi River's catchment region at Eha-Amufu was examined for the presence of heavy metals, and Agwu *et al*. (2023) determined whether the water was suitable for human consumption. They utilized relevant heavy metal pollution indicators and measures of heavy metal toxicity. Throughout both rainy and dry seasons, all water samples exhibited a slightly alkaline pH, ranging from 7.58 to 7.90. During the rainy season, sodium was the only mineral that showed a significantly higher concentration. Notably, magnesium was the dominant mineral in surface water, particularly in the downstream section, with concentrations of 8.41 mg/l in the dry season and 13.31 mg/l in the rainy season. The average levels of trace metals, including lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), iron (Fe), nickel (Ni), mercury (Hg), and manganese (Mn), exceeded the recommended limits for drinking water quality, except for zinc (Zn) and magnesium (Mg). Pearson's correlation analysis revealed associations between certain physico-chemical properties and specific heavy metals, apart from pH, suggesting that pH is not the primary factor influencing the distribution of heavy metals in surface water. Notably, nickel (Ni), arsenic (As), and manganese (Mn) displayed contamination factors exceeding 6.0, indicating a very high level of contamination, while the ecological risk index for arsenic (As), cadmium (Cd), and mercury (Hg) exceeded 320, signifying a serious ecological risk. Overall, the heavy metal pollution indices, along with the heavy metal toxicity load at all sampling sites, surpassed the established threshold, indicating deteriorated water quality unsuitable for human consumption.

2.3 Physico-chemical Parameters in Sediment

Sediments are an integral and inseparable part of the aquatic environment and play a very important role in the physico-chemical and ecological dynamics of any aquatic system.

Sediments can emanate from the erosion of bedrocks and soil or from the decomposition of plants and animals. Therefore, there is a higher tendency for metal deposits to be retained in sediments than for them to be released into the water column. In addition, sediment and their attached microbes make a substantial contribution to the biogeochemical processes of river ecosystems (Rastogi *et al.* 2011; Sanchez-Andrea *et al.* 2011), such as nutrient transformations, energy flow, food web and self-purification (Gerbersdorf *et al.* 2011), due to their valuable services in the ecosystem, changes in fungal assemblages could provide insight into the physico-chemical assessment of river water quality and ecosystem health (Amaral-Zettler *et al.* 2008; Liu *et al.* 2003). It has been demonstrated that the sediments can accumulate contaminants and pathogenic organisms at the concentration of 10 - 1000 times higher than the overlying water. Information on the study of sediment profile provides a better view on the impact of human activities on the ecosystem revealing the ultimate ability of sediment to acts as sink for heavy metals (Emmanuel and Chukwu, 2010).

Sediments have been used to monitor the pollution of aquatic environments because pollutants like heavy metals, which are usually present in low concentration in the water column, tend to accumulate in the sediments and attain considerable concentrations, according to Forstner and Wittmann's (1983) study on heavy metal pollution in aquatic environments. Sediment analysis, according to Forstner (1995), is used to identify sediment accumulations, identify sources of contamination, and choose crucial locations for frequent water monitoring. Because they are quickly absorbed by particulate matter, pollutants that are released to surface waters may not remain soluble and may evade detection by water analysis.

Aquatic ecosystems are disrupted by the increasing levels of heavy metals, and the species that thrive there collect large amounts of heavy metals including copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), and others. According to Kuntal and Reddy (2014), as a result, these metals are assimilated and transported across food chains through amplification. In plainer terms, the presence of heavy metals in sediment can cause problems with human health as well as the loss of aquatic life.

The physicochemical characteristics of the sediment are affected by anthropogenic sources, according to Adesuyi *et al.* (2016)'s investigation of the sediment from Nwaja Creek in Nigeria's Niger Delta. The average amounts of clay, silt, and sand varied from 64.28% to 72.36% to 14.00%, 18.71% to 27.32% to 22.17%, and 8.40% to 6.28% to 9.76% to 4.59%, respectively. They have more clay than other sediments, according to the sediment particle size distribution. Particle distribution, pH (3.9-8.5), and phosphate (5.5-15.5 kg/mg) show minimal monthly and spatial variations, in contrast to the significant monthly and spatial variations seen in conductivity (23.0 - 567.0 uS/cm), total organic carbon (0.98% - 4.58%), and nitrate concentration (0.45 - 11.9 mg/kg).

In an ecological investigation of the soft sediment marine benthos in the Gulf of Guinea, Nigeria, Olomukoro and Dirisu (2011) presented a thorough analysis of the richness and abundance of macroinvertebrate species throughout a longitudinal gradient. With 33 distinct taxa, they divided the taxonomic kingdom into three main groups: Mollusca, Crustacea, and Annelida. Notably, Gastropods were the most prevalent, constituting 78.79% of the recorded density. The distribution of benthic organisms in the designated sampling site showed low evenness, with lower abundance along the shoreline and higher abundance offshore. The scarcity of soft-bottom benthic organisms was attributed to frequent dredging and intense development activities in the area

In the study conducted by George *et al.* (2010) on sediment particles in Okpoka Creek in the Niger Delta, the researchers found that the sediment consisted of three main components: Sand, Clay, and Silt. Their analysis revealed mean values of 73.97% for sand, 22% for clay, and 27% for silt. Notably, Okpoka Creek had a higher proportion of sand compared to

Sombreiro River, while it had a greater percentage of clay and silt. This difference could be attributed to the fact that Okpoka Creek is a brackish and tidal environment, whereas Sombreiro River is a freshwater habitat. Consequently, the varying sand content may be due to these habitat distinctions.

Another investigation by Daka and Moslen (2013) focused on the spatial and temporal variations of physicochemical parameters in sediment from Azuabie Creek in the Upper Bonny Estuary, Niger Delta. Their findings indicated that pollution had significant effects on the physicochemical characteristics of the sediments in the study area, consequently impacting the benthic community in the estuarine creek. Additionally, the analysis of particle size demonstrated that the sediments primarily had a composition of sandy-mud, and this textural composition remained largely consistent throughout the research period.

Examining seasonal changes in the physicochemical quality of sediment from Ikoli Creek in the Niger Delta, a study by Seiyaboh *et al.* (2016) found that, apart from pH, there were no statistically significant differences ($P>0.05$) between the two seasons investigated for each of the physicochemical parameters. This suggests that seasons did not appear to have a discernible impact on the physicochemical quality of the sediment from Ikoli Creek.

Furthermore, Seiyaboh *et al.* (2016) conducted a separate study on the geographical variation in the physicochemical properties of sediment from Epie Creek in Bayelsa State, Nigeria. Their research revealed significant differences ($P<0.05$) among the various locations studied, except for pH. These findings imply that anthropogenic waste from market and municipal sources had a noticeable impact on the quality of sediment in these areas.

To investigate the variables influencing the benthic macrofauna in an erosional biotope, Olomukoro and Egborge (2003) carried out a study in the Warri River, Nigeria. Apart from conductivity, turbidity, and organic matter, the study's conclusions showed notable variations in the bottom sediment's physical and chemical characteristics among the several study stations.

Research on the presence of heavy metals in sediment samples taken from the River Nun in the Akassa region was carried out by Gijo and Alagoa (2022). The primary objective of this investigation was to assess the quantities of these metals within the sediment, with potential implications for the well-being of aquatic organisms and humans within the food chain. The study's findings indicated that the concentrations of heavy metals at various sampling stations followed this order: lead (Pb) > zinc (Zn) > nickel (Ni) > cadmium (Cd) > manganese (Mn). Additionally, it was observed that the levels of these metals decreased as the distance from the shoreline increased. Notably, there were statistically significant differences in the concentrations of heavy metals across all the surveyed stations. The levels of these metals were found to be higher than those reported in some comparable studies, while they were lower than findings in others. Consequently, the researchers concluded that human activities on land near river catchment areas had a substantial impact on the levels of heavy metals present in the receiving water bodies.

Using several contamination indicators, Anani and Olomukoro (2017) examined the concentration of heavy metals in benthic sediment in the Ossiomo River in Benin City, Nigeria. The concentrations of Fe, Mn, Zn, Cu, Cr, Cd, Pb, Ni, and V differed separately between the stations with significant differences ($p < 0.05$) and no significant differences ($p > 0.05$), with their rankings being as follows: Fe > Mn > Zn > Cu > Cr > Cd > Pb > Ni > V. The majority of the ambient heavy metals calculated in this study were over the national and international unity standards when compared to their standard limits. To evaluate the level of heavy metal contamination in the riverbed, the Enrichment Factors, Pollution Index (PI), and Nemerow Integrated Pollution Index (NIPI) were utilized. With EF levels >1, PI and NIPI values >3, all of the indices demonstrated different grades of defined pollution. The primary lithogenic (of volcanic origin) and human-made causes of pollution were both.

The physicochemical characteristics and heavy metal concentrations in water samples and sediments from the Ellah River in the Esan Southeast Local Government Area of Edo State, Nigeria, were investigated by Ogbeibu and Iyorah (2015) to assess the river's quality state. All tested indicators fell below the safe drinking water standards established by the WHO, and sediment heavy metal concentrations were likewise minimal. The mean levels of Ca, PO_4, Fe, and Cr in surface water showed a significant geographic variation ($P<0.05$) according to an analysis of variance (ANOVA), with station 4 having the highest values. Except for Ni and V, all heavy metal sediment contents varied considerably ($P<0.001$) among the sites, with station 3 having the highest values. Heavy metal concentrations in sediment were often greater than in surface water. The distribution coefficient Kd ranged from 0.00 in vanadium to 2010 kg/l in nickel, showing that the bonding of contaminants to the sediment system is greatly impacted by the sediment matrix. The sequence of metals' hydrophobicity—their attraction for sediment—was Ni>Zn>Cd >Mn >Pb>Cu>Cr>Fe>V.

An examination by Marcus *et al.* (2013) of the amounts of organic matter and trace metals in the sediment of the Bonny River and the creeks nearby Okrika in Rivers State, Nigeria, found anthropogenic trace metal enrichment. Large standard deviations show temporal and regional fluctuations that are mostly caused by anthropogenic waste intake. The Bonny River and nearby creeks were discovered to have enriched trace metal sediments, mostly as a result of direct ingestion of home and industrial wastes as well as indirect ingestion through tributary rivers and runoff waters. The main sources of trace metals in the sediment are metal inputs that are anthropogenic. The buildup of nickel in the bottom sediment, however, seems to have been significantly influenced by fast sedimentation.

In their investigation of the levels of Cu, Pb, Cd, Zn, and Ca in water and sediments from the Ebute Ogbo River catchments in Ojo, Lagos, Nigeria, Adeniyi *et al.* (2011) found that the amounts of these metals had decreased between 2008 and 2009. Cu and Zn levels, however, were rising. However, the metal load in the soil samples showed lower values for the samples from 2009. percentages in the sediment samples, were below the advised limits. The variations of arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mn), nickel (Ni), lead (Pb), vanadium (V), and zinc (Zn) in the sediments of the Ajawere River, Oke-Osun Farm Settlement, Osogbo, Nigeria, were evaluated by Oyekunle *et al.* (2011). In order to evaluate the degree of the water body's contamination, Maitera *et al.* (2011) conducted a study to measure the trace metal levels in the River Benue. The findings imply that the amounts of trace metals in the River Benue were often higher in the sediment samples than the water samples.

The factor known as the seasonal factor provided a complementary 21.94% to the overall variance in water quality, according to Adeogun *et al.* (2012) factor analysis (FA) study of the Ona River. The sediment component accounted for 39.95% of it. Sediment variables were identified as the primary driver of water quality using discriminant analysis (DA), with seasonal factors playing a supporting role. By contrasting these two variables, the FA shows that non-seasonal causes, more especially human activities, were responsible for the greatest fluctuations in the quality of the water and sediment. In the Niger Delta of Nigeria, Ezekiel *et al.* (2013) also investigated how flooding affected the sediments in the Amassoma Flood plain. After flooding, all sediment physical and chemical characteristic values were greater than they had been beforehand.

The physico-chemical characteristics of the water and sediment of the Mada River in Nasarawa State were studied by Tukura *et al.* (2012). Their findings revealed that the physico-chemical traits of the surface water and sediment exhibited fluctuations linked to different seasons, whereas variations across various sites did not follow consistent patterns. The researchers also highlighted the possibility that alterations in the chemical composition of both water and sediment might contribute to the observed disparities in the physical and chemical characteristics.

The amount of pollution in the River Okhuaihe was determined by Ogiesoba-Eguakun *et al.* (2022) through their examination of sediment samples. In all, 28 physical and chemical characteristics were examined using established procedures on sediment samples collected from 4 locations. A high $P < 0.01$ (significant difference) was detected in nitrate, electrical conductivity, available phosphorus, zinc, lead, chromium, and total hydrocarbon content, while cadmium, manganese, potassium, total nitrogen, and total organic carbon were $P < 0.05$ (significantly different) across the studied stations. The Duncan multiple range test showed that station 3 was the source of variance for these parameters. All other parameters showed no $P > 0.05$ (significant difference) across the studied stations. Temporal examination revealed disparities in the arid and rainy periods, for all studied parameters. The mean heavy metal concentrations in the study dwindled in this order: Fe > Zn > Mn > Cd > Cu > Pb > Cr > Ni > V. The principal component analysis results revealed two components that influenced the sediment characteristic of River Okhuaihe, with eigenvalues > 1 accounting for 96.811% of the sum variance. The pollution load index of stations 1, 2, 3, and 4 was 3.54, 2.60, 4.07, and 4.02, respectively, which were greater than the threshold, showing high contamination. They concluded that River Okhuaihe was highly polluted with specific sources of organic wastes from farming activities which in turn influenced the pH and metal solubility contents of the water body.

In the bottom sediments of the Okhuo River, Oscar *et al.* (2015) found that they could only distinguish between 23 distinct taxa. 54% of the population and most of the fauna were annelids, most especially polychaetes and oligochaetes. The study also highlighted the influence of physicochemical factors on the distribution of macroinvertebrates in the river's sediment. A prior investigation conducted by Powell in 1984 linked changes in hydrocarbon concentration to oil leakage rather than meteorological conditions. The presence of hydrocarbons in the sediment of the Sombreiro River could potentially harm benthic communities.

In their research of the sediment communities in the Lagos Lagoon, Ajao and Fagade (1990) made the hypothesis that the distribution of the organisms that dwell in or on the sediments is greatly influenced by the sediments' structure. A similar finding was made by Ikomi *et al.* (2005) in their analysis of the macrobenthic invertebrate composition, distribution, and abundance of the upper reaches of the Ethiope River in the Niger Delta.

While studying the impact of agricultural land use on stream insect populations, Dance and Hynes (1980) found that the type and intensity of agricultural activities influence sediment load, which in turn affects the types of insects that can inhabit a stream. A reduction in the diversity of micro-invertebrate species is a result of intensive agricultural land usage. Hill (1976) notes that channelization of water courses is a component of agricultural land drainage, and that such drainage plans may have a significant influence on hydrology, sediment load, water temperature, chemistry, and aquatic life.

The physico-chemical and microbiological characteristics of oil-impacted sediment were examined by Akani *et al*. (2008) in Ejama-Ebubu, Rivers State. They found that the silt had a greater proportion of sand and varied in particle size from sandy to clay to mud. Their study suggested that the presence of petroleum hydrocarbons influenced nutrient availability, sediment pH, and organic carbon content. Oil-impacted stations exhibited lower available phosphorus, lower pH, and higher organic carbon content compared to the control station.

A study on heavy metals and macroinvertebrate communities in the bottom sediment of Ekpan Creek, Warri, Nigeria, was carried out by Olomukoro and Azubuike (2009). Apart from iron and zinc, they discovered that station 2 had the highest values for every parameter. Human activities had a greater impact on heavy metal concentrations during the dry season, with dilution effects occurring during the rainy season. The primary sources of metals in water were attributed to the chemical weathering of minerals and soil leaching.

The heavy metal concentrations in water samples from the Ovia River, which were Fe > Mn > Zn > Cu > Pb, were reported by Omoigberale and Eweka in 2010. The water samples did not include any traces of chromium (Cr) or cadmium (Cd), and the concentrations of the heavy metals that were found were under the WHO's 2011 regulation limits.

Ezekiel *et al.* (2011) studied the sediment physical and chemical characteristics of Sombreiro River, Niger Delta. They found that the sediments at all locations had an acidic pH, which is consistent with the water's pH. Phosphate concentrations were higher than nitrate concentrations, and sediment particle sizes ranging from sand to silt, with sand predominating across all sites, were also noted. The sampled locations had a range of other properties, such as conductivity, organic carbon, nitrate, phosphate, sulphate, and total hydrocarbon concentration. Adeleye *et al.* (2011) looked at the dynamics and distributions of pollutants in sediments around the Lagos Lagoon Ecosystem. Fe > Zn > Pb > Cu was found to be the distribution of heavy metals gin sediments, and this tendency clearly shows that sediments absorb and accumulate metals from the streams discharged to them.

2.4 Sediment Quality Indices

Using ecological and human health risk indicators, Bawa-Allah (2023) assessed the heavy metal contamination in Nigerian surface freshwaters and sediment. The outcome demonstrated that Nigerian surface freshwater concentrations of Cd, Cr, Mn, Ni, and Pb are greater than the maximum values advised for drinking water. The World Health Organization and the US Environmental Protection Agency both produced heavy metal contamination indices that were much higher than the threshold value of 100 (13,672.74 and 1890.65, respectively) based on drinking water quality standards. These findings suggest that the surface waters weren't fit for human consumption. The indices for cadmium's enrichment factor, contamination factor, and ecological risk factor were all greater than their respective upper limits (40, 6, and 320 respectively): 684.62, 41.73, and 1251.90. These findings suggest that cadmium plays a substantial role in the ecological danger brought on by surface water contamination in Nigeria. According to the investigation's findings, children and adults who are exposed through ingestion and dermal routes to the levels of heavy metal pollution in Nigerian surface waters suffer both non-carcinogenic and carcinogenic dangers.

2.5 Benthic Macroinvertebrates Relationship with Physico-chemical Parameters

According to Culp and David (1972), the populations of benthic macro invertebrates reflect the underlying biotic and abiotic characteristics of stream ecosystems. Much emphasis has been paid to their usage as bio-indicators of aquatic consequences linked to environmental disturbances (Tsui and McCart, 1981). Ogbeibu and Oribhabor (2002), Imoobe and Ohiozebau (2009), Omoigberale and Ogbeibu (2010), Olomukoro and Dirisu (2012) and others have extensively studied biomonitoring studies and the use of macrobenthic crustaceans to assess the quality of water bodies that comprise both lotic and lentic varieties. Mayflies (Ephemeroptera), caddisflies (Trichoptera), stoneflies (Plecoptera), beetles (Coleoptera), crayfish and amphipods (Crustaceans), aquatic snails (Mollusca), biting midges (Chironomids), and leeches (Hirudinea) were among the macroinvertebrates used in studies on aquatic pollution.

The most diverse group of fresh water benthic macroinvertebrates is the aquatic insects. Cairn and Dickson (1991) reported that the Ephemeroptera, Plecoptera, Trichoptera and Diptera are commonly or perhaps always the four Orders used in Environment Assessment. However, they also reported that of all aquatic organisms, the giant bug, *Belostoma fluminea* (Order Hemiptera), is considered by many to be among the most tolerant to extreme conditions, high chloride, high BOD_5, low oxygen, low pH, etc. However, it has no indication value because its life cycle does not depend entirely on water quality.

Chironomid organisms exhibit varying responses to environmental stress caused by harmful substances. In general, Chironomid larvae have the potential to serve as an effective early warning system for detecting potential long-term negative effects of toxic agents at individual, population, and community levels. They can be employed as a cost-efficient method to indicate the overall environmental health of aquatic ecosystems (Deepak *et al.*, 2019).

Using the Dipteran family Chironomidae, Mezgebu *et al*. (2019) assessed the effects of human activity on Ethiopia's rivers and streams. To gather Chironomidae samples from heavily contaminated areas, where *Chironomus alluaudi* and *Chironomus imicola* were indicative of highly polluted water bodies, a variety of portable square frame hand nets with a mesh size of 500m and dimensions of 25 × 25 cm were employed. However, in areas with moderate contamination, *Polypedium wittei, Polypedium bipustulatem*, and *Dicrotenipus septemmaculatus* were identified as signs of moderate pollution since they were more prevalent there. The presence of the *Conchapelopia* genus was linked to less polluted locations, signifying excellent water quality. Locations with extremely high pollution exhibited low numbers of chironomid taxa overall. Therefore, assessing the composition of larval Chironomidae communities is a valuable approach for evaluating the impact of human activities on rivers when analysed at the level of genetic species identification. However, it's important to note that in this study, this method was not considered a rapid bioindicator tool due to the time required for sample processing.

Again, in a study by Mezgebu *et al.* (2019), benthic macroinvertebrates were employed to evaluate the effects of diverse stressors arising from industrial and agricultural operations on the waterways in the Sebeta region of Ethiopia. The investigation revealed that human activities such as laundry (GR_1), livestock watering (MT_1), and crop cultivation (KR_2) have minimal impact on the streams and rivers they flow into. These water bodies exhibit a dissolved oxygen level ranging from 5.01 to 7.86 mg/l, fostering the existence of 9 to 13 different benthic macroinvertebrate species. On the other hand, streams and rivers that receive effluents and waste from tanneries (AB_3), textile factories (GR_2), breweries (MT_2), and distilleries (AB_2) experience significant deterioration. This is evident in the elevated levels of total phosphorus (reaching up to 35.14 mg/l) and markedly low dissolved oxygen concentrations (as low as 1.54 mg/l), which can only sustain 5 to 8 types of benthic macroinvertebrates. The water bodies coursing through Sebeta town have undergone substantial degradation, largely due to the presence of industries in the vicinity.

The Epe lagoon's non-insect benthic phytomacrofauna and water quality were both studied by Edokpayi *et al.* (2010) to see how land-based pollution were influencing these two areas. Their research revealed that these pollutants had detrimental effects, leading to a reduction in dissolved oxygen and pH levels, an increase in biochemical oxygen demand (BOD_5) and phosphates, and an overall decline in both the population and diversity of the studied taxa. Out of the 65 individuals collected from five different locations along the lagoon, only eight distinct taxa were identified. Furthermore, the study highlighted the prevalence of the Lymnaeidae taxa, which indicated a clear presence of pollution. This dominance of Lymnaeidae had negative consequences for other benthic macroinvertebrates, which were less able to tolerate the harmful effects of pollutant discharges. Overall, the findings of this study underscore the importance of considering the response of benthic phytomacrofauna when assessing the impacts of pollution on aquatic ecosystems.

A survey of the macroinvertebrate flora in Egbe Reservoir in Ekiti State, Nigeria, was conducted by Edward and Ugwumba (2011). The investigation found 18 macroinvertebrate taxa in the phyla Mollusca and Arthropoda. Odonata and Ephemeroptera had the lowest diversity and numerical abundance, whereas gastropods had the highest numerical abundance, variety, and evenness. The low number of Ephemeroptera and Odonata, which are markers of clean water in the survey, further supported the abundance of the snail *Melanoides turberculata*, which suggests that the reservoir may be heading towards organic contamination.

Similarly, a survey of the macroinvertebrate species in Egbe Reservoir, Ekiti State, Nigeria, was carried out by Edward and Ugwumba (2011). Eighteen macroinvertebrate taxa belonging to the phyla Mollusca and Arthropoda were identified by this survey. Odonata and Ephemeroptera showed the lowest diversity and numerical abundance, whereas gastropods showed the most evenness, diversity, and numerical abundance. The high abundance of the gastropod *Melanoides turberculata*, which is an indicator of potential organic pollution, was further corroborated by the low abundance of Ephemeroptera and Odonata, which are typically associated with clean water in the survey.

A 3 km section of a perennial rainforest stream in southern Nigeria was researched by Edokpayi and Osimen (2001) to characterize the macrobenthic faunal features of pools (dam site stations) and flows. At the end of the research, a total of 84 invertebrate taxa made up of 2,535 individuals were recorded, while the overall faunal abundance was not significantly different at the study stretch. The abundance of the major taxonomic groups was however significantly different ($P < 0.05$) at the study stations. In this study, Hemiptera and Diptera were the most abundant invertebrate groups recorded and the high number of benthic invertebrates observed reflected the physical and chemical stability of the study stream.

A multivariate approach was employed by Osimen *et al.* (2021), recognize and categorize potential indicator macroinvertebrate species in a reservoir located in southern Nigeria. Based on PCA, sites 1 and 4 were shown to have greater and less influence, respectively. Site 4 reported elevated mean values of pollution showing physico-chemical variables such BOD_5, phosphate, and TSS, whereas Site 1 recorded an increased concentration of DO. The 28 macroinvertebrate species that were identified over the whole research period were dominated by Diptera, with Site 4 having a greater absolute abundance of this genus. Sites 1 and 2 were found to constitute cluster B according to the NMDS, demonstrating similarities in the assemblage structure of the species reported at both sites, whereas cluster A represented a mixture of macroinvertebrate taxonomic assemblages from all the sampled sites. While Mytilus dubia was the sole taxon discovered and categorized as being extremely tolerant of pollution, CCA and other categorization analysis revealed and classified Centroptilum spp. to be particularly susceptible to pollution.

According to Ayoade *et al.* (2010) who studied the physico-chemical parameters, composition, and abundance of macrobenthic invertebrates in the river Ogbere, the mean values for nitrate, dissolved oxygen, total suspended solids, and biochemical oxygen demand were not within allowable standard limits suitable for aquatic life and domestic uses. Sediments have higher levels of metals than surface water, according to records. Since the poor water quality caused the majority of the macrobenthic invertebrates present in the waterbed to be pollution-tolerant species, the River Ogbere was usually viewed as being polluted.

At the Okhuo River in Benin City, Edo State, Ehiorobo (2007) conducted research on the ecology of the non-insect benthic macroinvertebrates associated with macrophytes. He recorded 10 taxa in all throughout the course of his research, which included members of the Oligochaete, Crustacean, Mollusca, and Arachnida classes. Crustaceans and oligochaetes dominated stations 1 and 2, whereas molluscs and arachnids dominated stations 2 and 3. Station 3 had the lowest value due to certain factors, which frequently occur at the station, notably after heavy rains and the activities that alter the bankroot. Station 2 had a higher value than the other stations in terms of taxonomic richness. Although it was a pristine environment, the researcher's results revealed that there was a significant variation in the abundance of the non-insect benthic macroinvertebrates across the three stations, and the species recorded were extremely rare in comparison to previous studies conducted in the river.

In the Niger Delta region of Nigeria, wooded rivers were the subject of an investigation by Edegebene *et al.* (2020) on the impact of urbanization on macroinvertebrate features. Principal component analysis was used to divide the 20 sites into three ecological categories: least impacted sites (LIS), moderately impacted sites (MIS), and highly impacted sites (HIS). Large body size, grazing, and hardshell were shown to be positively significantly linked with LIS on the RLQ, according to their findings based on RLQ (R = physico-chemical variables, L = macroinvertebrate taxa, and Q = macroinvertebrate characteristics) and fourth-corner analyses. Additionally, they were either strongly negatively connected with decreasing DO or significantly favourably correlated with rising water temperature, nutrients, BOD5, and flow rate. These characteristics were therefore thought to be vulnerable to urban contamination in forested waterways. In forested rivers, behaviours like burrowing, predation, and pupa aquatic stage were judged tolerable to urban pollution since they were favourably connected with HIS and significantly negatively correlated with rising DO. Box plots and a Kruskal-Wallis test showed that the three sensitive characteristics, except for grazing, were considerably higher at LIS (p 0.05), whereas the three tolerant traits, apart from burrowing, were significantly higher at MIS ($p>0.05$). Overall, this study showed that urban pollution has distinct effects on macroinvertebrate features in rivers that are covered with forest.

According to a study by Ofonmbuk *et al.* (2014), variables like pH, BOD, EC, DO, and air temperature had an impact on the diversity and abundance of benthic macroinvertebrates in Ediene Street in Akwa-Ibom State, Nigeria. It is possible that anthropogenic pollution and stress caused the macrobenthos to decline downstream. Ogunwenmo *et al.* (2004) examined the macrobenthic fauna, sediment type, and physico-chemical parameters of an estuary stream and an artificial pond in the western section of the Lagos lagoon. Although the temporal, physical, and chemical characteristics of the water and sediment in this research were typical for the tropics, the pH was consistently alkaline and the sediment was all silt. The artificial pond had experienced succession, and the macrobenthic fauna had a low density and variety. The phyla Annelida, Mollusca, and Arthropoda all had six species present. An unstable, physically regulated habitat with a low species density has been created because of human-induced stresses.

In the South-South region of Nigeria, in the Etim Ekpo River, Udeme *et al*. (2020) carried out a study titled "Evaluation of Benthic Macroscopic Invertebrates and Chemical Properties." The study identified three major groups of aquatic invertebrates: Arthropoda, comprising five different species; Polychaeta, which represented the annelids; and molluscs, indicated by two gastropod snail species. The abundance breakdown showed that Arthropoda held the highest percentage (73.7%) of the overall population, followed by Annelids (21.9%), while Mollusca accounted for the smallest portion (4.4%). Notably, the dominant species was *Macromia magnifica*, constituting 27.97% of the total, whereas Pila ovate had the lowest presence (1.63%). Additionally, the research revealed that most of the identified invertebrates were species capable of enduring polluted conditions, implying an environment under stress. The biodiversity indices indicated disturbances in the ecosystem. Both the invertebrate community and the physical characteristics of the river unveiled significant impacts from human-induced activities within the river's catchment area.

In a separate investigation, Moslen and Ameki (2018) explored the consequences of human interventions on the benthic macroinvertebrate community of Isiokpo Stream located in the Niger Delta region of Nigeria. A total of 120 organisms were accounted for in the study. The distribution of abundance in percentage followed the order of Insecta > Crustacea > Oligochaeta, although this distribution was uneven across the various research sites. Site 3 had the highest organism count, trailed by site 1, while site 2 displayed the lowest population, and the disparities among these sites were noteworthy. Human influence and anthropogenic actions around site 2 were predominantly responsible for the decreased organism count observed there. The study's outcomes concluded that human activities exerted negative impacts on the aquatic invertebrate community of the Isiokpo Stream, posing potential repercussions for the region's overall biodiversity.

The factors influencing the benthic macrofauna in the erosional biotope of the Warri River in Nigeria were studied by Olomukoro (2008). Except for conductivity, turbidity, and organic matter, which did not significantly vary, the study's results demonstrated substantial changes in the physical and chemical properties of the bottom sediment among the several research stations. The most prevalent benthic organism observed in the study was Nematoda, and it was found to have a strong positive correlation with Oligochaeta and Mollusca within the benthos community. The highest densities of fauna were observed during the dry season.

In a subsequent study, Olomukoro and Catherine (2009) focused on examining heavy metal concentrations and macroinvertebrate communities in the bottom sediment of Ekpan Creek, also located in Warri, Nigeria. The heavy metals analysed included Lead, Iron, Zinc, Copper, and Chromium. The results revealed variations in chemical parameters, with station 2 exhibiting the highest values across all parameters except for Iron and Zinc. Additionally, the study documented a total of 1135 individual organisms belonging to 19 macroinvertebrate taxa, with Mollusca being the most dominant group, followed by Insecta, Crustacean, and Polychaeta.

In the Niger Delta of Nigeria, Ositadinma (2021) studied the marine benthic macrofauna along the Forcados River. The study's objective was to determine the species' abundance and makeup. With 82% of the total, molluscs predominated, followed by polychaete worms (9.30%) and crustaceans (7.44%). A total of 215 species from 24 taxa were identified; the greatest diversity was seen in molluscs, with 11 species. The most prevalent mollusc species was Turritella communis, although the appearance of the hardy polychaete *Capittela capitata* was noteworthy. The study advocated longer-term research for better insights and identified poor species diversity, which was probably caused by human activity.

The colonisation of artificial substrates (such as cement bricks and ceramic tile) and macrophytes by macroinvertebrates in a first-order stream was studied by Olomukoro and Eloghosa (2009). Samples were taken from substrates following exposure times of 4, 7, 14, 21, and 40 days, according to the research. There were 903 individuals discovered, with cement bricks and ceramics recording 32 and 31.1% of the total, respectively, and macrophytes having a density of 36.9%. Benthic growth was seen throughout the four-day exposure period, suggesting that some early colonists existed. However, while most of the species were present during the whole course of our investigation, late colonizers were not seen. Estimates of species richness and overall diversity were made for the substrates, and values for the ceramic substrate were greater than those for the other substrates. However, there were noticeable differences in species richness and overall density between the exposure times in the two substrates.

Awareness on the consequences of water pollution was carried out by Abowei *et al.*, (2012), where they did a study on the effects of water pollution on benthic macro fauna species composition in Koluama Area of Bayelsa, Nigeria. The diversity of macrobenthic invertebrates in this study was generally low which is not unusual in the Niger Delta. Umeozor (1995) reported 23 species form New Calaber River; Hart Zabbery (2005) reported 30 species belonging to 20 families and 5 classes and George *et al.* (2010) reported 19 species from Okpoka Creek sediments. Polychaete was dominant in the brackish water station (Degema) and this was attributed to their level of pollution tolerance.

In order to analyse the integrity of the Orogodo River in sub-Saharan Africa, Olomukoro *et al.* (2022) conducted a study on the water quality using physicochemical and biological indicators. All the physicochemical parameters of the water did not differ significantly ($p > 0.05$) between the stations. It was listed in the following sequence, decreasing, for the heavy metals: station 2 comes after station 3, then station 1, then station 3. Seven (pH, TSS, TDS, HCO3, Cl, P, and SO_4) of the twenty-six (26) chemical and physical parameters that were examined were in good compliance with the Federal Ministry of Environment's acceptable or standard levels. The findings from the examination of the chemical and physical parameters agreed with the results from the WQI calculation. The high values observed demonstrated the extreme pollution at all of the study locations. This demonstrated how significantly human activities have damaged the water system. Apart from chironomids, the rat-tailed maggot (*Eristalis tenax*), and the family Hirudinea, which were almost exclusively found at station 2, the majority of the macrobenthic faunas identified were dispersed throughout the three stations. Station 2 had the fewest taxa. Because this species is a fundamental indication of an ecosystem sentinel, it was able to demonstrate the ecological effect. Station two was significantly contaminated, according to all the biotic indices used to estimate water quality, whereas stations 3 and 1 were just marginally affected.

Eight species from four distinct phyla and six classes made up the benthic macrofaunal community, according to Wokoma and Umesi's (2016) investigation on the species composition and abundance of the benthic community along the brackish water axis of the Sombreiro River. In the report, Polychaetes were the most dominant class with 3 species and the others Crustacea, Insecta, Gastropoda, Bivalvia and Pisces were represented by one species each. While polychaetes and gastropods were observed in all stations, others were found in only one site each. Polychaetes were the most abundant with 104 individuals representing 70.27%, followed by Gastropoda with 39 individuals (26.35%), Insecta is next with 2 individuals (1.35%) and others (Crustacea, Bivalvia and Pisces) contributed 1 individual each (0.67%).

The potential applications of *Chironomus* sp. larvae in stream characterization were evaluated by Rotimi and Iloba (2009) through their study of the larvae's distributional relationship and occurrence at several places in a fourth order stream in southern Nigeria. The water condition of the stations was ordered as 1>2>3 in decreasing order of water quality. The variations in the physical and chemical condition of the stations appear to have direct influence on the occurrence of *Chironomus* sp. where the total density of *Chironomus* sp. differed significantly ($P<0.05$) among the three stations. The maximum numbers of the species were recorded in station 3 followed by station 2, while the species were not encountered in station 1. The relative abundance of *Chironomus* sp observed appear to reflect the physical and chemical conditions of the various sites along the stream and could be used in characterizing the stream.

The impact of sawmill wood wastes on the distribution of benthic macro-invertebrates at the Sapele section of Benin River, Niger Delta, Nigeria, was investigated by Arimo and Osakwe (2006). More sensitive species such as Ephemeroptera or Plecoptera were completely absent from station 2, the impacted site. Species abundance was similar in station 1 and 3, indicating that the wood wastes must have adversely affected the distribution of these macro invertebrates, especially the intolerant species. The wood waste discharge not only altered the water chemistry but also stimulated the abundance of less-sensitive macro invertebrate species. Sampling a similar biotope in River Orogodo, Arimoro *et al.* (2007a) reported 27 species of macro invertebrates attached to the plant: *Nymphaea lotus* and *Pistra stratiotes*. Clearly, the dipterans particularly chironomid larvae and water mites (Hydracarina) were the preponderant species contributing over 25% each of the total phytophilous invertebrates density while the annelids were the least, contributing only 0.46% to the density. The association of macro invertebrates with these aquatic macrophytes is largely because they depend on the macrophytes for shelter, food and as refuge since they depend on the macrophytes for shelter, food and refuge from predators. No Odonata or Plecoptera nymph was collected from *Nymphaea lotus* during the period of the study. It was hypothesized that this plant discharged certain compounds that prevented these nymphs from colonizing it. Furthermore, the general morphology of *Pistia stratiotes* ensured better colonization by phytophilous macro invertebrates.

In Onwudinjo's comprehensive study of the Benin River (Onwudinjo, 1990), various physical and chemical parameters, as well as some biological aspects, were investigated. The temperature exhibited minimal fluctuations, except at Ogorode, where thermal pollution was observed. Additionally, the research confirmed the river's acidic nature, with pH levels ranging from 4.4 to 6.9. Furthermore, there was a rising gradient in dissolved solids, total solids, conductivity, salinity, chlorinity, sodium, and potassium levels from Ogorode to Ogheye, a village approximately 2 km away from the Atlantic Ocean.

There were 22 different types of organisms affixed to the roots of the water hyacinth in the Benin River, according to a study by Ekelemu *et al.* (1999). The most common group of animals in the colony was comprised of gastropods, which made up 41.24% of all animals, whilst annelids were the least common, making up only 0.08%. The morphological traits of the vegetation layer and the physical and chemical characteristics of the surrounding water are influenced by the root environment, and our investigation provided evidence for this theory.

To determine if environmental factors influence the macroinvertebrate assemblages in the Wupa River, Abuja, Nigeria, Omovoh *et al.* (2022) conducted research on these organisms. The PCA and CCA generated findings indicated that physico-chemical factors were critical in shaping the assemblage structure of macroinvertebrates. Sulphate, phosphate, BOD, and turbidity were physico-chemical variables that were comparatively greater in Stations 2 and 3 than in Station 1. It was advised to use macroinvertebrate species as a stand-in for biological monitoring of riverine systems in the research region and Northern Nigeria generally, including *Melanoides moerchi*, *Culex* sp., and *Oligoneux* sp.

Ibemenuga and Inyang (2006) collected 11420 macroinvertebrates from the Ogbei Stream in Anambra State, representing 4 classes, 13 orders, 28 families, and 50 species. In terms of population size, Hemiptera, Coleopera, and Insecta dominated the fauna. This study shows that substrate composition, water quality, and food availability all had an impact on the macroinvertebrate distribution, abundance, and diversity of the aquatic body that was investigated.

A comparative study of the benthic macro-invertebrates of the eastern part of Lagos Lagoon and the western, industrialized part of the Lagoon was carried out by Nkwoji and Igbo (2010). Pollution tolerant and opportunistic species like the Polychaete worms were more abundant in the western part of the Lagoon than in the eastern part. In all, species diversity and abundance were generally more in the eastern part than in the western part which was indicative of the level of the impact by human induced stresses on the western part of the Lagoon. Similarly, the variability in the abundance of functional groups, functional diversity measures, and functional structure of western part of the Lagos Lagoon macrobenthic invertebrate communities in relation to the environmental features was examined by Uwadiae *et al.* (2012). The most important environmental variables shaping variations in the densities of functional groups and functional structure were transparency, depth, DO and BOD. The same environmental variables (i.e, transparency, depth, DO and BOD) accounted for variability in functional richness and functional diversity. Lagos Lagoon receives a complex mixture of domestic and industrial wastes and several studies have reported that nutrients mainly nitrogen and phosphorus are increasingly entering the Lagoon in large quantities (Nwankwo, 1993), and environmental degradation and charges in water quality of the Lagoon have been implicated as major causes of decline in the general biodiversity of the Lagoon (Ikusemiju, 1975; Nwankwo, 1996; Brown and Oyenekan, 1998). The high levels of BOD, low DO and poor transparency observed in this study was indicative of a degraded environment and was similar to the results of earlier studies (Oyenekan, 1988; Ajao and Fagade, 1990 and Nwakwo, 1993) on the Lagoon.

A study to evaluate the impact of anthropogenic influences on the Ogba River using water chemistry and macroinvertebrate was conducted by Arimoro *et al.* (2015) over a period of 6 months between January and June 2012. Based on the canonical correspondence analysis (CCA), 5-day biochemical oxygen demand (BOD_5), sulphate, nitrate and phosphate were the main factors that help to shape the macroinvertebrate assemblage structure of the Ogba River. Benthic macroinvertebrates clustered strongly by stations than by seasons indicating that water quality differences between the stations were responsible for the observed differences in the biotic assemblage. The preponderance of naidid oligochaetes, *Baetid* nymphs and certain tolerant dipteran taxa including chironomids and ceratopogonids at all four stations was an indication that the entire water body was stressed. The Odonatans were the single most abundant taxa; their dominance could be attributed to the vegetative nature of the stream, favouring Odonata colonisation. Overall, the responses of macroinvertebrates to stress were reflected by the different assemblage structures recorded at the four study stations. Substrate and microhabitat obliteration and poor water quality appeared to be the factors responsible for the observed assemblage structure in the river.

The state and diversity of the benthic fauna communities in the Udu-Ughievwen wetlands were evaluated by Olomukoro and Abdul-Rahman (2014) during a six-month survey. They documented a total of twelve taxonomic groups, which comprised Ephemeroptera (37.63%), Diptera (20.45%), Coleopterans (4.21%), and Trichoptera. Additionally, they identified other groups, including Mollusca (3.45%), Amphibians (2.85%), Hemiptera (2.27%), and Arachnida (0.42%). The predominance of Ephemeroptera in most of the surveyed sites was indicative of the overall health and good environmental quality of the Udu-Ughievwen wetlands. This study highlighted the presence of a diverse array of macroinvertebrates in wetland ecosystems.

Similarly, Iyiola and Asiedu (2020) assessed the water quality of Ogunpa River, Southwestern Nigeria, using benthic macro-invertebrates. Temperature (26^{o}C), dissolved oxygen (5.05 mg/L), chemical oxygen demand (29.53 mg/L), nitrate (4.40 mg/L), and pH (7.82) were the average water parameters measured. Temperature and pH did not differ from station C in a way that was statistically significant ($P>0.05$), however, COD and nitrate did (P0.05). *Lymnaea truncatula, Lymnaea glabra*, *Chironomus* sp., *Gyrius* sp., *Anisoptera*, *Hirudo* sp., and *Tubifex* sp., seven (7) benthic macro-invertebrates from five (5) families, were identified. Overall, 9,989 macro-invertebrates were counted from all the sites, with station C having the highest relative abundance (35.3%) overall. The Lymnaeidae family had the largest abundance (53.1%), while Odonata had the lowest (6.9%). The river was under stress from pollution, as evidenced by the high abundance of the pollution-tolerant benthic macroinvertebrate *L. truncatula* (36.5%).

Studying benthic macroinvertebrates in the Ovia River in Edo State, Iyabgaye *et al.* (2017) noted the high species richness and diversity typical of tropical rivers with rapid flow. They counted 1,135 individuals from 45 species, with Diptera being a sub-dominant order and Ephemeroptera as the main order. ANOVA showed substantial ($P<0.05$) variations in the density of macroinvertebrates among the stations, which were ascribed to the presence of greater quantities of Dipterans and Ephemeropterans at locations. The EPT ratio (Ephemeroptera-Plecoptera-Trichoptera) showed little influence on the quality of the water. The study emphasized the healthy ecosystem in the Ovia River and concluded that benthic macroinvertebrates are useful markers for monitoring water quality.

A research effort by Omoigberale and Ogbeibu (2010) whose aim was to evaluate the impact of oil exploration and production on the benthic macroinvertebrate fauna in Osse River documented a total of fifty-seven taxa of benthic macroinvertebrates. Ephemeroptera emerged as the most dominant taxa, while Hemiptera constituted the least abundant among all those collected. The most prevalent families encompassed Naididae, Alpheidae, Chironomidae, Baetidae, and Libellulidae. Moreover, there were significant variations in the overall abundance of benthic macroinvertebrates across the study locations. The temporal patterns revealed higher levels of benthic macroinvertebrate abundance during the dry season compared to the rainy season.

In a study on the effects of building roads and bridges on the macrobenthic invertebrates of the Ikpoba River (Ogbeibu, 1987; Ogbeibu and Victor, 1989; Victor and Ogbeibu, 1991), it was found that the construction activities led to siltation and sedimentation, which significantly decreased the abundance and species diversity of the Bank-root macro-invertebrate communities. On the other hand, the erosional biotope's organisms and water chemistry were not considerably impacted.

To determine the composition, number, diversity, and distribution of the macrobenthic invertebrates in the Ossiomo River, Ogbeibu and Odeka (2015) researched the river's macrobenthic invertebrates. In four designated stations along the river, they documented a total of 65 species, 2,380 individuals, spread throughout 3 phyla, 5 classes, 13 orders, and 32 families. The two leading taxa identified were Ephemeroptera and Diptera, which made up 37.98% and 37.73%, respectively, of the total abundance of the macrobenthic invertebrates. Plesiopora representatives, who made up 15.48% of the total, were given subdominant rank, whilst uncommon species included members of the orders Decapoda, Hemiptera, Coleoptera, Odonata, Plecoptera, and Trichoptera, each of which contributed less than 5%. There was a significantly significant ($P<0.01$) variation in the macrobenthic invertebrate abundance between the sites. The abundance of macrobenthic invertebrates was substantially greater at stations 1, 2, and 3 than it was at station 4 according to posteriori Duncan Multiple Range comparisons. The taxonomic composition between stations 1, 2, and 3 did not significantly differ when the Jaccard and Bray Curtis similarity indices were applied. All the stations have high species diversity as measured by Shannon-Wiener, with stations 4 and 1 having the greatest and lowest values, respectively. These stations also independently reported the greatest and lowest evenness scores. The Ossiomo River showed a healthy and ecologically stable ecology with little disturbance.

2.6 Multimetrix Index of Benthic Macroinvertebrate Community of fresh Waters

Multimetric Indices

Benthic macroinvertebrate assemblages are the most often utilised assemblages globally among the creatures used as biological indicators in research and monitoring programs (Resh, 2008). Characteristics including high diversity, a relatively long lifespan, bottom-dwelling lifestyle, and sensitivity on environmental disturbance make them suitable for assessing the ecological status of lotic ecosystems (Rosenberge and Resh 1993; Allan and Castillo, 2007).

As biological indicators, they can provide insights into the current and past conditions of a water body and integrate the effects of cumulative stressors (Barbour *et al.*, 1999; Bonada *et al.*, 2006).

Research aiming to create a measurement of human impact that is attuned to various degrees of disturbance can be developed through two approaches. One approach involves utilizing a continuous gauge of human disturbance, as demonstrated by Karr and Chu (1997) and Ofenbock *et al.* (2004). Alternatively, the other method involves employing a collection of samples that depict undisturbed or "reference" conditions, as exemplified by the work of Stoddard *et al.* (2008).

In developing multimetric indices using benthic macroinvertebrates in various stream environments worldwide, a great number of metrics (up to 237 [Whittier *et al.*, 2007]) have been examined and accordingly evaluated in streams (Barbour *et al.*, 1999; Klemm *et al.*, 2002; Kerans and Karr 1994; Böhmer *et al.*, 2004; Ode *et al.*, 2005; Stoddard *et al.*, 2008; Purcell *et al.*, 2009). However, the practical number of metrics and their properties that have ended up being included in the developed indices vary among different multimetric indices. This indicates the possibility of metric variability responding to different environmental gradients in specific geographic regions. Moreover, the robustness of selected metrics requires relatively long-term validation for practical use, not only because the metric data used in the index development do not reflect the range of long-term changes, but also because the streams targeted for the assessment are facing various environmental pressures. Therefore, biological indices, including multimetric indices developed geographic regions or environments, are frequently used elsewhere (Purcell *et al.*, 2009). Such metrics may be less useful when applied in regions other than that where the species–environment relationships were originally assessed (Hill *et al.*, 2003; Blocksom and Johnson, 2009).

In order to assess wetlands next to agricultural fields in Northeast China, Haitao *et al.* (2019) created an MMI based on aquatic invertebrates. Four core indicators were selected to build the MMIs: total number of taxa, number of Hemiptera taxa, Proportion of Gastropoda, and Proportion of Predators. Four ordinal rating categories for the wetland condition were defined: poor, fair, good, and excellent. Of the impaired wetlands, the condition of 76.2% was rated as poor or fair. The MMIs were robust in discriminating reference wetlands from impaired wetlands, demonstrating potential as a biomonitoring tool to assess freshwater wetlands and restoration efforts in northeastern China.

To evaluate the water quality of streams and wadeable rivers in the Lao PDR, Sripanya *et al.* developed a benthic macroinvertebrate-based MMI in 2023. A total of 40 samples were gathered for their study from different regions of the nation, and 11 core metrics, including Total taxa, EPT taxa, Ephemeroptera taxa, % Diptera, % Plecoptera, % Tolerant, Beck's biotic index, % Intolerant, Filterers taxa, % Sprawlers, and % Burrowers, were chosen to be included in the final index. It was discovered that the developed Lao MMI was sensitive enough to distinguish between places with little anthropogenic effect (reference sites) and stressed sites. The Lao MMI also had a distinct advantage over traditional physicochemical approaches since it was able to categorize the water quality of 40 sampling locations into four distinct classes—excellent (25%), good (10%), fair (60%), and bad (5%), which the physicochemical method was unable to achieve. Furthermore, because it largely relies on family and EPT genera levels for benthic macroinvertebrate diagnosis, the Lao MMI was judged to be both affordable and simple to use for biomonitoring.

An investigation of the effects of water quality on benthic macroinvertebrates in the groundwater-dependent Barotse Floodplain was carried out by Banda *et al.* in 2023. To investigate the effects of water quality on macroinvertebrates at the subclass-taxonomic level, the researchers used Canonical Correspondence Analysis (CCA). Furthermore, factor analysis was employed to pinpoint the fundamental mechanisms accountable for the noted fluctuations in water quality. The findings of the study revealed that the Barotse Floodplain harboured a distinct collection of macroinvertebrates, including Odonata, Mollusca, Ephemeroptera, Hemiptera, Decapoda, and Coleoptera. These macroinvertebrate communities were affected by several factors, such as the flood pulse, salinity resulting from groundwater inflow, and biogeochemical processes during the expansion and contraction of the floodplain-river interaction. The research demonstrated the effectiveness of biomonitoring in capturing natural environmental patterns, like flooding, and suggested its potential for monitoring extreme impacts of phenomena like climate change.

In addition to the conventional physico-chemical examination, Nguyen *et al.* (2014) developed and implemented a multimetric index to evaluate the biological water quality of rivers in Vietnam. Fifteen monitoring stations in the Cau River watershed in northern Vietnam gathered macroinvertebrate samples. The range, stability, sensitivity, and response to anthropogenic influences of eighteen potential measures were evaluated. The Biological Monitoring Working Party (BMWP) - Viet, total number of species, Margalef index, number of Ephemeroptera, Plecoptera, and Trichoptera (EPT), and percentage of insects were five metrics that were kept in the calculation of the MMI. Five water quality classifications, from class one (good biological state) through class five (poor biological status), make up the MMI. The study showed that the multimetric technique is appropriate for use in the national monitoring and assessment program in Vietnam.

A Multimetric Benthic Macroinvertebrate Index for the Assessment of Stream Biotic Integrity in Korea was developed by Jun *et al.* (2012). Watershed, chemical, and physical parameters were used to identify reference and impaired conditions. Using a stepwise process that assessed measure variability, redundancy, sensitivity, and reactivity to environmental gradients, eight out of the initial 34 potential metrics were chosen. Number of taxa, percentage of Ephemeroptera Plecoptera-Trichoptera (EPT) individuals, percentage of a dominating taxon, percentage of taxonomic abundance without Chironomidae, Shannon's diversity index, percentage of gatherer individuals, percentage of filterers and scrapers, and Korean saprobic index were the metrics used. The multimetric index was able to tell reference conditions apart from impaired ones. Each core metric's quartile range and responsiveness to anthropogenic perturbations were used to create a grading system. By combining the individual metric scores, the multimetric index was categorized, and the value range was quadrupled to provide narrative criteria (Poor, Fair, Good, and Excellent) to represent the biological integrity of the study's streams.

To assess natural wetlands in Southwest Ethiopia, Mereta *et al.*, (2013) created a multimetric index focused on benthic macroinvertebrates. They created this index with information from 222 samples that were taken from 63 sites spread throughout eight different wetlands over the course of two years. To differentiate between pristine and deteriorated sites, they relied on a combination of physico-chemical and hydro-morphological factors, such as land use patterns, habitat alterations, hydrological changes, and chemical water quality. In their quest, they evaluated 58 potential metrics, encompassing various aspects of macroinvertebrate communities, including family diversity, composition, tolerance indicators, and the presence and abundance of functional feeding groups. They selected metrics for the final index based on their capacity to effectively distinguish between untouched and disturbed sites, their correlation with the level of human interference, chemical measurements, and the extent to which they overlapped with other metrics. The metrics chosen for the ultimate index included the overall family richness, the family richness of Ephemeroptera, Odonata, and Trichoptera (EOT), and the percentage of filterer–collectors. This final index, derived from the sum of scores from these three metrics, was divided into five water quality categories, ranging from very poor to very good. This final multimetric macroinvertebrate index (MMI) developed by

Mereta *et al.* effectively discriminated between pristine and degraded wetland sites and exhibited a strong negative response to various degrees of disturbance (R2 = 0.86, $p < 0.05$). Furthermore, when tested against a validation dataset, it achieved an 80% accuracy rate in correctly classifying instances and a Cohen's Kappa value of 0.6. By combining three indicators of habitat quality, the MMI demonstrated its effectiveness in distinguishing between untouched and disturbed sites in river-associated wetlands in Southwest Ethiopia. Additionally, the MMI exhibited a robust connection to a wide array of water quality measures and human-induced disturbances. These findings suggest that macroinvertebrate communities are reliable indicators for assessing the ecological health of wetlands.

Ethiopia's highland rivers' ecological health was evaluated by Lakew and Moog (2015) through the development of a multimetric index based on benthic macroinvertebrates (BMI). Based on hydro-morphological, land use, physical, and chemical parameters, BMI were gathered from 22 reference sites and 82 degraded sites. Only nine core measures were chosen out of 75 that could have been investigated to incorporate the multimetric index based on their propensity to differentiate between reference and impaired sites, the strength of their connection with relevant environmental factors, and their independence from other metrics. The metrics that were kept in the multimetric index were the total number of taxa, EPT-BH (1sp) (Ephemeroptera, Plecoptera, and Trichoptera taxa where Baetidae and Hydropsychidae taxa are considered if they consist of more than one taxon),% Oligochaeta and Red Chironomidae,% COPTE (Coleoptera, Odonata, Plecoptera, Trichoptera, and Ephemeroptera), ASPTSASS (Average South African Scoring System Per Taxa), FBI (Family Biotic Index), shredders, and collector gathering; EPT-BCH (EPT sans Baetidae, Caenidae, and Hydropsychidae). Five river quality classes (high, good, moderate, poor, and awful) were created using the final index generated from these criteria. A validation method revealed that the indicator was sensitive to the existing spectrum of human disturbances in Ethiopian highland rivers and stable under various hydrological circumstances. The newly created MMI was described as strong and sensitive to a wide range of human influences, including changes in land use and the physical and chemical deterioration of Ethiopia's central and southeast highland rivers. This index was thought to be a good monitoring tool for the research region and could be used to create a biomonitoring network for other highlands in the county that were similar. The index, according to the researchers, offered trustworthy and scientifically sound data that decision-makers could use to plan and put into practice preservation and restoration actions.

To evaluate the impact of various stressors on the ecological condition of the Afromontane-savanna Mara River in Kenya/Tanzania, Masese *et al.* (2023) tested the applicability and performance of diversity and richness indices, regional biotic indices, and a macroinvertebrates-based index of biotic integrity (M-IBI). The results of this study demonstrated that, despite the widespread use of diversity and richness indices, which gauge the structure of macroinvertebrate communities, to gauge the degree of anthropogenic disturbance in streams and rivers, these indices did not perform well enough in the Afromontane-savanna rivers. Most of the variety and richness indicators examined underwent poor performance and were unable to distinguish between various degrees of human distress. Overall, the M-IBI outperformed biotic and diversity indices because to its superior capacity to discriminate across different types of sites. The ineffectiveness of regional biotic indices in determining the ecological state of the river served as more proof that indices created elsewhere must be tested and validated before being used in bioassessment programs and decision-making.

The Zio River's benthic macroinvertebrate population's response to human activities and water quality was evaluated by Tampo *et al.* (2021). Data from 20 sites were evaluated over three periods using Spearman's Correlation, Factor Analysis (FA), and Canonical

Correspondence Analysis (CCA). The study separated macroinvertebrate species into three groups: tolerant Prosobranchia, Bivalvia, Lepidoptera, Heteroptera, and Coleoptera (PBLHC) species; resilient species, such as Oligochaeta, Hirudinea, Diptera, and Pulmonates (OHDP); and sensitive Ephemeroptera, Plecoptera, Trichoptera, and Odonata (EPTO). These findings demonstrated how human disturbances and water quality factors impacted population structure. The most dependable macroinvertebrate-based metrics were EPTO measurements, which were 13 of them that successfully identified changes in water quality. The findings of this study highlight the importance of macroinvertebrates in bioassessment initiatives.

An investigation was conducted by Edegbene *et al.,* (2019) to create and implement a macroinvertebrate-based multimetric index for evaluating the water quality conditions of affected urban river systems in the Nigerian Niger Delta. Only five candidates out of seventy-seven (77) tested metrics—Hemiptera abundance, Coleoptera + Hemiptera, Chironomidae + Oligochaeta, evenness index, and logarithm of relative abundance of very large body size (>40–80 mm)—were kept and included in the final Niger Delta urban multimetric index (MINDU). The validation dataset revealed a 75% connection for the moderately damaged station and an 83.3% correspondence between the index result and the physico-chemically based categorization for the least impacted station. The Heavily Impacted Station's performance was 22.2%. The recently created MINDU was approved for use by environmental managers and government authorities for routine monitoring of rivers and streams affected by urban pollution after it proved helpful as a biomonitoring tool in the Nigerian Niger Delta area

Using macroinvertebrates as indicators, Edegbene *et al*., (2019) developed a multimetric assessment technique for River Chanchaga in the North Central region of Nigeria. They conducted seasonal sampling of both macroinvertebrates and physicochemical variables at four different locations: station 1 (the least impacted control station), along with three downstream stations, namely stations 2, 3, and 4. Their evaluation focused on a total of 29 macroinvertebrate metrics, which were grouped into four categories: richness, abundance, composition, and diversity. These metrics were scrutinized to determine their capacity to distinguish between the stations, their consistency across seasons, and their potential redundancy. From the pool of 29 metrics, only 13 metrics met all the predefined criteria, and these selected metrics were then combined to establish the final Chanchaga multimetric index (MMIchanchaga). When this newly formulated index was employed, it brought to light that the water quality at stations 2 and 3 was classified as fair, while station 4 exhibited poor water quality. Additionally, a minor decline in water quality was observed during the rainy season compared to the dry season. Among the individual metrics, three stood out as particularly responsive to changes in water quality: EPT richness, the proportion of EPT taxa, and Shannon diversity. Utilizing the Bray–Curtis similarity measure, the analysis disclosed that stations 2 and 3 displayed greater resemblance to each other in comparison to their similarity with the other stations. In summary, the devised multimetric index proved to be a valuable tool and its' development marked a significant initial stride in the creation of such indices within Nigeria's context.

To monitor, assess, and manage Nigerian wooded riverine ecosystems affected by urban pollution, Edegbene *et al*., (2022) developed a multimetric index (MMI) based on macroinvertebrates. The locations were divided into three disturbance groups using the physico-chemical variables: least-impacted sites (LIS), moderately impacted sites (MIS), and substantially impacted sites (HIS). For the development of the MMI, 59 prospective macroinvertebrate measures were chosen and evaluated. They used screening techniques, metric scoring, and testing for seasonality, repeatability, and redundancy to determine the final metrics for the MMI development. Finally, five metrics—Trichoptera abundance, % Chironomidae+Oligochaeta, Coleoptera richness, Simpson diversity, and Shannon-Wiener index—were chosen for the MMI development. Four of the five integrated metrics—Trichoptera abundance, Coleoptera richness, Simpson diversity, and Shannon-Wiener diversity—were determined to be pollution-sensitive. The remaining metric%Chironomidae+Oligochaeta, however, was tolerant to contamination. The MMI they created was robust and considered beneficial for biomonitoring forested riverine systems draining partially urbanizing catchments since it combines both sensitive and tolerance measures.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Geographic Location

Edo State in Southern Nigeria lies between Latitudes 05° 44'N and 07°34'N and Longitudes 005° 04'E and 005° 44'E. It has an area of about 19,794 square kilometers and falls in the rainforest region of Nigeria. Ikpe community has an area of 120 km^2, and its main land use is for fishery and agriculture. Orhionmwon, Irogbe, and Okhuaihe Rivers flowing through the community are impaired mainly with untreated wastewater discharged from the community as surface runoff from adjacent draining lands.

Three lotic water bodies around Ikpe community were selected for the study. Project sites for this work were chosen from the various study areas using the Garmain GPS, while the ArcGIS software program was used to map out the study areas. Eight sampling points were generated in the study areas and were subsequently surveyed.

The study sites for this research were:

I. Orhionmwon River in Ikpoba Okha Local Government Area lies within Latitude 06° 12'7.31N and Longitude 005° 45'34.49E. It is a tributary of the Benin River, Southern Nigeria and its stretches over a 250km distance between Edo State and Delta State.
II. Irogbe River in Ikpoba Okha Local Government Area lies within Latitude 06° 12'46.05N and Longitude 005°40'20.75E.
III. Okhuaihe River at Ikpe Community in Ikpoba Okha Local Government Area lies between Latitude 06° 2′24.86″N and Longitude 005° 45′16.82″E.

Each of the study sites have two sampling points (a disturbed site and an undisturbed site).

3.1.2 Climate

The study area falls within the tropical regions of the world and is located in the tropical rain forest of Southern Nigeria. The climate condition of the study area is characterized by rainy/wet seasons and dry seasons. The physico-chemical properties of the river changes with season. In the wet season, there is high flow rate, high turbidity due to influx, decreased transparency and increased depth especially after heavy rainfall while in the dry season; there is low or no flow rate and increased transparency (Ekhator *et al*., 2013). The period of rainy season is usually from April to October, and dry season from November to March, with temperature ranging from 22 C – 31 C (Olomukoro 1983). Variation in weather and climate conditions affect ambient and water temperature of the river as well as other physical and chemical proprieties of the rivers (Awachie 1980; Ikusemiju, 1981).

3.1.3 Geology

The study area is underlain by sedimentary rock, which is made up of over 90% porous, coarse sand with clay into beds with ground water retention capacity. The topography is hilly down the slope with some vegetation. This is a typical characteristic of the Benin formation (Omoigberale and Ogbeibu, 2010).

3.1.4 Vegetation and Land Use

The study area has experienced deforestation over the years and it is assumed to be due to a gradual increase in the population size and thus increased demand for forest-based products of the settlement around the river. The main occupations include farming, cassava processing, cattle rearing, piggery, sand excavation, mechanical repairs of motorcycles, sales of building materials, fishing, hunting, trading and palm wine tapping. Vegetation surrounding the river is composed of Riparian and Macrophytes vegetation. Riparian Vegetation; *Bambusa bambusa* (Bamboo trees), *Elaeis guineensis* (Palm trees), *Manihot utilissima* (Bitter cassava), *Havea brasiliensis* (Rubber tree), *Musa paradisiaca* (Plantain)and Macrophytes vegetation; *Ludwiga duccurens* (Willow primrose), *Acrocerans zizanoides* (Oat grass), Vegetable fern (*Diplazium sammatic*), *Lemna* sp (Duckweed), *Dryopteris filixmas* (Basket fern), floating *Salvinia* sp, *Nymphaea lotus* (Water lily) and Water hyacinth (*Eichhornia crassipes*).

3.1.5 Human Activities

Ikpe Community has an estimated population of approximately 600 inhabitants, consisting predominantly of Ijaw and Urhobo ethnic groups, with a smaller representation of the Benin people. This demographic information was obtained through direct physical interviews conducted with residents of the community. The main occupations of the inhabitants of the community are farming, fishing, boat transportation, swimming, bathing, local gin production, palm wine production, timber and lumber production, broom making, mat weaving, carpentry specialized in making woody tents and building canoe and some spiritual activities.

3.1.6 Sampling Stations

In each of the three river areas under research, two sample stations were chosen. The reference station is the first sample location, which is an undisturbed site upstream. The second sampling location is a damaged site downstream (impacted station).

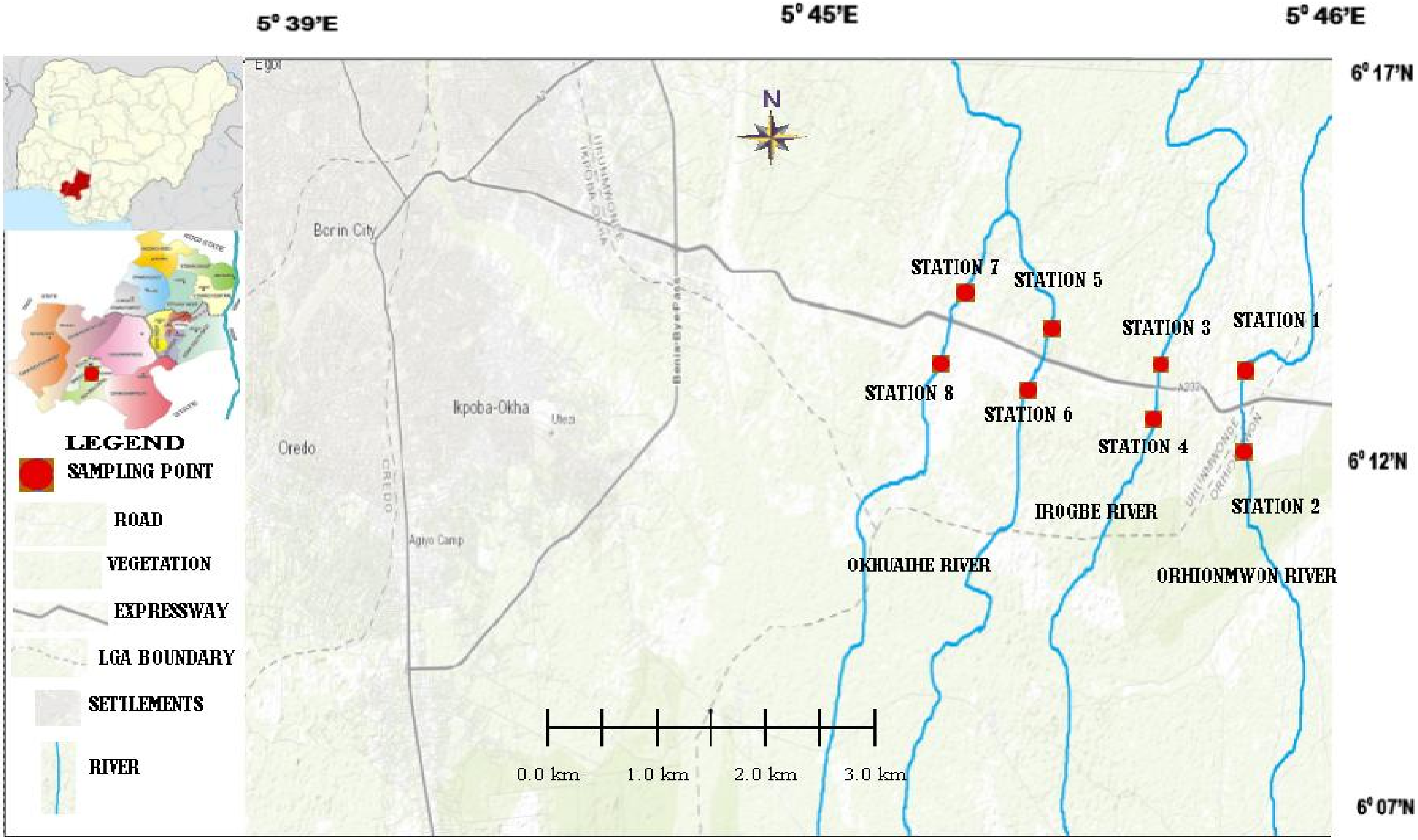

Figure 3.1: A map showing the various Rivers at Ikpe community, Edo State, Nigeria with the study locations

Location 1: Orhionmwon River situated in Ikpe community of Ikpoba Okha Local Government Area, Edo State draws its water from Ikpoba River whose headwaters originate from the Ishan Plateau. In the east coastal plain to northeast of Benin City, with an elevation of about 230m above sea level (Odigie, 2015) and flows southwards joining Ossiomo River which empties into Benin River and eventually into the Atlantic Ocean. The river lies between Longitude 005°45’35.57″E and 005°45’34.19″E and latitude 06°12’08.72″ and 06°12’06.31″N. The inhabitants are notable for plantain/banana farming, fishing, local gin preparation, lumbering, boat transportation and spiritual activities. The study area was divided into two sampling sites namely, reference station (upstream) and impacted station (downstream).

Impacted Station (Station 1): It is situated about 0.9km downstream from the control station and lies on Latitude 06° 12’08.72″N and Longitude 005°45’35.57″E with an elevation of 6.47m below sea level (Plate 3.2). The substratum was composed of sand bed and mud. The water is quite turbid during rainy season and clear during dry season. The station is disturbed by anthropogenic activities such; farming, boat transportation, domestic activities, fishing, dumping of refuse, recreation and defecation by both humans and livestock.

Reference Station (Station 2): This station lies on Latitude 06° 12’06.31″N and longitude 005° 45’ 34.19″E which is located upstream of the river (Figure 3.1). It served as the control point for the study, because there was little or no evidence of impact or disturbance at the station (Plate 3.1). It has an elevation of 9.93m below sea level. Some of the inhabitants of the community use this site for spiritual activities as the water is clean. Vegetation types present in this station are; *Raffia palm, Musa* sp., *Colocasia esculenta*, *Eichhornia crassipes*, *Pennisetum purpureum* and *Hevea brasiliensis*.

Plate 3.1: Reference Site of Orhionmwon River

Plate 3.2: Impacted Site of Orhionmwon River

Location 2: Irogbe River is in a serene, waterside village called Ikpe Community, in Ikpoba-Okha Local Government Area, Edo State, Nigeria within Latitude 06^0 12’18.17″N and Longitude 005° 45'20.96″E (Figure 3.1). The river runs across Benin-Abraka Express Road, 30 kilometres from Benin City lying within the tropical rainforest of Southern Nigeria with an average elevation of about 22.02m below sea level. The river is one of which empties into Ossiomo River and in turn, flows into the Atlantic Ocean. The study area was divided into two sampling sites namely, reference station (upstream) and impacted station (downstream).

Impacted Station (Station 3): It is situated about 1km in the lower course from the control station and lies on Latitude 6° 12' 17.66″N and Longitude 5° 45'20.8″E with an elevation of 28.47m below sea level (Plate 4.4). Anthropogenic activities which have affected the ecological health of the station include; farming, domestic activities, fishing, dumping of refuse, recreation, defecation by both humans and livestock, local gin production, animal hunting, boat transportation, wood lumbering and spiritual activities. Vegetation types present in this station are; macrophytes, watermoss (*Salvinia nymphellula*), duckweed (*Lemna pausicostata,* Raphia palm (*Raphia hookeri*), *Sida acuta* (Stubborn grass) and *Colocasia esculenta* (wild Cocoyam plant).

Reference Station (Station 4): This station is located at Latitude 06^o 12’18.17″N and Longitude 005° 45'20.96″E with an elevation of 22.02m below sea level. It served as the control point for the study, because there was little or no evidence of impact at the station (Plate 3.3). The water in this station is very clear. The anthropogenic activities observed in the station are fishing and boat transport. Vegetation types present in this station are; *Rhizophora, Avicennia, Azolla* spp., *Utricularia* spp., *Eichhornia crassipes*, *Mimosa pundica* (Sensitive plant), Ferns, *Elaeis* *guineensis* (Palm tree), *Sida acuta* (Stubborn grass) and Bahama grasses. The substratum contains mixture of sandy, human wastes and organic matter.

Plate 3.3: Reference Site of Irogbe River

Plate 3.4: Impacted Site of Irogbe River

Location 3: The Okhuaihe River can be found in the calm waterside village known as Ikpe Community, situated in the Ikpoba-Okha Local Government Area of Edo State, Nigeria. It is positioned at Latitude 06^{o} 12'N and Longitude 005° 45'E (Figure 3.1). This river crosses the Benin-Abraka Express Road, approximately 30 kilometres away from Benin City, and is situated within the lush tropical rainforest of Southern Nigeria. The Okhuaihe River holds significance as one of the primary rivers that flow into the Ossiomo River, eventually emptying into the Atlantic Ocean. For the purposes of the study, the area was divided into two sampling sites: the reference station (upstream) and the impacted station (downstream).

Impacted Station (Station 5): Located approximately 0.9 kilometres downstream from the control station, this site is positioned at Latitude 06° 12' 24.18" N and Longitude 005° 45' 15.99"E, with an elevation of 8.48 meters below sea level (Plate 3.6). Anthropogenic activities included domestic tasks, fishing, waste dumping, recreational activities and defecation by both humans and livestock. Vegetation in this area includes macrophytes, watermoss (*Salvinia* *nymphellula*), duckweed (*Lemna pausicostata*), water hyacinth (*Eichhornia crassipies*), Raphia palm (*Raphia hookeri*), pawpaw (*Carica papaya*) and *Colocasia esculenta* (wild Cocoyam plant).

Reference Station (Station 6): This specific location is situated roughly 500 meters before the Orhionmwon bridge at Latitude 06° 12' 25.19" N and Longitude 005°45' 17.12"E, with an elevation of 37.87 meters below sea level. It serves as the reference point for our study because it shows clear signs of reduced impact, as indicated in Plate 3.5. This station is categorized by its transparency and anthropogenic activities observed in this area primarily involve fishing. The vegetation types present at this site include *Rhizophora, Avicennia, Azolla* spp., *Utricularia* spp., *Eichhornia crassipes*, *Mimosa pundica* (Sensitive plant), Ferns, Bahama grasses and wild cocoyam. The substratum contains mixture of sandy, human wastes and organic matter.

Plate 3.5: Reference Site of Okhuaihe River 1

Plate 3.6: Impacted Site of Okhuaihe River 1

Location 4: Okhuaihe River 2 is a tributary of the Okhuaihe River, rejoining the main channel several kilometres downstream. Like the earlier description, it is situated in the tranquil riverside settlement of Ikpe Community, within Ikpoba-Okha Local Government Area, Edo State, Nigeria, at Latitude 06°12’N and Longitude 05°45’E (Figure 3.1). The river crosses the Benin–Abraka Expressway, approximately 30 kilometres from Benin City, and lies within the tropical rainforest zone of Southern Nigeria, with an average elevation of 1.87 m above sea level. For the study, the river was divided into two sampling sites: a reference station (upstream) and an impacted station (downstream).

Impacted Station (Station 7): It is about 0.7 kilometres downstream from the control station is located. It is 1.87 meters above sea level and is in Latitude 06° 12' 29.93" N and Longitude 005° 45' 3.84" E (Plate 3.8). During the wet season, the water is quite murky; during the dry season, it is rather clean. The ecological stability of the station has been impacted by anthropogenic activity such as boat transportation, local gin manufacturing, logging, local broom production, farming, laundry activities, fishing, garbage disposal, and animal and human excrement are some of these activities. Vegetation types present in this station are; macrophytes are watermoss (*Salvinia nymphellula*), duckweed (*Lemna pausicostata*), water hyacinth (*Eichhornia crassipies*), Raphia palm (*Raphia hookeri*), pawpaw (*Carica papaya*) and *Sida acuta* (Stubborn grass)

Plate 3.7: Reference Site of Okhuaihe River 2

Plate 3.8: Impacted Site of Okhuaihe River 2

Reference Station (Station 8): This station is located 1.4 meters above sea level in latitude 06° 12' 28.76' N and longitude 005°45' 8.55'E and is 200 meters from location 3 (Plate 3.7). This sample location's water is clear. Fishing is anthropogenic activity that was seen at the station. Vegetation types present in this station are; *Rhizophora, Avicennia, Azolla* spp., *Utricularia* spp., *Eichhornia crassipes*, Ferns, *Elaeis guineensis* (Palm tree), *Sida acuta* (Stubborn grass) and Bahama grasses.

3.2 Sampling Periodicity

Sampling was carried out twelve times in two years. The period of sampling began August, 2021 to October, 2021 for the wet season and November, 2021 to March, 2022 for the dry season for the first year. In the second year, the period of sampling was also repeated as stated above (August, 2022 to October, 2022 for the wet season and November, 2022 to March 2024 for the dry season). All samples were collected from eight sampling site between the hours of 07.30hrs and 09.00hrs.

3.2.1 Collection of Water Samples

To assess physical and chemical characteristics, water and sediment samples were collected simultaneously at every sampling site. Additionally, biota samples at each location were collected to assess species diversity and composition. Prior to usage, all field equipment were inspected and calibrated in accordance with the manufacturer's instructions.

To obtain surface water samples, a clean, pre-rinsed one-litre sample bottle is immersed below the water sub-surface, filled, and then retrieved. Subsequently, these samples were transported to the laboratory in coolers with ice pack to preserve their integrity by slowing down chemical and biological processes that can degrade the sample and alter test results. For the evaluation of dissolved oxygen (DO) and biochemical oxygen demand (BOD_5), separate 250mL reagent bottles with glass stoppers were used to collect water samples. While filling the reagent bottles with water, the stopper was removed from beneath the water's surface and the bottles were submerged. Before removing the bottles from the water, the stopper was reinserted while still submerged, ensuring that no air bubbles entered the bottles (APHA, 2017; Ogbeibu and Ogiesoba-Eguakun, 2019).

To assess dissolved oxygen (DO), the water's oxygen content was immediately fixed by introducing 1mL each of Winkler's Solutions A (containing Manganous Sulphate) and B (comprising Potassium Hydroxide in Potassium Iodide). As for samples intended for BOD_5 analysis, they were promptly enclosed in opaque black polyethylene bags prior to their transportation to the laboratory.

Water samples for heavy metal analysis, were collected in glass bottles that had been meticulously cleaned with acid. To prevent heavy metals from adhering to the container's surface during transport and storage, concentrated nitric acid was added to the water samples. For other routine physico-chemical parameters, 1-liter water sample bottles were employed to collect water from approximately 20cm beneath the water's surface (APHA, 2017; Ogbeibu and Ogiesoba-Eguakun, 2019).

3.2.2 Collection of Sediment Samples

Sediment samples were collected from the eight designated sampling stations at the study site by scooping from the same locations where the water samples were collected (Van Walt, 2014). However, care was taken when the sampler is raised through the water column during retrieval to minimise the loss of extremely fine material. These sediment samples were then carefully placed in a foil paper, appropriately labelled, and transported to the laboratory for further examination.

3.3 Physical and Chemical Parameters of Water

3.3.1 Air and Water temperatures (^oC)

This was carried out in-situ using mercury in glass thermometer by holding the thermometer in the air and a stable reading was recorded, while water temperature was determined by immersing the thermometer in the water and stable reading were recorded (APHA, 2017).

3.3.2 Hydrogen Ion Concentration (pH)

The pH of the water samples was determined *in situ* using the HANNA pH meter (model HI8424). It was calibrated using buffer solutions 4, 7 and 10. The pH meter was then dipped into the water and the reading taken when it was steady (APHA, 2017).

3.3.3 Flow Rate/Velocity (cm/s)

The surface floatation method was used to assess flow velocity. To conduct this, a small, sealed plastic bottle filled with water until its top is just above the water's surface was thrown on the water's surface and allowed to freely flow over a given distance, with the time needed to flow through that distance measured using a timer. The velocity was computed and result documented using the following formula:

$$\text{Flow rate} = \frac{\text{total distance travelled (cm)}}{\text{Time spent (s)}} \qquad (3.0)$$

3.3.4 Transparency

A Secchi-disc was used to measure this parameter. Using a calibrated rope, the secchi-disc was progressively placed into the water body at the various stations; the values recorded were the depth at which the secchi-disc sank into the water and the depth at which it reappeared when hauled out.

The average of the two depths was used to get the transparency reading:

$$\frac{\text{Point of emergence} + \text{Point of disappearance}}{2} \qquad (3.1)$$

3.3.5 Water Depth (cm)

The Secchi-disc was used to do this in-situ. It was thrown into the water body with a calibrated rope until it touched the river bottom; the measurement was marked on the rope and recorded at this point. This procedure is alternated with dipping a calibrated pole into the water body at the various sampling stations or dipping a long stick into the shallow sample stations until it touches the water bottom and measuring the wet portion of the stick with a measuring tape and recording the reading.

3.3.6 Electrical Conductivity (µS/cm)

A conductivity meter (HACH 44600-00) was used to measure the conductivity of water samples *in situ* in µScm^{-1}. The probe was dipped into the container of the samples, until a stable reading was obtained and recorded in micro-siemens per centimetre (µs/cm). Care was taken to ensure that the terminals of the meter are not in contact with the wall of the beaker, while the reading was being taken (APHA, 2017).

3.3.7 Turbidity (NTU)

Turbidity was measured in NTU (Nephelometric Turbidity Units). This was determined using a visible spectrophotometer VS72IG. The cuvettes were washed and rinsed with distilled water. One of the cuvettes was filled to mark with the sample and the other is filled to mark with distilled water. The cuvettes with distilled water were used to standardize the spectrophotometer. The samples were read at a wavelength of 420nm (APHA, 2017).

3.3.8 Total Suspended Solids (TSS) (mg/L)

This was obtained by subtracting the total dissolved solids (TDS) from the total solids (TS) (Onyeonwu, 2000).

$$TSS = TS - TDS$$ (Onyeonwu, 2000) (3.2)

3.3.9 Total Dissolved Solids (TDS) (mg/L)

The total dissolved solids were determined using the conductivity meter (HACH 44600-00). Place the meter's probe into the water sample in the beaker, ensuring it is submerged to the correct level until a stable reading in mg/L is obtained and recorded. The conductivity of the sample was read from the conductivity meter and the value multiplied by 0.666 to give the TDS (Onyeonwu, 2000).

TDS (mg/L) = Conductivity value × 0.666 (APHA, 2017) (3.3)

3.3.10 Total Solids (mg/L)

This was done using the Gravimetric method. 10ml of the samples were measured into a pre-weighed evaporating dish, which was oven dried at a temperature of $103^{\circ}C$ to $105^{\circ}C$ for 2½ hours. The dish was cooled in a desiccator at room temperature and weighed. The total solids were represented by the increase in weight of the evaporating dish (Onyeonwu, 2000).

$$\text{Total solids (mg/L)} = \frac{(W2-W1)\text{ mg x } 1000}{\text{ml of sample used}} \qquad \text{(Onyeonwu, 2000)} \quad (3.4)$$

Where W1 = initial weight of evaporating dish

W2 = Final weight of the dish (evaporating dish + residue)

3.3.11 Dissolved Oxygen (DO) (mg/L)

It was determined using the Winkler method *in situ*. Water samples were collected in the field, using 250ml DO glass bottles with stoppers. The bottles were filled and stopped below the water surface. This was done to avoid air bubbles from entering the water samples. The samples were fixed by adding 2ml of Winkler A solution manganese (II) sulphate ($MnSO_4$) and 2ml of Winkler B solution (alkaline-iodide-azide) each, forming a precipitate. The bottle is gripped firmly and inverted vigorously. In the laboratory, 2ml of concentrated sulphuric acid (H_2SO_4) was added to the sample to dissolve the precipitate. Thereafter, aliquot of 100ml was measured into a 250ml conical flask and two drops of freshly prepared starch indicator was added and thoroughly shaken. The solution was titrated against 0.025M sodium thiosulphate solution ($NaS_2O_3.5H_2O$), until it became colourless. The volume of sodium thiosulphate used was equal to the amount of dissolved oxygen (DO) in mg/L in the sample (APHA, 2017; Ogbeibu and Ogiesoba-Eguakun, 2019).

3.3.12 Biological Oxygen Demand (BOD_5) (mg/L)

Water samples for BOD_5 determination were collected in amber coloured reagent bottles, by immersing the bottle into the water and corking it below the water surface, to prevent air bubbles. The bottles were tied in black polythene bags to prevent light penetration. Then, the samples were incubated at 20ºC for 5 days in the laboratory. The dissolved oxygen was determined at the beginning and end of the incubation period using the Winkler's method (APHA, 2005; Ogbeibu and Ogiesoba-Eguakun, 2019).

$$BOD_5\ (mg/L) = DO_1 - DO_5 \qquad \text{(APHA, 2017) (3.5)}$$

Where, BOD_5 = Biological oxygen demand at day five

DO_1 = dissolved oxygen at day one

DO_5 = dissolved oxygen at day five

3.3.13 Determination of Calcium and Magnesium (mg/L)

Flame photometric method was adopted in the determination of the exchangeable bases (calcium and magnesium) concentration in the water samples. This was determined using the Technicon auto analyser flame photometer IV, pre-calibrated using known concentrations of Ca^{2+} and Mg^{2} with lithium as internal standards. Samples were placed in the small cups in the sample tray module. Then, it is aspirated automatically into the mixing module. The mixing of lithium and sample occurred, and the Teflon tube was checked regularly for good bubble pattern. The mixed sample is passed to the flame chamber, where it is atomized and flared with the aid of propane gas. The concentration of each anion was measured by the colour intensity of the flame, which is obtained from an attached recorder (Philips and Greenway, 2008; Ikhuoriah and Oronsaye, 2016; Ogbeibu and Ogiesoba-Eguakun, 2019).

3.3.14 Chloride (mg/L)

This was determined by MOHR's method (APHA, 2017). This method employs silver nitrate ($AgNO_3$) as titrant and 10% $K_2Cr_2O_4$ solution as the endpoint indicator. The chloride ion presents in the samples precipitates as white sliver chloride. Firstly, a reddish-brown colour comparison blank was prepared by adding 1ml potassium chromate and then 0.2ml 0.02 M $AgNO_3$ to 100ml distilled water in a clean conical flask. It was shaken gently and then allowed to settle. Then, 100ml of sample was put into a conical flask, with the aid of a pipette followed by 1ml of potassium chromate indicator and titrated. A constant stirring with 0.02M $AgNO_3$ until a slight red precipitate occurs shows the presence chloride. The value of chloride ion concentration is inferred from the equation:

$$Cl^{-}\ (\text{mg/L}) = \frac{\text{Molarity} \times \text{Titre} \times \text{Mol. Wt}}{\text{Aliquot taken}} \qquad \text{(APHA, 2017) (3.6)}$$

3.3.15 Phosphate (PO_3^-) (mg/L)

Phosphate was determined using the ascorbic acid method, APHA (2017). A 5ml of the sample was measured into a 50ml flask, 1ml of ascorbic acid was added and the solution made up to 25ml by adding 19ml of distilled water. The blue coloured solution was read after 30minutes, using visible spectrophotometer VS72IG at a wavelength of 660nm.

$$PO_4\ (\text{mg/L}) = \frac{\text{Instrument reading} \times \text{slope reciprocal} \times \text{col. Vol}}{\text{Aliquot taken}} \qquad \text{(APHA, 2017) (3.7)}$$

3.3.16 Nitrite (NO_2^-) (mg/L)

This was determined by the Spectrophotometric method, where 10ml of the water sample was pipetted into a flask. 2ml of Hydrochloric Acid was added and 2ml of Sulphanilic Acid. The solution was allowed to stand for 5 minutes, before 10ml of α-napthylamine was added and allowed to stand for 30 minutes. 30ml of distilled water was added to dilute the solution. A considerable quantity was poured in a curvette and placed in the spectrophotometer. The reading was taken at a wavelength of 520nm (Onyeonwu, 2000).

3.3.17 Nitrate (NO_3^-) (mg/L)

This was determined by the colorimetric method, where 5ml of sample was pipetted into a 50ml flask. 1ml of Brucine was added and 5ml of conc. Sulphuric acid (H_2SO_4) was carefully be added. 14ml of distilled water was added to make it up to 25ml, the solution was shaken in between reagent addition. The absorbance was then read at a wavelength of 470nm, using the visible spectrophotometer VS72IG (Onyeonwu, 2000).

$$NO_3\ (\text{mg/L}) = \frac{\text{Instrument reading} \times \text{slope reciprocal} \times \text{col. Vol}}{\text{Aliquot taken}} \qquad (3.8)$$

(Onyeonwu, 2000)

3.3.18 Ammonium-Nitrogen (NH4N) (mg/L)

5ml of the filtrate from the Sodium Acetate extract was pipetted into a flask. 2.5ml of Alkaline Phenol, 1ml Sodium Potassium Tartrate and 2.5ml of Sodium Hypochlorite or Bleach were then added into the extract. The solution was shaken well in between each addition. The solution was read colourimetrically at 636nm against the ppm as blank. A standard solution was prepared using the same reagent to serve as the blank solution (Onyeonwu, 2000).

3.3.19 Sulphate (SO_4^{2-}) (mg/L)

This was determined by the colorimetric method, where 5ml of sample was pipetted into a 50ml flask. 1ml of Gelatin-$BaCl_2$ reagent was added into the flask with 19ml of distilled water. The solution was made up to 25ml and shaken in between reagent addition. The absorbance was then read at 420nm, using the visible spectrophotometer VS72IG (Onyeonwu, 2000).

3.3.20 Determination of Heavy Metals in Water Samples (mg/L)

Digestion

Water samples were digested using aluminium block digester 110. The digestion was carried out by taking 100ml of the sample. 4ml Perchloric acid, 20ml concentrated nitric acid and 2ml Concentrated Tetraoxosulphate VI acid was added to the sample. This was digested using aluminium block digester 110. The mixture was heated until white fumes evolved and clear solution appeared. Thereafter, the samples were allowed to cool, before transferring into 100ml volumetric flask. The solution was filled to the 100ml mark with distilled water, before mixing thoroughly. The sample was allowed to stand overnight (in place of centrifuge) to separate insoluble materials. It was filtered through 0.45µMillipore type filter paper.

Heavy metals such as; Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Chromium (Cr) and Lead (Pb) were analysed using the Atomic Absorption Spectrophotometer (AAS) Solaar 969 Unicam Series model. Each metal has a hollow cathode lamp for its determination. The instrument was set up at wavelengths specific to each element for analysing. Distilled deionized water aspiration between each reading was conducted. Readings of the absorbance were obtained by observing the steady galvanometer reading in 1min - 2mins. Analysis for each sample was done in triplicate to get representative results (Oribhabor and Ogbeibu, 2009; Ogbeibu and Ogiesoba-Eguakun, 2019).

3.4 Physical and Chemical Parameters of Sediment

Upon arrival at the laboratory, the samples were meticulously recorded in the Samples Record Book for inventory purposes. Subsequently, the sediment samples were arranged on racks to undergo a drying process. The Sediment Samples were air-dried first, before taken into the oven to be dried at 80^0C for 48 hours to remove moisture. The dried samples were grounded into very fine sediments by means of a porcelain mortar to achieve homogenous samples. Precautions were taken to avoid contamination during drying, grinding, sieving and storage. All chemicals and reagents were of analytical reagent grade quality.

3.4.1 Hydrogen Ion Concentration (pH)

The pH of the sediment samples was determined using the HANNA pH meter (model HI8424). It was calibrated using buffer solutions 4.0, 7.0 and 10.0. The water samples were put in a beaker, which were gently rotated by stirring the content. The pH meter was then dipped into the beaker and the reading taken when it was steady (APHA, 2017).

3.4.2 Electrical Conductivity (µS/cm)

A conductivity meter (HACH 44600-00) was used to measure the conductivity of water samples in μScm^{-1}. To measure conductivity, prepare a sediment–water mixture at a standardized ratio (e.g., 1:5) using distilled water. Allow the mixture to settle, then measure the conductivity of the supernatant with an EC meter or probe. Ensure the probe is immersed only in the clear liquid, avoiding contact with the sediment or container walls, for accurate results. Since conductivity is temperature-sensitive, readings should be taken at a consistent temperature, ideally around 25 °C.

3.4.3 Total Organic Matter (%)

Walkley-Black method (WB) – one gram of soil sample was placed into 250ml Erlenmeyer and 10ml of 1N of $K_2Cr_2O_7$ (Potassium Dichromate) was added. 10ml of concentrated H_2SO_4 (Hydrogen Sulphide) was also added and then 50ml of deionized water was added after 30 minutes. 3ml of concentrated H_3PO_4 and 0.5ml of 1% diphenylamine indicator were added, then, the solution was titrated slowly with 1N of $FeSO_4$ solution until a green colour endpoint is obtained.

3.4.4 Phosphate (mg/kg)

Phosphate in sediments was determined by first extracting it from the sediment using NaOH. Afer which, a 5mL of the filtrate was pipetted into a 50ml flask. Adjust the pH of the solution to 5 as follows. Add 3 drops of the p-nitrophenol, when a yellow colour was obtained, add some drops of 2M NH_4OH until yellow. Then, add 2M HCL dropwise until colourless (the pH now falls between 3 and 5). Distilled water was added to make the solution 30ml, then 10ml of the Ascorbic Acid reagent was added. The solution is then read spectrophotometrically at 660nm (APHA, 2017).

$$\text{P (mg/kg)} = \frac{\text{Instr. reading x Slope Recip. x Colour Vol. x Extract Vol.}}{\text{Weight of Sample x Aliquot Taken}} \qquad (3.10)$$

3.4.5 Extraction of Ammonium-Nitrogen (mg/kg)

100g of the sodium acetate was dissolved in 500ml of water. 30ml of acetic acid was added and made up to 1litre with water. 10g of the soil sample was weigh into a 150ml plastic bottle. 40ml of the extracting solution was added and shaken for 30minutes. Filtration of the solution was done, to obtain the filtrate for the determinations of NH_4-N.

10ml of the filtrate was pipetted into a 50ml flask and distilled water was added to bring the volume to 20ml. Then, 1ml of the Gelatine – $BaCl_2$ reagent was added and allowed to settle for 30minutes. The solution was mixed properly and a standard solution was also made using the same procedure. The solution was read at a wavelength of 420nm in a spectrophotometer to obtained NH_4-N (APHA, 2017).

3.4.6 Heavy Metals in Sediments Samples (mg/kg)

Digestion

The Perchloric-Nitric acid-Sulphuric acid digestion methods were used to obtain the heavy metals in the samples. Sediment samples were digested by taking 100g of the dried sediment sample and adding 4ml Perchloric acid, 20ml concentrated Nitric acid and 2ml concentrated Tetraoxosulphate VI acid. The mixture was digested using aluminium block digester 110. Complete digestion was observed, when white crystalline mixtures are obtained, after the disappearance of the white chlorate forms. The final content was allowed to cool. Filtration of the mixture was carried out using a Whatman filter paper No. 541, to determine the heavy metals (Iron, Manganese, Zinc, Copper, Chromium and Lead). The filtrate was analysed using Solaar 969 Unicam Series Atomic Absorption Spectrometer (AAS) (Osakwe and Peretiemo-Clarke, 2013).

3.5 Benthic Macroinvertebrates

Benthic macro invertebrates were collected from the bank roots and shallow erosional biotope using a composite sampling method. Two applicable sampling procedures were adopted for the collection of the macrobenthic invertebrates. These procedures are as follows:

3.5.1 Kick Method

The modified Kick sampling technique earlier described by Victor and Ogbeibu (1985) was used in collecting benthic macroinvertebrates from the bankroot biotope of each station which is an efficient sampling method for large mobile organisms and a greater number of general organisms. The method was carried out by kicking or using a sieve to dislodge the macrobenthic invertebrates from the macrophytes on the bank roots. It was carried out using the sieve of a mesh size of 150µm to scrap the roots of the macrophytes on the bank roots. The samples were washed in water, sieved and placed in a plastic container. The macrobenthic organisms that were collected with the method were fixed with 10% formalin concentration (Arimoro *et al.*, 2007; Arimoro and Ikomi, 2008).

3.5.2 Scooping

Bottom sediments were collected using a scoop and small bucket and subsequently emptied into a bigger bowl. Sodium Chloride was added for three to five minutes, before stirring vigorously to facilitate floatation of the organisms. The liquid medium and floating fauna were sieved through a mesh sieve of size 0.05mm. The sieved macrobenthic samples were poured into a wide mouth labelled plastic containers and preserved with 10% formalin solution (Olomukoro and Dirisu, 2012; 2014; Woke and Aleleye-Wokoma, 2015). All samples were taken for taxonomic examination, using identification keys at the Laboratory in the Department of Animal and Environmental Biology, University of Benin, Edo State.

3.5.3 Sorting

Benthic Samples were sorted in the laboratory using forceps and sorting pins. Sorting of the samples was done using the American Optical Dissecting Microscope Model 570 with magnification of 25x - 40x. A Hand Lens was also used to view large specimens during sorting. All samples were placed in different petri dishes and light rays from the condenser were focused on the specimens. All the organisms in the various petri dishes were sorted out, placed into different labelled vial bottles and preserved in 4% formalin. Direct counting was done using a gridded Petri dish and a dissecting microscope (Arimoro *et al.*, 2007; Olomukoro and Dirisu, 2014; Woke and Aleleye-Wokoma, 2015).

3.5.4 Identification and counting

Temporal slide was made of representative specimen and viewed under the Olympus compound microscope. Identification to the lowest possible taxonomic level was performed under light microscope using keys of benthic macroinvertebrates and photographs of specimens were taken and measured to scale. The benthic macroinvertebrates were identified with identification keys and some basic texts. Organism identification was made possible using morphological features and illustrations provided by works of Ogbeibu (1991) and Olomukoro (1996), respectively. Specifically, Oligochaete were identified using Pennak, 1953; Ward and Whipple, 1959; Brinkhurst, 1966; Ephemeroptera using Pennak, 1953; Mellanby, 1963; Needham and Needham 1978; Gillies 1980; Ogbeibu, 1991; Odonata with Pennak, 1953; Ward and Whipple, 1959; Ogbeibu 1987, 1991; Diptera with the aid of Pennak, 1953; Needham and Needham 1962; Ogbeibu 1987, 1991; Coleoptera with Ward and Whipple, 1959; Plecoptera using Pennak, 1953; Ward and Whipple, 1959; Needham and Needham, 1978 and Nematoda with the use of Ward and Whipple, 1959. Guide to Aquatic Invertebrate Families of Mongolia, by Bouchard and Paul, (2012) were also used for identification. Counting was manually done into different taxa.

3.6 Statistical Analysis

3.6.1 Analysis of Variance (ANOVA)

Basic statistical measures of central tendency and dispersion were employed to characterise the sampling stations based on their physicochemical conditions. Inter-station comparisons were conducted to assess significant variations in the physical and chemical parameters using parametric Analysis of Variance (ANOVA) and the Independent Samples *t*-Test. Where significant differences ($p < 0.05$) were observed, Duncan's Multiple Range (DMR) test was applied to identify the specific locations of variation. Data analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 23.0, while graphical representations were generated with Microsoft Excel (2010) for Windows (Ogbeibu, 2014). The mean values obtained were further compared with the water quality standards established by the Federal Ministry of Environment (FME)

3.6.2 Correlation and Principal Component Analysis (PCA)

Principal Component Analysis (PCA), a data reduction statistical tool was employed to reduce the acquired data, in order to generate the parameters responsible for the variation in water quality of the river. This analysis was computed using the SPSS 23.0 and Microsoft Excel application. Principal Component Analysis (PCA) provides the most significant and meaningful variables, which can show the source of the variation. During the analysis, less significant variables were excluded from the whole data set with very minimum loss of original information (Singh *et al.*, 2004: Shrestha and Kazama, 2007).

3.6.3 Determination of Water Quality Index (WQI)

The WQI was calculated by means of a weighted arithmetic water quality index recognized by Brown *et al*., (1972) for the National sanitation foundation (NSFW), some-times called NSFWQI as adopted by Iloba *et al*. (2021). The following equation represents the weighted arithmetic water quality index (WQIA):

$$WQI_A = \sum_{i=1}^{n} w_i q_i \Big/ \sum_{i=1}^{n} w_i \qquad (1)$$

Where, n denotes the number of variables or parameters, wi is the relative weight of the ith parameter and, qi is the water quality rating of the ith parameter. The unit weight (wi) of the various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters. Wi=1/Si, and K= constant given as; K=1/∑1/Si (2)

qi= 100 [(Vi –Vid) / (Si –Vid)] (3)

Where:

Vi is the observed value of the ith parameter, Si is the standard acceptable value of the ith parameter and Vid is the ideal value of the ith parameter in pure water. All the ideal values (Vid) are taken as zero for drinking water, except pH and dissolved oxygen (Tripathy and Sahu, 2005). For pH, the ideal value is 7 and 14.6 for dissolved oxygen.

Table 3.1: Classification of water quality Index and status

WQI Index	Status
0 – 25	Excellent water quality
26 – 50	Good water quality
51 – 75	Poor water quality
76 – 100	Very poor (bad) water quality
Above 100	Unsuitable for drinking purpose

(Boah *et al*., 2015)

3.6.4 Evaluation of Data – Risk Assessment

Some quantitative indices were used to assess the heavy metal contamination and to allow for ease of comparison between the determined parameters.

These indices include Enrichment Factor (EF), Contamination Factor (CF) and Contamination Degree (CD), Geo-accumulation Index (Igeo) and Potential Ecological Risk Index (PERI) as previously discussed by (Caeiro *et al.,* 2005; Gong *et al*., 2008; Zoynab *et al.,* 2008; Rapant *et al*., 2008; Sekabira *et al.,* 2010; Nweke and Ukpai, 2016). The definitions and equations for the indices are stated below.

3.6.4.1 Enrichment Factor (EF)

As proposed by Duce (1975), enrichment factor (EF) was employed to assess the degree of contamination and to understand the distribution of the elements of anthropogenic origin from sites by individual elements in soil. Fe is chosen as the normalizing element, while determining EF values, since it is one of the widely used reference element (Loska *et al.,* 2003; Kothai *et al.,* 2009; Chakravarty and Patgiri, 2009; Seshan *et al.,* 2010; Sekabira *et al.,* 2010; Nweke and Ukpai, 2016). The formula for enrichment factor is stated below:

Enrichment Factor = (X⁄Fe) soil ⁄ (X⁄Fe) background Levy *et al.,* (1992). (3.12)

Where (X⁄Fe) $_{\text{soil}}$ is the ratio of heavy metal (X) to Fe in the soil samples from mining sites and X⁄Fe) background is the natural background value of the Metal-Fe ratio. Normalizing element, Fe, with natural background value of 921.238 mg/kg was used in the study.

The EF values close to unity indicate crusted origin, those less than 1.0 suggest a possible mobilization or depletion of metals, whereas EF > 1.0 indicates that the element is of anthropogenic origin (Zsefer, *et al.,* 1996; Nweke and Ukpai, 2016).

Table 3.2: Adjusted grading standard of Potential Ecological Risk of Heavy Metals in Sediment.

E^i_R	**Pollution degree**	**Ri**	**Risk level**	**Risk degree**
EiR< 30	Slight	Ri < 40	A	Slight
30 ≤ EiR< 60	Medium	40 ≤ Ri < 80	B	Medium
60 ≤ EiR< 120	Strong	80 ≤ Ri < 160	C	Strong
120 ≤ EiR< 240	Very Strong	160 ≤ RI 320	D	Very strong
EiR ≥ 240	Extremely strong	RI ≥ 320	-	-

E^i_R is the potential ecological risk index of a single element; RI is a comprehensive potential ecological risk index.

Source: Jiang *et al.* (2014)

According to Sutherland (2000), five categories are recognized based on enrichment factor (EF).

When EF < 2 depletion of mineral enrichment or no enrichment

$2 \leq EF < 5$ moderate enrichment

$5 \leq EF < 20$ significant enrichments

$20 \leq EF < 40$ very high enrichment

$EF > 40$ extremely high enrichment

3.6.4.2 Pollution Load Index (PLI) and Contamination Factor (CF)

Pollution severity and its variation were determined with the use of pollution load index. The pollution load index was gotten as concentration factor. This concentration factor is the quotient obtained by dividing the concentration of each metal. The pollution load index of the place was calculated as the n-root of the product of the n-CFs obtained for metals analysed (Ogbeibu *et al*., 2014; Nweke and Ukpai, 2016).

The CF and PLI are expressed as follows:

CF = metal concentration / background concentration of the same metal and;

The contamination factor (CF) was used to determine the contamination status of soil in the present study. Assessed as the ratio obtained by dividing the concentration of each metal in the soil by baseline or background value (concentration in uncontaminated soil):

$$CF_{metal} = \frac{C_{metal}}{C_{background}} \quad \text{(Hakanson, 1980)} \quad (3.13)$$

According to Hakanson (1980), CF values are interpreted as follows:

If CF < 1: it means that low contamination exists.

If 1 < CF > 3: it means that moderate contamination exists.

If 3 < CF < 6: it means that considerable contamination exists.

If CF > 6: it means that very high contamination exists.

While PLI can be expressed as

$$PLI\ of\ a\ study\ area = n\sqrt{C_f^i 1 \times C_f^i\ 2 \times C_f^i\ \ 3 \times C_f^i\ \ldots\ \times C_f^i\ n} \quad - - - \qquad (3.14)$$

For assessing the level of heavy metal pollution this empirical index provides a simple, comparative means.

When PLI > 1, it means that a pollution exists; otherwise,

When PLI < 1, there is no metal pollution.

3.6.4.3 The Geoaccumulation Index (Igeo)

As proposed by Ihenyen (1998), geo-accumulation index (Igeo) has been widely used to evaluate the extent of heavy metal contamination associating with the sediment.

Muller, (1969) and Boszke *et al*. (2004) express Igeo as:

$$\text{Igeo} = \text{Log2}\ (C_n / 1.5\ B_n) \qquad \text{(Ihenyen, 1998)} \qquad (3.15)$$

Where C_n is the metals concentration in soil samples and B_n is the geochemical background concentration of the metal (n). Factor 1.5 is the background matrix correction factor, due to lithospheric effects. The geoaccumulation index consists of seven classes (0 to 6), indicating various degrees of enrichment above the background values and ranging from unpolluted to very highly polluted (Chakravarty and Patgiri, 2009).

Class 0 (practically unpolluted): Igeo ≤ 0

Class 1 (unpolluted to moderately polluted): $0 <$ Igeo < 1

Class 2 (moderately polluted): $1 <$ Igeo < 2;

Class 3 (moderatelyto heavily polluted): $2 <$ Igeo < 3;

Class 4 (heavily polluted): $3 <$ Igeo < 4;

Class 5 (heavily to extremely polluted): $4 <$ Igeo < 5;

Class 6 (extremely polluted): 5 > Igeo

3.6.4.4 Potential Ecological Risk Index (PERI)

The potential ecological risk index method of Hakanson (1980) was used to evaluate heavy metal contamination from the perspective sedimentology, reflected in equation below. It was adopted to evaluate the heavy metal pollution in the sediment samples. It also used to associate ecological and environmental effects with their toxicology and the toxic-response factor T_{ri} of Cu, Zn, Mn, Fe and Pb. An ecological risk factor (*Er*) quantitatively expressed as the potential ecological risk of a given contaminant are given by Hakanson (1980) in equation below.

$$Er = Tr \cdot Cf \qquad \text{(Ihenyen, 1980)} \qquad (3.16)$$

Where *Tr* is the toxic-response factor for a given substance and *Cf* is the contamination factor. The following terminologies are used to describe the ecological risk factor: $Eri < 40$, low potential ecological risk; $40 \leq Eri < 80$, moderate potential ecological risk; $80 \leq Eri < 160$, considerable potential ecological risk; $160 \leq Eri < 320$, high potential ecological risk; and $Eri \geq 320$, very high ecological risk. The potential ecological risk index (PERI) was in the same manner as degree of contamination defined as the sum of the risk factors.

$$\mathrm{RI} = \sum_{i=1} Er$$

Where *Eri* is the single index of ecological risk factor, and m is the count of the heavy metal. The following terminologies are used for the potential ecological risk index as given by Hakanson (1980); RI < 150, low ecological risk; 150 ≤ RI < 300, moderate ecological risk; and $RI > 600$, very high ecological risk (Table II).

3.7 Benthic Macroinvertebrates Diversity Indices

In the present study, calculation of diversity indices was done using Shannon Wiener diversity (H’), to calculate for general diversity (Odigie and Olomukoro, 2016). It is a more powerful diversity index.

$$H' = \frac{N \log N - \Sigma_i^s = 1 f1 \log f1}{N}$$ (Green, 1979) (3.17)

Where: N = Total number of individuals,

$f1$ = Number of individuals in species and

S = Number of species.

Margalef diversity (d) used to calculate for taxa richness,

$$d = \frac{S - 1}{\text{In}\,(N)}$$ (Green, 1979) (3.18)

Where; S = Total number of species,

N = Total number of individuals,

In = Natural or Nape rian logarithm (Loge).

Pielou Evenness (E) will be used to calculate for the even distribution of individuals in the various species recorded.

$$E = \frac{H}{H_{max}} = \frac{H}{\log S}$$ (Green, 1979) (3.19)

Where,

H = Ratio of observed diversity H_{max} or $\log S$ = Maximum expected diversity.

The above bio-indices reflected and compared the even occurrence, general diversity and taxa richness of benthic macroinvertebrates in the five rivers.

Simpson Index (D)

$$D = \sum_{i=1}^{s} \frac{ni\,(ni-1)}{N\,(N-1)}$$ (Green, 1979) (3.20)

Where,

ni = the number of individuals in the ith species,

Ni = the total number of individuals, was also employed to assess the number of abundant species in all five rivers studied.

The computer software pack Paleontological Statistics (PAST 3.0) was employed to ascertain, the benthic fauna that were present in each specific sampling station. Other simple statistical tools like percentage distribution, composition, density and occurrence were applied in the study. All statistical analysis and graphical presentations were done with SPSS version 23.0 and MS-Excel package.

3.8 Metrics Selection for Multimetric Index Development

Thirty-nine metrics in five groups which include taxa abundance (absolute number of macroinvertebrate individuals), taxa composition (relative abundance), taxa richness and diversity indices, which includes; Shannon wiener index, Margalef index, Simpson diversity and evenness (Odume *et al*., 2012; Mereta *et al*., 2013; Edegbene *et al*., 2019; Fierro *et al*., 2018) were selected (Table 3.3). Trait information was obtained from Krynak and Yates (2018) and Odume *et al.* (2018). A fuzzy coding system of (0 – 3) affinity scores was applied for awarding trait information to the various taxa. A score of 0 was awarded to a taxon, if the taxon has no affinity to the trait attribute. A score of 1 was awarded if the affinity is low, 2 if the affinity is moderate and 3 if it is high (Chevenet *et al*., 1994). Measures of abundance were included as part of candidate metrics to be tested, to represent all component of macroinvertebrate community structures.

The Ikpe Community River Biotic Index (ICRBI) was adopted using macroinvertebrate taxonomic metrics, which indicates sensitivity of the macroinvertebrate community in the selected Ikpe Rivers. This index was adopted for the study of the three Rivers in Ikpe, Edo State. This means they were strongly correlated with Water physicochemical variables and enabled discrimination of the various Stations. The asterisked metrics in the Table 3.3 was incorporated in the development of the Multimetric Index.

Table 3.3: Selected taxonomically based macroinvertebrate metrics measures of absolute abundance, relative abundance, richness and diversity applied to macroinvertebrate data collected at the Rivers in Ikpe community, Edo State, Nigeria

Metrics	Definitions	Predicted response to deteriorating water quality
Abundance measure		
EPT abundance	Absolute number of individuals in Ephemeroptera, Plecoptera and Trichoptera	-
Ephemeroptera abundance	Absolute number of individuals in Ephemeroptera	-
ETOC abundance	Absolute number of individuals in Ephemeroptera Trichoptera, Odonata and Coleoptera	-
Chironomidae + Oligochaeta abundance	Absolute number of individuals in Chironomidae and Oligochaeta	+
Mollusca + Decapoda abundance	Sum of the absolute number of individuals in Mollusca and Decapoda	
Diptera abundance*	Absolute number of individuals in Diptera	+
Decapoda abundance*	Absolute number of individuals in Decapoda	-
Mollusca abundance*	Absolute number of individuals in Mollusca	+
Coleoptera abundance*	Absolute number of individuals in Coleoptera	-
Odonata abundance*	Absolute number of individuals in Odonata	-
Trichoptera abundance*	Absolute number of individuals in Trichoptera	-
Coleoptera + Hemiptera abundance*	Sum of the absolute number of individuals in Coleoptera and Hemiptera	-
EPT/Chironomidae ratio	Ratio of EPT individuals to Chironomidae individuals	-
Measures of composition (relative abundance)		
% Chironomidae + Oligochaete*	Percentage of individuals in Chironomidae + Oligochaeta taxa relative to the entire sample	+
% Mollusca	Percentage of individuals in Mollusca taxa relative to the entire sample	+
% Trichoptera	Percentage of individuals in Trichoptera taxa relative to the entire sample	
% Coleoptera + Hemiptera*	Percentage of individuals in Coleoptera and Hemiptera taxa relative to the entire sample	-

% ETOC	Percentage of individuals in Ephemeroptera, Trichoptera, Odonata and Coleoptera taxa relative to the entire sample	-
% Diptera	Percentage of individuals in Diptera taxa relative to the entire sample	+
% Decapoda*	Percentage of individuals in Decapoda taxa relative to the entire sample	+
% Ephemeroptera	Percentage of individuals in Ephemeroptera taxa relative to the entire sample	-
% EPT	Percentage of individuals in Ephemeroptera, Plecoptera and Trichoptera taxa relative to the entire sample	-
Richness measures		
EPT richness*	Absolute number of taxa in EPT	-
ETOC richness	Absolute number of taxa in ETOC	-
Hemiptera + Diptera richness*	Absolute number of taxa in Hemiptera and Diptera	-
Diversity measures		
Simpson diversity	Weighted towards the abundance of commonest genus/species/taxa (Ogbeibu, 2005)	-
Evenness index	Evenness of taxa within sample (Clarke and Warwick 1994)	-
Margalef Index (taxa diversity index) *	Accounts for both number of taxa and individuals and is independent of sample size (Ogbeibu 2005)	-
Shannon diversity index*	Information statistics index taking account of the contribution of individual taxa to the diversity while assigning greater weight to dominant taxa (Ogbeibu, 2005)	-
Traits attributes		
CRA	Logarithm of the relative abundance of Crawlers	-
Log Spr	Logarithm of relative abundance of Sprawler	+
Log Ska	Logarithm of relative abundance of Skater	-
Log Bur	Logarithm of relative abundance of Burrower	+
CG	Collectors Gath	+
CGS	Coll Gath Scrap	Varies
FF	Filter Feeders	Varies
PH	Predators (Habitual)	-
Pr	Predators	+
SC	Scavengers	-
SG	Scrapers Grazers	-
S	Shredders	-
Cl	Clingers	-

SW	Swimmers	Varies
Fl	Fliers	Varies

*Integrated metrics for the development of the Ikpe Community River Biotic Index (ICRBI)**.**

Metrics were selected based on taxonomic composition and self-adoption. Metrics were defined according to Odume *et al*. (2012) and Mereta *et al*. (2013).

(+) indicated that the metric increases with deteriorating water quality, while (-) indicated that the metric decreases with deteriorating water quality.

3.8.1 Index Development

Five steps were followed in developing the index and these include subjecting all candidate metrics to; (a) sensitivity test, (b) seasonality test, (c) redundancy test, (d) integration of selected metrics into the multimetric index and (e) index validation.

3.8.1.1 Sensitivity Test

Candidate metrics were tested for their potential to discriminate between the Impacted Station (IS) from the Reference Station (RS). Box plots were used to visualize the metrics. Two levels of discrimination were considered satisfactory. First, a metric is deemed sensitive, if there is an overlap between the Interquartile ranges (IQRs) of the IS and those of the RS, but the medians are outside of the interquartile ranges (Edegbene *et al*., 2019; Odume *et al*., 2012). Second, a metric is considered sensitivity, if the IQR of the IS do not overlap with those of the MIS and HIS (Odume *et al*., 2012; Edegbene *et al*., 2019). Metrics that met all or any of the criterion will be selected for further testing.

Selected metrics based on the box plot visualization was further tested for significant differences, using the Mann–Whitney (*U*) test. Mann–Whitney (*U*) test and Kolmogorov–Smirnov test was used to show, if the metrics are normally distributed.

Metrics exhibiting a significant difference between the RS and the IS at ($p < 0.05$) were retained for further analysis (Barbour *et al*., 1996). Boxplots were done using Statistical version 13.4.14 (TIBCO Software Inc., 2018). Kolmogorov–Smirnov test of normality and Mann–Whitney tests were computed, using Paleontological Statistical Package (PAST; Hammer *et al*., 2001).

3.8.1.2 Seasonality Test

Metrics that were deemed sensitive after confirmation with Mann–Whitney Test were further subjected to seasonality test for seasonal stability. Box plots were used to visualize metrics' seasonal stability. Kruskal–Wallis test was used to confirm seasonally stable metric (Baptista *et al*., 2007; Baptista *et al*., 2013). Only metric data from the least impacted stations were used for seasonality test, to avoid the confounding effect of pollution on seasonal variation of metrics (Edegbene *et al*., 2019; Odume *et al*., 2012).

3.8.1.3 Redundancy Test

Redundant metrics convey the same or similar information (Odume *et al*., 2012). Spearman's rank correlation coefficient (r) was performed on the seasonally stable metrics, to explore co-linearity between the metrics. Metrics with correlation values (Spearman's $r \geq .78$, $p < .05$) were considered redundant (Edegbene *et al*., 2019). Non-redundant metrics were selected for integration to the Multimetric Index. Where two or more metrics shows redundant, only one of such metrics was selected for inclusion in the Multimetric Index (Edegbene *et al*., 2019).

3.8.1.4 Integration of the Metrics into a Multimetric Index

The selected metrics were standardized by using the minimum value, lower quartile (25%), mid-quartile (50%), upper quartile (75%) and maximum value of each metric datasets according to the method described in Baptista *et al*. (2007). Lower, mid and upper quartiles were computed with Microsoft Excel, 2019 version. Metrics that was predicted to increase, with increasing urban pollution were assigned a score of 5. If the metric value was below the upper quartile (75%) of the reference site, a score of 3 was awarded. If metric value was above the 75%, and a score of 1 was awarded. This means the metric value was above the maximum value of the reference site. On the other hand, for metrics that will be predicted to decrease with increasing urban pollution, a score of 5 will be awarded, if metric value of reference site was greater than or equal to lower quartile (25%). A score of 3 was assigned, if the metric value was between the minimum value and < 25% of the reference site. When, a score of 1 is assigned, the metric value is lower than the minimum value of reference site.

3.8.1.5 Validation of the Multimetric Index

A separate macroinvertebrates dataset sampled was used to validate the developed Multimetric Index. To test the efficacy of the developed index, the index score was calculated for the station per sampling occasion. The index performance was assessed by calculating the percent correspondence, between the index result and the initial station categorization based on the physicochemical variables. The index performance for the reference site was determined by assessing, the percent correspondence of reference site falling in the very good – good water quality categories. For Impacted Site, it was assessed by evaluating the correspondence of Impacted Site falling in the fair–very poor water quality.

3.9 Relating the selected Metrics to Physicochemical Variables

Metrics selected for integration into the Multimetric Index were correlated with physicochemical variables to visualize their distribution a redundancy analysis (RDA) ordination plane. A test of unimodality and linearity, using a detrended correspondence analysis (DCA), returned a gradient length of < 3 indicating that the dataset was linear and thus an RDA was used for the final ordination. A Monte Carlo test at 999 permutations was used to test for the level of significance between the RDA axes (Legendre and Legendre, 2012). The RDA and Monte Carlo test was computed using vegan package, within the R Programming Environment (Oksanen *et al*., 2019).

Co-linear physicochemical variables ($r \geq 0.80$) were removed from the RDA Ordination Analysis (Edegbene *et al.*, 2019).

3.9.1 MMI scoring or rating methodology

As previous studies have shown, the continuous scoring method's increased sensitivity and decreased variability led to the computation of MMI ratings (Blocksom, 2003; Stoddard *et al.*, 2008). The 5th and 95th percentiles were used for normalisation in order to bring the selected metrics' wide ranges to a scale of 0 to 10. Interpolating data between the minimum and maximum was a part of this procedure (Vander Laan *et al.*, 2013). According to Fierro *et al.* (2018), this normalisation technique aids in lessening the impact of outliers that could distort the measure analysis. Three essential steps are included in the Ikpe community River Biotic Index (ICRBI) rating process:

(1) Once the core metrics for all sites were computed;

(2) by solely interpolating values between the 5th percentile (floor) and the 95th percentile (ceiling), these metric values were normalised to a 0–10 scale. Positive metrics received a score of 10, while those with values below the floor received a score of 0. The reverse scoring scheme was used for negative metrics. In particular, the 5th percentile of all site values was the floor and the 95th percentile of reference (least disturbed) values was the ceiling for metrics that dropped with disturbance (positive metrics) (Equation 3.21). On the other hand, the 95th percentile of all site values served as the ceiling and the 5th percentile of reference values served as the floor for metrics that increased with disturbance (negative metrics) (Equation 3.22).

$$\text{positive metrics} = 10 \times \frac{\text{metric score} - \text{Bottom limit}}{\text{Top limit} - \text{Bottom limit}} \#(3.21)$$

$$\text{negative metrics} = 10 \times \left[1 - \left(\frac{\text{metric score} - \text{Bottom limit}}{\text{Top limit} - \text{Bottom limit}}\right)\right] \#(3.22)$$

(3) The final Ikpe community River Biotic Index (ICRBI) score, which is scaled from 0 to 100, was determined by multiplying the total by 10 divided by n (where n is the number of final metrics) after each site's unique core metric values were normalised to a range of 0 to 10. The following formula can be used to express the ICRBI score:

$$\text{ICRBI} = \frac{10}{\text{n}} \times \sum_{\text{i}=1}^{\text{n}} \text{Metric}_{\text{i}} \#(3.23)$$

Where, $Metric_i$ represents the score of the i-th metric normalised to the 0 – 10 range and n is the number of core metrics.

Four quality categories were developed to assess the ecological status of Ikpe community streams: good, fair, poor, and very poor. The scores from the reference sites in the calibration data were used to construct these categories. The reference site scores' 25th percentile was chosen as the cutoff point for defining "good" and "fair" performance. The scoring range for the "fair-poor" and "poor-very poor" borders was divided into three equal intervals, ranging from the minimum score (0) to the "good-fair" boundary (25th percentile of reference site scores).

CHAPTER FOUR

RESULTS

The results of the Physical and Chemical Parameters of Water and Sediment from the study of the Three Rivers in Ikpe community of Edo State are presented along with the Benthic Macroinvertebrates Fauna that was collected during the study period (August, 2021 – January, 2023).

4.1 PHYSICAL AND CHEMICAL PARAMETERS OF THE WATER SAMPLES

The Summary of the Physical and Chemical Parameters of the Water Samples are presented in Table 4.1.

4.1.1 Air Temperature (°C)

The mean value and standard deviation for Air temperature ranged from 26.75±2.09 °C to 28.42±2.06°C. The minimum value (24.00 °C) was recorded in the reference Stations of Orhionmwon and Okhuaihe Rivers 2, another was recorded in the impacted station of Okhuaihe river 2, while the highest value (31.00 °C) was recorded in the Impacted and Reference stations of Irogbe River station and impacted stations of Orhionmwon and Okhuaihe river 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values at the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Air temperature are shown in Figure 4.1. The mean and standard deviation value for Air temperature in the wet season (26.83±1.65 ^{o}C) was lower than the dry season value of (29.25±1.48 ^{o}C) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

Table 4.1: Spatial Variation of Physical and Chemical Parameters of Water from the Study area

	SAMPLING STATIONS									
	Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River			
	STATION 1 (IP)	STATION 2 (RF)	STATION 3 (IP)	STATION 4 (RF)	STATION 5 (IP)	STATION 6 (RF)	STATION 7 (IP)	STATION 8 (RF)	P-Value	FME
PARAMETERS	Mean ± SD (Min-Max)									
Air temperature (^{o}C)	28.42±2.06 (25.0-31.0)	27.67±1.97 (24.0-30.0)	28.41±2.06 (25.0-31.0)	28.42±2.06 (25.0-31.0)	28.42±1.78 (26.0-30.0)	28.42±1.78 (26.0-30.0)	27.67±2.27 (24.0-31.0)	26.75±2.09 (24.0-30.0)	$P>0.05$	-
Water temperature (^{o}C)	26.08±1.44 (24.0-30.0)	25.83±0.72 (21.0-26.0)	26.08±1.44 (24.0-30.0)	26.08±1.44 (24.0-30.0)	25.16±0.94 (24.00-26.00)	25.83±0.94 (25.00-28.00)	26.42±1.31 (25.00-30.00)	25.83±1.11 (23.00-27.00)	$P>0.05$	35
pH	5.87±0.34^{bc} (5.30-6.30)	5.96±0.25^{abc} (5.50-6.30)	5.88±0.26^{abc} (5.5-6.3)	5.88±0.26^{abc} (5.50-6.30)	5.87±0.24^{c} (5.50-6.30)	6.07±0.15^{abc} (5.80-6.30)	5.79±0.32^{ab} (5.30-6.30)	5.64±0.34^{a} (5.30-6.30)	$p<0.05$	6.5-8.5
Depth (m)	0.49±0.33 (0.11-1.0)	0.43±0.26 (0.12-1.0)	0.33±0.13 (0.12-0.6)	0.33±0.13 (0.12-0.6)	0.37±0.16 (0.12-0.60)	0.50±0.31 (0.15-1.0)	0.38±0.26 (0.11-0.85)	0.43±0.29 (0.11-0.85)	$p>0.05$	
Flow rate (m/s)	0.72±1.04 (0.00-3.00)	0.82±1.32 (0.00-3.00)	0.76±1.34 (0.00-3.00)	0.76±1.34 (0.00-3.00)	1.52±1.55 (0.01-3.00)	0.09±0.87 (0.00-0.2)	0.68±1.07 (0.00-3.00)	1.19±1.08 (0.01-3.00)	$p>0.05$	
Width (m)	13.56±3.64^{c} (9.0-20.0)	13.79±3.66^{c} (8.5-20.00)	7.58±4.06^{a} (2.00-15.00)	7.58±4.06^{a} (2.00-15.00)	17.08±2.01^{d} (14.00-20.00)	7.58±4.06^{d} (2.00-15.00)	7.43±3.70^{a} (2.0-13.00)	10.22±1.52^{ab} (7.00-13.00)	$p<0.01$	
Electrical Conductivity (µS/cm)	120.42±55.63^{ab} (52.50-219.80)	73.01±44.67^{bcd} (12.50-161.30)	78.76±52.53^{abc} (12.50-181.6)	78.76±52.54^{abc} (12.50-181.60)	71.68±44.97^{d} (12.50-155.50)	78.76±52.54^{bc} (12.50-181.60)	126.17±57.14^{cd} (40.80-219.80)	150.33±67.81^{d} 81.30-295.80)	$p<0.01$	1000
Transparency	1.07±0.69 (0.2-2.4)	0.81±0.25 (0.4-1.2)	0.58±0.37 (0.2-1.5)	0.58±0.38 (0.2-1.5)	0.67±0.21 (0.4-1.0)	0.94±0.27 (0.6-1.5)	0.84±0.82 (0.2-2.4)	1.17±0.81 (0.2-2.4)	$p>0.05$	
Turbidity (NTU)	27.17±44.41^{a} (5.0-165)	25.92±44.88 (1.0-165.00)	13.42±7.00 (1.0-25.0)	13.42±7.00 (1.0-25.00)	9.58±5.45 (1.0-18.0)	39.83±45.08 (5.0-165.00)	14.67±6.40 (5.0-25.00)	11.25±4.79 (5.0-22.0)	$p>0.05$	5
Total Dissolved Solids (mg/L)	58.85±29.99 (24.20-119.20)	46.22±20.35 (21.40-80.60)	49.32±23.15 (20.50-90.70)	49.32±23.15 (20.50-90.70)	45.67±20.57 (21.40-77.50)	48.45±18.93 (24.20-80.60)	61.94±30.59 (20.50-119.50)	80.08±47.45 (19.50-163.50)	$p>0.05$	500
Dissolved Oxygen (mg/L)	1.40±1.09 (0.20-4.30)	1.11±0.64 (0.20-2.30)	1.52±1.75 (0.50-6.80)	1.52±1.74 (0.50-6.8)	1.05±0.66 (0.60-2.50)	1.10±0.65 (0.20-2.0)	1.80±1.89 (0.50-4.30)	1.58±1.37 (0.5-4.4)	$p>0.05$	7.5
Biological Oxygen Demand (mg/L)	3.55±1.19 (0.50-5.40)	3.51±1.30 (0.50-5.40)	3.62±0.80 (1.5-4.6)	3.62±0.80 (1.50-4.60)	3.39±1.04 (1.10-4.30)	3.63±1.53 (0.50-5.40)	3.65±0.58 (2.80-4.60)	3.47±0.58 (2.80-4.6)	$p>0.05$	0
Chloride (mg/L)	10.83±3.44 (7.06-14.12)	10.60±3.68 (7.06-14.22)	10.60±3.68 (7.06-14.22)	10.60±3.68 (7.06-14.22)	10.60±3.68 (7.06-14.22)	10.60±3.69 (7.06-14.17)	10.83±3.44 (7.06-14.12)	11.25±3.23 (7.06-14.12)	$p>0.05$	250
Phosphate (mg/L)	0.11±0.064 (0.01-0.20)	0.22±0.29 (0.01-0.88)	0.27±0.29 (0.01-0.88)	0.27±0.29 (0.01-0.88)	0.20±0.30 (0.01-0.88)	0.12±0.04 (0.03-0.15)	0.16±0.12 (0.01-0.40)	0.09±0.08 (0.01-0.20)	$p>0.05$	3
Nitrate (mg/L)	0.79±0.55 (0.23-2.12)	0.90±0.57 (0.25-2.12)	1.05±1.12 (0.22-4.36)	1.05±1.12 (0.22-4.36)	0.89±0.49 (0.23-1.65)	0.89±0.67 (0.25-2.15)	0.94±1.12 (0.22-4.36)	0.73±0.40 (0.22-1.47)	$p>0.05$	10
Ammonium (mg/L)	0.20±0.18 (0.03-0.72)	0.25±0.21 (0.09-0.72)	0.37±0.55 (0.09-2.04)	0.37±0.54 (0.09-2.04)	0.22±0.16 (0.09-0.64)	0.34±0.27 (0.12-0.77)	0.32±0.55 (0.03-2.04)	0.16±0.10 (0.03-0.32)	$p>0.05$	1
Sulphate (mg/L)	8.58±11.51 (2.00-43.00)	9.33±11.16 (3.00-43.00)	6.58±3.82 (3.00-17.00)	6.58±3.82 (3.00-17.00)	5.08±2.50 (3.00-10.00)	13.33±13.77 (3.00-43.00)	5.83±4.26 (2.00-17.00)	4.08±2.94 (2.00-10.00)	$p>0.05$	200

Table 4.1: Spatial Variation of Physical and Chemical Parameters of Water from the Study area Contd.

SAMPLING STATIONS

	Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River			
	STATION 1 (IP)	STATION 2 (RF)	STATION 3 (IP)	STATION 4 (RF)	STATION 5 (IP)	STATION 6 (RF)	STATION 7 (IP)	STATION 8 (RF)	P-Value	FME
Iron (mg/L)	0.55±0.27 (0.37-1.32)	0.56±0.26 (0.37-1.32)	0.71±0.47 (0.41-2.13)	0.71±0.47 (0.41-2.14)	0.53±0.11 (0.42-0.75)	0.62±0.34 (0.37-1.32)	0.69±0.49 (0.38-2.14)	0.54±0.19 (0.38-0.87)	$p>0.05$	1
Manganese (mg/L)	0.04±0.01 (0.01-0.06)	0.05±0.01 (0.03-0.07)	0.04±0.01 (0.03-0.07)	0.04±0.01 (0.03-0.07)	0.04±0.01 (0.03-0.07)	0.05±0.01 (0.03-0.06)	0.04±0.02 (0.01-0.07)	0.04±0.01 (0.01-0.06)	$p>0.05$	0.05-0.5
Copper (mg/L)	0.32±0.04 (0.25-0.38)	0.32±0.03 (0.28-0.38)	0.32±0.04 (0.21-0.38)	0.32±0.05 (0.21-0.38)	0.32±0.03 (0.28-0.36)	0.34±0.05 (0.28-0.46)	0.32±0.05 (0.21-0.38)	0.32±0.04 (0.25-0.37)	$p>0.05$	1
Zinc (mg/L)	0.40±0.16 (0.24-0.74)	0.38±0.14 (0.25-0.74)	0.40±0.16 (0.25-0.84)	0.39±0.16 (0.25-0.84)	0.34±0.03 (0.28-0.38)	0.41±0.18 (0.25-0.74)	0.41±0.18 (0.24-0.84)	0.38±0.14 (0.23-0.65)	$p>0.05$	5
Chromium (mg/L)	0.06±0.01 (0.04-0.09)	0.06±0.02 0.04-0.10)	0.06±0.01 (0.04-0.10)	0.06±0.02 (0.04-0.10)	0.06±0.02 (0.04-0.10)	0.06±0.01 (0.05-0.09)	0.06±0.01 (0.04-0.09)	0.05±0.01 (0.04-0.09)	$p>0.05$	0.05

Where: $p < 0.01$ indicates highly significant difference; $p > 0.05$ indicates no significant difference, IP = Impacted while RF Reference

Table 4.2: Wet and dry season Variation of Physical and Chemical Parameters for Water Samples from the Selected Rivers.

	Wet Season			**Dry Season**			**Sig.**
Parameter	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	
Air temperature (°C)	26.83±1.65	24.00	30.00	29.25±1.48	26.00	31.00	$p < 0.01$
Water temperature (°C)	25.95±0.71	24.00	28.00	25.73±1.42	23.00	30.00	$p>0.05$
pH	5.90±0.34	5.3	6.3	5.84±0.23	5.33	6.16	$p>0.05$
Depth (m)	0.47±0.30	0.11	1.0	0.35±0.16	0.15	0.83	$p<0.01$
Flow rate (m/s)	1.05±1.33	0.005	3.00	0.58±1.01	0.00	3.00	$p>0.05$
Width (m)	12.06±5.04	2.0	20.0	10.06±3.81	3.00	18.00	$p<0.01$
Electrical Conductivity (µS/cm)	119.34±58.42	15.50	295.80	78.60±49.71	12.5	216.50	$p<0.01$
Transparency	0.71±0.39	0.2	1.5	0.96±0.66	0.2	2.4	$P>0.05$
Turbidity (NTU)	25.23±37.86	7.0	165.00	13.58±12.23	1.0	73.00	$P<0.05$
Total Dissolved Solids (mg/L)	65.37±26.93	33.60	163.50	44.59±28.06	19.50	142.50	$P<0.01$
Dissolved Oxygen (mg/L)	0.99±0.46	0.50	1.90	1.78±1.70	0.2	6.80	$p<0.01$
Biological Oxygen Demand (mg/L)	3.82±0.41	3.10	4.60	3.29±1.30	0.5	5.4	$p<0.05$
Chloride (mg/L)	12.31±2.98	7.06	14.22	9.16±3.15	7.06	14.12	$p<0.01$
Phosphate (mg/L)	0.20±0.21	0.01	0.81	0.16±0.22	0.01	0.88	$p>0.05$
Nitrate (mg/L)	0.74±0.42	0.22	1.65	1.07±1.01	0.38	4.36	$p>0.05$
Ammonium (mg/L)	0.31±0.18	0.12	0.72	0.25±0.48	0.03	2.04	$p>0.05$
Sulphate (mg/L)	8.08±10.97	2.00	43.00	6.77±3.66	3.00	17.00	$p>0.05$
Iron (mg/L)	0.75±0.44	0.42	2.14	0.48±0.08	0.37	0.83	$p<0.01$
Manganese (mg/L)	0.04±0.01	0.03	0.07	0.04±0.01	0.01	0.07	$p<0.01$
Copper (mg/L)	0.33±0.04	0.32	0.38	0.32±0.04	0.21	0.46	$p>0.05$
Zinc (mg/L)	0.48±0.15	0.32	0.84	0.30±0.04	0.23	0.37	$p<0.01$
Chromium (mg/L)	0.06±0.02	0.04	0.10	0.05±0.01	0.04	0.07	$p<0.01$

Where: $p < 0.01$ indicates highly significant difference; $p > 0.05$ indicates no significant difference, IP = Impacted while RF Reference

4.1.2 Water Temperature (°C)

The mean value and standard deviation for Water temperature ranged from 25.16±0.94 °C to 26.42.50±1.31°C. The minimum value (23.00 °C) was recorded in the reference Station of the Okhuaihe River 2. The highest value (30.00 °C) was recorded in both the Impacted and Reference stations of Irogbe River and another in the impacted stations of Orhionwon and Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Water temperature are shown in Figure 4.2. The mean and standard deviation value for Water temperature in the dry season (25.73±1.42 °C) was slightly lower than the wet season value of (25.96±0.71 °C) from the various stations in Table 4.2. There was a no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

4.1.3 pH

The mean value and standard deviation for pH ranged from 5.64±0.34 to 6.07±0.15. The minimum value (5.30) was recorded in the Reference station of Orhionmwon River and both the Impacted and Reference Stations of Okhuaihe River 2, while the highest value (6.30) was recorded in all the rivers studied. Analysis of Variance (ANOVA) showed that there was a significant difference in the mean values of the study stations ($p < 0.05$) (Table 4.1). Duncan Multiple Range Test revealed that the impacted station of Okhuaihe River 1 was the cause of difference (Table 4.1). The spatial and temporal variations of pH are shown in Figure 4.3. The mean and standard deviation value for pH in the wet season (5.90±0.34) was higher than the dry season value of (5.84±0.23) from the various stations in Table 4.2. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

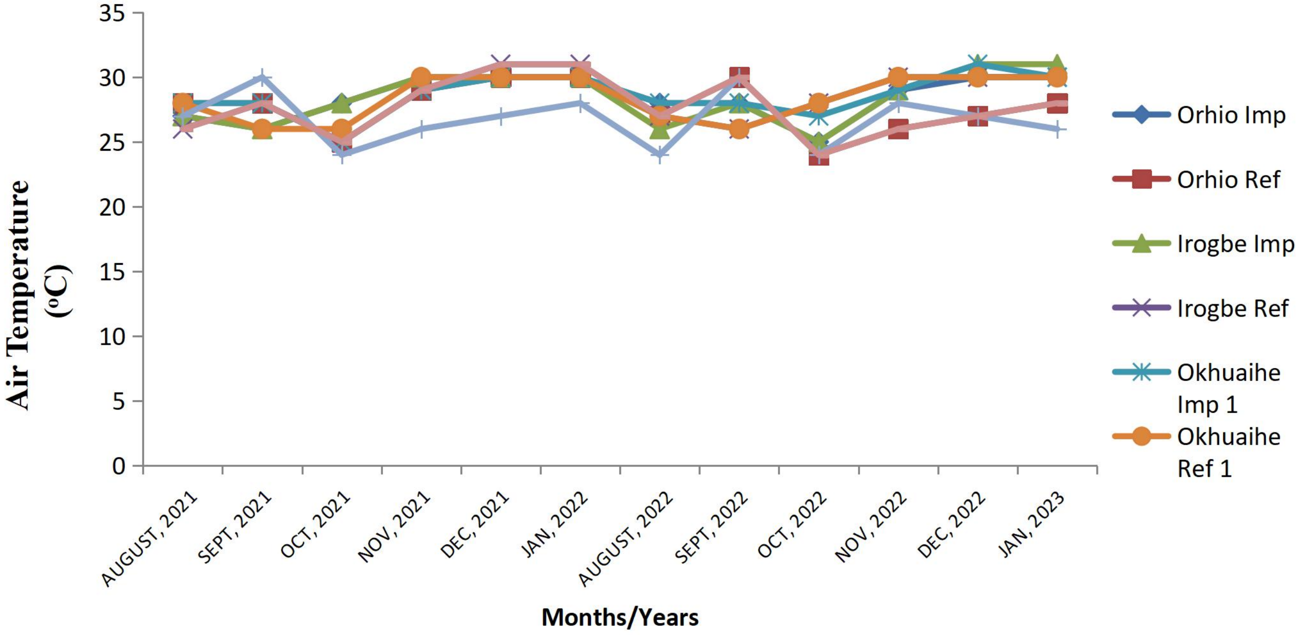

Figure 4.1: Spatial and Temporal Variations of Air temperature across the Stations

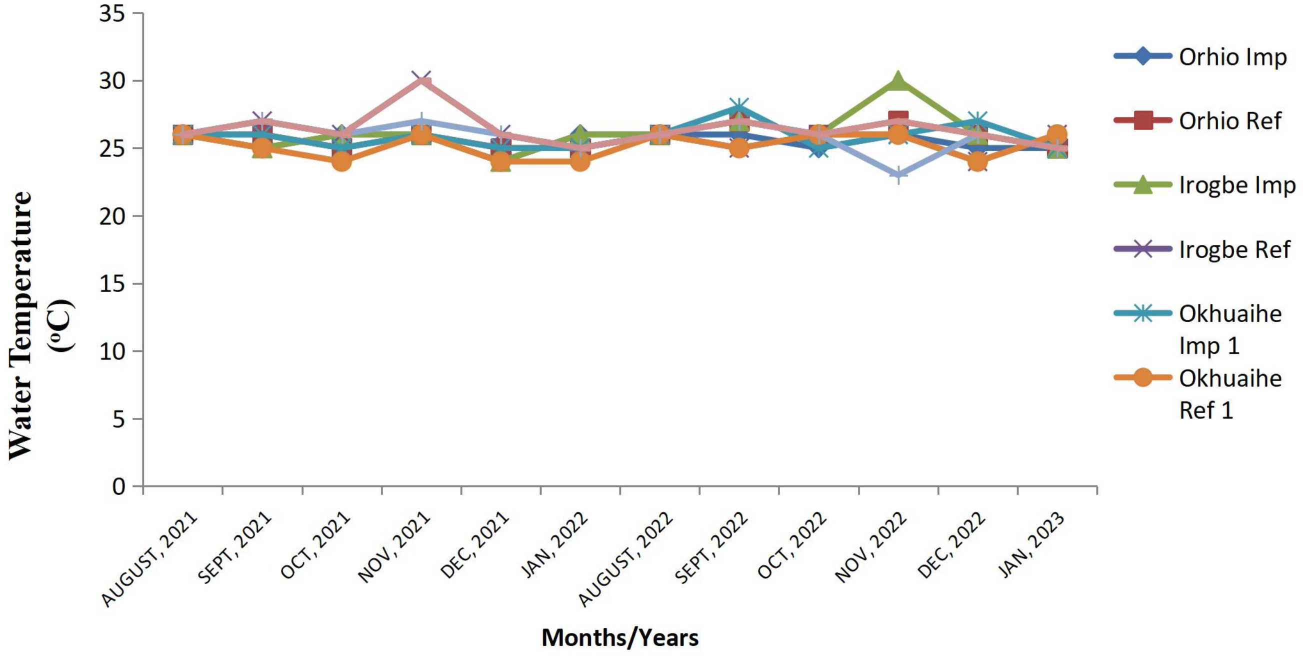

Figure 4.2: Spatial and Temporal Variations of Water temperature across the Stations

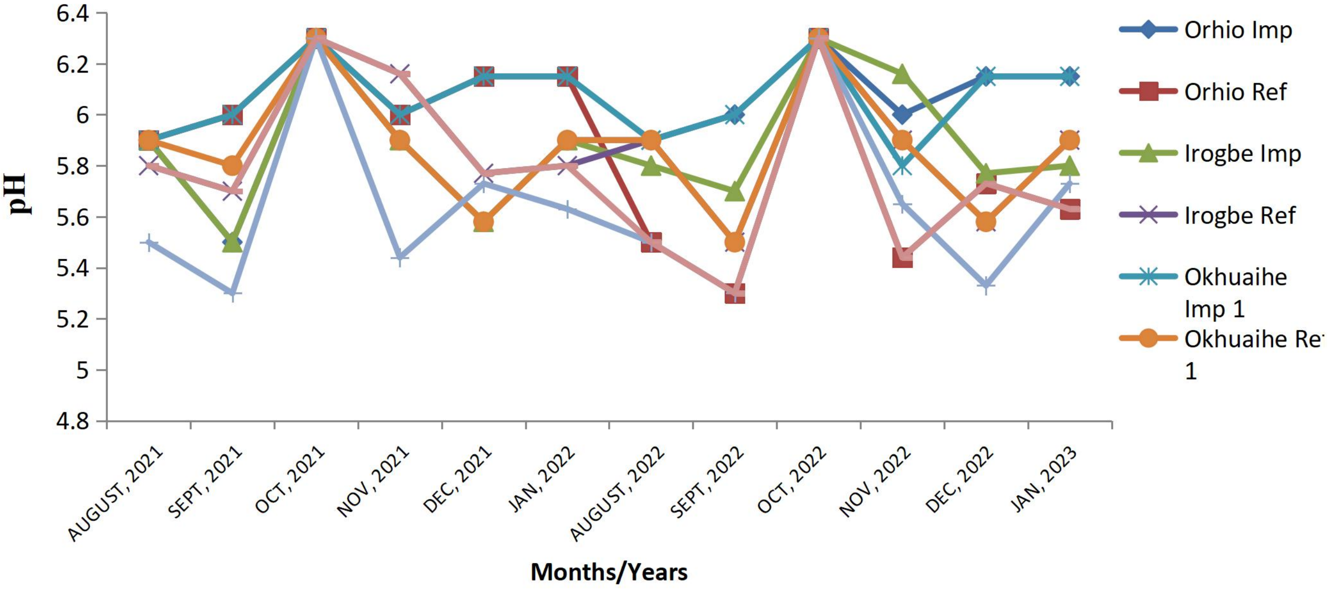

Figure 4.3: Spatial and Temporal Variations of pH across the Stations

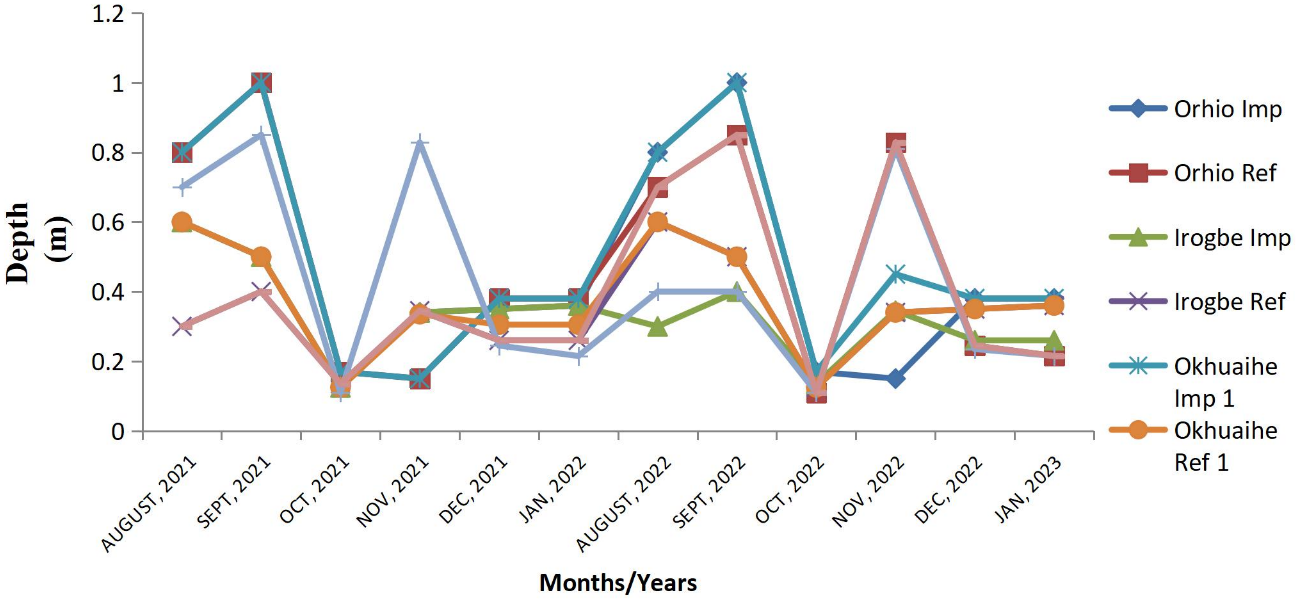

Figure 4.4: Spatial and Temporal Variations of Depth across the Stations

4.1.4 Depth (m)

The mean value and standard deviation for Depth ranged from 0.33±0.13 m to 0.50±0.31 m. The minimum value (0.11 m) was recorded in the impacted station of Orhionmwon River and both the Reference and Impacted Stations of Okhuahi River 2, while, the highest value (1.00 cm) was recorded in both the Reference and Impacted Stations of Orhionmwon River, and the reference station of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Colour are shown in Figure 4.4. The mean and standard deviation value for Depth in the wet season (0.47±0.30 m) was higher than the dry season value of (0.35±0.16 m) from the various stations in Table 4.2. There was a significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.5 Flow rate (m/s)

The mean value and standard deviation for flow rate ranged from 0.09±0.87m to 1.52±1.55 m. The minimum value (0.00m) was recorded in all stations apart from reference and impacted stations of Okhuaihe river 1 and 2 respectively. while the highest value (3.00m) was recorded in all stations apart from the reference site of Okuaihe 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Transparency are shown in Figure 4.5. The mean and standard deviation value for flow rate in the wet season (1.05±1.33 m) was higher than the dry season value of (0.58±1.01 m) from the various stations in Table 4.2. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

4.1.6 Width (m)

The mean value and standard deviation for Width ranged from 7.43±3.70 m to 17.08±2.01 m. The minimum value (2.00 m) was recorded in both the Impacted and Reference Stations of Irogbe River, reference station of Okhuahi river 1 and impacted Station of Okhuaihe River 2, while the highest value (20.00 m) was recorded in both the Impacted and Reference Stations of Orhionmwon River, and impacted station of Okhuaihe 1. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (Table 4.1). Duncan Multiple Range Test revealed that the Impacted and reference Stations of Okhuaihe River 1 were the cause of difference (Table 4.1). The spatial and temporal variations of width are shown in Figure 4.6. The mean and standard deviation value for width in the wet season (12.06±5.04 m) was higher than the dry season value of (10.06±3.81 m) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

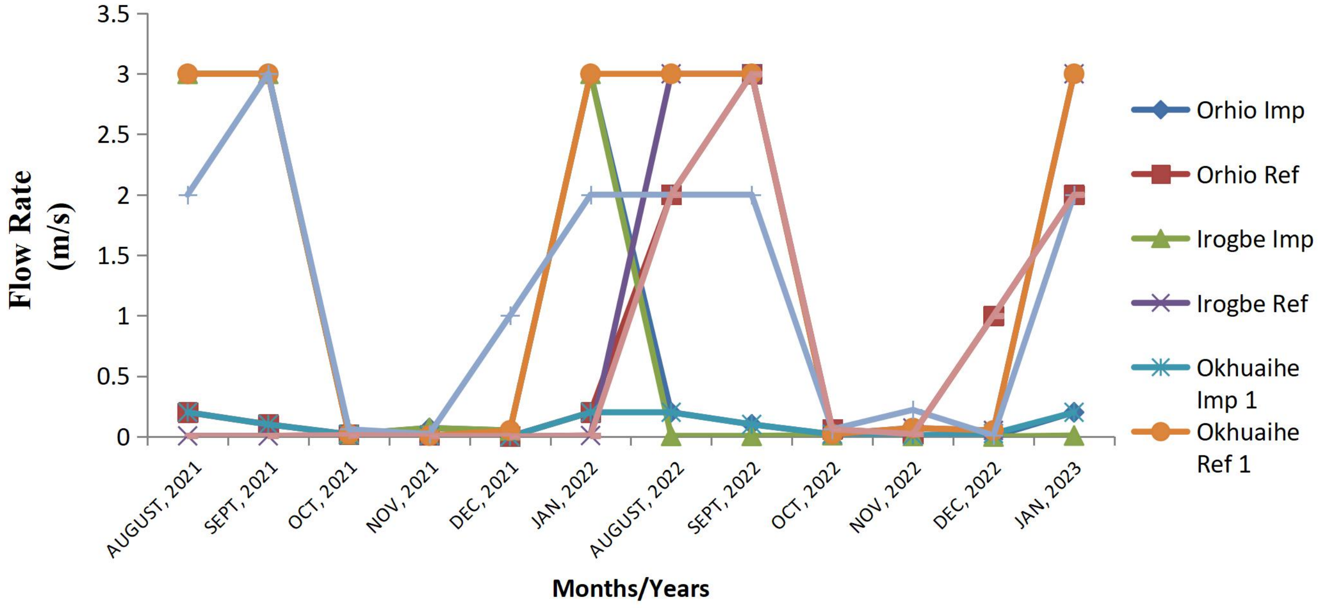

Figure 4.5: Spatial and Temporal Variations of Flow rate across the Stations

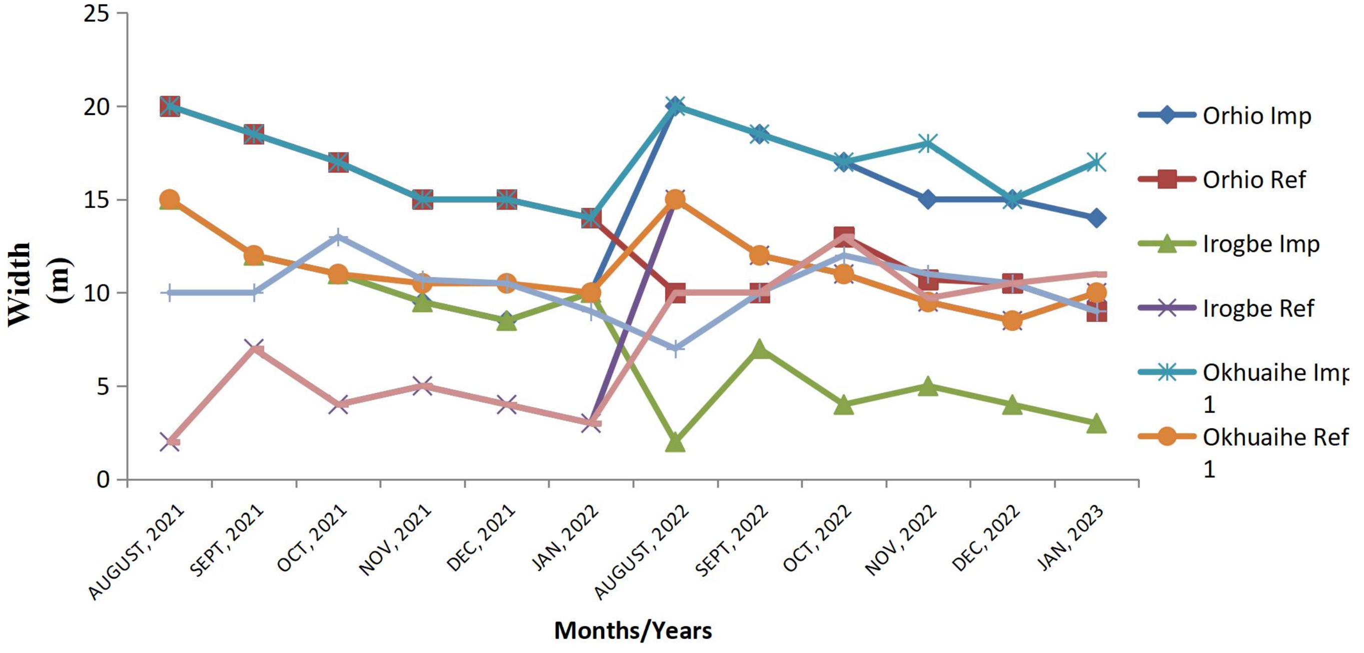

Figure 4.6: Spatial and Temporal Variations of width across the Stations

4.1.7 Electrical Conductivity (µS/cm)

The mean value and standard deviation for Electrical Conductivity ranged from 71.68±44.97 µS/cm to 150.33±67.81 µS/cm. The minimum value (12.50 µS/cm) was recorded at the Reference Stations of Orhionmwon and Okhuaihe 1 Rivers and both the Reference and Impacted Stations of Irogbe River while, the highest value (295.80 µS/cm) was recorded in the reference station of Okhuahi River 2. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (Table 4.1). Duncan Multiple Range Test revealed that the reference Station of Okhuaihe River 2 was the cause of difference (Table 4.1). The mean and standard deviation value for Electrical Conductivity in the wet season (119.34±58.42 µS/cm) was higher than the dry season value of (78.60±49.71 µS/cm) from the various stations in Table 4.7. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.8 Transparency (cm)

The mean value and standard deviation for Transparency ranged from 0.58±0.38 cm to 1.17±0.81 cm. The minimum value (0.20 cm) was recorded in both the Impacted and Reference Stations of Irogbe and Okhuaihe 2 Rivers, and the impacted station of Orhionmwon River, while the highest value (2.4 cm) was recorded in both the Impacted and Reference Stations of Okhuaihe River 2 and the impacted Station of Orhionmwon River. Analysis of Variance (ANOVA) showed that there was no high significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Transparency are shown in Figure 4.8. The mean and standard deviation value for transparency in the wet season (0.71±0.39 cm) was lower than the dry season (0.96±0.66 cm) from the various stations in Table 4.2. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

Figure 4.7: Spatial and Temporal Variations of Electrical Conductivity across the Stations

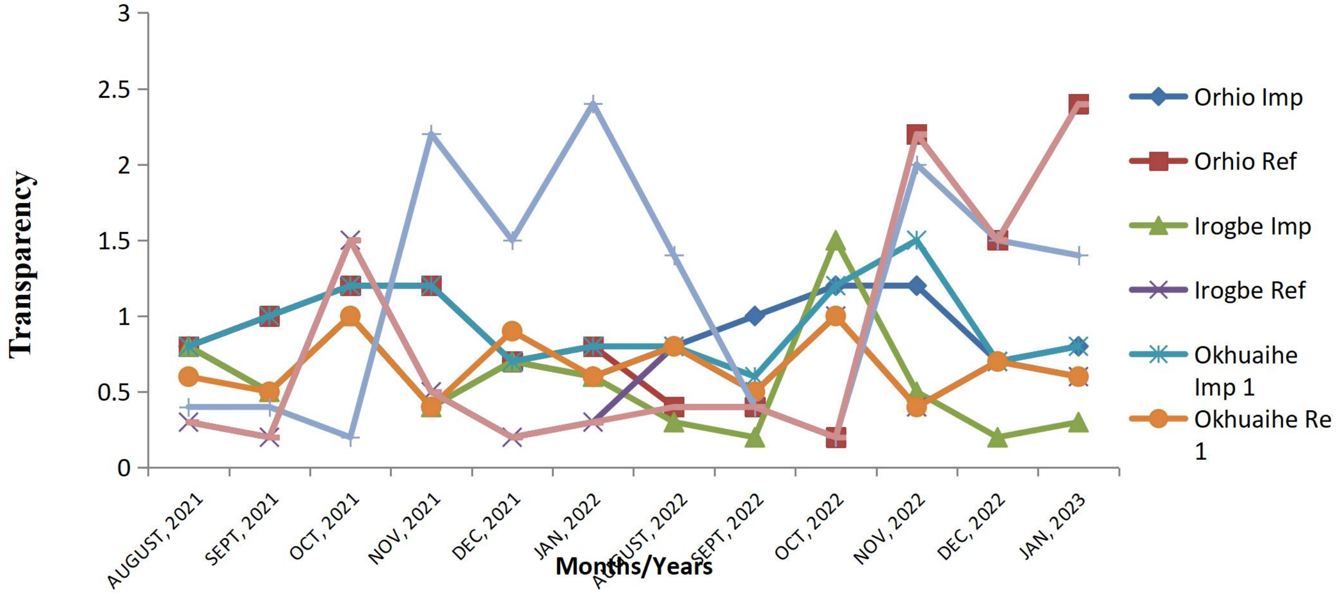

Figure 4.8: Spatial and Temporal Variations of Transparency across the Stations

4.1.9 Turbidity (NTU)

The mean value and standard deviation for Turbidity ranged from 9.58±5.45 NTU to 39.83±45.08 NTU. The minimum value (1.00 NTU) was recorded in the reference stations of both Orhionmwon and Irogbe River and impacted stations of Irogbe and Okhuaihe River 1, while the highest value (165.00 NTU) was recorded in both the Impacted and Reference Stations of Orhionmwon River and the refence station of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Turbidity are shown in Figure 4.9. The mean and standard deviation value for Turbidity in the wet season (25.23±37.86 NTU) was higher than the dry season value of (13.58±12.23 NTU) from the various stations in Table 4.2. There was a significant difference ($p < 0.05$) between the wet and dry season values as shown in Table 4.2.

4.1.10 Total Dissolved Solids (mg/L)

The mean value and standard deviation for Total Dissolved Solids ranged from 45.67±20.57 mg/L to 80.08±47.45 mg/L. The minimum value (19.50 mg/L) and maximum value (163.5 mg/L) were both recorded at the reference Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Total Dissolved Solids are shown in Figure 8. The mean and standard deviation value for Total Dissolved Solids in the wet season (65.37±26.93 mg/L) was higher than the dry season value of (44.59±28.06 mg/L) from the various stations in Table 4.10. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

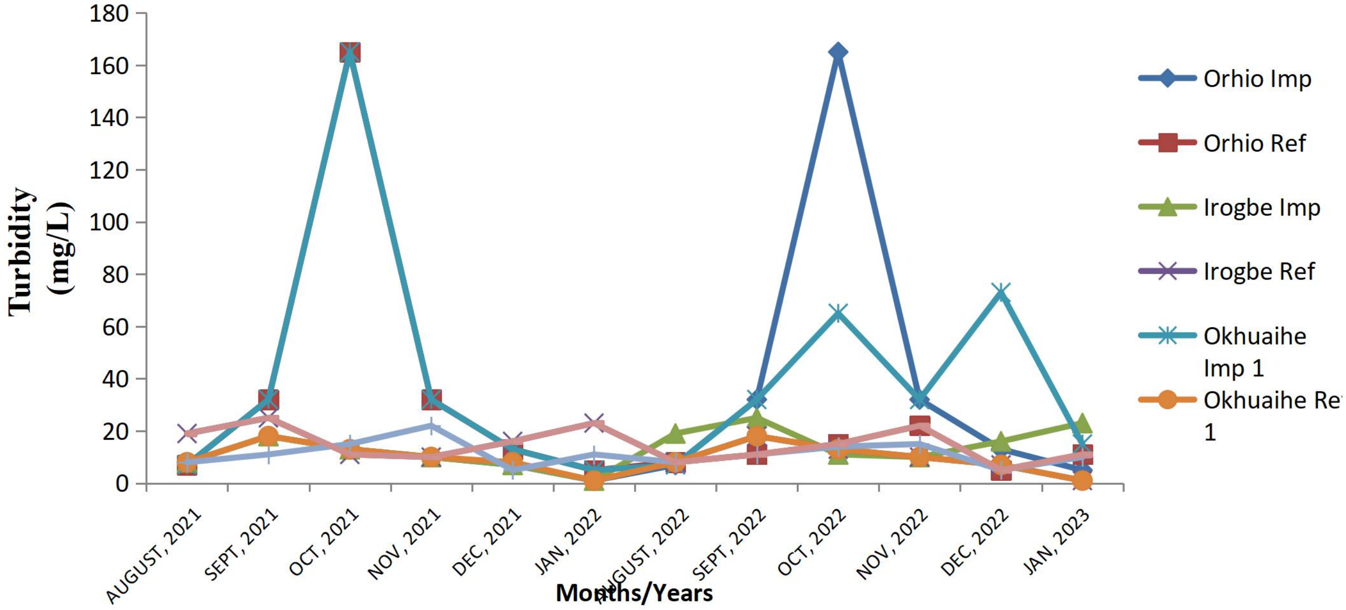

Figure 4.9: Spatial and Temporal Variations of Turbidity across the Stations

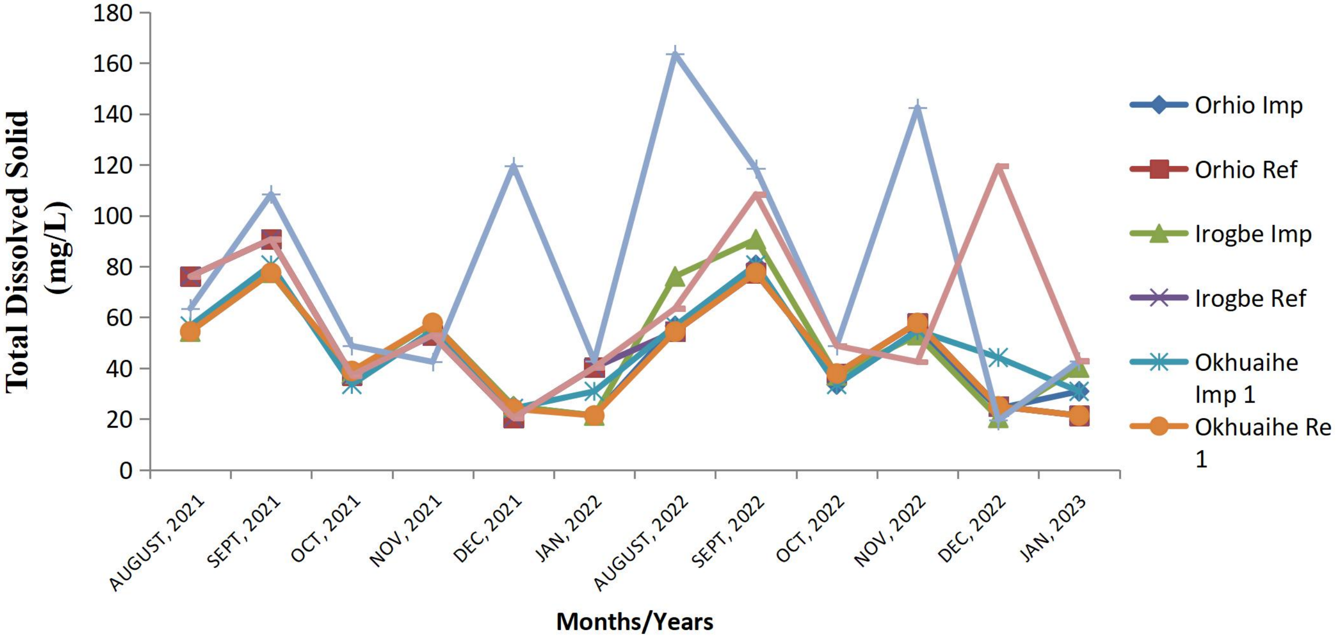

Figure 4.10: Spatial and Temporal Variations of Total Dissolved Solid across the Stations

4.1.11 Dissolved Oxygen (mg/L)

The mean value and standard deviation for Dissolved Oxygen ranged from 1.05±0.66 mg/L to 1.80±1.89 mg/L. The minimum value (0.20 mg/L) was recorded in both the Impacted and Reference Stations of Orhionmwon River and the reference Station of Okhuaihe River 1, while the highest value (6.80 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Dissolved Oxygen are shown in Figure 10. The mean and standard deviation value for Dissolved Oxygen in the wet season (0.99±0.46 mg/L) was lower than the dry season value of (1.78±1.70 mg/L) from the various stations in Table 4.11. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.12 Biological Oxygen Demand (mg/L)

The mean value and standard deviation for Biological Oxygen Demand ranged from 3.39±1.04 mg/L to 3.66±0.58 mg/L. The minimum (0.50 mg/L) and the maximum values (5.40 mg/L) were recorded in both the Impacted and Reference Stations of Orhionmwon River and the reference Station of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Biological Oxygen Demand are shown in Figure 4.12. The mean and standard deviation value for Biological Oxygen Demand in the wet season (3.82±0.41 mg/L) was higher than the dry season value of (3.29±1.30 mg/L) from the various stations in Table 4.2. There was a significant difference ($p < 0.05$) between the wet and dry season values as shown in Table 4.2.

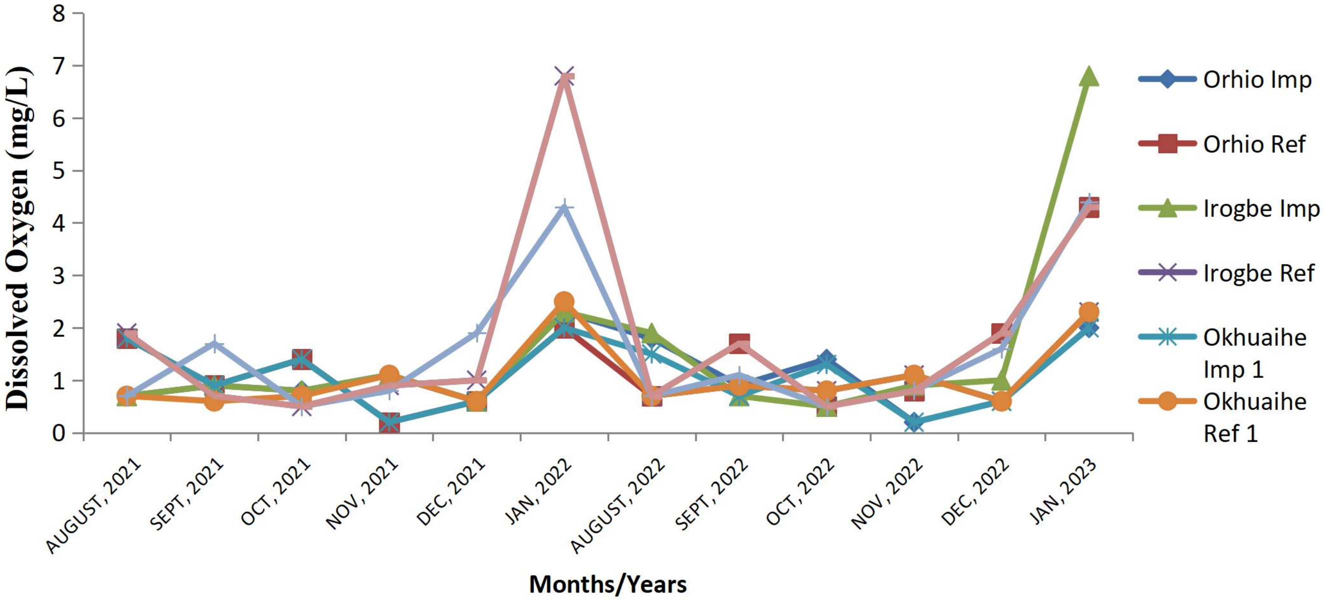

Figure 4.11: Spatial and Temporal Variations of Dissolved Oxygen across the Stations

Figure 4.12: Spatial and Temporal Variation of Biological Oxygen across the Stations

4.1.13 Chloride (mg/L)

The mean value and standard deviation for Chloride ranged from 10.60±3.44 mg/L to 11.25±3.23 mg/L. The minimum value (7.06 mg/L) was recorded at all sampling stations, while the highest value (14.22 mg/L) was recorded in both the Impacted and reference Stations of Irogbe River, the reference Station of Orhionmwon river and impacted station of Okhuaihe river 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Chloride are shown in Figure 4.13. The mean and standard deviation value for Chloride in the wet season (12.32±2.98 mg/L) was higher than the dry season value (9.16±3.15 mg/L) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.14 Phosphate (mg/L)

The mean value and standard deviation for Phosphate ranged from 0.09±0.08 mg/L to 0.27±0.29 mg/L. The minimum value (0.01 mg/L) was recorded in all the Impacted and Reference Stations in this study, apart from the reference station of Okhuaihe River 1, while the highest value (0.88 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River and the impacted Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Phosphate are shown in Figure 4.14. The mean and standard deviation value for Phosphate in the wet season (0.20±0.21 mg/L) was higher than the dry season value of (0.16±0.22 mg/L) from the various stations in Table 4.2. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

Figure 4.13: Spatial and Temporal Variation of Chloride across the Stations

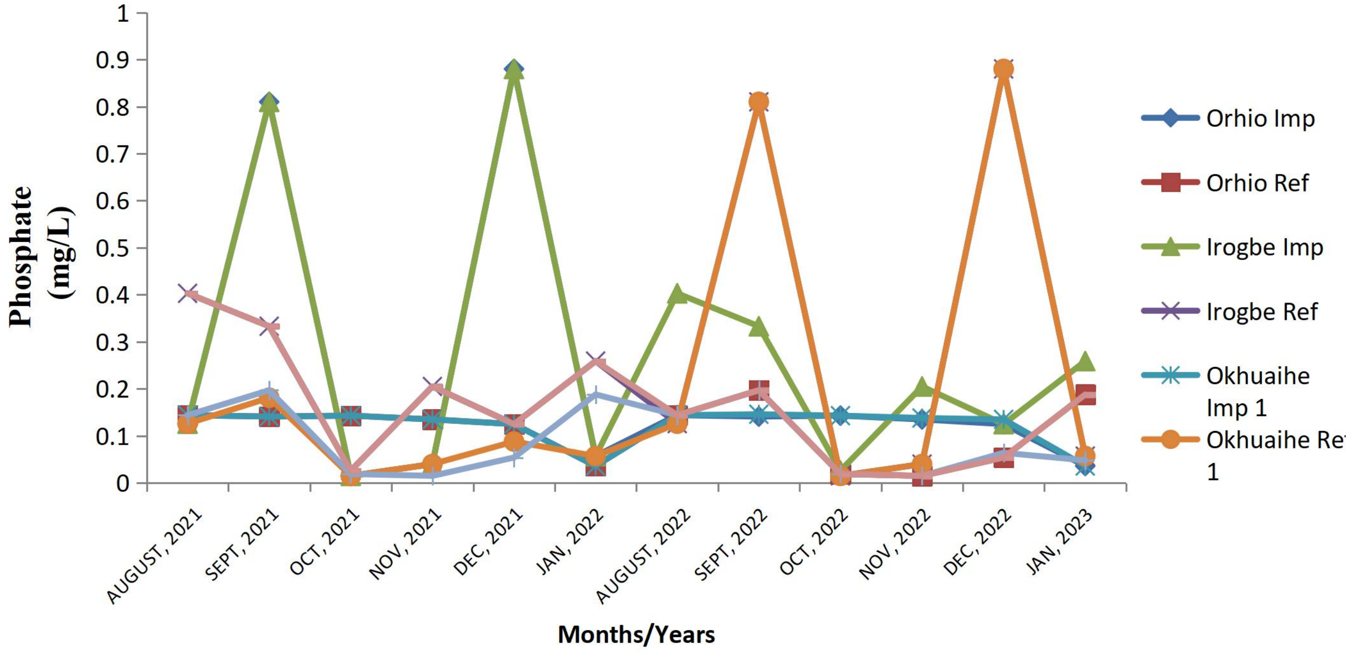

Figure 4.14: Spatial and Temporal Variation of Phosphate across the Stations

4.1.15 Nitrate (mg/L)

The mean value and standard deviation for Nitrate ranged from 0.73±0.40 mg/L to 1.05±1.12 mg/L. The minimum (0.22 mg/L) and maximum values (4.36 mg/L) were recorded in both the Impacted and Reference Stations of Irogbe River and the impacted Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Nitrate are shown in Figure 4.15. The mean and standard deviation value for Nitrate in the wet season (0.74±0.42 mg/L) was higher than the dry season value of (1.07±1.01 mg/L) from the various stations in Table 4.15. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

4.1.16 Ammonium (mg/L)

The mean value and standard deviation for Ammonium ranged from 0.16±0.10 mg/L to 0.37±0.55 mg/L. The minimum value (0.03 mg/L) was recorded in both the Impacted and Reference Stations of Okhuiahe River 2 and the impacted Station of Orhionmwon River, while the highest value (2.04 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River and the impacted Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Ammonium are shown in Figure 4.16. The mean and standard deviation value for Ammonium in the wet season (0.31±0.18 mg/L) was higher than the dry season value of (0.25±0.48 mg/L) from the various stations in Table 4.16. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in Table 4.2.

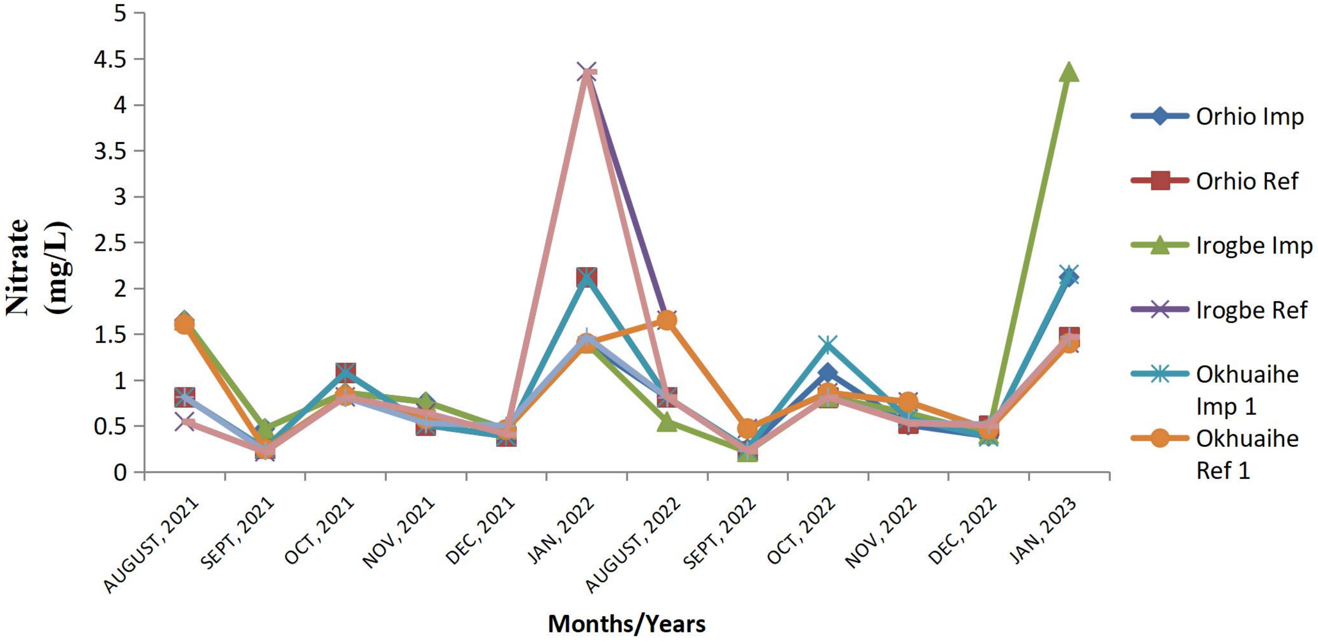

Figure 4.15: Spatial and Temporal Variation of Nitrate across the Stations

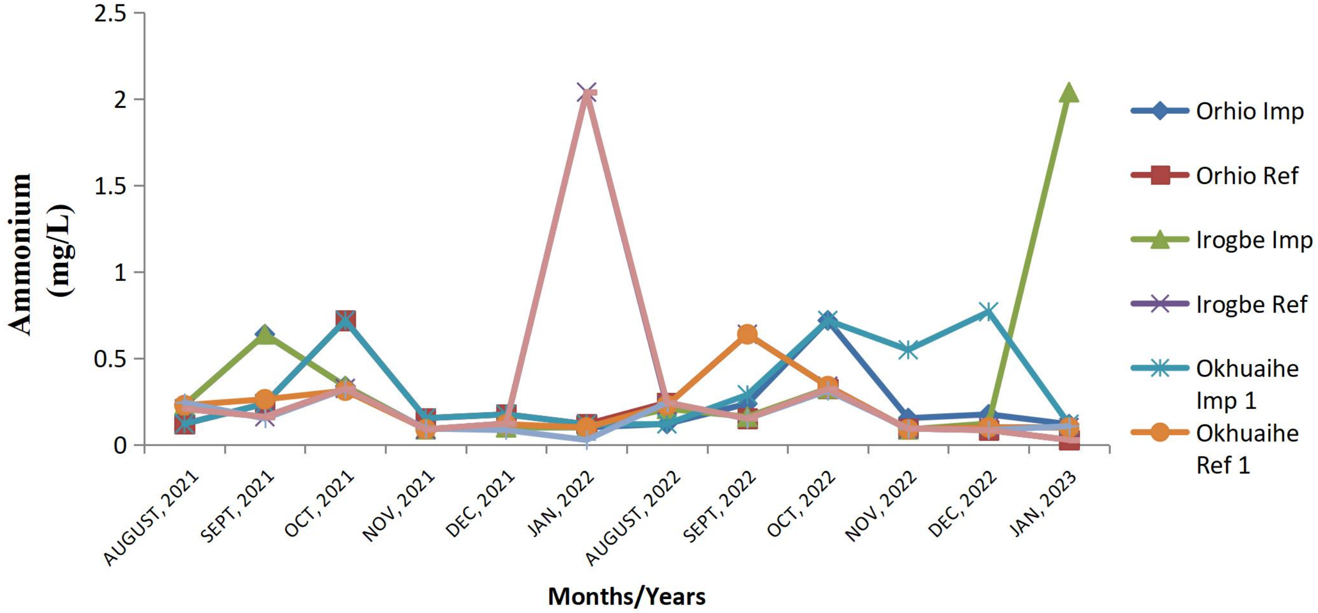

Figure 4.16: Spatial and Temporal Variation of Nitrate across the Stations

4.1.17 Sulphate (mg/L)

The mean value and standard deviation for Sulphate ranged from 4.08±2.94 mg/L to 13.33±13.77 mg/L. The minimum value (2.00 mg/L) was recorded in both the Impacted and Reference Stations of Okhuiahe River 2 and the impacted Station of Orhionmwon River, while the highest value (43.00 mg/L) was recorded in both the Impacted and Reference Stations of Orhionmwon River and the reference Station of Okhuaihe 1 River. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations (p > 0.05) (Table 4.1). The spatial and temporal variations of Sulphate are shown in Figure 4.17. The mean and standard deviation value for Sulphate in the wet season (8.08±10.97 mg/L) was higher than the dry season value of (6.77±3.66 mg/L) from the various stations in Table 4.2. There was no significant difference (p > 0.05) between the wet and dry season values as shown in Table 4.2.

4.1.18 Iron (mg/L)

The mean value and standard deviation for Iron ranged from 0.533±0.11 mg/L to 0.710±0.47 mg/L. The minimum value (0.37 mg/L) was recorded in both the Impacted and Reference Stations of Orhionmwon River and the reference Station of Okhuaihe River 1, while the highest value (2.14 mg/L) was recorded in both the Reference and Impacted Stations of Irogbe River and the Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations (p > 0.05) (Table 4.1). The spatial and temporal variations of Iron are shown in Figure 4.18. The mean and standard deviation value for Iron in the wet season (0.75±0.44 mg/L) was higher than the dry season value of (0.48±0.08

mg/L) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

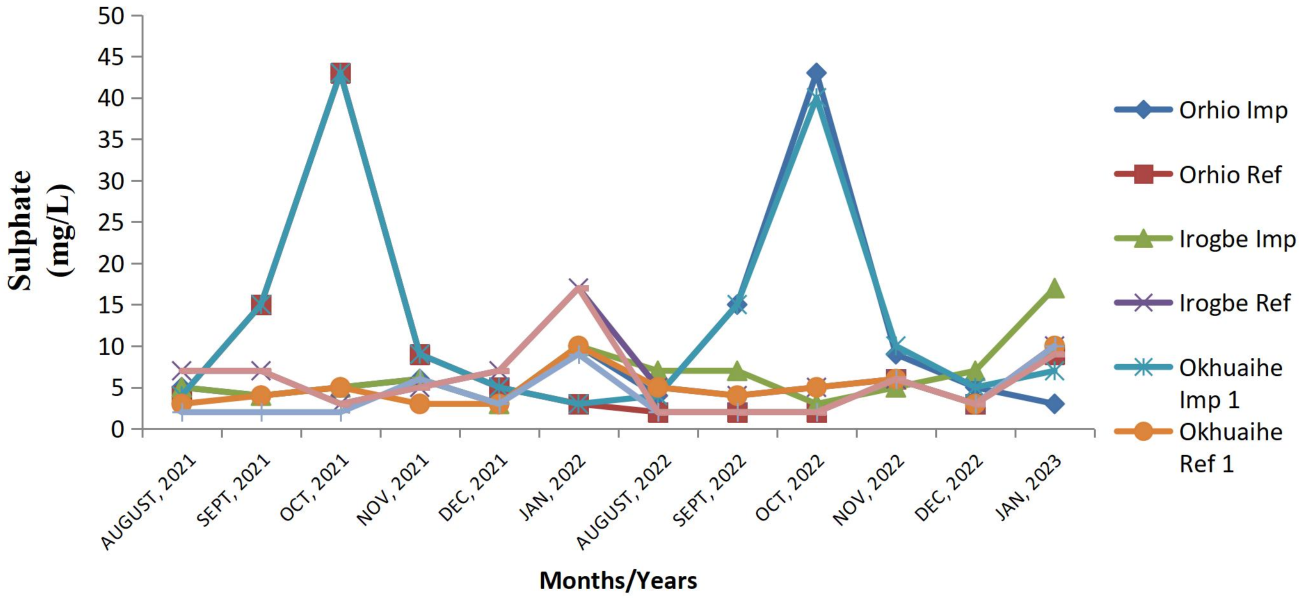

Figure 4.17: Spatial and Temporal Variation of Sulphate across the Stations

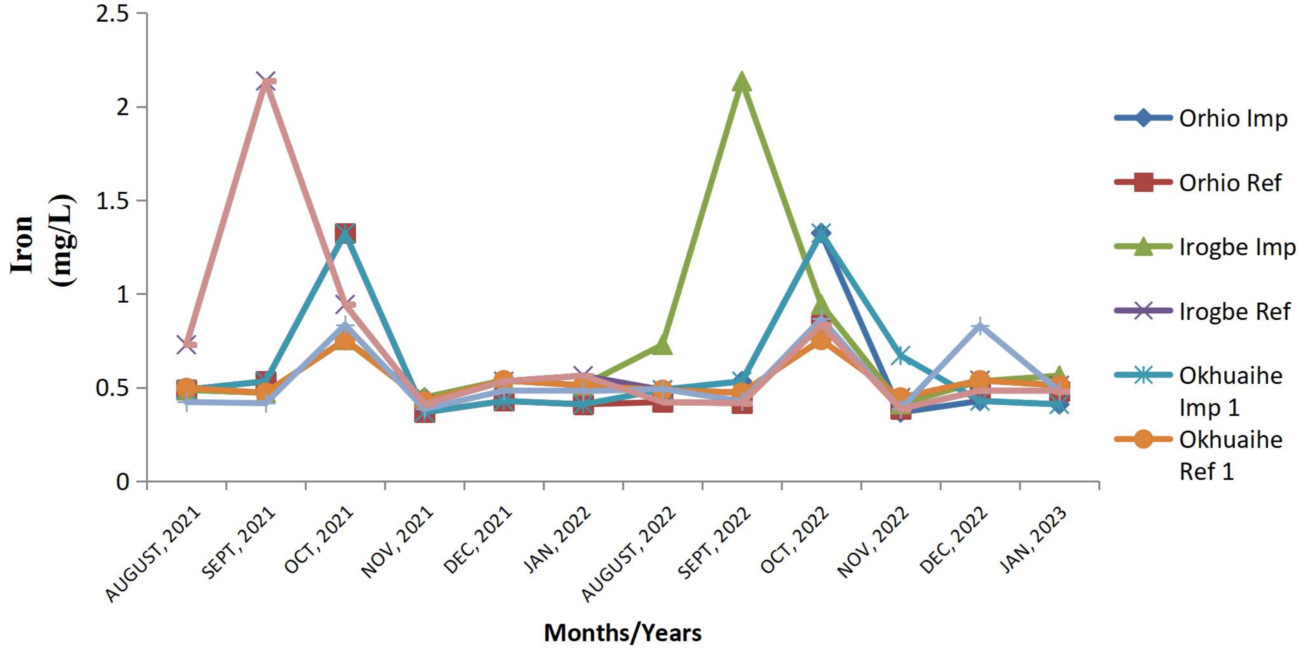

Figure 4.18: Spatial and Temporal Variation of Iron across the Stations

4.1.19 Manganese (mg/L)

The mean value and standard deviation for Manganese ranged from 0.04±0.01 mg/L to 0.05±0.01 mg/L. The minimum value (0.013 mg/L) was recorded in both the Impacted and Reference Stations of Okhuaihe River 2 and the impacted Station of Orhionmwon River, while the highest value (0.074 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River, the impacted Stations of Okhuaihe rivers 1 and 2, and the reference Station of Orhionmwon River. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Manganese are shown in Figure 4.19. The mean and standard deviation value for Manganese in the wet season (0.049±0.011 mg/L) was higher than the dry season value of (0.412±0.014 mg/L) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.20 Copper (mg/L)

The mean value and standard deviation for copper ranged from 0.317±0.04 mg/L to 0.34±0.05 mg/L. The minimum value (0.212 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River and the impacted Station of Okhuahi River 2, while the highest value (0.46 mg/L) was recorded in the reference Station of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of copper is shown in Figure 4.20. The mean and standard deviation value for copper in the wet season (0.33±0.04 mg/L) was higher than the dry season value of (0.32±0.05 mg/L) from the various stations in Table 4.2. There was no significant difference (*p* > 0.05) between the wet and dry season values as shown in Table 4.2.

Figure 4.19: Spatial and Temporal Variation of Manganese across the Stations

Figure 4.20: Spatial and Temporal Variation of Copper across the Stations

4.1.21 Zinc (mg/L)

The mean value and standard deviation for Zinc ranged from 0.347±0.035 mg/L to 0.415±0.184 mg/L. The minimum value (0.235 mg/L) was recorded in the reference Station of Okhuahi River 2, while the highest value (0.843 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River and the impacted Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Zinc are shown in Figure 4.21. The mean and standard deviation value for Zinc in the wet season (0.48±0.15 mg/L) was higher than the dry season value of (0.30±0.04 mg/L) from the various stations in Table 4.2.

There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

4.1.22 Chromium (mg/L)

The mean value and standard deviation for Chromium ranged from 0.055±0.014 mg/L to 0.065±0.013 mg/L. The minimum value (0.038 mg/L) was recorded in both the Impacted and Reference Stations of Okhuaihe River 2 and the Reference Station of Orhionmwon River, while the highest value (0.10 mg/L) was recorded in both the Impacted and Reference Stations of Irogbe River, Reference and Impacted Stations of Orhionmwon and Okhuaihe 1 Rivers, respectively. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (Table 4.1). The spatial and temporal variations of Chromium are shown in Figure 4.22. The mean and standard deviation value for Chromium in the wet season (0.067±0.019 mg/L) was higher than the dry season value of (0.05±0.01 mg/L) from the various stations in Table 4.2. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in Table 4.2.

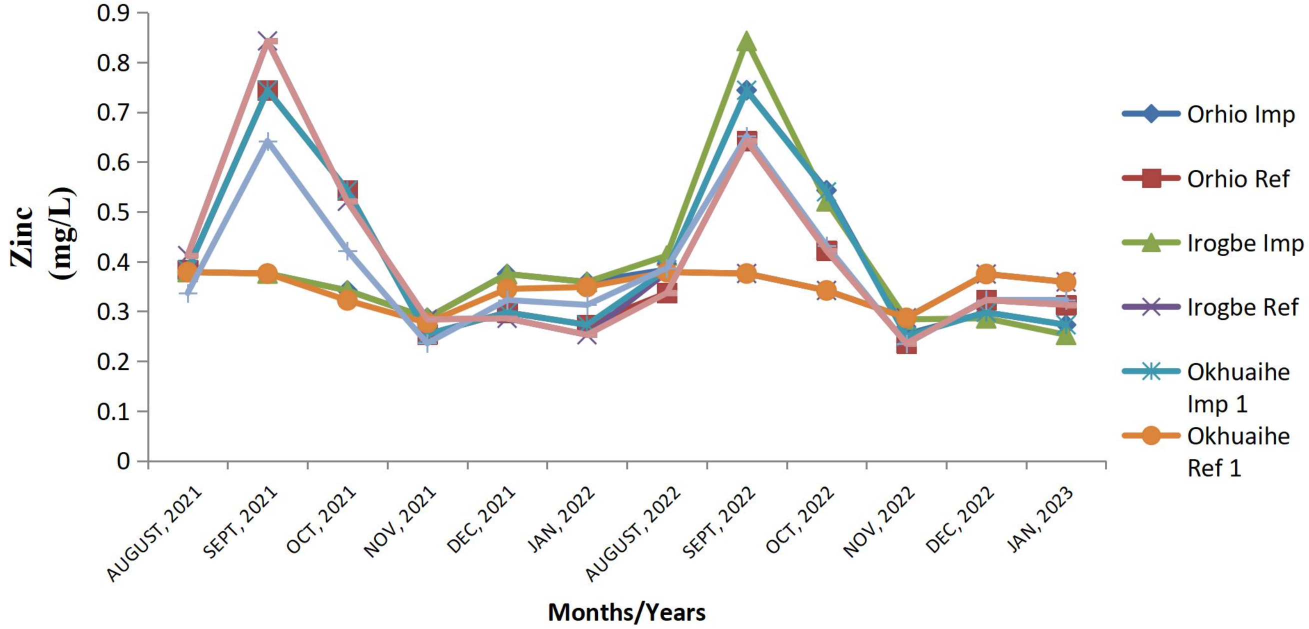

Figure 4.21: Spatial and Temporal Variation of Zinc across the Stations

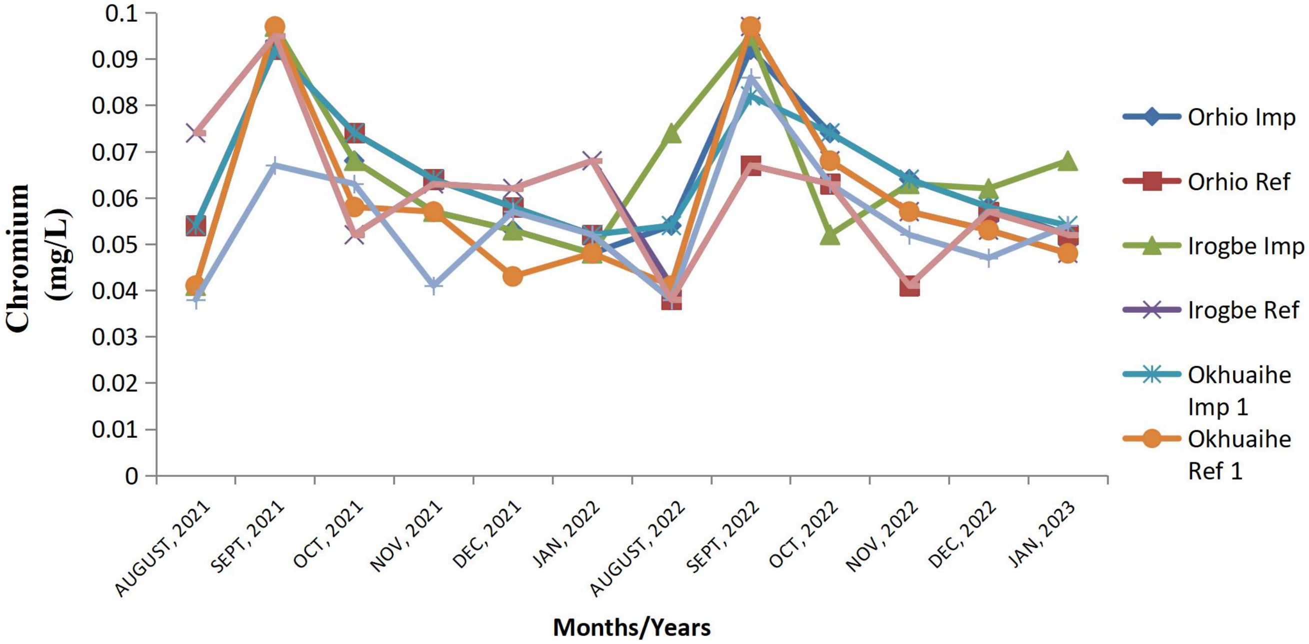

Figure 4.22: Spatial and Temporal Variation of Chromium across the Station

Table 4.3: Spatial Variation of Chemical Parameters of Sediment Samples from the Selected Rivers.

	SAMPLING STATIONS								
	Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River		
	STATION 1 (IP)	STATION 2 (RF)	STATION 3 (IP)	STATION 4 (RF)	STATION 5 (IP)	STATION 6 (RF)	STATION 7 (IP)	STATION 8 (RF)	P-Value
PARAMETERS	Mean ± SD (Min-Max)								
pH	5.36±0.76 (4.30-6.50)	5.25±0.97 (4.10-6.70)	5.40±0.92 (4.20-6.30)	5.57±0.93 (4.20-6.60)	5.57±0.92 (4.20-6.60)	5.68±0.89 (4.30-6.70)	5.67±1.12 (3.50-7.20)	5.67±0.76 (4.50-6.50)	$p>0.05$
Electrical Conductivity (µS/cm)	75.00±17.32 (50.00-100.00)	68.33±19.41 (50.00-100.00)	66.67±19.22 (50.00-100.00)	72.50±17.64 (50.00-100.00)	74.16±17.82 (50.00-100.00)	64.17±16.21 (40.00-90.00)	63.33±15.56 (40.00-90.00)	60.00±20.89 (40.00-90.00)	$p>0.05$
Phosphate (mg/kg)	2.62±0.83 (1.33-3.92)	2.44±0.79 (1.33-3.61)	4.77±5.72 (1.33-16.92)	4.74±5.70 (1.33-16.92)	4.80±5.70 (1.33-16.97)	3.01±1.17 (0.93-4.54)	3.41±2.21 (1.08-6.58)	5.14±2.53 (1.56-8.60)	$p>0.05$
Nitrate (mg/kg)	1.99±1.44 (10.27- 4.7)	1.95±1.48 (0.27- 4.7)	1.99±1.46 (0.23-4.70)	1.99±1.41 (0.37- 4.70)	1.96±1.38 (0.23-4.70)	3.52±4.29 (0.82-12.59)	4.56±5.75 (1.54-16.85)	1.87±1.05 (0.93-3.91)	$p>0.05$
Iron (mg/kg)	368.77±37.49 (319.13-428.73)	364.15±34.44 (327.12-425.75)	374.65±35.31 (329.11-428.75)	376.24±34.41 (329.11-428.75)	374.01±38.78 (329.11-448.75)	375.09±35.83 (335.55-428.23)	415.05±71.47 (375.28-567.53)	390.59±44.35 (347.65-476.36)	$p>0.05$
Zinc (mg/kg)	81.04±8.93 (62.98-94.17)	78.53±13.31 (54.68-92.17)	83.20±9.70 (67.98-92.17)	82.79±9.29 (67.98-92.17)	83.11±9.79 (67.62-93.27)	79.91±3.67 (73.37-85.24)	83.00±9.96 (65.33-95.28)	81.13±8.41 (65.45-93.77)	$p>0.05$
Copper (mg/kg)	45.21±5.41^{bc} (37.29-55.23)	44.79±5.22^{bc} (36.26-51.23)	46.79±4.61 (38.29-51.23)	46.21±4.36^{c} (38.29-51.23)	46.79±4.61^{bc} (38.29-51.23)	42.94±4.69^{c} (35.47-48.76)	37.91±5.79^{ab} (26.54-43.78)	41.31±5.78^{a} (29.63-47.35)	$p<0.01$
Manganese (mg/kg)	9.57±1.65^{a} (7.25-12.76)	9.90±1.11^{a} (8.26-11.76)	10.40±1.25 (8.26-11.76^{a})	10.39±1.18^{a} (8.26-11.74)	12.36±1.22^{b} (10.11-14.42)	10.40±1.25^{a} (8.26-11.76)	14.28±2.29^{a} (12.01-18.34)	10.67±1.55^{a} (12.78-20.56)	$p<0.01$
Chromium (mg/kg)	18.51±1.85^{bcd} (15.44-20.68)	18.01±2.90^{cd} (11.44-21.68)	18.76±2.45^{bcd} (14.44-21.68)	18.26±2.31^{d} (14.44-20.68)	18.87±2.85^{ab} (14.44-24.68)	16.19±1.75^{d} (13.57-18.47)	14.28±2.29^{a} (12.01-18.34)	16.43±2.63^{a} (12.78-20.56)	$p<0.01$
Silt (mg/kg)	14.58±1.88 (11.00-17.00)	12.83±2.37 (10.00-16.00)	12.67±1.92 (74.00-77.00)	12.42±2.19 (10.00-16.00)	12.25±2.30 (9.00-16.00)	12.00±2.29 (9.00-16.00)	12.25±3.65 (8.00-19.00)	12.08±1.83 (9.00-15.00)	$p>0.05$
Sand	76.33±1.83^{a} (1.33-3.92)	75.75±1.21^{a} (73.00-77.00)	76.08±0.90^{a} (74.00-77.00)	76.17±0.72^{a} (75.00-77.00)	76.16±1.47^{c} (74.00-79.00)	96.92±2.35^{a} (93.00-100.00)	82.16±6.91^{c} (74.00-96.00)	95.25±5.58^{b} (80.00-100.00)	$p<0.01$
Clay (mg/kg)	14.92±1.50^{bc} (13.00-18.00)	13.83±0.83^{c} (13.00-15.00)	12.83±1.27^{b} (11.00-15.00)	12.92±1.24^{b} (11.00-15.00)	12.50±1.44 (10.00-15.00)	10.42±1.56^{b} (8.00-13.00)	13.33±2.67^{bc} (9.00-17.00)	13.50±2.15^{b} (10.00-16.00)	$p<0.01$

Where: $p < 0.01$ indicates highly significant difference; $p < 0.05$ indicates significant difference; $p > 0.05$ indicates no significant difference, IP = Impacted while RF Reference

Table 4.4: Dry and Wet season Variation of Chemical Parameters of Sediment Samples from the Selected Rivers

	SEASONS						
	Wet Season			**Dry Season**			**P- Value**
Parameter	**Mean ± SD**	**Min**	**Max**	**Mean ± SD**	**Min**	**Max**	
pH	5.21±0.97	3.50	7.20	5.83±0.70	4.30	6.80	$p<0.01$
Electrical Conductivity (µS/cm)	69.79±18.15	40.00	100.00	66.87±17.76	40.00	90.00	$p>0.05$
Phosphate (mg/kg)	4.18±5.13	0.93	16.97	3.55±1.34	2.27	7.31	$p>0.05$
Nitrate (mg/kg)	3.51±3.69	0.93	16.85	1.45±0.86	0.24	3.91	$p>0.05$
Iron (mg/kg)	404.15±45.86	332.75	567.53	355.49±25.22	319.13	401.42	$p<0.01$
Zinc (mg/kg)	77.24±10.31	54.68	95.28	85.94±5.31	73.37	94.17	$p>0.05$
Copper (mg/kg)	41.08±5.63	26.54	48.65	46.90±4.10	38.45	55.23	$p<0.01$
Manganese (mg/kg)	10.11±1.62	7.26	14.42	10.72±1.52	7.53	13.94	$p>0.05$
Chromium (mg/kg)	18.17±2.69	12.08	24.68	16.66±2.68	11.44	20.65	$p<0.01$
Silt (mg/kg)	10.87±1.61	8.00	15.00	14.39±1.68	10.00	19.00	$p<0.01$
Sand	81.97±9.46	73.00	100.00	81.72±8.84	74.00	100.00	$p>0.05$
Clay (mg/kg)	13.35±1.78	9.00	18.00	12.71±2.20	8.00	17.00	$p>0.05$

Where: $p < 0.01$ indicates highly significant difference; $p < 0.05$ indicates significant difference;

$p > 0.05$ indicates no significant difference.

4.2 CHEMICAL PARAMETERS OF THE SEDIMENT SAMPLES

The Summary of the Chemical Parameters of the Sediment Samples was presented in the Table 4.3.

4.2.1 pH

The mean value and standard deviation for pH ranged from 5.25±0.97 to 5.68±0.89. The minimum value (3.50) and maximum value (7.20) were both recorded in the Impacted Station of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of pH are shown in Figure 4.23. The mean and standard deviation value for pH in the wet season (5.21±0.97) was lower than the dry season value of (5.83±0.70) from the various stations in table 4.4. There was a high significant difference ($p < 0.01$) between the wet and dry season values.

4.2.2 Electrical Conductivity (µS/cm)

The mean value and standard deviation for Electrical Conductivity ranged from 60.00±20.89 µS/cm to 75.00±17.32 µS/cm. The minimum value (40.00 µS/cm) was recorded in both the Impacted and Reference Stations of Okhuaihe River 2 and the Reference Station of Okhuaihe River 1, while the highest value (100.00 µS/cm) was recorded in both the Impacted and Reference Stations of Orhionmwon and Irogbe Rivers and the Impacted Station of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Electrical Conductivity are shown in Figure 4.24. The mean and standard deviation value for Electrical Conductivity in the wet season (69.79±18.15 µS/cm) was higher than the dry season value of (66.87±17.76 µS/cm) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

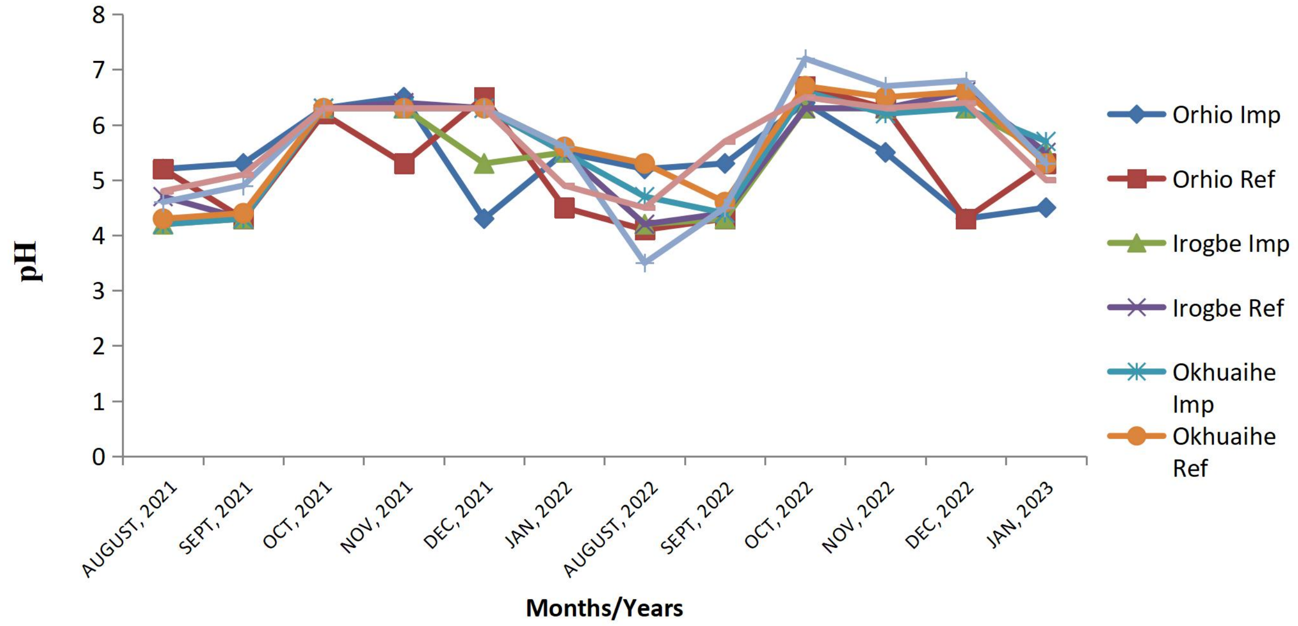

Figure 4.23: Spatial and Temporal Variations of pH for Sediment Samples

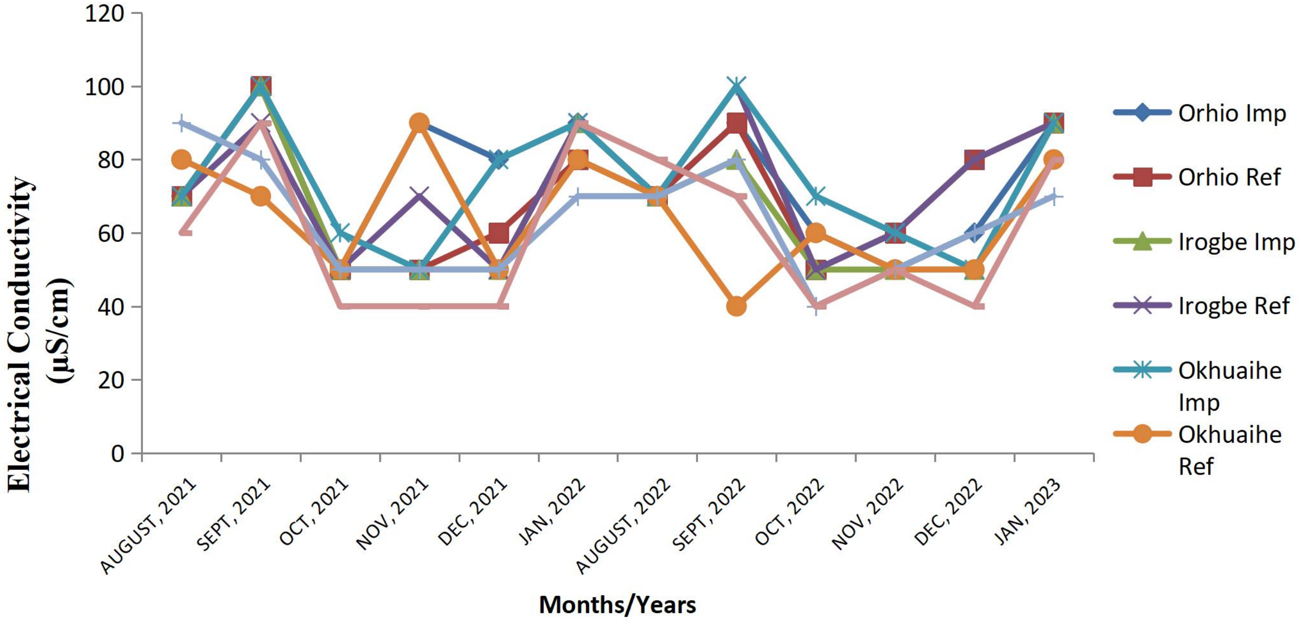

Figure 4.24: Spatial and Temporal Variations of Electrical Conductivity for Sediment Samples

4.2.3 Phosphate (mg/kg)

The mean value and standard deviation for Phosphate ranged from 2.44±0.79 mg/kg to 5.14±2.53 mg/kg. The minimum value (0.93 mg/kg) was recorded in the Reference Site of Okhuaihe River 1, while the highest value (16.97 mg/kg) was recorded in the Impacted Site of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Phosphate are shown in Figure 4.25. The mean and standard deviation value for Phosphate in the wet season (4.18±5.13 mg/kg) was higher than the dry season value of (3.55±1.34 mg/kg) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

4.2.4 Nitrate (mg/kg)

The mean value and standard deviation for Nitrate ranged from 1.87±1.05 mg/kg to 4.56±5.75 mg/kg. The minimum value (0.237 mg/kg) was recorded in both the Impact Sites of Irogbe and Okhuaihe Rivers 1 respectively, while the highest value (16.85 mg/kg) was recorded in the Impact Site of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Nitrate are shown in Figure 4.26. The mean and standard deviation value for Nitrate in the wet season (3.51±3.69 mg/kg) was higher than the dry season value of (1.45±0.86 mg/kg) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

Figure 4.25: Spatial and Temporal Variations of Phosphate for Sediment Samples

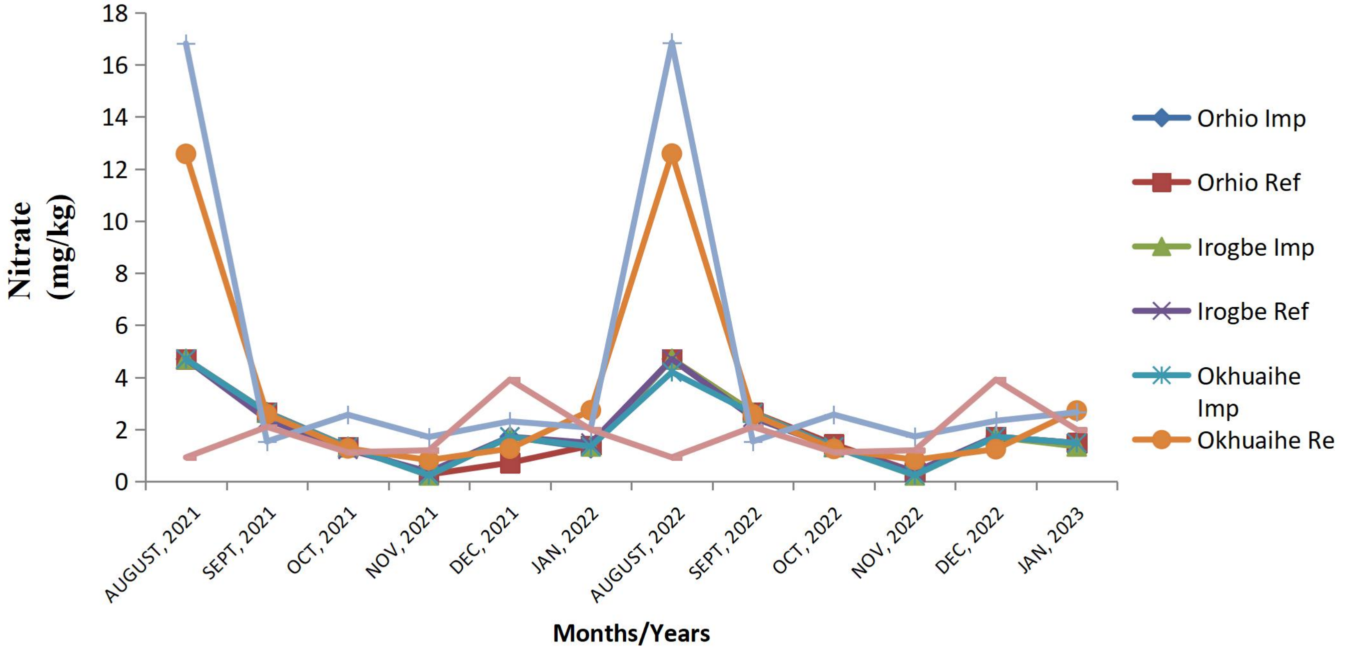

Figure 4.26: Spatial and Temporal Variations of Nitrate for Sediment Samples

4.2.5 Iron (mg/kg)

The mean value and standard deviation for Iron ranged from 364.15±34.44 mg/kg to 415.05±71.48 mg/kg. The minimum value (319.13 mg/kg) was recorded in the Impacted Site of Orhionmwon River, while the highest value (567.53 mg/kg) was recorded in the Impact Site of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Iron are shown in Figure 4.27. The mean and standard deviation value for Iron in the wet season (404.15±45.86 mg/kg) was higher than the dry season value of (355.49±25.22 mg/kg) from the various stations in table 4.4. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in table 4.4.

4.2.6 Zinc (mg/kg)

The mean value and standard deviation for Zinc ranged from 78.53±13.31 mg/kg to 83.20±9.70 mg/kg. The minimum value (54.68 mg/kg) was recorded in the Reference Station of Orhionmwon River, while the highest value (95.28 mg/kg) was recorded in the Impact Site of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Zinc are shown in Figure 4.28. The mean and standard deviation value for Zinc in the dry season (85.94±5.31 mg/kg) was higher than the wet season value of (77.24±10.31 mg/kg) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

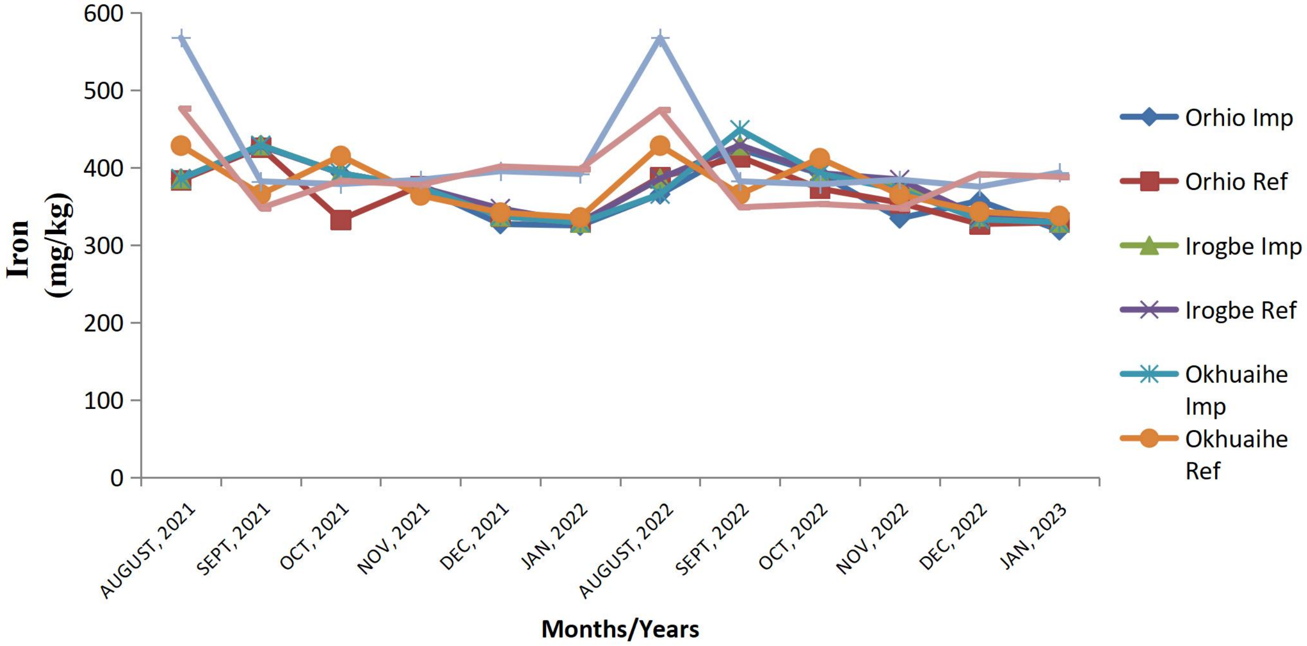

Figure 4.27: Spatial and Temporal Variations of Iron for Sediment Samples

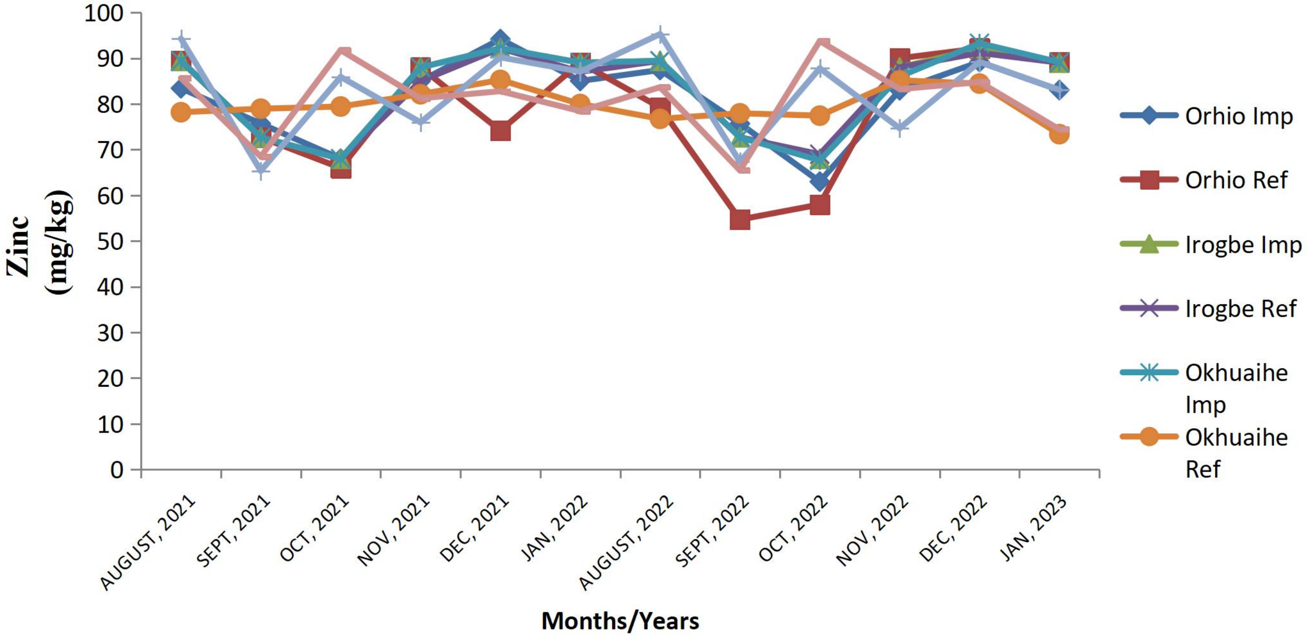

Figure 4.28: Spatial and Temporal Variations of Zinc for Sediment Samples

4.2.7 Copper (mg/kg)

The mean value and standard deviation for Copper ranged from 37.91±5.79 mg/kg to 46.79 ±4.61 mg/kg. The minimum value (26.54 mg/kg) was recorded at the Impact Station of Okhuaihe River 2, while the highest value (55.23 mg/kg) was recorded in the Impact Site of Orhionmwon River. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (table 4.3). Duncan Multiple Range Test revealed that both the Reference and Impacted Stations of Irogbe and the reference Station of Okhuaihe River 1 were the cause of difference (table 4.3). The spatial and temporal variations of Zinc are shown in Figure 4.29. The mean and standard deviation value for Copper in the dry season (46.90±4.10 mg/kg) was higher than the wet season value of (41.08±5.63 mg/kg) from the various stations in table 4.4. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in table 4.4.

4.2.8 Manganese (mg/kg)

The mean value and standard deviation for Manganese ranged from 9.57±1.65 mg/kg to 12.36±1.22 mg/kg. The minimum value (7.25 mg/kg) was recorded in the Impacted Site of Orhionmwon River, while the highest value (14.42 mg/kg) was recorded in the Impacted Site of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was high significant difference in the mean values of the study stations ($p < 0.01$) (table 4.3). Duncan Multiple Range Test revealed that the impacted Station of Okhuaihe River 1 was the cause of difference (table 4.3). The spatial and temporal variations of Manganese are shown in Figure 4.30. The mean and standard deviation value for Manganese in the wet season (10.11±1.62 mg/kg) was lower than the dry season value of (10.72±1.52 mg/kg) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

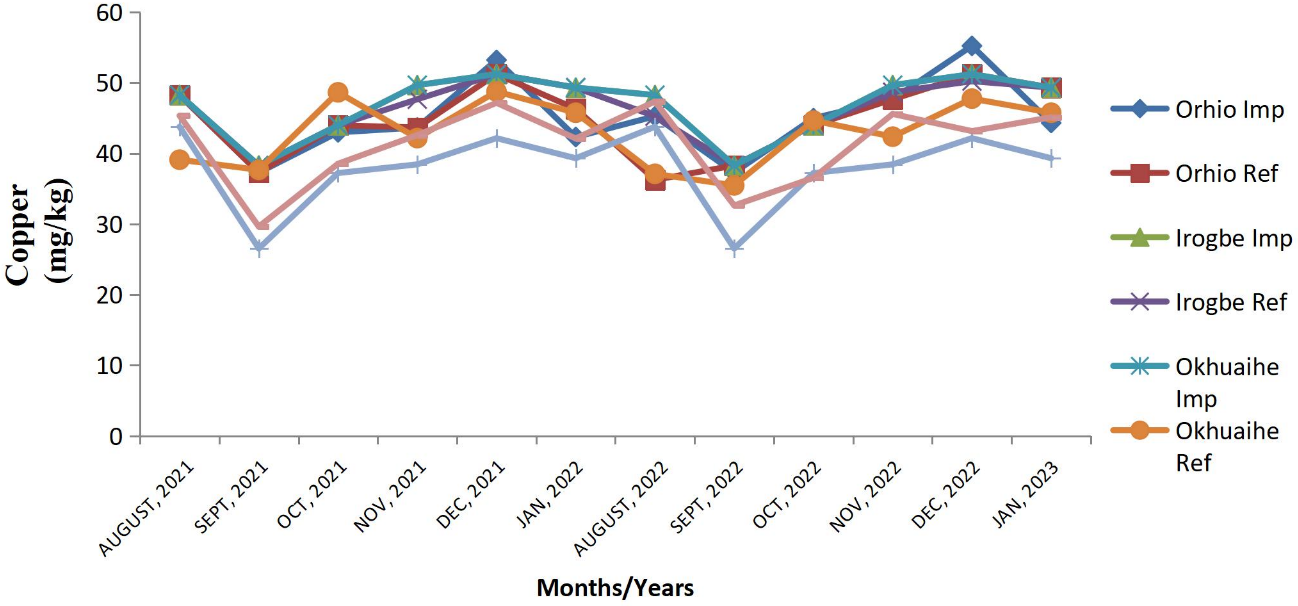

Figure 4.29: Spatial and Temporal Variations of Copper for Sediment Samples

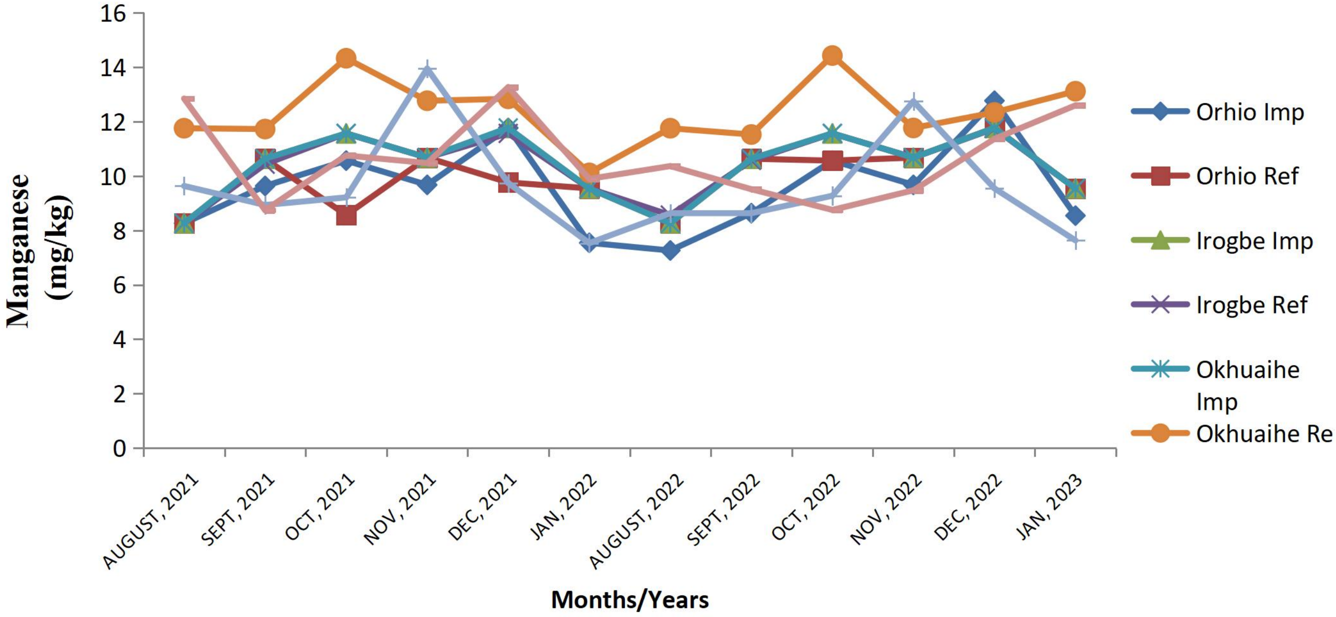

Figure 4.30: Spatial and Temporal Variations of Manganese for Sediment Samples

4.2.9 Chromium (mg/kg)

The mean value and standard deviation for Chromium ranged from 14.28±2.29 mg/kg to 18.87±2.85 mg/kg. The minimum value (11.44 mg/kg) was recorded in the Reference Site of Orhionmwon River, while the highest value (24.68 mg/kg) was recorded in the Impacted Site of Okhuaihe River 1. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (table 4.3). Duncan Multiple Range Test revealed that both the Reference Stations of Irogbe and Okhuaihe River 1 was the cause of difference (table 4.3). The spatial and temporal variations of Chromium are shown in Figure 4.31. The mean and standard deviation value for Chromium in the wet season (18.17±2.69 mg/kg) was higher than the dry season value of (16.66±2.68 mg/kg) from the various stations in table 4.4. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in table 4.4.

4.2.10 Silt (mg/kg)

The mean value and standard deviation for Silt ranged from 12.00±2.29 mg/kg to 14.58±1.82 mg/kg. The minimum value (8.00 mg/kg) was recorded in the Impacted Site of Okhuaihe River 2, while the highest value (19.00 mg/kg) was also recorded in the Impacted Site of Okhuaihe River 2. Analysis of Variance (ANOVA) showed that there was no significant difference in the mean values of the study stations ($p > 0.05$) (table 4.3). The spatial and temporal variations of Silt are shown in Figure 4.32. The mean and standard deviation value for Silt in the dry season (14.39±1.68 mg/kg) was higher than the wet season value of (10.87±1.60 mg/kg) from the various stations in table 4.4. There was a high significant difference ($p < 0.01$) between the wet and dry season values as shown in table 4.4.

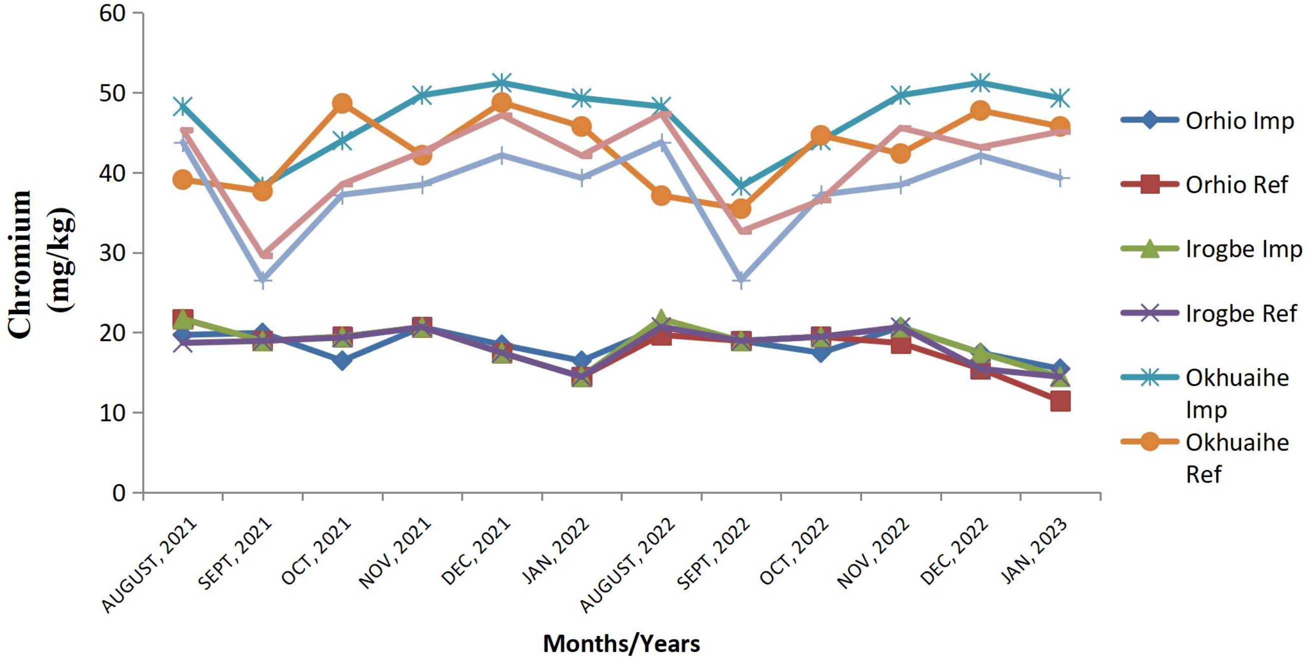

Figure 4.31: Spatial and Temporal Variations of Chromium for Sediment Samples

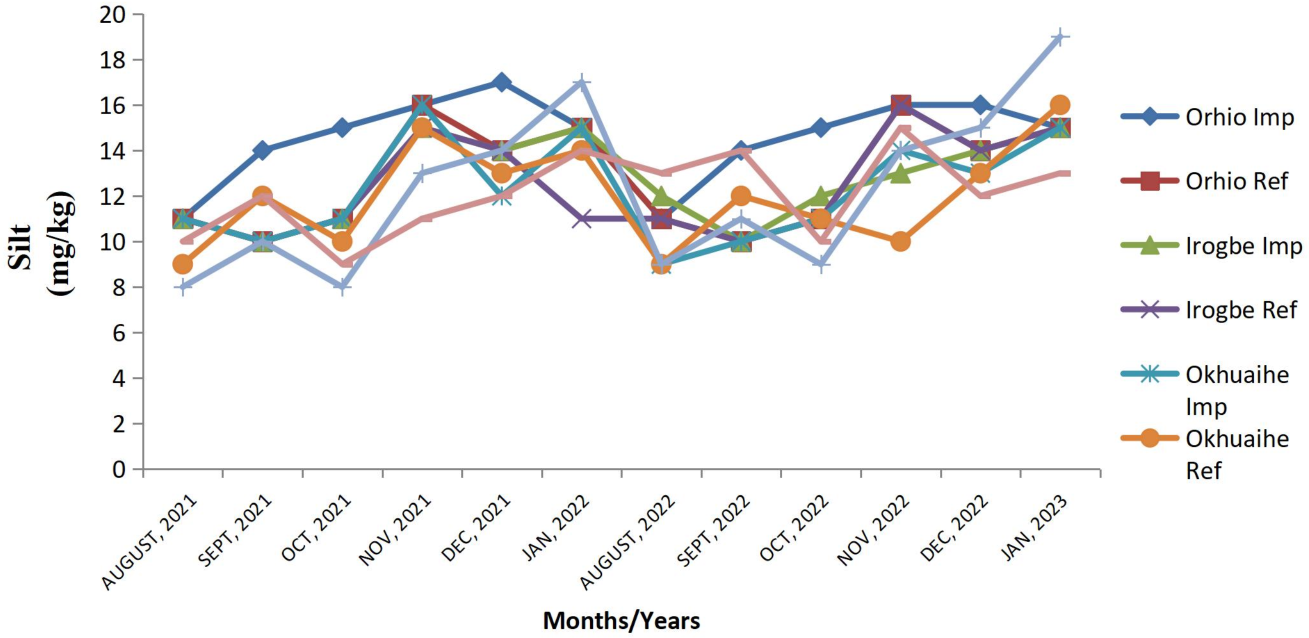

Figure 4.32: Spatial and Temporal Variations of Silt for Sediment Samples

4.2.11 Sand (mg/kg)

The mean value and standard deviation for Sand ranged from 75.75±1.21 mg/kg to 96.92±2.35 mg/kg. The minimum value (73.00 mg/kg) was recorded in both the Reference and Impacted Site of Orhionmwon River, while, the highest value (100.00 mg/kg) was recorded in the Reference Sites of Okhuaihe Rivers 1 and 2. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (table 4.3). Duncan Multiple Range Test revealed that both the Impacted Stations of Okhuiahe rivers 1 and 2 were the cause of difference (table 4.3). The spatial and temporal variations of Sand are shown in Figure 4.33. The mean and standard deviation value for Sand in the wet season (81.98±9.46 mg/kg) was higher than the dry season value of (81.73±8.84 mg/kg) from the various stations in table 4.4. There was no significant difference ($p < 0.01$) between the wet and dry season values as shown in table 4.4.

4.2.12 Clay (mg/kg)

The mean value and standard deviation for Clay ranged from 10.42±1.56 mg/kg to 14.92±1.50 mg/kg. The minimum value (8.00 mg/kg) was recorded in the Reference Site of Okhuaihe River 1, while the highest value (18.00 mg/kg) was recorded in the impacted Sites of Orhionmwon Rivers. Analysis of Variance (ANOVA) showed that there was a high significant difference in the mean values of the study stations ($p < 0.01$) (table 4.3). Duncan Multiple Range Test revealed that Reference Stations of Orhionmwon River was the cause of difference (table 4.3). The spatial and temporal variations of Chromium are shown in Figure 4.34. The mean and standard deviation value for Clay in the wet season (13.35±1.78 mg/kg) was higher than the dry season value of (12.71±2.20 mg/kg) from the various stations in table 4.4. There was no significant difference ($p > 0.05$) between the wet and dry season values as shown in table 4.4.

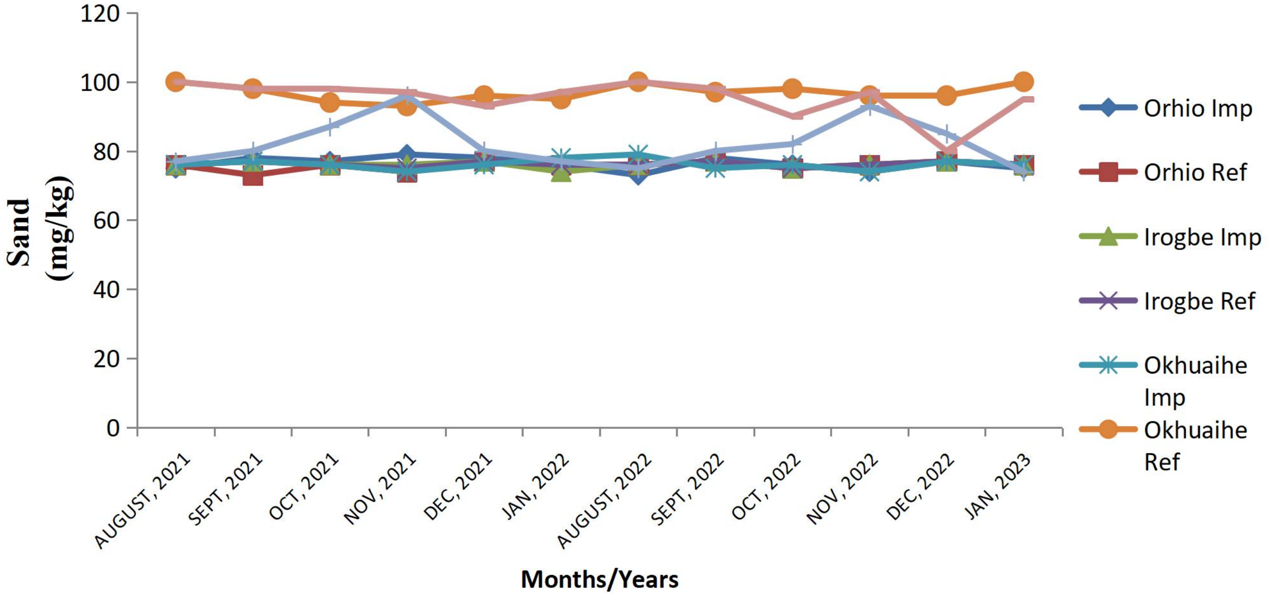

Figure 4.33: Spatial and Temporal Variations of Sand for Sediment Samples

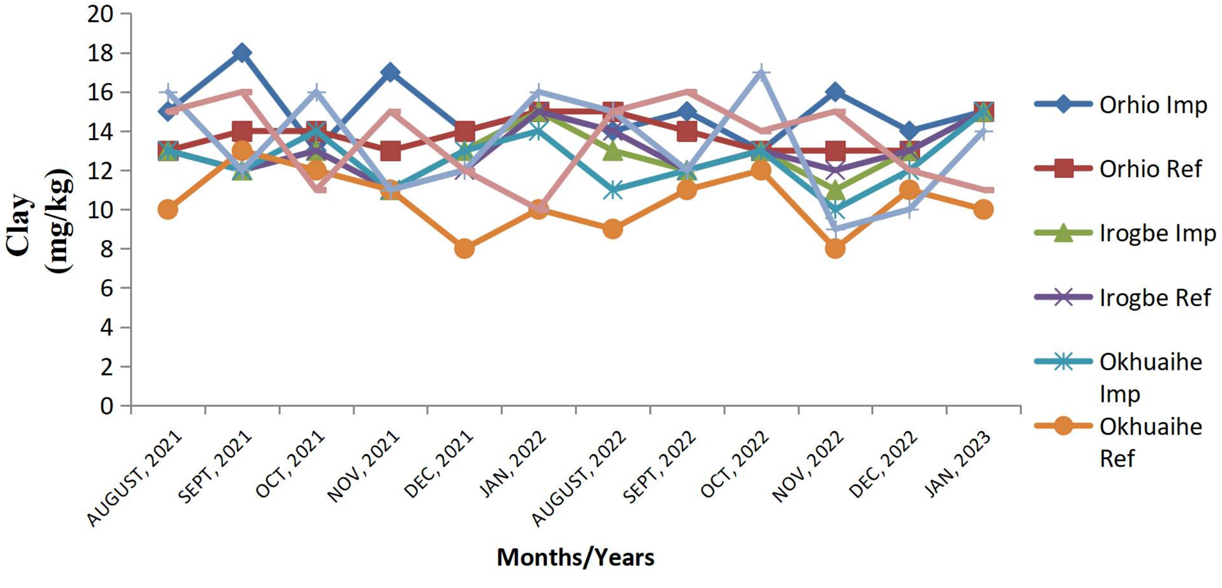

Figure 4.34: Spatial and Temporal Variations of Clay for Sediment Samples

4.3 Assessment Indices of Water and Sediment Samples of the Selected Study Stations

4.3.1 Water Quality Index (WQI)

The WQI values for the sampled locations ranged from 9.3503 at the Reference Site of Okhuaihe 1 River to 16.5331 at the Impacted Site of Okhuaihe River 2 (Table 4.5). Based on the standard classification table (Table 4.5), all eight stations had excellent water quality. The average WQI value of (12.4777) fell within the permissible limits (< 50) for excellent drinking water (Ogbeibu and Ogiesoba-Eguakun, 2019).

4.3.2 Principal Component Analysis (PCA) for Water Parameters

The analysis was conducted on log-transformed water quality data to minimize skewness and standardise the variables. Eight principal components (PCs) with eigenvalues greater than 1 were extracted after Varimax rotation, cumulatively explaining 79.94% of the total variance in the dataset. The first principal component (PC1) accounted for 20.35% of the total variance and exhibited high positive loadings on Depth (0.757) and Phosphate (0.737). This component represents nutrient and ionic enrichment influenced by sediment depth and phosphate accumulation within the aquatic environment. The second component (PC2) contributed 15.01% of the variance, with strong loadings on Sulphate (0.848) and Turbidity (0.737). This factor reflects turbidity and sulphate load resulting from surface runoff and erosion, which are often linked to land disturbance and wastewater inflows (Simeonov *et al.*, 2003). The third component (PC3) explained 11.86% of the total variance, characterized by high positive loading on Chloride (0.845) and strong negative loading on Air Temperature (-0.824). This component suggests ionic and thermal variations, indicating salinity changes that may arise from evaporation, dilution cycles, or seasonal temperature fluctuations.

Table 4.5: Summary of WQI values at the Various Stations of the Selected Rivers

Stations	WQI	Water Quality
Orhionmwon (Impacted Station)	10.74	Excellent
Orhionmwon (Reference Station)	14.82	Excellent
Irogbe (Impacted Station)	10.31	Excellent
Irogbe (Reference Station)	10.31	Excellent
Okhuaihe 1 (Impacted Station)	13.35	Excellent
Okhuaihe 1 (Reference Station)	9.35	Excellent
Okhuaihe 2 (Impacted Station)	16.53	Excellent
Okhuaihe 2 (Reference Station)	14.41	Excellent

< 50 = Excellent;

50 – 100 = Good;

100 – 200 = Poor;

200 – 300 = Very poor (bad) water;

> 300 = Unsuitable (unfit) for drinking (Tyagi, 2013; Boah *et al*., (2015); Ogbeibu and Ogiesoba-Eguakun, 2019).

The fourth component (PC4), accounting for 7.92% of the total variance, showed a strong negative loading on Dissolved Oxygen (-0.848) and a positive loading on Manganese (0.687). This indicates oxygen–nutrient interactions and possible reducing or anoxic conditions, which can promote metal mobilization in sediments. The fifth component (PC5) explained 7.21% of the variance, with high loadings for Zinc (0.873) and Iron (0.758), suggesting trace metal pollution from industrial effluents or geogenic sources. The sixth component (PC6) contributed 6.35% of the total variance and showed high correlations with Electrical Conductivity (0.776) and Water Temperature (0.764), indicating a conductivity–temperature relationship that reflects ionic concentration and thermal influence. The seventh component (PC7) accounted for 6.09% of the total variance and exhibited a strong loading for Copper (0.881), representing heavy metal contamination possibly from urban runoff.

Finally, the eighth component (PC8) explained 5.16% of the variance, with high loadings on Width (0.869) and Transparency (0.657), indicating a morphometric and optical factor associated with channel width and water clarity. Overall, the first three components (PC1–PC3) accounted for over 47% of the total variance, capturing the dominant chemical and physical processes governing water quality in the study area.

4.3.3 Principal Component Analysis (PCA) for Sediment Parameters

This analysis was conducted on log-transformed sediment quality data to minimise skewness and standardise the variables. From table 4.7, five principal components (PCs) with eigenvalues greater than 1 were extracted, collectively explaining 76.83% of the total variance after Varimax rotation. This indicates that these five components adequately describe the multivariate structure of the sediment dataset. The first component (PC1) accounted for 19.29% of the total variance and showed high positive loading on Silt (0.828) and strong negative loadings on Nitrate (-0.786) and Iron (-0.742). This represents a textural–nutrient factor, suggesting that fine-grained, silt-rich sediments are associated with reduced nitrate and iron concentrations, possibly due to adsorption or reduced mobility in finer textures. The second component (PC2) explained 16.59% of the total variance, with strong loadings on Clay (-0.838) and Manganese (0.810). This indicates a grain–metal association factor, emphasizing the interaction between sediment grain size and metal distribution. High manganese concentrations in finer particles suggest retention or co-precipitation with clay minerals.

The third component (PC3) contributed 15.26% of the variance and showed high loading on Electrical Conductivity (0.833), with moderate positive loading on Phosphate (0.675) and negative loading on pH (-0.719). This component, termed the physico-chemical factor, reflects the influence of ionic strength and acidity on nutrient solubility and mobility in sediments. These variables originated primarily from run-off with high load of solids and wastes from point sources of pollution like agricultural fields and domestic areas (Simeonov *et al.*, 2003). The fourth component (PC4) accounted for 13.60% of the variance, with strong positive loadings on Zinc (0.885) and Copper (0.763). This represents a metal enrichment factor, highlighting the co-occurrence of trace metals likely from anthropogenic inputs such as industrial discharge, corroded materials, or agricultural effluents.

The fifth component (PC5) explained 12.08% of the total variance and showed a high loading for Chromium (0.893) with a negative loading for Sand (-0.529). This chromium–sand association factor suggests that chromium tends to accumulate in finer sediments where adsorption to clay and organic matter is favoured. Overall, the first three components explained approximately 51%

of the total variance, capturing the dominant textural and chemical processes influencing sediment characteristics in the study area.

4.3.4 Risk Assessment

4.3.4.1 Pollution Load Index (PLI)

The values obtained in relation to PLI at the various rivers: Orhionmwon, Irogbe, Okhuaihe 1, and Okhuaihe 2 were 1.01, 1.01, 0.79, and 0.96 respectively (table 4.9). Table 4.8 shows the summary of concentrations of heavy metals in sediment samples. Table 4.9 shows the summary of contamination factors that accumulated to the PLI value at the various stations, while Figures 4.39 and 4.40 bear the graphical representations for the contamination factors and PLI respectively. Generally, Okhuaihe River 1 bore the lowest value and Orhionmwon River had the highest value of PLI respectively. From the values, Okhuaihe 1, and Okhuaihe River 2 had no metal pollution PLI < 1, while Orhionmwon and Irogbe Rivers had metal pollution PLI > 1.

4.3.4.2 Geoaccumulation Index (*Igeo*)

Table 4.10 shows the summary of the Geoaccumulation Index values for the various heavy metals in the Selected Rivers. Generally, the *Igeo* value was highest for Orhionmwon River and lowest at Okhuaihe River 1. When comparing its value with individual heavy metals, the *Igeo* of Copper for Okhuaihe River 1 was the lowest, while its Chromium value for the same Okhuaihe 1 River was the highest when compared with the rest rivers. Figure 4.41 shows the summary of Igeo of heavy metal contamination in various Sediment Samples. Muller (1969) distinguished seven classes of geoaccumulation index. The Igeo values ranged from -4.95 to -2.86 with an average of -3.49. All the metals (Cr, Cu, Fe, Mn and Zn) Igeo values were virtually uncontaminated (Igeo $\leq$ 0). Based on the mean values of Igeo, the degree of heavy metal pollution in the sediments yielded the following ranking: Mn > Zn > Fe > Cr > Cu.

Table 4.6: Rotated Component Matrix[a] and Eigenvalues of Principal Component Analysis for Water Parameters

Parameters	Components							
	1	2	3	4	5	6	7	8
pH	-0.825	0.207	0.055	0.052	0.113	-0.074	-0.007	0.073
Depth	**0.757**	-0.063	-0.21	0.064	-0.033	0.183	-0.03	0.24
Phosphate	0.737	0.283	-0.02	0.078	0.196	-0.185	-0.051	-0.313
Sulphate	-0.103	**0.848**	-0.121	-0.267	0.149	-0.126	-0.074	0.143
Turbidity	-0.044	0.737	0.375	0.251	0.127	0.102	0.27	0.043
FlowRate	0.509	-0.529	0.065	-0.343	0.007	-0.259	0.062	0.376
Ammonium	-0.099	0.413	0.352	0.113	0.192	-0.356	0.29	-0.288
Chloride	-0.092	0.118	**0.845**	0.042	-0.14	0.036	-0.23	0.068
AirTemp	0.205	0.111	-0.824	0.001	-0.331	-0.067	-0.07	-0.077
BOD	0.234	0.39	0.513	0.349	-0.118	0.229	0.138	-0.165
DO	0.124	0.083	-0.337	-0.848	0.022	-0.092	0.113	-0.172
Manganese	0.027	0.202	-0.194	0.687	0.425	-0.129	0.094	-0.193
Nitrate	-0.356	0.041	0.033	-0.614	-0.256	-0.43	-0.279	-0.113
Zinc	0.186	0.058	0.007	0.155	**0.873**	0.204	0.203	0.047
Iron	-0.364	0.263	0.177	0.055	**0.758**	0.005	0.008	-0.211
EC	0.058	0.008	0.187	-0.08	0.231	**0.776**	-0.066	0.061
Water Temp	-0.018	0.001	-0.039	0.173	-0.05	**0.764**	-0.04	-0.186
Copper	-0.112	0.046	-0.128	-0.053	0.087	-0.133	**0.881**	0.002
Chromium	0.083	0.439	-0.054	0.23	0.409	0.003	0.573	-0.161
TDS	0.461	-0.065	0.314	0.087	0.009	0.463	0.546	-0.024
Width	0.026	-0.044	-0.017	0.2	0.039	-0.154	0.071	**0.869**
Transparency	-0.085	0.199	0.178	-0.242	-0.291	0.068	-0.266	0.657
Eigenvalues	**4.477**	**3.302**	**2.609**	**1.743**	**1.585**	**1.397**	**1.34**	**1.135**
% Variance	**20.349**	**15.009**	**11.859**	**7.921**	**7.207**	**6.351**	**6.089**	**5.158**
% Cumulative	**20.349**	**35.358**	**47.217**	**55.137**	**62.344**	**68.695**	**74.784**	**79.942**

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalisation.[a]

a. Rotation converged in 15 iterations.

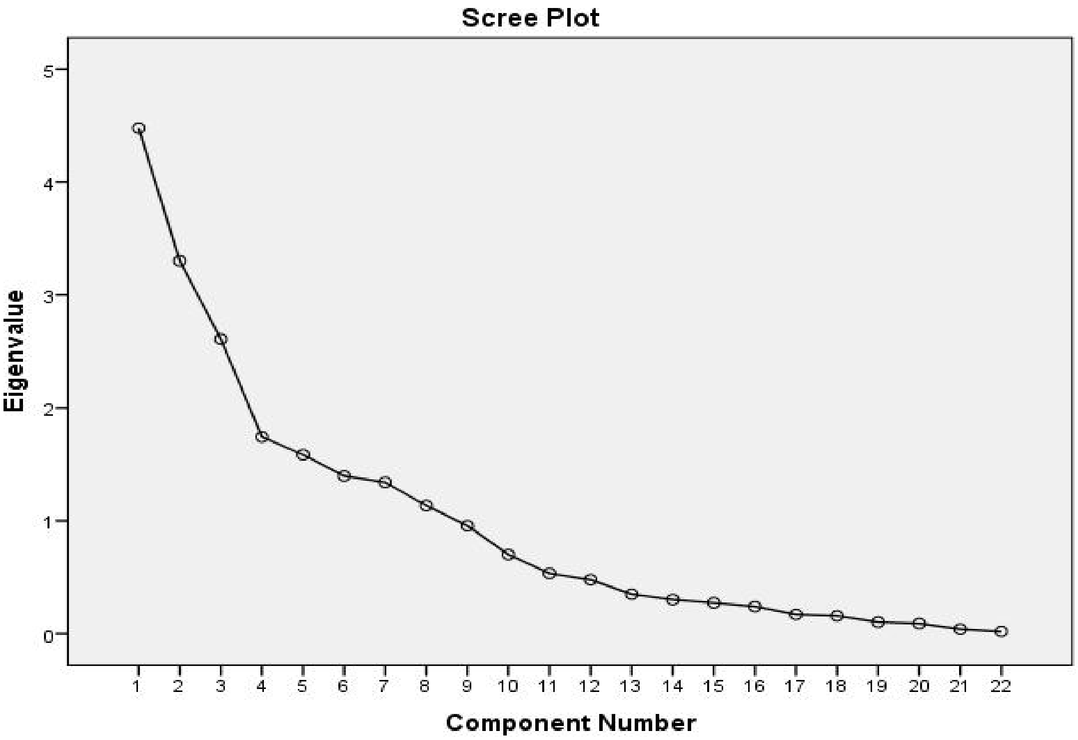

Figure 4.35: Screen Plot of Water Parameters on PCA

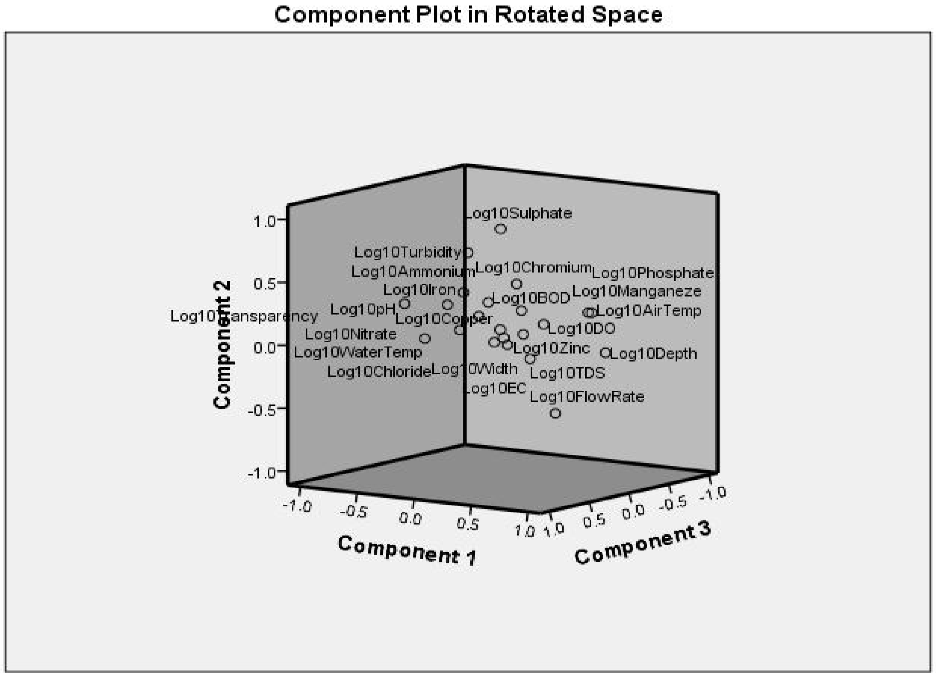

Figure 4.36: Component Plot in Rotated Space of Water Parameters on PCA.

Table 4.7: **Rotated Component Matrix^a of the Principal Component Analysis for Sediment Parameters**

	Components				
Parameters	**1**	**2**	**3**	**4**	**5**
Silt	**0.828**	-0.064	0.099	0.23	-0.073
Nitrate	-0.786	-0.131	0.257	0.135	-0.272
Iron	-0.742	0.063	0.052	-0.236	0.272
Clay	0.015	-0.838	-0.022	-0.022	-0.038
Manganese	0.098	0.81	-0.193	-0.038	0.089
Sand	-0.216	0.618	-0.151	-0.095	-0.529
EC	-0.04	-0.263	**0.833**	-0.039	0.006
pH	0.485	0.199	-0.719	-0.105	-0.085
Phosphate	0.184	0.32	0.675	-0.338	-0.22
Zinc	0.067	-0.066	-0.019	**0.885**	-0.104
Copper	0.328	0.07	-0.144	**0.763**	0.377
Chromium	-0.151	0.074	-0.071	0.044	**0.893**
Eigenvalues	**2.315**	**1.991**	**1.831**	**1.632**	**1.45**
% Variance	**19.294**	**16.594**	**15.257**	**13.602**	**12.084**
% Cumulative	**19.294**	**35.889**	**51.146**	**64.748**	**76.831**

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization.^{a}

a. Rotation converged in 7 iterations.

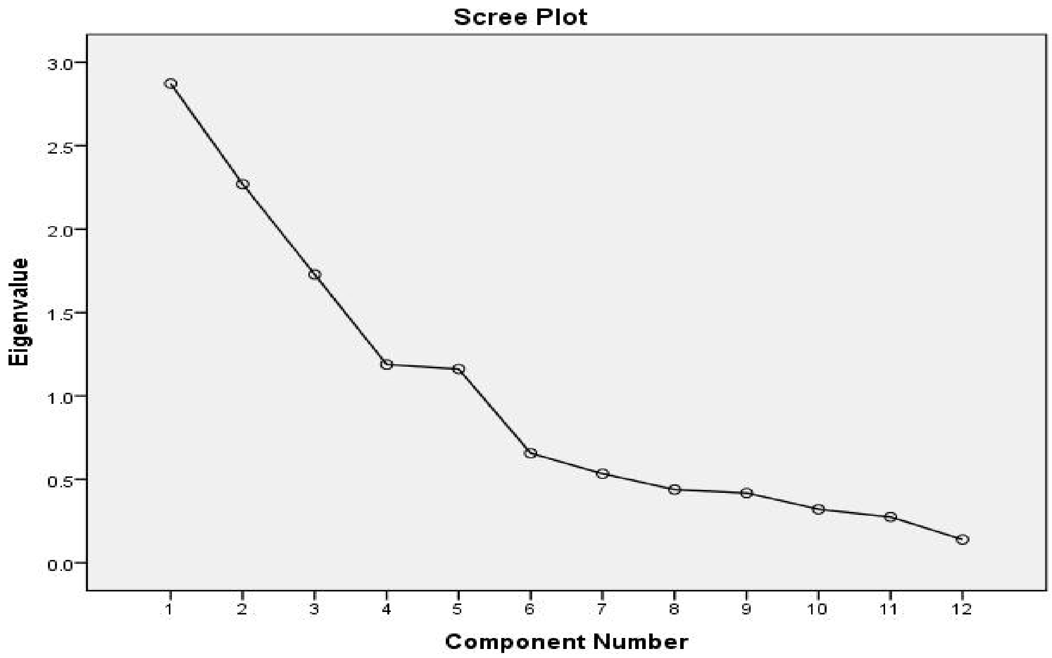

Figure 4.37: Screen Plot of Sediment Parameters on PCA

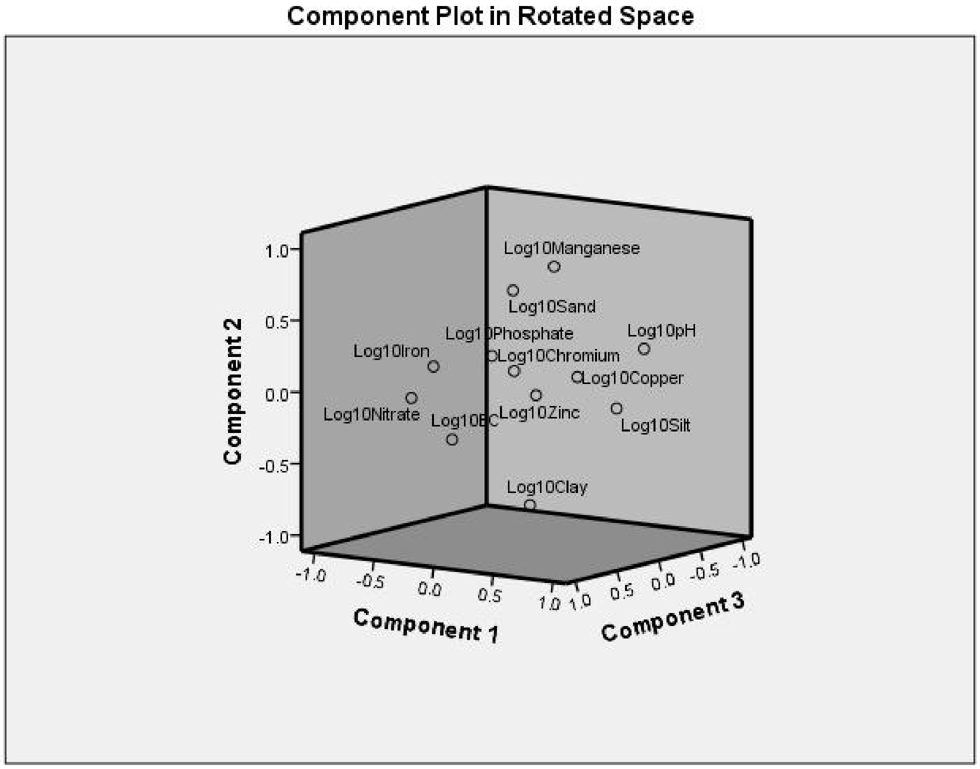

Figure 4.38: Component Plot in Rotated Space of Sediment Parameters on PCA.

Table 4.8: The Concentrations of Heavy Metals in Sediment Parameters of the Selected Water Bodies

Parameters	Orhionmwon Ref	Orhionmwon Imp	Irogbe Ref	Irogbe Imp	Okhuaihe 1 Ref	Okhuaihe 1 Imp	Okhuaihe 2 Ref	Okhuaihe 2 Imp
Chromium	18.01	18.5	18.26	18.76	16.19	18.88	16.435	14.28
Copper	44.8	45.2	46.21	46.8	42.94	10.4	41.315	37.91
Iron	364.15	368.8	376.24	374.65	375.1	374.01	390.6	415.05
Manganese	9.9	9.57	10.39	10.4	12.365	10.4	10.67	9.62
Zinc	78.5	81.04	82.8	83.21	79.91	83.11	81.13	83
Average	**103.072**	**104.622**	**106.78**	**106.764**	**105.301**	**99.36**	**108.03**	**111.972**
SD	**148.3894**	**150.2739**	**153.2802**	**152.4337**	**153.2179**	**156.5259**	**160.3815**	**171.9015**

Table 4.9: The Contamination Factor and Pollution Load Index of Heavy Metals in Sediments of the Selected Water Bodies

Stations	**Contamination Factor**					
	Cr	**Cu**	**Fe**	**Mn**	**Zn**	**PLI**
Orhionmwon	1.03	1.01	1.01	0.97	1.03	**1.01**
Irogbe	1.03	1.01	1.00	1.00	1.00	**1.01**
Okhuaihe 1	1.17	0.24	1.00	0.84	1.04	**0.79**
Okhuaihe 2	0.87	0.92	1.06	0.90	1.02	**0.96**

4.3.4.3 Potential Ecological Risk

Table 4.11 shows the summary of the Potential Ecological Risk values for the various heavy metals. The RI values for the sediment samples of the various rivers; Orhionmwon, Irogbe, Okhuaihe 1, and Okhuaihe 2 were 10.11, 10.12, 6.42 and 9.31 respectively. Figure 4.42 shows the representation of the Potential Ecological Risk values across the sampled rivers of the study. For the individual heavy metals, their ecological risk factor values ranged as follow Fe (0.99 – 1.06), Cu (1.21 – 5.06), Mn (0.84 – 1.00), Cr (1.74 – 2.055) and Zn (1.01 – 1.04). The PERI values were ranged from 6.4215 in Okhuaihe River 1 to 10.12 in Irogbe River with an average of 8.99. This shows that the potential ecological risk was low (*Eri* < 40) and the Risk Index was also low (RI < 150) Hakanson, (1980).

Table 4.10: Summary of Spatial Variations in the Index of Geoaccumulation Values

Stations	Heavy Metals						Igeo Class	Pollution Level
	Cr	Cu	Fe	Mn	Zn	Igeo Value		
Orhionmwon	0.68	0.67	0.68	0.64	0.69	-2.86	0	Uncontaminated
Irogbe	0.68	0.68	0.66	0.67	0.67	-2.87	0	Uncontaminated
Okhuaihe 1	0.78	0.16	0.66	0.56	0.69	-4.95	0	Uncontaminated
Okhuaihe 2	0.58	0.61	0.71	0.60	0.68	-3.28	0	Uncontaminated

Table 4.11: Summary the Spatial Variations in the Values of Potential Ecological Risk Index

Stations	Ecological Risk Factor (Er)					
	Cr	Cu	Fe	Mn	Zn	PERI
Orhionmwon	2.05	5.04	1.01	0.97	1.03	**10.11**
Irogbe	2.05	5.06	1.00	1.00	1.00	**10.12**
Okhuaihe 1	2.33	1.21	1.00	0.84	1.04	**6.42**
Okhuaihe 2	1.74	4.59	1.06	0.90	1.02	**9.31**

4.4 Benthic Macrofauna

The Benthic macrofauna studied in the Selected Rivers were found to belong to three Phyla. These are Phylum Annelida, Phylum Arthropoda and Phylum Mollusca. A total of 2694 individuals distributed in 59 different species, consisting of 1 species of Arachnida, 5 species of Haplotaxida, 1 species of Decapoda, 7 species of Ephemeropteran, 9 species of Hemipteran, 10 species of Coleopteran, 2 species of Trichopteran, 12 species of Dipteran, 2 species of Hymenoptera, 9 species of Odonatan, 1 species of Plecoptera, and 3 species of Gastropoda (table. 4.12).

4.4.1 Checklist of Macrofauna from the Selected Rivers

Phylum: Annelida

Class: Clitellata

Order: Haplotaxida

Family: Naididae

Branchiura sowerbyi		Plate 4.1
Nais sp.	Piguet, 1906	Plate 4.2
Pristina sp.		Plate 4.3
Branchiodrilus sp.		Plate 4.4

Family: Lumbriculidae

Lumbriculus variegatus		Plate 4.5

Phylum: Arthropoda

Class: Arachnida

Order: Trombidiformes

Family: Hydryphantes

Hydryphantes incertus	Koenike, 1893	Plate 4.6

Class: Crustacea

Order: Decapoda

Family: Atyidae

Caridina africana	Kingsley, 1883	Plate 4.7

Class: Insecta		
Order: Ephemeroptera		
Family: Baetidae		
Baetis sp.	Leach, 1815	Plate 4.8
Centroptilum sp.	Eaton, 1869	Plate 4.9
Cloeon sp.	McDunnough, 1925	Plate 4.10
Pseudocloeon sp.	Klapalek, 1905	Plate 4.11
Family: Leptophlebiidae		
Leptophlebia sp.	Westwood, 1840	Plate 4.12
Adenophlebiodes sp.	Ulmer, 1932	Plate 4.13
Family: Heptageniidae		
Heptagenia sp.		Plate 4.14
Order: Hemiptera		
Family: Gerridae		
Gerris lacustris	Linnaeus, 1758	Plate 4.15
Family: Belostomatidae		
Belostoma sp.		Plate 4.16
Lethocerus sp.	Mayr, 1853	Plate 4.17
Family: Veliidae		
Microvelia sp.	Westwood, 1834	Plate 4.18
Velia sp.	Latreille, 1804	Plate 4.19
Rhagovelia sp.		Plate 4.20
Family: Naucoridae		
Pelocaris femoratus	Palisot de Beauvois, 1820	Plate 4.21
Family: Nepidae		
Nepa apiculata	Uhler, 1862	Plate 4.22
Family: Notonectidae		
Notonecta sp.	Linnaeus, 1758	Plate 4.23
Order: Coleoptera		
Family: Hydrophilidae		
Hydrophilus sp.	Geoffroy, 1762	Plate 4.24

Philhydrus sp.	Thomson, 1859	Plate 4.25
Family: Dytiscidae		
Amphiops gibbos	Erichson, 1843	Plate 4.26
Derallus sp.		Plate 4.27
Dytiscus marginalis	Linnaeus, 1758	Plate 4.28
Copelatus sp.	Erichson, 1832	Plate 4.29
Hydrovatus sp.		Plate 4.30
Laccophilus sp.		Plate 4.31
Family: Elmidae		
Dubiraphia sp.	Sanderson, 1954	Plate 4.32
Promoresia sp.	Sanderson, 1954	Plate 4.33
Order: Trichoptera		
Family: Hydropsychidae		
Hydropsyche sp.	Pictet, 1834	Plate 4.34
Family: Hydroptilidae		
Agraylea sp.	Curtis, 1834	Plate 4.35
Order: Diptera		
Family: Chironomidae		
Ablabesmyia sp.	Johannsen, 1905	Plate 4.36
Chironomus fractilobus	Kieffer, 1923	Plate 4.37
Chironomus transvalensis	Kieffer, 1923	Plate 4.38
Pentaneura sp.	Johannsen, 1905	Plate 4.39
Polypedilum sp.	Kieffer, 1912	Plate 4.40
Family: Ceratogonidae		
Leptoconops sp.		Plate 4.41
Dasyhelea sp.		Plate 4.42
Family: Culicidae		
Anopheles sp.		Plate 4.43
Culex sp. (larvae)	Linnaeus, 1758	Plate 4.44
Family: Sciomyzidae		
Sciomyzidae larvae		Plate 4.45

Family: Stratiomyidae		
Stratiomyid sp.		Plate 4.46
Family: Tanyderidae		
Protoplasa sp.	Osten-Sacken, 1859	Plate 4.47
Order: Hymenoptera		
Family: Formicidae		
Formicida sp.		Plate 4.48
Pogonomyrmex sp.	Mayr, 1868	Plate 4.49
Order: Odonata		
Family: Gomphidae		
Gomphus sp.	Leach, 1815	Plate 4.50
Family: Libellulidae		
Libellula sp.	Linnaeus, 1758	Plate 4.51
Sympetrum striolatum	Charpentier, 1840	Plate 4.52
Sympetrum fonscolombei	Say, 1832	Plate 4.53
Tholymis sp.		Plate 4.54
Family: Coenagrionidae		
Coenagrion pulchellum	Van der Linden, 1823	Plate 4.55
Coenagrion scitulum	Rambur, 1842	Plate 4.56
Enallagma sp.	Charpentier, 1840	Plate 4.57
Family: Lestidae		
Lestes dryas	Leach, 1815	Plate 4.58
Order: Plecoptera		
Family: Perlidae		
Neoperla sp.	Needham, 1905	Plate 4.59
Phylum: Mollusca		
Class: Gastropoda		
Order: Architaenioglossa		
Family: Ampullaridae		
Pila ovata	Olivier, 1804	Plate 4.60

Pomacea lineata		Plate 4.61

Order: Cycloneritida

Family: Neritida

Neritina sp.	Rafinesque, 1815	Plate 4.62

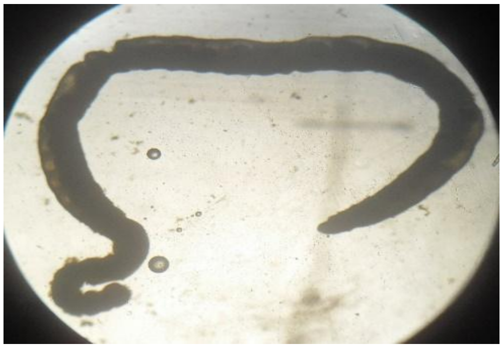

Plate 4.1: ***Branchiura sowerbyi***

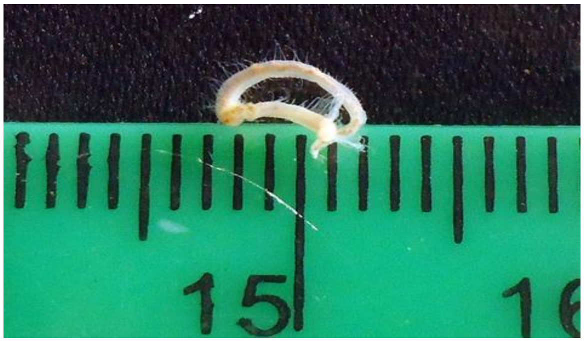

Plate 4.2a: ***Nais* sp.**

Plate 4.2b: ***Nais* sp.**

Plate 4.3: ***Pristina* sp.**

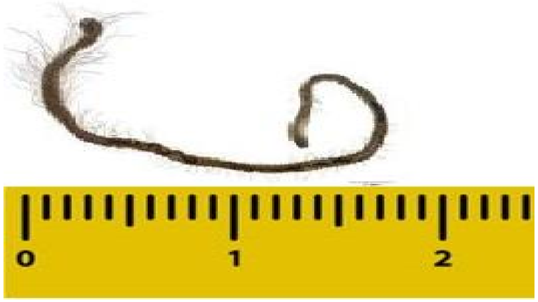

Plate 4.4: ***Branchiodrilus* sp.**

Plate 4.5: ***Lumbriculus variegatus***

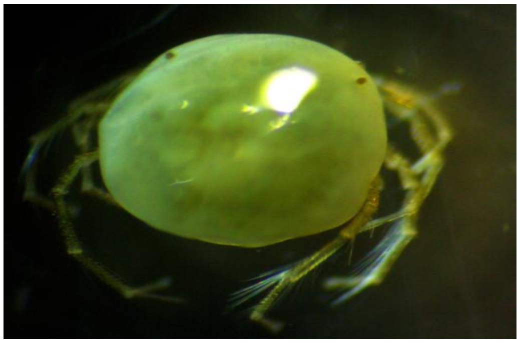

Plate 4.6: *Hydryphantes incertus*

Plate 4.7: *Caridina africana*

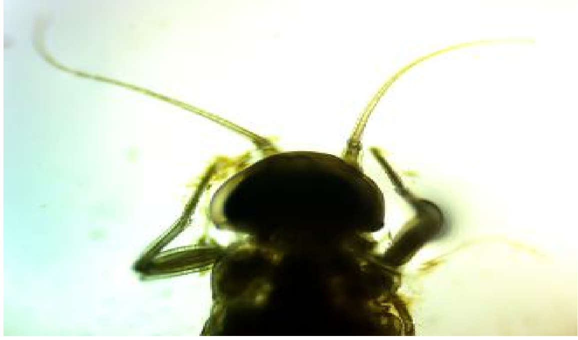

Plate 4.8a: *Baetis* sp. (Anterior view)

Plate 4.8b: *Baetis* sp. (Posterior view)

Plate 4.9: *Centroptilum* sp.

Plate 4.10a: *Cloeon simplex*

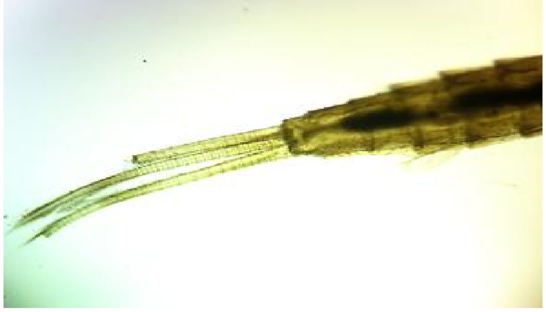

Plate 4.10b: *Cloenis cylindroculum* (Anterior view)

Plate 4.10c: *Cloenis cylindroculum* (Posterior

view)

Plate 4.11: ***Pseudocloeon*** **sp.**

Plate 4.12: ***Leptophlebia*** **sp.**

Plate 4.13a: ***Adenophlebiodes*** **sp.**

Plate 4.14: ***Heptagenia*** **sp**

Plate 4.15: ***Gerris lacustris***

Plate 4.16: ***Belostoma*** **sp.**

Plate 4.17: ***Lethocerus*** **sp.**

Plate 4.18: ***Microvelia*** **sp.**

Plate 4.19: ***Velia*** **sp.**

Plate 4.20: ***Rhagovelia*** **sp.**

Plate 4.21: ***Pelocaris femoratus***

Plate 4.22: ***Nepa apiculata***

Plate 4.23: ***Notonecta*** **sp.**

Plate 4.24: ***Hydrophilus*** **sp.**

Plate 4.25a: ***Philydrus*** **sp. (Anterior view)**

Plate 4.25b: ***Philydrus*** **sp. (Posterior view)**

Plate 4.26: ***Amphiops gibbos***

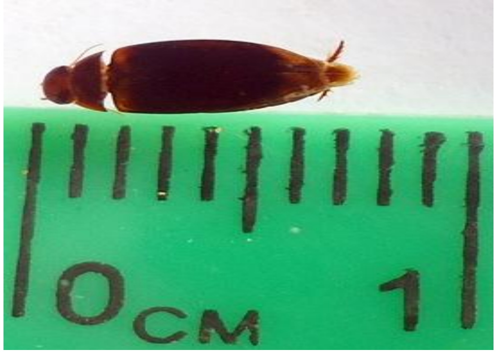

Plate 4.28: ***Dytiscus marginalis***

Plate 4.29: ***Copelatus*** **sp.**

Plate 4.30: ***Hydovatus*** **sp.**

Plate 4.31a: ***Laccophilus sp*****. (anterior region)**

Plate 4.31b: ***Laccophilus sp*****. (posterior region)**

Plate 4.32a: ***Dubiraphia*** **sp. larva**

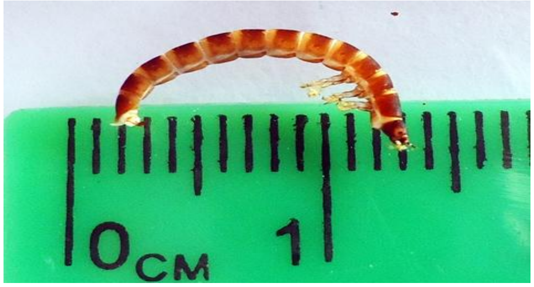

Plate 4.33b: ***Dubiraphia*** **sp. (Abdominal reg**

Plate 4.35: ***Hydropsyche*** **sp.**

Plate 4.36: ***Agraylea*** **sp.**

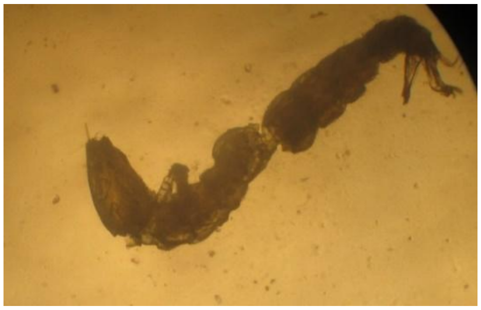

Plate 4.37: ***Ablabesmyia*** **sp.**

Plate 4.38a: ***Chironomus fractilobus*** **(Anterior region)**

Plate 4.38b: ***Chironomus fractilobus*** **(Posterior region)**

Plate 4.39a: ***Chironomus transvalensis*** **(Anterior region)**

Plate 4.39b: ***Chironomus transvalensis*** **(Posterior region)**

Plate 4.40a: ***Pentaneura*** **sp. (Anterior region)**

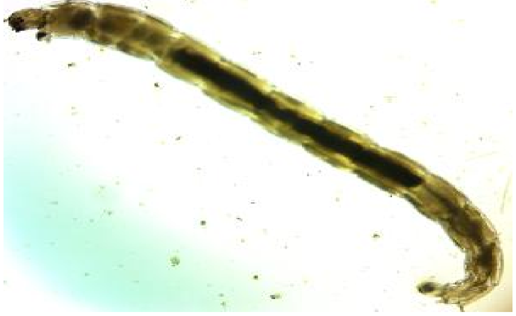

Plate 4.40b: ***Pentaneura*** **sp. (Posterior region)**

Plate 4.41: ***Polypedilum*** **sp.**

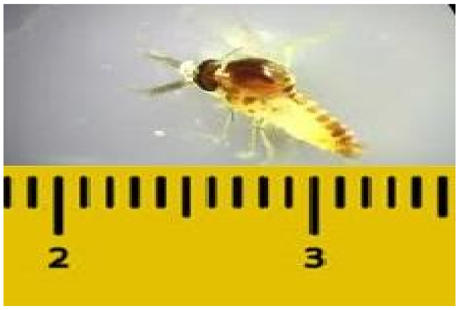

Plate 4.42: ***Leptocconops*** **sp.**

Plate 4.43: ***Dasyhelea*** **sp**

Plate 4.44: ***Anopheles*** **sp. (larvae)**

Plate 4.45: ***Culex*** **sp. (larvae)**

Plate 4.48: ***Protoplasa* sp.**

Pla

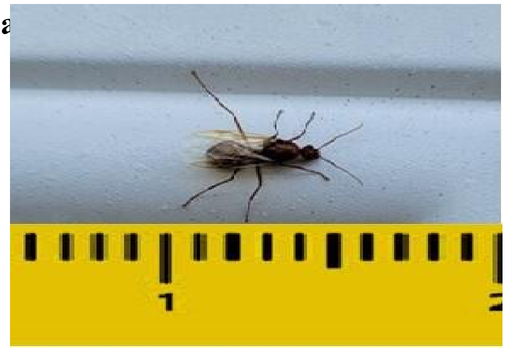

Plate 4.49: Formicida

Plate 4.50: ***Pogonomyrmex* sp.**

Plate 4.51: ***Gomphus* sp.**

Plate 4.52: ***Libellula sp*.**

Plate 4.53: ***Sympetrum striolatum***

Plate 4.54: *Sympetrum fonscolombei*

Plate 4.55: *Tholymis* sp.

Plate 4.56: *Coenagrion pulchellum*

Plate 4.57: *Coenagrion scitulum*

Plate 4.58a: *Enallagma* sp. (Head region)

Plate 4.58b: *Enallagma* sp. (lamellae)

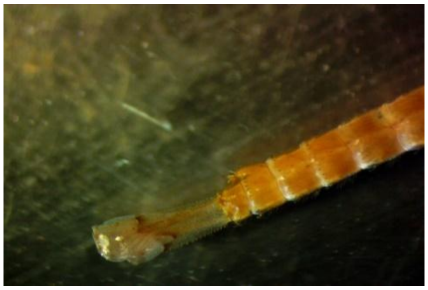

Plate 4.59a: *Lestes dryas* (Anterior view)

Plate 4.59b: *Lestes dryas* (Posterior view)

Plate 4.60: *Neoperla* sp.

Plate 4.61: *Pila ovata*

Plate 4.62: ***Pomacea lineata***

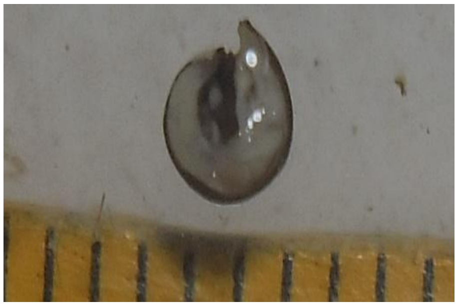

Plate 4.63: ***Neritina* sp.**

4.4.2 Community Structure

From the four rivers examined, two points were selected on each river. These are the reference and impacted locations. The benthic macroinvertebrate samples collected from these locations were studied to assess the taxa composition, abundance, distribution, diversity and dominance. The results acquired were used to evaluate the water quality of the river.

4.4.3 Composition, Abundance and Distribution of Macrobenthic Invertebrates

Generally, the taxa composition, abundance and distribution are shown in Table 4.12. A total of 233 taxa comprising 2694 individuals were gathered from the two sampling methods. In table 4.13, the relative abundance of Benthic Macroinvertebrates across the various study stations are represented. The overall abundance of the benthic macroinvertebrates from various study stations, when subjected to Chi-Square goodness of fit test showed no significant difference ($p > 0.05$) across the stations as shown in Table 4.14. Figure 4.43 shows the spatial variations for relative abundance in macroinvertebrates obtained from the study sites.

4.4.3.1 Dominant Orders of Macroinvertebrates

The distribution of macrobenthic invertebrate assemblages at various stations showed that Diptera, Ephemeroptera and Coleoptera were the dominant taxa recording a total of 1005, 473 and 407 individuals respectively. The sub-dominant taxa were Hemiptera, Odonata and Haplotaxida with a total of 276, 155 and 115 individuals respectively (Figure 4.44).

The distribution of macrobenthic invertebrates among the various stations increased in the order Orhionmwon River (Impacted Station) > Irogbe River (Impacted Station) > Irogbe River (Reference Station) > Orhionmwon River (Reference Station) > Okhuaihe River 2 (Impacted Station) > Okhuaihe River 1 (Reference Station) > Okhuaihe River 1 (Impacted Station) >

Okhuaihe River 2 (Reference Station). Species abundance was highest in the Okhuaihe River 2 (Reference Station) with a total of 545 individuals and lowest at Irogbe River (Impacted Station) with a total of 40 individuals (Table 4.14).

Table 4.15 shows the various Diversity Indices of Benthic Macroinvertebrates in the Selected Rivers. From the table, Dominance Index was highest in Irogbe River (Impacted Station) and least in Okhuaihe River 1 (Impacted Station), while, Shannon Wiener Index was highest in Okhuaihe River 1 (Impacted Station) and least in Irogbe River (Impacted Station). Margalef Index was highest in Okhuaihe River 2 (Reference Station) and least in Orhionmwon River (Reference Station), while, Evenness Index was highest in Orhionmwon River (Impacted Station) and least in Irogbe River (Impacted Station).

Table 4.12: Abundance and Distribution of Macrobenthic invertebrates at the Rivers in Ikpe Community, Edo State (August, 2021 – January, 2023)

Taxa		Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River	
		Reference	Impacted	Reference	Impacted	Reference	Impacted	Reference	Impacted
Arachnida (Trombidiformes)	*Hydryphantes incertus*	0	0	0	0	0	0	3	0
Haplotaxida	*Branchiura sowerbyi*	2	0	0	0	2	0	3	0
	Branchiodrilus sp.	4	0	0	8	2	0	1	0
	Nais sp.	0	0	0	0	28	19	9	17
	Pristina sp.	0	0	0	2	0	1	0	1
	Lumbriculus variegatus	4	0	0	2	5	0	5	0
Decapoda	*Caridina Africana*	14	16	6	6	9	6	12	12
Ephemeroptera	*Baetis sp.*	46	20	134	142	3	8	3	1
	Centroptilum sp.	0	0	0	0	5	18	13	10
	Cloeon sp.	0	0	0	0	1	10	3	0
	Pseudocloeon sp.	0	0	0	0	3	10	9	9
	Heptagenia sp.	0	2	0	0	0	2	0	0
	Leptophlebia sp.	0	0	0	0	4	2	8	2
	Adenophlebiodes sp.	0	0	0	0	0	0	0	5
Hemiptera	*Pelocaris femoratus*	0	0	0	0	0	2	4	2
	Gerris lacustris	0	0	0	0	34	29	55	39
	Belostoma sp.	0	0	2	0	1	0	1	0
	Lethocerus sp.	0	0	0	0	7	5	13	6
	Microvelia sp.	0	0	0	0	9	7	6	3
	Rhagovelia sp.	0	2	0	4	1	2	1	3
	Velia sp.	0	0	0	0	1	2	1	3
	Notonecta sp.	0	0	0	0	3	1	4	2
	Nepa apiculate	0	0	0	0	4	7	6	4
Coleoptera	*Hydrophilus* sp.	0	0	0	0	1	12	21	11
	Amphiops gibbos	0	0	0	0	33	47	27	34

	Taxa	Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River	
		Reference	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**
	Derallus sp.	0	0	2	0	2	0	1	0
	Dytiscus marginalis	0	0	0	0	38	53	48	22
	Copelatus sp.	0	0	0	0	6	7	5	2
	Hydrovatus sp	0	0	2	0	0	0	0	0
	Laccophilus sp	2	0	2	0	2	0	1	0
	Promoresia sp.	0	0	0	0	4	0	1	0
	Dubiraphia sp.	0	0	0	0	1	2	1	4
	Philhydrus sp.	0	0	0	0	1	4	4	6
Trichoptera	*Hydropsyche* sp.	0	0	0	2	0	0	4	1
	Agraylea sp.	0	0	0	0	3	14	8	9
Diptera	*Chironomus fractilobus*	60	5	41	6	82	62	91	67
	Chironomus transvaalensis	54	3	45	6	80	61	75	84
	Anopheles sp	0	0	2	0	3	0	2	0
	Culex sp. (larva)	10	0	8	2	3	7	0	1
	Polypedilum sp.	0	0	0	0	2	8	4	2
	Pentaneura sp.	0	0	0	0	27	19	0	0
	Protoplasa sp.	0	0	0	0	0	3	1	0
	Ablabesmyia sp.	4	2	8	8	0	0	4	2
	Leptoconops sp	22	0	8	2	6	0	1	0
	Dasyhelea sp	0	0	2	0	2	0	1	0
	Sciomyzidae larvae	0	0	2	0	2	0	0	0
	Stratiomyid sp.	0	2	0	0	1	0	0	0
Hymenoptera	Formicidae	0	0	0	2	0	1	0	0
	Pogonomvrmex sp.	0	0	0	0	2	1	2	2
Odonata	*Gomphus* sp.	0	0	0	0	6	4	1	0
	Libellula sp.	0	0	0	0	21	20	21	12
	Sympetrum striolatum	0	0	0	0	6	4	2	8
	Sympetrum fonscolombei	0	0	0	0	3	2	1	1
	Tholymis sp.	0	2	0	0	0	2	0	1

	Taxa	**Orhionmwon River**		**Irogbe River**		**Okhuaihe 1 River**		**Okhuaihe 2 River**	
		Reference	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**
	Enallagma sp.	0	0	0	0	8	6	2	4
	Coenagrion pulchellum	0	0	0	0	0	0	1	0
	Coenagrion scitulum	0	0	0	0	1	0	2	0
	Lestes dryas	0	6	0	4	0	2	2	0
Plecoptera	*Neoperla* sp.	0	0	0	0	6	5	37	6
Gastropoda	*Pila ovata*	0	0	0	0	1	1	2	0
	Pomacea lineata	0	0	6	12	3	4	2	3
	Neritina sp.	0	0	0	0	3	9	13	13
	Number of Species	**11**	**10**	**15**	**15**	**49**	**43**	**52**	**38**
	Number of Individuals	**222**	**60**	**270**	**208**	**481**	**491**	**548**	**414**

Table 4.13: Relative Abundance of Benthic Macroinvertebrates across the Study Stations

Taxa	Number of Species	Relative Abundance (%)
Branchiura sowerbyi	7	0.26
Lumbriculus variegatus	16	0.59
Chironomus fractilobus	414	15.37
Chironomus transvalensis	408	15.14
Ablasbesmyia sp.	28	1.04
Baetis sp.	357	13.25
Heptagenia sp.	4	0.15
Dasyhelea sp.	5	0.19
Pomacea lineata	30	1.11
Caridina africana	81	3.01
Rhagovelia sp.	13	0.48
Culex sp.	31	1.15
Lestes sp.	14	0.52
Tholymis sp.	5	0.19
Pristina sp.	4	0.15
Sciomyzidae larvae	4	0.15
Laccophilus sp.	7	0.26
Derallus sp.	5	0.19
Anopheles sp.	7	0.26
Belostoma sp.	4	0.15
Leptoconops sp.	39	1.45
Hydrovatus sp.	2	0.07
Formicidae	3	0.11
Branchiodrilus sp.	15	0.56
Stratiomyid	3	0.11
Hydropsyche sp.	7	0.26
Hydryphantes incertus	3	0.11
Nais sp.	73	2.71
Centroptilum sp.	46	1.71
Cloeon sp.	14	0.52
Pseudocloeon sp.	31	1.15

Taxa	**Number of Species**	**Relative Abundance (%)**
Leptophlebia sp.	16	0.59
Adenophlebiodes sp.	5	0.19
Pelocaris femoratus	8	0.30
Gerris lacustris	157	5.83
Lethocerus sp.	31	1.15
Microvelia sp.	25	0.93
Velia sp.	7	0.26
Notonecta sp.	10	0.37
Nepa apiculate	21	0.78
Hydrophilus sp.	45	1.67
Amphiops gibbos	141	5.23
Dytiscus marginalis	161	5.98
Copelatus sp.	20	0.74
Promoresia sp.	5	0.19
Dubiraphia sp.	8	0.30
Philhydrus sp.	15	0.56
Agraylea sp.	34	1.26
Polypedilum sp.	16	0.59
Pentaneura sp.	46	1.71
Protoplasa sp.	4	0.15
Pogonomvrmex sp.	7	0.26
Gomphus sp.	11	0.41
Libellula sp.	74	2.75
Sympetrum striolatum	20	0.74
Sympetrum fonscolombei	7	0.26
Enallagma sp.	20	0.74
Coenagrion pulchellum	1	0.04
Coenagrion scitulum	3	0.11
Neoperla sp.	54	2.00
Pila ovata	4	0.15
Neritina sp.	38	1.41
Total	**2694**	**100**

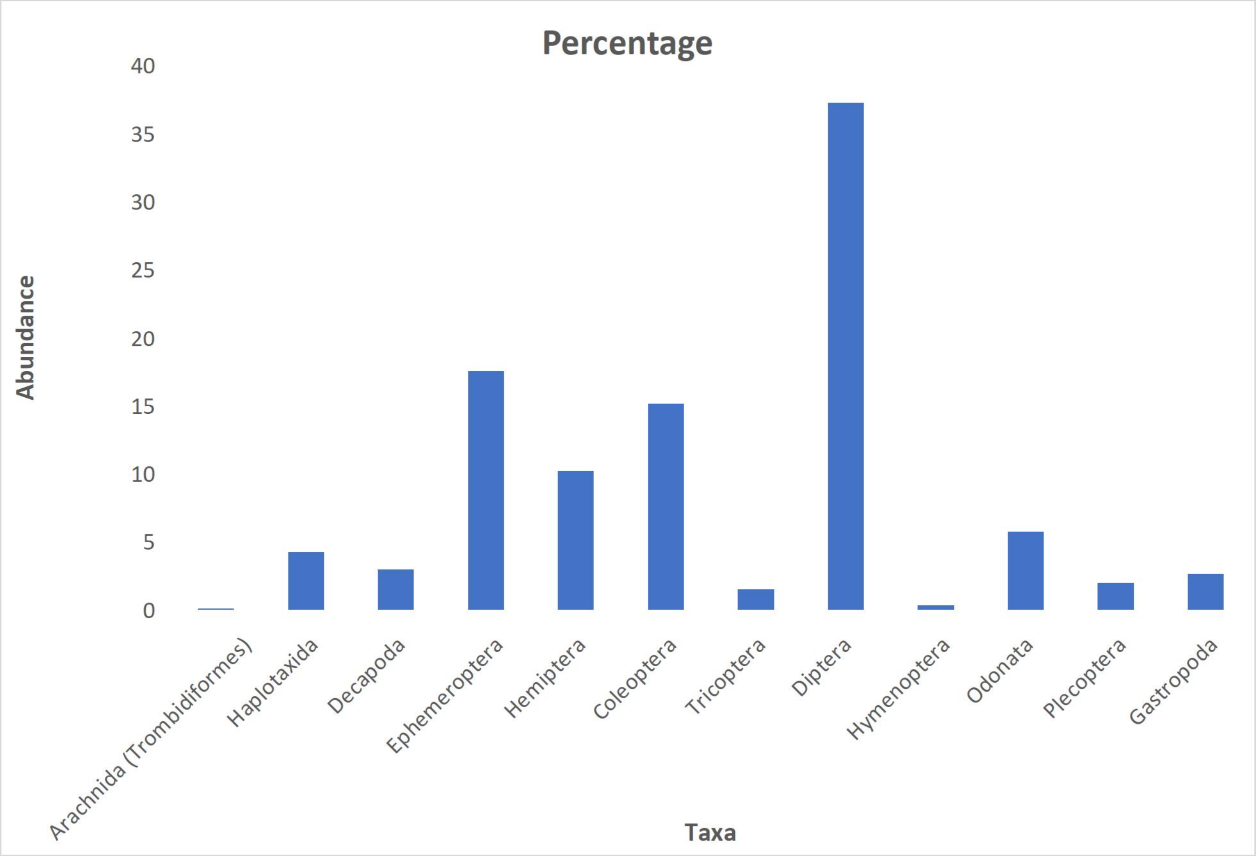

Figure 4.39: Percentage Abundance of Benthic Macroinvertebrates across the Study Stations

Table 4.14: Spatial Distribution of Benthic Macroinvertebrates Composition across the Stations

Diversity Indices	Orhionmwon River		Irogbe River		Okhuaihe 1 River		Okhuaihe 2 River		P-Value
	Reference	Impacted	Reference	Impacted	Reference	Impacted	Reference	Impacted	
Arachnida	0	0	0	0	0	0	3	0	$p > 0.05$
Haplotaxida	10	0	0	12	37	20	18	18	
Decapoda	14	16	6	6	9	6	12	12	
Ephemeroptera	46	22	132	142	16	50	36	27	
Hemiptera	0	2	2	4	60	55	91	62	
Coleoptera	2	0	6	0	88	125	109	79	
Trichoptera	0	0	0	2	3	14	12	10	
Diptera	150	12	116	24	208	160	179	156	
Hymenoptera	0	0	0	2	2	2	2	2	
Odonata	0	8	0	4	45	40	32	26	
Plecoptera	0	0	0	0	6	5	37	6	
Gastropoda	0	0	6	12	7	14	17	16	
Total	**222**	**60**	**270**	**208**	**481**	**491**	**548**	**414**	

Note: $p > 0.05$ = No Significant difference

Table 4.15: Diversity Indices of Benthic Macroinvertebrates in the Selected Rivers

Diversity Indices	**Orhionwon River**		**Irogbe River**		**Okhuaihe 1 River**		**Okhuaihe 2 River**	
	Reference	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**	**Reference**	**Impacted**
Taxa_S	11	10	15	15	49	43	52	38
Individuals	222	60	270	208	481	491	548	414
Dominance_D	0.19	0.21	0.30	0.48	0.08	0.07	0.08	0.09
Simpson_1-D	0.81	0.79	0.70	0.52	0.92	0.93	0.92	0.91
Shannon_H	1.87	1.87	1.67	1.40	3.00	3.11	3.04	2.86
Evenness_eˆH/S	0.59	0.65	0.35	0.27	0.41	0.52	0.40	0.46
Margalef	1.85	2.20	2.50	2.62	7.77	6.78	8.09	6.14
Equitability_J	0.78	0.81	0.62	0.52	0.77	0.83	0.77	0.79

4.4.4 Abundance of Benthic groups across ecological status of Rivers

The results showed that across the 10 benthic groups, only the abundance of Coleopteran was significant across ecological status (W = 56, p-value = 0.004185), which indicates that there was sufficient evidence that the abundance of Coleoptera was different between reference sites and impacted sites with impacted having high abundance of coleopteran than reference sites (Fig 4.40).

However, Haplotaxida (W = 31.5, p-value = 1.000), Diptera (W = 48.5, p-value = 0.09217), Ephemeroptera (W = 36, p-value = 0.712), Gastropoda (W = 44, p-value = 0.07598), Decapoda (W = 21.5, p-value = 0.2846), Hemiptera (W = 35, p-value = 0.7876), Odonata (W = 20.5, p-value = 0.2374), Trichoptera (W = 40.5, p-value = 0.2697) and Hymenoptera (W = 36, p-value = 0.3816) did not show any significant difference between impacted and reference sites therefore did not reveal sufficient evidence that both sites were different for these benthic taxa.

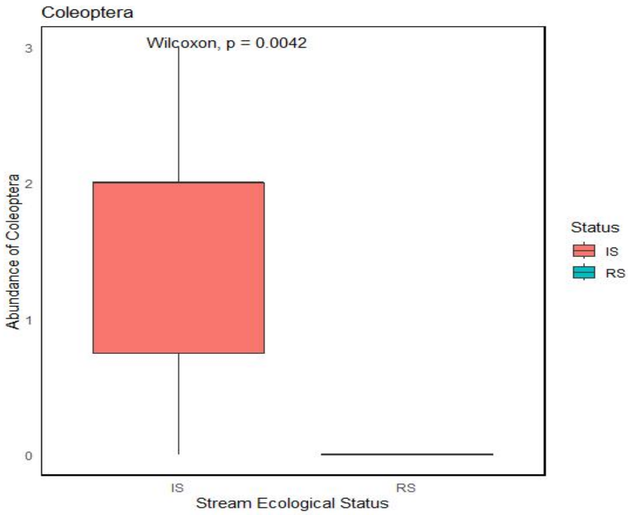

Figure 4.40: Box plots comparing the abundance of coleopteran between Impacted (IS) and Reference (RS) site.

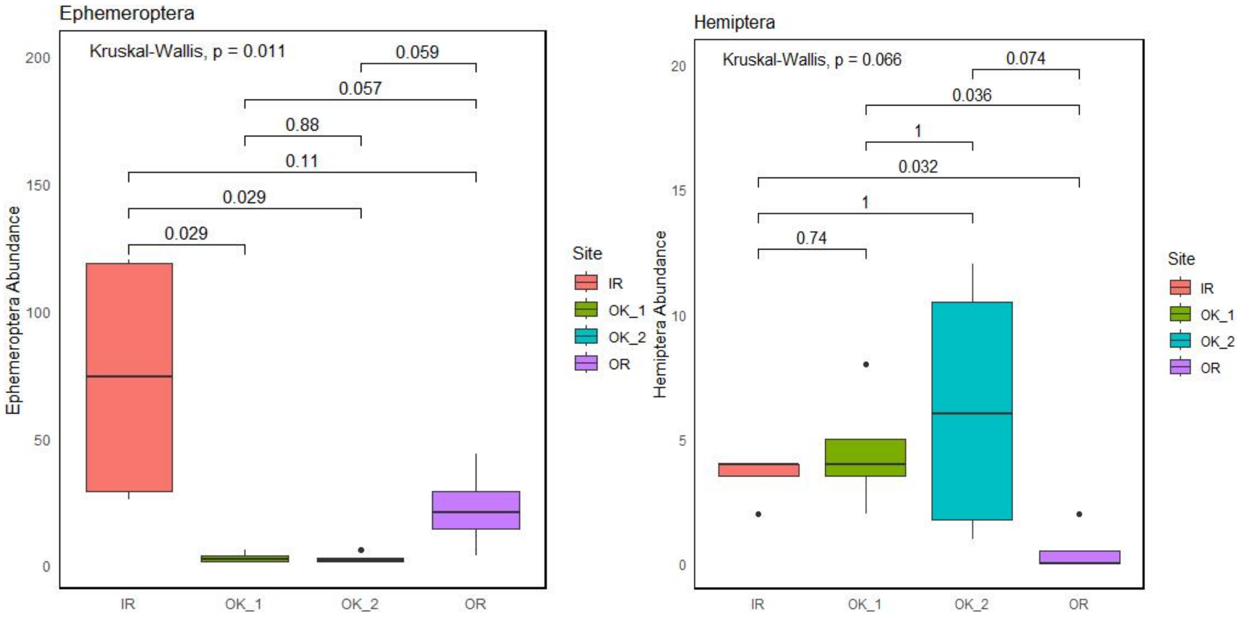

Figure 4.41: Box plots comparing the abundance of significant benthic taxa across sites.

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Species indices did not show significant difference across pollution status

$F_{1,\,14}$ = 2.338, p-value= 0.1485: Abundance across reference and impacted sites

$F_{1,\,14}$ = 0.3166, p-value= 0.5826: Richness across reference and impacted sites

$F_{1,\,14}$ = 0.237, p-value= 0.6339: Diversity across reference and Impacted sites

W = 38.5, p-value = 0.5283: Dominance across reference and Impacted sites

W = 35.5, p-value = 0.7525: Evenness across reference and Impacted sites

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$F_{3, 12}$ = 0.4136, p-value= 0.7463: Abundance across stations

$F_{3, 12}$ = 13.7, p-value= 0.0003512: Richness across stations

$F_{3, 12}$ = 5.692, p-value= 0.01164: Diversity across stations

χ = 9.2728, df = 3, p-value = 0.02588: Dominance across stations

χ = 10.891, df = 3, p-value = 0.01233: Evenness across stations

4.4.4.1 Abundance of Benthic groups across four stream stations

To compare the abundance of benthic groups across sites of the sampled streams, Kruskal-Wallis Chi square test was conducted. This is a non-parametric Anova test and it was used analyse the abundance of the response variables (benthic groups) across sites.

The results revealed a significant difference in the abundance of Ephemeroptera and a slight difference in the abundance of Hemiptera across sites (Table 4.16). Across all benthic taxa, Ephemeroptera had the highest abundance, followed Hemiptera, while Haplotaxida reported the lowest abundance across stations (Table 4.16). Furthermore, results of pairwise comparison using Wilcoxon method showed that the difference in Ephemeroptera abundance across the four sites was significant between stations IR and OK_1, IR and OK_2, OK_1 and OR, and OK_2 and OR (Figure 4.46). However, the difference in the abundance of Hemiptera across sites was driven by IR and OR, and OK_1 and OR (Figure 4.46).

However, other benthic taxa did not show any significant difference in abundance across sites (Table 4.16).

Table 4.16: Results of Kruskal-Wallis rank sum test showing benthic taxa relationship across sites

Taxa	**χ**	**Df**	**p-value**
Haplotaxida	0.730	3	0.866
Diptera	5.201	3	0.158
Ephemeroptera	11.128	3	**0.011**
Gastropoda	1.179	3	0.758
Decapoda	5.771	3	0.123
Hemiptera	7.210	3	**0.066**
Odonata	4.794	3	0.188
Coleoptera	1.730	3	0.630
Trichoptera	2.808	3	0.422
Hymenoptera	3.000	3	0.392

χ =Kruskal-Wallis chi-squared; df =degree of freedom

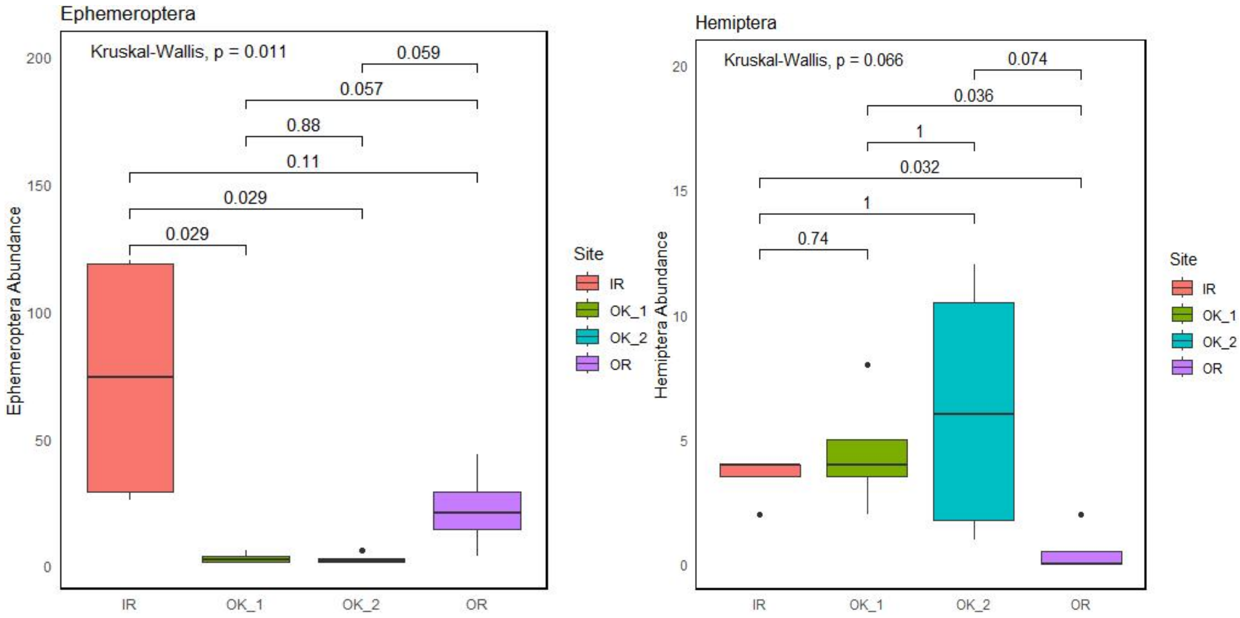

Figure 4.42: Box plots comparing the abundance of significant benthic taxa across sites.

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Species indices did not show significant difference across pollution status

$F_{1,14}$ = 2.338, p-value= 0.1485: Abundance across reference and impacted sites

$F_{1,14}$ = 0.3166, p-value= 0.5826: Richness across reference and impacted sites

$F_{1,14}$ = 0.237, p-value= 0.6339: Diversity across reference and Impacted sites

W = 38.5, p-value = 0.5283: Dominance across reference and Impacted sites

W = 35.5, p-value = 0.7525: Evenness across reference and Impacted sites

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$F_{3,12}$ = 0.4136, p-value= 0.7463: Abundance across stations

$F_{3,12}$ = 13.7, p-value= 0.0003512: Richness across stations

$F_{3,12}$ = 5.692, p-value= 0.01164: Diversity across stations

χ = 9.2728, df = 3, p-value = 0.02588: Dominance across stations

χ = 10.891, df = 3, p-value = 0.01233: Evenness across stations

To find out which group are statistically different from one another, each significant model was subjected to a post hoc test. TukeyHSD post hoc test was used for linear models involving richness ($F_{3,\ 12}$ = 13.7, p-value= 0.0003512) and diversity ($F_{3,\ 12}$ = 5.692, p-value= 0.01164), while Kruskal-wallis test was used for models involving dominance (χ = 9.2728, p-value = 0.02588) and evenness (χ = 10.891, p-value = 0.01233).

Overall, macroinvertebrate richness showed significant difference across sites, with stations IR having the highest richness, while OR having the lowest richness. There was a difference in Macroinvertebrate richness between stations OK_2 and OR, OK_1 and OR, IR and OR, IR and OK_2.

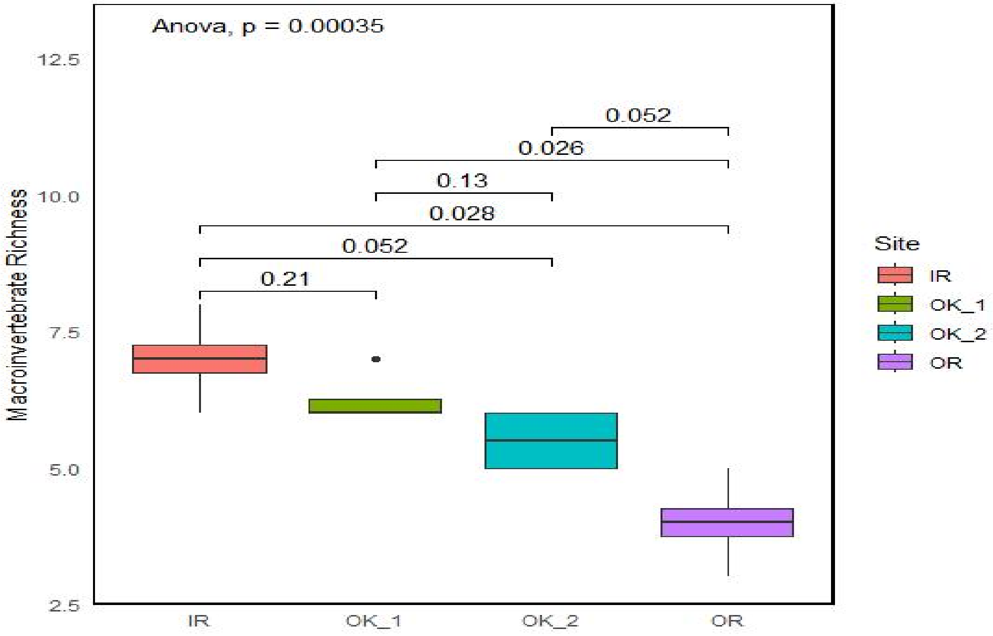

Figure 4.43: Box plots showing post-hoc comparison for macroinvertebrate richness across four stations.

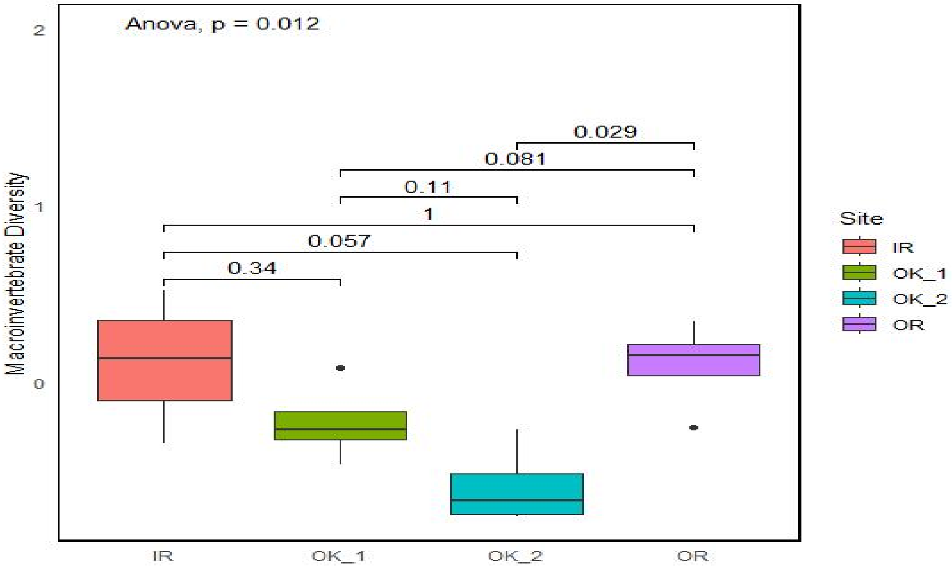

Figure 4.44: Box plots showing post-hoc comparison for macroinvertebrate diversity across four stations

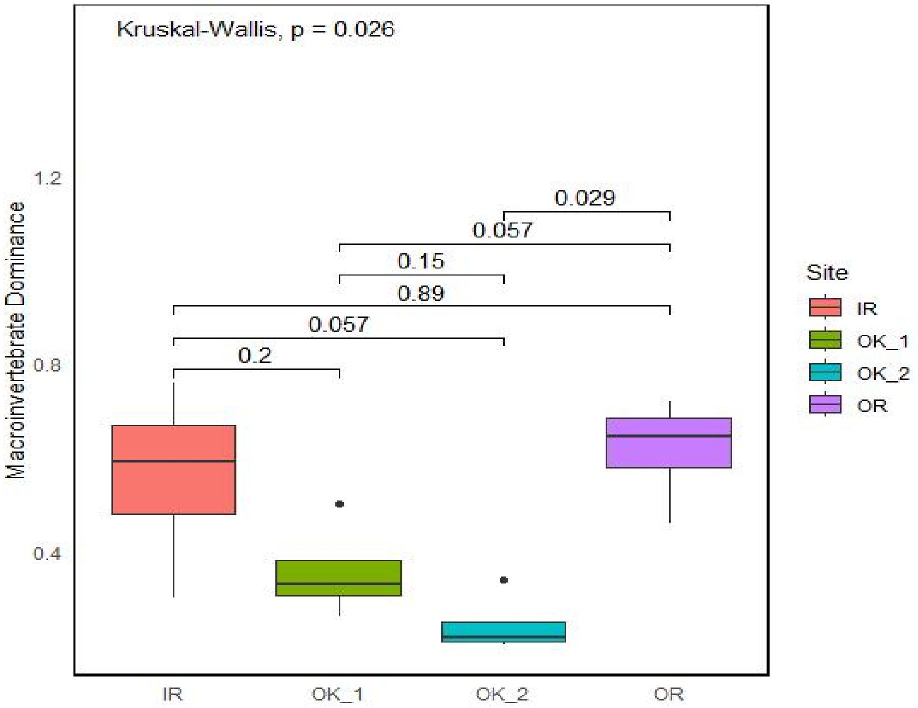

Figure 4.45: Box plots showing post-hoc comparison for macroinvertebrate dominance across four stations

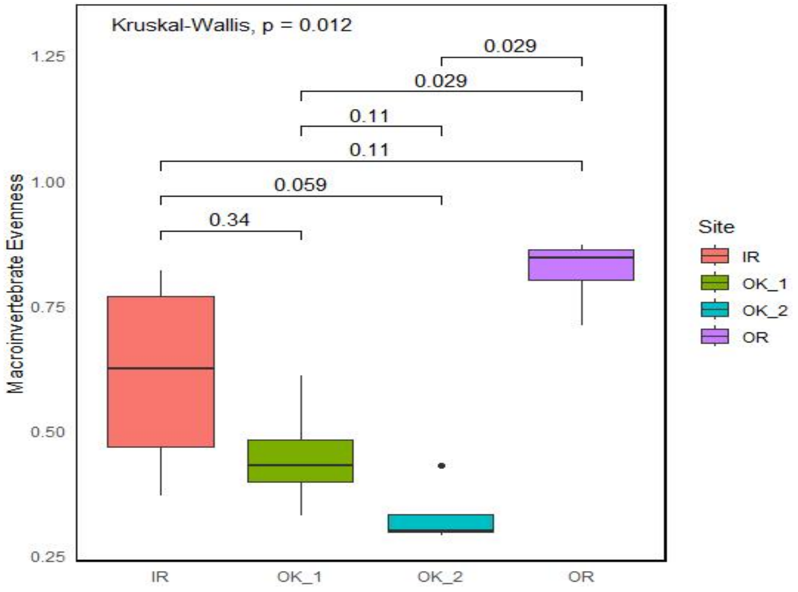

Figure 4.46: Box plots showing post-hoc comparison for macroinvertebrate evenness across four stations

4.5 Development of Multimetric Index for the Selected Rivers in Edo State

4.5.1 Metric Screening

Out of 39 metrics applied, 29 passed the sensitivity test (Table 4.17) and among the 14 seasonally stable metrices (Table 4.18), only three were deemed non-repeatable (Table 4.19) and non-redundant (Table 4.20). However, in addition to the three non-redundant metrices, metrices such as Ephemeroptera, Odonata-Coleoptera Abundance (Odo.Col) and one trait-based measure, Abundance of Fliers (Fl) that scaled through the seasonality test and deemed repeatable (Table 4.17) were included in the MMI rating.

Table 4.17: Sensitivity output of macroinvertebrate metrics

Metrices Across pollution status	**Sensitivity**	**W**	**p-value**
Dec	Sen	30.50	0.92
Aca	Dis	36.00	0.38
Col	Sen	33.00	0.96
Dip	Dis	39.00	0.08
Eph	Sen	29.50	0.83
Gas	Dis	24.00	0.42
Hem	Sen	27.50	0.67
Hym	Dis	26.00	0.50
Odo	Sen	27.00	0.63
Oli	Sen	34.00	0.87
Ple	Sen	36.50	0.65
Tri	Sen	28.00	0.69
Chironomidae	Dis	48.00	0.10
Odo-Col	Sen	25.00	0.49
Chi-Oli	Dis	47.00	0.13
EPT	Sen	33.50	0.92
ETOC	Sen	27.00	0.64
Gas-Dec	Sen	21.50	0.29
Gas-Dip	Sen	31.00	0.96
Tabn	Sen	42.00	0.33
Tdiv	Sen	27.00	0.65
Teve	Sen	26.00	0.56
Tric	Sen	26.00	0.56
Tdom	Sen	29.50	0.83
CG	Dis	45.00	0.19
CGS	Sen	29.00	0.78
FF	Sen	43.50	0.24
PH	Dis	40.00	0.17
Pr	Sen	38.50	0.53
Sc	Sen	24.50	0.46
SCG	Sen	29.00	0.79
Sh	Sen	31.50	1.00
Bu	Dis	45.50	0.17
Cl	Sen	32.50	1.00
Cr	Sen	27.00	0.63
CS	Dis	42.00	0.25
Fl	Sen	42.50	0.27
Sk	Sen	24.50	0.44
Sw	Sen	41.00	0.38

Table 4.18: Seasonal stability output of macroinvertebrate metrics

Seasonal stability	X	p-value	Status
Dis	0.3590	0.5491	Stable
Dis	0.3784	0.5385	Stable
Dis	3.0000	0.0833	Stable
Sen	0.7875	0.3749	Unstable
Sen	0.0875	0.7674	Unstable
Dis	2.1875	0.1391	Stable
Sen	0.3836	0.5357	Unstable
Dis	0.3784	0.5385	Stable
Dis	0.0875	0.7674	Stable
Dis	1.3494	0.2454	Stable
Sen	0.7500	0.3865	Unstable
Dis	1.0457	0.3065	Stable
Sen	0.7500	0.3865	Unstable
Dis	0.7500	0.3865	Stable
Sen	0.3333	0.5637	Unstable
Dis	0.1898	0.6631	Stable
Sen	0.0854	0.7702	Unstable
Dis	0.1898	0.6631	Stable
Dis	0.3784	0.5385	Stable
Sen	0.0897	0.7645	Unstable
Sen	1.3333	0.2482	Unstable
Sen	0.1898	0.6631	Unstable
Dis	0.1921	0.6612	Unstable
Sen	1.0000	0.3173	Unstable
Sen	0.0000	1.0000	Unstable
Dis	0.1898	0.6631	Unstable
Dis	3.4521	0.0632	Stable
Sen	4.3418	0.0372	Unstable
Dis	0.3333	0.5637	Stable

Table 4.19: Repeatability potential (S:N) of macroinvertebrate metrics

Metrics	S	N	S:N	Status
Decapoda	16.60	11.43	1.45	Rejected
Aca	0.56	0.00	0.00	Rejected
Coleoptera	810.93	1070.86	0.76	Rejected
Diptera	1844.43	1599.14	1.15	Rejected
Ephemeroptera	1145.46	1213.27	0.94	Rejected
Gastropoda	12.13	12.50	0.97	Rejected
Hemiptera	815.93	603.98	1.35	Rejected
Hymenoptera	0.78	0.79	1.00	Rejected
Odonata	83.83	65.93	1.27	Rejected
Oligochaeta	59.90	40.50	1.48	Rejected
Plecoptera	39.72	2.55	15.55	Retained
Trichoptera	17.73	28.21	0.63	Rejected
Chironomidae	1838.53	1544.98	1.19	Rejected
Odo.Col	1357.80	1620.79	0.84	Rejected
Chi.Oli	1901.58	1484.70	1.28	Rejected
EPT	1056.80	1137.36	0.93	Rejected
ETOC	1646.12	2203.70	0.75	Rejected
Gas.Dec	25.60	14.79	1.73	Rejected
Gas.Dip	1289.56	1817.36	0.71	Rejected
Tabn	10102.52	9834.27	1.03	Rejected
Tdiversity	0.14	0.08	1.64	Rejected
Taxa evenness	0.01	0.01	0.59	Rejected
Trichoptera	9.36	7.36	1.27	Rejected
Tdom	0.01	0.01	1.14	Rejected
Collectors Gath	2511.58	2096.13	1.20	Rejected
Coll Gath Scrap	70.50	102.70	0.69	Rejected
Filter Feeders	8.43	2.55	3.30	Retained
Predators (Habitual)	0.47	0.00	0.00	Rejected
Predators	2289.05	1684.41	1.36	Rejected
Scavengers	21.58	23.55	0.92	Rejected
Scrapers Grazers	1085.07	1219.98	0.89	Rejected
Shredders	0.60	1.13	0.53	Rejected
Burrowers	2395.30	1916.86	1.25	Rejected
Clingers	412.80	289.64	1.43	Rejected
Crawlers	188.65	260.86	0.72	Rejected
Swimmers	2.40	0.86	2.80	Retained
Fliers	28.66	7.93	3.62	Retained
Skaters	472.92	388.21	1.22	Rejected
Swimmers	1133.13	1284.13	0.88	Rejected

Table 4.20: Multicolinearity of macroinvertebrate metrics that pass stability test ($r \geq 0.78$, $p < 0.05$)

Metrics	Dec	Col	Eph	Oli	Tri	Odo. Col	EPT	Gas.Dec	Tabn	Teve	Tdom	CGS	FF	Pr	Sc	Fl	Sw
Dec	**1.00**	-0.46	-0.21	-0.11	-0.69	-0.39	-0.48	0.27	-0.26	0.69	-0.01	-0.04	-0.55	-0.22	-0.28	0.04	-0.80
Col	-0.46	**1.00**	-0.27	0.44	0.64	**0.96**	-0.04	0.19	0.71	-0.22	0.70	0.76	0.29	0.71	**0.78**	0.48	0.37
Eph	-0.21	-0.27	**1.00**	0.49	-0.15	-0.29	**0.90**	0.24	0.38	-0.36	0.00	0.11	0.69	0.33	0.14	0.36	0.64
Oli	-0.11	0.44	0.49	**1.00**	0.38	0.38	0.53	**0.80**	**0.88**	-0.28	0.49	**0.78**	0.51	**0.88**	**0.79**	**0.88**	0.56
Tri	-0.69	0.64	-0.15	0.38	**1.00**	0.57	0.13	0.06	0.38	-0.60	0.13	0.26	0.17	0.38	0.61	0.24	0.48
Odo.Col	-0.39	**0.96**	-0.29	0.38	0.57	**1.00**	-0.11	0.06	0.66	-0.05	0.76	0.73	0.16	0.71	0.72	0.54	0.27
EPT	-0.48	-0.04	**0.90**	0.53	0.13	-0.11	**1.00**	0.21	0.49	-0.43	0.13	0.22	**0.87**	0.43	0.20	0.31	**0.84**
Gas.Dec	0.27	0.19	0.24	**0.80**	0.06	0.06	0.21	**1.00**	0.58	-0.08	0.22	0.60	0.25	0.55	0.48	0.59	0.22
Tabn	-0.26	0.71	0.38	**0.88**	0.38	0.66	0.49	0.58	**1.00**	-0.23	**0.78**	**0.94**	0.65	**0.98**	**0.86**	**0.83**	0.60
Teve	0.69	-0.22	-0.36	-0.28	-0.60	-0.05	-0.43	-0.08	-0.23	**1.00**	0.33	0.05	-0.44	-0.11	-0.44	0.02	-0.63
Tdom	-0.01	0.70	0.00	0.49	0.13	0.76	0.13	0.22	**0.78**	0.33	**1.00**	**0.89**	0.36	**0.81**	0.58	0.67	0.18
CGS	-0.04	0.76	0.11	**0.78**	0.26	0.73	0.22	0.60	**0.94**	0.05	**0.89**	**1.00**	0.46	**0.94**	**0.79**	**0.80**	0.34
FF	-0.55	0.29	0.69	0.51	0.17	0.16	**0.87**	0.25	0.65	-0.44	0.36	0.46	**1.00**	0.54	0.35	0.26	**0.85**
Pr	-0.22	0.71	0.33	**0.88**	0.38	0.71	0.43	0.55	**0.98**	-0.11	**0.81**	**0.94**	0.54	**1.00**	**0.84**	**0.91**	0.55
Sc	-0.28	0.78	0.14	**0.79**	0.61	0.72	0.20	0.48	**0.86**	-0.44	0.58	**0.79**	0.35	**0.84**	**1.00**	0.76	0.42
Fl	0.04	0.48	0.36	**0.88**	0.24	0.54	0.31	0.59	**0.83**	0.02	0.67	**0.80**	0.26	**0.91**	0.76	**1.00**	0.33
Sw	-0.80	0.37	0.64	0.56	0.48	0.27	**0.84**	0.22	0.60	-0.63	0.18	0.34	0.85	0.55	0.42	0.33	**1.00**

Table 4.21: Comparison of core metrics

		5th percentile (Bottom Limit	95th percentile (Top Limit)	Metric score	+ve metrics	-ve metrics
Decapoda Abundance	Dec	2.50	10.00	5	47.25	7.75
Trichoptera Abundance	Tri	0.00	14.50	10	100.00	0.00
Taxa Evenness	Teve	0.30	0.88	0	-0.64	10.64
Ephemeroptera Abundance	Eph	5.00	99.50	10	94.95	5.05
Odonata-Coleoptera Abundance	Odo.Col	5.00	83.50	10	94.94	5.06
Abundance of Fliers	Fl	0.00	8.50	5	50.00	5.00

Three biological conditions were assigned categories to the final MMI scores, poor (<2.0), fair (2.0-4.0), and good (>5.0), according to Ganasan and Hughes, 1998.The final MMI score was 6.66, an indication that the water was good.

4.5.2 Correlation of Environmental variables

To correlate the final selected metrices with environmental variables, a correlation test was performed on environmental variables using the Spearman's correlation test with environmental variables that were highly collinear ($r \geq 0.80$) removed from the ordination analysis (Edegbene *et al*., 2022). After Spearman's correlation test, 11 out of the 17 environmental variables were incorporated into the ordination analysis with the final selected metrices.

In performing an ordination, core metrics were subjected a linearity test using the Detrended Correspondence Analysis (DCA). Following the rule of thumb, if the first axis length is >4 a CCA is recommended but if it is <4, an RDA is preferable (Ter Braak and Šmilauer, 2002).

From DCA result, the first axis length was <4, necessitating an RDA to test the association between core metrics and environmental variables.

From the RDA analysis, 91% of the variation in the MMI metrics was explained by the physicochemical parameters (Table 4.21).

To test for the significance of the redundancy analysis, a permutational test (*permutest*) using *anova.cca* at 999 permutations (Oksanen 2005) and the result revealed a significant difference between both components of the RDA (Table 4.20)

Table 4.22: DCA components for core metrics

DCA Component	**DCA1**	**DCA2**	**DCA3**	**DCA4**
Eigenvalues	0.53	0.22	0.06	0.06
Additive Eigenvalues	0.53	0.22	0.07	0.05
Decorana values	0.54	0.06	0.02	0.01
Axis lengths	1.87	1.73	0.88	1.14

DCA- Detrended Correspondence Analysis

Table 4.23: Variance partitioning and permutational test output of MMI correlation with physicochemical variables

	Variance	**Proportion**	**F**	**Pr(>F)**
Total	2566.00	1.00		
Constrained	2333.00	0.91	3.64	0.04
Unconstrained	233.10	0.09		

From the RDA biplot, Taxa evenness, Decapoda abundance, Trichoptera abundance and abundance of fliers were negatively correlated with Air Temperature, Nitrate, Dissolved Oxygen and Transparency. On the contrary, Ephemeroptera abundance was positively correlated with Flow velocity, Chloride, BOD_5, Ammonia, Phosphate, water temperature and hydrogen ion concentration (Figure 4.54). However, only Odonata + Coleoptera abundance revealed no correlation with physicochemical variables.

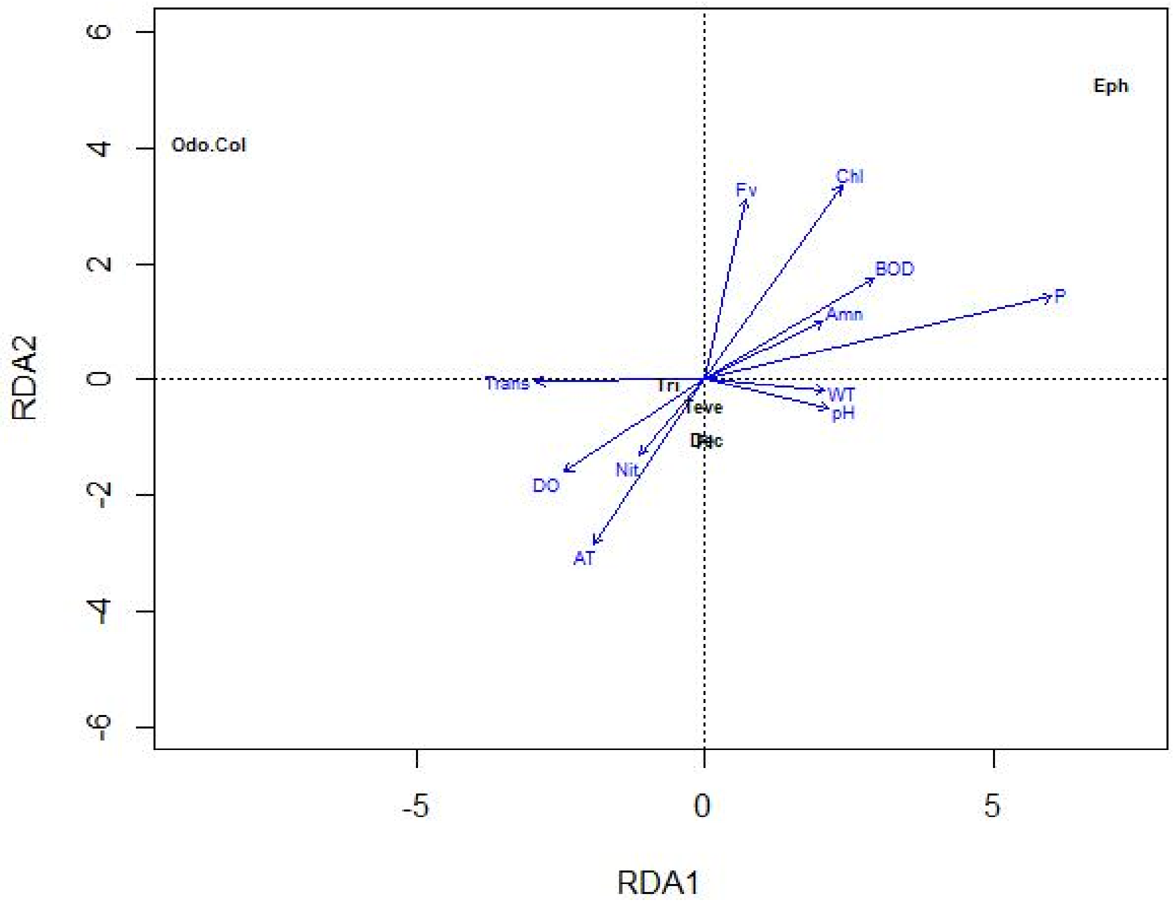

Figure 4.47: Biplot of Redundancy analysis of the correlation between MMI metrics and physio-chemical variables

Physicochemical variables: Trans= Transparency, AT = Air Temperature, Nit = Nitrate, DO= Dissolved Oxygen, pH = Hydrogen ion Concentration, WT = Water Temperature, P = Phosphate, Amn = Ammonium, BOD = Biochemical Oxygen Demand, Chl = Chloride, Fv = Flow Velocity. MMI metrics: Odo.Col = Odonata+Coleoptera Abundance, Eph = Ephemeroptera Abundance, Tri = Trichoptera Abundance, Teve = Taxa Evenness, Dec = Decapoda Abundance, Fl = Abundance of Fliers

CHAPTER FIVE

DISCUSSION

An essential component of keeping an eye on and preserving the health of aquatic ecosystems is the measurement of water quality (Bunn *et al.,* 2010). Rivers are essential natural resources that support human activities such as home usage, industry, and agriculture, as well as other forms of life. However, human activities like industrialization, urbanization, and agricultural practices can cause water quality to decline, endangering human health and the environment. Assessing the overall health of riverine ecosystems may be achieved by utilizing biological markers, such as macroinvertebrate indices, and physicochemical metrics to evaluate water quality (López-López and Sedeño-Díaz 2015; Aazami *et al.,* 2020).

5.1.1 Physical and Chemical Parameters of the River

The water and air temperatures observed in these three rivers followed a similar pattern to what is typically seen in the Niger Delta region, with higher temperatures recorded during the dry season months (Arimoro *et al.,* 2008). However, in this study, anthropogenic factors increased water temperature by indirect mechanisms like deforestation that reduces shade, urbanisation and impervious surfaces that increase runoff and thermal capture, and reduced groundwater inflow from pumping. These activities lead to loss of shading, reduced groundwater exchange, and the effects of a warming global climate and apparently cause net warming of water temperatures. This compares favourably with Caissie, 2006; Hester and Doyle, 2011; and Somers *et al*., 2013. Regarding the pH levels, the three rivers exhibited a range between 5.3 and 6.3, with the Orhionmwon River having the lowest pH among the three, indicating that all the rivers were within the acidic range, this is similar to the findings of Onyegeme *et al.,* 2018. Increased pH in this study can be explained by the fact that rainforest vegetation and underlying geology (parent material/alluvium/shale, etc.) control soil pH. Where heavy rainfall causes leaching and strongly acidifies soils despite rainforest inputs. This compares favourably with studies by Ogeh and Ukodo, 2012; Okonofuah *et al*., 2023. Interestingly, the mean pH across four river stations was higher, potentially due to runoff and diffuse sources of organic pollution from industrialization practices (Ogbomida *et al.,* 2016; Neimi *et al.,* 2017). Seasonal variations had little impact on the pH levels, with slightly higher pH values recorded during the rainy season compared to the dry season. This finding aligns with previous studies conducted in southern Nigeria, which reported higher pH levels during the wet months (Ogbeibu 1991; Okogwu, 2010; Imoobe, 2011). However, it's important to note that the mean pH values did not differ significantly between the dry and wet seasons from a statistical standpoint ($P>0.05$).

The Okhuaihe 2 River had the greatest conductivity value of the research, which varied from 12.50 to 295.80 µS/cm. These results compare favourably to other freshwater body conductivity values in southern Nigeria (Adefemi and Awokunmi 2010; Kolawole *et al.,* 2011). During the rainy season, the mean conductivity readings were noticeably higher. In addition, mean conductivity values increased dramatically (119.34 µS/cm) and somewhat (78.60 µS/cm) during the dry season. This increase was probably caused by an increase in runoff from nearby logging, farming, home chores, gin manufacturing, farming, garbage disposal, and human and animal waste. The mean conductivity values varied statistically significantly between the two seasons, with the wet seasons recording a greater value.

Overall, nitrate, phosphate, and sulphate data show that the nutritional parameters were frequently found to be within the acceptable limits (FME) throughout the studied stations. When compared to the results of Adefemi and Awokunmi (2010), the values for the sulphate parameter showed favourability; the Orhionmwon and Okhuaihe rivers had the greatest value (43.00 mg/L), while the Irogbe and Okhuaihe rivers had the lowest value (17.00 mg/L). But although nitrate had the greatest mean value (1.07±1.01 mg/L) in the dry season, sulphate and phosphate had the highest mean levels (8.08±10.97 and 0.16±0.22 mg/L, respectively) during the rainy season. The primary cause of the elevated nutrient content during the rainy season may have been the constant flow of runoff into the river. The nitrate parameter concurs with Asabor's (2019) conclusion that the mean concentration of all nutritional parameters in the Orogodo River was greater during the dry season, even though the results for sulphate and phosphate conflict with it.

When the mean dissolved oxygen (DO) concentration in this research was compared to the results of Agbaire and Obi (2009), it was low, ranging from 0.20 mg/L to 6.80 mg/L in the dry season and 0.5 to 1.90 mg/L in the rainy season. This demonstrates unequivocally how seasonality impacted DO concentration, which agrees with a study by Odo *et al.,* (2022), where DO was found to be higher in dry season. In contrast to the rapid pace at which bacteria decompose organic matter during the rainy season, which lowers dissolved oxygen levels by consuming it, the high values of dissolved oxygen measured during the dry season were partially caused by the decreased rate of bacterial decomposition. Moreover, aquatic bodies often have reduced flow rates and less mixing during the dry season due to decreased rainfall, which concentrates pollutants, increases water temperatures, and creates thermal stratification, preventing the mixing of water layers. Higher dissolved oxygen levels can result from the concentration of oxygen-rich surface waters caused by this stratification. Because of human and animal waste disposal and animal faeces in the river at Okhuaihe 1 River, it had the lowest mean DO value. According to studies, human and animal wastes has large levels of organic matter, which causes DO depletion very fast (Chapman, 1996; Arimoro *et al.,* 2007; Omole and Ogbiye, 2013).

According to Oram (2014), a water sample with BOD of 1 and 2 mg/L indicates very clean water, 3.0 mg/L indicates, moderately clean water, and > 5 mg/L indicates pollution sources nearby. The mean BOD levels throughout the river stations varied from 0.50 mg/l to 5.40 mg/l, with rivers Orhionmwon and Okhuaihe 1 having the highest concentrations. The BOD content varied seasonally, with 3.10 to 4.60 mg/L in the wet season and 0.5 to 5.4 mg/L in the dry season. The high readings obtained during the wet season are due to an increased load of organic contaminants released into the water. According to Arimoro *et al.,* (2007), the biodegradation of organic materials increased oxygen tension in the water, raising BOD. Surprisingly, in this study, BOD peaked in November at the impacted sites of Orhionmwon river and Okhuaihe River 1 which is a dry season period. This may be because of the decreased volume of water in the rivers which no longer enjoyed the dilution from direct precipitation and runoff but was still subject to a considerable volume of wastes from anthropogenic and animal activities which correlates with findings by Kwadzah, and Iorhemen, in 2015. DO and BOD readings differed considerably between dry and wet seasons ($P < 0.05$, respectively).

The quantity of zinc and copper in the water across the river stations in this investigation was found to be lower than the Federal Ministry of Environment's maximum recommended level for drinking water standards. Conversely, the concentrations of Iron, Manganese, and Chromium exceeded the permissible limit. Numerous studies have previously revealed that trace elements like Copper and Zinc are below the regulatory limit, whereas Iron, Manganese, and Chromium are over it (Orjiekwe *et al.,* 2013; Asante *et al.,* 2014). These findings confirm this conclusion. Except for Chromium, the mean concentrations of the heavy metals examined in this study varied considerably between the two seasons. The wet season had a considerably higher Iron content (2.14 mg/L), which was consistent with findings by Wogu and Okaka (2011).

5.1.2 Physicochemical Parameters of Sediment Samples

The pH and electrical conductivity of sediment ranged from (3.50 to 7.20 and 40.00 µS/cm to 100.00 µS/cm) respectively. The pH values of the sediments were acidic to neutral across the stations which compares favourably with observation by Adesuyi *et al.* (2016) for pH (3.9 to 8.5) with electrical conductivity between 23.0 and 567.0 µS/cm. High temperatures could be responsible for the low pH values reported, as decomposition of organic matter usually occurs with an increase in temperature. Aquatic organisms are sensitive to pH changes and biological treatment requires pH control or monitoring. Surface waters having a pH value below six can be hazardous to aquatic life (Fisher and Wood, 2004). A work done by Gao *et al.* (2012) stated that low pH in water affects oxygen level, thus aquatic organisms survive more in a slightly alkaline water environment. Certain physiological effects on plants and animals are often affected by the number of available ions in the water. In this study, conductivity range was similar to report by Otolo *et al.* (2017) on the sediment studies of Ethiope river, Delta state, Nigeria.

Results from this investigation indicated that the mean values of Phosphate and Nitrate from the Selected Rivers ranged from (2.44 mg/kg – 5.14 mg/kg and 1.87 mg/kg – 4.56 mg/kg) respectively. The study area's nutritional content is reflected in the phosphate and nitrate levels, which exhibit notable changes between stations and months. The high nutrient levels recorded at some sites may be caused by untreated domestic and agricultural wastes from surrounding human settlements, which may have excessive amounts of these nutrients. The nitrate concentration in this study agrees with the range (2.60 - 4.10 mg/kg) recorded by Ezekiel *et al.* (2011) for Sombreiro River. The phosphate values found in this research is also consistent with the range reported by Adesuyi *et al.* (2016).

The mean concentration of heavy metals in the order of dominance is showed: $Fe^{3+} > Zn^{2+} > Cu^{2+} > Cr^{2+} > Mn^{2+}$. Similar reports about Iron dominating heavy metal in sediments has been reported by Wogu and Okaka, 2011; Omoigberale *et al.,* 2013; Imiuwa *et al.,* 2014 and Ogiesoba-Eguakun *et al.*, 2022. Ecological problems include bioaccumulation in aquatic species and possible health issues for humans who depend on these water sources due to the predominance of iron and other heavy metals in sediments. The humic substance in the soil (derived from organic leftovers) is a major contributing component for Iron dominance. Metal in the soil may be mobilized or immobilized by organic materials.

5.1.3 Principal Component Analysis for Water and Sediment Parameters

The PCA results reveal that water quality variations in the study area are driven by both natural hydrogeochemical processes and anthropogenic activities such as effluent discharge, erosion, and urban runoff. The PCA for Water Parameters revealed that Phosphate, Depth, Sulphate, Turbidity, Chloride, Manganese, Zinc, Iron, Electrical Conductivity, Water Temperature, Width and Copper were the most important factors controlling the water quality in the selected rivers. The results were similar to the Principal Component Analysis from Odigie and Olomukoro (2020) in Ijala, Warri, Delta State.

In summary, the PCA analysis for water demonstrated that water quality in the study area is shaped by a combination of nutrient enrichment, suspended solids, metal contamination, and hydro morphological dynamics. The interplay of natural processes such as flow and sediment interaction with human-induced pressures including wastewater discharge, agricultural runoff, and industrial effluents explains the observed spatial and seasonal variability in water quality. These findings align with previous studies that identified similar drivers of aquatic pollution in Edo State, Nigeria (Erhenhi and Omoigberale, 2020; Osikhuemhe and Olomukoro, 2025).

The PCA results for sediment shows that its quality in the study area is influenced by both natural textural properties and human-induced metal inputs. Component 1 links silt, nitrate, and iron, indicating that fine sediments enhance nutrient retention. Component 2 associates clay and manganese, suggesting metal adsorption on finer particles. Component 3 reveals that low pH increases conductivity and phosphate solubility, affecting sediment chemistry. Component 4 identifies zinc and copper as pollution indicators from industrial or agricultural sources. Component 5 shows chromium enrichment in fine sediments, indicating long-term contamination. Overall, the PCA demonstrates that sediment composition and geochemical conditions collectively influence the distribution of nutrients and metals. Natural textural characteristics (silt, clay) and anthropogenic metal inputs (Zn, Cu, Cr, Mn) jointly shape sediment quality. These findings are consistent with previous research in Usen, Edo State, Nigeria (Arimoro *et al*., 2015; Ogbeibu and Ogiesoba-Eguakun, 2019; Ogiesoba-Eguakun *et al*., 2022 and Osikhuemhe and Olomukoro, 2025b).

5.1.4 Risk Assessment

One important indicator of the amount of metal pollution in aquatic bodies is the Pollution Load Index (PLI). It shows the level of pollution, and the variance in it depends on the concentration factor. The contamination factor shows that there was little heavy metal contamination in any of the stations. If the Pollution Load Index (PLI) is less than zero (zero), then there is no metal pollution; if the PLI is equal to or greater than 1, then heavy metal contamination is present in the sediment (Tomlinson *et al.,* 1980). The PLI values of the study area ranged from (0.79 at Okhuaihe River 1.0 to 1.01 at Orhionmwon River), which further indicates that the sediment samples from studied stations varied from “no significant metal pollution” to “moderate metal pollution”. This can be explained by the degree to which anthropogenic activities are a primary cause in the stations (Ogiesoba-Eguakun *et al*., 2022 and Yawo *et al*., 2022).

The Igeo is a quantitative measure used to assess the degree of heavy metal pollution in sediments and soils. The Geoaccumulation index was distinguished into seven classes (0 to 6) by (Müller, 1969, Chakravarty and Patgiri, 2009). Adopting this measure, the Geoaccumulation index values ranged from -2.86 to 4.95 with an average of -3.49. All the metals (Cr, Cu, Fe, Mn and Zn) Igeo values were practically uncontaminated (Igeo $\leq$ 0). The low levels of contamination in the stations could be a sign of little anthropogenic influence in the areas under study as well as a potential self-purification mechanism for the river and the direction of the water flow.

There are five pollution degrees and four risk levels recognized with respect to a comprehensive potential ecological risk index according to Jiang *et al.* (2014). The ecological risk index values varied in relation to heavy metal. For the individual heavy metals, their ecological risk factor values ranged as follow Fe (0.99 – 1.06), Cu (1.21 – 5.06), Mn (0.84 – 1.00), Cr (1.74 – 2.05) and Zn (1.00 – 1.04). The PERI values were ranged from 6.42 in Okhuaihe River 1 to 10.12 in Irogbe River with an average of 8.99. This shows that the potential ecological risk was low (*Eri* < 40) and the Risk Index was also low (RI < 150) (Hakanson, 1980; Jiang *et al.*, 2014).

Metal concentrations did not significantly differ between reference and impacted sites. However, elevated metal levels can pose toxicological risks to macroinvertebrates, impacting their survival and reproductive success (Mebane *et al*., 2020). While no significant differences were observed, monitoring metal concentrations is crucial for assessing long-term ecological impacts on macroinvertebrate communities.

5.1.5 Macroinvertebrate Composition, Abundance and Diversity

The major taxa represented the various river stations include Arachnida, Haplotaxida, Decapoda, Ephemeroptera, Hemiptera, Coleoptera, Trichoptera, Diptera, Hymenoptera, Odonata, Plecoptera, and Gastropoda. Notable species include *Baetis* sp., *Centroptilum* sp., *Caridina Africana, Chironomus fractilobus*, and *Hydrophilus* sp.

The total number of individuals is highest in Okhuaihe 2 River (548 at the reference site and 414 at the impacted site), followed by Okhuaihe 1 River (481 at the reference site and 491 at the impacted site), Irogbe River (270 at the reference site and 208 at the impacted site), and Orhionmwon River (222 at the reference site and 60 at the impacted site).

5.1.5.1 Orhionmwon River

The absence of *Hydryphantes incertus* in both the reference and impacted areas indicates a potential sensitivity or specific habitat requirements for this Arachnida species. Studies in other parts of the world suggest that water mites are reliable bioindicators of ecosystem health due to their sensitivity to pollution and changes in water quality (Di Sabatino *et al*., 2000; Goldschmidt, 2016). This could explain their absence on both sites, as the conditions in the sampled streams may not have met the specific requirements for *Hydryphantes incertus*. Notably, the Haplotaxida *Branchiura sowerbyi* showed no individuals in the impacted area, suggesting vulnerability to environmental changes. This is consistent with findings from previous research where *Branchiura sowerbyi*, is known to thrive in organically rich and oxygenated sediments but becomes less abundant in polluted or heavily impacted environments (Arimoro and Keke, 2021). Naididae (Clitellata) exhibited substantial differences between the reference and impacted areas, particularly with *Nais sp*. and *Lumbriculus variegatus*. Naididae, including species like *Nais* sp., are often found in a variety of freshwater environments and can tolerate moderate pollution levels. However, their presence in higher numbers in reference areas, compared to impacted areas, indicates that they are somewhat sensitive to severe degradation. This is consistent with findings from previous research, where Naididae species tend to decrease in abundance as water quality deteriorates due to factors such as organic pollution or heavy metal contamination (Odume, 2020; Dallas, 2004). The abundance of *Lumbriculus variegatus* in the reference area as compared to the impacted area aligns with global studies showing that it can tolerate a range of environmental conditions but becomes less dominant in areas where pollution is severe, particularly where there is sediment contamination (OECD, 2008). Its lower numbers in impacted areas could be a result of increased sediment toxicity or nutrient loading, further supporting its role as a bioindicator of environmental health. Decapoda, represented by *Caridina africana*, showed a higher abundance in the impacted area, which may indicate a certain level of resilience or adaptation to environmental changes. This finding aligns with global studies that report the capacity of some crustaceans to thrive in disturbed environments, often due to their adaptability to fluctuating water quality and pollutants (Mosley and Flinders, 2017). Ephemeroptera, such as *Baetis* sp., displayed a decline in abundance in the impacted area, suggesting potential sensitivity to environmental stressors. This pattern has been similarly documented in studies across Nigeria and Africa, highlighting the vulnerability of Ephemeroptera to habitat degradation and environmental stressors (Olomukoro and Ezemonye, 2007; Iyagbaye *et al*., 2017).

5.1.5.2 Irogbe River

In Irogbe River, *Branchiodrilus sp*. of Haplotaxida exhibited higher abundance in the impacted area, implying a potential preference for altered conditions. This pattern has been similarly observed in other studies, where *Branchiodrilus* species are often found in areas with increased organic pollution, suggesting their adaptability to disturbed environments (Keke *et al*., 2021). Similar to Orhionmwon River, Naididae (Clitellata) and *Lumbriculus variegatus* showed higher abundance in the impacted area, further confirming their association with pollution-tolerant habitats (Odume *et al*., 2016). Decapoda (*Caridina africana*) maintained consistent abundance across reference and impacted areas, a finding that aligns with broader research indicating that some crustaceans can adapt to fluctuating water quality (Edward and Ugwumba, 2011). Decapoda had been recognized to be intolerant to induced environmental degradation, according to Ogbeibu and Oribhabor (2002). The Species of decapods documented in this study have been recognised by Ogbeibu and Oribhabor (2002) at Ikpoba River, Omoigberale and Ogbeibu (2010) at Osse River, Olomukoro and Ezemonye (2007) in the study of aquatic invertebrates in southern Nigeria.

Ephemeroptera *Baetis sp.* exhibited a decline in abundance in the impacted area, aligning with observations from Orhionmwon River. Hemiptera (*Gerris lacustris*) and Coleoptera (*Amphiops gibbos*) displayed higher abundance in the impacted area, suggesting a potential response to environmental changes, possibly due to their tolerance of altered habitat conditions. This aligns with studies by Mohammed *et al*. (2021) and in contrast to Arimoro and Keke (2016).

5.1.5.3 Okhuaihe 1 and Okhuaihe 2 Rivers

The rivers Okhuaihe 1 and Okhuaihe 2 displayed similar patterns in macroinvertebrate composition and abundance. Notably, Naididae (Clitellata) and certain taxa within Decapoda maintained higher abundance in the impacted areas, a trend observed in other studies on pollution-tolerant taxa (Arimoro and Keke, 2021). Ephemeroptera *Baetis* sp. again showed a decline in abundance in the impacted areas, indicating potential sensitivity, which indicated less favourable conditions of the water and aligns with findings by Olomukoro and Abdul-Rahman (2010) on the species' response to environmental stressors.

Hemiptera (*Gerris lacustris, Belostoma* sp.) and Coleoptera (*Dytiscus marginalis*) displayed higher abundance in the impacted areas of both rivers, as previously reported in similar studies of macroinvertebrates responding to pollution (Mohammed *et al*., 2021). This suggests a potential adaptation or preference for altered environmental conditions.

5.1.6 Overall Trends

Across all rivers, it is evident that the Okhuaihe Rivers (1 and 2) have higher macroinvertebrate diversity and abundance compared to the other two rivers, there were notable differences in the macroinvertebrate composition, abundance, and diversity between reference and impacted areas. The variations observed in different taxa indicate the complex response of macroinvertebrates to environmental changes. Some taxa, such as Naididae (Clitellata) and certain Decapoda species, displayed higher abundance in impacted areas, suggesting resilience or adaptability, which aligns with the findings of Anyanwu *et al*. (2021). In contrast, Ephemeroptera, specifically *Baetis* sp., exhibited a consistent decline in abundance in impacted areas, indicating potential vulnerability to environmental stressors as observed in previous studies by Olomukoro and Ezemonye, 2007, Olomukoro and Abdul-Rahman (2010), Ogbeibu *et al*. (2013) and Iyagbaye *et al*. (2017).

5.1.7 Seasonal and spatial variation of Macroinvertebrates fauna across the Stations in the three rivers

The spatial distribution of benthic macroinvertebrate composition across stations in the rivers of Ikpe Community, Edo State, unveils nuanced insights into fauna's seasonal and temporal variation. This discussion synthesizes the findings from the provided data focusing on taxonomic abundance and its implications.

5.1.7.1 Orhionmwon River

In this river, the absence of Arachnida suggests a consistent absence throughout the study period. Haplotaxida exhibits differing abundances between reference and impacted areas, possibly indicating fluctuating environmental conditions. Decapoda and Hemiptera show modest abundance with slight variations, while Ephemeroptera indicates a subtle increase in impacted areas which may reflect adaptive shifts over time, in contrast to findings from Arimoro and Ikomi (2008).

5.1.7.2 Irogbe River

Here, Haplotaxida displays pronounced differences in abundance between reference and impacted areas, suggestive of local environmental perturbations. Ephemeroptera notably increases in impacted areas, hinting at temporal shifts in community composition, aligning with studies that suggest these taxa may indicate changing conditions (Mathers *et al*., 2017). Coleoptera also shows heightened abundance in impacted areas, suggesting sensitivity to environmental alterations as noted in Olomukoro and Ezemonye (2007).

5.1.7.3 Okhuaihe 1 River

Like the Irogbe River, Haplotaxida showcases notable disparities in abundance, indicating varying environmental influences. Ephemeroptera exhibits a conspicuous increase in impacted areas, indicating a potential shift toward species that are more adaptable to anthropogenic changes (Idowu *et al.*, 2020). Coleoptera displays significant abundance in impacted areas, possibly reflecting the influence of anthropogenic stressors.

5.1.7.4 Okhuaihe 2 River

Haplotaxida demonstrates comparable abundances between reference and impacted areas in this river, suggesting a degree of stability. Ephemeroptera and Coleoptera also show slight increases in impacted areas, indicating potential responses to environmental changes as suggested by studies on African rivers (Edegbene *et al.*, 2020).

5.1.8 The Implications of Variations in Water Parameters on Macroinvertebrate Composition, Abundance, and Diversity

The examination of spatial variation in physical and chemical parameters across selected rivers provides critical insights into the potential influences on macroinvertebrate communities within the Ikpe Community, Edo State. These findings underscore the complex interplay between water quality parameters and macroinvertebrate fauna, shaping the ecological dynamics of freshwater ecosystems.

5.1.8.1 Temperature, Depth, Flow Rate, and Width Effects

Although temperature, depth, flow rate, and width did not exhibit significant differences between sites, their roles in shaping macroinvertebrate habitat preferences are noteworthy. These physical parameters influence macroinvertebrate distribution and abundance, with taxa such as Trichoptera and Odonata exhibiting preferences for specific flow regimes and water depths (Mathers *et al.*, 2017).

5.1.8.2 Transparency, Turbidity, and Their Impacts

Although transparency and turbidity did not exhibit significant differences, their variations indicate potential alterations in habitat suitability for macroinvertebrates. Clearer waters typically support diverse macroinvertebrate communities, while increased turbidity may favour sediment-tolerant taxa such as Gastropoda (*Pomacea lineata*) and Chironomidae as observed by (Rabeni *et al.,* 2005; Mathers *et al.,* 2017).

5.1.8.3 pH Variation and Its Effects on Macroinvertebrates

Across all rivers, pH levels exhibited significant differences between reference and impacted sites. Such variations can profoundly influence macroinvertebrate communities, as pH directly affects physiological processes and habitat suitability for various taxa (Idowu *et al.,* 2020). For instance, the Orhionmwon River showed significant pH differences, impacting macroinvertebrate diversity and abundance. Ephemeroptera and Hemiptera taxa exhibited notable shifts in abundance at impacted sites, possibly due to pH alterations.

5.1.8.4 Electrical Conductivity (EC) and its Ecological Implications

Significant differences in EC were observed between reference and impacted sites in most rivers. High EC levels can indicate pollution or salinity, potentially affecting macroinvertebrate communities by altering habitat conditions (Edegbene *et al*., 2020). The Okhuaihe 2 River experienced notable EC variations, affecting macroinvertebrate composition and diversity. Diptera and Coleoptera taxa showed sensitivity to EC changes, with notable declines in abundance at impacted sites.

5.1.8.5 Nutrient Concentrations and Their Effects on Macroinvertebrate Communities

Nutrient concentrations, including phosphate, nitrate, and ammonium, varied between reference and impacted sites across rivers. While no consistent patterns were observed, nutrient enrichment can lead to eutrophication, altering macroinvertebrate community structure. The Okhuaihe 1 River exhibited significant changes in nutrient concentrations, impacting macroinvertebrate abundance and diversity. Ephemeroptera and Plecoptera taxa were particularly affected by nutrient alterations, indicating potential shifts in community composition. The increased nutrient load, a common result of anthropogenic activities, may promote eutrophication, affecting the abundance of sensitive taxa like *Ephemeroptera* and *Plecoptera* (Olomukoro and Ezemonye, 2007).

5.1.9 Identification of Priority Rivers and Macroinvertebrates for Conservation

Based on the observed changes in water parameters and their ecological implications, priority rivers and macroinvertebrates for conservation can be identified. The Orhionmwon River and Okhuaihe 2 River exhibited significant alterations in pH and EC, impacting macroinvertebrate diversity and abundance. Additionally, taxa such as Ephemeroptera and Diptera showed sensitivity to environmental changes, highlighting their importance for conservation efforts.

5.1.10 Water Quality Index

The WQI values ranged from 9.3503 (Okhuaihe I, Reference Station) to 16.5331 (Okhuaihe II, Impacted Station). According to the provided classification criteria in Table 4.5, all stations fell within the "Excellent" water quality category, with WQI values less than 50.

Across the four rivers, there was a relatively narrow range of WQI values, indicating that the overall water quality was consistently excellent. However, some spatial variations could be observed.

Orhionmwon River: The impacted station (10.7427) had a slightly lower WQI value compared to the reference station (14.8219), suggesting a potential impact on water quality at the impacted site. The findings here were in a similar range to WQI values (11.24-16.15) reported by Oboh and Agbala (2017) for the Siluko River in Edo State.

Irogbe River: Both the impacted and reference stations have the same WQI value (10.3099), indicating no discernible difference in water quality between the two sites. These findings were also similar to the conclusions by Egun and Ogiesoba-Eguakun (2018)

Okhuaihe I River and Okhuaihe II River: The impacted station (13.3450) exhibited a higher WQI value than the reference station (9.3503), which could be attributed to various factors, including potential sources of pollution or natural variations in water quality parameters. Similar to Okhuaihe I, Okhuaihe II impacted station (16.5331) had a higher WQI value compared to the reference station (14.4089), implying a potential impact on water quality at the impacted site. These values were slightly higher than the water WQI values (9.17-10.40) recorded for Okuaihe River by Egun and Ogiesoba-Eguakun (2018).

5.1.11 Comparison of Benthic Macroinvertebrate Abundances across Stations

The comparison of benthic macroinvertebrate group abundances across different ecological statuses of streams provides valuable insights into the effects of environmental disturbance on aquatic ecosystems. The use of the Mann-Whitney U test, a non-parametric test, is appropriate for comparing the abundance of benthic groups between reference sites (RS) and impacted sites (IS) because it does not assume a normal distribution in the data, making it a robust method for analyzing ecological data (Edegbene *et al*., 2022).

5.1.11.1 Significance of Coleoptera abundance

The results of the Mann-Whitney U test indicated that Coleoptera was the only benthic group with a statistically significant difference in abundance between the reference and impacted sites ($W = 56$, $p = 0.004185$). Specifically, Coleoptera showed higher abundance in impacted sites compared to reference sites. This finding suggests that Coleoptera, particularly certain beetle species, may be more resilient to environmental stressors or that impacted sites provide conditions more conducive to their proliferation. Such a pattern has been observed in other studies, where Coleoptera tend to thrive in habitats with altered hydrology or increased organic matter (Mbah and Vajime (1989).

Higher abundance of Coleoptera in impacted sites could be associated with factors such as nutrient enrichment, increased organic pollution, or habitat modifications resulting from human activities, which may favour certain beetle species. Mohammed *et al*. (2021) reported similar findings in streams affected by agricultural runoff and urbanization in Nigeria, where Coleoptera were more abundant in impacted areas due to the availability of organic detritus and altered flow conditions. This report is in contrast to Arimoro and Keke (2016) who reported that the abundance of some coleopteran groups indicates total pollution-free.

5.1.11.2 Non-significant differences in other Benthic groups

For the other nine benthic groups (Haplotaxida, Diptera, Ephemeroptera, Gastropoda, Decapoda, Hemiptera, Odonata, Trichoptera, and Hymenoptera), the Mann-Whitney U test did not reveal significant differences in abundance between reference and impacted sites. This result suggests that these taxa may be less sensitive to the ecological disturbances present in the impacted streams or that the impact was not strong enough to elicit a significant response in their populations.

5.1.11.3 Haplotaxida

The lack of significant difference in Haplotaxida (W = 31.5, p = 1.000) could be due to their ability to thrive in a wide range of environmental conditions, including those with varying levels of pollution. Haplotaxida, particularly oligochaetes, are often considered pollution-tolerant species, capable of surviving in degraded habitats with low dissolved oxygen and high levels of organic pollution (Thorne and Williams, 1997; Buss *et al*., 2002; Buss and Salles 2007; Masese *et al*., 2013; Mazzoni *et al*., 2014; Arimoro and Keke 2017, 2021)). This tolerance may explain why their abundance did not significantly differ between reference and impacted sites.

5.1.11.4 Diptera

Although Diptera (W = 48.5, p = 0.09217) did not show a statistically significant difference, the p-value suggests a trend toward significance, indicating that Diptera, particularly Chironomidae (non-biting midges), may exhibit some response to environmental stressors. Dipterans are considered tolerant of pollution, particularly those in the Chironomidae family, which are known to dominate in disturbed habitats ((Mbah and Vijime, 1989; Umeham, 1989; Iyagbaye *et al*., 2017). However, the lack of significance in this study could be due to high variability in Diptera abundance across the sites.

5.1.11.5 Ephemeroptera

Ephemeroptera (W = 36, p = 0.712), a group known for its sensitivity to pollution, did not show a significant difference between reference and impacted sites. This finding is surprising given that Ephemeroptera, particularly mayflies, are often used as bioindicators of good water quality due to their preference for clean, oxygen-rich environments (Arimoro and Ikomi, 2008; Odume *et al.,* 2012). However, the absence of a significant difference might indicate that the level of disturbance in the impacted sites was not severe enough to reduce Ephemeroptera populations, or that other factors, such as habitat structure or flow velocity, played a more significant role in shaping their abundance.

5.1.11.6 Gastropoda, Decapoda, Hemiptera, Odonata, Trichoptera, and Hymenoptera

The non-significant differences in Gastropoda, Decapoda, Hemiptera, Odonata, Trichoptera, and Hymenoptera abundances suggest that these groups either have a broad tolerance to environmental changes or that the specific stressors in the impacted sites did not disproportionately affect their populations. For example, Gastropoda (W = 44, p = 0.07598) are often associated with a range of water quality conditions, and some species are known to tolerate nutrient enrichment and organic pollution (Strzelec and Krolczyk, 2004). Similarly, Odonata (W = 20.5, p = 0.2374) are known to be relatively resilient to habitat changes, especially dragonflies, which can adapt to a wide range of environmental conditions (Arimoro *et al*., 2015; Mohammed *at al*., 2021).

5.1.11.7 Ecological Implications

The results of this study highlight the importance of Coleoptera as potential indicators of environmental disturbance in freshwater ecosystems. Their increased abundance in impaired sites suggests that they may serve as useful bioindicators for detecting moderate to severe habitat degradation, particularly in streams affected by anthropogenic activities such as agriculture, urbanization, and pollution (Edegbene *et al*., 2022). On the other hand, the lack of significant differences in other taxa may reflect either their resilience to moderate levels of disturbance or the need for more sensitive analytical techniques to detect subtle ecological changes.

The findings also suggest that the ecological status of streams can influence the community composition of benthic macroinvertebrates, but the responses of individual taxa may vary depending on their ecological tolerances and life history traits. Similar patterns have been observed in other African river systems (Kashian and Burton, 2000; Arimoro and Muller, 2010; Mereta *et al*., 2012; Mereta *et al*., 2013).

5.1.11.8 Benthic group abundance across river stations

In analysing the abundance of benthic groups across four river stations using the Kruskal-Wallis Chi-square test, a non-parametric ANOVA test, the study reveals important patterns in how benthic macroinvertebrate communities respond to varying ecological conditions at different sampling sites. This approach is effective in dealing with ecological data that may not follow a normal distribution, making it highly suitable for this type of biological assessment (Odume, 2016; Edegbene *et al*., 2022).

5.1.11.9 Significant differences in Ephemeroptera and Hemiptera abundance

The Ephemeroptera group, also known as mayflies, exhibited a significant difference in abundance across the four stations (χ = 11.128, df = 3, p = 0.011). This is consistent with previous studies that identify Ephemeroptera as sensitive bioindicators of water quality, often thriving in clean, oxygen-rich waters and responding negatively to pollution and habitat degradation (Barber James *et al*., 2008; Sharma and Rawat, 2009; Arimoro and Muller, 2010; Shelly *et al*., 2011). The significant variation in their abundance across sites suggests that some stations may offer better ecological conditions, such as higher dissolved oxygen and less organic pollution, favourable for mayflies.

In this study, post-hoc pairwise comparisons using the Wilcoxon method indicated that the differences in Ephemeroptera abundance were particularly pronounced between stations Irogbe and Okhuaihe 1, Irogbe and Okhuaihe 2, Okhuaehi 1 and Orhionmwon, and Okhuaihe 2 and

Orhionmwon. This suggests that certain stations, particularly Orhionmwon (one of the impacted sites), may be subject to environmental stressors that reduce the abundance of sensitive taxa like Ephemeroptera.

Hemiptera also showed a slight but notable difference in abundance across stations (χ = 7.210, df = 3, p = 0.066). While Hemiptera are generally considered more tolerant to pollution compared to Ephemeroptera, their abundance still fluctuated across stations, possibly driven by habitat factors such as vegetation cover and flow regime. The post-hoc analysis revealed that the differences were mainly driven by stations Irogbe and Orhionmwon, and Okhuaihe 1 and Orhionmwon, indicating that Orhionmwon is ecologically distinct from the other stations in terms of its suitability for Hemiptera.

These findings are consistent with research from African freshwater ecosystems where environmental gradients, particularly related to anthropogenic impacts, can lead to significant spatial variation in benthic communities (Arimoro and Ikomi, 2008; Emere and Nasiru, 2009; Arimoro *et al*., 2015; Arimoro and Keke, 2016). The spatial distribution of sensitive taxa like Ephemeroptera and moderately tolerant groups like Hemiptera highlights the importance of site-specific ecological factors in shaping community structure.

5.1.11.10 Non-significant differences in other Benthic groups

The other benthic groups, including Haplotaxida, Diptera, Gastropoda, Decapoda, Odonata, Coleoptera, Trichoptera, and Hymenoptera, did not exhibit significant differences in abundance across the stations (Table 4.16). This suggests that these taxa may have broader tolerance ranges to the environmental conditions present at the different sites or that the variation in ecological stressors was not strong enough to elicit significant changes in their abundance.

For example, Diptera (especially Chironomidae) are known to be highly tolerant to a wide range of environmental conditions, including pollution and low oxygen levels (Mbah and Vijime, 1989; Umeham, 1989; Victor and Ogbeibu, 1991; Edegbene *et al*., 2015; Arimoro and

Keke 2016). Their abundance did not vary significantly, likely due to their capacity to thrive in both reference and impacted sites. Coleoptera and Odonata, on the other hand, are more mobile and may be able to relocate to more favourable conditions within the river system, explaining the lack of significant variation in their abundance (Arimoro and Keke, 2016).

5.1.11.11 Species Indices across Pollution Status and Stations

The analysis of species indices, including abundance, richness, diversity, dominance, and evenness, provides further insights into the ecological status of the stream stations. Notably, the study found no significant differences in abundance, richness, diversity, dominance, or evenness between reference and impacted sites, indicating that the overall macroinvertebrate community structure was relatively similar across the pollution gradient (F1, 14 = 2.338, p = 0.1485 for abundance; F1, 14 = 0.3166, p = 0.5826 for richness).

However, when comparing species indices across stations, significant differences were observed for richness (F3, 12 = 13.7, p = 0.0003512), diversity (F3, 12 = 5.692, p = 0.01164), dominance (χ = 9.2728, p = 0.02588), and evenness (χ = 10.891, p = 0.01233). These results indicate that the ecological conditions at the different stations have a measurable impact on the macroinvertebrate community structure, with Irogbe (a less impacted or reference station) showing the highest species richness, while Orhionmwon (an impacted site) exhibited the lowest richness.

The Tukey HSD post-hoc test revealed that the significant differences in richness were driven by comparisons between stations Okhuaihe 2 and Orhionmwon, Okhuaihe 1 and Orhionmwon, Irogbe and Orhionmwon, and Irogbe and Okhuaihe 2, underscoring the ecological disparity between the least impacted and most impacted stations. These findings are consistent with studies from Nigerian rivers, which show that human impacts, such as agricultural runoff, urban pollution, and habitat modification, often result in reduced species richness and altered community composition (Dallas and Day 2004; Bonada *et al.*, 2006; Keke *et al.*, 2020; Edegbene *et al.*, 2021).

5.1.11.12 Ecological Implications

The significant differences in Ephemeroptera and species richness across the stream stations highlight the sensitivity of these metrics to ecological disturbances, making them useful indicators for bioassessment and stream health monitoring. Ephemeroptera, as pollution-sensitive taxa, are valuable bioindicators for detecting changes in water quality, while species richness is often associated with habitat complexity and environmental stability (Arimoro *et al.*, 2010; Keke *et al.*, 2021; Edegbene, 2020).

The overall non-significant differences in most benthic taxa suggest that these groups may either be more tolerant of the environmental conditions present across the stations or that the stressors at the impacted sites were not severe enough to significantly reduce their populations. This aligns with global patterns in freshwater ecosystems, where certain macroinvertebrate groups exhibit varying levels of sensitivity to pollution and habitat alteration (Arimoro *et al.*, 2010; Imoobe and Ohiozebau 2010, Gbarakoro and Jude, 2022; Akpan *et al.*, 2024).

5.1.11.13 Metric Screening for Multimetric Index (MMI) Development

Among the 14 seasonally stable metrices observed in this study, only three metrics were identified as non-redundant and non-repeatable (Table 4.17 and Table 4.20) and were retained for further analysis. Additionally, metrices such as Ephemeroptera abundance, Odonata-Coleoptera abundance (Odo.Col), and one trait-based measure, Abundance of Fliers (Fl), which passed the seasonality and repeatability tests, were included in the Multi-Metric Index (MMI) rating.

These findings align with the research conducted by Edegbene *et al.* (2019), who emphasized the importance of selecting non-redundant and ecologically relevant metrics for assessing aquatic ecosystem health in the Niger Delta region. Similarly, Odume (2020) highlighted the significance of repeatability in metric selection, underscoring that only robust and seasonally stable metrics should be used in environmental assessments, particularly in tropical environments like South-South Nigeria.

5.1.11.14 Repeatability Potential of Macroinvertebrate Metrics

The repeatability potential (S ratio) of various macroinvertebrate metrics was calculated to determine their reliability (Table 4.17). Metrics with low S ratios, such as Decapoda abundance, were rejected due to high variability. In contrast, metrics such as Plecoptera (S= 15.55), Filter Feeders (S= 3.30), and Abundance of Fliers (S= 3.62) were retained for further analysis due to their stability.

Plecoptera and Filter Feeders are reliable indicators of stream health in tropical African rivers, particularly in the face of anthropogenic stressors such as industrial pollution and agricultural runoff which assigns with Anyanwu *et al.* (2022). The inclusion of trait-based metrics like Abundance of Fliers, as demonstrated by Edegbene and Arimoro (2012), Keke *et al*., (2021) and Edegbene and Akamagwuna (2022), further strengthens the multi-metric approach to biological assessments, as these metrics capture the ecological functions of aquatic insects.

5.1.11.15 Multicollinearity of Macroinvertebrate Metrics

A multicollinearity test was performed on the macroinvertebrate metrics that passed the stability test ($r \geq 0.78$, $p < 0.05$). Metrics that showed high collinearity were excluded to avoid redundancy. For example, metrics such as Decapoda abundance and Odonata-Coleoptera abundance exhibited high collinearity, while metrics like Ephemeroptera abundance and Abundance of Fliers were retained due to their low collinearity (Table 4.20). In this study, Decapoda abundance and Odonata-Coleoptera abundance despite their high collinearity were selected due to their ecological significance for producing accurate and reliable biotic indices which aligns with Edegbene *et al*. (2021) argument.

5.1.11.16 MMI Rating

The Multi-Metric Index (MMI) rating was calculated based on the core metrics retained after the screening process. The interquartile ranges, mean, median, and standard deviation of these metrics were plotted to assess the differences in macroinvertebrate assemblages between the two types of sites.

In line with the conclusions of Iyagbaye *et al*. (2017), the comparison between impacted and reference sites demonstrates that metrics like Ephemeroptera abundance are highly sensitive to environmental disturbances, making them reliable indicators of water quality.

5.1.11.17 Final Ikpe Community River Biotic Index (ICRBI)

The final Ikpe Community River Biotic Index (ICRBI) was calculated to be 6.66, indicating good water quality which according to Ganasan and Hughes, (1998) in their biological condition categorisation and is consistent with the findings of Akpan (2024) in Eye-Asana River.

Decapoda abundance, Trichoptera abundance, Taxa evenness, Ephemeroptera abundance, Odonata-Coleoptera abundance, and abundance of Fliers are the six metrics that we included in the final MMI for this study. Due to their ecological significance, Decapoda abundance, Odonata-Coleoptera abundance, and Taxa evenness were all included in the MMI rating (Mereta *et al*., 2013, Melo *et al*., 2015, Edegbene *et al*., 2022). Similar criteria were used in previous studies to integrate redundant metrics into an MMI, which depended on equitable representation of all metric measures chosen for MMI creation (Edegbene *et al*., 2019, Mereta *et al*., 2013, Aura *et al*., 2017). Several authors have reported that while taxa in the Odonata and Coleoptera are tolerant of pollution, those in the Order Decapoda and Trichoptera are sensitive to it (Edegbene *et al*., 2012, Mereta *et al*., 2013, olomukoro and Dirisu, 2014, Melo *et al*., 2015, Odume *et al*., 2016, Edegbene *et al*., 2019).

In conclusion, the metric screening process in this study aligns with global best practices for aquatic bioassessment, as demonstrated by the works of Edegbene, Odume, and other researchers. Continued monitoring and the inclusion of robust metrics, as advocated by Odume

(2016) and Edegbene (2022), are essential for effective environmental management and policy formulation in Nigeria and beyond.

5.1.11.18 Redundancy Analysis (RDA) and Environmental Variables

The RDA results revealed that 91% of the variation in the multimetric indices (MMI) was explained by physicochemical parameters. This high explanatory power signifies a strong link between environmental conditions and the biological metrics used to assess water quality (Edegbene, 2019, Edegbene *et al.*, 2022). Significant correlations were found between certain core metrics and specific environmental variables:

1. Negative Correlations: Taxa evenness, Decapoda abundance, Trichoptera abundance, and abundance of fliers were negatively correlated with air temperature, nitrate, Dissolved Oxygen (DO), and transparency. These relationships highlight the sensitivity of these macroinvertebrate groups to changes in key water quality parameters, a finding consistent with other studies from tropical aquatic systems (Isibor *et al.*, 2016; Olomukoro and Ezemonye, 2007; Keke *et al.*, 2021).
2. Positive Correlations: Ephemeroptera abundance exhibited strong positive correlations with flow velocity, chloride, BOD_5, ammonia, phosphate, water temperature, and hydrogen ion concentration (pH). This group's preference for fast-flowing, oxygen-rich, and nutrient-rich environments has been documented in several studies from Nigeria (Arimoro *et al.*, 2010; Oribhabor and Enange 2013; Oke *et al.*, 2016; Iyagbaye *et al.*, 2017; Omoigberale *et al.*, 2020; Ugo *et al.*, 2024).

Interestingly, Odonata + Coleoptera abundance showed no significant correlation with any of the environmental variables. This lack of association may suggest that these taxa are more generalist in their habitat requirements or respond to other unmeasured variables, such as predation pressure or habitat structure (Imoobe, 2006; Imoobe and Ohiozebau, 2010; Akinpelu *et al.*, 2025)

5.1.11.19 Implications for Water Quality Monitoring

The results of this study align with findings from other studies in Nigeria and Africa, which have shown that environmental parameters such as DO, nitrate, and phosphate are critical indicators of water quality (Adesuyi *et al*., 2015; Akankali *et al*., 2017; Donald and Blessing, 2019). The correlation between physicochemical parameters and macroinvertebrate abundance can serve as a valuable tool for monitoring aquatic health. For instance, the positive correlation between Ephemeroptera abundance and BOD_5, a measure of organic pollution, suggests that these taxa could serve as bioindicators of organic enrichment in freshwater systems.

In conclusion, this study provides evidence that environmental variables significantly influence the distribution and abundance of macroinvertebrate communities in tropical streams. These findings are consistent with previous research from Nigeria, where the use of macroinvertebrates as bioindicators has been validated for assessing the health of aquatic ecosystems (Odume, 2016; Edegbene *et al*., 2022). The use of robust statistical tools, such as Spearman’s correlation and ordination techniques like RDA, underscores the importance of selecting appropriate methods for analysing complex ecological datasets, ultimately contributing to more accurate assessments of ecosystem health.

5.1.11.20 Multimetric conclusion

The multimetric indices reveal that environmental factors like pH, electrical conductivity, and nutrient concentrations significantly impaired macroinvertebrate composition, abundance, and diversity across rivers. Ephemeroptera and Diptera showed sensitivity to altered conditions, while Haplotaxida and Coleoptera exhibited resilience in impacted areas. Factors like flow rate, turbidity, and habitat variability influenced taxa preferences, with sediment-tolerant species thriving in higher turbidity. Rivers such as Orhionmwon and Okhuaihe 2 are highlighted for conservation due to significant ecological alterations and impairment.

5.2 Contribution to Knowledge

1. Providing baseline Data on water quality and macroinvertebrate diversity in the Ikpe community rivers, which can guide future conservation efforts and influence water resource management policies in Nigeria.
2. Multimetric Index adoption: The research adopted a robust multimetric index based on macroinvertebrate responses to environmental parameters, offering a reliable tool for assessing the biological integrity and ecological health of freshwater systems.

5.3 Conclusion

This study explored the influence of water quality on macroinvertebrate communities in various rivers, revealing significant seasonal and spatial variations in parameters such as pH, electrical conductivity, and nutrient concentrations. Taxa like Ephemeroptera (e.g., *Baetis* sp.) were sensitive to environmental stressors, showing declines in impacted areas, while others like Naididae and Decapoda (e.g., *Caridina africana*) displayed resilience. Physical parameters such as transparency and flow rate also played a role in shaping macroinvertebrate distribution by influencing the abundance of Trichoptera and Ephemeroptera both Negatively and positively respectively. The research highlighted differences in macroinvertebrate diversity and abundance between reference and impacted sites, emphasizing the complexity of ecosystem responses to environmental changes. A multimetric index was adopted using abundance of Decapoda, Trichoptera, Ephemeroptera, Odonata-Coleoptera, Fliers alongside Taxa evenness, indicating good river quality and providing a valuable tool for assessing the biological integrity of aquatic ecosystems. The study underscores the importance of macroinvertebrate taxa as bioindicators, offering critical insights for conservation efforts and water quality management in freshwater systems.

Recommendation: The study emphasises the need for targeted conservation efforts in priority rivers such as Orhionmwon and Okhuaihe 2 to mitigate anthropogenic impacts and protect aquatic biodiversity. Based on the findings, it is recommended that regular water quality monitoring be implemented in these rivers to track seasonal and spatial variations in key parameters such as pH, electrical conductivity, and nutrient levels. Conservation efforts should prioritize sensitive taxa like Ephemeroptera to preserve biodiversity, especially in impacted areas. The development and application of the multimetric index should be expanded to other freshwater ecosystems to improve biological integrity assessments. Restoration programs should target rivers showing significant ecological disruptions, particularly where human activities have led to degradation. Lastly, public awareness campaigns on the ecological importance of maintaining water quality should be promoted to encourage sustainable water resource management.

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APPENDIX

WATER QUALITY INDEX FOR ORHIONMWON RIVER (IMPACTED)

Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.96	6.5-8.5	0.153846	0.020665	0.134323	208	27.93917
EC	73	1000	0.001	0.020665	20.66507	7.3	150.855
TURBIDITY	25.92	5	0.2	0.020665	0.103325	518.4	53.56385
TDS	46.22	500	0.002	0.006738	3.3691	9.244	31.14396

DO	1.11	7.5	0.133333	0.006738	0.050537	190	9.601935
BOD$_5$	3.51	0.05	20	0.006738	0.000337	7020	2.365108
SULPHATE	9.33	100	0.01	0.006738	0.67382	9.33	6.286741
NITRATE	0.896	50	0.02	0.006738	0.33691	1.792	0.603743
PHOSPHATE	0.22	5	0.2	0.006738	0.033691	4.4	0.14824
CHLORIDE	10.6	250	0.004	0.006738	1.68455	4.24	7.142492
MANGANESE	0.477	0.5	2	0.006738	0.003369	95.4	0.321412
IRON	0.56	0.3	3.333333	0.006738	0.002021	186.6667	0.377339
ZINC	0.38	3	0.333333	0.006738	0.020215	12.66667	0.256052
CHROMIUM	0.06	0.05	20	0.006738	0.000337	120	0.040429
AMMONIUM	0.25	1	1	0.006738	0.006738	25	0.168455
COPPER	0.325	1	1	0.006738	0.006738	32.5	0.218992
Total			**48.39085**		**27.09108**		**291.0329**
WQ1 = 10.74275852							

WATER QUALITY INDEX FOR ORHIONMWON RIVER (REFERENCE)

Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.87	6.5-8.5	0.153846	0.020665	0.134323	226	30.35698
EC	120.42	1000	0.001	0.020665	20.66507	12.042	248.8487
TURBIDITY	27.17	5	0.2	0.020665	0.103325	543.4	56.14698
TDS	58.85	500	0.002	0.006738	3.3691	11.77	39.65431
DO	1.4	7.5	0.133333	0.006738	0.050537	185.9155	9.395518
BOD$_5$	3.55	0.05	20	0.006738	0.000337	7100	2.392061

SULPHATE	8.58	100	0.01	0.006738	0.67382	8.58	5.781376
NITRATE	0.79	50	0.02	0.006738	0.33691	1.58	0.532318
PHOSPHATE	0.11	5	0.2	0.006738	0.033691	2.2	0.07412
CHLORIDE	10.84	250	0.004	0.006738	1.68455	4.336	7.304209
MANGANESE	0.04	0.5	2	0.006738	0.003369	8	0.026953
IRON	0.55	0.3	3.333333	0.006738	0.002021	183.3333	0.370601
ZINC	0.397	3	0.333333	0.006738	0.020215	13.23333	0.267507
CHROMIUM	0.059	0.05	20	0.006738	0.000337	118	0.039755
AMMONIUM	0.2	1	1	0.006738	0.006738	20	0.134764
COPPER	0.32	1	1	0.006738	0.006738	32	0.215622
Total			**48.39084615**		**27.09107652**		**401.541792**
WQ1 = 14.82192085							

WATER QUALITY INDEX FOR IROGBE RIVER (IMPACTED)

Parameter	**Test Result**	**FME Limits (Si)**	**1/Si**	**K**	**Weightage (Wi)**	**Quality Rating (Qi)**	**[(Wi)(Qi)]**
Ph	5.88	6.5-8.5	0.153846	0.020665	0.134323	224	30.08834
EC	78.76	1000	0.001	0.020665	20.66507	7.876	162.7581
TURBIDITY	13.42	5	0.2	0.020665	0.103325	268.4	27.73252
TDS	49.32	500	0.002	0.006738	3.3691	9.864	33.2328
DO	1.52	7.5	0.133333	0.006738	0.050537	184.2254	9.310105

BOD$_5$	3.62	0.05	20	0.006738	0.000337	7240	2.439228
SULPHATE	6.58	100	0.01	0.006738	0.67382	6.58	4.433736
NITRATE	1.05	50	0.02	0.006738	0.33691	2.1	0.707511
PHOSPHATE	0.27	5	0.2	0.006738	0.033691	5.4	0.181931
CHLORIDE	10.6	250	0.004	0.006738	1.68455	4.24	7.142492
MANGANESE	0.049	0.5	2	0.006738	0.003369	9.8	0.033017
IRON	0.71	0.3	3.333333	0.006738	0.002021	236.6667	0.478412
ZINC	0.39	3	0.333333	0.006738	0.020215	13	0.26279
CHROMIUM	0.06	0.05	20	0.006738	0.000337	120	0.040429
AMMONIUM	0.37	1	1	0.006738	0.006738	37	0.249313
COPPER	0.32	1	1	0.006738	0.006738	32	0.215622
Total			**48.39085**		**27.09108**		**279.3063**
WQ1 = 10.30990028							

WATER QUALITY INDEX FOR IROGBE RIVER (REFERENCE)

Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.88	6.5-8.5	0.153846	0.020665	0.134323	224	30.08834
EC	78.76	1000	0.001	0.020665	20.66507	7.876	162.7581
TURBIDITY	13.42	5	0.2	0.020665	0.103325	268.4	27.73252
TDS	49.32	500	0.002	0.006738	3.3691	9.864	33.2328
DO	1.52	7.5	0.133333	0.006738	0.050537	184.2254	9.310105

BOD$_5$	3.62	0.05	20	0.006738	0.000337	7240	2.439228
SULPHATE	6.58	100	0.01	0.006738	0.67382	6.58	4.433736
NITRATE	1.05	50	0.02	0.006738	0.33691	2.1	0.707511
PHOSPHATE	0.27	5	0.2	0.006738	0.033691	5.4	0.181931
CHLORIDE	10.6	250	0.004	0.006738	1.68455	4.24	7.142492
MANGANESE	0.049	0.5	2	0.006738	0.003369	9.8	0.033017
IRON	0.71	0.3	3.333333	0.006738	0.002021	236.6667	0.478412
ZINC	0.39	3	0.333333	0.006738	0.020215	13	0.26279
CHROMIUM	0.06	0.05	20	0.006738	0.000337	120	0.040429
AMMONIUM	0.37	1	1	0.006738	0.006738	37	0.249313
COPPER	0.32	1	1	0.006738	0.006738	32	0.215622
Total			**48.39085**		**27.09108**		**279.3063**
WQ1 = 10.30990028							

WATER QUALITY INDEX FOR OKHUAIHE RIVER 1 (IMPACTED)

Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	6.07	6.5-8.5	0.153846	0.020665	0.134323	186	24.98406
EC	92.67	1000	0.001	0.020665	20.66507	9.267	191.5032
TURBIDITY	39.83	5	0.2	0.020665	0.103325	796.6	82.30896
TDS	48.45	500	0.002	0.006738	3.3691	9.69	32.64658
DO	1.1	7.5	0.133333	0.006738	0.050537	190.1408	9.609053

BOD$_5$	3.63	0.05	20	0.006738	0.000337	7260	2.445967
SULPHATE	13.33	100	0.01	0.006738	0.67382	13.33	8.982021
NITRATE	0.89	50	0.02	0.006738	0.33691	1.78	0.5997
PHOSPHATE	0.12	5	0.2	0.006738	0.033691	2.4	0.080858
CHLORIDE	10.6	250	0.004	0.006738	1.68455	4.24	7.142492
MANGANESE	0.047	0.5	2	0.006738	0.003369	9.4	0.03167
IRON	0.62	0.3	3.333333	0.006738	0.002021	206.6667	0.417768
ZINC	0.41	3	0.333333	0.006738	0.020215	13.66667	0.276266
CHROMIUM	0.065	0.05	20	0.006738	0.000337	130	0.043798
AMMONIUM	0.342	1	1	0.006738	0.006738	34.2	0.230446
COPPER	0.34	1	1	0.006738	0.006738	34	0.229099
Total			**48.39085**		**27.09108**		**361.5319**
WQ1 = 13.34505467							

WATER QUALITY INDEX FOR OKHUAIHE RIVER 1 (REFERENCE)

Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.87	6.5-8.5	0.153846	0.020665	0.134323	226	30.35698
EC	71.68	1000	0.001	0.020665	20.66507	7.168	148.1272
TURBIDITY	9.58	5	0.2	0.020665	0.103325	191.6	19.79713
TDS	45.67	500	0.002	0.006738	3.3691	9.134	30.77336
DO	1.05	7.5	0.133333	0.006738	0.050537	190.8451	9.644642

BOD$_5$	3.39	0.05	20	0.006738	0.000337	6780	2.28425
SULPHATE	5.08	100	0.01	0.006738	0.67382	5.08	3.423006
NITRATE	0.89	50	0.02	0.006738	0.33691	1.78	0.5997
PHOSPHATE	0.2	5	0.2	0.006738	0.033691	4	0.134764
CHLORIDE	10.6	250	0.004	0.006738	1.68455	4.24	7.142492
MANGANESE	0.045	0.5	2	0.006738	0.003369	9	0.030322
IRON	0.534	0.3	3.333333	0.006738	0.002021	178	0.35982
ZINC	0.347	3	0.333333	0.006738	0.020215	11.56667	0.233816
CHROMIUM	0.059	0.05	20	0.006738	0.000337	118	0.039755
AMMONIUM	0.22	1	1	0.006738	0.006738	22	0.14824
COPPER	0.32	1	1	0.006738	0.006738	32	0.215622
Total			**48.39085**		**27.09108**		**253.3111**
WQ1 = 9.350351589							

WATER QUALITY INDEX FOR OKHUAIHE RIVER 2 (IMPACTED)

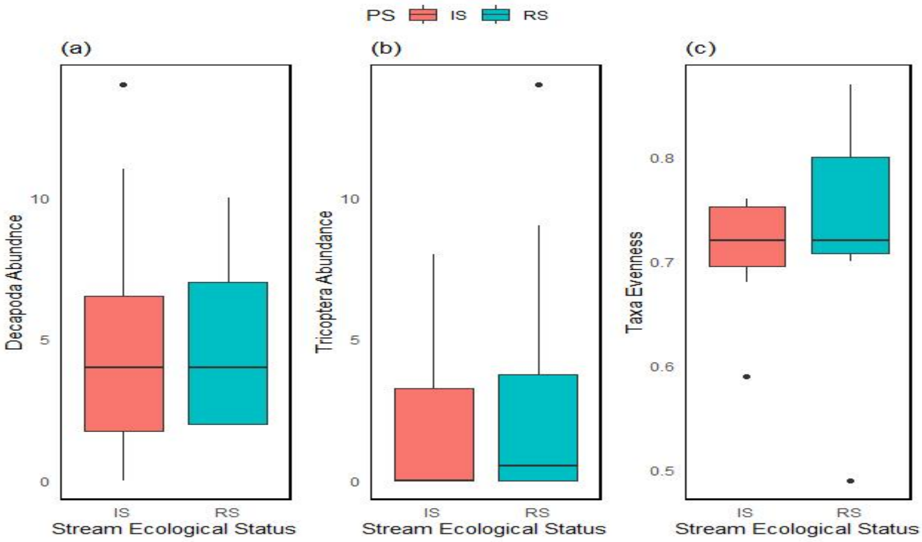
Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.64	6.5-8.5	0.153846	0.020665	0.134323	272	36.53584
EC	150.33	1000	0.001	0.020665	20.66507	15.033	310.6579
TURBIDITY	11.25	5	0.2	0.020665	0.103325	225	23.2482
TDS	80.08	500	0.002	0.006738	3.3691	16.016	53.95951
DO	1.58	7.5	0.133333	0.006738	0.050537	183.3803	9.267398

BOD$_5$	3.47	0.05	20	0.006738	0.000337	6940	2.338155
SULPHATE	4.08	100	0.01	0.006738	0.67382	4.08	2.749186
NITRATE	0.73	50	0.02	0.006738	0.33691	1.46	0.491889
PHOSPHATE	0.092	5	0.2	0.006738	0.033691	1.84	0.061991
CHLORIDE	11.25	250	0.004	0.006738	1.68455	4.5	7.580475
MANGANESE	0.04	0.5	2	0.006738	0.003369	8	0.026953
IRON	0.54	0.3	3.333333	0.006738	0.002021	180	0.363863
ZINC	0.385	3	0.333333	0.006738	0.020215	12.83333	0.259421
CHROMIUM	0.055	0.05	20	0.006738	0.000337	110	0.03706
AMMONIUM	0.161	1	1	0.006738	0.006738	16.1	0.108485
COPPER	0.3175	1	1	0.006738	0.006738	31.75	0.213938
Total			**48.39085**		**27.09108**		**447.9003**
WQ1 = 16.53312966							

WATER QUALITY INDEX FOR OKHUAIHE RIVER 2 (REFERENCE)

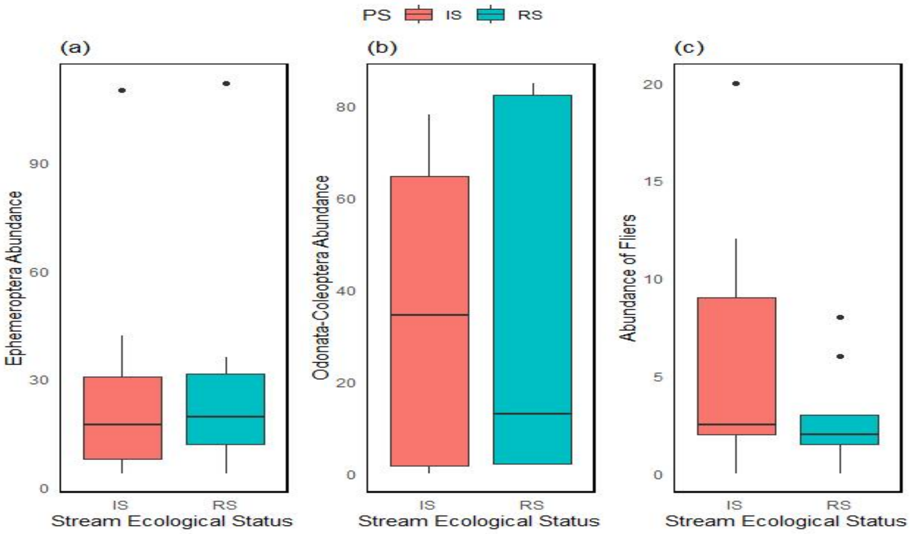
Parameter	Test Result	FME Limits (Si)	1/Si	K	Weightage (Wi)	Quality Rating (Qi)	[(Wi)(Qi)]
pH	5.78	6.5-8.5	0.153846	0.020665	0.134323	244	32.77479
EC	126.17	1000	0.001	0.020665	20.66507	12.617	260.7311
TURBIDITY	14.67	5	0.2	0.020665	0.103325	293.4	30.31565
TDS	61.94	500	0.002	0.006738	3.3691	12.388	41.73641
DO	1.81	7.5	0.133333	0.006738	0.050537	180.1408	9.103688

BOD$_5$	3.66	0.05	20	0.006738	0.000337	7320	2.466181
SULPHATE	5.83	100	0.01	0.006738	0.67382	5.83	3.928371
NITRATE	0.95	50	0.02	0.006738	0.33691	1.9	0.640129
PHOSPHATE	0.164	5	0.2	0.006738	0.033691	3.28	0.110506
CHLORIDE	10.84	250	0.004	0.006738	1.68455	4.336	7.304209
MANGANESE	0.04	0.5	2	0.006738	0.003369	8	0.026953
IRON	0.69	0.3	3.333333	0.006738	0.002021	230	0.464936
ZINC	0.406	3	0.333333	0.006738	0.020215	13.53333	0.273571
CHROMIUM	0.061	0.05	20	0.006738	0.000337	122	0.041103
AMMONIUM	0.323	1	1	0.006738	0.006738	32.3	0.217644
COPPER	0.321	1	1	0.006738	0.006738	32.1	0.216296
Total			**48.39085**		**27.09108**		**390.3516**
WQ1 = 14.40886159							



Comparison of core metrics (Decapoda, Trichoptera and Taxa Evenness) between the Impacted sites (IS) and Reference sites (RS). Boxes represent interquartile ranges (25th–75th percentiles).

Closed circles at the bottom and top of each box indicate the 5th and 95th percentiles, respectively. The mean (horizontal dotted line), median (horizontal solid line), and standard deviation (error bar) are shown in the box plots.



Comparison of core metrics (Ephemeroptera, Odonata-Coleoptera and Fliers) between the Impacted sites (IS) and Reference sites (RS). Boxes represent interquartile ranges (25th–75th percentiles). Closed circles at the bottom and top of each box indicate the 5th and 95th percentiles, respectively. The mean (horizontal dotted line), median (horizontal solid line), and standard deviation (error bar) are shown in the box plots.