

**ASSESSMENT OF PHYSICOCHEMISTRY AND
PLANKTON TAXA OF THE OTAMIRI RIVER
SYSTEM IN OWERRI, IMO STATE**

BY

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ENGINEERING)**

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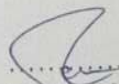
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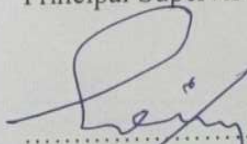
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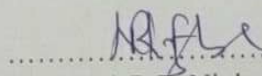
This is to certify that this work "Assessment of Physicochemistry and Plankton taxa of the Otamiri River in Owerri, Imo State" was carried out by **OSUEBI, EMMANUEL CHIKEZIE**, (Registration Number 20154944948) in partial fulfilment of the requirements for the award of the degree of Master of Science (M.Sc) in Environmental Management, Department of Environmental Management, School of Environmental Sciences, Federal University of Technology, and Owerri.


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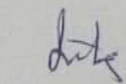
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DEDICATION

This work is sincerely dedicated to ALMIGHTY GOD for His divine grace and providence through the period of this work.

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in FUTO

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ABSTRACT

Plankton could serve as bio-indicators of pollution in water bodies, and this makes them important in the assessment of water pollution. This study investigated the interactions of some physicochemical attributes and plankton abundance and diversity in the upper and middle reaches of the Otamiri River in Owerri, Imo State. Plankton samples were collected at four sampling locations and identified through direct microscopy. Descriptive statistics, variation plots, ANOVA, Duncan Multiple Range test, and correlation were used to analyze data at $p < 0.05$ level. Mean levels of Dissolved Oxygen (DO), water temperature, electrical conductivity, and Total Dissolved Solids (TDS) (Sig. $F_{\text{value}} = 0.000$ each), Biological Oxygen demand (BOD) (Sig. $F_{\text{value}} = 0.035$), pH (Sig. $F_{\text{value}} = 0.025$), Total Suspended solids (TSS) (Sig. $F_{\text{value}} = 0.004$), turbidity (Sig. $F_{\text{value}} = 0.005$), PO_4^{3-} ions (Sig. $F_{\text{value}} = 0.029$) and SO_4^{2-} ions (Sig. $F_{\text{value}} = 0.003$) all differed significantly across the sampling locations of the river at $p < 0.05$. Phytoplankton abundance comprised of a total of 9 genera each of bacillariophyceae and cyanophyceae, 6 genera of chlorophyceae, 2 genera each of euglenophyceae and xanthophyceae, and 1 genus each of charophyceae and pyrrophyceae. The most abundant diatom genus was *Diatom* sp while that for cyanophyceae was *Aphanizomenon flos-Aquae*. Sampling location 3 (Ihiagwa/Umuchima) recorded the highest phytoplankton and zooplankton abundances (158 & 7 cells/organisms/mL) while the pristine/control location 1 (Egbu) had the least abundance of 108 & 2 cells/organisms/mL respectively. Significant spatial inequality was observed in abundances of the cladoceran (Sig. $F_{\text{value}} = 0.030$), xanthophycean and euglenophycean (Sig. $F_{\text{value}} = 0.011$ each) taxa at $p < 0.05$. Phytoplankton taxa were more diverse, with Margalef's Index (I) range of 2.56-5.03, than zooplankton taxa with I values ranging from 0.51-1.44. DO correlated with euglenophyceae ($r = -0.679$), xanthophyceae ($r = -0.673$) ($p < 0.05$), and chlorophyceae ($r = -0.747$) ($p < 0.01$), and TSS correlated with bacillariophyceae ($r = 0.629$) ($p < 0.05$). Low abundance of plankton recorded in the study most probably reflects a perturbed aquatic ecosystem lacking in vital nutrients and other factors necessary for a thriving biotic community.

Keywords: Plankton, Biotic Index, Physicochemical parameters, Otamiri River, Nutrients

CHAPTER ONE

2.0

INTRODUCTION

1.1. Overview

The name plankton comes from the Greek word πλανκΤΟς ('Planktos'), meaning "wanderer" or "drifter". It is a collective term for a variety of marine and freshwater organisms that drift on or near the surface of the water. Their movement depends largely on tides, currents, and winds, because they are too small or weak to swim against the currents. Many authors have since defined plankton as all those animals and plants which live freely in the water and which because of their limited powers of locomotion, are more or less passively drifted by water current (Johnson and Allen, 2012). All those living organisms which float "wily-nilly" in free water and are independent of the shore and bottom. A mixed group of tiny plants and animals floating, drifting, or feebly swimming in water mass. A drifting organisms that inhabit the water column of oceans, seas and bodies of freshwater (Sharma, Singh and Chauhan, 2016). The evolution of "the myriad of microscopic, one-celled life forms (plankton) floating on the rich biochemical soup of this planet's bodies of water" dates back to some 400 million years ago when there had not been "the fantastic permutation of multi-cellular life forms which have since developed through the millennia" (Medvinsky et al, 2002).

Though some form of plankton are capable of independent movement and can swim hundreds of metres vertically in a single day- a behaviour called diel

vertical migration, their horizontal position is primarily determined by the surrounding currents. All oxygen breathing organisms are indebted to plankton because of their significant contribution of oxygen through millennia of photosynthesis. Additionally, plankton are responsible for the formation of oil over pre-historic times when the sun shone on these microorganisms called plankton drifting in seas and produced, through photosynthesis, small globules of oil within their cells. Many microscopic fossils from sediments are extraordinarily related in nature or alike to living microscopic plankton. This shows that some species of plankton have remained virtually unchanged for many years (Fernando *et al.*, 2002).

Aside from representing the bottom levels of a food chain, plankton supports up to commercially important fisheries, even as they play a major role in the biogeochemical cycles of many important chemical elements including carbon cycle. Phytoplankton fixes carbon in sunlit surface water through the process of photosynthesis. Through zooplankton grazing, this carbon enters the plankton food web, where it is either respired to provide metabolic energy, or accumulates as biomass or debris (Valina *et al.*, 2014). As organic materials, they are typically denser than water and tend to sink.

The abundance and distribution of plankton are strongly dependent on factors such as light (solar radiation), ambient nutrients concentrations, the physical state of the water column, and the abundance of other plankton.

1.2 Statement of Problem

Several studies have been conducted on Otamiri River, including those on the physicochemical properties and microbiological community of the river; those on the effects of contaminants from a landfill into the Otamiri River, and *those* on the interactions of human activities and geological processes on the Otamiri River. Of these works, plankton is left out even as it occupies a vital position in trophic and biogeochemical cycles in aquatic systems. Many groups of organisms have been used as indicators of water quality or environmental changes in fresh water bodies. These include algae, macrophytes, protozoa, and fish (Zabbey *et al.*, 2008).

Otamiri River is one of the fresh waters in South Eastern Nigeria that boost economic activities and produces water for drinking and other domestic activities for people living within the environ. I had to study Otamiri River to know the water quality level and also to know how the water supports the plankton live.

The use of biological indicators in conjunction with physicochemical variables have been identified and also recommended as a fundamental prerequisite for

the establishment of ecological baseline status of aquatic environment (Heath, 2018). There are three principal reasons for this recommendation. These are:

1. The limitations of chemical analytical capabilities;
2. The unpredictability of biological impacts of complex chemical interactions through analytical methods alone;
3. The unsuitability of chemical analysis alone for the formations of environmental policies.

It is in this cue that the current study undertook to investigate the interactions of plankton taxa of the Otamiri River and its physicochemical attributes, in order to further understand its ecodynamics. This attempt is reinforced in the face of increasing anthropogenic perturbations on the aquatic system occasioned by increasing socio-economic pressures in the study area. The discharge of industrial and domestic wastes as well as in-stream sand mining by local inhabitants along the course of the river have the potentials to alter abundance and diversity of such biological indicator species as plankton.

1.3 Aim and Objectives

The aim of this work was to investigate the interactions of plankton taxa of the Otamiri River and its physicochemical attributes, in order to understand its ecodynamics in space. To achieve this aim, the following objectives were utilized:

- Determination of plankton abundance and diversity of the Otamiri River in Owerri, south-eastern Nigeria;
- Determination of Diversity and Similarity indices of plankton taxa of the river in the area;
- Determination of some physicochemical attributes of the river in the area;
- Determination of spatial variations in plankton diversity and physicochemical attributes of the river; and
- Determination of possible influences of the physicochemical attributes of the river on the plankton taxa.

1.4 Significance of Study

Plankton are the foundations of aquatic food webs, and in their diversities are essential components of the aquatic community structure. This underscores the need for this study.

This investigation will also elucidate plankton biotopes of this important aquatic ecosystem in south-eastern Nigeria. The study will also improve the many understandings of the potential consequences of man-made activities on the Otamiri River, especially in relation to plankton abundance and diversity.

The significance of this study to water pollution control is that it will help to identify and control those anthropogenic activities that can pollute the river water which reduces the water quality and other organisms in nature such as plankton that are found in all seas, lakes and oceans ecosystems, which play a critical role in maintaining the health and balance of the oceans and its complex food webs. The oxygen, nutrients and biomass they produce also sustain terrestrial life from the food we eat to the air we breathe. Therefore, the significance of this study to water pollution control is to assure a continuing abundance of water that is safe to use for ourselves and future generations.

1.5 Scope and Delimitation of Study

This work covered zooplankton and phytoplankton taxa of the planktonic assemblage along longitudinal gradient of the Otamiri River. The study was conducted between the upper and middle reaches of the Otamiri River; between Egbu and Owerri in Imo State, south-eastern Nigeria.

The physicochemical characteristics measured in this study includes the nutrients (NO_3^- , SO_4^{2-} , PO_4^{3-}) as well as dissolved oxygen, pH, temperature, electrical conductivity, total dissolved solids, total suspended solids, turbidity, and biological oxygen demand.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Classification of plankton

According to Ogbuagu (2014), there are basically three ways of classifying plankton. These are classifications based on life cycle, functional, and size groups.

2.1.1 Classification based on life cycle

Within the plankton itself, certain members spend part, while others spend their entire life cycles as part of the community. This has led to the following classifications:

- Holoplankton are those organisms that spend their entire life cycles as part of the plankton. Examples of these include most algae, copepods, salps, and jelly fish.
- Monoplankton are those organisms that are only plankton for part of their lives (usually in the larval stage), and then graduate either nekton or benthic existence. These include the larvae of sea urchins, sea stars, crustaceans, marine worms, and most fish.

2.1.2 Classification based on functional group

This is the most popularly used classification of plankton and it divides the plankton community into broad producer, consumer, and recycler groups. Based

on this classification criterion, plankton are divided into three broad functional groups or trophic levels.

- Phytoplankton, (derived from the Greek word “Phyton”) are autotrophic pro- or eukaryotic algae that live near the water surface (euphotic zone) where there is sufficient light to support photosynthesis. They are unicellular microscopic algae (Medvinsky, 2002). Phytoplankton concentrations depend not only on nutrient availability, light, temperature, and ultraviolet (UV) stress, but also strongly on the grazing losses due to zooplankton activity.
- Zooplankton, (derived from the Greek word “Zoon”, meaning animal) are small protozoans or metazoans such as crustaceans and other animals that feed on other plankton or even some eggs and larvae of larger animals such as fish, crustaceans, and annelids. Practically every major group of animals has its representatives in the zooplankton either as adult or larvae. The zooplankton communities not only depend on phytoplankton availability, but also on grazing pressure as well as solar UV and temperature (Rautio and Tartarotti, 2010).

2.1.3 Classification based on size groups

Plankton is also often described in terms of their sizes. The Wikipedia Encyclopaedia (2007) makes the following divisions currently used for plankton, based on their sizes.

- Mega plankton, 2×10^{-1} - 2×10^0 m (=20-200cm)
- Macro plankton, 2×10^{-2} – 2×10^{-1} m (=2- 20cm)
- Meso plankton, 2×10^{-4} – 2×10^{-2} m (=0.2mm-2cm)
- Micro plankton, 2×10^{-5} – 2×10^{-4} m (=20-200 μ m)
- Nano-plankton, 2×10^{-6} – 2×10^{-5} m (=2-20 μ m)
- Pico plankton, 2×10^{-7} - 2×10^{-6} m (=0.2-2 μ m). These are mostly bacteria.
- Femtoplankton, $< 2 \times 10^{-7}$ m (= <0.2 μ m). These consist of aquatic virus.

However, some of these terms may be used interchangeably with very different boundaries, especially on the larger end of the scale. The existence and importance of nano- and even smaller plankton was only recently discovered in the 1980s, but they are thought to make up the largest portion of all plankton in abundance and diversity.

2.2 Biogeochemical significance of plankton

According to Ogbuagu *et al.* (2011), all oxygen-breathing creatures, including humans, are indebted to the phytoplankton, because through millennia of photosynthesis, they have contributed significantly to the oxygen we breathe. Furthermore, much of the oil that we use today probably began millions of years ago when the sun shone on plankton drifting in prehistoric seas and produced, through photosynthesis, minute globules of oil within these cells.

Some microscopic fossils from sediments are remarkably similar to living microscopic plankton, indicating that some species have remained virtually unchanged for millions of years. Aside from representing the bottom levels of a food chain that leads up to commercially important fisheries, plankton ecosystems play a role in the biogeochemical cycles of many important elements such as the carbon cycle. Bacterioplankton also play roles in ecological pathways such as nitrogen fixation, nitrification, denitrification, remineralisation, and methanogenesis (Spaak and Bauchrowitz, 2010).

Use of modern epifluorescence microscopy techniques have revealed that bacterioplankton productivity is far greater than previously thought; having high division and turnover rates (Breitbart, 2012).

Phytoplankton fixes carbon in euphotic zones of water bodies via photosynthesis. Essentially, through zooplankton grazing, this carbon enters the planktonic food web, where it is either respired to provide metabolic energy, or accumulates as biomass or detritus. As living or dead organic materials, these detritus are typically denser than water and so tend to sink and transport carbon from surface waters to the deep seas. This process is known as biological pump and is one of the reasons that the oceans constitute the largest, active pool of carbon on earth (Ogbuagu, 2014).

2.3 Biological indicators of pollution

Many groups of organisms have been used as indicators of water quality or environmental changes in freshwater bodies, including algae, macrophytes, protozoa and fish (Allah *et al.*, 2020). The use of biological indicators in conjunction with physicochemical variables has been identified and recommended as a fundamental prerequisite for the establishment of ecological baseline status of any environment (Heath, 2018). They proffered three principal reasons for this recommendation as follow:

- The limitations of analytical capabilities,
- The unpredictability of the biological impacts of complex chemical interaction through analytical methods alone, and
- The unsuitability of chemical analyses alone for the formulation of environmental policies.

2.4 Importance of plankton in trophic relationships

The rich diversity of animal life in estuaries represents a complex food web. The foundation of the estuarine food web is plankton. These microscopic animals are more diverse and essential to food webs and community structure than are vertebrates. Zooplankton feed on phytoplankton and are, in turn, eaten by fish and other animals. Dead plankton makes up an important element of the organic bottom layer of estuaries. Benthic (bottom-dwelling) fauna such as

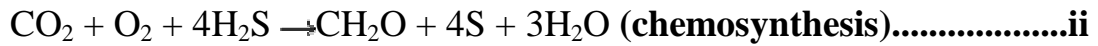
barnacles, bryozoans, sponges, mussels, and hydroids live on the rich estuary floor. Fish, crabs, and shrimp take advantage of the large numbers of invertebrates found in estuaries. This extremely high productivity makes the estuary an attractive nursery habitat for many crustacean and fish species- and such an attractive fishing ground for humans.

2.5 Plankton and primary production

Primary Production is the production of organic compounds from atmospheric or aquatic carbon (iv) oxide, principally through the process of photosynthesis, with chemosynthesis being much less important. Almost all life on earth is directly or indirectly reliant on primary production. The organisms responsible for primary production are known as Primary Producers or autotrophs, and form the base of the food chain. In terrestrial ecoregions, these are mainly plants, while in aquatic ecoregions algae are primarily responsible. Primary production is distinguished as either *Net* or *Gross*, the former accounting for losses to processes such as cellular respiration, but the latter not.

Regardless of its source, this energy is used to synthesize complex organic molecules from simpler inorganic compounds such as carbon (IV) oxide (CO₂) and water (H₂O). The following two equations are simplified representations of photosynthesis (top) and one form of chemosynthesis (bottom):





In both cases, the end point is reduced Carbohydrate (CH₂O), typically molecules such as glucose or other sugars. These relatively simple molecules may then be used to further synthesise more complicated molecules, including proteins, complex carbohydrates, lipids, and nucleic acids, or be respired to perform work. Consumption of primary producers by heterotrophic organisms, such as animals, then transfers these organic molecules (and the energy stored within them) up the food web, fuelling all of the Earth's living systems.

Gross Primary Production (GPP) is the rate at which an ecosystem's producers capture and store a given amount of chemical energy as biomass in a given length of time. Some fraction of this fixed energy is used by primary producers for cellular respiration and maintenance of existing tissues (i.e., growth respiration and maintenance respiration). The remaining fixed energy (i.e., mass of photosynthate) is referred to as Net Primary Production (NPP).

$$\text{NPP} = \text{GPP} - \text{Respiration (by plants).....iii}$$

Net Primary Production is the rate at which all the plants in an ecosystem produce net useful chemical energy. It is equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (GPP) and the rate at which they use some of that energy during respiration. Some net

primary production goes toward growth and reproduction of primary producers, while some is consumed by herbivores.

Both gross and net primary productions are in units of mass/area/time. In terrestrial ecosystems, mass of carbon per unit area per year ($\text{gC}/\text{m}^2/\text{yr}$) is most often used as the unit of measurement.

2.6 Factors affecting plankton primary production in aquatic ecosystems

The factors limiting primary production by plankton in aquatic ecosystems are also very different from those on land. The availability of water, obviously, is not an issue (though its salinity can be). Similarly, temperature, while affecting metabolic rates, ranges less widely in the ocean than on land because the heat capacity of seawater buffers temperature changes, and the formation of sea ice insulates it at lower temperatures. However, the availability of light, the source of energy for photosynthesis, and mineral nutrients, the building blocks for new growth, play crucial roles in regulating primary production in the ocean.

Iron, a micronutrient, has also been discovered to exert very significant influence on primary production, to extents surpassing nutrients in oceanic High-Nutrient, Low-Chlorophyll (HNLC) regions (Marra et al., 2002). However high enough concentrations of the heavy metals (Cu, Pb, Al, and Hg) could be phytotoxic especially at low pH where metals are more soluble (Van der Kuij et al, 2014; Lundqvist, 2016).

2.6.1 Light

The sunlit zone of the ocean is called the photic zone (or euphotic zone). This is a relatively thin layer (10–100 m) near the ocean's surface where there is sufficient light for photosynthesis to occur. For practical purposes, the thickness of the photic zone is typically defined by the depth at which light reaches 1% of its surface value. Light is attenuated down the water column by its absorption or scattering by the water itself, and by dissolved or particulate material within it (including phytoplankton).

Net photosynthesis in the water column is determined by the interaction between the photic zone and the mixed layer. Turbulent mixing by wind energy at the ocean's surface homogenises the water column vertically until the turbulence dissipates (creating the aforementioned mixed layer). The deeper the mixed layer, the lower the average amount of light intercepted by phytoplankton within it. The mixed layer can vary from being shallower than the photic zone, to being much deeper than the photic zone. When it is much deeper than the photic zone, this results in phytoplankton spending too much time in the dark for net growth to occur. The maximum depth of the mixed layer in which net growth can occur is called the critical depth. As long as there are adequate nutrients available, net primary production occurs whenever the mixed layer is shallower than the critical depth.

Both the magnitude of wind mixing and the availability of light at the ocean's surface are affected across a range of space- and time-scales. The most characteristic of these is the seasonal cycle (caused by the consequences of the Earth's axial tilt), although wind magnitudes additionally have strong spatial components. Consequently, primary production in temperate regions such as the North Atlantic is highly seasonal, varying with both incident light at the water surface (reduced in winter) and the degree of mixing (increased in winter). In tropical regions, such as the gyres in the middle of the major basins, light may only vary slightly across the year, and mixing may only occur episodically, such as during large storms or hurricanes.

2.6.2 Nutrients

Mixing also plays an important role in the limitation of primary production by nutrients. Inorganic nutrients, such as nitrate, phosphate and silicic acid are necessary for phytoplankton to synthesise their cells and cellular machinery. Because of gravitational sinking of particulate material (such as plankton, dead or faecal material), nutrients are constantly lost from the photic zone, and are only replenished by mixing or upwelling of deeper water. This is exacerbated where summertime solar heating and reduced winds increases vertical stratification and leads to a strong thermocline, since this makes it more difficult for wind mixing to entrain deeper water. Consequently, between mixing events,

primary production (and the resulting processes that leads to sinking particulate material) constantly acts to consume nutrients in the mixed layer, and in many regions this leads to nutrient exhaustion and decreased mixed layer production in the summer (even in the presence of abundant light). However, as long as the photic zone is deep enough, primary production may continue below the mixed layer where light-limited growth rates are often more abundant.

2.7. Water Quality Assessment

In modern ecological studies, the maintenance and assessment of water quality are important procedures leading to the monitoring of the ecodynamics of aquatic systems. Three modern approaches that are available for the description of water quality. They are:

- Qualitative measurements (such as physicochemical parameter in water, sediments or biological tissues).
- Biochemical/biological tests (such as BOD estimations, estimations of primary productivity, toxicity testing, etc).
- Semi-qualitative and quantitative description (including biological indicators and species inventories).

According to Eze (2005), the actual process of water quality assessment is an evaluation of the physicochemical and ecological aspects of the water in relation to its natural quality, human effects and intended uses, i.e. basically to

verify whether the observed water quality is suitable for its intended use. This includes monitoring, which involves the collection of information at specified localities and at regular intervals to:

- Obtain information concerning substances entering the environment, their quantities, sources and distribution.
- Evaluate the effects of these substances within the environment.
- Provide a basis for detecting trends in concentrations and effects, and to establish cause and effect relationships (e.g. acidification and eutrophication).
- Examine how far inputs, concentrations and trends can be modified by what and at what cost.

The basic philosophy of water quality assessment remains the same for both marine and freshwater systems, although more has been published concerning freshwaters, largely because of its greater importance to human domestic activities.

2.7.1. Assessment Procedures and Protocols

- 1. Chemical Assessment Techniques:** These techniques involve regular sampling of water in the natural system and/or at some point in the abstraction and treatment process and of most effluents before they are

released back into the environment (Eze, 2005). In assessing the water quality, the following chemical parameters are often used:

- Organoleptic parameters, e.g. colour, turbidity, odour and taste.
- Physicochemical parameters e.g. temperature, pH, conductivity, Ca, Mg, K, Na, chlorides, and sulphate.
- Parameters relating substances undesirable in excess amounts, e.g. nitrates, nitrites, ammonia, hydrocarbons, phosphates, phenols, and organochlorines.
- Parameters relating toxic substances, e.g. pesticides, polynuclear aromatic hydrocarbons (PAHs), heavy metals.
- Microbiological parameters, e.g. total and faecal coliforms and faecal streptococci.
- Minimum requirement for softened water, e.g. total hardness and alkalinity.

2. Biological Assessment Technique: This technique takes into account the effect of changes in the environment on organisms. These effects on organisms include deaths, migration, decrease in production, and lower populations. These changes could take one or more of the following trends as outlined below.

- Changes in species composition: This could be as a result of death or migration of intolerant populations from the area and colonization by tolerant forms.
- Changes in dominant groups: This could be caused by decline in populations of previously dominant forms, increase in other and tolerant forms.
- Impoverishment of species: This could arise as a result of loss of intolerant forms.
- High mortality of sensitive life stages, due to physiological and/or biochemical responses to pollutants.
- Changes in physiology/metabolism, due to cellular responses to sublethal toxins and pollutants.
- Histological/morphological deformities.

In addition to the followings, biological surveillance in aquatic systems has also proven valuable in assessing water quality as well as detecting pollution. This is elucidated in the observation that aquatic organisms exhibit a lasting response to the intermittent pollution episodes, which may be missed during routine chemical monitoring (which only samples a relatively tiny volume of water at a particular point in time) (Allan et al., 2020).

Aquatic organisms also provide an assessment of the average water quality over a period of time. Organisms could also accumulate and magnify low levels of chemicals, which may be below the detection limits of analytical chemical methods, but which can be analyzed from biological tissues. Additionally, biological methods also provide information on the impact of pollutants on the ecology of the system, which chemical methods, by themselves cannot do (Ekweozor et al., 2020).

However, biological techniques are not devoid of limitations. For example, they are unable to give an accurate measure of the exact quantity of pollutants and concentrations of chemicals. They may not also pick up slight changes in water quality that do not impact significantly on the ecological system, but which nevertheless might be of significance to consumer processes (Oliveira et al., 2012).

3. Ecological Assessment Techniques (EcA): According to Tamuno (2005), EcA is an evaluation of the biological condition of an ecological system by using biological surveys and other direct measurements of biota resident in the system of interest. Ecological techniques are devised to monitor and assess organic pollution and the simplest approach is to look for indicator species in a sample from the aquatic habitat. From here, one can infer from the presence of known intolerant or sensitive species

the quality of a water body. For example, the presence of stoneflies and mayflies in rivers and streams could indicate high oxygen and low organic pollution levels. Otherwise, the absence of these species and presence of high numbers of known tolerant species such as sewage fungus and tubificid worms could indicate polluted water. The marine environment also has its own similar set of tolerant and intolerant species. For example, the marine worm, *Capitella* is a well-known tolerant species to pollution (Gregory, 2014).

Table 2.1.shows trend in pollution tolerant phytoplankton genera.

2.8. Biotic Indices of Pollution

The extension of the foregoing idea has led to the establishment of the various biotic indices for whole communities, be it of marine or freshwater origins (Stomp et al., 2011). Generally, the establishment of biotic indices takes into account the assigning of each type of organism a score on some scale according to its tolerance to pollution; with the low scores assigned to the tolerant species and the high scores assigned to intolerant, clean water forms (Table 2.1). The scores (points) are then totaled for the sample to give the biotic index, which can be compared to samples in the past or from other, unpolluted sites. The followings are examples of biotic indices:

- The British Monitoring Working Party Method, used by the National Water Council of the United Kingdom (Stomp et al., 2011)
- The Trent Biotic Index (Castillo et al., 2020), which was devised for organic pollution in the River Trent in the United Kingdom (Allan et al., 2020).
- The Environmental Research Unit Index of 1992 in Ireland, where the species are arranged into four basic groups, depending on their known tolerance to organic pollution as Sensitive, Less Sensitive, Tolerant, and Most Tolerant.
- Index of Community Sensitivity for Heavy Metal Pollution (Suter II, 2016). This index is relatively new and measures the sensitivity of each of thirteen dominant taxa, which is then summed to give an overall score for the site.

Table 2.1. Trend in Pollution tolerance of some Phytoplankton genera in decreasing order

S/No	Genus	Group
1	<i>Oscillatoria</i>	B
2	<i>Phormidium</i>	B
3	<i>Anacystis</i>	B
4	<i>Anabaena</i>	B
5	<i>Arthrospira</i>	B
6	<i>Lyngbya</i>	B
7	<i>Agmenellum</i>	B
8	<i>Spirulina</i>	B
9	<i>Nitzschia</i>	D
10	<i>Navicula</i>	D
11	<i>Syndera</i>	D
12	<i>Melosira</i>	D
13	<i>Gomphonema</i>	D
14	<i>Cyclotella</i>	D
15	<i>Flagillaria</i>	D
16	<i>Surrirela</i>	D
17	<i>Stephanodiscus</i>	D
18	<i>Cymbella</i>	D
19	<i>Hantzchia</i>	D
20	<i>Diatoma</i>	D
21	<i>Achnanthes</i>	D
22	<i>Pinnularia</i>	D
23	<i>Asterionella</i>	D
24	<i>Cocconeis</i>	D
25	<i>Staironeis</i>	D
26	<i>Cymatopleura</i>	D
27	<i>Euglena</i>	F
28	<i>Chlamydomonas</i>	F
29	<i>Phacus</i>	F
30	<i>Pandorina</i>	F
31	<i>Lepocinclis</i>	F
32	<i>Cryptomonas</i>	F

33	<i>Trachelomonas</i>	F
34	<i>Carteria</i>	F
35	<i>Chlorogonium</i>	F
36	<i>Eudorina</i>	F
37	<i>Pyrobotrys</i>	F
38	<i>Spondylomorum</i>	F
39	<i>Synura</i>	F
40	<i>Gonium</i>	F
41	<i>Scenedesmus</i>	G
42	<i>Chlorella</i>	G
43	<i>Stigeoclonium</i>	G
44	<i>Ankistrodesmus</i>	G
45	<i>Closterium</i>	G
46	<i>Micractinium</i>	G
47	<i>Spirogyra</i>	G
48	<i>Pediastrum</i>	G
49	<i>Ulothrix</i>	G
50	<i>Oocystis</i>	G
51	<i>Actinastrum</i>	G
52	<i>Coelastrum</i>	G
53	<i>Cladophora</i>	G
54	<i>Golenkinia</i>	G
55	<i>Chlorococcum</i>	G
56	<i>Cosmarium</i>	G
57	<i>Tribonema</i>	G
58	<i>Selenastrum</i>	G
59	<i>Dictyosphaerium</i>	G
60	<i>Crucigenia</i>	G

B-blue-green alga (=8), D-diatom (=18), F-flagellate (protozoa)(=14), G-green alga (=18)

(Modified from Palmer, 1978)

2.9. Ecological Indices

There exists another general approach based on changes in the overall number of species and dominance levels. According to Eze (2005), a mild, yet important ecological assessment technique may not eliminate all clean water indicator species but might reduce their numbers and increase numbers of more tolerant forms. Such changes may not be detected by biotic indices but can be from the calculation of diversity indices. The more diverse the community, the better for water quality assessment. Thus, one would compare values over time or between unpolluted and suspected sites.

Hubbel, (2011), Indices express the relative importance of each species of organism, are without dimension and are independent of sample size and as such, have been widely used in processing biological data. A diversity index can therefore be defined as simple multivariate variance measure across species. Diversity indices serve both qualitative and quantitative uses, in that, aside from providing insight into the dynamics of the aquatic community, the bulk of numerical data are reduced, and can thus be related to other environmental data to establish their interactive effects (Hubbel, 2011). Table 2.2 shows some commonly used indices in ecological studies.

Table 2.2. Some Commonly used Ecological Indices

Index	Formula	Function	Remarks
Kothe species Index (Brodie and Doberski, 1991)	$I = \frac{Su - Sd}{Su} \times 100$ where Su is No. of species above outfall, Sd, No. of species below outfall	Pollution Index	Value of Index limited by possibility that there may be more species below outfall than above
Modified species deficit (Hellowell 1977)	$I = \frac{Su - Sm}{Su} \times 100$ Where Sm is No. species missing at downstream site	Pollution Index	Overcomes problems cited above
Pollution Index (Brodie and Doberski, 1991)	$I = 2C_1 - C_2$ Where C ₁ is No. of macroinvertebrates species intolerant and C ₂ No. of macroinvertebrates tolerant to modest organic pollution	Pollution Index	Index rarely exceeds 10
Williams α-Index (Elliot, 1971)	$S = \alpha \ln N/\alpha$	Diversity Index	α is independent of the sample size and is proportional to the number of species
Margalef's Index (Margalef 1961)	$D = S - I/\ln N$, where S is No. of species and N, total No. of individuals of all species	Diversity Index	More sensitive to changes in number of species than number of individuals
Simpson's Index (Elliot, 1971)	$D = \frac{\sum n_i (n_i - 1)}{N(N-1)}$ where n is No. of individuals in the species	Diversity Index	Measures population in terms of population constraints, and not sensitive to the presence of rare species and are also independent of sample size

Shannon-Weinner Index (Lambert, 2002)	$H' = -\sum p_i \log p_i$, where p_i is proportion of individuals in the i th species	Diversity Index	Suitable for estimating average diversity from a sample of population of unknown size
Sequential Comparison Index (Campbell, 1974)	$I = R/N$, where R is No. of changes in species per scan and N , total number scanned	Diversity Index	Can only be derived from sample examination
Coefficient of Similarity (Elliot, 1971)	$I = \frac{c}{a+b+c}$, where a is No. of species in community A, b , No. in community B, and c , No. in both communities	Comparative Index	Express similarity between ratio of the actual number of species common to both community and total number of species found in both
Sørensen's Quotient of Similarity (Tingle, 2002)	$I = \frac{2c}{a+b}$	Comparative Index	Expresses number of common species as a ratio of possible number of species per community
Mountford Index of Similarity (Tingle, 2002)	$I = \frac{2c}{2ab-(a+b)c}$	Comparative Index	
Distance Measures (Sokal and Rohlf, 1969)	$D_{jh} = \sqrt{\sum (p_{ij} - p_{ih})^2}$, where D_{jh} is distance between communities, p_{ij} proportion of species i in community j , and p_{ih} proportion	Distance Measure	Useful where there are true alternative

(Source: Sowunmi, 2001)

CHAPTER THREE

3.0

METHODOLOGY

3.1 Study Area

Owerri, the study area is located within the coordinates 5.485° Northing and 7.085° Easting (Fig. 3.1). The city consists of 3 Local Government Areas which includes Owerri Municipal, Owerri North, and Owerri West local government areas. It has a population estimate of about 400,000 people in 2006 and land area of 40sq miles (100km square) (NPC, 2006). The terrain is almost flat to the West and small rolling hills run from the North to the South.

The Otamiri River that was investigated rises south from Egbu and courses past Owerri; through Nekede, Ihiagwa, Eziobodo, Olokwu Umuisi, Mgbirichi and Umuagwo (Fig. 3.1), onto Ozuzu in Etche, Rivers State. In Etche, the river first confluences with Oge-Ochie River at Nihi, and further with the Imo River at Umuebulu. The length of the river from its source to its earlier, minor confluence with the Uramiriukwa River at Emeabiam in Imo State is 30km. The Otamiri watershed covers about 10,000km².

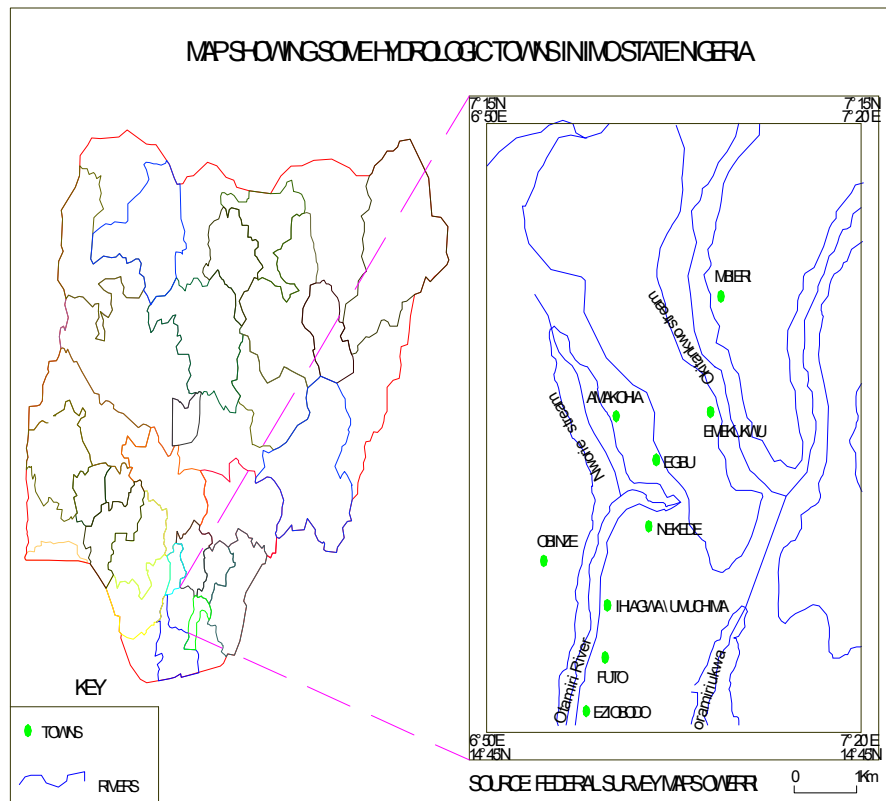


Fig 3.1. Map of Nigeria and Owerri showing the four sampling locations on Otamiri River

3.2 Climate, Vegetation, Hydrology and Economic Activities

Owerri experiences 200-250 cm annual rainfall with subequatorial climate. The area sits in the rainforest and produces many agricultural products such as yams, cassava, corn, rubber and palm products. Two seasons- the wet and dry seasons prevail in the area. The dry season is influenced by the North-East Trade Wind which moves over the region during the period (November-February).

The watershed of Otamiri River is mostly covered by depleted rain forest vegetation, with mean temperatures of 27°C throughout the year. The river has a maximum average flow of 10.7m³/s in rainy season (September-October) and minimum average flow of about 3.4m³/s in the dry season (November-February). The total annual discharge of this 3.74 x 10⁷m³ comes from direct runoff from rainfall and constitutes the safe yield of the river. Sand and gravel mining (Plate 3.1) is a principal resource use of the river in the northern and western parts, while at the southern part which is the upper course, the water is collected mainly for other commercial uses such as drinking by the rural inhabitants. Farming is also practiced along the banks of the river.



Plate 3.1. A truck loading mined sand at one of the sampling locations in FUTO

3.3 Sampling Design

Sampling was made along longitudinal gradient of the river; covering the upper and middle reaches. All sampling was made during the wet (rainy) season of 2019. Sampling was made for plankton and water.

3.4 Sampling Locations

Sampling was conducted at 4 sampling locations; with the upper reaches of the river serving as control location. Three sampling points each were selected at each sampling location. The sampling locations were sited at Egbu, Nekede, Umuchima, and the Federal University of Technology, Owerri (FUTO).

Sampling location 1 was sited at Egbu, the upper course of the river, and served as control. Sampling location 2 was sited at Nekede; about ... km from Egbu. Sampling location 3 was sited at Umuchima/Ihiagwa; about ... km from Nekede, while sampling location 4 was sited in FUTO; about ...n from Umuchima.

3.6. Field Sampling

The methods described by APHA (2000), Grant (2002), and Anene (2003) were adopted in collection of water and plankton samples.

3.6.1. *In situ* measurements

Water temperature, electrical conductivity, pH, turbidity, total dissolved solids, and dissolved oxygen were determined electrometrically *in situ* with the HANNA HI 9828 VI.4 PH/ORP/EC/DO meter that had been pre-calibrated with the standard HI 9828-25 kit calibration solution. The preferred parameter was read off the LCD of the meter.

3.6.2. Sampling for plankton

Sampling for plankton was done with plankton net of mesh size 55um (Fig. 3.2). The net was towed aboard a canoe horizontally for 5 minutes during navigations downstream the river channel at each sampling point. Afterwards,

the content of the net which contains mixed concentrations of plankton samples was transferred into a plastic container. Samples were preserved with 4% formaldehyde solution in the containers until needed for identification.

3.6.3. Water sample collection

Water samples for biological oxygen demand were collected in 250 mL brown bottles. Water samples for the other physicochemical parameters were collected in 500 mL sterile plastic containers. Samples were taken to the laboratory as soon as possible in an ice-cooler to maintain their integrity.

3.6. Laboratory Analyses

3.6.1. Plankton Identification

With a wide mouthed pipette, 1ml of the plankton subsample that had been mixed by inverting the field sample container was withdrawn and placed on a Sedge-Wick-Rafter-counting chamber and observed by direct microscope. Key provided by Essien and Ofor (2012) were used for species identification. Counts were made in triplicates and their averages taken and expressed a number of organism per millilitre of water.

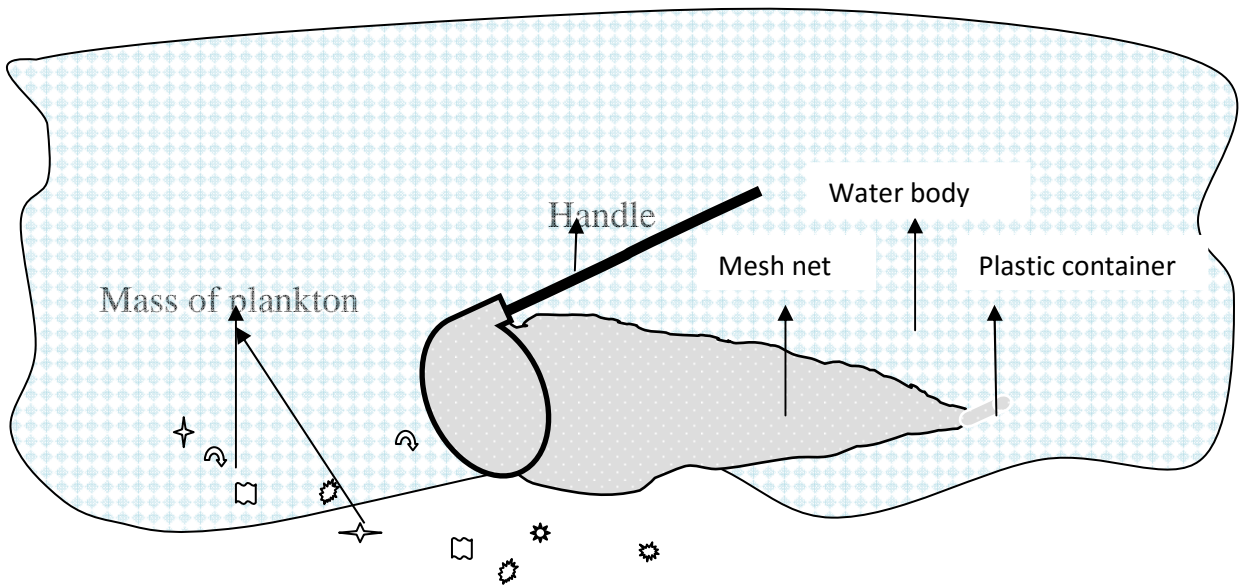


Fig 3.2. Plankton net used for sample collection

3.6.2. Water sample analysis

1. Determination of Nitrate ions

The cadmium reduction method was employed in the determination of nitrate levels of the water samples. A cadmium based reagent pillow was added into 25ml of the water sample in a cuvette and shaken for 1 minute and allowed to stand for another 5 minutes for complete reaction to occur. The absorbance and concentration in mg/l was read at 500nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

2. Determination of Sulphate ions

The barium chloride (Turbidometric) method was adopted. The barium chloride based powdered reagent pillow was added into 25ml of water sample. The mixture was properly mixed and allowed to stand for 5 minutes for reaction to occur. The absorbance and concentration in mg/L was read at 450nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

3. Determination of Phosphate ions

The ascorbic acid method was adopted for the determination of phosphate level of the river water. Ascorbic acid based reagent powdered pillow was added into 25ml of the water sample in a cuvette. The sample was allowed to stand for 2 minutes for reaction to occur. The absorbance and concentration in mg/l was read at 890nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

4. Determination of Total Suspended Solids (TSS)

An aliquot of the sample was filtered through a weighed glass-fibre filter paper, and the filter paper was oven-dried at 105°C for 3 hours according to ASTM D1888-78 method. The weight of the filter paper was measured with a Mettler H78AR analytical balance. The difference in weight was taken as the TSS in mg/l.

5. Determination of 5-day Biological Oxygen Demand (BOD₅)

DO was determined after 5 days incubation period at 20 ± 1 °C with same HANNAH HI 9828 V1.4 PH/ORP/EC/DO meter and the BOD₅ value calculated as follows:.

$$\text{BOD}_5 \text{ (mg/L)} = \frac{D_1 - D_2}{P}$$

Where D_1 is dissolved oxygen of the dilution sample 15 minutes after preparation, D_2 is dissolved oxygen of the diluted sample after incubation period of 5 days, and P , decimal fraction of sample used

3.7 Statistical Analysis

The SPSS v.23.0 and MS Excel[®] statistical soft wares were used to analyse data. Descriptive statistics was used to explore means and standard errors of the physicochemical parameters measured. The relationships between the plankton groups identified and physicochemical variables was explored using Pearson correlation coefficient (r) at $p < 0.05$ significant level. The test of homogeneity in mean variance of the physicochemical parameters and plankton taxa across the sampling locations was conducted with the One-way Analysis of Variance (ANOVA), and their means separated with the Duncan Multiple Range test at the 95% confidence interval.

Biological analyses for Diversity and Similarity indices were explored with the Margalef's Index, D , and Sørensen's Quotient, I respectively according to the formula:

Margalef's Index of species diversity, $D = \frac{S-1}{\ln N}$ (where S is the number of species present and N , the total number of individuals of all species present) (Margalef, 1961).

Sørensen's Quotient of species similarity, $I = \frac{2c}{(a + b)}$ (where a , b and c are the number of individuals in communities A, B and C respectively) (Tingle, 2002).

CHAPTER FOUR

4.0 RESULTS AND ANALYSES

4.1. Water Quality Parameters

Results of the physicochemical attributes of the Otamiri River in the study area across the sampling locations are shown in Appendixes 1. Surface water temperature varied from 27.58 to 28.63 °C, with a mean of 27.92 ± 0.11 °C, pH ranged from 5.38 to 6.32, with a mean of 6.15 ± 0.01 , while turbidity varied from 3.00-6.40, with a mean value of 4.62 ± 0.34 NTU during the study period (Table 4.1).

The Total Suspended Solids (TSS) varied from 2.00-6.60, with a mean of 4.42 ± 0.45 mg/L, Dissolved Oxygen varied from 0.91-1.63, with a mean value of 1.35 ± 0.07 mg/L, and Biological Oxygen Demand (BOD) ranged from 0.88-1.41, with a mean value of 1.12 ± 0.05 mg/L. Electrical conductivity and Total Dissolved Solids (TDS) varied from 14.00-39.00 (27.00 ± 2.18) $\mu\text{S}/\text{cm}$ and 7.00-20.00 (13.75 ± 1.07) mg/L, while the nutrients (NO_3^- , PO_4^{3-} , & SO_4^{2-} ions) varied from 0.20-0.70 (0.38 ± 0.03), 0.50-1.60 (1.11 ± 0.08), and 8.00-12.20 (10.33 ± 0.34) mg/L respectively (Table 4.1).

Table 4.1. Descriptive statistics of the physicochemical parameters of Otamiri River in Owerri

Parameters	Minimum	Maximum	Mean	SE
Water temperature (°C)	27.58	28.63	27.92	0.11
pH	5.32	6.32	6.15	0.01
Turbidity (NTU)	3.00	6.40	4.62	0.34
Total Suspended Solids (mg/L)	2.00	6.50	4.42	0.45
Dissolved Oxygen (mg/l)	0.91	1.63	1.35	0.07
Biological Oxygen Demand (mg/L)	0.88	1.41	1.12	0.05
Total dissolved solids (mg/l)	19.00	38.00	27.63	0.42
Conductivity (µS/cm)	14.00	39.00	27.00	2.18
Nitrate (mg/L)	0.20	0.70	0.38	0.03
Phosphate (mg/L)	0.50	1.60	1.11	0.08
Sulphate (mg/L)	8.00	12.20	10.33	0.34

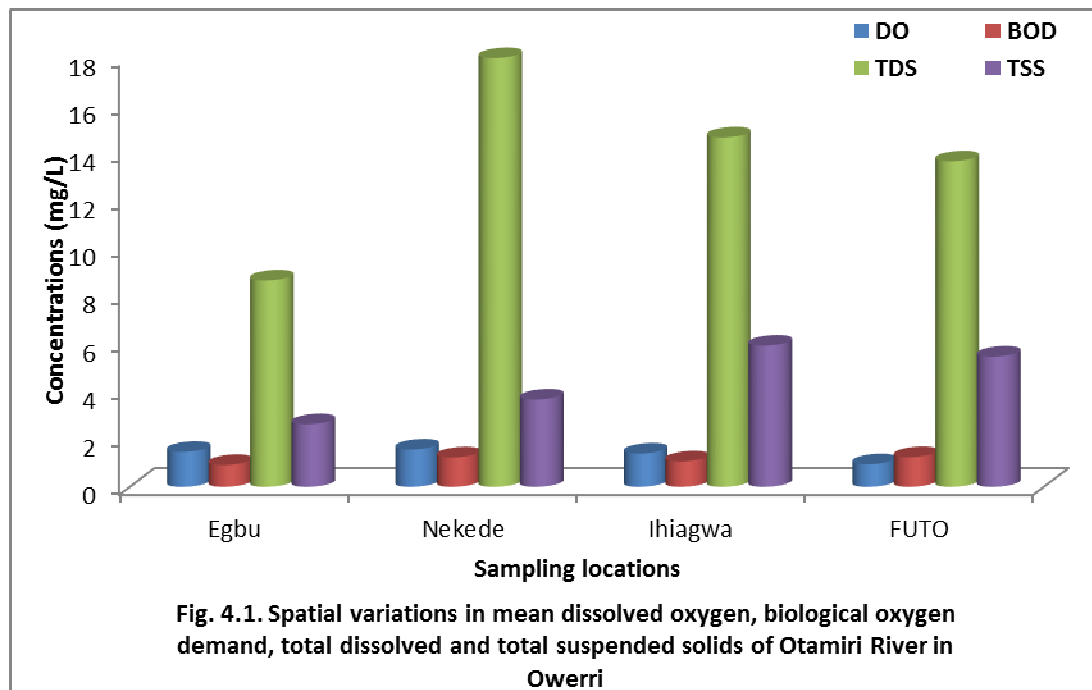
SE=standard error of mean

4.2. Spatial variation in physicochemical parameters

The physicochemical parameters measured in water also varied spatially. At Egbu (Control location), mean (\pm SE) Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) were 1.47 (\pm 0.01), 0.92 (\pm 0.03), 8.67 (\pm 1.20) and 2.63 (\pm 0.32) mg/L respectively (Fig. 4.1). At Nekede, their respective mean values were 1.57 (\pm 0.03), 1.24 (\pm 0.06), 18.00 (\pm 1.15) and 3.67 (\pm 0.45) mg/L. At Ihiagwa/Umuchima they were 1.40 (\pm 0.09), 1.07 (\pm 0.09), 14.67 (\pm 0.33) and 5.93 (\pm 0.22) mg/L. However, at FUTO, their mean values were 0.95 (\pm 0.03), 1.25 (\pm 0.08), 13.67 (\pm 0.33) and 5.47 (\pm 0.75) mg/L respectively.

Figure 2 shows that at Egbu, mean (\pm SE) of hydrogen ion concentrations (pH), water temperature, electrical conductivity and turbidity were 6.78 (\pm 0.03), 28.51 (\pm 0.06) °C, 16.67 (\pm 2.19) μ S/cm and 3.03 (\pm 0.03) NTU respectively. At Nekede, their mean values were 5.88 (\pm 0.24), 27.81 (\pm 0.02) °C, 36.00 (\pm 2.08) μ S/cm and 4.50 (\pm 0.29) NTU respectively. At Ihiagwa/Umuchima the respective mean values were 6.10 (\pm 0.12), 27.70 (\pm 0.01) °C, 28.67 (\pm 0.33) μ S/cm and 5.43 (\pm 0.48) NTU. However, at FUTO, their mean values were 5.87 (\pm 0.26), 27.67 (\pm 0.07) °C, 27.00 (\pm 0.58) μ S/cm and 5.50 (\pm 0.47) NTU respectively.

Mean concentrations of nitrate, phosphate and sulphate ions were 0.53 (± 0.09), 1.13 (± 0.12) and 8.77 (± 0.43) mg/L (Egbu); 0.37 (± 0.03), 1.40 (± 0.12) and



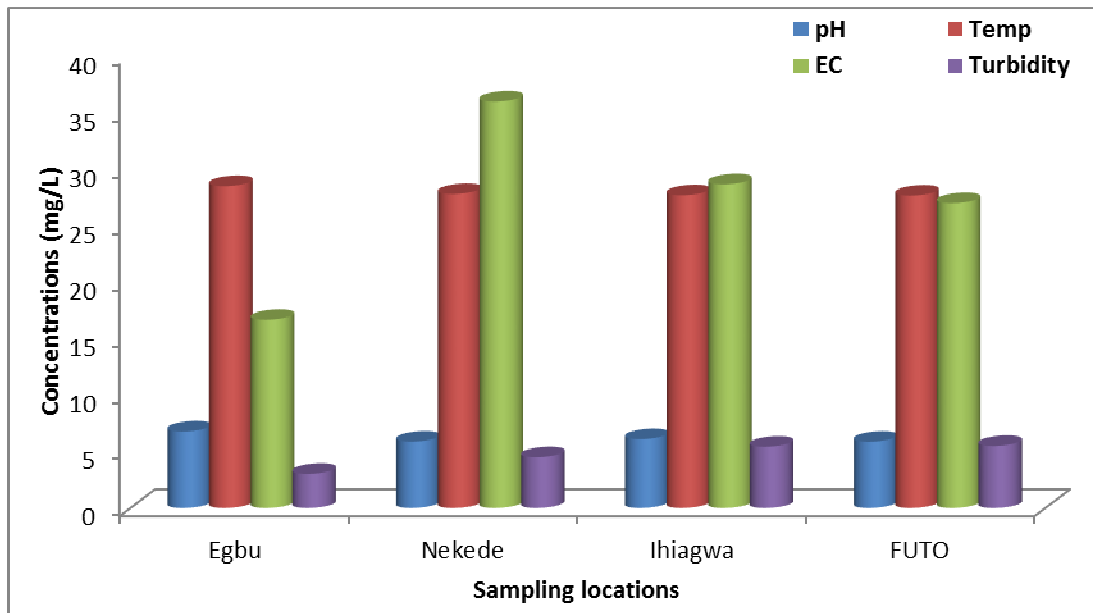


Fig. 4.2. Spatial variations in mean pH, water temperature, electrical conductivity and turbidity of Otamiri River in Owerri

11.40 (± 0.49) mg/L (Nekede); 0.30 (± 0.06), 0.77 (± 0.15) and 10.13 (± 0.18) mg/L (Ihiagwa/Umuchima); and 0.30 (± 0.06), 1.13 (± 0.07) and 11.00 (± 0.12) mg/L (FUTO) (Fig. 4.3).

The One-way Analysis of variance (ANOVA) test revealed that mean levels of DO, water temperature, electrical conductivity, and TDS (Sig. $F_{\text{value}}=0.000$ each), BOD (Sig. $F_{\text{value}}=0.035$), pH (Sig. $F_{\text{value}}=0.025$), TSS (Sig. $F_{\text{value}}=0.004$), turbidity (Sig. $F_{\text{value}}=0.005$), PO_4^{3-} ions (Sig. $F_{\text{value}}=0.029$) and SO_4^{2-} ions (Sig. $F_{\text{value}}=0.003$) all differed significantly across the sampling locations of the river at $p < 0.05$ (Appendix 2).

A post-hoc mean separation using the Duncan Multiple Range Test further revealed that mean DO differed significantly between FUTO and the other locations, and between Nekede and Ihiagwa/Umuchima; BOD differed between Egbu and Nekede and Egbu and FUTO; pH and temperature differed between Egbu and the other locations; while electrical conductivity and TDS differed between Egbu and Nekede and Ihiagwa=FUTO (Table 4.2). TSS differed between Egbu=Nekede and Ihiagwa/Umuchima=FUTO; turbidity differed between Egbu and the other locations; NO_3^- ions differed between Egbu and Ihiagwa/Umuchima=FUTO; PO_4^{3-} ions differed between Nekede and Ihiagwa/Umuchima; while SO_4^{2-} ions differed between Egbu and the other locations, as well as Nekede and Ihiagwa/Umuchima (Table 4.2).

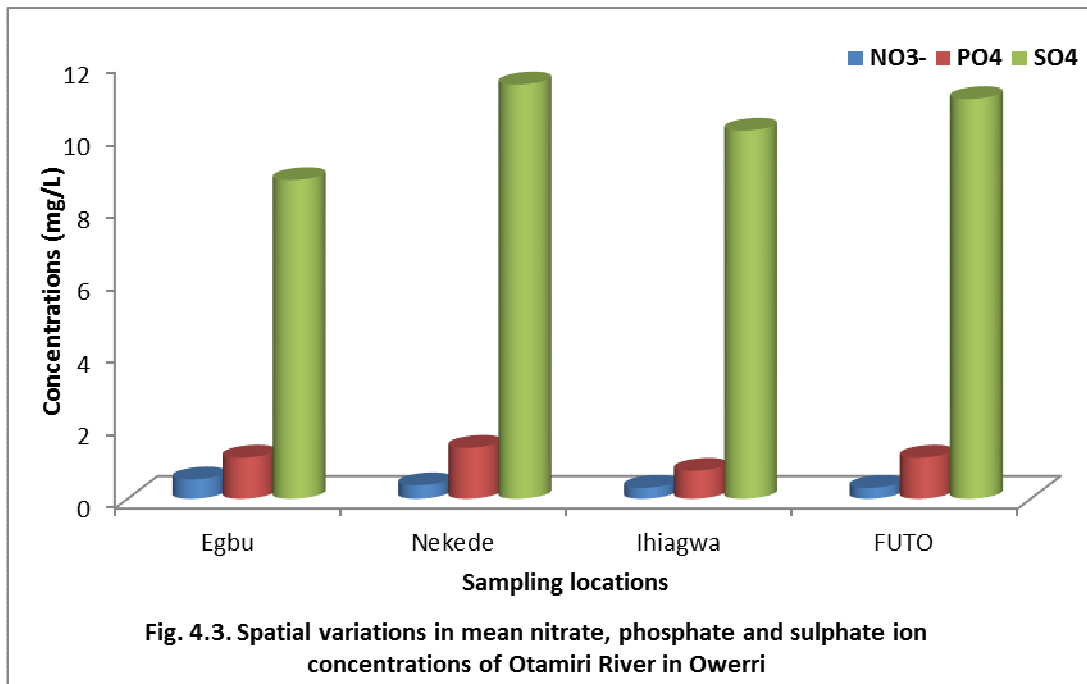


Table 4.2. Mean separation of the physicochemical parameters of Otamiri River in Owerri using Duncan Multiple Range Test ($p < 0.05$)

Parameters	Sampling Locations			
	Egbu	Nekede	Ihiagwa	FUTO
Dissolved Oxygen (mg/L)	1.4733 ^{ab}	1.5700 ^a	1.4000 ^b	0.9533 ^c
Biological Oxygen Demand (mg/L)	0.9233 ^b	1.2367 ^a	1.0667 ^{ab}	1.2500 ^a
pH	6.7833 ^a	5.8800 ^b	6.1000 ^b	5.8700 ^b
Temperature (°C)	28.5133 ^a	27.8067 ^b	27.7000 ^b	27.6733 ^b
Electrical conductivity ($\mu\text{S}/\text{cm}$)	16.6667 ^c	36.0000 ^a	28.6667 ^b	27.0000 ^b
Total Dissolved Solids (mg/L)	8.6667 ^c	18.0000 ^a	14.6667 ^b	13.6667 ^b
Total Suspended Solids (mg/L)	2.6333 ^b	3.6667 ^b	5.9333 ^a	5.4667 ^a
Turbidity (NTU)	3.0333 ^b	4.5000 ^a	5.4333 ^a	5.5000 ^a
Nitrate (mg/L)	0.5333 ^a	0.3667 ^{ab}	0.3000 ^b	0.3000 ^b
Phosphate (mg/L)	1.1333 ^{ab}	1.4000 ^a	0.7667 ^b	1.1333 ^{ab}
Sulphate (mg/L)	8.7667 ^c	11.4000 ^a	10.1333 ^b	11.0000 ^{ab}

Values with same superscript along same row are not significantly different at $p < 0.05$ level

4.3. Composition and Abundance of Plankton taxa

A total of 47 genera of plankton were identified in the study. Of this, the phytoplankton composed of 43 genera while the zooplankton composed of 4 genera. These genera belong to 8 classes of phytoplankton which includes 10 genera of bacillariophyceae, 18 genera of cyanophyceae, 12 genera of chlorophyceae, 3 genera of xanthophyceae, 2 genera of euglenophyceae, and 1 genera each of pyrrophyceae, charophyceae, copepod, cladocera, protozoa and fish eggs.

4.3.1. Abundance of phytoplankton taxa

Two plankton groups- phytoplankton and zooplankton were studied in this research, and the pattern of their abundances varied spatially. Seven phytoplankton families- Bacillariophyceae, Cyanophyceae, Chlorophyceae, Euglenophyceae, Pyrrophyceae, Charophyceae and Xanthophyceae were identified in this study (Appendixes 3a-3d). Diatoms (Bacillariophyceae) counts ranged between 12 and 46 (27 ± 3) organisms/ml, blue-green algae (Cyanophyceans) ranged between 6 and 23 (14 ± 2) organisms/ml, while the green algae (Chlorophyceans) ranged between 2 and 19 (7 ± 1) organisms/ml. Of these, the diatoms were most abundant while charophyceans were least abundant. The order of abundance was Bacillariophyceae>Cyanophyceae>Chlorophyceae>Xanthophyceae>Euglenophyceae>Pyrrophyceae>Charophyceae.

Phytoplankton abundance comprised of a total of 9 each of diatoms and blue-green algae genera, 6 green algae genera, 2 each of euglenophycean and xanthophycean genera, and 1 each of charophycean and pyrrophycean genera. The most abundant diatom genera were *Diatoma* sp while that for cyanophyceae was *Aphanizomenon flos-Aquae*.

4.3.2. Abundance of zooplankton taxa

Four zooplankton classes were identified during the study period (Appendix 3). The classes were cladocera, copepoda, protozoa and pisces (fish eggs). Zooplankton was lower in abundance than the phytoplankton assemblages. Maximum counts only were recorded for the zooplankton classes. The order of abundance of the classes was cladocera and copepoda > protozoa > fish eggs.

4.4. Spatial abundance in plankton taxa

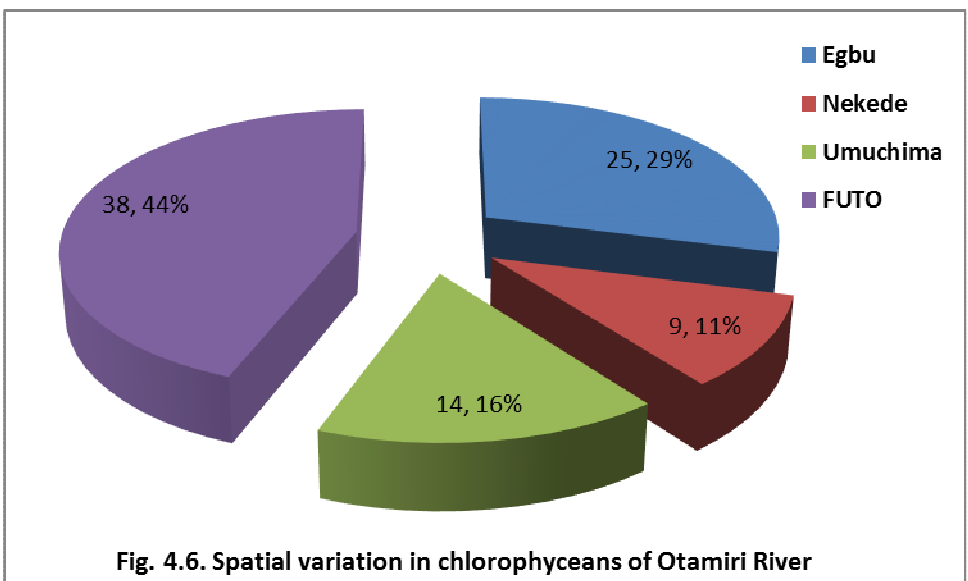
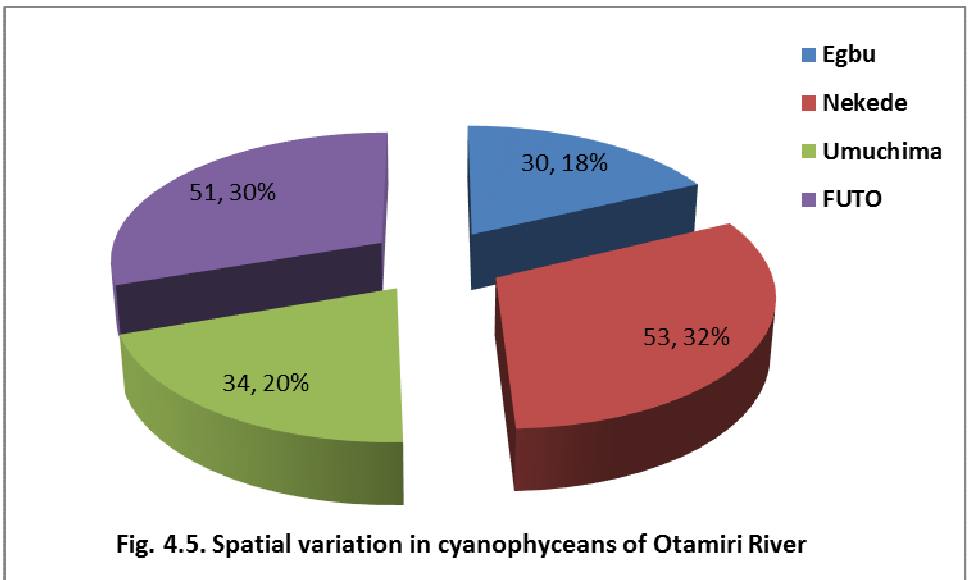
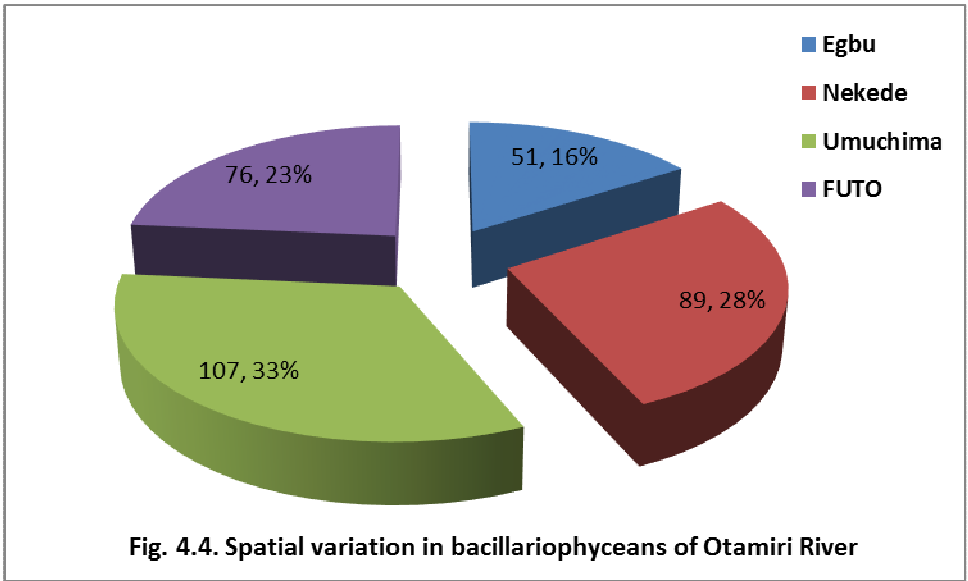
4.4.1. Phytoplankton taxa

Variations were also observed in plankton abundance across the sampling locations. Sampling location 3 (Ihiagwa/Umuchima) recorded the highest plankton abundance (158 organisms/ml) while Egbu had the least abundance of 108 organisms/ml (Appendix 3).

Bacillariophycean counts were highest at Ihiagwa/Umuchima (107 organisms/ml; 67.7%) and least at Egbu (51 organisms/ml; 49.2%) (Fig 4.4). Highest abundance of 53 organisms/ml (34.2%) was recorded at Nekede for the

blue-green algae (cyanophyceans), while Egbu recorded the least abundance of 30 organisms/ml (27.8%) for the taxa (Fig 4.5). The green algae was most abundant at FUTO (38 organisms/ml; 21.7%) and least abundant at Nekede (9 organisms/ml; 5.8%) (Fig 4.6). However the other phytoplankton families were not identified at several sampling locations.

At sampling location 1 (Egbu), the order of abundance of the phytoplankton was bacillariophyceae (951; 49.2%)>cyanophyceae (30; 27.8%)>chlorophyceae (25; 23.2%)>xanthophyceae (2; 1.8%)>euglenophyceae=pyrrophyceae=charophyceae (0; 0.0%). At Nekede, the order of the abundance was bacillariophyceae (89; 57.4%)>cyanophyceae (53; 34.2%)>chlorophyceae (9; 5.8%)>pyrrophyceae (4; 2.6%)>xanthophyceae=euglenophyceae=charophyceae (0; 0.0%). In sampling location 3 (Ihiagwa/Umuchima), the order of abundance was bacillariophyceae (107; 67.7%)>cyanophyceae (34; 21.5%)>chlorophyceae (14; 8.9%)>euglenophyceae =charophyceae (0; 0.0%). In location 4 (FUTO), the order of abundance was bacillariophyceae (76; 43.4%)>cyanophyceae (51; 29.1%)>chlorophyceae (38; 21.7%)>xanthophyceae=euglenophyceae (4; 2.3%)>charophyceae (2; 1.1%)>pyrrophyceae (0; 0.0%).



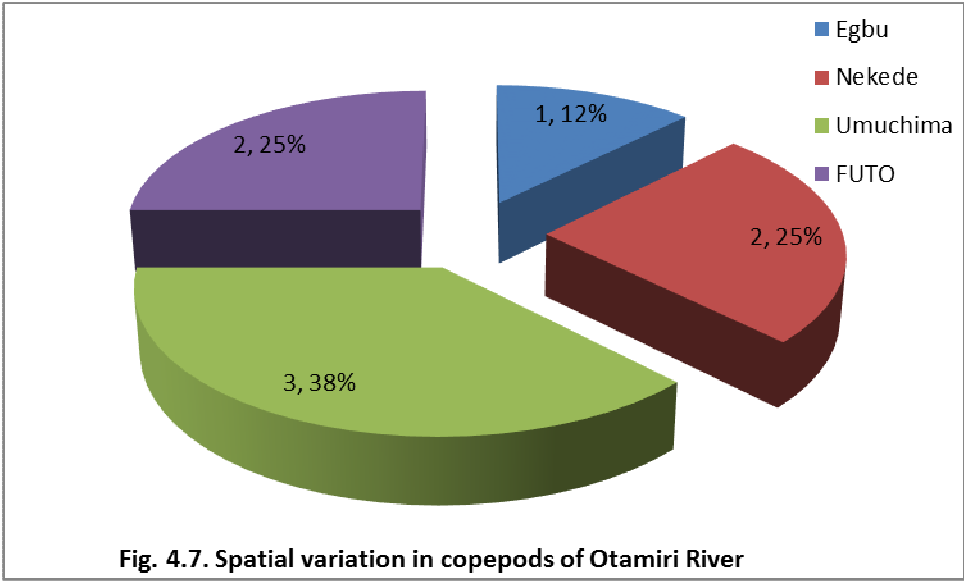
4.4.2. Zooplankton taxa

Zooplankton classes identified were comparatively lower in abundance than phytoplankton groups. Cladocerans were absent in Egbu; fish eggs were absent at Nekede, Umuchima and FUTO; while protozoans were absent in Egbu, Nekede and Umuchima. However, zooplankton abundance were highest at Umuchima and FUTO (7 organisms/ml each) and least at Egbu and Nekede (2 organisms/ml each) (Appendix 3). At Egbu, the order of abundance of zooplankton was copepoda=pisces (fish eggs) (91; 50.0%)>cladocera=protozoa (0; 0.0%). At Nekede the order was cladocera=copepod (2; 50.0%)>pisces (fish eggs)-protozoa (0; 0.0%). At Ihiagwa, the order of abundance was cladocera (4; 57.1%)>copepod (3; 42.9%)>pisces (fish eggs)=protozoa (0; 0.0%), and at FUTO, the order was protozoa (3; 42.8%)>cladocera=copepod (2; 28.6%)>piscea (fish eggs) (0; 0.0%).

Zooplankton classes were dominated by the cladocerans- *Daphnia hyaline*, and the copepod- *Canthocamptus staphylinus* (Fig. 4.7). However, the protozoan- *Arcella arenaria* was only found in FUTO.

4.4.3. Variance equality in plankton abundance

The test of variance equality in mean abundances of plankton taxa using the one-way Analysis of Variance (ANOVA) revealed significant abundance



inequality in the cladoceran (Sig. $F_{\text{value}}=0.030$), xanthophycean and euglenophycean (Sig. $F_{\text{value}}=0.011$ each) taxa at $p<0.05$ (Appendix 4).

A further mean separation with the Duncan Multiple Range Test revealed that the observed numerical inequalities in bacillariophyceae was between Egbu and Ihiagwa/Umuchima, in chlorophyceae and xanthophyceae was between Nekede and FUTO, and in euglenophyceae was between FUTO and the other locations (Table 4.3).

4.5. Plankton Diversity and Similarity Indices

Phytoplankton taxa were generally more diverse, with Margalef's Index (I) ranging from 2.56-5.03, than zooplankton group with I values ranging from 0.51-1.44 during the study period (Table 4.4a). Generally, the order of magnitude in spatial diversity of phytoplankton was FUTO (5.03)>Ihiagwa (4.54)>Nekede (3.14)> Egbu (2.56) and that for zooplankton was Egbu (1.44)>FUTO (1.03)>Nekede (0.72)>Ihiagwa/Umuchima (0.51).

Table 4.4b shows the Sørensen's Quotient of Similarity (QS) of the combined phytoplankton and zooplankton species identified during the study period. Generally, moderate species similarities were observed between sampling points 2 & 1 in Egbu and Ihiagwa/Umuchima, and between sampling points 3 & 1 in Egbu, Nekede, and Ihiagwa/Umuchima, and between sampling points 3, 1 & 2 in FUTO. However, comparatively low QS values were recorded between

sampling points 2 & 1 in FUTO, and sampling points 3 & 2 in Nekede and Ihiagwa/Umuchima.

4.6. Relationships between physicochemical variables and plankton assemblages

Table 4.5 shows the Pearson correlations (r) between the physicochemical characteristics measured and plankton taxa identified in the Otamiri River. Some physicochemical variables showed significant influences on plankton families. However, at $p < 0.05$, DO correlated negatively with euglenophyceae ($r = -0.679$) and xanthophyceae ($r = -0.673$). At $p < 0.01$, DO correlated negatively with chlorophyceae ($r = -0.747$).

At $p < 0.05$, BOD correlated positively with cyanophyceae ($r = 0.619$), and TSS correlated with bacillariophyceae ($r = 0.629$). Other physicochemical parameters measured did not show significant influences on the plankton families identified.

Table 4.3. Mean separation in Numerical abundance of plankton taxa identified across the sampling locations in Otamiri River using Duncan Multiple Range Test (p<0.05)

Plankton taxa	Sampling Locations			
	Egbu	Nekede	Ihiagwa	FUTO
<u>PHYTOPLANKTON:</u>				
Bacillariophyceae	17.0000 ^b	29.6667 ^{ab}	35.6667 ^a	25.3333 ^{ab}
Cyanophyceae	10.0000 ^a	17.6667 ^a	11.3333 ^a	17.0000 ^a
Chlorophyceae	8.3333 ^{ab}	3.0000 ^b	4.6667 ^b	12.6667 ^a
Xanthophyceae	0.6667 ^{ab}	0.0000 ^b	0.0000 ^b	1.3333 ^a
Pyrrophyceae	0.0000 ^a	1.3333 ^a	0.3333 ^a	0.0000 ^a
Euglenophyceae	0.0000 ^b	0.0000 ^b	0.6667 ^{ab}	1.3333 ^a
Charophyceae	0.0000 ^a	0.0000 ^a	0.0000 ^a	0.6667 ^a
<u>ZOOPLANKTON:</u>				
Cladocera	0.3333 ^a	0.6667 ^a	1.3333 ^a	0.6667 ^a
Copepoda	0.0000 ^a	0.6667 ^a	1.0000 ^a	0.6667 ^a
Fish eggs	0.3333 ^a	0.0000 ^a	0.0000 ^a	0.0000 ^a
Protozoa	0.0000 ^a	0.0000 ^a	0.0000 ^a	1.0000 ^a

Values with same superscript along same row are not significantly different at p<0.05 level

Table 4.4a. Margalef's Index of species Diversity (I) of plankton taxa of Otamiri River in Owerri

Index	Sampling locations							
	Egbu		Nekede		Ihiagwa		FUTO	
	Phytoplankton	Zooplankton	Phytoplankton	Zooplankton	Phytoplankton	Zooplankton	Phytoplankton	Zooplankton
Margalef's Diversity	2.56	1.44	3.17	0.72	4.54	0.51	5.03	1.03

Table 4.4b. Sørensen's Quotient of species Similarity (QS) of plankton taxa of Otamiri River in Owerri

Sampling Points	Sampling locations			
	Egbu	Nekede	Ihiagwa/Umuchima	FUTO
	1 2	1 2	1 2	1 2
1	-	-	-	-
2	0.59	0.58	0.50	0.49
3	0.59 0.50	0.62 0.46	0.60 0.36	0.67 0.60

Table 4.5. Correlations (r) between the physicochemical parameters and plankton taxa of Otamiri River in Owerri

Plankton taxa/ Physicochemical parameters	DO	BOD	pH	Temp	EC	TDS	TSS	Turbid	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
Bacillariophyceae	-0.023	0.136	0.435	-0.482	0.500	0.495	0.629*	0.510	-0.392	0.156	0.468
Cyanophyceae	-0.309	0.619*	0.206	-0.324	0.430	0.438	0.397	0.458	-0.032	0.295	0.565
Chlorophyceae	-0.747**	0.220	0.311	0.052	-0.429	-0.420	0.330	0.141	-0.091	-0.034	-0.099
Euglenophyceae	-0.679*	0.135	0.392	0.285	-0.005	-0.031	0.159	0.391	-0.066	-0.013	0.269
Pyrrophyceae	0.296	0.060	-0.104	-0.156	0.489	0.441	-0.031	0.122	0.019	0.507	0.489
Charophyceae	-0.513	0.073	0.330	-0.089	-0.045	-0.063	0.298	0.478	0.058	0.099	0.128
Xanthophyceae	-0.673*	-0.004	0.138	-0.011	-0.437	-0.453	-0.017	-0.034	0.149	-0.070	0.063
Cladocera	-0.123	-0.181	0.344	-0.342	0.260	0.273	0.428	0.366	0.272	-0.021	0.158
Copepoda	0.092	-0.015	0.016	-0.135	-0.012	-0.057	0.173	-0.087	-0.156	0.052	0.306
Protozoa	-0.513	0.073	0.330	-0.089	-0.045	0.063	0.298	0.478	0.058	0.099	0.128
Pisces (Fish eggs)	-0.444	-0.004	0.204	0.111	-0.126	-0.138	0.133	0.326	0.075	0.164	-0.079

*=significant at p<0.05 level; **=significant at p<0.01 level; DO=dissolved oxygen; BOD=biological oxygen demand; Temp=water temperature;

EC=electrical conductivity; TDS=total dissolved solids; TSS=total suspended solids; Turbid=turbidity

CHAPTER FIVE

5.0. DISCUSSION, SUMMARY AND CONCLUSION

5.1. Discussion

Like any other aquatic ecosystem, the physicochemical characteristics and plankton abundance and diversity of the Otamiri River in Owerri is prone to ecological imbalances resulting from both natural and anthropogenic impacts arising from man's quest for the exploitation of natural resources. At the time of this investigation, there was ongoing intensive in-stream sand mining by local inhabitants along the course of the river, as well as other domestic activities in the catchments of the sampling locations.

5.1.1. Physicochemical parameters

Water temperature

The water temperature range in the present study was similar to those reported by Sowunmi (2001), Eze (2005), and Tamuno (2005) for natural inland water in the tropics. The National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) recommends that temperature increases by a 7-Day Average of the Daily Maximum (7-DADMax) levels in surface waters for fisheries in Nigeria should not be more than 0.3 °C above the natural background conditions and values in this study fall within this regulation. The observed marked spatial variations in water temperature reflects some degree of microclimatic variations in temperature regime provided by riparian covers and

shades, as well as varying anthropogenic activities at these locations leading to constant but gradential heat transfers. The marked differences in temperature regime of the river mostly between Egbu and the other locations correspond with the control location's (Egbu) comparatively lesser anthropogenic perturbations (such as sand mining and domestic waste disposal practices). This confirms that localized man-made activities could significantly alter the physicochemical status of an ecosystem. However, similar spatial heterogeneity was not observed by Sowunmi (2001) in Ologe Lagoon and River Owo in Western Nigeria and Ogamba *et al.* (2004) in Elechi Creek of the Niger Delta.

Kambo and Dutta (2015) the physical, chemical and biological processes, as well as numerous other variables are affected by temperature. Furthermore, when nutritional conditions (including temperature) are favourable, growth rates, especially of bacteria and phytoplankton increases. In addition to determining how pollutants, parasites and other pathogens interact with aquatic residents, temperature also influences the solubility of dissolved gases such as oxygen and ammonia in water column (UNEP GEMS, 2006). These thus brings to fore the importance of favourable water temperature to ecosystems processes and balance.

Turbidity

Mean value of 4.62 ± 0.34 NTU recorded in this study was below the NESREA 10.00 NTU limit for aquatic life in surface waters in Nigeria, even as the UNEP GEMS (2006) states that water bodies that have high turbidities (low transparencies) are not good for drinking. Ongoing in-stream sand mining activities at the sampling locations and the periodic lotic distribution of suspended sediments so introduced in water column may have contributed slightly to the overall turbidity of the river. In this study, increasing turbidity was also associated with increasing pH. This indicates that some of the suspended solids constituting the murkiness of water were not humic and so, alkaline. The observed spatial inequalities in turbidities at the sampling locations could reflect varying degrees of perturbations at the locations. Though turbidity is not necessarily harmful to fish (Tamuno, 2005), the resulting reduction of sunlight intensity in the water column decreases the primary productivity of water body (Adakole *et al.*, 2003) thus, impacting negatively on the entire ecological trophic chains.

Total Suspended Solids (TSS)

Ongoing in-stream mining activities by local inhabitants could contribute suspended particulate materials along the river course. Tamuno (2005) had pointed out the contributory effect of sand mining and dredging on TSS of two Niger Delta water bodies in Kolo and Otuoke communities, and so did Eze

(2005) and among others, in the Niger Delta. The suspended solids that constituted TSS in this study were alkaline in nature. Waters classified with TSS of 278 mg/l and above as grossly polluted, while NESREA (2011) recommends values not greater than 0.25 mg/l good for aquatic life in surface waters. This thus makes the segments of the river studied unsuitable for optimal aquatic life.

Total Dissolved Solids (TDS)

The high solvating nature of water makes it an excellent medium for several substances in the environment to dissolve in. Since many of these solutes could be pollutants in the aquatic environment, TDS levels have thus been used to evaluate the purity of water. In the present study, TDS values were higher in the more impacted locations (Nekede, Ihiagwa/Umuchima and FUTO) than the control (Egbu). Mean TDS values were fairly inversely followed by pH; a trend that was also observed by Atobatele *et al.* (2005) and was attributed to increases in major ions dissolved in the water from underlying rocks or washed by rain which affects pH of aquatic systems.

pH

According to the UNEP GEMS (2006), the importance of pH in aquatic environment lies in its close link to biological productivity, even as the tolerance of individual species varies. The marked spatial variation in pH at the

sampling locations of this study indicates somewhat unstable habitat, which could be linked to unstable photosynthetic rates that could be measured as primary productivity. According to Grant (2002), the pH of water is affected considerably as photosynthetic activity removes carbon (IV) oxide from water and shifts the carbonate-bicarbonate equilibrium. The slightly acidic pH range of this study conformed to values previously reported in Niger Delta freshwaters (Ogbuagu and Ayoade, 2011). The minimum range of pH in this study falls outside the NESREA 6.5–8.5 recommended limits for aquatic life. These pH make it somewhat unsuitable for fish production in this river (Adakole and Anunne, 2003; Adakole *et al.*, 2003; Akinrele, 2015).

Dissolved oxygen (DO)

Slightly higher Do values were recorded in the impacted than pristine control location. This could indicate more turbulence of the river at those locations that incorporated oxygen than at the pristine location. The significant spatial variation in DO indicates varying mixing and anthropogenic effects on this lotic water body. The amount of dissolved oxygen also depends highly on temperature, as higher temperatures will reduce dissolved gases. Being the case in this study, similar observations had been made for an annual cycle in the Murray River, Australia. It has been recommended by the World Health Organization that water in a distribution system should always contain adequate DO. Under anaerobic conditions, microbial reduction of nitrate to nitrite and

also sulphate to sulphide occurs, often giving rise to odour problems. The oxygen depletion increases ammonia toxicity and fish susceptibility to diseased conditions. These buttress the importance of adequate dissolved oxygen in any aquatic ecosystem. Albeit, the mean DO (1.35 ± 0.07 mg/L) of this river is outside WHO 3.0-7.0mg/l guideline limits for drinking water. NESREA recommends a value of not less 6.00 for aquatic life, and so, mean values recorded in this study are outside the regulatory limits.

Biological Oxygen Demand (BOD)

Bell (2019) BOD fluctuation could occur due to sediments being transported into water bodies and particles of organic debris derived from excretion, death and decay of plants and animals. It is known that higher oxygen utilization will lead to higher carbon (IV) oxide evolution from respiration (UNEP GEMS, 2006). Oxygen demanding wastes are often associated with high nutrient contents such as nitrates, sulphates and phosphates (Adesiyun, 2005). However, BOD range of this river indicated that the water was fairly clean, going by Katyal (2011) ranking of levels less than 1.0 mg/l as clean, 3.0 mg/l as fairly clean, 5.0mg/l as doubtful, and 10.0mg/l as polluted. Also, going by NESREA recommended limit of 3.0 mg/l, the river was unsuitable for aquatic life. Though seemingly unobtainable in a natural ecosystem, Faurie *et al.*, (2001) recommends a BOD value of 0 mg/l for a best potable water supply.

Electrical Conductivity

Conductivity had a relatively wide range during the study period, and the overall pattern of spatial variations in electrical conductivity and TDS were fairly similar; an observation Atobatele *et al.* (2005) had earlier explained to be due to the presence of more dissolved ions in solution. This explanation most likely accounts for the observation during the rainy season, since the Otamiri River is freshwater and the study area is not affected by saline water intrusions (Sikoki and Zabbey, 2008). At low levels of electrical conductivity, major ions may determine the nature of the fauna (Adakole *et al.*, 2003). The observed significant spatial difference in conductivity indicates varying introduction and presence of these ions. Conductivity values fell within acceptable limits, going by CSPI (2009) maximum value of 1000 $\mu\text{S}/\text{cm}$ for drinking water in Nigeria.

Nitrate

Primary producers assimilate inorganic nitrogen as ammonium (NH_4^+) and nitrate (NO_3^-) ions and organic nitrogen is returned to the inorganic nutrient pool through bacterial decomposition and excretion of NH_4^+ and amino acids by living organisms (UNEP GEMS, 2006). This underpins the importance of nitrate in major cellular components of organisms, as well as the entire ecosystem. In this study, nitrate values corresponded with findings from the works of Chindah and Braide (2001) in a Swamp Forest stream, Obunwo *et al.* (2004) in Minichida stream, and Ogamba *et al.* (2005) in Elechi Creek, all in the Niger Delta. Some inhabitants of the study area are agrarian and so, through their occupations could contribute nitrates from farmland fertilizer applications

into the water body. Nitrate values recorded in this study falls below the WHO 50 mg/l limits for drinking water and NESREA 9.10 mg/l for aquatic life. NO_3^- range of this study was also similar to those recorded for major Nigerian inland waters (Dejen *et al.*, 2004). The non-significant spatial variation in nitrate concentrations at the sampling locations indicates homogeneity in natural and anthropogenic inputs at those locations.

Phosphate

Like other nutrients, the sources of phosphate in aquatic environments has been identified as natural weathering of minerals in the drainage basin, biological decomposition, and runoff from human activities in urban and agricultural areas (UNEP GEMS, 2006). The range of PO_4^{2-} ions in this study was within safe limits of the WHO for drinking water and NESREA for aquatic life. Values recorded in this study were also within the range of many Nigerian inland waters as reported by Izah (2016). However, they were lower than those recorded for Minichia stream (Obunwo *et al.*, (2004) and River Ogunpa (Atobatele *et al.*, 2005). Phosphate and nitrate are also important for plankton bloom and eutrophication (Saggiroro et al., 2012). The marked spatial variation in phosphate concentration across the locations implies heterogeneous natural and anthropogenic inputs.

Sulphate

The concentrations of sulphate ions in freshwater could also be contributed by the use of sulphate containing detergents by local inhabitants during washing. The values of SO_4^{2-} recorded in this study were outside the WHO limits of 3.00–6.00 mg/l for drinking water. NESREA recommends maximum sulphate ion level of 100 mg/L for aquatic life while CSPI (2009) also recommends maximum value of 100 mg/L for drinking water. These requirements therefore place the Otamiri River below the limits. Albeit, the sulphate content of this river was less than those recorded for River Ogunpa in Ibadan (36.60 ± 4.52 mg/L).

5.2. Plankton Abundance and Distribution

Emphasis have been placed on the multiple effects of natural or altered conditions on plankton dynamics and compositions in an aquatic environment (Eze, 2005; Chattopadhyay and Barik, 2009; Altaf *et al.*, 2010). When compared with the works of Rai *et al.* (2006) in other river systems, the Otamiri River in Owerri recorded comparatively low plankton abundance and diversity, especially of the zooplankton. This paucity could be attributed to environmental perturbations (Ogwejifor, 2000; EPA, 2003), especially arising from ongoing intense in-stream sand mining by local inhabitants and other domestic activities like waste disposal, which causes high turbidity and thus, decreased plankton abundance and diversity. Okogwu and Ugwumba (2006) made similar observations. The health of the biotic community of any aquatic

system is a function of the abundance and diversity of plankton as primary producers. The much lower abundance of zooplankton than phytoplankton conforms to ecological trophism, whereby there are usually more primary producers than consumers in a food chain. Grant (2002) had observed that a steady input of pollutants over time could result to changes in the biological community composition of water bodies. The current study recorded lower phytoplankton genera, especially when compared with the work of Sowunmi (2001) and Clarke (2004) in Rivers Owo and Ologe Lagoon, respectively. Ogamba *et al.* (2004) in Elechi Creek, all in the Niger Delta also recorded higher plankton abundances. Akoma and Imoobe (2009) also recorded higher plankton genera (26), while Chattopadhyay and Banerjee (2007) recorded lower (7) genera.

The quantitative order of dominance of dominance of the phytoplankton in this study (bacillariophyceae>cyanophyceae>chlorophyceae>xanthophyceae>euglenophyceae>pyrrophyceae>charophyceae) followed the general pattern for most Nigerian inland waters as reported by SPDC (2015) and elsewhere by Rai *et al.* (2006) and Akoma and Imoobe (2009). The quantitative order of dominance of the zooplankton in this study (cladocera=copepoda>protozoa>fish eggs) had earlier been observed in segments of Imo River in Oyiabo LGA, Rivers State by Zabbey *et al.* (2008). The dominance of diatoms in the study has also been reported in many other rivers in the Niger Delta (Chindah and Braide, 2001; Ogamba *et al.*, 2004; Edoghotu and Aleleye-

Wokoma, 2007; Zabbey *et al.*, 2008) and elsewhere by Akoma and Imoobe (2009) in Lake Tana, Ethiopia, and Altaf *et al.* (2010) in Wular Lake, Kashmir. This dominance could be attributed to the bacillariophycean ability to grow under the conditions of optimum tropical weather conditions, such as high solar radiation and high ambient temperature prevalent in the area. This reason however is opposed to the findings of Altaf *et al.* (2010) that the dominance of diatoms was as a result of weak light and low temperature prevalent in their study area.

The dominance of the cyanophyceans came after that of the bacillariophyceans, and this conforms to the findings of Altaf *et al.* (2010) that the blue-green algae have worldwide distribution and that majority of species are cosmopolitan in the tropics. They further attributed their habitat preference successes to inherent high photosynthetic abilities, as well as the ability of certain species (e.g. *Anabaena* sp.) of the group in freshwater to fix atmospheric nitrogen to supplement their nitrogen requirements (Kapoor and Arora, 2000). The least abundance recorded for the charophyceans phytoplankter indicates that this group either utilized the least of the environmental factors provided, or were most negatively influenced by limiting effects. The abundance of the copepodan and cladoceran populations over others zooplankton taxa was most probably due to their ability to withstand and survive in varying limnological conditions prevailing during the study period. Highest density of phytoplankton was recorded for the bacillariophyceae in Umuchima, while the lowest density was

recorded in Egbu. The abundance of bacillariophyceae at all the sampling locations indicates that they are more stable in the aquatic ecosystem.

5.3. Biotic Diversity

Generally, biotic diversity was low, especially of the zooplankton when compared with the works of Zabbey *et al.* (2008) on Imo River at Oyigbo LGA and Ogamba *et al.* (2004) in Elechi Creek Complex, all in the Niger Delta. Comparatively, Zabbey *et al.* (2008) recorded a mean phytoplankton Margalef's diversity of up to 5.395, similar to a mean Margalef's value of 5.03 recorded in the current study. However, Zabbey *et al.* (2008) recorded mean zooplankton Margalef's diversity of 0.882, comparable to the current study's diversity. This paucity of zooplankton diversity could be attributed to perturbations in water columns, especially from sand mining and other domestic activities, which must have exerted selective effects on the biological assemblages (Ogbuagu and Ayoade, 2012). Zabbey *et al.* (2008) have also identified sand mining as being responsible for low plankton abundance and diversity in the Imo River, even as Tamuno (2005) had also identified the activity as exerting deleterious effects on plankton community composition in the Niger Delta area.

For the zooplankton, the cladocerans and copepodans were most diverse. The moderate to low species similarities across the sampling locations, especially of the zooplankton relate to trophic niche and relationships between the groups of animals and phytoplankton. The highest phytoplankton and zooplankton

diversities recorded in FUT0 could be attributed to more human perturbations that introduced nutrient to the water body, while the lower diversities recorded at Egbu, the pristine location could reflect less human activities that introduces nutrients. Increasing anthropogenic activities such as farming, sand mining, piggery going on at the lower course of the river is capable of increasing the nutrient concentration and other essential elements from sampling location 2 (Nekede) to sampling location 4 (FUTO). This nutrient may have supported the growth of plankton at sampling locations 2 (Nekede) through to location 4 (FUTO).

5.4. Relationships between Plankton abundance and physicochemical parameters

The abundance and diversity of plankton taxa were to some extent influenced by the physicochemical characteristics of the river. However, many of the physicochemical parameters did not exert significant influences on the plankton abundance. Majority of the influences of these parameters on plankton abundance and diversity were from dissolved oxygen, biological oxygen demand and total suspended solids. The inverse relationships between BOD and TSS and the plankton groups indicates strict narrow requirements of the variables by these classes of organisms; excess availability of which may have become inhibitory to them. Edoghotu and Aleleye-Wokoma (2007) had observed negative correlations between DO and the bacillariophyceae,

euglenophyceae and cyanophyceae of Ntawoba Creek in Port Harcourt. However, the negative correlations observed between plankton in the current study and TSS had also been recorded by Zabbey *et al.* (2008); that high suspended particles arising from sand dredging and seasonal flooding constitutes high turbidity in the Imo River in Oyigbo that affect species abundance and diversity indirectly through reduced productivity.

In the current study, increasing BOD has been observed to exert negative influences on plankton abundance. Zabbey *et al.* (2008) also made similar observation in Imo River. This is because high demands for oxygen by other aquatic microbials would starve plankton of the essential nutrients. Protozoans are pollution tolerant species. As a matter of fact, the increased number of protozoans in FUTO indicates that the pollution levels along the course of the river.

5.5. Summary

The current work revealed the followings:

1. The sampling locations of the Otamiri River in the urban areas of Owerri (Nekede, Ihiagwa/Umuchima and FUTO) were more prone to pollution than the pristine Egbu location;
2. There were significant spatial variations in the levels of dissolved oxygen, water temperature, electrical conductivity, total dissolved solids, biological oxygen demands, pH, total suspended solids, turbidity,

phosphate and sulphate ion concentrations of the river during the study period;

3. The cladoceran, xanthophycean, and euglenophycean plankton abundances differed significantly across the sampling locations of the study;
4. The spatial order of magnitude of plankton diversity was FUTO>Ihiagwa/Umuchima>Nekede>Egbu;
5. Moderate plankton similarities were recorded in the study;
6. Dissolved oxygen, biological oxygen demand, and total suspended solids exerted significant influences on abundance of the phytoplankton taxa.

5.6. Conclusion

Increasing anthropogenic activities are suspected to be responsible for variations in plankton abundance along the course of the Otamiri River in Owerri.

5.7. Recommendations

The present study indicates the need for comprehensive monitoring of plankton for proper management of a freshwater aquatic ecosystem. Sequel to this, concerned state authorities have to take appropriate actions to control indiscriminate sand mining along the course of the river. This is because this activity has potential to affect plankton abundance of the river.

CONTRIBUTION OF THIS STUDY TO KNOWLEDGE

The contribution of this study to knowledge is that it shows the need for comprehensive monitoring of plankton and the level of contamination of water quality parameters for proper management of a freshwater aquatic ecosystem.

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APPENDIXES

Appendix 1. Physicochemical characteristics of Otamiri River across the sampling locations in Owerri

Sampling location: EGBU			
Parameters	Sampling points		
	1	2	3
DO (mg/L)	1.49	1.48	1.45
BOD (mg/L)	0.99	0.88	0.9
pH	6.83	6.79	6.73
Temperature (°C)	28.63	28.45	28.46
Conductivity (µS/cm)	21	15	14
TDS (mg/L)	11	8	7
TSS (mg/L)	2	2.9	3
Turbidity (NTU)	3	3.1	3
NO₃⁻ (mg/L)	0.4	0.7	0.5
PO₄³⁻ (mg/L)	1.3	1.2	0.9
SO₄²⁻ (mg/L)	8	9.5	8.8
Sampling location: NEKEDE			
Parameters	Sampling points		
	1	2	3
DO (mg/L)	1.63	1.55	1.53
BOD (mg/L)	1.13	1.35	1.23
pH	5.43	5.97	6.24
Temperature (°C)	27.79	27.78	27.85
Conductivity (µS/cm)	32	39	37
TDS (mg/L)	16	20	18
TSS (mg/L)	2.8	3.9	4.3
Turbidity (NTU)	4.5	4	5
NO₃⁻ (mg/L)	0.4	0.3	0.4
PO₄³⁻ (mg/L)	1.2	1.4	1.6
SO₄²⁻ (mg/L)	10.5	11.5	12.2
Sampling location: IHIAGWA/UMUCHIMA			
Parameters	Sampling points		
	1	2	3
DO (mg/L)	1.57	1.35	1.28
BOD (mg/L)	1.17	1.15	0.88
pH	5.92	6.32	6.06
Temperature (°C)	27.69	27.7	27.71
Conductivity (µS/cm)	28	29	29
TDS (mg/L)	14	15	15
TSS (mg/L)	5.5	6.1	6.2
Turbidity (NTU)	4.9	6.4	5

NO₃⁻ (mg/L)	0.2	0.4	0.3
PO₄³⁻ (mg/L)	0.8	0.5	1
SO₄²⁻ (mg/L)	10.4	9.8	10.2
Sampling location: FUTO			
	Sampling points		
Parameters	1	2	3
DO (mg/L)	1.02	0.93	0.91
BOD (mg/L)	1.18	1.16	1.41
pH	5.98	6.25	5.38
Temperature (°C)	27.58	27.82	27.62
Conductivity (µS/cm)	28	26	27
TDS (mg/L)	14	13.00	14
TSS (mg/L)	4.00	5.9	6.5
Turbidity (NTU)	4.8	6.4	5.3
NO₃⁻ (mg/L)	0.3	0.4	0.2
PO₄³⁻ (mg/L)	1.00	1.2	1.2
SO₄²⁻ (mg/L)	11.2	10.8	11

Appendix 2. Test of Homogeneity in mean variance ($p < 0.05$) of physicochemical parameters at different locations of Otamiri River in Owerri

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
DO	Between Groups	.670	3	.223	30.230	.000
	Within Groups	.059	8	.007		
	Total	.729	11			
BOD	Between Groups	.216	3	.072	4.716	.035
	Within Groups	.122	8	.015		
	Total	.338	11			
pH	Between Groups	1.664	3	.555	5.383	.025
	Within Groups	.824	8	.103		
	Total	2.488	11			
Temp	Between Groups	1.422	3	.474	67.009	.000
	Within Groups	.057	8	.007		
	Total	1.479	11			
EC	Between Groups	571.583	3	190.528	26.585	.000
	Within Groups	57.333	8	7.167		
	Total	628.917	11			
TDS	Between Groups	134.250	3	44.750	19.889	.000
	Within Groups	18.000	8	2.250		
	Total	152.250	11			
TSS	Between Groups	21.436	3	7.145	10.381	.004
	Within Groups	5.507	8	.688		
	Total	26.943	11			
Turb	Between Groups	11.903	3	3.968	9.757	.005
	Within Groups	3.253	8	.407		
	Total	15.157	11			
NO3	Between Groups	.109	3	.036	3.119	.088
	Within Groups	.093	8	.012		
	Total	.202	11			
PO4	Between Groups	.609	3	.203	5.076	.029
	Within Groups	.320	8	.040		
	Total	.929	11			
SO4	Between Groups	12.229	3	4.076	11.429	.003
	Within Groups	2.853	8	.357		
	Total	15.082	11			

Appendix 3a: Abundance and diversity in plankton of Otamiri River at Egbu (Sampling location 1)

Plankton Species	Sampling points			Total Occurrence/ml	% composition
	1	2	3		
PHYTOPLANKTON					
<u>Bacillariophyceae (Diatoms)</u>					
<i>Diatoma</i> sp	17	18	9		
<i>Melosira granulata</i>	-	-	2		
<i>Nitzschia kutzingiana</i>	1	3	-		
<i>Amphipleura pellucida</i>	-	-	1		
Total	18	21	12	51	47.2
<u>Cyanophyceae</u>					
<i>Aphanizomenon flos-aquae</i>	5	10	4		
<i>Lyngbya limnetica</i>	-	3	1		
<i>Raphidiopsis mediterranea</i>	1	-	2		
<i>Phormidium tenue</i>	-	-	4		
Total	6	13	11	30	27.8
<u>Chlorophyceae</u>					
<i>Closterium lanula</i>	2	2	7		
<i>C. intermedium</i>	-	2	-		
<i>Spirogyra</i> sp	5	1	4		
<i>Tetrastrum elegans</i>	-	2	-		
Total	7	7	11	25	23.2
<u>Xanthophyceae</u>					
<i>Ophiocytium</i> sp	-	1	1		
Total	0	1	1	2	1.8
Grand Total				108	
ZOOPLANKTON					
<u>Copepoda</u>					
<i>Canthocamptus staphylinus</i>	-	1	-		
Total	0	1	0	1	50.0
<u>Pisces</u>					
Fish eggs	1	-	-		
Total	1	0	0	1	50.0
Grand Total				2	

Appendix 3b: Abundance and diversity in plankton of Otamiri River at Nekede (Sampling location 2)

Plankton Species	Sampling points			Total Occurrence/ml	% composition
	1	2	3		
PHYTOPLANKTON					
<u>Bacillariophyceae (Diatoms)</u>					
<i>Diatoma</i> sp	13	22	30		
<i>D. elongatum</i>	5	-	3		
<i>Melosira varians</i>	1	1	3		
<i>M. granulata</i>	-	2	1		
<i>Nitzschia kutzingiana</i>	2	-	-		
<i>Amphipleura pellucida</i>	1	-	3		
<i>Stauroneis</i> sp	2	-	-		
Total	24	25	40	89	57.4
<u>Cyanophyceae</u>					
<i>Aphanizomenon flos-aquae</i>	4	17	8		
<i>Microcystis aeruginosa</i>	2	2	-		
<i>Oscillatoria princeps</i>	2	3	7		
<i>Phormidium tenue</i>	2	-	3		
<i>P. angustissium</i>	-	1	-		
<i>Rivularia planctonella</i>	-	-	2		
Total	10	23	20	53	34.2
<u>Chlorophyceae</u>					
<i>Closterium lanula</i>	1	-	4		
<i>Netrium digitus</i>	-	2	-		
<i>Coleochaete</i> sp	1	1	-		
Total	2	3	4	9	5.8
<u>Pyrrophyceae(Dinoflagellata)</u>					
<i>Gymnodinium aeruginosum</i>	1	-	3		
Total	1	0	3	4	2.6
Grand Total				155	
ZOOPLANKTON					
<u>Cladocera</u>					
<i>Daphnia hyalina</i>	1	1	-		
Total	1	1	0	2	50.0
<u>Copepoda</u>					
<i>Canthocamptus staphylinus</i>	-	-	2		
Total	0	0	2	2	50.0
Grand Total				4	

Appendix 3c: Abundance and diversity in plankton of Otamiri River at Umuchima (Sampling location 3)

Plankton Species	Sampling points			Total Occurrence/ml	% composition
	1	2	3		
PHYTOPLANKTON					
<u>Bacillariophyceae (Diatoms)</u>					
<i>Amphipleura pellucida</i>	2	-	-		
<i>Cyclotella comta</i>	-	-	1		
<i>C. kutzingiana</i>	-	2	-		
<i>Diatoma</i> sp	25	18	31		
<i>D. elongatum</i>	6	2	7		
<i>Melosira varians</i>	-	2	-		
<i>M. granulata</i>	-	-	2		
<i>Nitzschia kutzingiana</i>	3	-	4		
<i>Amphipleura pellucida</i>	1	-	1		
Total	37	24	46	107	67.7
<u>Cyanophyceae</u>					
<i>Aphanizomenon flos-aquae</i>	1	12	5		
<i>Microcystis aeruginosa</i>	3	3	-		
<i>Phormidium tenue</i>	-	-	2		
<i>Rivularia planctonella</i>	1	1	-		
<i>Oscillatoria princeps</i>	-	3	-		
<i>O. lauterbornii</i>	1	-	-		
<i>Gloeotrichia</i> sp	-	-	2		
Total	6	19	9	34	21.5
<u>Chlorophyceae</u>					
<i>Closterium lanula</i>	-	2	-		
<i>C. kutzingiana</i>	1	-	-		
<i>Cosmacladium saxonicum</i>	2	1	2		
<i>Desmidium</i> sp	-	2	1		
<i>Onychonema filiforme</i>	-	1	-		
<i>Stichococcus scopulinus</i>	1	-	1		
Total	4	6	4	14	8.9
<u>Euglenophyceae</u>					
<i>Euglena tripteris</i>	1	1	-		
Total	1	1	0	2	1.3
<u>Pyrrophyceae(Dinoflagellata)</u>					
<i>Gymnodinium aeruginosum</i>	-	-	1		
Total	0	0	1	1	0.6
Grand Total				158	
ZOOPLANKTON					
<u>Cladocera</u>					
<i>Daphnia hyalina</i>	1	-	3		
Total	1	0	3	4	57.1
<u>Copepoda</u>					
<i>Canthocamptus staphylinus</i>	2	-	1		
Total	2	0	1	3	42.9
Grand Total				7	

Appendix 3d: Abundance and diversity in plankton of Otamiri River at FUTO (Sampling location 4)

Plankton Species	Sampling points			Total Occurrence/ml	% composition
	1	2	3		
PHYTOPLANKTON					
<u>Bacillariophyceae (Diatoms)</u>					
<i>Amphipleura pellucida</i>	-	4	3		
<i>Diatoma</i> sp	8	11	12		
<i>D. elongatum</i>	2	14	3		
<i>Fragilaria brevistriata</i>	2	1	4		
<i>Melosira pusilla</i>	1	-	1		
<i>Cyclotella comta</i>	-	1	5		
<i>C. kutzingiana</i>	-	2	-		
<i>Stauroneis</i> sp	1	-	1		
Total	14	33	29	76	43.4
<u>Cyanophyceae</u>					
<i>Aphanizomenon flos-aquae</i>	3	10	8		
<i>Anabaenopsis</i> sp	2	4	-		
<i>Phormidium tenue</i>	1	-	1		
<i>P. mucicola</i>	-	1	-		
<i>P. angustissium</i>	2	2	7		
<i>Oscillatoria lacustris</i>	-	1	3		
<i>O. lauterbornii</i>	-	2	-		
<i>Raphidiopsis curvata</i>	1	1	-		
<i>Chlorogloea microcystoides</i>	-	-	2		
Total	9	21	21	51	29.1
<u>Chlorophyceae</u>					
<i>Cosmacladium saxonicum</i>	4	4	11		
<i>Spyrigyra</i> sp	2	4	7		
<i>Netrium digitus</i>	-	3	-		
<i>Coleochaete</i> sp	1	-	-		
<i>Stichococcus scopulinus</i>	-	1	1		
Total	7	12	19	38	21.7
<u>Euglenophyceae</u>					
<i>Euglena tripteris</i>	-	2	1		
<i>Epithemia</i> sp	1	-	-		
Total	1	2	1	4	2.3
<u>Charophyceae</u>					
<i>Nitella</i> sp	-	2	-		
Total	0	2	0	2	1.1
<u>Xanthophyceae</u>					
<i>Tribonema vulgare</i>	2	-	1		
<i>T. viride</i>	-	1	-		
Total	2	1	1	4	2.3
Grand Total				175	
ZOOPLANKTON					
<u>Cladocera</u>					
<i>Daphnia hyalina</i>	-	2	-		
Total	0	2	0	2	28.6
<u>Copepoda</u>					
<i>Canthocamptus staphylinus</i>	1	-	1		
Total	1	0	1	2	28.6
<u>Protozoa</u>					
<i>Arcella arenaria</i>	-	3	-		
Total	0	3	0	3	42.8
Grand Total				7	

Appendix 4. Test of Homogeneity in mean variance ($p < 0.05$) of plankton taxa at different locations of Otamiri River in Owerri

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Baccill	Between Groups	554.917	3	184.972	2.284	.156
	Within Groups	648.000	8	81.000		
	Total	1202.917	11			
Cyano	Between Groups	136.667	3	45.556	1.186	.375
	Within Groups	307.333	8	38.417		
	Total	444.000	11			
Chloro	Between Groups	165.667	3	55.222	5.020	.030
	Within Groups	88.000	8	11.000		
	Total	253.667	11			
Xantho	Between Groups	3.667	3	1.222	7.333	.011
	Within Groups	1.333	8	.167		
	Total	5.000	11			
Pyrro	Between Groups	3.583	3	1.194	1.792	.227
	Within Groups	5.333	8	.667		
	Total	8.917	11			
Eugleno	Between Groups	3.667	3	1.222	7.333	.011
	Within Groups	1.333	8	.167		
	Total	5.000	11			
Charo	Between Groups	1.000	3	.333	1.000	.441
	Within Groups	2.667	8	.333		
	Total	3.667	11			
Clado	Between Groups	1.583	3	.528	.487	.701
	Within Groups	8.667	8	1.083		
	Total	10.250	11			
Copep	Between Groups	1.583	3	.528	.792	.532
	Within Groups	5.333	8	.667		
	Total	6.917	11			
F_eggs	Between Groups	.250	3	.083	1.000	.441
	Within Groups	.667	8	.083		
	Total	.917	11			
Proto	Between Groups	2.250	3	.750	1.000	.441
	Within Groups	6.000	8	.750		
	Total	8.250	11			