TITLE PAGE

STUDY ON WATER QUALITY PARAMETERS AND BENTHIC FAUNA DIVERSITY OF OTAMIRI RIVER IN OWERRI, IMO STATE, NIGERIA.

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REG NO: PG/M.Sc./14/67604

A PROJECT SUBMITTED IN PARTIAL FULFILMENT FOR THE AWARD OF MASTERS DEGREE IN HYDROBIOLOGY IN THE DEPARTMENT OF ZOOLOGY AND ENVIRONMENTAL BIOLOGY, FACULTY OF BIOLOGICAL SCIENCES UNIVERSITY OF NIGERIA, NSUKKA

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MARCH, 2016

APPROVAL PAGE

Obiyor Kelvin Ikenna, a postgraduate student in the department of Zoology and Environmental Biology and with the registration number PG/M.Sc/14/67604 has satisfactorily completed the requirements of course and research work for the degree of Master of Science (M.Sc) in Hydrobiology.

The work embodied in this thesis report is original and has not been submitted in part or full for any other diploma or degree of this or any other university.

We approve that this project was carried out under our supervision.

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DEDICATION

This work is dedicated to God Almighty whose love and grace lifted me up to this level.

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ABSTRACT

The study on the physic-chemical parameters and benthic fauna diversity of Otamiri River, Nigeria was carried out from June to December 2015. Water and benthic organisms samples were collected monthly from three sampling stations along the stream. Dissolved oxygen bottles of 1000 ml were used to collect water samples which were fixed with wrinkleōs reagent at the sampling stations. Eckman grab, scoop net, hook and line, cast net, traps and dugout canoe with paddle were used to collect the benthic macro fauna for six months (June-August and October to December). The results of the study yielded 229 benthic organisms belonging to 15 species and 14 families. In relation to stations, Station 3 had more species and higher abundance of benthic organisms than other sampled stations. In Station 1, only six species of benthic organisms were recorded while Station 2 had 11 species and Station 3, 13 species of benthic organisms. Majority of the sampled benthic organisms were localized and restricted to one sampled station which was Station 3. The abundance of benthic organisms in Otamiri River was dependent on season. More benthic organisms were recorded in dry season than in rainy season. The diversity indices yielded high diversity in Station 3 than the other two studied stations. More species dominated with high diversity index in dry season than in wet season in all the sampled stations. Mean values of surface water temperature 26.67±0.63 ^{0}C, depth 1.96±0.48 m, COD 25.11±0.24 mg/L, BOD 5.47±0.04 mg/L, DO 5.91±0.19 mg/L, Alkalinity 10.66±0.21 mg/L, pH 6.73±0.16, TDS 315.2±48.5 mg/L, Hardness 0.64±0.08 mg/L, Turbidity 4.52±0.16 NTU and TSS 8.68±0.75 mg/L were recorded. There were fluctuations between the physico-chemical parameters caused by anthropogenic activities, stress to the aquatic life and pollution. Shannon wieners diversity index H = 2.24 was higher in Station 2, while Simpsonōs dominance index D= 8.5 was also high at Station 2. Temperature, Depth, BOD and TSS correlated positively and favoured the abundance and of *Synodontis* spp. Temperature, BOD, Turbidity and TSS were also positively correlated and favoured the abundance of *C. nigrodigitatus* and *C. armatum*. Negative correlation was recorded in *P. serratus* in all parameters and in all seasons and stations *C. nigrodigitatus* was the most abundant species recorded in the present study (32.65%) while the least abundance species was *P. serratus* (1.25%) and both were found only in Station 3. The pH, BOD, TDS, hardness, turbidity, DO, BOD, COD and temperature ranges fall within WHO recommendations. Government should make laws restricting dredging and sand mine activities in the sampled area.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The benthic macro fauna are those organisms that live at the bottom of a water body and are used to detect changes in the natural environment (Idowu and Ugwumba, 2005; Akaahan *et al*., 2015). Studies of aquatic bodies have established the existence of relationships between water quality and macro and micro-invertebrate diversity (Teferi *et al.,* 2013). They serve as monitor for the presence of pollutants, their effects on the ecosystem and the progress of environmental clean-up process (Nkwoji *et al.,* 2010). The assessment of the biotic condition compliments the physico-chemical parameters in aquatic environment condition determination (Madhushankha *et al.*, 2014).

Macro-invertebrate organisms form an integral part of an aquatic environment and are of ecological and economic importance as they maintain various levels of interaction between the community and the environment (Sharma *et al.,* 2013). According to Marques *et al.,* 2003), knowledge of the structure of the benthic macro-invertebrate community provides precise and local information on recent events, which can be seen in their structuring. The use of invertebrates and fish as bio-indicators of water quality has been advocated by several researchers (Adakole and Annune, 2003). The use of macro-invertebrate diversity for bio-assessment provides a simpler approach compared to other environmental quality assessment procedures. This is because, macro-invertebrates can be sampled quantitatively and the relative sensitivity or tolerance of some of them to contamination is known (Adakole and Annune, 2003). Species vary in their degree of tolerance with the result that under polluted conditions, a reduction in species diversity is the most obvious effect (Emere, 2000; Olomukoro and Egborge, 2003; Sharma *et al.,* 2013).

Macro-benthic invertebrates are used as bio-indicators because of their extended residency period in specific habitats. More so, the presence or absence of particular benthic species in a particular environment act as a pointer to the water quality status. The abundance of benthic fauna mainly depends on physical and chemical properties of their habitat as they respond more quickly if any changes in water quality occur. They are most frequently used in biomonitoring for these reasons (Mohan *et al.*, 2013). Modification to macrobenthic invertebrate distribution affects important role they play such as mineralization, mixing of sediments and flux of oxygen into sediment and cycling of organic matter (George *et al.,* 2009), which further contribute to indication of water status. The technique of using macro-benthic invertebrates as bio-indicators is a cost effective method widely used in the Northern American and European ecoregions (Azrina *et al.,* 2005) but not a popular method in the African region in river classification due to the lack of expertise and information on benthic macro-invertebrate populations.

There have been several studies on the relation of the aquatic macrobenthos diversity and water sediment with physic-chemical status of the aquatic ecosystem (Garg *et al.,* 2009; Quasin *et al.,* 2009; Edokpayi *et al.,* 2010 and Madhushankha *et al.*, 2014). In lentic freshwaters, the benthic invertebrates play essential roles in key ecosystem processes, such as food chain dynamics, productivity, nutrient cycling and decomposition. The lotic and lentic inland waters, as well as brackish and marine waters in the tropics are habitats for a variety of macro-invertebrate fauna. Work on the macro-invertebrate fauna in the tropics has shown that the quantitative collection of key species from natural aquatic habitat or that modified by man can provide a means of estimating various ecological parameters, such as richness or evenness in diversity (Odo *et al.,* 2007). Their distribution and abundance are directly related to different environmental factors such as food availability and quantity, sediment type, substrate, and water quality (Arslan *et al*., 2007, and Odabasi *et al*., 2009). They also show considerable spatial variation with lake and across lakes (Baudo *et al*., 2001; Pamplin and Rocha, 2007; Smiljkov *et al*., 2008). In reservoirs, the benthic macro-invertebrate community may be particularly susceptible to water-level changes that alter sediment exposure, temperature regime, wave-induced sediment redistribution and basal productivity (McEwen and Butler, 2010).

The occurrence and distribution of macro-invertebrate are governed mostly by the physical and chemical quality of water and immediate substrate of occupation. Water quality variables such as temperature, dissolved oxygen, pH and nutrients have considerable effects on the life of aquatic organisms, the physical nature of the substratum, depth, and nutritive content and degree of stability and others. They affect species composition and distribution, diversity, stability, production and physiological conditions of the organisms (Sharma *et al.,* 2013). Macro-invertebrate organisms are threatened by changes in these parameters in their habitat which are usually associated with pollution, erosion and siltation (Lydeard *et al.,* 2004).

Humans are adjudged to be the principal driver of change on the earthôs surface. Such impact may shape the earth in small subtle ways and sometimes in big catastrophic ways (Karr, 2005). These effects may result in a plethora of consequences felt by plants, animals and even humans alike. One major natural component of the earth is the aquatic environment which is home for a vast array of diverse organisms from those with a planktonic existence through pelagic organisms to benthic species. Human activities also interfere with this environment.

Freshwater bodies contain diverse habitats within and around which support myriads of species of both plants and animals and are important sources of water for human activities. In some instances freshwaters have been dammed to provide potable water for urban settlements and the Otamiri River is one of such freshwater bodies which are used for domestic purposes by the generality of Nekede and Ihiagwa communities. Adeogun and Oyebamiji (2011) reported that most surface waters in Nigeria have been used as the most expedient way of disposing wastes especially effluents. The likely impact of human interference on freshwater bodies necessitated this present investigation to appraise the variations in the physic-chemical parameters and likely changes that may have occurred in the macro-benthic invertebrate community of Otamiri River.

1.2 Justification of the Study

The need for good water quality has been of growing concern in Nigeria and worldwide as anthropogenic activities is fast degrading most water bodies. These activities which include agricultural practices, human domestic activities and dredging, all result in pollution of the natural habitats of aquatic organisms. The people residing close to Otamiri River are predominantly farmers and occasional dredgers. They use poultry droppings as well as chemical fertilizers to enrich their farmlands. These constitute pollutants which drain into the river through run-offs. In view of this, the study attempts to evaluate the quality of the river water as well as assess the benthic fauna diversity which is often disturbed by dredging activities. In Owerri municipal council, Otamiri River and underground water supply from private boreholes are the main sources of water for domestic and other uses, especially when the public water supply becomes epileptic. Otamiri River drains areas of diverse geology, soils and land use, and like other surface waters, the river is liable to pollution from atmospheres and also from the composition of the soils and rocks through which the surface basin filters down into rivers. In addition, pollution of the river can result from human activities such as dumping of solid wastes and discharge of effluents from industries into the river. Since Owerri urban and its environs depend partly on water from Otamiri River for their domestic uses, there is a need to assess the quality of the river water. To the best of my knowledge, no work has been reported on the diversity of benthic fauna of Otamiri River, hence the need to study various fauna groups and their diversity.

The findings will provide information on the water quality of the river and the diverse species of benthos in the river. It will also provide useful information on the richness of the Otamiri River.

1.3 Objective of the Study

General objective of this study is to evaluate the water quality variables and the benthic organisms in Otamiri River.

Specific objectives of this study were to:

i. determine the benthic organisms diversity of Otamiri River;
ii. assess the water quality of Otamiri River;
iii. determine the relationship between water quality parameters and composition of benthic fauna in Otamiri River and
iv. determine the effect of season on physico-chemical parameters of the water and composition of benthic organisms.

1.4 Literature Review

1.4.1 Water quality parameters

Several studies had dealt with the relationship between the aquatic macrobenthos diversity, water sediment and physico-chemical status of the aquatic ecosystem (Quasin *et al.,* 2009; Garg *et al.,* 2009 and Edokpayi *et al.,* 2010). Water quality plays a vital role in the distribution, abundance and diversity of aquatic organisms. A short-term exposure of benthic organisms to water of poor quality causes an alteration in the community structure due to the elimination of the species that are intolerant to stress and proliferation of stress tolerant species (Woke and Wokoma 2007). The physical and chemical characteristics of water are important parameters as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic organisms (Obot *et al.,* 2014). Important physical and chemical parameters influencing aquatic environment are temperature, rainfall, pH, salinity, dissolved oxygen, Biological Oxygen Demand, Turbidity (Adakole and Annune 2003).

The following guide defines each variable, discusses the importance of the variable to the aquatic environment and lists potential anthropogenic sources.

1.4.1.1 Temperature

This is a measurement of the intensity (not amount) of heat stored in a volume of water. Surface water temperatures naturally range from 0°C under ice cover to 40°C in hot springs. Natural sources of heat include: solar radiation, transfer from air, and condensation of water vapor at the water surface, sediments, precipitation, surface runoff and groundwater. Temperature is the primary influencing factor on water density (Integrated Land Management Bureau, 2010).

Importance: Temperature affects the solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species. Vertical stratification patterns that naturally occur in lakes affect the distribution of dissolved and suspended compounds (ILMB, 2010).

Anthropogenic sources: industrial effluents, agriculture, forest harvesting, urban developments, mining.

1.4.1.2 Turbidity

This is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU). The extinction depth (for lakes), measured with a Secchi disc, is an alternative means of expressing turbidity (ILMB, 2010).

Importance: High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant. (ILMB, 2010).

Anthropogenic sources: forest harvesting, road building, agriculture, urban developments, sewage treatment plant effluents, mining, industrial effluents.

1.4.1.3 pH

This is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a maximum of 14) is basic (the higher the number, the more basic the water), (ILMB, 2010).

Importance: Higher pH values tend to facilitate the solubilization of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5, (ILMB, 2010).

Anthropogenic sources: mining, agriculture, industrial effluents, acidic precipitation (derived from emissions to the atmosphere from cars and industry).

1.4.1.4 Dissolved oxygen (DO)

This is a measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of streams can take place in areas of waterfalls and rapids, (ILMB, 2010).

Importance: Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments. Oligotrophic (low nutrient) lakes tend to have increased concentrations of dissolved oxygen in the hypolimnion (deeper waters) relative to the epilimnion (defined as orthograde oxygen profiles). Eutrophic (high nutrient) lakes tend to have decreased concentrations of dissolved oxygen in the hypolimnion relative to the epilimnion (defined as clinograde oxygen profiles), (ILMB, 2010).

Anthropogenic causes of decreased DO: forest harvesting, pulp mills, agriculture, sewage treatment plant effluent, industrial effluents, impoundments (dams).

1.4.1.5 Total hardness

The hardness of water is generally due to the presence of calcium and magnesium in the water. Other metallic ions may also contribute to hardness. Hardness is reported in terms of calcium carbonate and in units of milligrams per litre (mg/L). Waters with values exceeding 120 mg/L are considered hard, while values below 60 mg/L are considered soft, (ILMB, 2010).

Importance: Harder water has the effect of reducing the toxicity of some metals (i.e., copper, lead, zinc, etc.). Soft water may have corrosive effect on metal plumbing; while hard water may result in scale deposits in the pipes. If the water has a hardness greater than 500 mg/L, then it is normally unacceptable for most domestic purposes and must be treated, (ILMB, 2010).

Anthropogenic sources: mining, industrial effluents

1.4.1.6 Alkalinity

This is the measurement of the water's ability to neutralize acids. It usually indicates the presence of carbonate, bicarbonates, or hydroxides. Alkalinity results are expressed in terms of an equivalent amount of calcium carbonate. Note that this does not mean that calcium carbonate was found in the sample. Natural waters rarely have levels that exceed 500 mg/L (ILMB, 2010).

Importance: Waters that have high alkalinity values are considered undesirable because of excessive hardness and high concentrations of sodium salts. Waters with low alkalinity have little capacity to buffer acidic inputs and are susceptible to acidification (low pH), (ILMB, 2010).

Anthropogenic sources that destroy alkalinity: mining, industrial effluents, acidic precipitation.

1.4.1.7 Total dissolved solids (TDS)

This is a measure of the amount of dissolved material in the water column. It is reported in mg/L with values in fresh water naturally ranging from 0-1000 mg/L. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated filterable residue values (ILMB, 2010).

Importance: High concentrations of TDS limit the suitability of water as a drinking and livestock watering source as well as irrigation supply. High TDS waters may interfere with the clarity, color, and taste of manufactured products. (ILMB, 2010)

Anthropogenic sources: mining, industrial effluent, sewage treatment, agriculture, road salts.

1.4.1.8 Total suspended solids (TSS)

This is a measure of the particulate matter that is suspended within the water column. Values are reported in mg/L, (ILMB, 2010).

Importance: High concentrations of TSS increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills. Settling suspended solids can cause impairment to spawning habitat by smothering fish eggs. Suspended solids also interfere with water treatment processes, (ILMB, 2010).

Anthropogenic sources: forest harvesting, road building, industrial effluents, urban developments, placer mining, municipal sewage treatment plants.

1.4.1.9 Conductivity

This is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Ions are dissolved metals and other dissolved materials. Conductivity is reported in terms of microsiemens per centimeter (ε S/cm). Natural waters are found to vary between 50 and 1500 ε S/cm, (ILMB, 2010).

Importance: Specific conductivity may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water [dissolved solids

= conductivity x 0.55 to 0.9 (the most often used is 0.65)]. Fish diversity typically is inversely proportional to conductivity, (ILMB, 2010).

Anthropogenic sources: mining, roads (de-icing salts), industrial & municipal effluents. High conductivity may also be naturally occurring.

1.4.1.10 Chloride

Of the halides, chloride appears in the highest concentrations in natural fresh water system, and is reported as mg/L, (ILMB, 2010).

Importance: Chloride is important in terms of metabolic processes, as it influences osmotic salinity balance and ion exchange. Higher chloride concentrations can reduce the toxicity of nitrite to aquatic life. Fish diversity typically is inversely proportional to chloride concentration, (ILMB, 2010).

Anthropogenic sources: municipal water supply disinfection, sewage treatment plant effluents, urban developments, industrial effluents, mining.

1.4.1.11 Sulphate

Sulphur is commonly found as a component of sedimentary and igneous rocks in the form of metallic sulphates. Sulphates are oxidized upon contact with aerated water, producing sulphate ions in solution, (ILMB, 2010).

Importance: When sulphate is less than 0.5 mg/L, algal growth will not occur. On the other hand, sulphate salts can be major contaminants in natural waters. Excessive levels in water may cause illness, (ILMB, 2010).

Anthropogenic sources: combustion of fuel, present in soils that are oxidized through natural processes, organic waste treatment, mine drainage, and evapourite sediments, such as anhydrite and gypsum.

1.4.1.12 Total phosphorus

This is a measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface waters, and is generally reported in εg/L or mg/L. (ILMB, 2010)

Importance: Since phosphorus is generally the most limiting nutrient, its input to fresh water systems can cause extreme proliferations of algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most fresh water systems. A general guideline regarding phosphorus and lake productivity is: <10 εg/L phosphorus yields is considered oligotrophic, 10-25 εg/L P will be found in lakes considered mesotrophic, and >25 εg/L P will be found in lakes considered eutrophic, (ILMB, 2010).

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban development (particularly from detergents), industrial effluents.

1.4.1.13 Orthophosphate ($PO^{-3}{}_{4}$)

This is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in εg/L or mg/L, (ILMB, 2010).

Importance: This form of phosphorus is the most readily available for uptake during photosynthesis. High concentrations of orthophosphate generally occur in conjunction with algal blooms, (ILMB, 2010).

Anthropogenic sources: sewage treatment plant effluent, agriculture, urban developments, industrial effluents.

1.4.1.14 Total nitrogen

This is a measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters. Total nitrogen is typically calculated by summing up nitrate, nitrite, and Kjeldahl nitrogen values.

Importance: The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present, be it ammonia, nitrite, nitrate, or organic nitrogen (ILMB, 2010).

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents, recreation, mining (blasting residuals).

1.4.2 Benthic fauna

Benthic fauna refers to various organisms found on (epifauna) and in (infauna) the seabed. Sediment-dwelling benthic fauna can be subdivided into the main groups of mussels/snails, crustaceans, bristle worms and echinoderms. A benthic fauna survey is an ecologically relevant parameter which, among other things, can indicate whether oxygen deficiency has occurred or not, at a certain place. Different kinds of equipment are used for benthic fauna sampling, depending on the water depth and the sediment type (Anon, 2015).

Benthos is the community of organisms which live on, in, or near the seabed, also known as the benthic zone. This community lives in or near marine sedimentary environments, from tidal pools along the foreshore, out to the continental shelf, and then down to the abyssal depths (Ryan, 2007).

Many organisms adapted to deep-water pressure cannot survive in the upper parts of the water column. The pressure difference can be very significant (approximately one atmosphere for each 10 meters of water depth) (Ryan, 2007).

Because light does not penetrate very deep into ocean-water, the energy source for deep benthic ecosystems is often organic matter from higher up in the water column which drifts down to the depths. This dead and decaying matter sustains the benthic food chain; most organisms in the benthic zone are scavengers or detritivores (Ryan, 2007).

The term *benthos* comes from the Greek noun ɓɏɜɗɞɠ "depth of the sea" (Ryan, 2007).

Benthos is also used in freshwater biology to refer to organisms at the bottom of freshwater bodies of water, such as lakes, rivers, and streams (Ryan, 2007).

Food sources

The main food sources for the benthos are algae and organic runoff from land. The depth of water, temperature and salinity, and type of local substrate all affect the presence of benthos. In coastal waters and other places where light reaches the bottom, benthic photosynthesizing diatoms can proliferate. Filter feeders, such as sponges and bivalves, dominate hard, sandy bottoms. Deposit feeders, such as polychaetes, populate softer bottoms. Fish, such as dragonets, as well as sea stars, snails, cephalopods, and crustaceans are important predators and scavengers (Encyclopedia Britannica, 2008).

Benthic organisms, such as sea stars, oysters, clams, sea cucumbers, brittle stars and sea anemones, play an important role as a food source for fish, such as the California sheephead, and humans (Encyclopedia Britannica, 2008).

By size

Macrobenthos: Macrobenthos comprises the larger, more visible, benthic organisms that are greater than 1 mm in size. Some examples are polychaete worms, bivalves, echinoderms, sea anemones, corals, sponges, sea squirts, turbellarians and larger crustaceans such as crabs, lobsters and cumaceans.

Microphotograph of typical macrobenthic animals, (from top to bottom) will include amphipods, polychaete worms, snails, and chironomous midge larvae.

Meiobenthos: Meiobenthos comprises tiny benthic organisms that are less than 1 mm but greater than 0.1 mm in size. Some examples are nematodes, foraminiferans, water bears, gastrotriches and micro crustaceans such as copepods and ostracodes, (Encyclopedia Britannica, 2008).

Microbenthos: Microbenthos comprises microscopic benthic organisms that are less than 0.1 mm in size. Some examples include bacteria, diatoms, ciliates, amoeba, and flagellates.

By type

Zoobenthos: Zoobenthos comprise the animals belonging to the benthos.

Phytobenthos: Phytobenthos comprise the plants belonging to the benthos, mainly benthic diatoms and macroalgae (seaweed), (Encyclopedia Britannica, 2008).

By location

Endobenthos: Endobenthos live buried, or burrowing in the sediment, often in the oxygenated top layer, i.e., a sea pen or a sand dollar, (Encyclopedia Britannica, 2008)

Epibenthos: Epibenthos lives on top of the sediments, i.e., like a sea cucumber or a sea snail crawling about. (Encyclopedia Britannica, 2008)

Hyperbenthos: Hyperbenthos lives just above the sediment, i.e., a rock cod, (Encyclopedia Britannica, 2008)

Fauna comes from the Latin names of what name Fauna, a Roman goddess of earth and fertility, the Roman god Faunus, and the related forest spirits called Fauns. All three words are cognates of the name of the Greek god Pan, and *panis* is the Greek equivalent of fauna. *Fauna* is also the word for a book that catalogues the animals in such a manner. The term was first used by Linnaeus in the title of his (1745) work *Fauna Suecica*.

1.4.2.1 Subdivisions of fauna

Cryofauna: *Cryofauna* are animals that live in, or very close to ice.

Cryptofauna: *Cryptofauna* are the fauna that exist in protected or concealed microhabitats.

Infauna: *Infauna* are benthic organisms that live within the bottom substratum of a body of water, especially within the bottom-most oceanic sediments, rather than on its surface. Bacteria and microalgae may also live in the interstices of bottom sediments. In general, infaunal animals become progressively smaller and less abundant with increasing water depth and distance from shore, whereas bacteria show more constancy in abundance, tending towards one million cells per milliliter of interstitial seawater (Encyclopedia Britannica, 2008).

Epifauna: *Epifauna*, also called *epibenthos*, are aquatic animals that live on the bottom substratum as opposed to within it, that is, the benthic fauna that live on top of the sediment surface at the seafloor.

Macrofauna: *Macrofauna* are benthic or soil organisms which are retained on a 0.5mm sieve. Studies in the deep sea define macrofauna as animals retained on a 0.3mm sieve to account for the small size of many of the taxa (Encyclopedia Britannica, 2008).

Megafauna: *Megafauna* are large animals of any particular region or time. For example, Australian megafauna (Encyclopedia Britannica, 2008).

Meiofauna: *Meiofauna* are small benthic invertebrates that live in both marine and fresh water environments. The term *Meiofauna* loosely defines a group of organisms by their size, larger than microfauna but smaller than macrofauna, rather than a taxonomic grouping. One environment for meiofauna is between grains of damp sand.

In practice these are metazoan animals that can pass unharmed through a 0.5 ï 1 mm mesh but will be retained by a 30 ï 45 εm mesh. The exact dimensions will vary from researcher to researcher. Whether an organism passes through a 1 mm mesh also depends upon whether it is alive or dead at the time of sorting (Encyclopedia Britannica, 2008).

Mesofauna: *Mesofauna* are macroscopic soil invertebrates such as arthropods or nematodes. Mesofauna are extremely diverse; considering just the springtails (Encyclopedia Britannica, 2008) approximately 6,500 species had been identified.

Microfauna: *Microfauna* are microscopic or very small animals (usually including protozoans and very small animals such as rotifers).

1.4.3 Relationship between water quality parameters and benthic fauna

Water quality plays a vital role in the distribution, abundance and diversity of aquatic organisms. A short-term exposure of benthic organisms to water of poor quality causes an alteration in the community structure due to the elimination of the species that are intolerant to stress and proliferation of stress tolerant species (Woke and Wokoma, 2007). The physical and chemical characteristics of water are important parameters as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic organisms (Obot *et al.*, 2014).

The health of the ecosystem is determined by the taxonomic composition of the community as well as its diversity. Benthic macro fauna are those organisms that live on or inside the deposit at the bottom of a water body (Idowu and Ugwumba, 2005). They are used to detect changes in the natural environment, monitor for the presence of pollution and its effect on the ecosystem in which organismsô lives and to monitor the progress of environmental cleanup (Nkwoji *et al.*, 2010). They are used in testing water bodies for the presence of contaminants (Nkwoji *et al.*, 2010). Studies have shown that there is entwining relationship between surface water quality and macro invertebrate diversity (Teferi, *et al.,* 2013).

The physico-chemical parameters of lakes, ponds and rivers have considerable effect on the aquatic life. These parameters determine the productivity of a water body. Thus, a change in the physico-chemical aspect of a water body brings about a corresponding change in the relative composition and abundance of the organisms in that water (Adeyemi *et al.*, 2009).

Eutophication due to poor water quality has been the most challenging global threat to the quality of water as a result of excess nutrients getting their way through run off during rainy seasons (Likens, 2010).

This process of enrichment with excess nutrients, primarily phosphorus and nitrogen, leads to enhanced growth of algae, periphyton and/or macrophytes, as well as increased biological productivity and decreased basin volume from the excessive addition of dissolved and particulate inorganic and organic materials to lakes and reservoirs (Cooke *et al.,* 2005; Likens, 2010).

CHAPTER TWO

MATERIALS AND METHODS

2.1 Study Area

The Otamiri River is one of the main rivers in Imo State, Nigeria and Located on latitude 7^0 06 ′E and longitude 5^0 30 ′N and at an elevation of 152 meters above sea level. The river takes its name from *Ota Miri*, a deity which owns all the waters that are called by its name, and who is often the dominating god of Mbari houses (Basden, 1966). The river runs south from Egbu past Owerri, Nekede, Ihiagwa and through Ozuzu Etche, in Rivers State, from where it flows to the Atlantic Ocean (Anyanwu, 2009). The length of the river from its source to its confluence at Emeabiam with the Uramiriukwa River is 30 kilometres (19 mi) (Anyanwu, 2009).

The vegetation of the sampled area is rain forest with the watershed is mostly covered by depleted rain forest vegetation, with mean temperatures of 27 °C (81 °F) throughout the year. Conversion of the tropical rainforest to grassland with slashes and burn practices is degrading soil quality.

Three sampling stations will be used. Sampled Station 1 is located at Owerri urban along Nekede road, where the state's refuse dump site is located and sand mining activities, while Station 2 is at No 8 Bus stop Umugwueze, Nekede, where sand mining activities take place and Station 3 is at Umuezerokam village which is the home of vegetable farming. The activities of sampled Stations 1 and 2 are, sand dredging and sand mines, farming and waste management dump station whereas, at Station 3 farming activities such as fishing, vegetable farm and cultivation. The seasons in these sampled areas are dry and wet seasons.

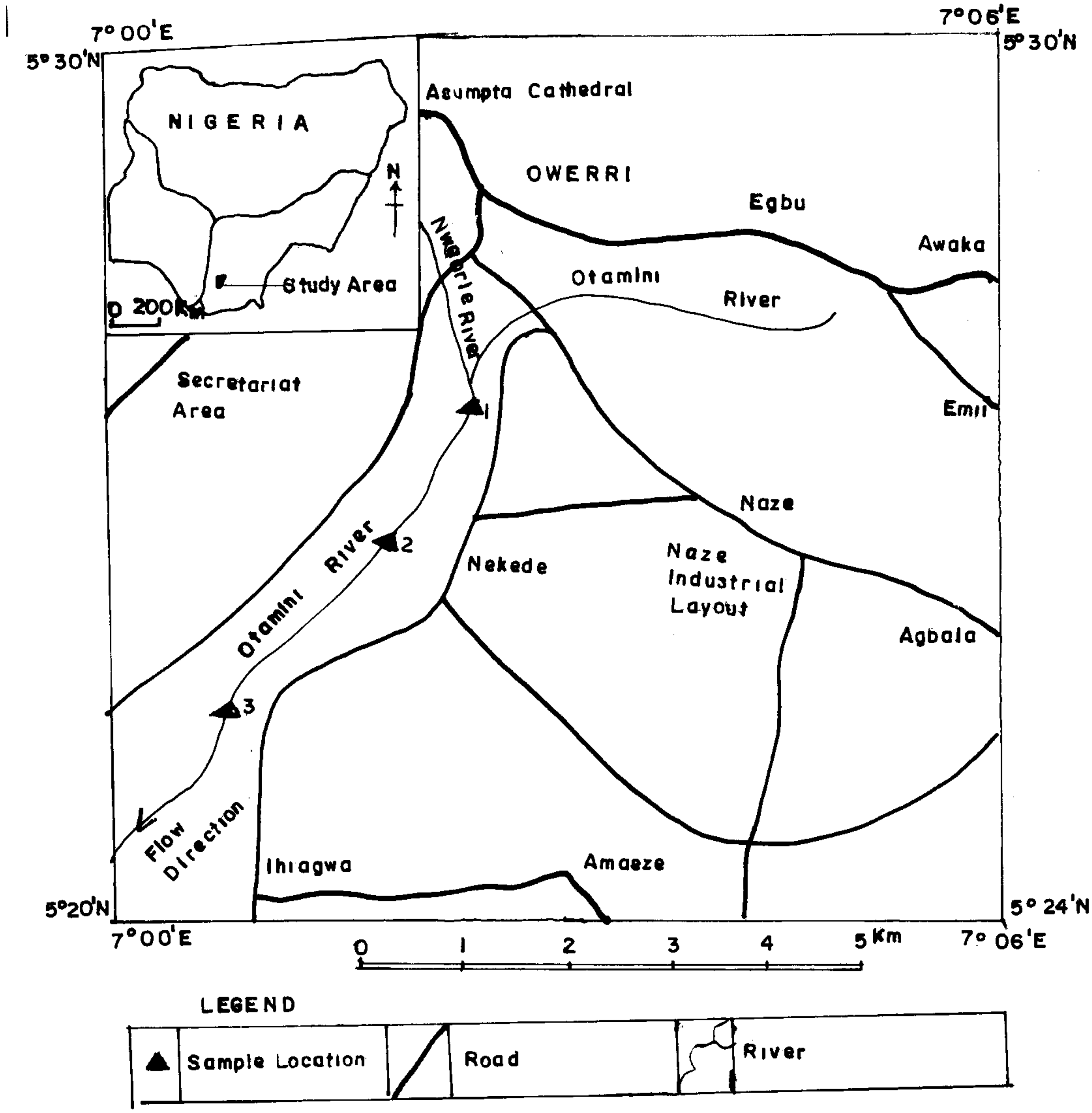

Fig. 1: Map of Otamiri River showing the sampled stations.
Source: Topographic Map of Nigeria, Federal Survey of Nigeria, 1967.

Station 1: Owerri Municipal, Station 2: Nekede and h 3: Umuezerokam Village, Nekede.

2.2 Sampling Method

Six consecutive months of fieldwork (once in a month) were carried out in Lower River Niger, Idah which covered both dry and rainy seasons. Water and sediment samples were collected from the three sampling stations (Station 1, Station 2 and Station 3) within the River. Each sampling station was subdivided into three sub-stations such that water and sediment samples were randomly collected in triplicates from each station. Dugout canoe with paddle was used for sampling within the River. All sample containers were washed and soaked overnight with 5% nitric acid and rinsed with distilled water prior to sampling. At the sampling site plastic containers for water sample collection were rinsed several times with the river water. This is in accordance with the methods of Wangboje and Oronsaye (2001).

2.3 Sample Collection

Water samples were collected from the three stations (Stations 1, 2 & 3) within the river for six months (June ï August and October ï December, 2015). The samples were collected in triplicates from each sampling stations. Dugout canoes with paddles were used during sampling within the river. At the sampling stations, BOD and DO containers to store water samples were rinsed several times with the river water. Vertebrates and macro invertebrate samples were stored in 30 - 40% ethanol for vertebrates and 10% formal saline for macro-invertebrates (Wangboje and Oronsaye, 2001).

2.3.1 Collection of water sample for physico-chemical analysis

Water samples for physico-chemical analysis were collected at 30cm depth in bottles of 1000ml capacity. Sampling bottles and containers were rinsed three times with river water at each sampling site before samples collection (Wangboje and Oronsaye, 2001). The water samples for physicochemical analysis were collected once every month for six (6) months; June ï December 2015. Surface water temperature, pH and turbidity were tested at each sampling stations with laboratory thermometer, digital pH meter, and secci disk respectively using the standard methods (APHA, 2005). Water samples for DO determination were collected using 250ml dissolve oxygen bottle and fixed separately with 2ml each of Wrinklerôs solution A and B (manganese sulphate, alkaliodide and conc. sulphric acid). BOD, COD, Alkalinity, Total Hardness, TSS and TDS were also determined using the standard methods (APHA, 2005).

i. Hydrogen-ion concentration (pH)

The pH of water and sediment samples was measured in the laboratory using the Hanna pH meter (Hi-1922 model). The meter was calibrated with pH buffer solution of 4.0, 7.0. After calibration, the electrode was removed from the pH 7 buffer solution and was rinsed severally with distilled water and blotted with soft tissue. It was then inserted into each of the samples (the electrode was rinsed with distilled water after each dipping) with the pH knob switched on. The readings were taken when the digital display was stable. At the end of the test, the electrode was rinsed again and stored immersed in distilled water.

ii. Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)

These were determined in the laboratory using the gravimetric method. AWhatman Filter paper No.1 (15cm) was oven dried and a 250ml Conical Flask was placed in an oven at 180^{o}C for 3 hours. Both were allowed to cool in a desiccator and then weighed. Exactly 100ml of water sample was filtered through the filter paper into the conical flask Thereafter, the water was evaporated to dryness on a hot plate (gently to avoid spouting) and the filter paper was placed in the oven set at 180^{o}C until a constant weight is obtained for record weights of the paper and flask separately. The total suspended solids and total dissolved solids for the samples were then calculated using the following formula:

i. Filter Paper

Weight of filter paper = X_1g

Weight of filter paper + residue = X_2g

Therefore, weight of residue (TSS) = (X_2-X_1)g.

Then TSS (mg/l) = $(X_2-X_1) \times 1000 \times 10$

ii. Conical Flask

Weight of empty conical flask = X g

Weight of Flask + Residue = Y g

Weight of Residue (TDS) =(Y ï X)g

Then TDS (mg/L) = $(Y-X)\times1000\times10$

iii. Turbidity

The determination of turbidity of water was conducted in-situ at the sampling stations using a 20cm diameter Secchi disc attached to a calibrated rope. The disc was painted in alternate black and white colours. With the aid of the graduated rope the disc was lowered gradually into the river. The depth at which it disappeared was recorded, the disc was then gradually drawn up and the depth at which it reappeared was also recorded. The average of the two depths was taken as the turbidity.

$$\text{Turbidity} = \frac{\text{depth of appearance} + \text{depth of disapperance}}{2}$$

iv. Alkalinity

The alkalinity of water samples was determined in the laboratory using the methyl orange titrimetric method. A 50 ml sample was measured into a conical flask. Two drops of methyl orange indicator was then added and the resulting mixture titrated against the standard 0.1M Hydrochloric acid (HCl) solution to a permanent pink colour end point at pH 4.5.

The following equation was used in the calculation:

$$\text{Alkalinity Mg calcium carbonate } (CaCo_3)/L = \frac{\text{[illegible]} \times \text{[illegible]} \times \text{[illegible]}}{\text{[illegible]}}$$

Where

A= Volume of acid used.

N= Normality of standard acid used

v. Hardness

Hardness of the water samples was determined according to the methods of APHA, (1999) by computing it from results of separate determinations of calcium and magnesium and reported as hardness by calculation that is ñhardness (calc)ò. It was computed using the following formula:

Hardness, mg equivalent $CaCO_3/L$ = 2.497 [Ca, mg/L] + 4.118 [Mg, mg/L]

vi. Dissolved Oxygen (DO)

Dissolved oxygen was estimated using the Azide modified techniques of Winklerôs method (APHA, 1992). At the sampling stations, a 250ml DO bottle was filled to the brim with River water and stoppered under water, care was taken to minimize contact with air. 1ml of manganese sulphate solution was added to the sample water below the surface followed by the addition of 1ml of potassium iodide solution. The stopper was closed tightly and the bottle shaken for maximum mixing of the contents. When the precipitate had settled, 1ml of concentrated sulphuric acid(H_2SO_4)was added to dissolve the precipitate. By this process, the iodine was released.In the laboratory, 100ml of the sample was transferred into a 250ml conical flask and 2 drops of starch indicator was added. This was titrated quickly with 0.025M sodium thiosulphate ($Na_2S_2O_3$) until the blue colour disappeared. Dissolved oxygen was calculated as follows:

$$\text{DO (mg/l)} = \frac{\text{[illegible]} \times \text{[illegible]} \times \text{[illegible]}}{\text{[illegible]}}$$

Where

N = normality of the titrant

vii. Biological oxygen demand (BOD)

Biological oxygen demand was determined after thorough aeration of the water sample. Thereafter, dissolved oxygen was determined on a suitable portion of the water sample and this was recorded as DO_1. A screw-topped incubation bottle was then filled to the brim with the remainder of the sample water. The bottle was sealed and incubated in the dark for five days at 20°C. After this, a DO determination of the incubated sample was carried out on a suitable portion and recorded as DO_5. BOD was calculated as the difference between the two DO determination levels and was recorded in mg/l

viii. Chemical Oxygen Demand (COD)

Chemical oxygen demand was determined by measuring a 50ml of water sample into a conical flask and 10ml of 0.00833Mpotassium dichromate ($K_2Cr_2O_7$) solution was added. After this, 1g of Mercury (II) sulphate ($HgSO_4$), 80ml of Silver sulphate (Ag_2SO_4)solution and a few beads were added to the solution. A reflux greaseless condenser was then fitted to the conical flask containing the mixture and heated gently to boiling. After boiling for exactly 10 minutes, it was then left to cool after which the condenser was rinsed with 50ml of water and the flask was cooled under running tap. Two drops of Ferroin indicator was added to the solution which was then titrated with 0.025M of Iron (II) ammonium sulphate ($Fe(NH_4)_2 (SO_4)_2 6H_2O$) until the colour changes from blue-green to red-brown. A blank DO determination was then carried out on a 50ml of water sample. The difference in value between the two titres gives the COD of the sample.

ix. Temperature

Water temperature of each station was measured in degree Celsius (°C) using laboratory thermometer calibrated from 0 ï 100°C. On each sampling day, the thermometer was dipped in water for about 5 minutes at a depth of 5cm. Temperature was recorded as soon as the reading stabilized.

x. Depth

The depth of the water at each sampling station was measured using a graduated rope with sinker. The rope was immersed in the water until the sinker touched the substratum. The reading was taken and recorded in meters.

2.3.2 Benthic vertebrate sampling

Vertebrate samples were randomly collected from each sampling station with cast net of 0.5mesh size, local trap (made from raffia palm), mali trap and hook and line, monthly for six months. Dugout canoes with paddles were used during the sampling within the river. The samples were kept in a container and labeled properly. Samples were stored in 30 - 40% Ethanol (Esenowo & Ugwumba, 2011) and were immediately transported to the laboratory of the Department of Zoology and Environmental Biology, University of Nigeria, Nsukka for identification. Benthic vertebrates were identified by means of identification keys provided by Bouchard (2000) and Dailey (2006).

2.3.3 Benthic macro invertebrate sampling

Three successive hauls of benthic samples were taken randomly from each sampled station using an Ekman grab and scoop net monthly for six months during the study period. The grab was lowered into the river and the bar released to close the grab. The contents of the grab were emptied into 10L plastic buckets labeled properly and transported to the laboratory for sorting and identification. The benthic maco-invertebrate samples were fixed with 10% formal saline (Esenowo and Ugwumba, 2011). During sorting, moderate volumes of water were added into the container to improve visibility (George *et al.,* 2009). Large benthic fauna were picked out using forceps while the smaller ones were obtained using a pipette. Identification keys provided by Bouchard (2004) and Dailey (2006) were used for fauna identification.

2.4 Statistical analysis

Data obtained were analyzed using SPSS version 20. Values were expressed as mean ± SE. Two-way Analysis of Variance (ANOVA) was used to determine significant differences among means of water quality parameters across stations and between seasons. Species diversity was calculated using Shannon wienerôs index (H) using the following equation;

$$H = -\sum_{1}^{N} p_i \ln p_i$$

Where: H = Species diversity index

P_i = the proportional abundance of species

n = the number of species

In = Natural log

× = Sum of the calculation

Species dominance was also calculated using Simpsonôs dominance index (D) using the formula;

$$D = \frac{1}{\sum_{1}^{N} p_i^2}$$

Where: D = Species dominance index

P_i = the proportional number of species

N = the number of species

× = Sum of the calculation

CHAPTER THREE
RESULTS

3.1 Species Composition, Abundance and Diversity of Benthic Organisms in Otamiri River.

The results of species composition, abundance and diversity yielded 229 benthic organisms belonging to 15 species and 14 families. Station 3 recorded more species and had highest abundance of benthic organisms than the other sampled stations while Station 1 had the least with only six benthic species. Station 2 had 11 species while Station 3 had 13 species of benthic organisms. Majority of the sampled benthic organisms were recorded in Station 3

The abundance of benthic organisms in Otamiri River were favoured by season as more benthic organisms were recovered in the dry season than in rainy season. *Chrysichthys nigrodigitatus* (32.65%) was the most abundant species recorded in the present study as against the least that was *Paleamon. serratus* (1.25%). Both occurred only in Station 3.

The diversity indices yielded high diversity in Station 3 than the other two studied stations. More species were recorded and with high diversity index in the dry season than the wet season in all the sampled Stations.

Table 1: Species composition and abundance of the benthic organisms in Otamiri River

FAMILY	SPECIES	S 1	S 2	S3	Otamiri river
Astacoidae	*Cambarellus diminutus*	0	6	23	29
Palaemonidae	*Palaemon serratus*	0	0	3	3
Tubificidae	*Tubifex tubifex*	9	3	9	21
Mochokidae	*Synodontis budgetti*	8	5	7	20
Mochokidae	*Synodontis soloni*	2	3	0	5
Calroteidae	*Chrysichthys nigrodigitatus*	0	0	83	83
Aeshnidae	*Aeshna cyanea*	3	5	10	18
Libellulidae	*Libellula incest*	0	4	3	7
Neopetaliidae	*Neopetalia punctata*	2	3	4	9
Clariidae	*Clarias gariepinus*	0	2	11	13
Notopteridae	*Papyrocranus afer*	0	1	7	8
Gecarcinidae	*Cardisoma armatum*	1	1	6	8
Nepidae	*Nepa cinerea*	0	1	3	4
		25	**34**	**170**	**229**

S1 = Station 1, S2 = Station 2, S3 = Station 3

Table 2: Species Composition and percentage abundance of the benthic organisms in Otamiri River

FAMILY	SPECIES	S 1 (%)	S 2 (%)	S3 (%)	Total (%) Otamiri river
Astacoidae	*C. diminutus*	0	17.65	13.53	12.66
Palaemonidae	*P. serratus*	0	0	1.77	1.31
Tubificidae	*T. tubifex*	36	8.82	5.29	9.17
Mochokidae	*S. budgetti*	32	14.71	4.12	8.7
Mochokidae	*S. soloni*	8	8.82	0	2.18
Calroteidae	*C. nigrodigitatus*	0	0	48.82	36.25
Aeshnidae	*A. cyanea*	12	14.71	5.88	7.86
Libellulidae	*L. incest*	0	11.77	1.77	3.06
Neopetaliidae	*N. punctata*	8	8.82	2.35	3.93
Clariidae	*C. gariepinus*	0	5.88	6.47	5.68
Notopteridae	*P. afer*	0	2.94	4.12	3.49
Gecarcinidae	*C. armatum*	4	2.94	3.53	3.49
Nepidae	*N. cinerea*	0	2.94	1.76	1.78
		25	**34**	**170**	**229**

Table 3: Species diversity of benthic fauna of Otamiri River.

		Station 1		Station 2		Station 3	
		H˜	D	H˜	D	H˜	D
Overall		1.52	3.83	2.24	8.5	1.83	8.35
Seasons	Wet	0.84	1.97	1.38	4	1.7	3.5
	Dry	1.95	6.33	2.25	8.68	1.83	3.77
Months	June	0.5	1.47	0	1	1.01	2.57
	July	0	1	1.09	3	1.29	2.81
	August	0.64	1.8	0	0	0.9	2.1
	October	1.47	3.77	1.88	6.23	2.11	5.27
	November	1.33	3.57	2.02	7.2	1.52	2.82
	December	1.05	2.77	1.56	4.53	1.61	3.38

H˜ = Shannon Wienner index   D = Simpsonôs dominance index

3.2 Physico-chemical Parameters of Otamiri River

3.2.1 Temperature

The results of the temperature values of Otamiri River are presented in Figure 2. The result showed monthly variation across the stations throughout the study period. In Station 1, the months of June, July and August were observed to have similar values. The months of June and July recorded the least mean temperature values of 25.33±0.33 with highest value (28.33±0.33) in the month of November. The value for the month of October differed significantly from those of other months. There was no observed difference between the values for the months of November and December. In Station 2, the highest mean temperature value of 28.70±0.33 was recorded in December with lowest value (26.67±0.33) recorded in the month of June and August. Similarities were observed in temperature values for the months of June and August, July and November as well as in October and December. In Station 3, the least mean temperature value of 27.67±0.33 and highest value of 29.30±0.67 were recorded in the months of August and June respectively. Values for the months of June, November and December were observed to be significantly similar when compared to July, August and October values.

Across the stations, values for the month of November was observed to be significantly higher in station 3 when compared to other stations and months but differed significantly from those of other stations. Values for the months of June, August and October were observed to be similar as well as those of July and December.

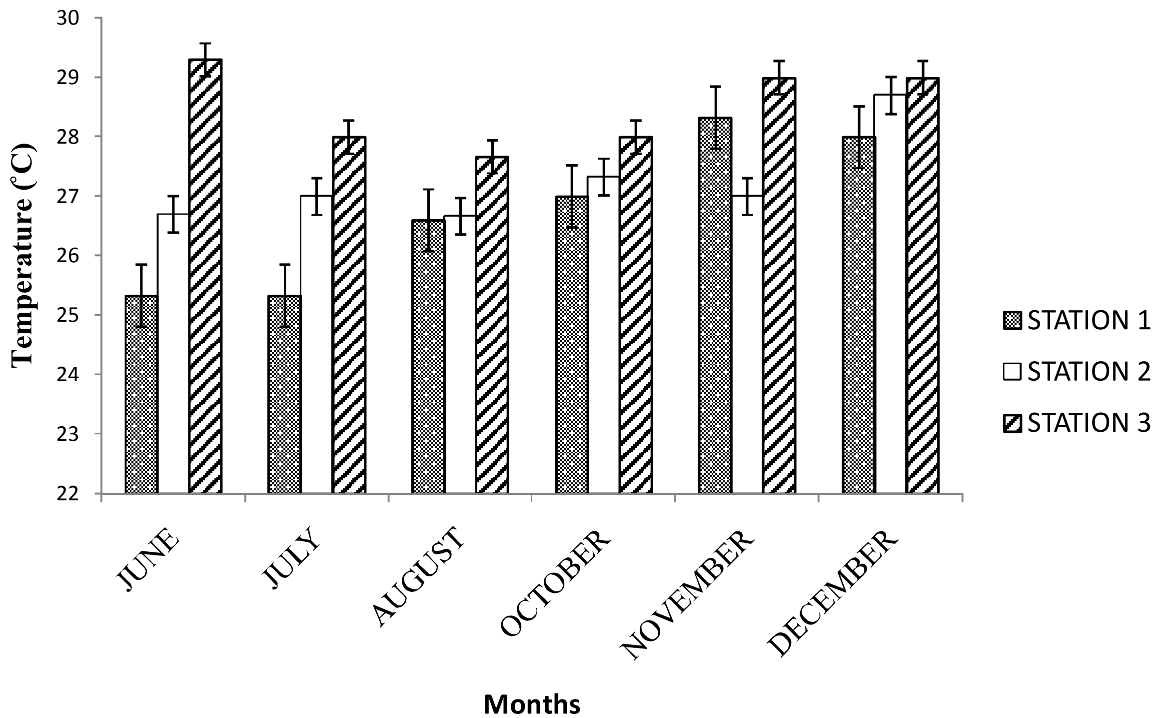

Figure 2: Mean-monthly variations in temperature (^{O}C) of Otamiri River in the three sampled stations

3.2.2 Depth

The results of the depth values of Otamiri River are presented in Figure 3. Due to on-going activities at the study area, we were restricted to a particular area throughout the study period. The results showed monthly variation across the stations throughout the study period. In Station 1, the highest mean depth of 4.21±0.27 was recorded in the month of June while the least value (0.46±0.09) was recorded in the month of December. There were no observed differences ($P>0.05$) in depth in the months of October, November and December whereas values for the month of August differed significantly from those of other months. At the same Station, values for the months of June and July were similar. They recorded high values all through the study period. In Station 2, the least depth value (0.71±0.06) was recorded in the month of August while the highest value (4.88±0.64) was recorded in the month of June. Values for the months of July, August, October, November and December were significantly similar whereas values for June differed significantly from those of other months ($P<0.05$). In Station 3, there were no significant differences ($P>0.05$) observed in the values of the months of June, August, October, November and December. At the same Station, the value for July was observed to be significantly different ($P<0.05$) from August and October values whereas values in other months were similar.

Across the stations, values for the months of June and August were observed to be similar as well as values for October and November whereas values for July and December were significant different ($P<0.05$) from other months and across stations.

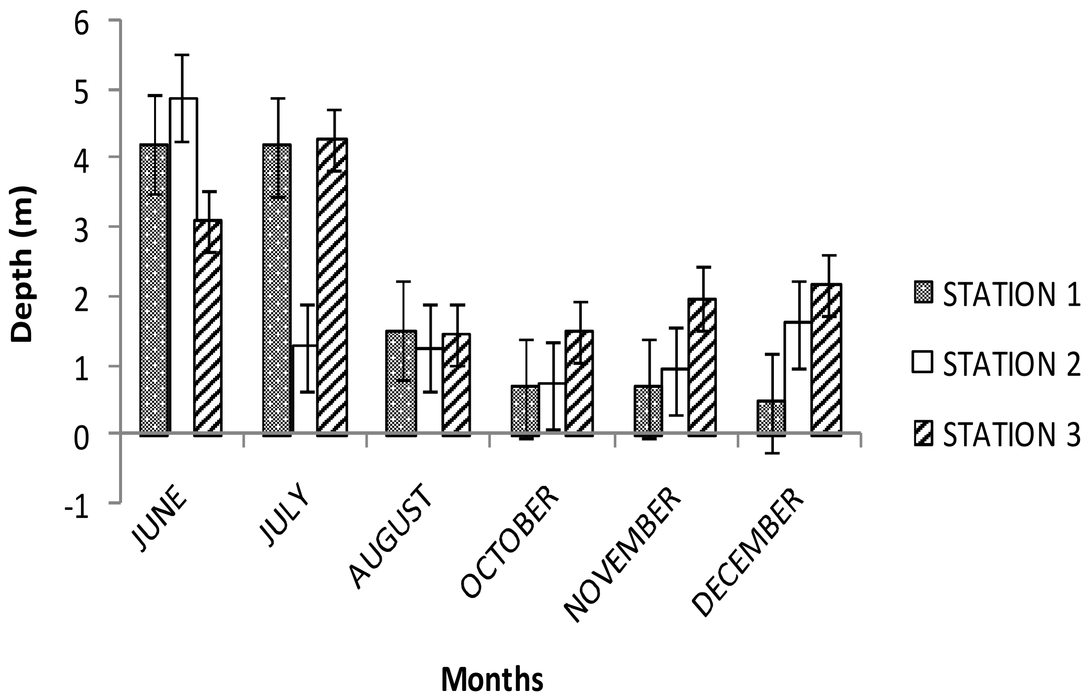

Figure 3: Mean-monthly variations in depth (m) of Otamiri River in the three sampled stations

3.2.3 Chemical Oxygen Demand (COD)

The results of the chemical oxygen demand of Otamiri River are presented in Figure 4. There were monthly variations in the values of COD observed through the study period. In Station 1, it was observed that values for all the months differed significantly ($P<0.05$) from each other. Similarly, same trend was observed in Stations 2 and 3 all through the study period.

Across the stations, COD was highest in the months of June, July, October and December at station 3 and also in the month of August except in Station 1 when compared to other stations.

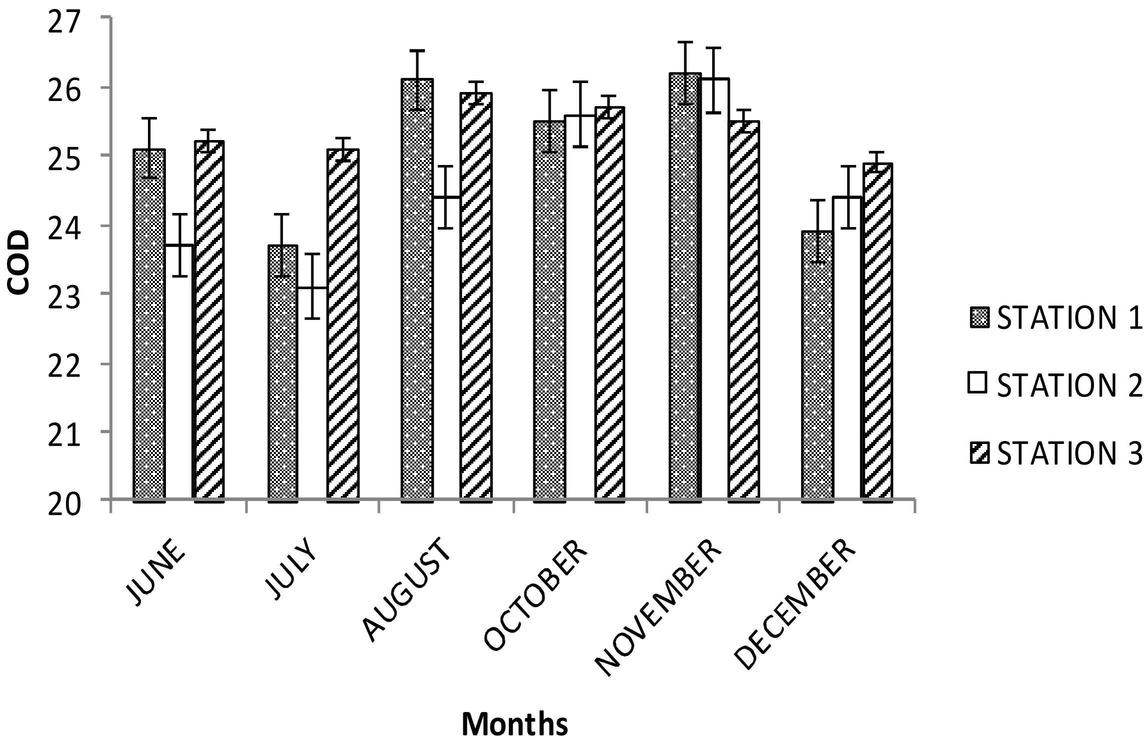

Figure 4: Mean-monthly variations of COD (mg/L) of Otamiri River in the three sampled stations

3.2.4 Biological Oxygen Demand (BOD)

The results of BOD values of Otamiri River are presented in Table 4. The results showed that there were monthly variations in BOD values across the stations all through the study period. In Station 1, the sand dredging location, it was observed that the BOD was significantly different during the months of the study except the months of June and August ($P<0.05$). The value ranged from the least (4.67±0.03) in November to the highest (5.87±0.03) for June and August. In Station 2, the least mean BOD value (5.07±0.03) were recorded in the months of October and November which were significantly less than the values for the other months. Values for the months of July and December were significantly less than the value for of June which had the highest recorded BOD value for that station. In Station 3, which had the undisturbed water body, the lowest BOD value was recorded in the month of November and was also observed to be significantly different from the values of other months ($P<0.05$). There were no observed significant difference between the values for the months of July, August and October ($P>0.05$). The values for the month of June was significantly higher in BOD value when compared to values of other months in this station ($P<0.05$). This value was not significantly different from the month of October value ($P>0.05$).

Across the stations, the variations observed were dependent on months. In the months of June and July, the BOD values for Stations 1 and 3 were similar and significantly higher than the value for Station 2 ($P<0.05$). Similar observation was made for Stations 2 and 3, as well as Stations 1 and 2 for November and December respectively whose values were significantly higher than those of the other stations for the respective months. In August, Station 1 mean BOD value was significantly higher than the value for Station 3 which was significantly higher than values recorded for Station 2 ($P<0.05$).

Table 4: Mean-monthly variations in BOD (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
June	5.87 ± 0.03^{e2}	5.70 ± 0.06^{d1}	5.87 ± 0.33^{d2}
July	5.70 ± 0.06^{d2}	5.40 ± 0.06^{c1}	5.70 ± 0.06^{c2}
August	5.87 ± 0.03^{e3}	5.27 ± 0.03^{b1}	5.70 ± 0.06^{c2}
October	5.27 ± 0.03^{b2}	5.07 ± 0.03^{a1}	5.80 ± 0.06^{cd3}
November	4.67 ± 0.03^{a1}	5.07 ± 0.03^{a2}	5.07 ± 0.03^{a2}
December	5.47 ± 0.03^{c2}	5.43 ± 0.03^{c2}	5.27 ± 0.03^{b1}

Values with same alphabets in a column are not significantly different (p>0.05). Values with same numbers in rows are not significantly different (p>0.05).

3.2.5 Dissolved Oxygen (DO)

The results of DO in Otamiri River (Table 4) showed that there were monthly variations in DO values across the stations during the study period. In Station 1, it was observed that the DO values were significantly different from the values of all other months except the months of July and October. The values ranged from the least (4.57±0.33) in June to the highest (6.50±0.06) in July and October. In Station 2, the least mean DO value (5.77±0.33) was recorded in the month of June and was significantly less when compared to values of other months. Values for the months of July and November were significantly higher than values of other months with the mean value of 6.47±0.03 ($P<0.05$). Values for the months of August and December were observed to be similar. In Station 3, the lowest DO value of (5.07±0.03) was recorded in the month of June which also shared similarity with the values of the months of July and August. There were significant differences in DO values recorded in the months of October, November and December ($P<0.05$). The value recorded in the month of October was significantly higher when compared to values for other months in this Station ($P<0.05$).

Across the stations, the variations were dependent on months. In the month of June, the DO values (5.87±0.03) of stations 1 and 3 were similar and significantly higher than the value recorded in Station 2 ($P<0.05$). A similar observation was made for values in Stations 1and 2 for July. In August, values for Stations 1 and 3 were similar but significantly lesser than the value for Station 2. In October, the DO of Station 3 was significantly higher than values for Stations 1 and 2. Similar observation was recorded in November in Station 2 whereas in December, values for Stations 1, 2 and 3 were similar.

Table 5: Mean-monthly variations in Dissolved Oxygen (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	4.57 ± 0.33^{a1}	5.77 ± 0.33^{a2}	5.67 ± 0.33^{a2}
JULY	6.50 ± 0.06^{e2}	6.47 ± 0.03^{c2}	5.87 ± 0.03^{a1}
AUGUST	5.70 ± 0.00^{b1}	6.00 ± 0.00^{b2}	5.80 ± 0.10^{a1}
OCTOBER	6.50 ± 0.06^{e2}	6.20 ± 0.06^{d1}	6.70 ± 0.06^{c3}
NOVEMBER	6.00 ± 0.00^{c1}	6.47 ± 0.03^{c3}	6.37 ± 0.03^{b2}
DECEMBER	6.20 ± 0.06^{d1}	6.00 ± 0.00^{b1}	6.20 ± 0.12^{b1}

Values with same alphabets in a column are not significantly different ($p>0.05$). Values with same numbers in rows are not significantly different ($p>0.05$).

3.2.6 Total Alkalinity

The results of total alkalinity of Otamiri River are presented in Table 5. In Station 1, the total alkalinity (12.7±0.02) was observed to be highest in the month of December and lowest (9.96±0.04) in the month of August. In the months of June, July and December, there were significant differences ($P<0.05$) whereas, there were no observed differences in total alkalinity between the months of August, October and November ($P>0.05$). In Station 2, the least mean alkalinity values (10.0±0.00) were recorded in the months of June and July which was significantly less when compared to values for other months. Values for the months of August, October, November and December were significantly different ($P>0.05$) from values for other months. Total alkalinity value (11.2±0.00) for the month of August was significantly higher than value for other months. In Station 3, the highest alkalinity value (12.5±0.01) was recorded in the month of October. This value was significantly different from values of other months. There were no significant differences in total alkalinity between the months of July, August, November and December ($P>0.05$), whereas the value for the month of June differed significantly ($P<0.05$).

Across stations, the variations observed were dependent on months. In the months of June and October, the total alkalinity in Station 3 was observed to be significantly higher than each other ($P < 0.05$). Total alkalinity values for the months of August and November in all the stations were observed to be similar whereas, values for the months of July and December differed significantly from those of other months ($P<0.05$).

Table 6: Mean-monthly variations in Total Alkalinity (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	10.2 ± 0.03^{b2}	10.0 ± 0.00^{a1}	11.3 ± 0.02^{b3}
JULY	11.1 ± 0.00^{c2}	10.0 ± 0.00^{a1}	10.0 ± 0.00^{a1}
AUGUST	9.96 ± 0.04^{a1}	11.2 ± 0.00^{e2}	10.0 ± 0.00^{a1}
OCTOBER	10.0 ± 0.00^{a1}	10.4 ± 0.00^{b2}	12.5 ± 0.01^{c3}
NOVEMBER	10.0 ± 0.00^{a1}	10.4 ± 0.01^{c2}	10.0 ± 0.12^{a1}
DECEMBER	12.7 ± 0.02^{d2}	10.7 ± 0.01^{d2}	10.0 ± 0.04^{a1}

Values with same alphabets in a column are not significantly different (p>0.05). Values with same numbers in rows are not significantly different (p>0.05).

3.2.7 pH

The results of the pH values of Otamiri River are presented in Table 7. In Station 1, pH value was observed to be significantly higher (7.37±0.03) in the month of July and lowest (6.00±0.00) in the month of August. pH values for the month of July and August differed significantly from values of other months (June, October, November and December) which were observed to be similar. In Station 2, the least mean pH value (5.70±0.00) was recorded in the month of June and was significantly less when compared to values for other months. pH values for the month of November was significantly higher ($P<0.05$) than values for other months with the mean value of 6.90±0.00, although similar value was recorded in the month of October. There were significant differences ($P<0.05$) in pH values in the months of June, July, August and December. In Station 3, values for the months of June and August recorded the least mean pH value (5.90±0.00) which was similar, whereas values for other months differed significantly ($P<0.05$) from values for June and August with November recording the highest mean pH value of 7.47±0.03.

Across stations, the variations of pH values were monthly dependent. In the months of June and July, the pH value of station 1 was similar and significantly higher than values for Stations 2 and 3. A similar observation was made in pH value for Stations 2 and 3 for August and November respectively. In October, similar pH values were also observed though pH values for the months of August and December differed significantly from those of other months ($P<0.05$).

Table 7: Mean-monthly variations in pH of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	6.73 ± 0.03^{b3}	5.70 ± 0.00^{a1}	5.90 ± 0.00^{a2}
JULY	7.37 ± 0.03^{c3}	6.60 ± 0.00^{c1}	6.80 ± 0.00^{b2}
AUGUST	6.00 ± 0.00^{a2}	6.33 ± 0.03^{b3}	5.90 ± 0.00^{a1}
OCTOBER	6.77 ± 0.08^{b1}	6.87 ± 0.03^{e1}	6.97 ± 0.03^{c1}
NOVEMBER	6.80 ± 0.00^{b1}	6.90 ± 0.00^{e2}	7.47 ± 0.03^{e3}
DECEMBER	6.70 ± 0.06^{b1}	6.80 ± 0.00^{d1}	7.20 ± 0.00^{d2}

Values with same alphabets in a column are not significantly different ($p>0.05$). Values with same numbers in rows are not significantly different ($p>0.05$).

3.2.8 Total Dissolved Solid (TDS)

The results of TDS of Otamiri River (Table 8) showed that there were monthly variations across the stations all through the study period. In Station 1, the TDS value (206.0±33.0) was lowest in the month of June and highest (421.0±0.58) in the month of August. There were no observed differences ($P>0.05$) between TDS values in the months of July, October, November and December whereas, differences were recorded in the months of June and August ($P<0.05$). In Station 2, the lowest mean TDS value (341.0±0.58) was recorded in the month of November while the highest value (521.0±0.58) was recorded in the month of June. Significant differences in TDS values were observed in all the months of this study ($P<0.05$). In Station 3, the highest TDS value (447.3±0.67) was recorded in the month of June while the least TDS value (321.0±0.56) was recorded in the month of July. TDS values for the months of June, July, November and December were significantly different ($P<0.05$) from August and October TDS values which were similar.

Across the stations, the variations recorded were dependent on months. The TDS values in June, July and October were higher in Stations 2. August value was highest in Station 1 whereas, values for November and December were highest in Station 3. There were no significant differences between TDS values for the months of November and December.

Table 8: Mean-monthly variations in Total Dissolved Solid (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	206.0 ± 33.0^{a1}	521.0 ± 0.58^{f3}	447.3 ±0.67^{e2}
JULY	331.0 ±0.56^{b2}	391.0 ±0.56^{d3}	321.0 ±0.56^{a1}
AUGUST	421.0 ±0.58^{c3}	349.3 ±0.58^{b1}	371.0 ±0.58^{c2}
OCTOBER	331.0 ±0.58^{b1}	421.0 ±0.58^{e3}	371.0 ±0.58^{c2}
NOVEMBER	301.0 ±0.58^{b1}	341.0 ±0.58^{a2}	351.0 ±0.58^{b3}
DECEMBER	301.0 ±0.58^{b1}	371.0 ±0.58^{c2}	381.0 ±0.58^{d3}

Values with same alphabets in a column are not significantly different ($p>0.05$). Values with same numbers in rows are not significantly different ($p>0.05$).

3.2.9 Total Hardness

The results of total hardness values of Otamiri River are presented in Table 9. The total hardness of Otamiri River showed monthly variations across the stations throughout the study period. In Station 1, it was observed that the total hardness was significantly different in all the months of the study with the highest mean value (0.89±0.00) recorded in the month of June while the least value (0.46±0.00) was recorded in the month of October. Similarly, values for Station 2 showed significant differences in all the months with the highest total hardness value (0.81±0.01) recorded in the month of November and lowest value (0.32±0.00) recorded in the month of June ($P<0.05$). In Station 3, total hardness values for the months of June, August and October were significantly similar whereas, values for other months differed significantly ($P<0.05$). The highest mean total hardness value (0.68±0.00) was recorded in the month of November while the lowest mean vALUE (0.55±0.00) was recorded in the month of July.

Across the stations, the variations in total hardness values were dependent on months. In the month of June, the total hardness value (0.89±0.00) of Station 1 was significantly higher than values for Stations 2 and 3 ($P<0.05$). Same similarity of total hardness values were observed in the months of July and December in Station 2. In the month of August and October, the total hardness values for of Stations 1, 2 and 3 were significantly similar whereas, values for November differed significantly from those of other months throughout the study period ($P<0.05$).

Table 9: Mean-monthly variations of Total Hardness (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	0.89 ± 0.00^{f3}	0.32 ± 0.00^{a1}	0.61 ± 0.01^{c2}
JULY	0.62 ± 0.00^{d2}	0.72 ± 0.00^{e3}	0.55 ± 0.00^{a1}
AUGUST	0.50 ± 0.00^{b1}	0.55 ± 0.00^{c2}	0.60 ± 0.03^{c3}
OCTOBER	0.46 ± 0.00^{a1}	0.52 ± 0.00^{b2}	0.60 ± 0.00^{c3}
NOVEMBER	0.80 ± 0.00^{e2}	0.81 ± 0.01^{f2}	0.68 ± 0.00^{d1}
DECEMBER	0.54 ± 0.00^{c1}	0.60 ± 0.00^{d3}	0.57 ± 0.00^{b2}

Values with same alphabets in a column are not significantly different ($p>0.05$). Values with same numbers in rows are not significantly different ($p>0.05$).

3.2.10 Turbidity

The results of the turbidity values of Otamiri River (Table 10) showed that there were variations across the months throughout the study period. In Station 1, the turbidity value was highest (7.03±0.04) in the month of November and lowest (2.97±0.03) in the month of June. There were no significant differences in turbidity values in the months of June and October ($P>0.05$). A similar trend was recorded in the months of July and August whereas, turbidity values in November and December differed significantly from those of other months ($P<0.05$). In Station 2, turbidity value was highest (8.00±0.06) in the month of December and lowest (2.00±0.00) in the month of June. Both June and December values differed significantly from those of other months ($P<0.05$) whereas, no significant difference was recorded between turbidity values in the months of July and August ($P<0.05$). Similarly, values for the months of October and November were observed to be similar. In Station 3, turbidity values for the months of June, November and December differed significantly ($P<0.05$) from the values for the months of July, August and October which were observed to be similar. The highest mean turbidity value (8.00±0.00) was recorded in the month of December while the lowest mean value (3.00±0.00) was recorded in the month of June.

Across the stations, the turbidity value of Station 2 was significantly higher than values for other months throughout the study period. Turbidity values for the months of July and August were observed to be similar for all the stations ($p > 0.05$).

Table 10: Mean-monthly variations in Turbidity (NTU) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	2.97 ± 0.03^{a2}	2.00 ± 0.00^{a1}	3.00 ± 0.00^{a2}
JULY	4.00 ± 0.06^{b1}	5.00 ± 0.00^{b2}	5.00 ± 0.12^{b2}
AUGUST	4.17 ± 0.17^{b1}	5.12 ± 0.12^{b2}	5.00 ± 0.00^{b2}
OCTOBER	3.00 ± 0.06^{a1}	6.02 ± 0.16^{c3}	5.03 ± 0.03^{b2}
NOVEMBER	7.03 ± 0.04^{d2}	6.00 ± 0.00^{c1}	6.00 ± 0.01^{c1}
DECEMBER	5.18 ± 0.03^{c1}	8.00 ± 0.06^{d2}	8.00 ± 0.00^{d2}

Values with same alphabets in a column are not significantly different (p>0.05). Values with same numbers in rows are not significantly different (p>0.05).

3.2.11 Total Suspended Solids (TSS)

The results of TSS values of Otamiri River are presented in Table 11. Monthly variations in TSS values were observed throughout the study period. In Station 1, the TSS value was highest (10.4±0.19) in December and lowest (6.54±0.00) in the month of August. TSS values for the months of July and August differed significantly ($P<0.05$) from those of other months. In the months of June and October, no significant differences were observed between TSS values. Similar trends were also recorded in the months of November and December. In Station 2, TSS values were significantly different in all the stations with the highest mean value (11.3±0.12) recorded in December and lowest mean value (6.88±0.00) recorded in August. In Station 3, the TSS values differed significantly throughout the months of the study. TSS value was observed to be highest (10.59±0.20) in the month of December and lowest (2.00±0.00) in the month of June.

Across the stations, TSS values in June and July were higher at Station 1 than in Stations 2 although they were significantly similar. TSS values in the months of August and October had no significant differences although both months had higher values in station 2. Significant differences were recorded in TSS values in the months of November (10.2 $\pm$ 0.00 and 9.92 $\pm$ 0.00 respectively) and December (10.4 $\pm$ 0.19 and 11.3 $\pm$ 0.12 respectively) at Stations 1 and 2 ($P<0.05$).

Table 11: Mean-monthly variations in TSS (mg/L) of Otamiri River in the three sampled stations

	Station 1	Station 2	Station 3
JUNE	8.66 ± 0.00^{c3}	7.42 ± 0.00^{c2}	3.69 ± 0.00^{a1}
JULY	7.48 ± 0.00^{b3}	6.92 ± 0.00^{b2}	6.40 ± 0.00^{c1}
AUGUST	6.54 ± 0.00^{a2}	6.88 ± 0.00^{a3}	5.92 ± 0.08^{b1}
OCTOBER	8.42 ± 0.00^{c2}	8.39 ± 0.00^{d3}	8.39 ± 0.00^{d1}
NOVEMBER	10.2 ± 0.00^{d3}	9.92 ± 0.00^{e1}	10.1 ± 0.00^{e2}
DECEMBER	10.4 ± 0.19^{d1}	11.3 ± 0.12^{f2}	10.59 ±0.20^{f1}

Values with same alphabets in a column are not significantly different ($p>0.05$). Values with same numbers in rows are not significantly different ($p>0.05$).

3.3 Correlation of Species Abundance of Benthic Organisms with Physico-Chemical Parameters

The results of the correlation of species abundance of benthic organisms with some physic-chemical parameters are presented in Table 12. The correlation of COD, pH, TDS and hardness has no relationship with the species composition and abundance.

The relationships between physicochemical parameters and abundance of vertebrates and macro-invertebrates recorded significant correlation at (0.05) level except TSS that recorded significant correlation at (0.01) level. TSS correlated positively with only *S. budgetti,* whereas, temperature correlated positively with *C. diminutus, S. budgetti, C. nigrodigitatus, L. insest, A. cyanea, P. afer, C. armatum and N. cinerea*.

Depth correlated negatively with *S. budgetti, C. gariepinus and C. armatum*. BOD correlated negatively with *S. budgetti, S. soloni, A. cyanea, C. armatum and N. cinerea*. DO correlated positively with *N. punctata*. Alkalinity correlated positively with *S. budgetti.* Turbidity correlated negatively with *T. Tubifex* but positively with *S. budgetti, C. armatum* and *N. cinerea*. TSS correlated positively with *C. diminutus, S. budgetti, C. armatum* and *N. cinerea.*

The regression plot of the significantly correlated variable are presented in figures 4 to 28 for all the physico-chemical parameters and abundance of the species in Otamiri River. The R^2 displayed a percentage of the abundance that could be explained by the physicochemical parameters.

BOD had an inverse association with the abundance of *S. budgetti,* with 33.35%, *S. soloni* 45.36%, *A. cyanea* 30.92%, *C. armatum* 36.01%, and *N. cinerea* 31.87%.

Depth had an inverse association with the abundance of *S. budgetti* with 37.78%, *C. gariepinus* 23.09% and *C. armatum* 25.14%.

Temperature had a direct association with the abundance of *C. diminutus* with 26.80%, *S. budgetti* 48.42%, *C. nigrodigitatus* 22.40%, *A. cyanea* 33.10%, *P. affer* 28.13%, *C.armatum* 38.91% and *N. cinerea* 37.50%.

Total Suspended Solids (TSS) had a direct association with the abundance of *C. diminutus* with 27.69%, *S. budgetti* 50.46%, *C. armatum* 25.52%, and *N. cinerea* 24.67%.

Turbidity had an inverse association with the abundance of *T. Tubifex* with 37.77% and a direct association with the abundance of *S. budgetti* 35.41%, *C. armatum* 23.67%, and *N. cinerea* 39.03%.

Total Alkalinity had a direct association with *S. budgetti* with 26.06%.

Dissolved Oxygen had a direct association with *N. punctata* with 24.99%.

Table 12: Correlation matrices of Species Abundance of Benthic Organisms with Physico-Chemical Parameters

	Temperature (^{O}C)	Depth (m)	COD (mg/L)	BOD (mg/L)	DO (mg/L)	Alkalinity (mg/L)	pH	TDS (mg/L)	Hardness (mg/L)	Turbidity (NTU)	TSS (mg/L)
C. diminutus	0.517*	-0.381	-0.138	-0.246	0.125	0.406	0.018	-0.116	-0.014	0.414	0.526*
P. serratus	-0.089	-0.015	0.100	0.022	-0.056	-0.202	0.087	-0.077	-0.056	-0.338	-0.032
T. tubifex	-0.342	0.115	0.208	0.311	-0.425	-0.298	-0.285	-0.132	0.030	-0.615**	-0.184
S. budgetti	0.696**	-0.615**	-0.180	-0.578*	0.418	0.510*	0.165	-0.045	-0.163	0.595**	0.710**
S. soloni	0.372	-0.378	0.428	-0.674**	0.231	-0.337	0.040	-0.015	0.089	0.299	0.314
A. Cambarellus	-0.130	0.319	-0.340	0.188	0.251	0.105	0.405	0.062	-0.040	-0.080	-0.201
C. nigrodigitatus	0.473*	-0.349	-0.044	-0.239	0.192	0.227	0.058	0.005	-0.064	0.330	0.334
L. incest	0.492*	-0.375	-0.324	-0.251	0.420	0.471	0.233	-0.015	-0.282	0.295	0.423
A. cyanea	0.575*	-0.444	0.167	-0.556*	0.392	-0.058	0.166	-0.001	-0.098	0.293	0.390
N. punctata	0.371	-0.289	-0.151	-0.383	0.500*	0.147	0.402	0.033	-0.239	0.157	0.260
C. gariepinus	0.448	-0.481*	-0.094	-0.163	0.224	0.319	-0.027	0.037	-0.262	0.211	0.337
P. afer	0.530*	-0.432	0.039	-0.378	0.197	0.173	0.074	-0.049	-0.031	0.373	0.439
C. armatum	0.624**	-0.501*	0.218	-0.600**	0.209	0.004	0.105	-0.059	0.080	0.487*	0.505*
N.cinerea	0.613**	-0.326	0.227	-0.565*	0.087	0.003	0.049	-0.088	0.283	0.625**	0.497*

COD= Chemical Oxygen Demand, BOD= Biological Oxygen Demand, DO= Dissolved Oxygen, TDS= Total Dissolved Solids, TSS= Total Suspended Solids
*** Correlation is significant at 0.05 level (2-tailed), ** correlation is significant at 0.01 level (2-tailed)**

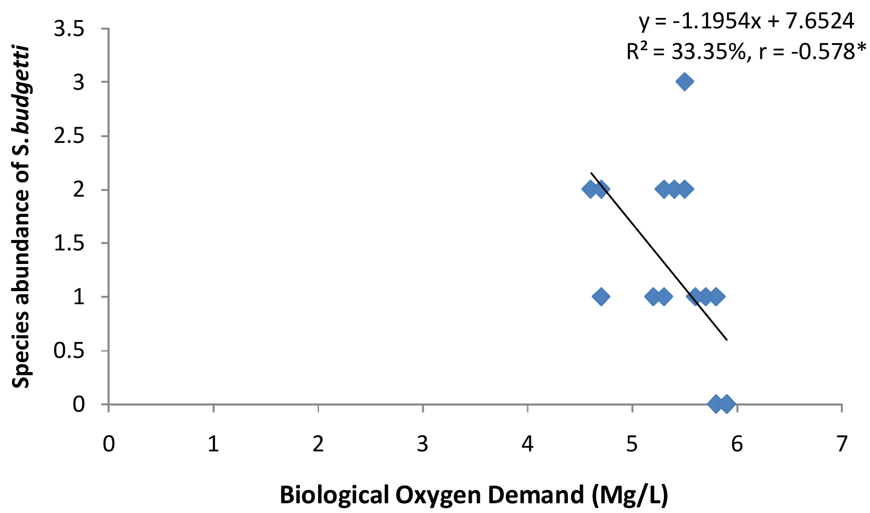

Figure 5: Relationship of species abundance of *S. budgetti* in Otamiri River with BOD

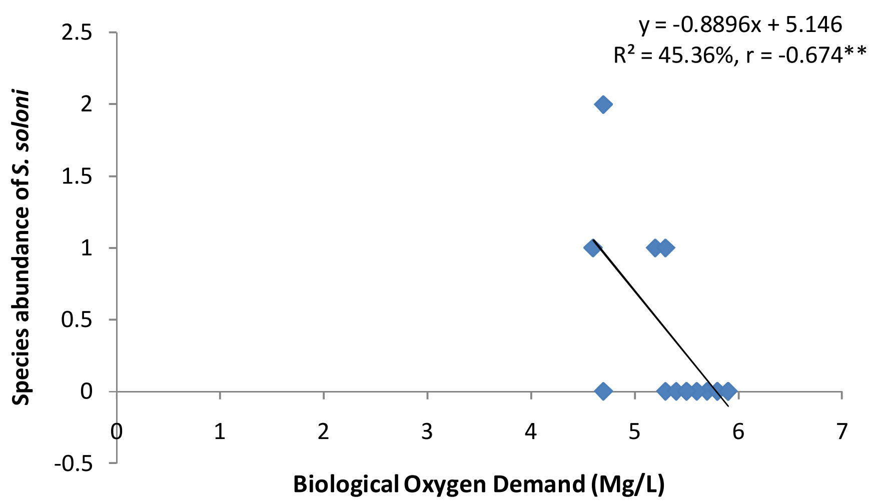

Figure 6: Relationship of species abundance of *S. soloni* in Otamiri River with BOD

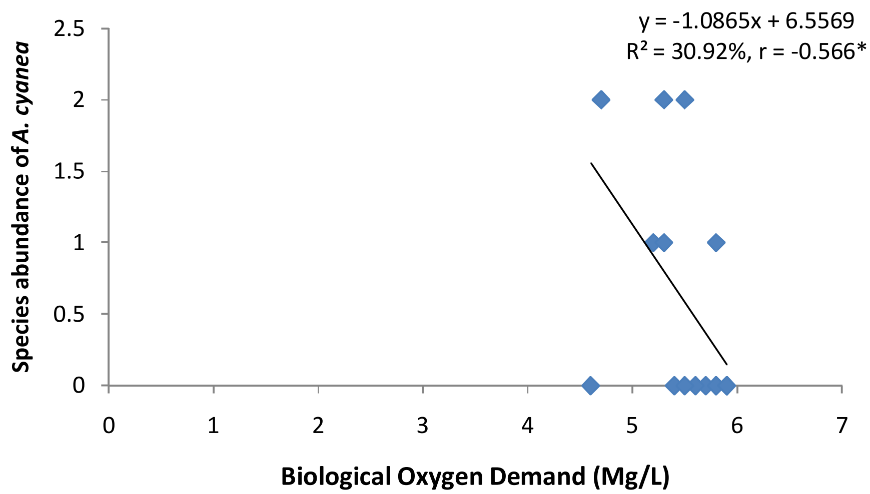

Figure 7: Relationship of species abundance of *A. cyanea* in Otamiri River with BOD

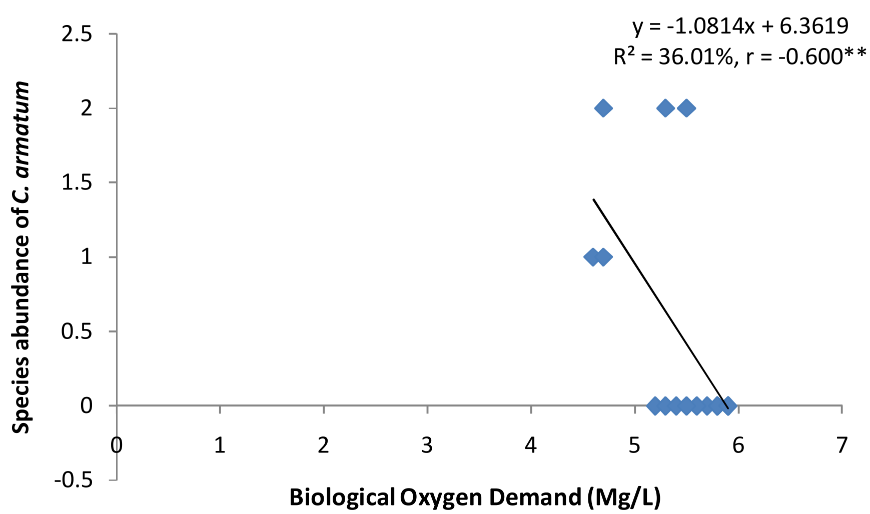

Figure 8: Relationship of species abundance of *C. armatum* in Otamiri River with BOD

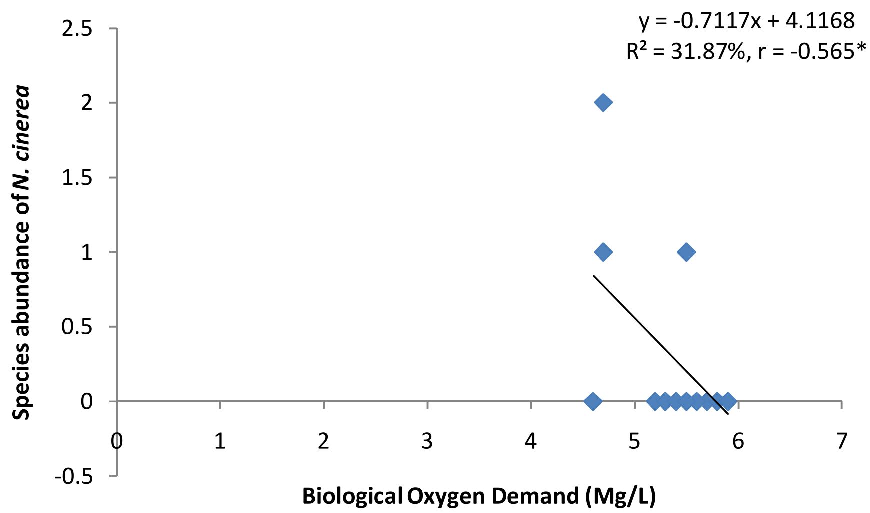

Figure 9: Relationship of species abundance of *N. cinerea* in Otamiri River with BOD

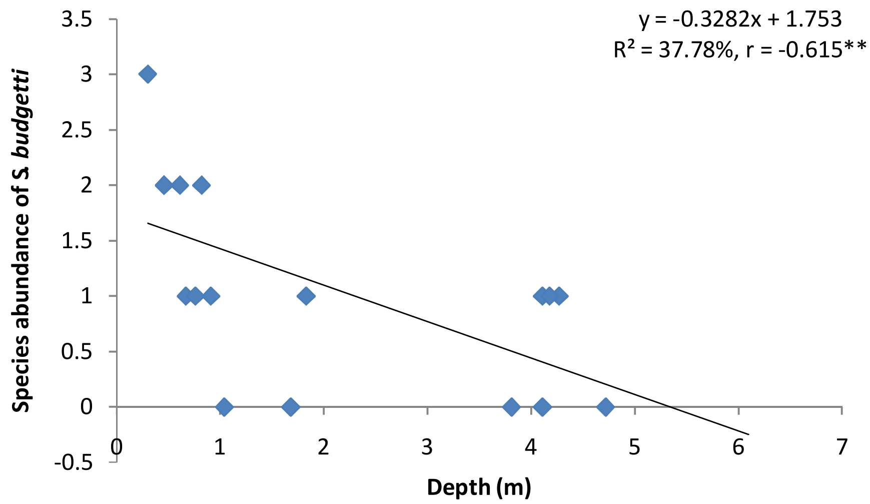

Figure 10: Relationship of species abundance of *S. budgetti* in Otamiri River with Depth

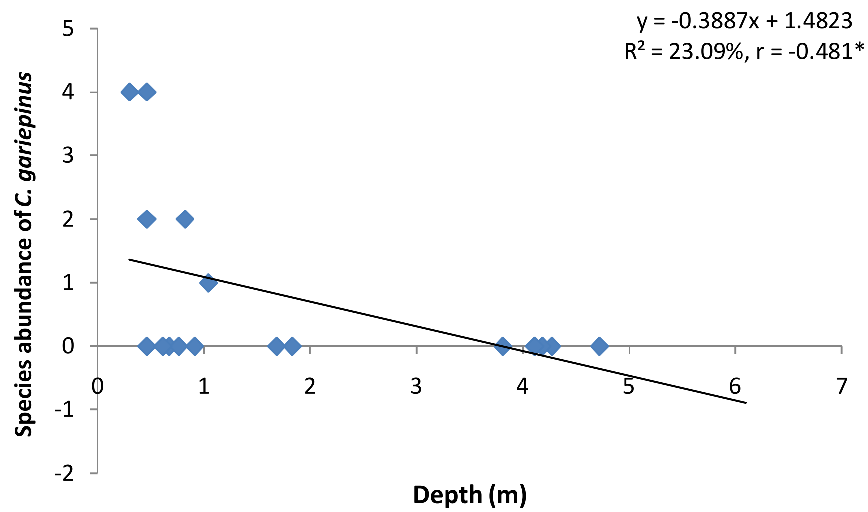

Figure 11: Relationship of species abundance of *C. gariepinus* in Otamiri River with Depth

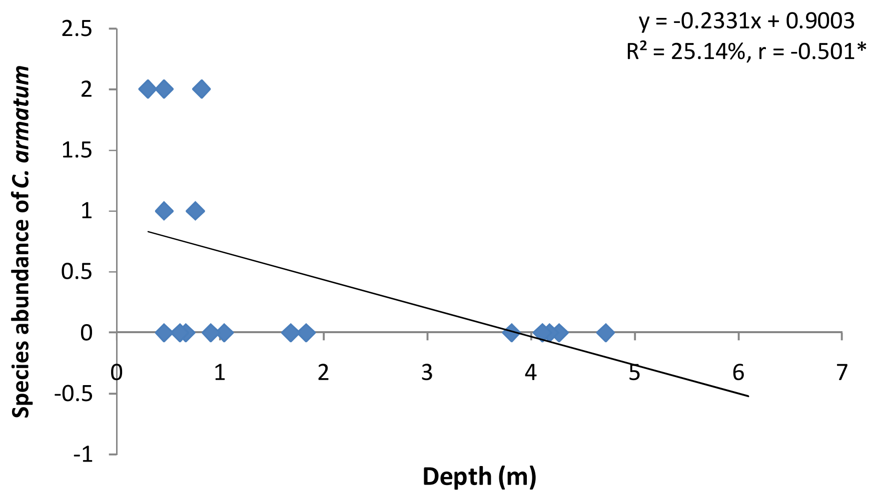

Figure 12: Relationship of species abundance of *C. armatum* in Otamiri River with Depth

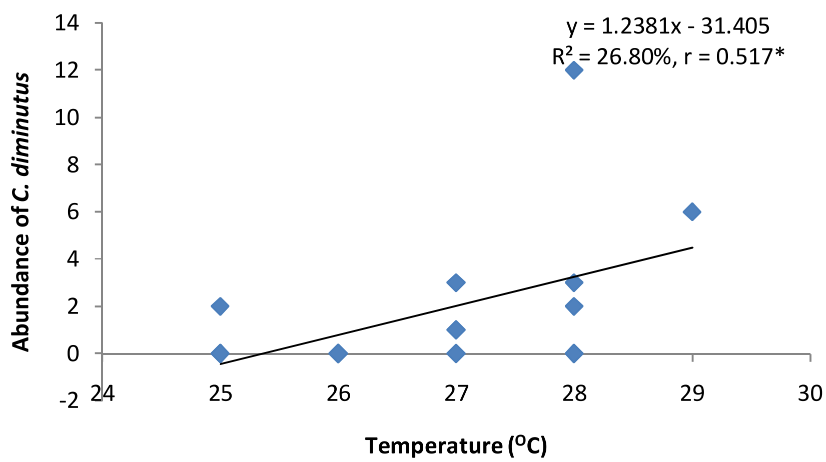

Figure 13: Relationship of species abundance of *C. diminutus* in Otamiri River with Temperature

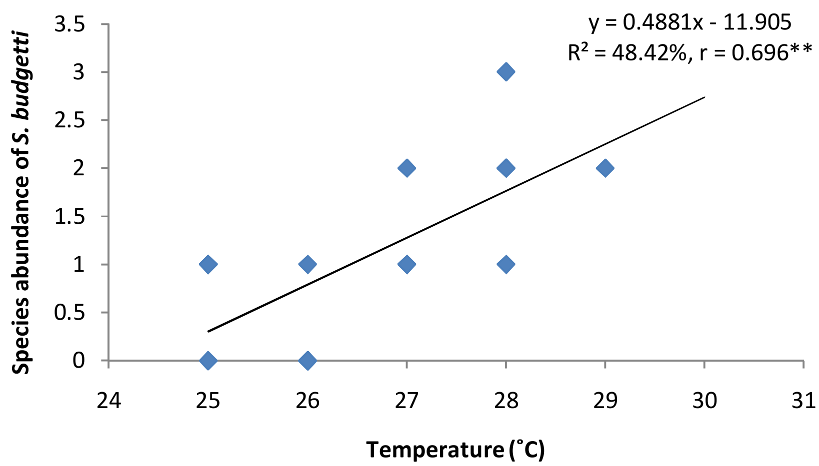

Figure 14: Relationship of species abundance of *S. budgetti* in Otamiri River with Temperature

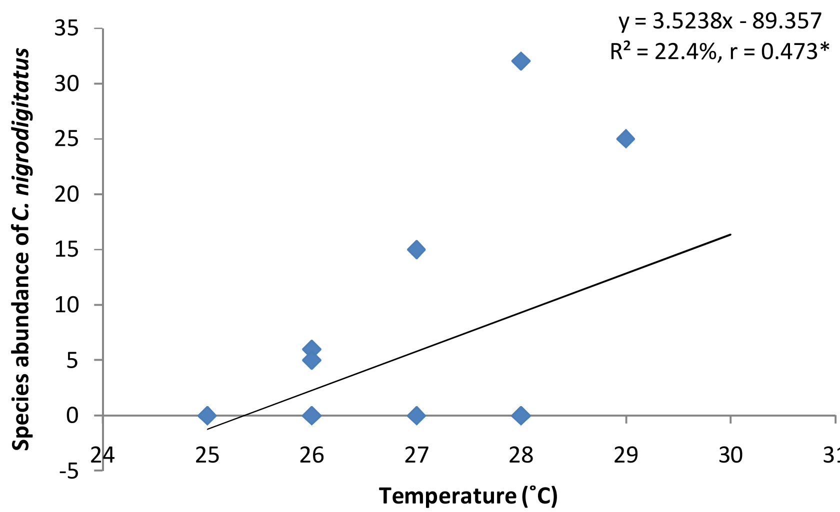

Figure 15: Relationship of species abundance of *C. nigrodigitatus* in Otamiri River with Temperature

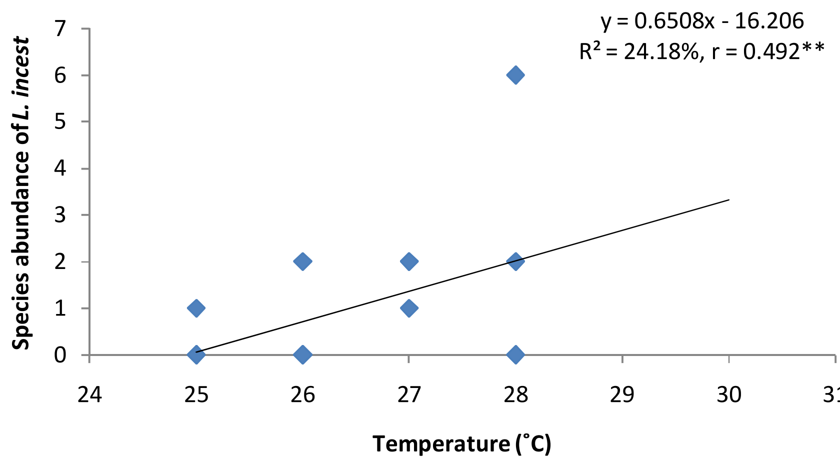

Figure 16: Relationship of species abundance of *L. incest* in Otamiri River with Temperature

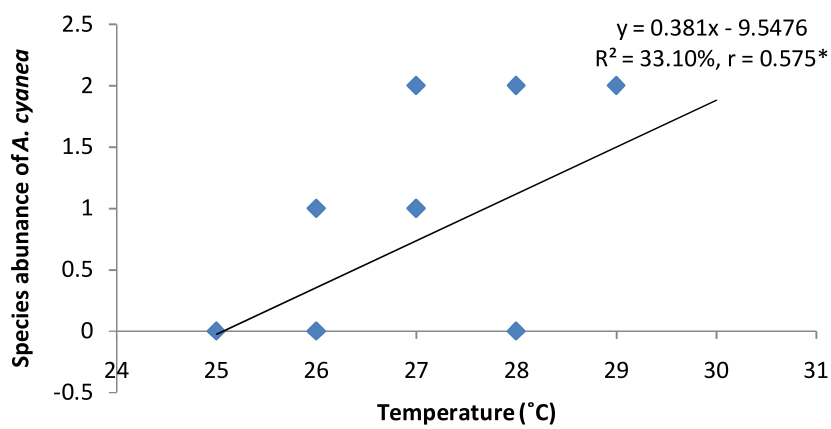

Figure 17: Relationship of species abundance of *A. cyanea* in Otamiri River with Temperature

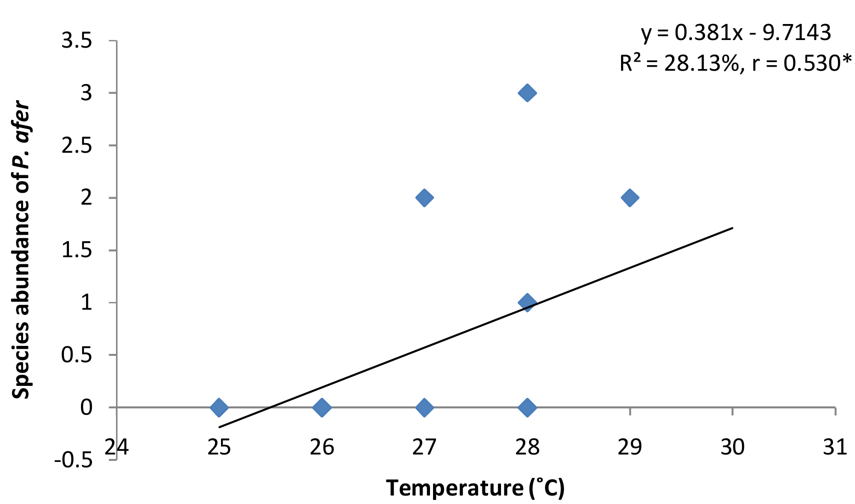

Figure 18: Relationship of species abundance of *P. afer in* Otamiri River with Temperature

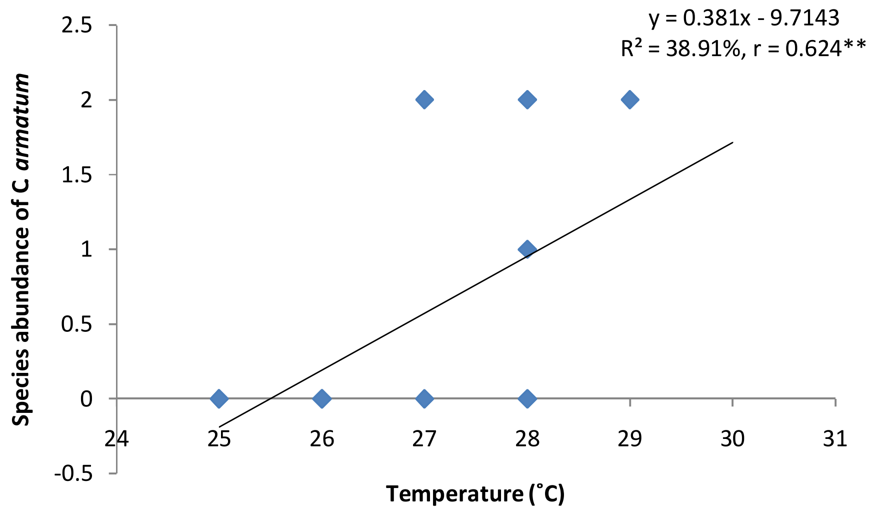

Figure 19: Relationship of species abundance of *C. armatum* in Otamiri River with Temperature

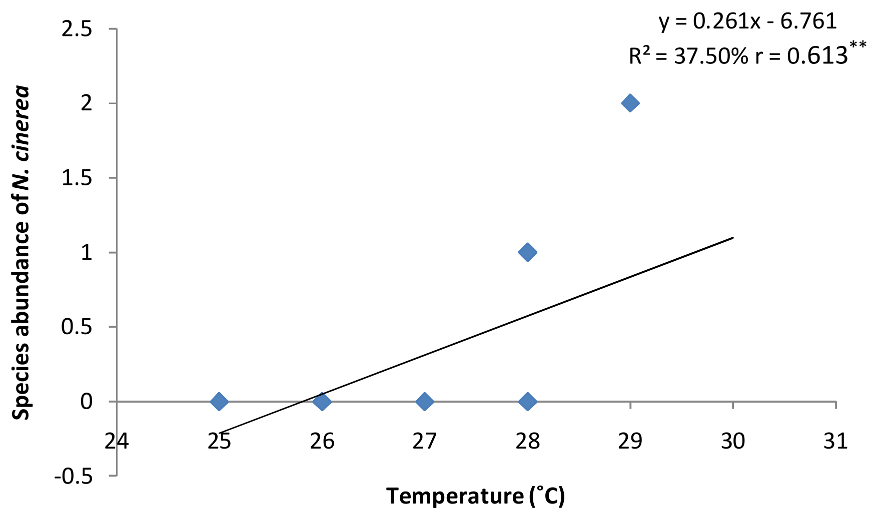

Figure 20: Relationship of species abundance of *N. cinerea* in Otamiri River with Temperature

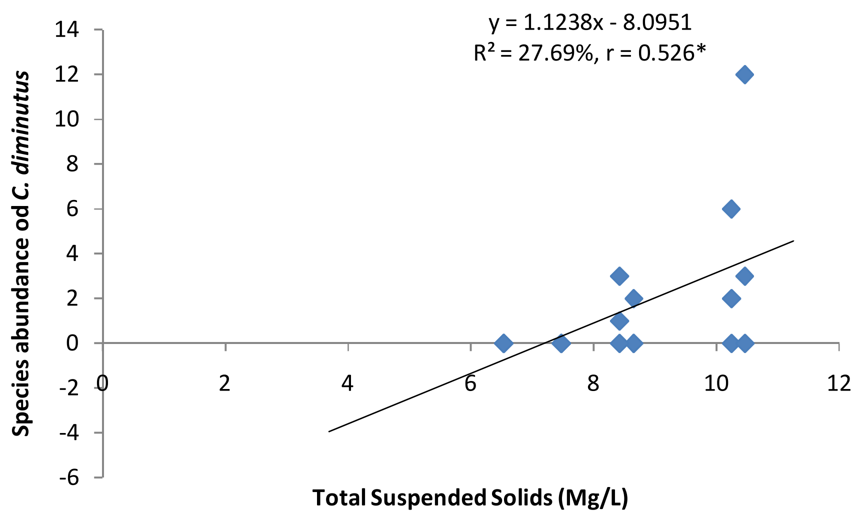

Figure 21: Relationship of species abundance of *C. diminutus* in Otamiri River with TSS

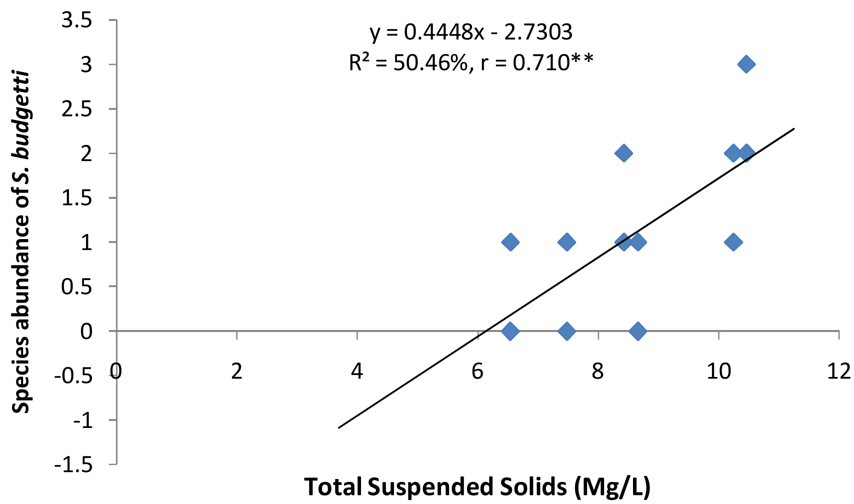

Figure 22: Relationship of species abundance of *S. budgetti in* Otamiri River with TSS

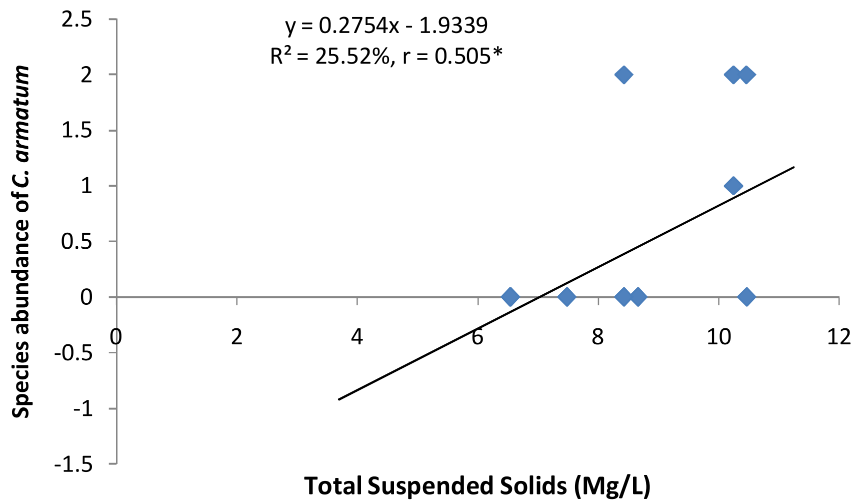

Figure 23: Relationship of species abundance of *C. armatum* in Otamiri River with TSS

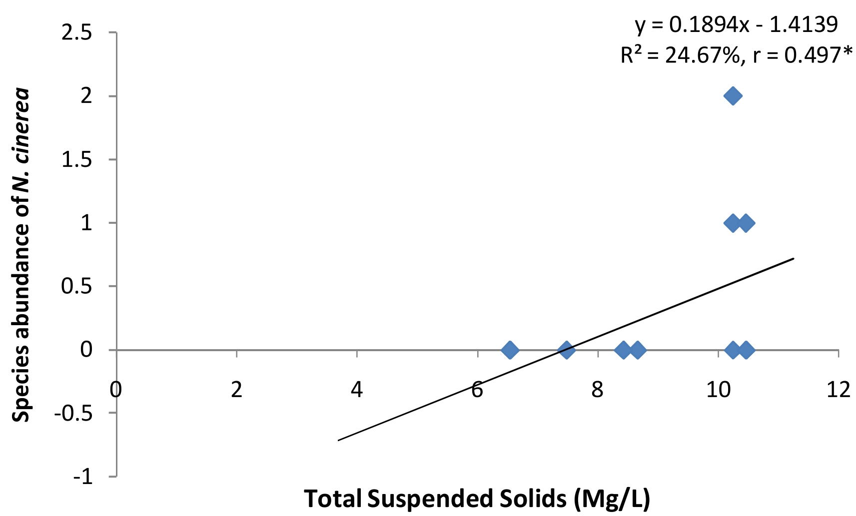

Figure 24: Relationship of species abundance of *N. cinerea* ***in*** Otamiri River with TSS

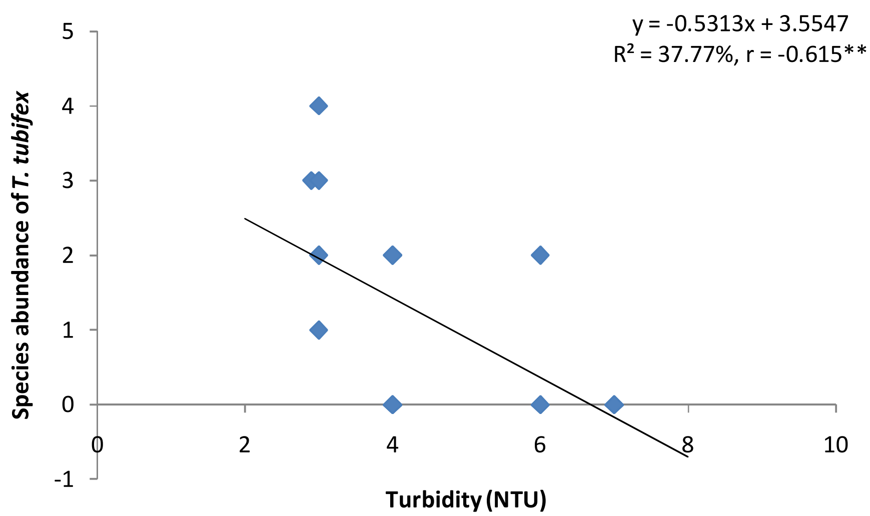

Figure 25: Relationship of species abundance of *T. tubifex* in Otamiri River with Turbidity

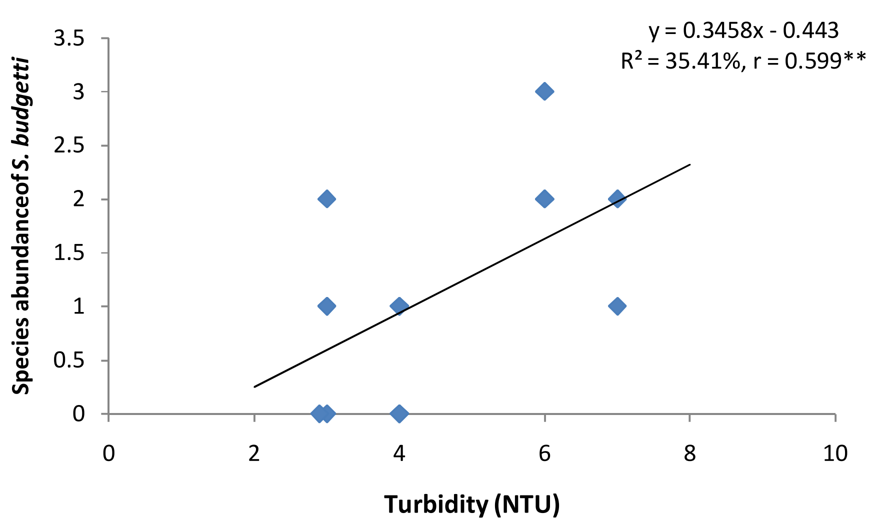

Figure 26: Relationship of species abundance of *S. budgetti* in Otamiri River with Turbidity

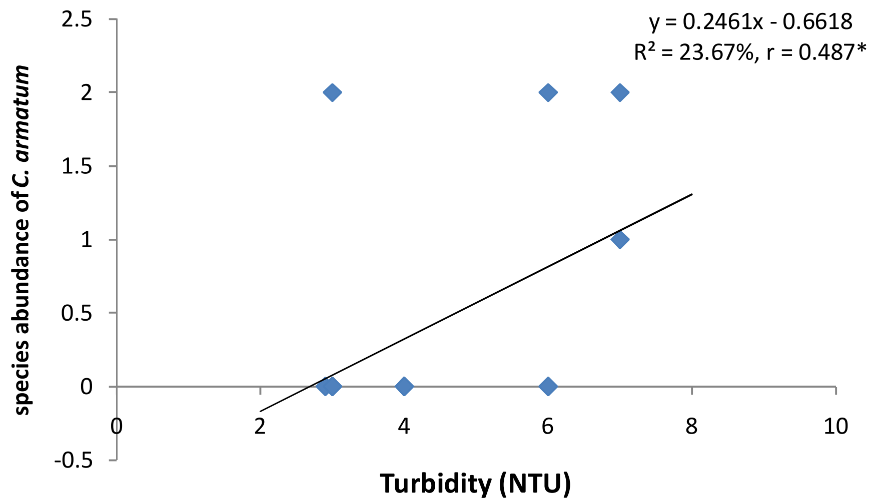

Figure 27: Relationship of species abundance of *C. armatum* in Otamiri River with Turbidity

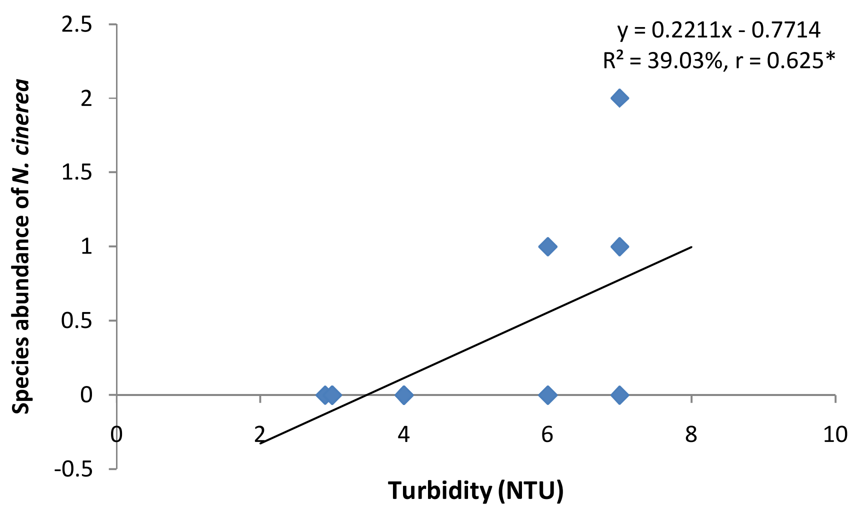

Figure 28: Relationship of species abundance of *N. cinerea* in Otamiri River with Turbidity

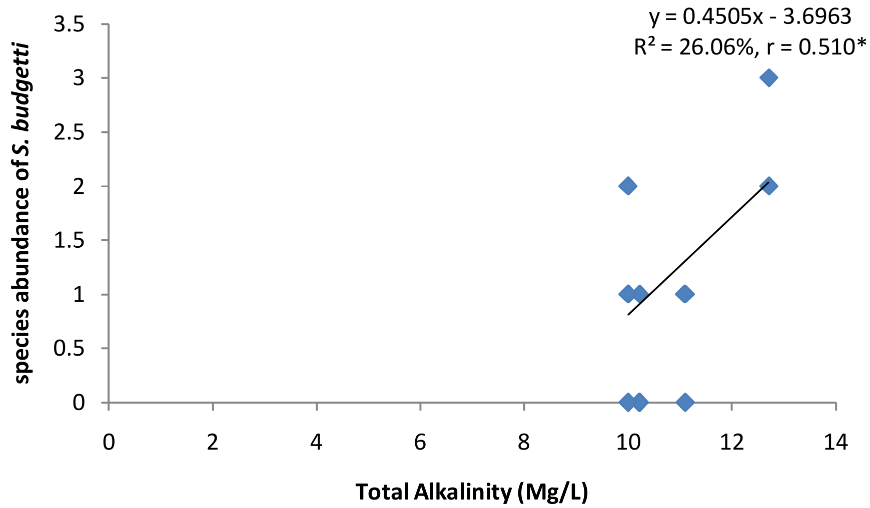

Figure 29: Relationship of species abundance of *S. budgetti* in Otamiri River with Alkalinity

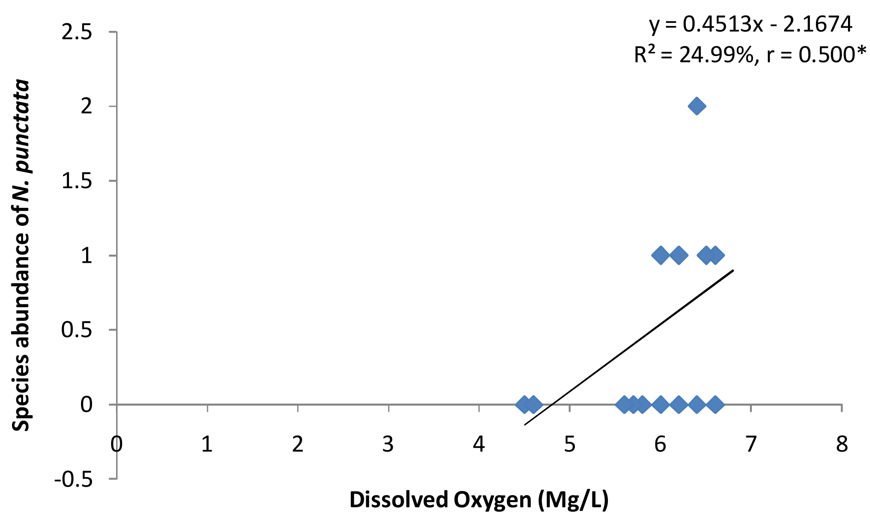

Figure 30: Relationship of species abundance of *N. punctata* in Otamiri River with DO

3.4 The Effect of Season on Physico-chemical Parameters of Otamiri River and Composition of Benthic fauna.

The results of the effect of season on the physico-chemical parameters are presented in Table 13. Temperature of Otamiri River at Stations 1 and 2 of both seasons differed significantly from Station 3 ($P<0.05$). Depth of Otamiri River at Station1 differed significantly from those of other stations during both seasons ($P<0.05$). COD was significant at Station 2 of both seasons whereas not significant at Stations 1 and 3 ($P<0.05$). DO was significant at Stations 1 and 3 ($P>0.05$) but at Station 2, it was not significant ($P>0.05$). pH was significant at Stations 2 and 3.($P<0.05$). BOD, Turbidity, TSS all followed a definite pattern between wet and dry seasons in all sampled stations and all were significant in the 3 stations and in both seasons whereas Alkalinity, Hardness, and TDS in both seasons were not significant ($P>0.05$).

Table 13: Seasonal variations of physico-chemical parameters of Otamiri River

	Stations	Wet	Dry	t-value	*P*
Temperature (^{O}C)	1	25.60±0.18	27.80 ± 0.22	-7.85(15.19)	0.00^{*}
	2	26.80 ± 0.22	27.70 ± 0.29	-2.44(15.02)	0.03*
	3	28.30 ± 0.33	28.70 ± 0.17	-8.94(11.77)	0.38^{ns}
Depth(m)	1	3.31± 0.46	0.61 ± 0.07	5.82(16)	0.00^{*}
	2	2.46 ± 0.63	1.08 ± 0.25	2.03(16)	0.06^{ns}
	3	2.93 ± 0.64	1.89 ± 0.12	1.58(16)	0.13^{ns}
COD(Mg/L)	1	24.99 ± 0.35	25.23 ± 0.34	-0.488(15.09)	0.63^{ns}
	2	23.74 ±0.19	25.38 ± 0.25	-5.30(14.97)	0.00^{*}
	3	25.39± 0.13	25.36 ± 0.12	-0.15(15.99)	0.88^{ns}
BOD(Mg/L)	1	5.81 ± 0.04	5.13 ± 0.12	5.37(16)	0.00^{*}
	2	5.46± 0.07	5.19 ± 0.06	2.85(15.89)	0.01*
	3	5.76± 0.04	5.38 ± 0.11	3.21(16)	0.01^{*}
DO(Mg/L)	1	5.59 ± 0.28	6.23 ± 0.07	-2.21(16)	0.04*
	2	6.08 ± 0.10	6.22 ± 0.07	-1.15(14.06)	0.27^{ns}
	3	5.78 ± 0.04	6.42 ± 0.08	-7.65(11.49)	0.00^{*}
Alkalinity(Mg/L)	1	10.44 ± 0.17	10.90 ± 0.45	-0.92(16)	0.35^{ns}
	2	10.40 ± 0.20	10.52 ± 0.05	-5.65(16)	0.58^{ns}
	3	10.45 ± 0.22	10.83 ± 0.42	-0.82(16)	0.43^{ns}
pH	1	6.70 ± 0.20	6.76 ± 0.03	-0.28(16)	0.79^{ns}
	2	6.21 ± 0.13	6.86 ± 0.02	-4.78(16)	0.00^{*}
	3	6.20 ± 0.15	7.21 ± 0.07	-6.05(16)	0.00*
TDS(Mg/L)	1	319.3 ± 32.60	311.0 ± 5.0	0.25(16)	0.80^{ns}
	2	420.4 ± 25.9	377.7±11.67	1.51(11.13)	0.16^{ns}
	3	379.8 ± 18.37	367.7 ±4.41	0.64(16)	0.53^{ns}
Hardness(Mg/L)	1	0.67 ± 0.06	0.60 ± 0.05	0.86(15.84)	0.41^{ns}
	2	0.53 ± 0.06	0.64 ± 0.04	1.60(14.79)	0.13^{ns}
	3	0.59 ± 0.01	0.62 ± 0.02	-1.76(13.53)	0.10^{ns}
Turbidity(NTU)	1	3.66 ± 0.17	5.33 0.60	-2.68(16)	0.02^{*}
	2	4.00 ± 0.50	6.67 0.33	-4.44(16)	0.00*
	3	4.33 ± 0.33	6.33 0.44	-3.62(14.89)	0.00^{*}
TSS(Mg/L)	1	7.56 ± 0.306	9.71 0.32	-4.83(15.95)	0.00*
	2	7.08 ± 0.09	10.04 0.34	-8.55(16)	0.00^{*}
	3	5.33 ± 0.42	9.54 0.34	-7.81(14.75)	0.00*

COD= Chemical Oxygen Demand, BOD= Biological Oxygen Demand, DO= Dissolved Oxygen, TDS= Total Dissolved Solids, TSS= Total Suspended Solids.

*= Significant difference, ns = No significant difference

CHAPTER FOUR

DISCUSSION AND CONCLUSION

4.1 Species Diversity and Composition of Otamiri River

Total of (13) families of benthic fauna were recorded in Otamiri River. This can be said to be high compared to the (4) families reported by Ogidiaka *et al.,* (2012) in Ogunpa River in Ibadan and the (10) families reported by Adjarho *et al* (2013) in Omna River, Ibadan but close to the (17) families reported by Obot *et al.,* (2014) in Ediene Stream, Akwa Ibom and the 20 families reported by Hart, and Zabbey (2005) in Woji Creek in the upper reaches of Bonny River in the lower Niger Delta. The difference in the Woji Creek may be attributed to the fact that it is a larger and brackish water system. Otamiri River being a freshwater body was dominated by Calroteidae (36.25%) with (1) species; other benthic fauna family had one species each except Mochokidae which recorded two species. The distribution pattern of Calroteidae showed that they were more abundant in Station 3. The dominance of *C. nigrodigitatus* at Station 3 compared to other stations indicated pollution, stress and high level of anthropogenic activities such as dredging in Stations 1 and 2.

Nwankwo and Akinsoji (1992) had attributed the low species abundance and diversity of some sites of a river to the pollution of such sites. The relative abundance of benthic fauna in each station of the present study is a reflection of the level of pollution of each station. Burger and Gochfeld, (2009) related the abundance and diversity of the benthic fauna to the health of the water body. Stations 1 and 2 in Otamiri River recorded relatively lower taxa and this could be attributed to the resultant effect of the bridge construction among other human activities ongoing at these stations.

Anthropogenic activities such as dredging often result in substratum instability and increased siltation. Edokpayi and Nkwoji (2007) had reported in a previous study that suspended silt has the ability of reducing light penetration and primary productivity and could clog the gills of aquatic fauna thereby smothering them. The occurrence of relatively higher taxa and individuals in station 3 may be an indication of lower degree of anthropogenic activities at the station compared to other stations. Overall diversity had been reported to be the product of all dynamic spatial and temporal changes affecting an urban stream community in nigeria(Victor and Ogbeibu 1991). It could also be a reflection of the extent to which the ecosystem has been perturbed by human activity.

The abundance and diversity of benthic fauna are generally affected by the physical and chemical characteristics of water, availability of food and substrate occupation (Odo, *et al*., 2007). In this study, such parameters like temperature, depth, BOD, DO, Alkalinity, turbidity and TSS were observed to have influenced the community composition of Otamiri River. This is in agreement with earlier reports of Ajao and Fagade, (1990a), Edokpayi and Nkwoji, (2007) and Brown and Oyenekan (1998).

4.2 Water Quality Parameters of Otamiri River

The water chemistry of an aquatic ecosystem is dependent on the physical and geological features of its drainage basin (Bishop 1973); Victor and Al-Mahrouqi, (1996). The temporal variations in some of the physical and chemical parameters of the water samples at the study stations during the period of study were negligible. This is in agreement with the observations of Nkwoji *et al.,* (2010) and Ajao and Fagade, (1990).

The temperature of Otamiri River showed monthly fluctuations across stations with Station 3 in the months of June, November and December recording the highest value of 29 ^{0}C. The minimum temperature was recorded in the months of June and July at Station 1. The mean value of temperature recorded was 27.11 ^{0}C. In the present study, water temperature ranged between 25 ^{0}C ï 29 ^{0}C. This finding conforms to earlier works by Okeke and Adinna (2013) in Otamiri River which recorded a mean temperature of 27.4 ^{0}C. Sharma *et al.,* (2012) and Yogesh (2001) also reported similar fluctuations in Narmada River and Dahikhura Reservoir, both in India.

The depth of Otamiri River within the sampled months recorded variations across the stations. This is due to high level of anthropogenic activities including dredging.

COD is the amount of dissolved oxygen required to cause chemical oxidation of the organic materials in water. COD is key indicator of the environmental health of a surface water supply. The chemical oxygen demand of Otamiri River recorded significant differences across the stations and in all the months except in October and December whose values were significantly similar ($p>0.05$). In the present study, the mean COD value of 25.18 mg/L was recorded. This result is in line with earlier works on the river by Akubugwo and Duru (2011) who recorded a mean COD of 28.92±3.32 mg/L. The range is within WHO (2004) recommended permissive limit of 200 mg/L and is suitable for aquatic life. This result disagrees with the works of Odo *et al.,* (2007) who reported a low mean COD value of 4.27 mg/L in Anambra River, Nigeria.

BOD is a fair measure of the amount of biodegradable organic material present in a sample of water. In the present study, the BOD ranged from 4.67 mg/L to 5.87 mg/L with a minimum value (4.67±0.03) at Station 1 in the month of November and a maximum value (5.87±0.33) at Station 3 in the month of June. The mean BOD value recorded in Otamiri River was 5.81 mg/L. This value exceeded WHO recommended value and disagreed with the finding by Akubugwo and Duru (2011) who reported a lower mean BOD value of 2.96±0.05 mg/L for same river. Similar observations were reported by Pathak and Mudgal (2005) and Khanna and Bhutani (2003) in Viela Reservoir and Satikund Pond, India. The high level of BOD in this study, might be attributed to the discharge of pollutants through anthropogenic activities, runoffs, and agricultural fertilizers into Otamiri River.

Dissolved oxygen in natural and waste water depends on the physical, chemical and biological activities in the water body. Dissolved oxygen content plays a vital role in supporting aquatic life and is susceptible to slight environmental changes. DO is an important limnological parameter which indicates the level of water quality an organic pollution causes in the water body (Wetzel and Likens, 2006). In the present study, the concentration of DO in Otamiri River water samples varied from 4.57 mg/L to 6.70 mg/L. The minimum DO value was recorded in the month of June at Station 1 while the maximum value was recorded in the month of October at Station 3. The mean DO value recorded in Otamiri River was 5.33 mg/L. This value disagreed with earlier reports on the river by Umunnakwe and Nnaji (2011) who reported a mean DO value of 2.00 mg/L.

Alkalinity of water is a measure of weak acid present in it and of the cautions balanced against them. The alkalinity value ranged from 9.96 mg/L to 12.7 mg/L. This range is below the permissible limit of 200 mg/L (WHO, 2004) and therefore, does not pose any adverse concern (Ideriah *et al.*, 2010). Low alkalinity is for low production, medium alkalinity is for medium production and high alkalinity is for high production (Olopade, 2013).

The pH is the measure of the concentration of hydrogen ions. It provides the measure of the acidity or alkalinity of a solution. In the present study the observed pH values which ranged from 5.70 to 7.47 showed that the Otamiri River varied from acidic to neutrality. Although low pH values were recorded in this study, they are not detrimental to aquatic life. Adebisi, (1981), King and Ekeh (1990) and Mama and Ado, (2003), attributed variations in pH to evapo-transpiration process, rainfall causing dilution of chemical substances chemical and biological processes in water. The mean pH value of 6.73±0.10 recorded during this study falls within the recommended range of 6.5 ï 8.5 set by the WHO and National Standard for Drinking Water Quality in Nigeria (WHO 2004, NSDWQ 2007). This value is in agreement with the report of Akaahan *et al*., (2015) which reported a mean pH value of 6.63±0.07 in River Benue at Makurdi, Benue State Nigeria. On the contrary, Umunnakwe and Nnaji (2011) reported a mean pH value of 5.23 in Otamiri River and this value disagreed with the value recorded in this study. Narasimha and Benarjee (2013) reported that pH range of 6.0 ï 9.0 is suitable for fish culture and growth. This result also agrees with the findings from this study as the pH obtained in Otamiri river during the study at most sample sites is suitable for the growth of fish community.

The total dissolved solids (TDS) in water consist of inorganic salts and dissolved materials. High values of TDS may lead to change in taste of water. During the present study, the mean TDS value obtained was 391.4 ± 48.51 mg/L. This result falls within WHO recommended value of 1000.00 mg/L and 500.00 mg/L of the National Standard for Drinking Water Quality (WHO, 2004, NSDWQ, 2007). This result conforms to the report of Eneji *et al.,* (2012). The TDS values obtained during the course of this study is suitable for fish culture and growth in Otamiri River.

Total hardness is the parameter of water quality used to describe the effect of dissolved salts (mostly Ca and Mg). It determines the suitability of water for domestic, industrial and drinking purposes. The observation of total hardness reveals that the monthly variation in the water - samples of Otamiri River ranged between 0.32 mg/L to 0.89 mg/L with minimum value at Station 2 in the month of June and maximum value at Station 1 in the month of June. This result agrees with the findings of Sharma and Chowdhary (2011) who reported a mean hardness of 471.16±221.40 mg/L in the Himalayan River, Tawi but disagreed with the findings of Akaahan *et al.*, (2015) who reported a mean hardness of 147.89±111.37 mg/L in River Benue, Makurdi, Benue State, Nigeria.

Turbidity in the water may be due to organic and inorganic constituents. Also, turbidity is often determined and used as surrogate measure of the total suspended solids (Bilotta and Brazier, 2008). During this study, the mean turbidity value obtained was 2.66 ± 0.16 NTU. This value is in line with the recommended standard for turbidity of 5.00 NTU (WHO, 2004, NSDWQ, 2005).

TSS is the sum total of the suspended solid particles and dissolved materials. TSS value ranged from 3.69 mg/L to 11.3 mg/L. Bilotta and Brazier (2008) reported that TSS value in excess of 8.00 mg/L increases the rate of drift of benthic fauna in surface water. Based on the above findings, the TSS concentration of Otamiri River during the course of this study may contribute to the drift of the benthic fauna in the river. The result from this study however disagreed with the findings of Longe and Omole, (2008) in River Illo, Ota Nigeria, who reported higher values of total suspended solids of 620.79±228.45 mg/L. Similarly, Ogunfowokan *et al.,* (2005) reported TSS concentration of 333.33±173.20 mg/L in a stream in South West Nigeria which also disagreed with the value obtained in the present study. TSS concentration between 80 ï 100 mg/L was reported to cause injury to the gills of fish (Fadaeiferd *et al.,* 2012).

4.3 The relationship between water quality parameters and composition of benthic fauna in Otamiri River

The relationship between water quality parameters and composition of benthic fauna of Otamiri River showed both direct and inverse relationships with some parameters. Parameters like COD, pH, TDS and hardness had no relationship with the species composition and abundance. Surface water temperature, depth, BOD, DO, alkalinity, turbidity and TSS had significant relationship with some benthic fauna such as *S. budgetti, C. nigrodigitatus, C. diminutus, L. insest, A. cyanea, P. afer, C. armatum, N. cinerea, C. gariepinus, S. soloni, N. punctata* and *T. tubifex*. The major factor that affects the occurrence and distribution of benthic fauna in lotic and lentic systems include physicochemical variables, the nature of the substrate, (bed material), water current, food availability, flood, drought, vegetation and shade (Hussain and Pandit, 2012). Nevertheless during this present study, COD, pH, TDS and hardness did not correlate significantly with any of the benthic fauna group throughout the study period. The lack of significant correlation between COD, pH, TDS, hardness and benthic fauna during this study may be due to other environmental variables that are interacting with the benthic fauna groups (Akaahan *et al*., 2015).

4.4 The effect of season on physico-chemical parameters of water and composition of benthic organisms

There were seasonal variations in physico-chemical parameters and composition of benthic fauna of Otamiri River. Benthic fauna were recorded in dry season than in wet season. This may be as a result of high rainfall that was observed during the wet season. In Stations 1 and 2, due to sand dredging, the depth has become very deep causing disturbances, stress and also reducing biodiversity. Some parameters like temperature, depth, COD, DO and pH showed significance difference ($P<0.05$) with benthic fauna composition at some stations. BOD, turbidity, TSS, showed great significance at $P<0.05$ between dry and wet seasons. Station 3 showed richness in species composition and has high biodiversity. This may be attributable to un-impacted site, less stress and less anthropogenic activities. This is reflected in the number of individuals recorded in that station. Burger and Gochfeld (2009) related the abundance of benthic fauna to the health of the water body.

4.5 Conclusion

The study revealed that Stations 1 and 2 of Otamiri River were influenced by anthropogenic activities which have influenced the fauna diversity of the area. Anthropogenic activities had caused severe stress to aquatic life in these two stations and had also led to erosion that drained into the river. It is concluded that the river is suitable for drinking having met WHO standards and also suitable for aquatic life with the range of DO recorded.

4.6 Recommendation

It is recommended that proper management of the river should be put in place to preserve its water quality and biodiversity for sustainable development. Government should make laws restricting dredging and sand mine activities in the study area.

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