PHYSICO-CHEMICAL PARAMETERS, PLANKTON AND MACRO-INVERTEBRATES IN CALABAR RIVER AT OKOMITA, CROSS RIVER STATE, NIGERIA

BY

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CERTIFICATION

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DEDICATION

This research work is dedicated to our God and Father, the God of all creation, the only wise God.

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ABSTRACT

Calabar River is an important waterbody in South-south Nigeria that supports a thriving fishery in the surrounding communities. Middle Calabar River, at Okomita area experiences intensive sand mining, effluents and solid wastes input from industries, farmlands, markets, slaughter houses, dumpsites and human settlements. Pollutants from these sources could adversely affect water quality and resident biota. Studies on physico-chemical parameters, plankton and macro-invertebrates have been carried out in Calabar area, downstream of Calabar River but not in Okomita. This study was carried out to investigate the physico-chemical parameters of surface water, diversity, abundance and distribution of plankton and macro-invertebrates in Calabar River at Okomita to ascertain its suitability for aquatic life and domestic uses.

Surface water, plankton and macro-invertebrates sampling were carried out monthly from September, 2014 to August, 2016 at six purposively selected sampling stations. Physico-chemical parameters including temperature, pH, Dissolved Oxygen (DO), hardness, conductivity, turbidity and metals were measured following standard methods. Plankton samples were collected with plankton net (55 µm mesh size). Macro-invertebrate samples were collected by kick sampling and with van-Veen grab (0.6 m^2) and sorted with sieve (0.5 mm mesh size). The biota were identified using standard identification guides. Descriptive statistics, Student's t-test, PCA, Shannon-Wiener's species diversity and Evenness and ANOVA were used to analyse the data at $\alpha_{0.05}$.

Surface water temperature (25.98±0.11^{o}C) and pH (7.84±0.06) were within NESREA and WHO recommended limits for aquatic life and drinking; iron (0.79±0.05 mg/L) and lead (1.12±0.03 mg/L) were higher, while DO (4.72±0.07 mg/L) and conductivity (22.11±0.77 µS/cm) were lower than the recommended limits. Water temperature, pH and turbidity were significantly different within stations and higher in the wet season. Bacillariophyceae (70.5%) dominated the phytoplankton population, while Dinophyceae (1.9%) was least. Rotifers (33.0%) dominated the zooplankton, while protozoans (2.6%) were least abundant. Insects (87.8%) dominated macro-invertebrates assemblage, while bivalves (1.4%) were least abundant. Significantly higher abundance of plankton was recorded in the wet season (phytoplankton, 67.5%; zooplankton, 52.7%), while higher abundance of macro-invertebrates was in the dry season (69.3%). Pollution-indicators were phytoplankton: *Oscillatoria tenuis* (2.4%), *Surirella oblonga* (2.4%) and *Melosira granulata* (2.2%); zooplankton: *Philodina species* (6.9%), *Brachionus forticula* (6.5%) and *Lecane lunaris* (5.6%) and macro-invertebrates: *Enithares species* (34.2%), *Mesovelia furcata* (8.9%) and *Gerris species* (7.2%). Species diversity in all the stations: 0.4–2.89 (phytoplankton), 1.31–1.75 (zooplankton) and 0–2.50 (macro-invertebrates) indicate that the river was moderately polluted. Principal Components 1-4 accounted for 50.1% variations in physico-chemical parameters and biota abundance, and indicated that seasons (wet: -0.80 and dry: 0.80) significantly modulated physico-chemical parameters and biota abundance. The PCA also revealed that hardness (0.66); DO (0.67) and turbidity (-0.69) were principal determinants of plankton (blue-green algae, 0.49; diatoms, -0.59; rotifers, -0.50 and cladocerans, -0.60) and macro-invertebrates (insects, 0.65 and bivalves, 0.65) abundance.

Abundance of pollution indicator biota, low diversity values and deviations of some physico-chemical parameters from recommended levels suggest that Calabar River at Okomita is under pollution stress and not suitable for aquatic life and domestic uses.

Keywords: Water quality, Pollution-indicators, Aquatic biota, Anthropogenic activities, Calabar River.

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CHAPTER ONE
INTRODUCTION

1.1 Background of the study

The biological, physical and chemical characteristics of any aquatic environment define its quality. Primary issues that affect aquatic environments are the decline in quality, the rapid depletion of water supplies, and the loss of biodiversity, and all of these require immediate attention. Freshwater bodies across the globe are the most valuable sources of water for human use; they provide water for domestic and agricultural uses and sometimes, they are dumping grounds for wastes (Adejuwon and Adelekun, 2012; Nnamonu *et al*., 2018; Iloba and Shomule, 2020). Freshwater bodies are also habitats which serve as homes for various plants and animals (Okeke and Adinna, 2013; Appolos *et al*., 2016; Amah-Jerry *et al*., 2017; Vincent *et al*., 2020). Fluctuations in some water quality parameters can affect the quality of life of some species resulting in changes in the community structure and the vulnerable species die leaving behind the most tolerant species. Some species fight for survival and proliferation while others decrease in number (Tyokumbur *et al*., 2002; Okeke and Adinna, 2013; Anago *et al*., 2013; Onyegeme-Okerenta *et al*., 2016; Edori *et al*., 2019).

Rivers are among the most prolific ecosystems on the planet because of the favourable conditions that support a variety of flora and fauna (Appolos *et al*., 2016; Verla *et al*., 2020). Majority of freshwater bodies around the world are becoming less portable and productive due to pollution (May *et al*., 2006; Arimoro, 2009; Amah-Jerry *et al*., 2017; Idowu *et al*., 2020). According to Jaji *et al*. (2007), Yakub and Ugwumba (2009), Osibanjo *et al*. (2011), Anyanwu (2012), and Amusan *et al*. (2018), Refuse, human sewage, and waste water from industrial, residential, and slaughterhouse sources are disposed of in rivers. According to Yinka *et al*. (2019) and Iyama *et al*. (2020), industrial growth has both direct and indirect negative effects on the environment. As a result, there may be an increase in industrial effluents, which, if released into the environment untreated, would pollute the water, sediment, and soil (Edori *et al*., 2019; Ugwumba and Esenowo, 2020). Deterioration and degradation of aquatic environments are top public issues at both national and international levels (Alinnor and Obiji, 2010; Vincent *et al*., 2020).

Anthropogenic discharges into freshwater bodies can reduce transparency and light penetration and these can adversely affect primary, secondary and tertiary productivities (Odiete, 1999; Badejo *et al*., 2017; Edegbene *et al*., 2019). Pollutants significantly affect biodiversity of aquatic ecosystems. Biodiversity losses are found more in aquatic than terrestrial environments (Sala *et al*., 2000; Davies *et al*., 2018). Suspended and precipitated organic matter in water are capable of adhering to pollutants particles by adsorption; these are substances of very low solubility and low degree of degradability (Edori *et al*., 2019). Depending on the physico-chemical and biochemical properties of a substrata, pollutants can persist in sediment over a long period (Adeyemo *et al*., 2008; Edori *et al*., 2019).

Pollutants reduce water quality by rendering water bodies unsuitable for aquatic life and domestic uses (Abowei and Sikoki, 2005; Agboghovwia *et al*., 2018; Ayandiran *et al*., 2018). Domestic sewage, urban runoffs, industrial effluents, and farm wastes are all potential sources of pollution. Among the pollutants are metals which at high concentrations become toxic (Akintujoye *et al*., 2013; Iyama *et al*., 2020). Other sources through which metals can be discharged into the aquatic ecosystems are thermal sources and radioactive wastes (Aderinola *et al*., 2009; Iyama *et al*., 2020). All these modify water and sediment compositions, thus affecting aquatic organisms.

Environmental challenges pertaining to the wellbeing and vitality of aquatic ecosystems are now becoming more prominent in Nigeria. In addition to conventional physical and chemical methodologies, bio-assessment has emerged as a reliable method for determining the impact of humans on aquatic ecosystems (Lydeard *et al*., 2004; Edegbene *et al*., 2020). A more reliable way to measure aquatic conditions is through biological assessment. Biological evaluation determines long-term water quality trends, even though physico-chemical measures are indicators of water quality at the time of sampling (Idowu *et al*., 2020). Species diversity has been the most frequently used parameter for biological assessment of environmental health (Mason, 1991; Singh *et al*., 2013; Akindele *et al*., 2015; Esenowo *et al*., 2017; Edegbene *et al*., 2020).

Plankton provides important source of food to larger aquatic organisms such as fish, crustaceans and molluscs (Thurman, 1997; Ugwumba, 2002; Ugwumba and Ugwumba, 2007; Brraich and Saini, 2015; Odulate *et al*., 2017). All environments of plankton are influenced by the imput of solar energy, narrowing primary production to surface water, and to geographical locations and seasons having abundant solar radiation (Agouru and Audu, 2012; Andem *et al*., 2019). Due to their quick turnover and sensitivity to environmental stressors, phytoplankton are effective indicators of water quality (Akoma and Imoobe, 2009; Effiong *et al*., 2018; Bwala, 2019). The trophic status and organic pollution in aquatic ecosystems are revealed by studies on phytoplankton diversity and abundance.

According to Antai and Joseph (2015) and Agarin *et al*. (2020), phytoplankton is the foundation of the nutrient cycle in any aquatic ecosystem. Being the main producers, they are essential to maintaining the balance between biotic and abiotic components. They are impacted by chemical, physical, and biological factors, which makes them useful tools in monitoring programs and trustworthy indicators of pollution (Adon *et al*., 2012; Essien-Ibok, 2013; Antai and Joseph, 2015; Asiegbu *et al*., 2019). The biological integrity or environmental health of a certain water body can be determined by looking at the abundance, composition, temporal patterns, and spatial dispersal of the aquatic organisms (Effendia *et al*., 2016; Mathias, 2019).
Zooplankton are utilised at the secondary trophic level to assess energy transfer. The distribution and quantity of zooplankton species can alter as a result of changes in primary production (Achionye-Nzeh and Isimaikaiye, 2010; Ikenweiwe *et al*., 2011; Jonah and George 2020). Zooplankton, which feed on phytoplankton and aids in the transformation of plant resources into animal tissues, are the primary sources of nutrition for higher animals like fish, especially their larvae (Akpan, 2015; Kwen *et al*., 2019; Oluwale and Ugwumba, 2019), and are also key components of the food chain for lower organisms like bacteria. Their population reflects the nature of any aquatic ecosystem (Okogwu, 2010; Ikhuoriah *et al*., 2015; Enerosisor *et al*., 2020).

Zooplankton is distributed worldwide, the species composition and community structure are sensitive to alterations in aquatic conditions, enrichment of nurients and different degrees of pollution (Jha and Barrat, 2003; Pramod *et al*., 2011; Erhenhi and Omoigberale, 2019). Therefore, they give several importance as indicators of river qualities. Zooplankton studies are necessary in water quality research as they are recognised as indicators of aquatic pollution (Aoyagui and Bonecker, 2004; Abowei and Sikoki, 2005; Ikhuoriah *et al*., 2015; Rao, 2017; Enerosisor *et al*., 2020; Balogun and Ajani, 2021).

Sediments mixing, and oxygen flow into sediments, mineralization, the recycling of biological materials and determining the water quality are all essential functions performed by macro-invertebrates in every aquatic environment (George *et al*., 2009; Iyagbaye *et al*., 2017; Edegbene *et al*., 2019). Macro-invertebrates were discovered to be excellent markers of episodic and the long-term results of anthropogenic activities, using their presence or absence, and their abundance in any aquatic environment (Rosenberg and Resh, 1998; Okorafor *et al*., 2012; Hovhannisyan and Shahnazaryan, 2016; Anyanwu *et al*., 2019). Macro-invertebrates assemblages is one of the indices that have proven to be useful measure for the health of rivers and are therefore used globally for river water quality studies (Omoigberale and Ogbeibu, 2010; Bonjoru *et al*., 2020).

Macro-invertebrates, like the other biota, are significant bio-indicators that provide a more thorough insight of the conditions of various aquatic environments than do physical, chemical, and microbiological data, which only reveal short-term changes (Ravera, 2000; Iyagbaye *et al*., 2017). Utilization of macro-invertebrates is the most widely used biological technique in evaluating freshwater bodies that receive residential and industrial effluents. Changes in water quality can have adverse impacts on species composition, abundance and diversity of macro-invertebrates (Imevbore, 1967; Ogidiaka *et al*., 2012; Amusan *et al*., 2018). Unlike fish, many macro-invertebrates may not move about much, and may not be able to move away from the effect of pollutants that reduce sediment and the quality of water. Thus, macro-invertebrates can give dependable information on stream and river water quality. Their long life cycle enable research conducted by scholars to determine any changes in environmental conditions (Edegbene *et al*., 2020).

The Calabar River is a significant river in southern Nigeria and is home to a variety of aquatic life. The river at Okomita in Cross River State provides a daily source of fish and edible macro-invertebrates such as prawns, bivalves, aquatic snails and crustaceans to the inhabitants of Okomita. The residents use bamboo traps to catch the macro-invertebrates. Bivalves and the snails are sometimes handpicked along the shorelines of the river at Okomita. The river is also used for bathing, swimming, washing of clothes (laundry), timbers transportation, refuse dumping and sand mining which could be potential sources of contamination, pollution and environmental degradation. Other anthropogenic activities, such as quarrying, rubber (latex) processing, palm oil processing, and butchering of animals also take place along Calabar River bank at Okomita. The proliferation of commercial establishments, coupled with indiscriminate dumping of untreated domestic and industrial wastes along the river banks could contaminate or pollute the river and adversely affect the resident biota.

1.2 Statement of the problem

Farming, refuse dumping, quarrying, automobile repair, butchering of animals and exploitation for products such as rubber (latex), palm oil processing and timber logging take place along Calabar River and its banks at Okomita. Effluents and solid wastes from industries, farmlands, Okomita Market, slaughter houses, dumpsites, rubber and oil palm plantations and human settlements around the area are directly discharged into the river. The river is also used for bathing, washing, timber transportation and sand mining. All these could be potential sources of contamination and pollution and are capable of adversely affecting the chemical and physical characteristics, including the composition and abundance of organisms in Calabar River at Okomita.

1.3 Justification of the study

There are many studies on the limnology of Nigerian freshwater bodies especially in the Niger Delta area. These include: Okogwu and Ugwumba (2013) in two tropical rivers, southeast Nigeria; Eyo *et al*. (2013) and Antai and Joseph (2015) in Great Kwa River, Calabar; Akpan (2015) in the Cross River Estuary, Southsouth Nigeria; Andem *et al*. (2019) in Idundu River, Southeastern Nigeria; Job and Bette (2020) in the Cross River System, Itu, Southern Nigeria; George *et al*. (2020) in River Etim Ekpo, Niger Delta to mention a few.

Studies on physico-chemical parameters, plankton and macro-invertebrates have been carried out in Calabar area of Calabar River such as Uttah *et al*. (2008); Okogwu and Ugwumba (2013); Andem *et al*. (2013); Andem *et al*. (2014); George and Antai (2015) and Ada and Job (2018), but similar work has not been done in Okomita area of the river. Similarly, studies on the impacts of bathing, washing, timber transportation and sand mining and effluents and solid wastes from industries, farmlands, Okomita Market, slaughter houses, dumpsites, rubber and oil palm plantations and human settlements on the physico-chemical parameters, plankton and macro-invertebrates of Calabar River have not been carried out at the Okomita area in the middle course of the river. Therefore, it is essential to investigate the physico-chemical characteristics, macro-invertebrates and plankton of Calabar River at Okomita. This will provide useful information for preservation of the water quality and resident biota of the area.

1.4 The aim of the study

The aim of the study was to investigate the physico-chemical parameters of surface water, diversity, abundance and distribution of plankton and macro-invertebrates from Calabar River at Okomita in Cross River State in order to ascertain the condition of the river during the study period.

1.5 The objectives of the study

The objectives of the study were to determine:

i. The surface water physico-chemical characteristics of Calabar River at Okomita.

ii. Spatial and temporal variations in the river's physico-chemical characteristics.

iii. Composition, abundance, distribution and diversity indices of plankton and macro-invertebrates in the river.

iv. Spatial and temporal variations in composition, abundance, distribution and diversity of the plankton and macro-invertebrates in the study area.

v. The relationships between physico-chemical parameters with plankton and macro-invertebrates abundance of the river.

CHAPTER TWO

LITERATURE REVIEW

2.1 Physico-chemical parameters

The survival of aquatic life depends on water quality characteristics. When the parameters exceed the threshold level, they become capable of negatively affecting both the nature and condition of the aquatic system and aquatic life. Significant chemical and physical elements affecting the aquatic environments include: hardness, alkalinity, temperature, pH, conductivity, Dissolved Oxygen (DO), Total Suspended Solids (TSD), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), and conductivity (Abowei and George, 2009; Iyama *et al*., 2017; Talabi *et al*., 2017; Popoola *et al*., 2019).

Concentration of DO is under the control of water temperature and biological or chemical processes occurring in the aquatic ecosystem (Edori *et al*., 2019). A river ecosystem with rapid rates of respiration and organic decay has DO values lower than a river ecosystem where photosynthesis occurs at a high rate (Edori *et al*., 2019). Polluted water with high level of organic matter can utilize high amount of DO during aerobic biological degradation which can reduce DO, reduce the quality of water, and adversely affect aquatic lives (Idowu *et al*., 2020). The amount of DO affects the growth, distribution, survival, behaviour and the physiology of aquatic organisms (Talabi *et al*., 2017; Toni *et al*., 2017; Mohammed *et al*., 2021).

Aquatic organisms have tolerant limit to water temperature which can affect their distribution. Most aquatic organisms can survive within a temperature of $< 30^{o}C$ (Akinfolarin *et al*., 2020). River waters show little thermal stratification due to the fact that turbulent flow ensures that heat is distributed equally (Adebisi, 1981; Arimieri *et al*., 2014; Akinfolarin *et al*., 2020). Water temperature impacts the rate of chemical processes and has an influence on reproduction and immunity of aquatic species (Idowu *et al*. 2020). According to the authors, extreme temperature fluctuations can be fatal to all aquatic life.

Water pH is crucial for determining the water quality because it influences various chemical processes, like metal toxicity and solubility (Fakayode, 2005; Edori *et al*., 2019). Water pH level for optimal biological productivity is between 7 and 8.5 while pH value below 4 is harmful to water-based life (Ayoade *et al*., 2019). According to Seiyeboh *et al*. (2016), changes in pH can be caused by industrial pollution, photosynthesis, or algal respiration. The solubility of many toxic and nutritious chemical compounds is influenced by the acidity levels of river water, which has an impact on how readily available these components are to aquatic species (Talabi *et al*., 2017).

Water hardness measures the level of magnesium and calcium compounds in water, particularly calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) in water. The concentration of these elements (magnesium and calcium) below threshold limit in water enables the water to react with soap and produce lather. More soap is needed for hard water to produce lather. Water is generally considered as soft when the calcium carbonate level is below 60 mg/L; levels between 120 – 180 mg/L is considered hard and levels above 180 mg/L is considered as very hard water (McGowan, 2000). Seepage of effluents and domestic wastes can cause high concentrations of calcium and magnesium (Ca^{2+} and Mg^{2+}) ions in river water (Talabi *et al*., 2017).

Evaluation of water quality is vital for human life and improvement. This is due to the fact that lakes, rivers, and reservoirs are utilized for domestic, commercial, and agricultural needs in addition to fish production. Aquatic ecosystem dynamics are influenced by the characteristics of water (Kolo and Oladimeji, 2004). Understanding the variables that contribute to the organism's continuous existence and finding out the causes of reduction and extinction of species is the ultimate goal of limnology (Ayoade *et al*., 2019). The dynamics of water quality may also exhibit intricate patterns and variations that depend on a variety of unpredictable causes. Some of the factors might be anthropogenic, hydrological and meteorological (Ayandiran, *et al*., 2018).

Surplus nutrients mainly phosphate, sulphate and nitrates are categorised as pollutants in wastes water (Talabi *et al*., 2017). Super phosphate fertilizer that is washed from the soil and compounds used to enhance the effectiveness of detergents are two sources of a significant amount of phosphate entering rivers and lakes (Edori *et al*., 2020). Because of lake eutrophication and the subsequent algal bloom, phosphate is regarded as a pollutant (Edori *et al*., 2020). Goldman and Horne (1983) and Odeyemi *et al*. (2018) reported that the main inputs of phosphorus into freshwater system are from storm surface water runoffs and precipitation. According to the authors under reference, Particles eroded from steep slopes onto which phosphates had been adsorbed are the cause of significant phosphorus fluxes. Domestic, industrial and agricultural waters are also main sources of phosphate, and phosphate containing detergents commonly contribute to a significant part of phosphate contained in domestic sewage. Unlike carbon dioxide, hydrogen, oxygen and nitrogen, phosphorus is not required for growth in large quantities although it is one of the most common limiting elements on land and in freshwaters (Talabi *et al*., 2017).

It is well established that water is necessary for both aquatic and terrestrial life in order to support movement, feeding, and to maintain body functions (Sikoki *et al*., 2008; Edori *et al*., 2020). The physico-chemical characteristics of water can consequently have a direct or indirect impact on aquatic life. Due to its physical characteristics, including surface tension and viscosity, water flows from a high altitude to a lower one. Such flow might transport significant volumes of suspended materials into bodies of water which will increase turbidity and reduce light penetration; thereby affecting their ability to sustain life of both plant and animal. Locations where the water current is slow, the suspended contaminants sink to the bottom and have a negative impact on macro-invertebrates and fish (Ekeh and Sikoki, 2003; Sikoki and Veen, 2004; Edward and Ugwumba, 2010; Esenowo and Ugwumba, 2010; Yakub and Ugwumba 2010; Adeogun *et al*., 2012).

The majority of pollutants are dumped in water bodies around the world, particularly the effluents from nearby industry. These industrial effluents significantly harm water bodies because of their capacity to alter The chemical and physical characteristics of the receiving water (Edori *et al*., 2019). The first effect of waste is degradation which is visible in the composition, diversity, and abundance of aquatic life. Frequently, water bodies quickly assimilate waste items they acquire without significantly degrading some quality standards. The extent to which this occurs is referred to as the water body's assimilative capacity (Adekunle and Eniola, 2008). Chemical elements found in water affect the biological activities that result in the inter-conversion of organic material of energy production and ultimately reduction of aquatic resources such as fishes and other biological components found in the aquatic ecosystems.

High conductivity and temperature as well as local availability of oxygen enhance blooms of zooplankton, which can easily be observed at the water edge (Ogbuagu *et al*., 2011; Odeyemi *et al*., 2018). Usoro *et al*. (2013) attributed the high conductivity of the Ikoli River, Niger Delta water and sediment to salt water intrusion from the Atlantic Ocean, demonstrating that the physico-chemical conditions in the water-sediment complex have a significant impact on the geochemical reactions that take place in the water and sediment column. Salts dissolve easily in water, especially at high temperature, leading to increase in electrical conductivity (Talabi *et al*., 20017). Electrical conductivity can be measured by electrical potential of ions in solution which on the other hand depends on available concentrations of charges as well as their mobility. The mobility of ions depends on viscosity which also depends on temperature (Talabi *et al*., 20017). Usoro *et al*. (2013), reported that, the high levels of cations in Ikoli River demonstrates how sensitive the river is to the introduction of chemical pollutants. Low water flow, municipal effluents, industrial discharges, and other anthropogenic factors can also contribute to poor water quality (Ekiye and Zejiao, 2010; Adewoyin and Okoh, 2020).

Freshwater is essential finite resource for industry, agriculture and human existence. Sustainable development is impossible without sufficient supplies of high-quality freshwater (Kumar, 1997; Gbarakoro *et al*., 2020). Over pumping of aquifers, discharge of toxic chemicals and water bodies contamination with substances that stimulate algal growth are some of the main causes of deterioration of water quality (Adakole and Annune, 2003; Chandan *et al*., 2017; Ugbeyide and Ugwumba, 2021). Another source of contaminants is the well-known phenomena of heavy metal discharges from smelting, mining, and industrial manufacture that directly contaminate surface water (Rajiv *et al*., 2012; Titilawo *et al*., 2019; Ugbeyide and Ugwumba, 2021). Water is essential for industrial, domestic and agricultural purposes, and provides adequate environments for aquatic biota especially fish which serves as a source of vital protein. Rivers provide significant social and economic benefits and are significant to people all over the world on a cultural and aesthetic level especially in tourism and recreation (Kumar *et al*., 2011; Adewuyi *et al*., 2017; Ayoade and Aderogba, 2020).

Agricultural practices contribute to the input of biological chemicals (both inorganic and organic), radiological and physical pollutants into the aquatic ecosystems (Mugagga and Nabaasa, 2016; Iloba and Shomule, 2020). The physical, chemical, biological and radiological pollutants include commercial and industrial solvents, acid salts and heavy metals, pesticides, sediments, plant nutrients, herbicides, decaying animals, radioactive materials, vegetable matter and living microbes like viruses, bacteria, and algae (Vollenwider, 1998; Seiyaboh *et al*., 2016; Ogamba *et al*., 2017; Aghoghovwia *et al*., 2018; Kigigha *et al*., 2018; Ugbeyide and Ugwumba, 2021). These contaminants could give water an unpleasant odour, taste, colour or affect turbidity, hardness, corrosiveness and staining or frothing (Vollenwider, 1998; Aghoghovwia *et al*., 2018). Water quality is a reflection of how the water's composition has been impacted by both natural and human causes, expressed in quantifiable amounts and related to intended water use (Iyama *et al*., 2017, 2020). Asuquo *et al*. (1999), stated that to lessen consequences of human societies on natural waters, there should be regular and comprehensive monitoring regime. The authors further highlighted that monitoring water resources can aid with decision-making that will preserve natural regions and enhance quality of life by quantifying water quality, identifying impairments, and identifying problems.

Kabir *et al*. (2002) reported that total dissolved solids are primarily used to illustrate the presence of various chemical compounds, such as nitrite, ammonia, nitrate, phosphate, certain acids, alkaline, sulphate, and metallic ions. These consist of dissolved and colloidal particles in water. When taking into account the bioavailability and mobility of pollutants, suspended solids and turbidity are the major parameters; clay and silt particles, plankton and organic matter in river water can influence turbidity (Seiyeboh *et al*., 2016; Talabi et a., 2017). Talabi *et al*. (2017), observed that mobility of contaminants was high in the wet season as a resultt of high turbidity.

Monitoring of surface water in Nigeria revealed that the major sources of inorganic and organic wastes into our streams and rivers are agricultural activities, industrialization and urbanization (Taiwo *et al*., 2012; Edori *et al*., 2020; Job and Bette, 2020). Wastes generated from these sources are indiscriminately dumped into the water bodies (Adakole and Annune, 2003; Yakub, 2004; Andem *et al*., 2019; George *et al*., 2020). Indiscriminate disposal of wastes into water bodies has the potential to raise water quality parameters like nutrients, organic matter, heavy metals, oil and soluble ions, as well as organic compounds like pesticides and poly-nuclear aromatic hydrocarbons (Iyama *et al*., 2020). This pollution affects both inland and coastal water bodies (Iyama *et al*., 2020). Duru *et al*. (2018) reported that organic wastes were the major factors responsible for the deterioration of Woji Creek water. Poor farming practices, poor environmental policies, climate change effects, sand mining, industrialisation, urbanisation, transportation, indiscriminate waste disposal causing river bank degradation have severely affected aquatic lives and have led to a decrease in biological activities in rivers (Dimowo, 2013a; Duru *et al*., 2018; Tesi *et al*., 2018).

2.2 Phytoplankton

Phytoplankton are one of the utmost significant biotic components that affect an aquatic ecosystem's performance, including food chain, energy flow, matter cycling and food web (Sinha and Islam, 2002; Aoyagui and Bonecker, 2004; Effiong *et al*., 2018). The ecologically vital aquatic living forms known as phytoplankton live in a variety of aquatic habitats. They are indeed the basic level of life in the aquatic environment. These diverse organisms represent the first step of conversion of light, carbon dioxide and nutrients through photosynthesis into sugars (providing energy used for growth in organisms) and oxygen as a by-product. Furthermore, most aquatic organisms rely on phytoplankton as a food source especially zooplankton.

Since they are tiny, photosynthesising creatures, phytoplankton live in the upper sunlight layer of almost all bodies of water. Thus, a large portion of the oxygen found in aquatic environments is provided by phytoplankton (Effiong and Inyang, 2016; Adeniyi and Akinwole, 2017). They are responsible for half of the planet's total photosynthetic activity (Eni *et al*., 2012; Eyo *et al*., 2013). Most freshwater and oceanic food webs depend on their cumulative ability to fix carbon molecules with energy (through primary production); chemosynthesis is a significant exception (Steinacher et. al, 2010; Adelakun *et al*., 2016). The level of nitrate and phosphate in the aquatic environment as well as their bioavailability affect the amount of phytoplankton, which is connected to aquatic animals in the food chain; the increase in nutrient concentrations increases primary productivity (USEPA, 1986; Iloba and Ikomi, 2018; Dirisu *et al*., 2019).

The quantity of plankton in every water body affects its productivity because generally speaking, they remain the main producers (primary and secondary). This is because the composition, distribution, the quantity and species diversity of plankton is employed to examine the biological integrity of a body of water (Rose *et al.,* 2021). Low phytoplankton composition and diversity were found in a research by Eyo *et al*. (2013) based on the nature and abundance of phytoplankton of the Great Kwa River, southeast Nigeria. The low number of phytoplankton was linked to the contaminated state of the water as a result of anthropogenic activities carried out along the river shores. Another study on phytoplankton carried out in polluted estuarine creek in Lagos State, Nigeria revealed four taxonomic groups in which Bacillariophyteae was highest in abundance and Dinophyteae the least (Onyema, 2007).

In the Lagos Lagoon in Southwest Nigeria, Ugwumba and Esenowo (2020) investigated the effects of human activity on plankton and macro-invertebrates assemblage. Their research showed that diatoms, particularly the pennate types, predominated the phytoplankton population. The authors attributed the abundance of diatoms to the fact that they are the most noticeable phytoplankton representatives in rivers, lakes and sea. Green algae: *Spirogyra* spp. and *S. africana,* as well as Blue-green algae: *Oscillatoria tenius* and *Microcystis flos-aquae* were discovered to be pollution indicator species in the phytoplankton, in light of the authors findings, indicating that the area of study was vulnerable to pollution. Esenowo *et al*. (2017), in the Nwaniba River in south-south Nigeria, found reduced proportion of species of *Navicula* and *Anabaena*, which suggested a mild amount of organic pollution. According to the authors, the reduced percentages of *Navicula* and *Anabaena* species abundance was a blatant sign that the river was experiencing a gradual pollution stress due to anthropogenic activities like waste water discharge from bathing, saw-milling and laundry, which might have a serious negative impact on the water characteristics.

A research carried out in Adiabo River, southeast Nigeria showed a high productivity of phytoplankton in the river (Eni *et al*., 2012). In their research on how certain water quality parameters affect phytoplankton diversity and abundance in the River Chepkoilel in Eldoret, Kenya, Akunga and Kembenya (2014) found that *Anabaena cirnalis* was the river's most prevalent phytoplankton species and the least abundant was *Schroidera setigera*. They observed that the phytoplankton in the river Chepkoilel were sensitive to alterations in the physico-chemical composition of the river.

In a tropical reservoir in southwest Nigeria, Ayoade and Aderogba (2020) investigated the regional and temporal distribution of plankton. According to their research, a significant portion of the phytoplankton community in the Awba Reservoir, University of Ibadan was composed of non-motile green algae with *Coelastrum chordati* and *Pediastum simplex* being most abundant. Dominating species from the Cyanophyceae (*Anabaena, Aphanocapsa, Microcystis*), the Chlorophyceae, and the Euglenophyceae (*Euglena acus*) encountered in the study were typical of mesotrophic and eutrophic lakes. The authors ascribed the rise in species to the ecosystem's high nutrient concentration. The less abundant of green algae, late in the wet season, was related to thermal stratification of Awba Reservoir surface water at the time of the study.

Bwala (2019) investigated the phytoplankton abundance in Maiduguri Metropolitan Area, Borno State, in the Rivers Nggada and Nggada-Bul. The author reported that phosphate acted as a restricting parameter and combined with nitrite (nitrogen), aided phytoplankton's development, growth, and abundance. The author also found out that where sulphate concentrations were high, phytoplankton abundance was low despite substantial influxes of phosphate and nitrite (eutrophication). Only one class, the Chlorophyceae, was found in locations with high sulfate concentrations, suggesting that these areas were poisonous for phytoplankton.

The lower River Niger at Agenebode was investigated between April and October 2015, and the high diversity and abundance of phytoplankton in those areas revealed good water quality and, consequently, sustainable fish production (Adeniyi and Akinwole, 2017). According to the authors, water quality that is closely connected to sustainable fish production is dependent on algae quality in any aquatic ecosystem. Hence in the time of the study, the lower Niger River at Agenebode was described as having a high primary productivity and rich in phytoplankton composition.

In Idundu River, Andem *et al*. (2019) underwent a bio-indicator-based community evaluation to examine plankton reactions to fluctuating water quality in southeast Nigeria. The most prevalent phytoplankton was Bacillariophyceae. Diverse human activities, including fishing, heavy industrial dredging and bathing at various sampling locations, had a significant impact on the distribution of plankton. Plankton abundance was significantly influenced by physico-chemical variables. The ecological diversity indices, such as the Margalef, Shannon Wiener, and equitability indices, demonstrated a favourable and healthy aquatic ecosystem. High equitability indices also indicated a favorable and healthy aquatic environment and even distribution of the plankton.

Agarin *et al*. (2020) in their work on the distribution of phytoplankton in Tin Can Island Creek of the Lagos Lagoon and the impact of fluctuating water quality reported that water parameters varied somewhat across all of the stations, and that the fluctuations had impact on the population of phytoplankton. Because there were numerous *Microcystis aeruginosa Kutzing*, the blue-green algae were numerically more abundant. Chlorophyll a had a low value. The authors attributed the low population of the other phytoplankton to fluctuations in the physico-chemical characteristics of the aquatic body which may have affected their distribution patterns. According to the authors, the other phytoplankton species had a hard time surviving due to the Creek's eutrophication and loss in photosynthetic depth, which changed the phytoplankton community species composition.

2.3 Zooplankton

Studies on zooplankton distribution and occurrence have been carried out extensively in Nigeria and other tropical waters. Notable among these are the works of Oronsaye and Egborge (1996); Iloba (2002); Ajah *et al*. (2005); Ekwu and Sikoki (2005); Job and Asuquo (2009); Offem *et al*. (2009); Okogwu (2010); Kumar *et al*. (2011); Okogwu *et al*. (2012); Davies and Ugwumba (2013); Dimowo (2013b); Arazu and Ogbeibu (2017); Olaniyan *et al*. (2018); Adedeji *et al*. (2019); Osaro and Osasele (2019); Job *et al*. (2019); Ayoade and Aderegba (2020); Jonah and George (2020); Obot *et al*. (2020) and Enerosisor *et al*. (2020). However, studies on the zooplankton of Calabar River has not been carried out in Okomita area.

Any aquatic ecosystem's fisheries and general public health may be significantly impacted by the zooplankton species composition, distribution, abundance, and diversity in that ecosystem (Jafari *et al*., 2011; Obot *et al*., 2020). Zooplankton respond to a variety of perturbations, including chemical compound releases. A study on the species diversity and distribution of zooplankton by Ekwu and Sikoki (2005) in the downstream of the Cross River Estuary showed that of the eleven phyla of zooplankton identified, the crustacean subclass Copepoda showed the highest abundance. It was also observed in their investigation that copepods were more in areas of high salinity and this supported earlier evidence of Oronsaye and Egborge (1996). Rotifers which were represented in nine taxa have been reported to prefer freshwater (Ovie, 1993; Iloba, 2002; Adedeji *et al*., 2019). Ctenophores had very low dominance hence were regarded as rare species. High species diversity was attributed to high productivity of the area which corroborated the report of Moses (2000).

Okogwu (2010) carried out a research on variations in the composition and abundance of zooplankton species by season in the floodplain of Ehoma Lake, Cross River State. The author ascribed a number of circumstances, including low water temperature, high nutritional condition, food availability, and egg hatching as contributed to the predominance of cladocerans during the wet season. Flood water was turbulent, which contributed to the low rotifer abundance throughout the wet season. Since 0.68 to 1.28 was the range of Shannon-Weiner diversity index and the values did not significantly change between seasons, it is possible that Ehoma Lake was not seriously threatened by pollution during the study period due to its stable physico-chemical condition. In two shallow tropical lakes (Ehoma and Iyieke) in the Cross River floodplain, Okogwu *et al*. (2012) conducted study on seasonal changes in the amount and biomass of micro-crustaceans in response to environmental variables. The authors explained that higher diversity and abundance of crustaceans during the wet months were because of homogenization within the surface water columns caused by flood water, which in turn caused the distribution of species among the various water columns. The dry season's low cladoceran variety and abundance were associated with unfavourable climatic factors such as high temperatures, poor transparency, and rising acidity.

Studies on diversity of zooplankton, and dynamics of limnological features of Cross River System by Offem *et al*. (2009) revealed that zooplankton occurrence in the river was probably affected by physico-chemical parameters. The investigation of the zooplankton population in Awba Reservoir, Ibadan affected by water hyacinth infestation carried out by Uka and Chukwuka (2007) identified 15 species. Rotifera was dominant followed by Cladocera. The least in abundance was Copepoda. Low abundance of zooplankton in the hyacinth infested area of Cross River System was observed. The low abundance of zooplankton observed was attributed to formation of a dense mat of water hyacinth on the water surface, thus reducing dissolved oxygen concentration in the water. Aoyagui and Bonecker (2004), reported that pH, dissolved oxygen, and conductivity had the greatest effect on zooplankton.

Job and Asuquo (2009), in their study on the Chaetognatha species distribution and abundance in the Cross River Estuary, Nigeria noted that, there was no appreciable spatial variation in species richness during their period of study. The reason for this was reported to be possibly associated with similarity of environmental conditions at the three stations that were sampled. According to Siokou-Frangou *et al*. (1998), Marcus (2004), Tse *et al*. (2007), and Job *et al*. (2019), the ability of individual zooplankton species to adapt to the environment influences the abundance of those species. The authors concluded that species diversity and species evenness varied only slightly during the study due to similar environmental conditions over spatial scales in the study area.

Sharma (1992), Omoregie (2017), Friday and Wokoma (2017) and Kwen *et al*. (2019) observed that dominance index of zooplankton dropped in heavily polluted waters. According to Kamat (2000) and Gaikwad *et al*. (2008), plankton can develop at water temperatures between 13.5 and 32.0^{o}C. The pH values of 6.0 to 8.5 indicate medium productivity, a pH range of 6.0 to 8.5 implies intermediate productivity, more than 8.5 extremely productive, and less than 6.0 poor productivity for zooplankton, according to Kurbatova (2005) and Kwen *et al*. (2019). Gaikwad *et al*. (2008), reported that reduction in electrical conductivity and alkalinity can reduce zooplankton population. A high value of alkalinity was found to be correlated with a high planktonic yield in the studies of Kiran *et al*. (2007).

Abowei and Ezekiel (2013), reported that the composition of zooplankton in the Koluama River of Niger Delta Area, Nigeria consisted mostly of copepods and cladocerans. With the exception of the decapod crustacean *Mysis* sp., the zooplankton community groups were evenly distributed among the sampling stations. The authors attribute this to ongoing industrial and human activities in the research area that constantly disturb the surface water column. Egborge (1994), Adedeji *et al*. (2019) and Jonah and George (2020) reported that zooplankton populations in freshwater bodies in Nigeria peaked in the dry months and low in the wet months.

Uttah *et al*. (2013), reported on the taxa structure and composition of zooplankton communities of Bonny Estuary. Due to anthropogenic influences, offshore sample locations had relatively increased zooplankton abundance and variety. The most prevalent zooplankton group were copepods. Due to their resilience, ability to adapt to shifting climatic conditions, and capacity to tolerate a variety of environmental pressures, copepods dominated the majority of aquatic ecosystems (Emmanuel and Onyema, 2007; Yakub *et al*., 2012; Uttah *et al*., 2013 and Ugwumba and Esenowo, 2020). The authors in reference credited the existence of a chitinous exoskeleton, which improves their capacity for survival in a variety of environmental circumstances, and the arrangement of zooplankton in coastal water bodies with the success of the crustaceans.

Krishnamoorthi and Selvakumar (2012) in Veeranam Lake, Cuddalore District, Tamil Nadu, India found five groups, namely: protozoans, rotifers, cladocerans, copepods and insects constituting the zooplankton population of the lake during the period of their investigation. Rotifers were the most dominant forms in every station during the dry period. During the wet season, cladocerans were the dominant forms in all the five stations. Rotifers showed superiority over other groups according to species diversity and population density. The authors attributed the abundance of rotifers to its reliance on phytoplankton and organic matter as food. Their findings showed that several abiotic factors such as temperature, dissolve oxygen, pH, etc. probably exerted considerable influence on the zooplankton abundance.

Davies and Ugwumba (2013) studied the impacts of tide on the zooplankton community of upper Bonny Estuary Tributary, in the Niger Delta. High levels of zooplankton density and species diversity were observed during the investigation. Gustavo *et al*. (2013) revealed that zooplankton diversities are often higher in estuaries than in other aquatic ecosystems, indicating the higher overall productivity of the estuarine environment. In terms of species composition, distribution abundance and diversity, tide has an impact on the zooplankton community. The fact that Copepods were the most prevalent taxon demonstrated that they were both vulnerable to both low and high tides (Gustavo *et al*., 2013). Tackx *et al*. (2004) in their work in Schelde Estuary reported that the lower brackish water transect of the estuary was dominated by copepods and a number of cladocerans. The natural circumstances of the body of water and the period of sampling were the reasons why the population of zooplankton species in their work differed from other studies. Copepods dominate most aquatic ecosystems because of their resilience and adaptability to changing environmental conditions and ability to withstand varying environmental stresses (Uttah *et al.,* 2013).

Ayoade and Aderogba (2020) carried out a survey on the plankton distribution in time and space at Awba Reservoir in southwest Nigeria. The zooplankton fauna in the reservoir was dominated by cladocerans during the study period, which was explained by the predators selective feeding on rotifers and other small-sized invertebrates, as well as fish. The authors claim that invertebrate predation has a bigger effect on microzooplankton than on macrozooplankton, frequently decreasing the population of the former. Depending on fish feeding strategy, fish predation may have an impact on zooplankton structure; selective feeders have a tendency to eliminate large species in favour of less vulnerable tiny forms. According to Jan *et al*. (2015) and Rao and Azmi (2019), cladocerans predominated in the Nigeen Lake, Kashmir, Himalaya, and the Keenjhar Lake in Sindh, Pakistan as well. Their abundance was linked to warmth, which facilitated egg hatching quickly, high nutritional conditions, and food availability. Thus, the dominance of *Bosminia* and *Camptocercus* spp. in a community of phytoplankton in the Awba Reservoir revealed that they consume the prominent colonial Chlorophyceae and Cyanophyceae. This further validated the eutrophic status of the reservoir (Ayoade and Aderogba, 2020).

In river Shasha, southwest Nigeria, Adedeji *et al*. (2019) investigated the zooplankton community structure, spatiotemporal distribution, abundant and diversity. The great abundance of the rotifer population found in the study was related to their ability to feed on a variety of foods, rapid development under favorable conditions, morphological variations or adaptations, and parthenogenetic reproduction techniques. Due to their propensity for warm waters and the low water level that favored their growth activities, rotifers predominated throughout the dry season. Because there was a lot of organic debris in the water body throughout the research period, the abundance of *Brachionus* species was a sign that the river was eutrophic. The relatively low abundance of Cladocera and Ostracoda was caused by waste materials in the water bodies and the hydrodynamics of this river, including the low water volume and short residence period. The high density and biomass of zooplankton during the rains were associated with the high population of phytoplankton, which was particularly abundant in the river during the wet season. The authors also reported that low fish predation during the rains due to their mating may have also supported a high population of zooplankton. Low temperature during the "harmattan" period, low availability of food sources, and high fish predation may be attributed to the drop in zooplankton during the dry season. The authors concluded that the zooplankton composition in the study indicated that River Shasha was active and capable of supporting a variety of fish species and populations at the time of investigation.

Jonah and George (2020) studied the effect of water quality on the composition of the zooplankton community in river Etim Ekpo, Akwa Ibom State. The authors reported that anthropogenic activity within the study stations changed the fundamental water quality characteristics, which then significantly affected the distribution and structure of the zooplankton community of the river. In the study, water quality parameters such as BOD, TDS, DO and nutrient concentration in both spatial and seasonal regimes affected the abundance and distribution of zooplankton.

Enerosisor *et al*. (2020) investigated the zooplankton diversity and abundance in the lower Opobo River, Rivers State. The month of March had the lowest number of zooplankton species reported, while the wet season's month of July had the largest number. The findings about the seasonal variation in zooplankton species abundance were explained by the water's chemical characteristics of the water. The evenness, Margalef's, and Shannon-Wiener diversity indices revealed a poorly diversified zooplankton community. The great quantity and dominance of copepods in comparison to other groups was thought to be the cause of the poor zooplankton species diversity.

Job *et al*. (2019) conducted research on zooplankton diversity and abundance in the lower Opobo River, Rivers State. With the exception of the majority of the species, which were station-specific, the zooplankton were evenly dispersed at each sampling station, illustrating a typical eutrophic freshwater environment. Copepods were the most prevalent of the five major zooplankton taxa (Cladocera, Copepoda, Decapoda, Rotifera, and Protozoa) in the lake environment during the research. Copepods are abundant because of their high reproductive potential and ability to join the zooplankton population standing stock, according to the authors. The presence of some zooplankton species at some locations and their absence at other locations were related to those species adaptability to the local environmental circumstances. The concept of retention mechanism and the copepods typically high reproduction ability, according to the scientists, may have been the only explanation for the great abundance of copepods found in Tinapa Lake at the time of the study.

Kwen *et al*. (2019) studied diversity of zooplankton species and physico-chemical factors in Bayelsa State's lower Taylor Creek area. The majority of the zooplankton found during their research came from station one, which had a calm water column structure. Under quiet, nearly stagnant conditions, rotifers have been observed to thrive (Ajuonu *et al*., 2011; Ekwu and Udo, 2013; Ovie *et al*., 2015). According to Kwen *et al*. (2019), Station One's favorable water quality, which promoted their growth and survival, is another potential explanation for why Station One had the highest concentration of zooplankton species compared to other stations. Ovie *et al*. (2015) and Seiyaboh *et al*. (2017) had previously observed that in aquatic water bodies, favourable water quality factors can influence the spatial distribution of zooplankton compositions. According to Kwen *et al*. (2019), the lower Taylor Creek's water quality was deemed to be relatively safe given that all physico-chemical parameters were within the ranges that were suitable for fish production and other uses while conducting the study. The many zooplankton species seen in the area of study was credited to the amount of nutrients present in the small water body due to continuing farming operations in the region.

Olaniyan *et al*. (2018), in their research on the spatiotemporal diversity of the zooplankton fauna of river Oluwa in Ilaje Local Government Area of Ondo State, attributed the abundance of rotifers to the fact that they evolved from freshwater. According to the authors, rotifers typically inhabit tropical water bodies with warm temperatures and are acclimated to warm water. The *Brachionus*, *Asplancha*, and *Filinia* genera were particularly numerous, indicating that the rotifers were composed of tropical assemblages. The Brachionidae dominance was linked to their extensive geographic distribution and the omnivorous diet of the majority of its species. According to the study in reference, Rotifera and Cladocera were more abundant during the dry season in the Oluwa River's zooplankton population. The authors claim that Oluwa River was unpolluted during the study period because it had a robust zooplankton fauna composition.

The distribution of zooplankton and the impact of prevalent anthropogenic and the effects of the environment on the fauna were studied by Erhenhi and Omoigberale (2019) in the Ethiope River, Delta State. There were 1,662 different zooplankton species included in the research findings. Zooplankton fauna were quantitatively dominated by copepod (*Tropocyclops prasinus*). Greatest concentration of copepods was seen at Station two (Umutu), where the substratum was covered in alluvial, and the scientists attributed this to the sediments' high nutrient retention and suspension, and river shape. The Pearson correlation study revealed that the following factors affected the abundance and diversity of zooplankton in river Ethiope, Delta State: temperature, total hydrocarbons, dissolved oxygen, bicarbonates, chlorides, phosphorus, zinc, copper, and nickel in the water.

2.4 Macro-invertebrates

The physical and chemical alterations of riverine ecosystems are recognisable through elasticity of the community structure of the organisms expressed numerically as index of pollution (Ogidiaka *et al*., 2012, Alam *et al*., 2016; Giorgio *et al*., 2016). Thus, benthic macro-invertebrates are ideal for such studies and hence, are frequently employed for biological water quality monitoring.

Although benthic fauna are used to follow long term monitoring programmes related to anthropogenic impacts, they however vary greatly in their responses to variations in water quality (Anyanwu *et al*., 2019; Umunnakwe *et al*., 2020). Some taxa are relatively tolerant of heavy metals and low dissolved oxygen conditions, while some are easily eliminated (Edward *et al*., 2016; Iyagbaye *et al*., 2017). Low micro-invertebrates species diversity in a river is indicative of pollution, while high species diversity indicates unpolluted environment, but the frequency of occurrence of resident species could also serve as a quantitative measure of the intensity of pollution (Miserendino *et al*., 2001; Iyagbaye *et al*., 2017).

Edokpayi and Ekikhalo (2001) studied the hydrobiology of Ibiekuma River, Ekpoma, Edo State, southern Nigeria; macro-benthic fauna characteristics of the river were also evaluated. The insects, hemipterans and dipterans were the most abundant macro-invertebrate groups recorded. The abundance of macro-invertebrates found was a sign of the study area's physical and chemical stability. Chukwu and Nwankwo (2003) evaluated the effects of land-based pollution on the hydrochemistry and macro-invertebrate fauna in a tropical West African Creek, Lagos. The type and quantity of macro-invertebrates were poor, and annelids dominated the taxonomic hierarchy. Similarities between macro-invertebrate species upstream and downstream were considerably different from each other. The scientists blamed substrate instability and stress brought on by effluents from land-based sources for the poor faunal variety and abundance.

The two dominant species were *Nais communis* and *Dero limnosa*, according to Arimoro *et al*. (2007a) who studied oligochaetes ecology and abundance as indicators of organic contamination in a southern Nigerian urban stream. Arimoro *et al*. (2007b) assessed the macro-invertebrates community pattern and diversity in regard to the condition of the Ase River water quality in the Niger Delta, Nigeria. All the physico-chemical variables analysed except for nitrate, biological oxygen requirement, water depth, and surface water temperature showed insignificant differences. Coleopterans were the most abundant group while aquatic mites (*Hydracarina*) were reported to occur sporadically. The authors concluded that these organisms identified during the study were indicators of fairly clean water condition and may be used in monitoring their impact as well as other freshwater bodies in southern Nigeria.

Atobatele *et al*. (2005) reported that benthic macro-invertebrates fauna in River Ogunpa, Ibadan were pollution-tolerant species such as the molluscs, *Melaniodes tuberlata*, *Physa waterloti and Bulinus globosus*; the midge fly larva (chironomids) as well as the annelids, *Tubifex* and *Brachydeutera spp*. The authors reported that these, in addition to the physico-chemical parameters showed that River Ogunpa was under pollution stress from oxygen-demanding organic wastes. Arimoro *et al*. (2008) studied the impact of cassava effluents on a tropical stream's benthic macr-oinvertebrate fauna in southern Nigeria. The results of their study indicated that effluents from cassava caused a rise in nitrates and biological oxygen demand and a reduction in pH and dissolved oxygen. Additionally, the cassava effluent caused a decline or complete extinction of several benthic macro-invertebrates in the research area and affected the oligochaetes and dipterans predominance at the discharge station.

Using select aquatic insects as bioindicators, Arimoro and Ikomi (2009) investigated the ecological soundness of the upstream of Warri River in Niger Delta. The composition, diversity, and species abundance of the river's aquatic insects were evaluated, as well as the impact of several physico-chemical factors. The macrophyte canopy cover and type of substrate were found to have an impact on the abundance and distribution of these aquatic entomofauna, according to the scientists. Woke *et al*. (2007a) carried out a survey on the composition and abundance of macroinvertebrates in the stream of Nta-Wogba in Port Harcourt, Nigeria. The most abundant groups were gastropods and insects. The results indicated that macro-invertebrates were heterogeneous and that vulnerable species were exterminated by pollutants from municipal discharges. Furthermore, the authors attributed the deterioration in water quality to the high levels of chemical oxygen demands (45 mg/L) and biochemical oxygen demands (10.4 mg/L) observed.

Woke *et al*. (2007b) studied the impact of organic waste pollution on the macro-invertebrates at Elechi Creek in Port Harcourt. In their findings, 19 taxa representing three groups namely polychaetes, molluscs and crustaceans were recorded. Macro-invertebrates density varied throughout the sampling stations. Pollution indicator species were polychaetes namely *Capitella capitata, Nephytys hombergi, Lumbrimereis trifelaris, Glycera convoluta, Nereis* sp. *and Cosura* sp. The authors further reported that sensitive species were eliminated by pollution while pollution tolerant species became predominant until checked by depleting nutrient availability. Ajao and Fagade, (2002) revealed that the Lagos Lagoon's benthos were most obviously impacted by pollutants when populations in some regions of the lagoon decreased and all benthic species were completely eradicated from some extremely contaminated areas. Arimoro and Osakwe (2006) investigated sawmill wood wastes influence on the distribution of macro-invertebrates at the Sapele stretch of the Benin River, Niger Delta, Nigeria. Twenty-one taxa of benthic macro-invertebrates were encountered and species abundance indicated that wood wastes negatively impacted these macroinvertebrates, mostly the tolerant species.

Odiete (1999); Keke *et al*. (2020); Iloba and Adamu (2020) reported that the utilization of benthic macro-invertebrates is the most widely used biological parameter in the assessment of freshwater bodies receiving domestic and industrial waste waters. Water quality can affect their distribution, abundance, and composition (Bonada *et al*., 2006; Arimoro and Keke, 2017; Idowu *et al*., 2020). The authors argued that variations in regional environmental conditions may be the cause of variances in the distribution of macro-benthic organisms. Macro-invertebrates are more reliable indicators than chemical and microbiological changes in aquatic environments, which at least demonstrate short-term variations (Iyagbaye *et al*., 2017; Edegbene *et al*., 2020).

Younes *et al*. (2005) and George *et al*. (2020) suggested that macro-invertebrate distribution and abundance is regulated by many factors among which are current, speed and temperature. Ajao and Fagade (1990) noticed that the significant polychaete species flourished in the western industrialised areas of Lagos Lagoon and were pollution-tolerant. The western industrial area received waste from industrial facilities along the shore. The authors observed that polychaetes like *Nereis* sp. and *Polydora* sp. and *Capitella capitata*, were discovered in close proximity to heavily polluted locations that contained organic debris, petroleum hydrocarbons and metals.

Amusan *et al*. (2018) in their Study which compared the macro-invertebrate population composition and the quality of water of river Ona and river Opa in southwest Nigeria observed that Chironomid larvae dominated Ona River whereas Trichopteran species dominated Opa River. In terms of diversity and richness of organisms, Opa River was superior. The species composition and variations in water quality, revealed that Ona River was under more stress than Opa River due to increasing impacts of human activities that led to the observed organically-induced polluted water body.

Edegbene *et al*. (2015) in their work on composition and variety of aquatic insects in an urban river in the North-central, Nigeria: implications of anthropogenicity reported poor overall abundance, distribution and composition of the insects. They also reported that species sensitive to pollution which were of the orders Ephemeroptera, Plecoptera, and Trichoptera were sometimes underrepresented or completely absent due to the river's deteriorating state as a result of multiple human activities. Their research showed that decreased aquatic insect diversity and abundance in the sampled stations of the River Chanchago were caused by increased human activity. The authors claimed that numerous activities, such as farming, illegal gold mining, and industrial operations, were carried out in the river's catchments, and could impose detrimental impacts on the aquatic organisms.

Anyanwu *et al*. (2019) studied macro-invertebrates as biological markers of the effluent quality that enters the Ossah River in Umuahia, southeast Nigeria. In contrast to the

molluscs discovered by Anyanwu and Jerry (2017) in the Ikwu River, Umuahia, southeast Nigeria, the species composition was dominated by insects. Most of the species that were observed belonged to groups that were tolerant of pollution, particularly *Chironomus* species, which are markers of organically polluted environments and may persist even in waters with low levels of dissolved oxygen (Mariantika and Retnaningdyah, 2014). Anyanwu *et al*. (2019) reported that Ossah River was impacted by waste water from a nearby industry that processed vegetable oil and had high levels of some physico-chemical parameters such as DO, pH, and BOD.
Iloba and Adamu (2020) investigated the ecological reactions of macro-invertebrates to human effects on a Delta State river that flows between rural and urban areas. The organically troubled water which were low in pH, were macro-invertebrates impoverished. The insect order Hemiptera were numerically most abundant during the period of study. *Ranatra linearis* contributed nearly half of the numbers recorded for the Hemiptera. The abundance of Hemiptera in the Anwai River resembled those found in the Ethiope River, Delta State, as reported by Iloba *et al*. (2019). Low values for all diversity indicators measured in the Anwai River supported earlier statements that the river's ecology has been impacted by human activity in and around it. Low values for certain water quality indicators including pH and Dissolved Oxygen (DO), abundance, and diversity indices of the fauna (less than 1.0), and long records of blood worms presence suggested that the Anwai River posed a threat to both aquatic life and humans who used the water.

Idowu *et al*. (2020) studied chemical, physical, and macro-benthos qualities of Ogbese River in Ado-Ekiti, Ekiti State. The authors reported that loss of habitats and niches as a result of human activity, severe floods and bank overflowing during the wet season, and the entry of anthropogenic contaminants from household and industrial activities were the main causes of the loss of benthic macro fauna throughout the survey. Because some species have evolved to thrive in almost anoxic conditions, or absence of oxygen supply predominate in contaminated water, *Chironomus* sp., which is present in the river, showed that the biodiversity was not significantly degraded in the water. The authors concluded that the abundance and distribution of macro benthos in the Ogbese River, Ado-Ekiti, were influenced by physico-chemical factors as a result of the strong, positive, and significant correlation between the physico-chemical parameters and macro benthos.

Olaniyan *et al*. (2019) investigated the status of macro-invertebrates in Oluwa River, Ondo State. The authors ascribed the higher relative abundance of pollution indicator species they discovered in the river - like *Pachymelanin aurita* and *P.* f*usa* - to organic pollution from surrounding disposal sites. The authors claim that the species that could withstand organic pollution in the river were physiologically and morphologically suited to endure low water quality. One of these adaptations was the development of hemoglobin, a pigment that increases an organism's affinity for oxygen even at very low concentrations. During the study period, *Pachymelania aurita* had the highest percentage abundance. The authors explained this by stating that they were able to adapt to the declining water quality. The Oluwa River's low diversity indices were a sign that it was somewhat polluted. The authors came to the conclusion that stress caused by land-based pollution, in addition to substrate instability potentially resulting from regular organic waste deposition in the river, had a notable effect on the macrobenthic composition, abundance, and diversity.

George *et al*. (2020), carried out evaluation of the Etim Ekpo River benthic macro-invertebrate community and water quality. There were a total of 429 individuals among nine species from three phyla that were noted. Mollusca were the least numerous group and Arthropoda were the most numerous. Low levels of species diversity were noted in the study, and the authors attributed it to anthropogenic activities like dredging, riparian zone removal, farming, and domestic activities within and around the river that altered the habitat structure and physico-chemical characteristics of the water body. These occurrences most likely played a role in the disturbance of the food chain, reproductive cycle, and life cycle. The authors reported that when organic fertilizers rich in nitrate and phosphate were used in agricultural activities close to water bodies, more nutrients entered the water, increasing nutrient concentrations like phosphate and nitrate, reducing dissolved oxygen, and ultimately increasing biochemical oxygen demand. The fact that every species of macroinvertebrate identified during the investigation could tolerate some level of contamination indicated that the river had been damaged by organic contaminants. The study's low Shannon Wiener diversity index values, particularly in stations one and three, further suggested that pollution stress was severe and was mostly caused by anthropogenic activity.

Emoyoma *et al*. (2020) investigated the effects of the mangrove forest and Nypa palm (*Nypa fruticans*) on the benthic macro-invertebrate community in the Adoni River, Rivers State, Nigeria. The findings of the application of the Shannon Weiner diversity index (H) revealed high values, with station one (control) having less diversity than other stations. This indicates that Nypa palm could form a microhabitat for the macri-invertebrates. *Tympanotonus fuscatus* was the species that was found to be most prevalent in the study. The macroinvertebrates that were observed were all freshwater species. The scientists attributed the apparent homogeneity in local environmental conditions to the uniformity in the distribution of macro-invertebrate in the Andoni River. The mangrove (Rhizophora)-dominated site (station three) had the highest concentration of benthic macroinvertebrates, whereas station one served as the control. According to the study, the Andoni River's intertidal macro-benthic invertebrate richness was notably low when compared to other river systems. Physical and chemical parameters did not vary when Nypa fruticans was present, demonstrating that Nypa palm does not have an impact on the growth of macro-invertebrates.

Moslen and Ameki (2018) studied the effects of human activity on macro-benthic community in Isiokpo Stream (Oriobojo), a Niger Delta Stream in Nigeria. The study showed a deteriorating and impacted environment evidenced by the poor macrobenthic fauna composition, distribution, abundance and diversity of the study area. The authors attributed the deterioration to increased human activities on the stream with negative consequences on its biotic strata. Insects, crustaceans and oligochaetes were the only three groups of benthic macro-invertebrates observed, and they were in low abundance across the study stations. The authors implied that fish population in the stream would be affected as a result of the low abundance of macro benthos as most fish depend on benthic organisms for food. This would ultimately lead to poor fish yield in the area.

Abbati *et al*. (2020) investigated the physico-chemical properties and composition of benthic macro-invertebrates in Garin Garba Stream, Tumu, Gombe State. The ability of Mollusca to endure various ecological challenges and their ability to adapt to changing ecological conditions were cited as reasons for their abundance. It was thought that anthropogenic activities like farming, car washing, and bathing had changed the substrate composition around the study stations and increased the amount of foreign compounds in the water, which ultimately changed the general surface water physical and chemical characteristics and made it difficult for aquatic organisms to develop, survive, and reproduce. Hassan and Umar (2018) reported that the bottom community in Kodon Stream, a tropical freshwater in Gombe State, is significantly impacted by the changing composition of substrates connected with different organic contamination types. Abbati *et al*. (2020) stated that Benthic invertebrates were used in the water as biological indicators or biomarkers of the Garin Garba Stream, Tumu, Gombe State. Therefore, any foreign substance inputs from riparian land usage may adversely impact living things since they heavily depend on dissolved oxygen for their metabolic processes.

Ogidiaka *et al*., (2012), in their research on benthic macroinvertebrates, chemical and physical properties of the Ogunpa River in Bodija, Ibadan, Oyo State linked the existence of species that can tolerate pollution, like *Chironomus* sp., *Lymnaea truncatula*, and *Lymnaea glabra*, to the effects of home and industrial wastes in the river. Because of the low DO, high BOD, and COD levels, abundance of pollution-tolerant benthic macro-invertebrates, and proper management, the authors came to the conclusion that the Ogunpa River in Bodija was polluted during the study period. Esenowo and Ugwumba (2010) reported that a variety of environmental factors, including water quality and movement, substrate instability, and food availability, contributed to the low number of macroinvertebrates in the Majidun River, Ikorodu, Lagos State.

Ugwumba and Esenowo (2020) in their study on human influence on the plankton and benthos assemblage of Lagos Lagoon in southwest Nigeria reported gastropods as the dominant organism during the period of study. The most significant contribution to the overall population of benthos was made by the genus *Pachymelania*, whose great prevalence and abundance were linked to their adaptation to freshwater and predilection for brackish water with a high salinity. The ability of the organisms to acclimatise to the locations with low organic materials found on the eastern side of Lagos Lagoon was proved by abundance of one of the most common bivalves, *Aloidies trigona*.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The study area

3.1.1 Description of the study area

Calabar River is located in Cross River State, south-south Nigeria and lies geographically between latitude 04^{o}54’N and 04^{o}56’N and longitude 08^{o}16’E and 08^{o}18’E (Figure 3.1). Calabar River originates from the Oban Hills in Akamkpa Local Government Area of Cross River State, Nigeria and flows southwards through the high rainforest of the southeast Coast of Nigeria and empties into Cross River. The river lies in the humid tropical rainforest belt. The zone is distinguished by a lengthy wet season between April and October with peak rainfall in June and dry season from November to March (Eze and Effiong, 2010; Ojo, 2014). Based on information from the data in the meteorological station in Calabar, Cross River State during the study period, average annual rainfall of the area was 2,750 mm, average temperature was 28.5^{o}C while the relative humidity was 73.66%.

The coastal shoreline is characterized by thick vegetation, changing from freshwater to mangrove swamp. The geology of Calabar River Basin includes the Cretaceous strata of the Calabar flank, the Pre-Cambrian Oban Massif and the sedimentary basin of the Niger Delta; the basin is roughly 43 km broad and 62 km long and covers an area of 1,514 km^2 (Eze and Effiong, 2010).

Okomita is situated in Akamkpa Local Government Area of Cross River State, Nigeria. The area is semi-urban and located within southern Nigeria's high rainforest belt. Effluents and solid wastes from industries, markets, slaughter houses, rubber and oil palm plantations and settlements around Okomita are directly discharged into Calabar River along its course. The river also provides an avenue for bathing, washing and sand mining. The river is also used for timber transportation and domestic water supply which could also be potential sources of contamination or pollution.

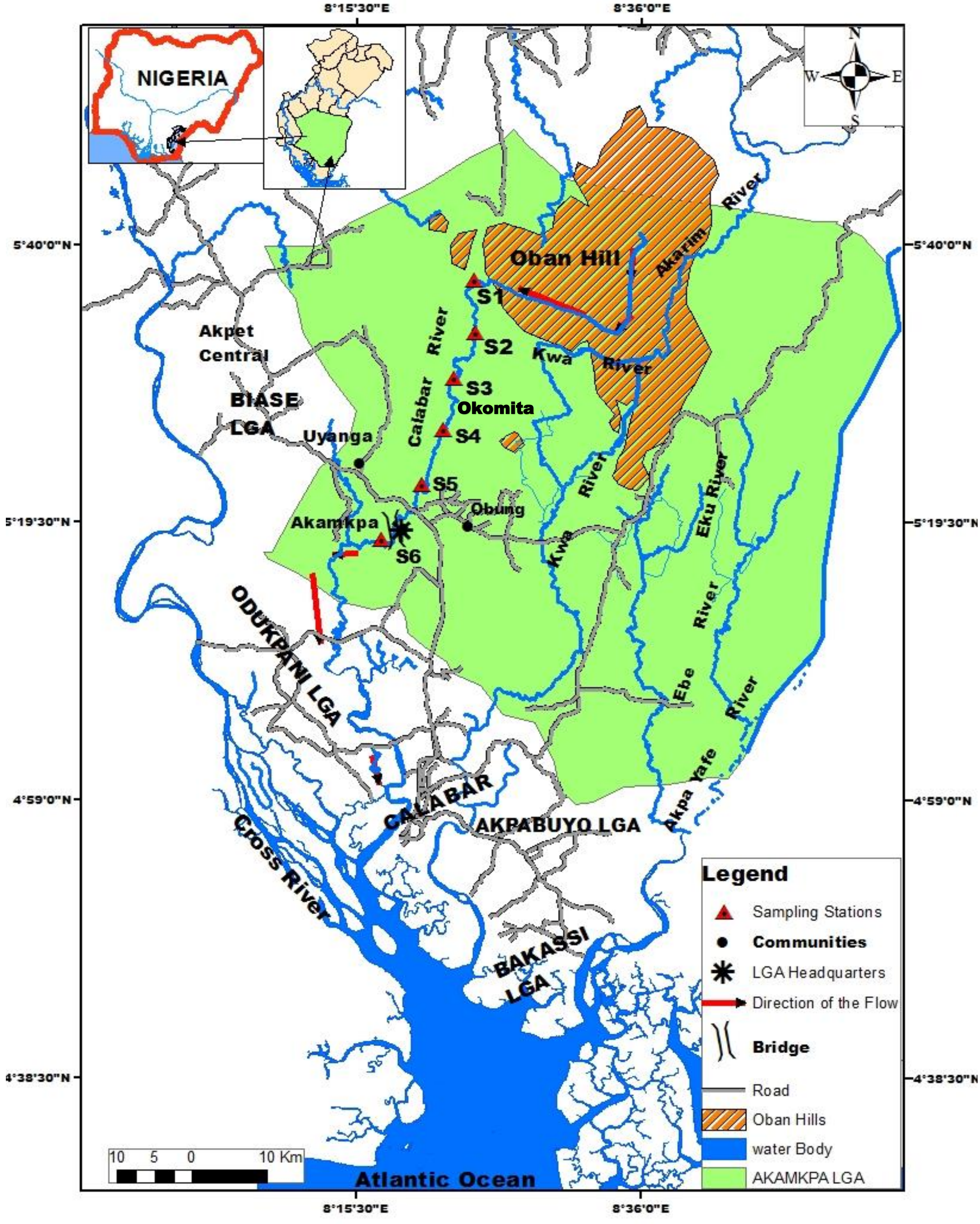


Figure 3.1. Map of Akamkpa Local Government Area indicating sampling stations (S1-S6) in Calabar River at Okomita (Map of Nigeria and Cross River State inserted)

The vegetation in the area is characterised by secondary forest, farmlands, oil palm (*Elaeis guineensis*) and rubber (*Ficus elastica*) plantations. The major occupations of the villagers are: trading, farming and hunting. Other activities in the area include sand mining, quarrying and wood logging.

3.1.2 Sampling stations

Six sampling stations S1-S6 were selected based on the anthropogenic activities along the length of Okomita area of Calabar River and also on the accessibility to the stations. The entire sampling area is characterised by rocky and sandy substrata with scanty muddy areas. Some of the rocks are exposed to the surface of the water. The rocky nature of the area could be the reason for lack of commercial fishing activities observed in the area since boats cannot easily be paddled on the water. The sampling stations covered a total distance of 4,800 m from station one to station six. The distance from one station to another and the latitudes and longitudes of each sampling station were measured with GERMIN GPS model 72H.

Station one (S1)

This station lies between latitude 05º09'52.9''N and longitude 007^{o}53$^{'}$23.6$^{''}$E and is the closest to Oban Hill. There are no residential buildings around this station and also no anthropogenic activity seen in this area. The water was clear at this station and the bottom was characterized by stony substratum while the shores were characterised by secondary forest on both the eastern and the western sides. The river velocity was low at this station. The bank root submerged and emergent macrophytes at this station were elephant grass.

Station two (S2)

This station is about 800 m away from Station one. It lies between latitude 05^{o}23$^{'}$30.9$^{''}$N and longitude 008^{o}19$^{'}$35.4$^{''}$E. Julius Berger quarry is located at this sampling station. The river bottom is sandy with scanty rocky areas. Sand mining takes place all year round at this station. There was also a timber depot at this station. The river was used to transport timber at this station (see Plate 3.1). The river shores were characterised by secondary forest on the eastern side and farmland on the western side. The river velocity was low at this station. There were no bank root submerged or emergent macrophytes in the water at this station.

Plate 3.1. Station two of the study area of Calabar River used for timber transportation at Okomita

Station three (S3)

This station is about 1200 m from Station two. It lies between latitude $05^{o}21^{'}52.9^{''}$N and longitude $008^{o}19^{'}04.5^{''}$E. Activities within and around this station included bathing, washing of clothes and harvesting of palm fruits. The western side of the river shore was characterised by oil palm (*Elaeis guineensis*) plantation while the eastern shore was characterised by secondary forest. The river bottom was rocky with scanty sandy areas. The river velocity was low at this station. The bank root submerged and emergent macrophytes at this station were elephant grass.

Station four (S4)

This station is about 1000 m from Station three. It lies between latitude $05^{o}20^{'}35.1''$N and longitude $008^{o}18^{'}18.2^{''}$E. Activities within this station included: sand mining, bathing, fetching water for household purposes and laundry. Heaps of sand were seen all year round at this station (see Plate 3.2). Household wastes were dumped directly into the river at this station. There was palm oil milling plant from which the effluents and solid wastes were channelled into the river. The river bottom was sandy at this station. The eastern side of the shore at S4 was characterised by rubber (*Ficus elastica*) plantation while the western side was characterised by human settlements. Harvesting and processing of rubber took place in the rubber plantation. The river velocity was low at this station. The bank root submerged and emergent macrophytes at this station were elephant grass.

Station five (S5)

This station is about 800 m from Station four. The station is close to Calabar-Ikom Express Road and lies between latitude $05^{o}18^{'}46.5^{''}$N and longitude $008^{o}17^{'}21.6^{''}$E. Okomita Market is situated very near the river at this station. A slaughterhouse which services Okomita Market was located near the river and the wastes from the abattoir were channelled directly into the river at this station. A mechanic workshop and waste dumpsite (Plate 3.3) were also at this station and near to the river. The river bottom is rocky with scanty sandy areas. The river velocity was high at this station. There were no bank root submerged or emergent macrophytes in the water at this station.

Plate 3.2. Station four of the study area showing heaps of sand (↗) from Calabar River at Okomita

Plate 3.3. Station five of the study area showing refuse dumpsite along Calabar River Bank at Okomita

Station six (S6)

This is the last sampling station; it is 1000 m from S5 and lies between latitude $05^o17^{'}03.0^{''}$N and longitude $008^o15^{'}54.0^{''}$E. Swimming, bathing and washing of clothes took place at this station. The shores were characterised by secondary forests on both sides. The water at this station was clear and the river bottom sandy with scanty rocky areas. The river velocity was high at this station. There were no bank root submerged or emergent macrophytes in the water at this station.

3.2 Sampling design

Longitudinal survey was employed, and this involved repeated monthly surface water collection for physico-chemical parameters and sampling of plankton and acro-invertebrates within a period of 24 months (September, 2014 to August, 2016). Sampling involved both *in situ* measurements and sample collection from the sampling stations for laboratory examination and analyses. Sampling for physico-chemical parameters, plankton and macro-invertebrates was done once in a month between 08.00-11.00 hours on sampling days. Laboratory analyses were carried out in Chemistry Laboratory, University of Calabar for physico-chemical parameters analyses and Zoology and Environmental Biology Laboratory, Department of Zoology and Environmental Biology, University of Calabar for plankton and macro-invertebrates identification and counting.

3.3 Physico-chemical parameters

3.3.1 Collection of water samples

Plastic bottles measuring two litres each were used to collect Surface water samples. The bottles were rinsed with distilled water at each sampling station, dipped into the river about 3 cm below the water surface, filled to the brim and closed securely. Each sampling involved the collection of three surface water samples. The water samples were transported to the Laboratory, Department of Chemistry University of Calabar, Calabar for analyses. The physico-chemical parameters that were examined included Water depth, air temperature, conductivity, transparency, turbidity, total hardness, total dissolved solids, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, water temperature and heavy metals (zinc, iron, magnesium, manganese, copper, cadmium, and lead).

3.3.2 Determination of physico-chemical parameters

3.3.2.1 Water depth

A long pole was inserted into the river, the level of water on the pole was marked and brought out of the river and measured with a measuring tape. The results were presented in metres.

3.3.2.2 Air temperature

Air temperature (^oC) was determined at the site of each station using a Jenway 430 Mercury-in-glass thermometer. The thermometer was held in the air and allowed to stabilise for three minutes and the reading was recorded. Three readings were taken, and the mean was calculated.

3.3.2.3 Surface water temperature

On-site measurements were conducted to evaluate the surface water temperature (^oC). The thermometer was immersed in the water to a depth of 10 cm and left there for three minutes to stabilise. Readings were taken three times and a mean value was obtained.

3.3.2.4 pH

The pH of the sampled water at each location was determined in the field using a Jenway 430 pH meter. The meter was standardised using prepared buffer solution in accordance with the manufacturer's instructions. The glass probe (glass electrode) of the meter was dipped into the water sample in order to determine its pH. The mean value of three readings was calculated and recorded.

3.3.2.5 Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD)

Utilizing a Jenway 970 model oxygen meter, dissolved oxygen was determined in situ. The meter was immersed into the water and was left for roughly five minutes to stabilise. Mean value of three readings was taken in mg/L. Water samples for BOD were collected from each station without air bubbles into one light and two dark 250 ml bottles. The battles were dipped into the water and the water collected gently, and the bottles stoppered inside the water to prevent air bubbles. The initial DO, that is the DO of the water in the light bottle, was determined immediately using Jenway 970 model meter. The meter was immersed into the water in the light bottle and allowed to stabilize for about 5 minutes. Readings were taken three times and the average value was calculated. The dark bottles were incubated for five days at 20^oC in a water bath model DQ-WB-01. The DO in the sample was determined after the incubation period following the method described above for determining initial DO and the difference between initial and final DO was the BOD, i.e. DO_1 - DO_5 = BOD (APHA/AWWA/WPCF, 2005). The DO1 was initial Dissolved Oxygen (DO) concentration (in mg/L), while D2 was the DO concentration (in mg/L) after 5 days incubation (APHA/AWWA/WPCF, 2005). The values were presented in mgDO/L.

3.3.2.6 Chemical Oxygen Demand (COD)

Measurement of COD was done using the dichromate reactor digestion method (Hach, 2003). One hundred mililitre (100 mL) of the sample was pipetted into a flask. Ten millilitres (10 mL) of sulphuric acid and 10 mL of 0.0125 N potassium permanganate solution were added to the sample. The solution was boiled in a water bath for thirty minutes, and then 10 mL of ammonium oxalate was added after boiling. The sample was titrated while hot with standard potassium permanganate ($KMnO_4$) until a pink colouration was observed as the end point.

The amount of COD in the sample was calculated as:

$$\mathrm{COD\ (mg/L)} = \frac{\text{mL of KMnO4 used in titration x 100}}{\text{ml of sample (100 mL)}} ------------ (3.1)$$

3.3.2.7 Conductivity

The water conductivity was measured at the site with the help of Jenway 4510 conductivity meter. The meter's electrode was immersed in the sample of water and after three minutes when the value had stabilized, the reading was taken. The mean conductivity value of three readings was calculated. Conductivity values were expressed in µS/cm.

3.3.2.8 Total Dissolved Solids (TDS)

Total Dissolved Solids was determined as described by Boyd and Lichtkoppler, 1979. A dried filter paper was used to filter 100 mL sample of water into a crucible of known weight and heated in a heater at 110^{o}C to dryness. The crucible with the dry sample was cooled in a desiccator and weighed**.** Total Dissolved Solids was calculated as:

$$\mathrm{TDS\ (mg/L)} = \frac{\text{(weght of dried residue + crucible, mg} - \text{weight of crucible, mg)x 1000}}{\text{100 (mL water sample)}} -------------------------------------- (3.2)$$

The measurement was performed three times and the mean was calculated and expressed in mg/L.

3.3.2.9 Total Suspended Solids (TSS)

Total suspended solids was determined as described by APHA/AWWA/WPCF (2005). A filter paper was oven-dried to constant weight. One hundred milliliter (100 mL) of water sample was passed through the dried filter paper. The filter paper with sample was then oven dried at 105^{o}C. It was removed and cooled in a desiccator. The paper was reweighed at 15 minutes intervals until constant weight was obtained. Total suspended solids was calculated as:

$$\mathrm{TSS\ (mg/L)} = \frac{(\text{weight of filter} + \text{dried recidue, mg} - \text{weight of filter, mg})\ \mathrm{X}\ 1000}{100\ (\text{ml water sample})} \qquad (3.3)$$

The measurement was performed three times and the mean was calculated and expressed in mg/L.

3.3.2.10 Hardness

Hardness was determined as described by APHA/AWWA/WPCF (2005). This was calculated by adding one millilitre of Iso-propyl alcohol and one millilitre of sodium hydroxide to 50 mL of water in a sterilised conical flask. The mixture was titrated against Ethylene-Diamine Tetraacetic Acid (EDTA) using a pinch of murexide indicator until the pink colour changed to purple. The reading was taken from the burette and the total hardness expressed as mg$CaCO_3$/L.

3.3.2.11 Alkalinity

One hundred millilitres of water sample was pipetted into a conical flask and titrated against 0.1 N hydrochloric acid from a burette using a mixed indicator solution. The mixed indicator solution was prepared by dissolving 0.02% methyl red in 95% alcohol and 0.1% of bromocresol green was added. The mixture was made up to 100 mL as described by Mackereth *et al.* (1978) and Boyd (1979). The colour of the mixture changed from light blue through grey to pink colour at the end. The average was calculated after this process was completed three times. The unit of measurements was mg$CaCO_3$/L.

3.3.2.12 Transparency

Transparency was determined as described by APHA/AWWA/WPCF (2005). Transparency (water clarity) was measured with a Secchi disc of 30 cm diameter black and white plate. A lead weight was suspended under the disc to ensure that it sank rapidly and vertically in water. The Secchi disc was lowered into the water at each station until it was no longer visible (step one). It was then slowly raised until it became visible once again (step two). The average of the depths from steps one and two were calculated to get the Secchi disc depth. The measurement was repeated three times for measurement precision and the mean value was calculated and recorded in metres.

3.3.2.13 Turbidity

Turbidity was determined using a nephelometer. A turbidity suspension of 40 Nephelometric Turbidity Units, NTU and pure water (zero NTU), respectively, were used to calibrate the nephelometer. The completely agitated water sample was placed in a nephelometric tube, the value was recorded when the reading in the meter stabilized. The unit of measurement was NTU.

3.3.2.14 Nitrate

A crucible was filled with a sample of 100 mL of water, which was then evaporated to dryness and cooled. Two millilitre of phenoldisulphonic acid was added and smeared around the crucible; after about 10 minutes, 10 mL of distilled water was added, followed by five millilitre of ammonia solution. Setting the UV/VIS/ Spectrophotometer (Jenway; model-6850), at the wavelength of 420 nm, the absorbance was obtained using distilled water as blank (APHA/AWWA/WPCF, 2005).

3.3.2.15 Sulphate

Fifty millilitres of sample was measured into a beaker with two cubic centimetre of conditioning reagent. The mixture was thoroughly stirred and 0.5g of barium chloride crystals was added and stirred for one minute. The sample was then turned into a cuvette (cell) and absorbance read in the UV-Spectrophotometer at the wavelength of 420 nm (APHA/AWWA/WPCF, 2005).

3.3.2.16 Phosphate

Deniges method was used to determine phosphate (APHA/AWWA/WPCF, 2005). In 100 mL of the water sample, one millilitre of Deniges reagent and five drops of stannous chloride were added. After thoroughly blending, the solution was let to stand for two minutes to allow for reaction. Using distil water as the blank, the absorbance was measured at a wavelength of 690 nm using a UV/VIS/Spectrophotometer (Jenway; model-6850).

3.3.2.17 Chloride

A sterile 250 mL conical flask was used to measure 50 mL of the sample. The conical flask turned light yellow after one millilitre of potassium chromate indicator was introduced. To reach the endpoint, the solution was titrated against a solution of silver nitrate until the colour changed from yellow to brick red (reddish brown). Silver nitrate volume titrated from the burette was noted. The procedure was repeated using distilled water in place of the water sample for the "blank," and the volume was recorded.

Chloride concentration was calculated as:

$$\mathrm{Chloride\ (mg/L)} = \frac{(\mathrm{V1} - \mathrm{V2})\ \mathrm{X\ N\ X\ 35.45\ X\ 1000}}{\mathrm{V}} \quad ----------- (3.4)$$

Where:

V1 = volume of silver nitrate for sample

V2 = volume of silver nitrate for blank

N = normality (standard silver nitrate solution) = 0.0141N

V = volume of sample taken

35.45 = equivalent weight of chlorine

3.3.2.18 Heavy metals

The determination of heavy metals was carried out by digesting 250 mL of samples of water with 10 mL analytical grade nitric acid to acidify it. The solution was evaporated in a crucible to approximately 25 mL, then filtered into a standard flask and diluted with distilled water (Farombi *et al*., 2007). In a water bath, the mixture was slowly heated until the acid was bleached. The digested water samples were analysed for zinc, iron, magnesium, manganese, copper, cadmium and lead using the Perkin Elmer (A Analyst 200) version 6.0 Atomic Absorption Spectrometer (AAS) using appropriate standards.

3.4 Plankton

3.4.1 Plankton sampling

Twenty litres plastic bucket was used to collect water sample five times (One hundred litres of water sample) from the water surface at each station and filtered through 55 µm mesh size plankton net (i.e. pour through method). The plankton were collected into a wide mouth plastic sample bottle and preserved in 4% formalin solution within five minutes following collection to prevent damage of plankton tissue via autolysis and bacterial activity. Each sample bottle containing preserved plankton was properly labelled and preserved in a box and taken to the laboratory for identification and enumeration of plankton.

3.4.2 Identification and counting of plankton samples

The identification and counting of plankton were carried out in the Department of Zoology and Environmental Biology, University of Calabar. In the laboratory, the samples from each station were allowed to settle and concentrate to 10 mL. One millilitre from each sample was taken using a pipette and observed under a Zeiss binocular microscope and all individual taxa present were identified and counted. Lugos iodine solution was used for staining the samples to enhance proper discernment of the morphological features of plankton species for proper identification (APHA/AWWA/WPCF, 2005). Plankton species were identified using identification guides of Edmondson (1959), Prescott (1970), Newell and Newell (1975), Durand and Lévêque (1980), Jeje and Fernado (1986), Sharma (1986) and Nwankwo (2004). The identified plankton species were sorted into different taxonomic groups for both the phytoplankton and zooplankton and photographs of some plankton species were taken with the aid of the Zeiss binocular microscope camera. Phytoplankton counts were expressed as number of cells/mL while zooplankton counts were expressed as number of organisms/mL.

3.5 Macro-invertebrates

3.5.1 Macro-invertebrates sampling

Macro-invertebrates sampling was carried out using two methods.

3.5.1.1 Kick sampling

Bank root macro-invertebrates were collected by kick sampling along the vegetated shore lines of the river at each sampling station following the procedure as explained by APHA/AWWA/WPCF (2005). The dimensions of the wooden framed net of 0.05µ mesh size used was one-meter-by-one-meter (1 m x 1 m) attached to two poles. The sampling involved vigorously disturbing the substratum and the vegetation by kicking upstream. The disturbed macro-invertebrates from the river bed were washed by current into the net held downstream to collect them. The macro-ivertebrates collected were emptied into a white enamel tray and sorted into different taxonomic groups. The organisms were preserved in specimen bottles containing 4% formalin.

3.5.1.2 Use of grab

A 0.6 m^2 (surface area) Van-veen grab was used to collect substrate macro-invertebrate samples from each sampling site. Three replicate hauls of sediment were made randomly by sending the grab down into the bottom in each sampling station. The sediment collected was poured into a plastic container, diluted with water and passed through 0.5 mm mesh size sieve to collect the benthic macro-invertebrates in the field. The residues retained on the sieve were rinsed into a white enamel tray and sorted using forceps to pick out the macro-organisms. By colouring the washed sediment samples with Rose Bengal solution, the sorting of the macro-invertebrates in the sediment sample was improved (APHA/AWWA/WPCF, 2005). Macro-invertebrates that were sorted were preserved in glass jars containing 4% formalin.

3.5.2 Identification and counting of macro-invertebrates

Organisms collected from each station were examined using x10 scanning lens and grouped into phyla. Each taxonomic group was placed in a vial filled with 4% formalin labelled with sampling station, name of the taxonomic group and date of sample collection. Thereafter, the animals in each vial were identified to species level with a compound microscope when needed using identification guides of Edmunds (1978), Pennak (1978), Durand and Lévêque (1980) and APHA/AWWA/WPCF (2005). The numbers of identified macro-invertebrate species were counted and recorded.

3.6 Data analyses

For each sampling station as well as the overall study region, the physico-chemical parameters mean and standard error of the mean were calculated. Combining the values for the dry and wet seasons, seasonal fluctuations in the values of physico-chemical parameters, plankton, and macro-invertebrates were determined. Using one-way Analysis of Variance (ANOVA), the differences between the values at the six stations in each season were checked for significance ($p<0.05$), while the combined differences between the two seasons were examined using an unpaired (independent) student t-test using SPSS software (version 20). Spatial variations in the values of the physico-chemical parameters, plankton and macro-invertebrates abundance within the six stations were tested for significant difference using ANOVA according to Ogbeibu (2005). Factor analysis, using Principal Components Analysis (PCA) was used to determine the relationships between the physico-chemical characteristics of the water with the abundance of plankton and macro-invertebrates.

Species richness and evenness of plankton and macro-invertebrates were determined both seasonally and for the entire study period (24 months). Shannon-wiener diversity index (H') was used to estimate both species richness and evenness of individual distribution among the stations (APHA/AWWA/WPCF, 2005; Ogbeibu, 2005) as follows:

$$\mathrm{H} = \frac{\mathrm{N\ In\ N} - (\mathrm{ni\ In\ ni})}{\mathrm{N}} \quad ------------------------(3.5)$$

Where;

H' = Shannon-Wiener diversity index

N = the total number of individual species in sample,

n_i = the total number of individuals of each species in sample.

Species equitability or evenness (E) was determined using the equation reported by (Pielou, 1966):

$$\mathrm{E} = \frac{\mathrm{H}}{\mathrm{In\ S}} \quad --------------------------(3.6)$$

Where;

E = equitability

H = the Shannon-Wiener index.

S = the total number of species in samples.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical parameters

4.1.1 Water depth

Water depth of Calabar River at Okomita during the study period ranged from 0.12 to 2.15 m with a mean value of 0.80±0.09 m (Table 4.1). A higher mean value (1.02±0.19 m) was recorded in the wet season compared to the dry season (0.63±0.18 m). The mean values of the wet and dry seasons did not significantly differ ($p>0.05$; Table 4.2). Mean water depth was highest, 1.66±0.06 m at Station Two and lowest, 0.51±0.05 m at Station Six (Table 4.3). Spatial variations in the water depth (Table 4.3) were significantly different ($p<0.05$). Temporal variation showed that the highest water depth, 1.36 m was recorded in October, 2015, while the lowest value, 0.47 m was recorded in March, 2015 (Figure 4.1). Temporal variations in the water depth were not significantly different ($p>0.05$).

4.1.2 Transparency

Transparency during the study period ranged from 0.12 to 2.15 m with mean value of 0.8±0.09 m (Table 4.1). A higher mean value of transparency, 1.02±0.19 m was recorded in the wet season, while the dry season value was 0.63±0.18 m, the difference was not significant ($p>0.05$) (Table 4.2). Transparency was highest, 1.66±0.06 m at Station Two and lowest, 0.51±0.05 m at Station Six (see Table 4.3). Spatial variations in transparency (Table 4.3) showed significant differences ($p<0.05$). Transparency had the highest value, 1.36 m in October, 2015 and the lowest, 0.47 m in March, 2015 (Figure 4.1). Temporal variations of transparency were not significantly different ($p>0.05$).

4.1.3 Air temperature

A mean value of 28.97±0.15°C (Table 4.1) was recorded for the air temperature, which ranged from 25.00 to 32.80°C. A higher mean seasonal value, 29.12±0.23°C was recorded in the wet season, while the dry season value was 28.76±0.54°C (Table 4.2).

Table 4.1. Physico-chemical parameters of surface water of Calabar River at Okomita at the time of the study

Parameters	Min	Max	Mean ± SE	NESREA, 2011	WHO, 2004	USEPA, 2010
Water depth (m)	0.12	2.15	0.85±0.09	-	-	-
Transparency (mg/L)	0.12	2.15	0.85±0.09	-	-	-
Air temp. (^oC)	25.00	32.80	28.97±0.15	-	-	-
Water temp. (^oC)	17.00	31.95	25.98±0.11	20-33	Ambient	-
pH	6.02	9.98	7.84±0.06	6.5-8.5	6.5-9.0	6.5-8.5
DO (mg/L)	2.09	6.74	4.72±0.07	6-8	6.0	-
BOD (mg/L)	0.78	3.88	1.86±0.03	4	-	-
COD (mg/L)	0.00	3.05	1.13±0.03	-	-	-
Conduct. (µS/cm)	12.80	60.20	22.11±0.77	-	1000	-
TDS (mg/L)	10.60	27.02	16.88±0.28	300	500	-
Hard. ($CaCO_3$) (mg/L)	7.21	38.75	18.65±0.56	-	150	-
Alkal. ($CaCO_3$) (mg/L)	5.00	28.50	15.59±0.36	-	-	20
TSS (mg/L)	0.00	2.68	0.79±0.04	0.25	≤5.0	-
Turbidity (NTU)	0.00	5.85	2.38±0.05	5	5	5
Zn (mg/L)	0.00	1.09	0.16±0.02	0.01	3	5
Fe (mg/L)	0.00	2.38	0.79±0.05	0.3	0.3	0.3
Mg (mg/L)	0.09	2.85	1.58±0.03	-	150	-
Mn (mg/L)	0.00	0.39	0.04±0.002	-	0.4	0.05
Cu (mg/l)	0.00	0.04	0.04±0.002	2-4	1.0	1.3
Cd (mg/L)	0.00	0.09	0.03±0.002	0.20-1.80	0.2-1.8	0.005
Pb (mg/L)	0.00	1.22	1.12±0.03	0.07	0.07	0.015
CL^- (mg/L)	1.23	11.20	6.09±0.17	300	250	250
SO_4^- (mg/L)	0.15	8.00	2.09±0.10	-	400	250
PO_4^- (mg/L)	0.00	7.30	0.96±0.11	3.50	-	-
NO_3^- (mg/L)	0.10	2.02	0.50±0.03	9.10	50	10

SE is Standard Error of Mean, Temp. is Temperature, DO is Dissolved Oxygen, BOD is Biochemical Oxygen Demand, COD is Chemical Oxygen Demand, Cond. is Conductivity, TDS is Total Dissolved Solids, TSS is Total Suspended Solids, Hard. is Hardness, Alk. is Alkalinity, Zn is Zinc, Fe is Iron, Mg is Magnesium, Mn is Manganese, Cu is Copper, Cd is Cadmium, Pb is Lead, CL^- is Chloride, SO_4^- is Sulphate, PO_4^- is Phosphate, NO_3^- is Nitrate.

Table 4.2. Seasonal variations of physico-chemical parameters of Calabar River at Okomita at the time of the study

Parameters	Wet Season Mean±SE	Dry Season Mean±SE
Water depth (m)	1.02±0.19	0.63±0.18
Transparency (mg/L)	1.02±0.19	0.63±0.18
Air temperature (^oC)	29.12±0.23	28.76±0.54
Water temp. (^oC)	26.43±0.14*	25.36±0.38*
pH	8.09±0.13*	7.50±0.15*
DO (mg/L)	4.17±0.10*	5.50±0.18*
BOD (mg/L)	1.70±0.12*	2.46±0.14*
COD (mg/L)	1.32±0.12*	0.86±0.07*
Conductivity (µS/cm)	20.92±1.85	23.79±1.16
TDS (mg/L)	18.45±0.74*	15.16±0.47*
Hardness ($CaCO_3$) (mg/L)	16.01±1.57*	22.35±0.83*
Alkalinity ($CaCO_3$) (mg/L)	13.31±0.64*	18.78±0.87*
TSS (mg/L)	0.98±0.07*	0.52±0.10*
Turbidity (NTU)	3.17±0.18*	1.29±0.12*
Zn (mg/L)	0.13±0.02	0.22±0.06
Fe (mg/L)	0.67±0.09	0.95±0.16
Mg (mg/L)	1.32±0.09*	1.94±0.11*
Mn (mg/L)	0.04±0.005	0.05±0.004
Cu (mg/L)	0.04±0.003	0.04±0.005
Cd (mg/L)	0.02±0.004	0.04±0.005
Pb (mg/L)	1.14±0.08	0.09±0.02
Cl^- (mg/L)	5.45±0.37*	7.00±0.44*
SO_4^- (mg/L)	1.87±0.17	2.40±0.28
PO_4^- (mg/L)	0.51±0.13*	1.60±0.40*
NO_3^- (mg/L)	0.50±0.08	0.50±0.06

SE is Standard Error of Mean, Temp. is Temperature, DO is Dissolved Oxygen, BOD is Biochemical Oxygen Demand, COD is Chemical Oxygen Demand, Cond. is Conductivity, TDS is Total Dissolved Solids, TSS is Total Suspended Solids, Hard. is Hardness, Alk. is Alkalinity, Zn is Zinc, Fe is Iron, Mg is Magnesium, Mn is Manganese, Cu is Copper, Cd is Cadmium, Pb is Lead, CL^- is Chloride, SO_4^- is Sulphate, PO_4^- is Phosphate, NO_3^- is Nitrate.

*** Values that are significantly different at p<0.05.**

Table 4.3. Spatial variations of physico-chemical parameters of Calabar River at Okomita at the time of the study

parameters	S1 Mean±SEM	S2 Mean±SEM	S3 Mean±SEM	S4 Mean±SEM	S5 Mean±SEM	S6 Mean±SEM
Water depth (m)	1.07±0.11^{abc}	1.66±0.06^{abc}	0.74±0.07^{ac}	0.52±0.05^{a}	0.63±0.06^{b}	0.51±0.05^{c}
Trans. (mg/L)	0.07±0.11^{abc}	1.66±0.06^{abc}	0.74±0.07^{ac}	0.52±0.05^{a}	0.63±0.06^{b}	0.51±0.05^{c}
Air temp. (^{o}C)	29.21±0.37^{a}	28.50±0.34	28.10±0.38^{a}	28.80±0.40	28.97±0.35	28.99±0.31
Water temp. (^{o}C)	24.99±0.65^{a}	26.52±0.31^{a}	26.19±0.40	26.00±0.44	26.18±0.47	26.00±0.48
pH	8.03±0.10^{ab}	8.21±0.16^{cde}	8.04±0.14^{fg}	7.71±0.20^{c}	7.52±0.12^{adf}	7.56±0.13^{beg}
DO (mg/L)	4.87±0.22^{a}	4.91±0.21^{b}	4.91±0.23^{c}	5.00±0.24^{d}	4.41±0.20	4.21±0.20^{abcd}
BOD (mg/L)	1.82±0.18	1.56±0.16	1.94±0.17	1.94±0.17	1.94±0.17	1.94±0.17
COD (mg/L)	1.03±0.18	0.99±0.15	0.97±0.14^{a}	1.37±0.19^{a}	1.27±0.89	1.13±0.11
Cond. (µS/cm)	29.51±1.90^{abcde}	22.17±0.76^{ad}	19.87±0.60^{b}	21.11±0.70^{c}	19.38±0.64^{d}	20.62±0.57^{e}
TDS (mg/L)	18.55±0.54^{ab}	18.73±0.94^{cd}	16.43±0.73	16.43±0.73	15.63±1.04^{ac}	15.50±0.87^{bd}
Hardness (mg/L)	17.36±1.73^{ab}	16.21±1.40^{cd}	18.13±1.14^{e}	16.08±0.87^{fg}	21.56±1.28^{acf}	22.52±1.08^{bdeg}
Alkalinity (mg/L)	17.98±0.78^{abc}	14.49±1.39^{a}	13.62±1.16^{bd}	14.20±0.07^{c}	16.98±1.10^{d}	16.28±1.12
TSS (mg/L)	1.10±0.13^{abc}	0.87±0.17	0.72±0.11^{a}	0.55±0.10^{b}	0.85±0.16	0.65±0.12^{c}
Turbidity (NTU)	2.290±0.25	2.76±0.33^{a}	2.61±0.24	2.04±0.22^{a}	2.28±0.2^{d}	2.33±0.14
Zn (mg/L)	0.13±0.011^{a}	0.34±0.08^{abcde}	0.09±0.01^{b}	0.17±0.03^{c}	0.12±0.02^{d}	0.13±0.02^{e}
Fe (mg/L)	0.42±0.11^{abcd}	0.54±0.12^{ef}	0.81±0.11^{a}	0.88±0.14^{b}	1.03±0.11^{ce}	1.06±1.13^{df}
Mg (mg/L)	1.40±0.96^{a}	1.50±0.12	1.43±0.70^{b}	1.64±0.09	1.83±0.12^{ab}	1.69±0.10
Mn (mg/L)	0.05±0.01	0.04±0.00	0.05±0.02	0.03±0.00^{a}	0.04±0.00	0.06±0.03^{a}
Cu (mg/L)	0.03±0.00	0.03±0.00	0.05±0.02	0.03±0.01	0.04±0.01	0.04±0.01
Cd (mg/L)	0.01±0.00^{abcde}	0.04±0.01^{acd}	0.03±0.01^{b}	0.02±0.00^{c}	0.03±0.00^{d}	0.03±0.00^{e}
Pb (mg/L)	0.04±0.01^{a}	0.05±0.01^{b}	0.05±0.01^{c}	0.05±0.01^{d}	0.14±0.06^{e}	0.37±0.10^{abcde}
Cl^- (mg/L)	7.42±0.48^{abc}	6.39±0.52	6.39±0.44	5.09±0.37^{a}	5.80±0.52^{b}	5.45±0.56^{d}
SO_4^- (mg/L)	2.47±0.30^{a}	2.75±0.37^{bcd}	2.12±0.18^{e}	1.32±0.09^{abce}	1.98±0.17^{c}	1.88±0.17^{d}
PO_4^- (mg/L)	1.61±0.33^{ab}	1.19±0.38	0.36±0.14^{ac}	0.43±0.15^{bd}	0.77±0.24	1.42±0.46^{cd}
NO_3^- (mg/L)	0.77±0.12^{abcde}	0.47±0.05^{a}	0.33±0.04^{bde}	0.33±0.02^{cfg}	0.52±0.06^{df}	0.57±0.05^{eg}

Groups with the same superscripts along the rows are not significant ($p>0.05$). Groups with different superscripts along the rows are significant ($p<0.05$). S1 is Station One, S2 is Station Two, S3 is Station Three, S4 is Station Four, S5 is Station Five and S6 is Station Six, SEM is Standard Error of Mean, Temp. is Temperature, DO is Dissolved Oxygen, BOD is Biochemical Oxygen Demand, COD is Chemical Oxygen Demand, Cond. is Conductivity, TDS is Total Dissolved Solids, TSS is Total Suspended Solids, Zn is Zinc, Fe is Iron, Mg is Magnesium, Mn is Manganese, Cu is Copper, Cd is Cadmium, Pb is Lead, CL^- is Chloride, SO_4^- is Sulphate, PO_4^- is Phosphate, NO_3^- is Nitrate.

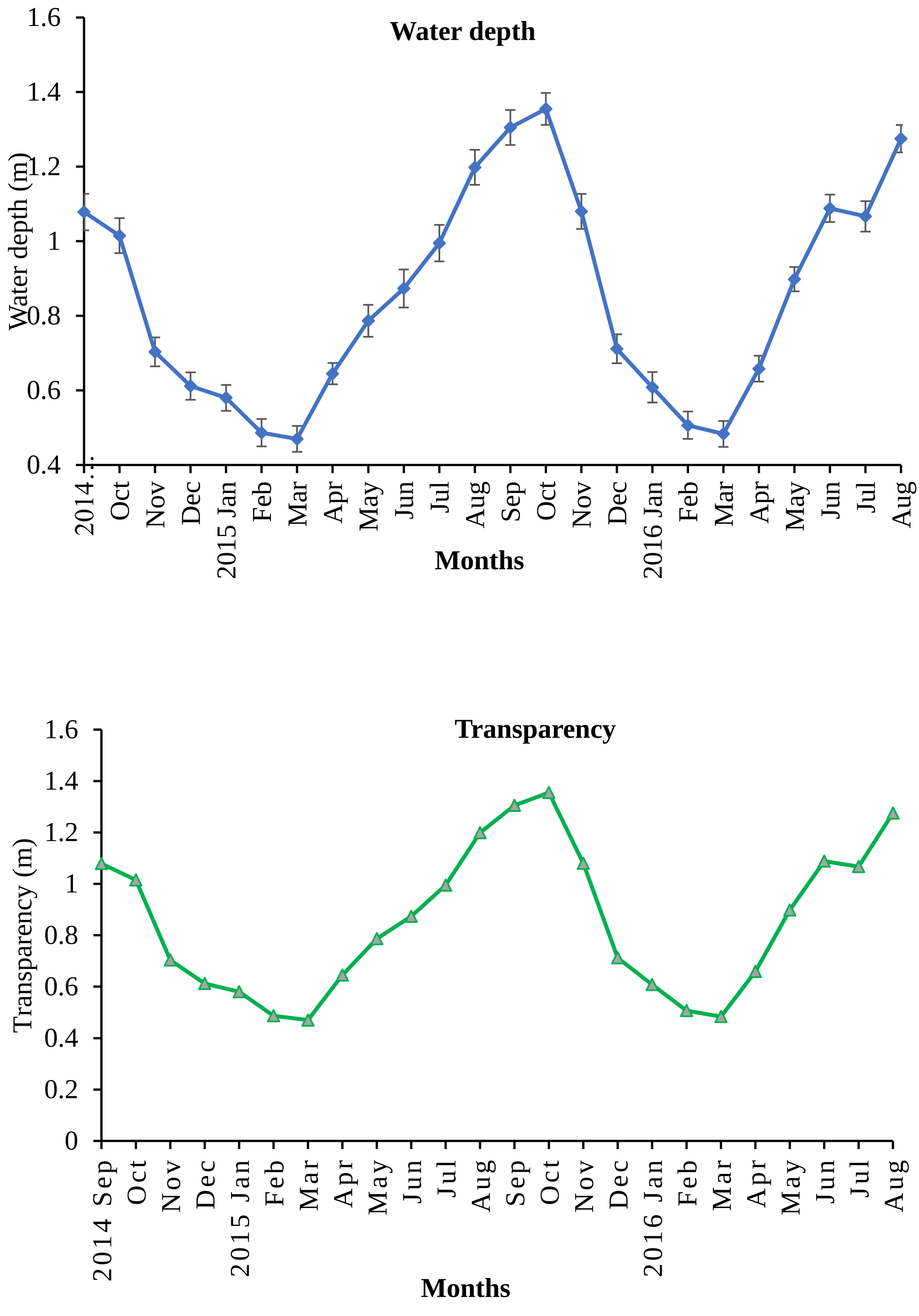


Figure 4.1. Temporal variations of water depth and transparency of Calabar River at Okomita at the time of the study

Seasonal variation was not significantly different ($p>0.05$). Significant differences in spatial variations (Table 4.3) were observed ($p<0.05$), with Station Three recording the lowest mean air temperature of 28.10±0.30^{o}C while the highest value, 29.21±0.37^{o}C was recorded at Station One. The temporal variations showed that air temperature was lowest (26.67^{o}C) in January, 2016 and highest (31.98^{o}C) in March, 2016 (Figure 4.2). Temporal fluctuations were not significantly different ($p>0.05$).

4.1.4 Water temperature

Water temperature varied from 17.00 to 31.95^{o}C (seTable 4.1). Mean value was highest in the wet season, 26.43±0.14^{o}C than dry season, 25.36±0.38^{o}C (Table 4.2). Water temperature showed significant spatial differences between Stations One and Two only, stations three to six did not show any significant difference, (Table 4.3). The lowest water temperature value was recorded at Station One (24.99±0.65^{o}C), and the highest at Station Two (26.52±0.31^{o}C). Monthly variations revealed that the lowest value, 21.83^{o}C was recorded in February, 2015 while the highest value, 29.79^{o}C was recorded in April, 2016 (Figure 4.2). Temporal variations in water temperature were significantly different ($p<0.05$). The mean value of water temperature was within NESREA (2011) recommended limit of 20-33^{o}C for aquatic life and domestic uses.

4.1.5 pH

The pH ranged from 6.02 to 9.98 with a mean value of 7.84±0.06 (Table 4.1). A higher seasonal value, 8.09±0.13 was recorded in the wet season, while the dry season value was 7.50±0.15 (Table 4.2). Seasonal variations showed significant difference ($p<0.05$). The pH also varied significantly within station ($p<0.05$) (Table 4.3), with the least value, 7.52±0.12 recorded at Station Five and the highest value, 8.21±0.16 recorded at Station Two. Higher values of pH were recorded in the wet months compared to the dry months. The peak pH value, 8.90 in terms of temporal variations was in September, 2015, while the least value, 6.71 was recorded in December, 2015 (Figure 4.3). Temporal variations were significantly different ($p<0.05$). The mean value of pH was within NESREA (2011) and WHO (2004) recommended limits of 6.5-8.5 and 6.5-9.0 respectively for aquatic life and domestic uses.

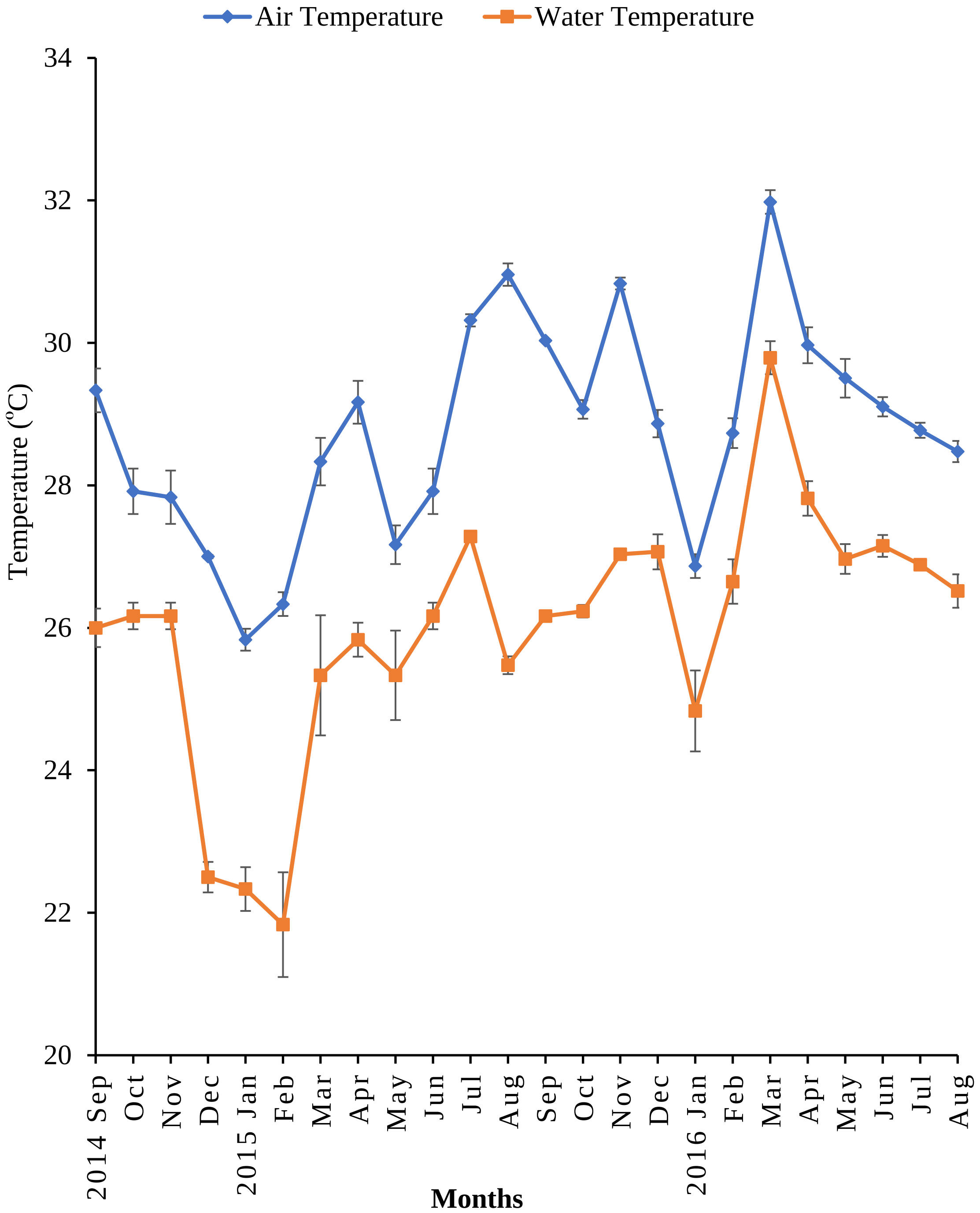


Figure 4.2. Temporal variations of air and water temperature of Calabar River at Okomita at the time of the study

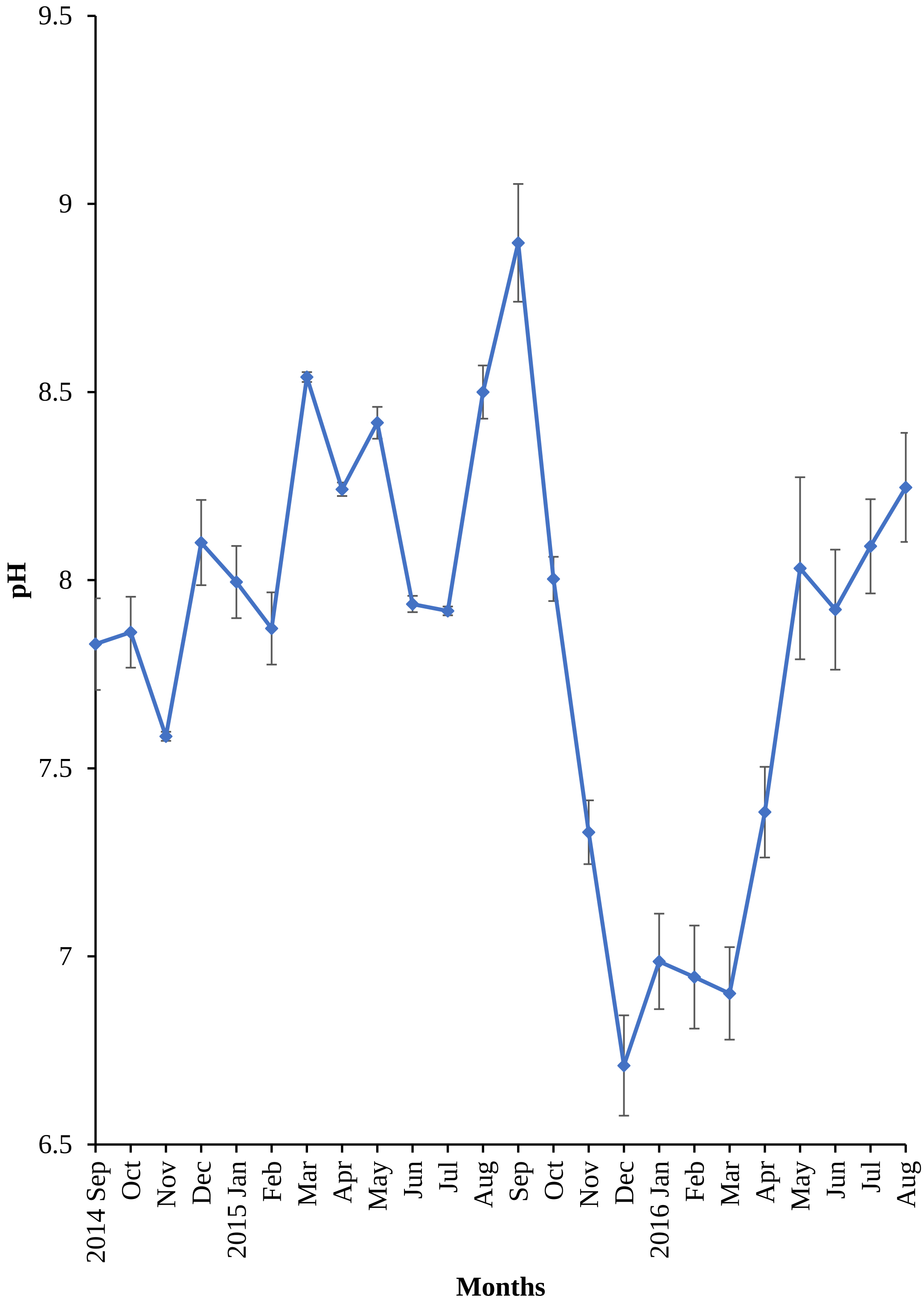


Figure 4.3. Temporal variations of pH of Calabar River at Okomita at the time of the study

4.1.6 Dissolved Oxygen

The mean concentration of Dissolved Oxygen (DO), which ranged from 2.09 to 6.74 mg/L, was 4.72±0.07 mg/L (Table 4.1). A higher value, 5.50±0.18 mg/L was recorded in the dry season, while the wet season value was 4.17±0.10 mg/L (Table 4.2). The seasonal differences in DO concentrations were significantly different at $p<0.05$. Values of DO at Station One, 4.87±0.22 mg/L; Station Two, 4.91±0.21 mg/L; Station Three, 4.91±0.23 mg/L and Station Four, 5.00±0.24 mg/L were significantly different from the concentration at Station Six (4.21±0.20 mg/L). The concentration in Station Five, 4.41±0.20 mg/L was not significantly different from the other stations. The dry months had higher DO values than the wet months. Temporal variations showed that the maximum value of DO, 6.07 mg/L was recorded in December, 2015, while the minimum value, 3.34 mg/L was recorded in May, 2016 (Figure 4.4). Temporal variations were significantly different ($p<0.05$). The mean value of dissolved oxygen was below NESREA (2011) and WHO (2004) recommended limits of 6-8 mg/L and 6.0 mg/L respectively for aquatic life and domestic uses.

4.1.7 Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) concentration ranged from 0.78 to 3.88 mg/L with a mean value of 1.86±0.03 mg/L (see Table 4.1). The mean seasonal concentration of the dry season, 2.46±0.14 mg/L was greater than the value, 1.70±0.12 mg/L in wet season (see Table 4.2). There were seasonal differences in the mean seasonal concentrations of BOD. The dry months had higher BOD concentrations than the wet months. Spatial variation did not show any significant difference (see Table 4.3). In terms of monthly variations, BOD was highest, 3.40 mg/L in March, 2016 and lowest 0.96 mg/L in June, 2015 (see Figure 4.4). There were significant differences ($p<0.05$) in the temporal variations of BOD. The mean value of BOD was below NESREA (2011) recommended limit of 4mg/L for aquatic life and domestic uses.

4.1.8 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) concentrations ranged from 0.00 to 3.05 mg/L with a mean value of 1.13±0.03 mg/L during the study period (Table 4.1). The average seasonal concentration of COD during the wet season, 1.32±0.12 mg/L was higher than the average seasonal concentration during the dry season, 0.86±0.07. There were significant seasonal variations in COD values (Table 4.2).

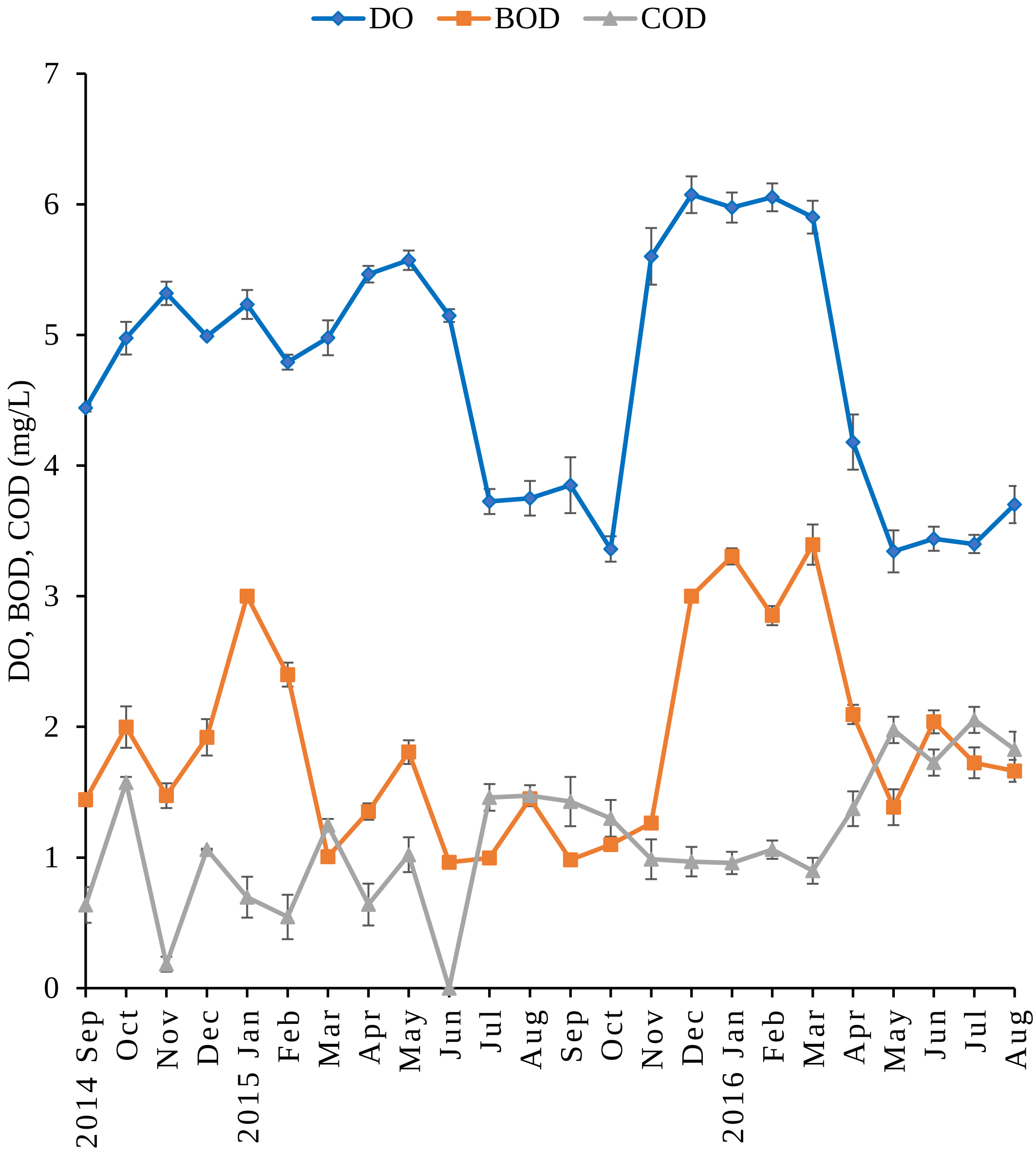


Figure 4.4. Temporal variatins in Dissolved Oxygen (DO), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) of Calabar River at Okomita at the time of the study

Stations Three, 0.97±0.14 mg/L and Four, 1.37±0.19 mg/L showed significant spatial variations, while other stations did not record any significant spatial variations (Table 4.3). The wet months had higher COD values than the dry months. The lowest, 0.00 mg/L monthly variation was recorded in June, 2015 and the highest, 2.05 mg/L was recorded in July, 2016 (Figure 4.4). There were significant differences ($p<0.05$) in the temporal variations of COD. The mean value of COD was below WHO (2004) recommended limit of 1000 mg/L for aquatic life and domestic uses.

4.1.9 Conductivity

Conductivity concentrations ranged from 12.80 to 60.20 µS/cm with a mean value of 22.11±0.77 µS/cm (see Table 4.1). The mean seasonal concentration of 23.79±1.16 µS/cm reported during the dry season exceeded the concentration, 20.92±1.85 µS/cm during the wet season. During the study period, seasonal variations did not differ significantly from one another (see Table 4.2). Mean spatial concentrations of conductivity differed significantly across stations (see Table 4.3). The value, 29.51±1.90 µS/cm of Station One was significantly different from the values of Stations Two to Five; the concentration, 22.17±0.76 µS/cm of Station Two was significantly different from the concentration, 19.38±0.64 µS/cm of Station Five at $p<0.05$ (see Table 4.3). The dry months recorded higher conductivity levels than the wet months. The highest value, 27.35 µS/cm of conductivity in terms of monthly variations was recorded in March, 2015, while the lowest, 19.15 µS/cm was recorded in July, 2015 (Figure 4.5). Temporal variations of conductivity were not significantly different ($p>0.05$). The mean value of coductivity was below WHO (2004) recommended limit of 1000 µS/cm for aquatic life and domestic uses.

4.1.10 Total Dissolved Solids

Total dissolved Solids (TDS) ranged from 10.60 to 27.02 mg/L with a mean concentration value of 16.88±0.28 mg/L (Table 4.1). The concentration of TDS, 18.45±0.74 mg/L was higher during the wet season than during the dry season, 15.16±0.47 mg/L. Between the two seasons, total dissolved solids fluctuated substantially (Table 4.2). Spatial variations showed that the concentration, 18.55±0.54 mg/L at Station One varied significantly with the concentrations at Stations Five, 15.63±1.04 mg/L and Six, 15.50±0.87 mg/L. Similarly, the concentration,

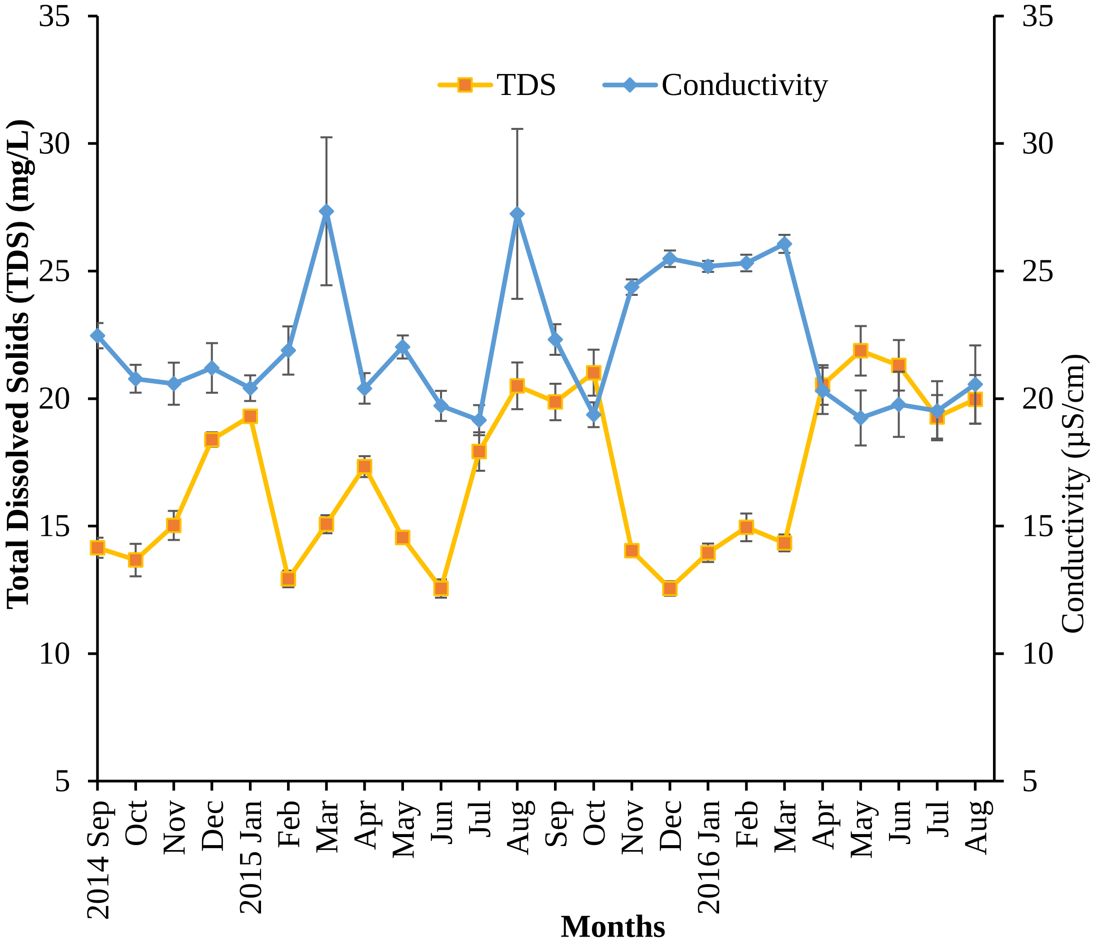


Figure 4.5. Temporal variations of conductivity and Total Dissolved Solids (TDS) of Calabar River at Okomita at the time of the study

18.73±0.94 mg/L at Station Two varied significantly with the concentrations at Stations Five, 15.63±1.04 mg/L and Six, 15.50±0.87 mg/L (Table 4.3). The wet months had higher TDS values than the dry months. The highest monthly TDS concentration, 21.8 mg/L was recorded in May, 2016 and the lowest, 12.55 mg/L was recorded in June and December, 2015 (Figure 4.5). There were significant differences ($p<0.05$) between the temporal variations of TDS. The mean value TDS was below NESREA (2011) and WHO (2004) recommended limits of 300mg/L and 500mg/L respectively for aquatic life and domestic uses.

4.1.11 Hardness

Hardness ($CaCO_3$) ranged from 7.21 to 38.75 mg/L with a mean value of 18.65±0.56 mg/L (Table 4.1). Higher mean concentration, 22.35±0.83 mg/L was recorded during the dry season compared to the concentration, 16.01±1.57 mg/L during the wet season (Table 4.2). Seasonal variations showed significant difference in water hardness during the study period. Spatial variations showed that hardness varied significantly between the stations (Table 4.3). The concentration, 17.98±1.73 mg/L at Station One varied significantly with the concentrations at Stations Five, 21.56±1.28 mg/L and Six, 22.52±1.08 mg/L. Similarly, the concentration, 16.21±1.40 mg/L at Station Two also varied significantly with the concentrations at Stations Five and Six. The dry months had higher hardness levels than the wet months. The highest, 29.16 mg/L mean monthly variation was recorded in March, 2016, while the lowest value, 13.63 mg/L was recorded in August, 2015 (Figure 4.6). Temporal variations of hardness showed significant differences ($p<0.05$). The mean value of hardness was below WHO (2004) recommended limit of 150 mg/L for aquatic life and domestic uses.

4.1.12 Alkalinity

With a mean concentration of 15.59±0.36 mg $CaCO_3$/L, alkalinity ranged from 5.00 to 28.50 mg $CaCO_3$/L (Table 4.1). Higher mean alkalinity, 18.78±0.87 mg $CaCO_3$/L was recorded during the dry season, while the wet season concentration was 13.31±0.64 mg $CaCO_3$/L (Table 4.2). The mean alkalinity varied significantly ($p<0.05$) between the wet and dry seasons. The concentration of alkalinity at Station One, 17.98±0.78 mg $CaCO_3$/L varied significantly with the concentrations at Stations Two, 14.49±1.39 mg $CaCO_3$/L, Three, 13.64±1.16 mg $CaCO_3$/L and Four, 14.20±0.07 mg $CaCO_3$/L (Table 4.3). Higher values of alkalinity were recorded in the dry months than wet months.

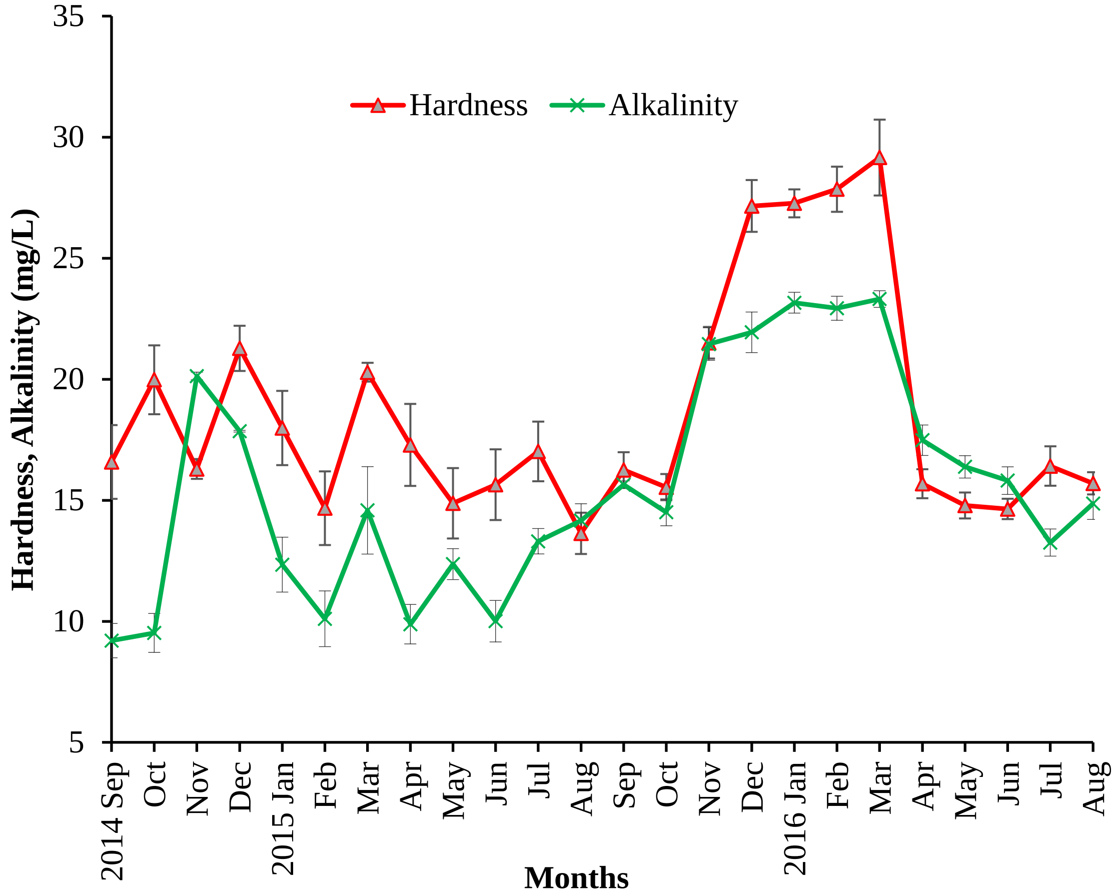


Figure 4.6. Temporal variations of hardness and alkalinity of Calabar River at Okomita at the time of the study

The highest concentration of alkalinity, 23.31 mg CaCO3/L was recorded in March, 2016, while the least concentration, 9.20 mg CaCO3/L was recorded in September, 2014 (Figure 4.6). There were significant differences ($p<0.05$) in the temporal variations of alkalinity.

4.1.13 Total Suspended Solids

With a mean value of 0.79±0.04 mg/L, the Total Suspended Solids (TSS) concentration ranged from 0.00 to 2.68 mg/L (Table 4.1). Concentration of TSS was higher, 0.98±0.07 mg/L in the wet season than the dry season, 0.52±0.10 mg/L at the time of the study (Table 4.2). The concentrations during the wet and dry seasons differed significantly ($p<0.05$). The TSS, 1.10±0.13 mg/L at Station One varied spatially with the concentrations at Stations Three, 0.72±0.11 mg/L, Four, 0.55±0.10 mg/L and Six, 0.65±0.12 mg/L (Table 4.3). Compared to the dry months, the wet months had higher TSS values. The highest concentration of TSS, 1.55 mg/L in terms of monthly variations was recorded in August, 2016, while the lowest concentration, 0.03 mg/L was recorded in December, 2015 (Figure 4.7). Temporal variations of TSS showed significant differences ($p<0.05$). The mean value of TSS was below WHO (2004) recommended limit of ≤5.0 mg/L for aquatic life and domestic uses.

4.1.14 Turbidity

The concentrations of turbidity ranged from 0.00 to 5.85 NTU with a mean value of 2.38±0.05 NTU (Table 4.1). Higher mean seasonal value, 3.17±0.18 NTU was recorded in the wet season, while the dry season was 1.29±0.12 NTU (Table 4.2). Seasonal changes revealed a significant seasonal difference ($p<0.05$). Turbidity in Stations Two, 2.76±0.33 NTU and Four, 2.04±0.22 NTU varied significantly (Table 4.3). Higher values of turbidity were recorded in the wet months compared to the dry months. Monthly variations showed that the highest mean concentration, 4.06 NTU was recorded in June, 2016, while the lowest, 0.96 NTU was in February, 2015 (Figure 4.7). There were significant differences in the temporal variations of turbidity ($p<0.05$). The mean value of turbidity was below NESREA (2011), WHO (2004) and USEPA (2010) recommended limit of 5 NTU for aquatic life and domestic uses.

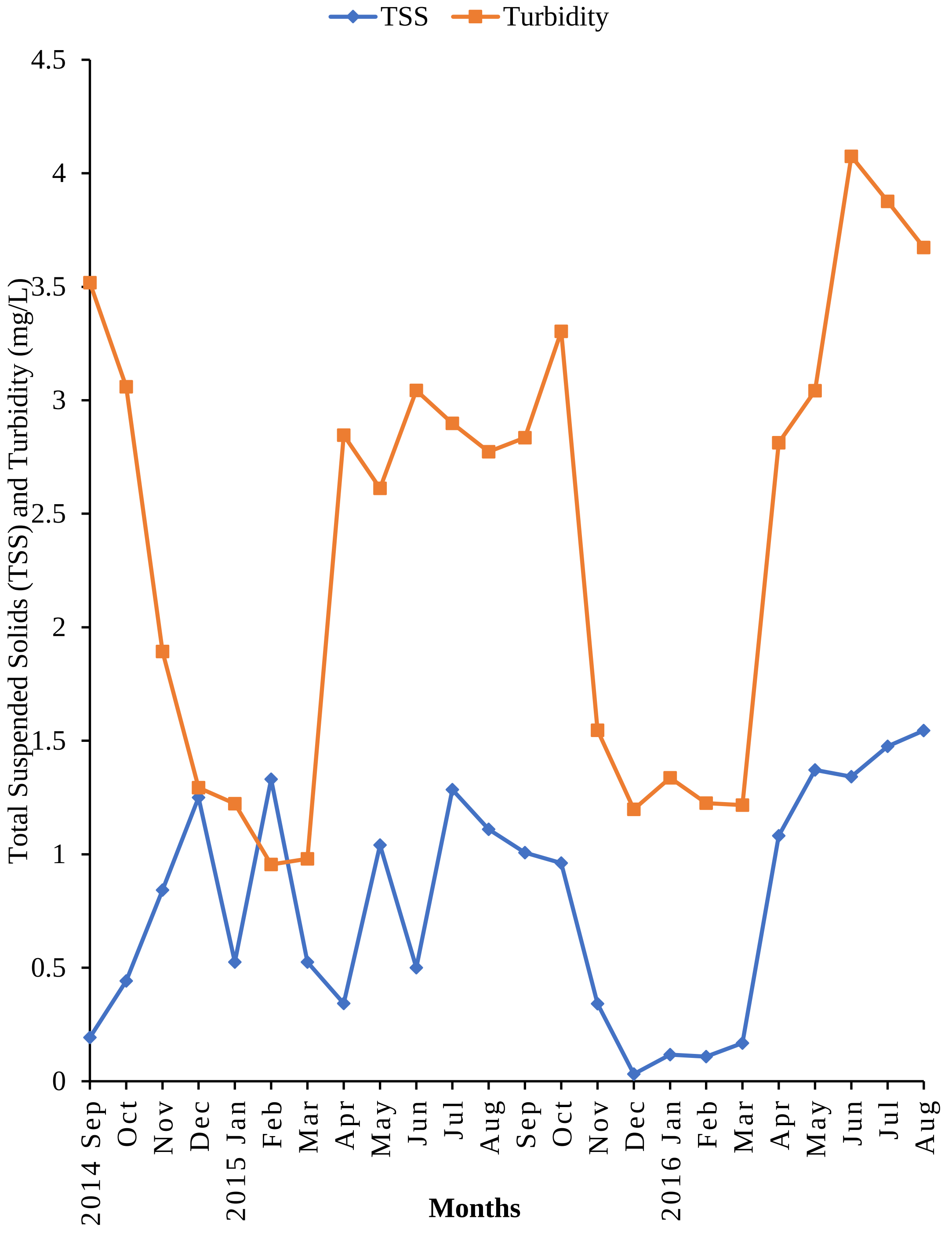


Figure 4.7. Temporal variations in total total suspended solids and turbidity of Calabar River at Okomita at the time of the study

4.1.15 Heavy metals

4.1.15.1 Zinc

With a mean value of 0.16±0.02 mg/L, zinc (Zn) concentrations ranged from 0.00 to 1.09 mg/L (Table 4.1). The wet season concentration, 0.13±0.02 mg/L, was lower than the dry season concentration, 0.2±20.06 mg/L. The two seasons (wet and dry) did not differ significantly from one another (Table 4.2). Spatial variations revealed that Zn concentration at Station Two varied significantly with the concentration at other stations. Station Two had the highest concentration, 0.34±0.08 mg/L, while Station Three had the lowest concentration, 0.09±0.01 mg/L at the time of the study (Table 4.3). Higher values of Zn were recorded in the dry than the wet season months. Monthly variations showed that the highest concentration, 0.44 mg/L was recorded in December, 2015, while the lowest concentrations, 0.00 mg/L were recorded in August and September, 2015 respectively (Figure 4.8). Temporal variations did not show any significant differences ($p>0.05$) in Zn. The mean value of Zn was below NESREA (2011) recommended limit of 0.01 mg/L but above WHO (2004) and USEPA (2010) recommended limits of 3 mg/L and 5 mg/L respectively for aquatic life and domestic uses.

4.1.15.2 Iron

Iron (Fe) concentrations ranged from 0.00 to 2.38 mg/L with mean concentration of 0.79±0.05 mg/L at the time of the study (Table 4.1). The dry season's concentration, 0.95±0.16 mg/L, was greater than the wet season's concentration, 0.67±0.09 mg/L. The two seasons did not significantly differ from one another (Table 4.2). Spatial variations showed that the concentration, 0.42±0.11 mg/L of Fe at Station One varied significantly with the concentrations at Stations Three, 0.81±0.11 mg/L; Four, 0.88±0.14 mg/L; Five, 1.03±0.11 mg/L and Six, 1.06±1.13 mg/L (Table 4.3). The highest mean concentration, 1.91 mg/L for monthly variations was recorded in May, 2015, while the lowest concentration, 0.15 mg/L was in July and September, 2015 (Figure 4.8). Temporal fluctuations of Fe did not show any significant differences ($p>0.05$). The mean value of Fe was below NESREA (2011), WHO (2004) and USEPA (2010) recommended limit of 5 mg/L for aquatic life and domestic uses.

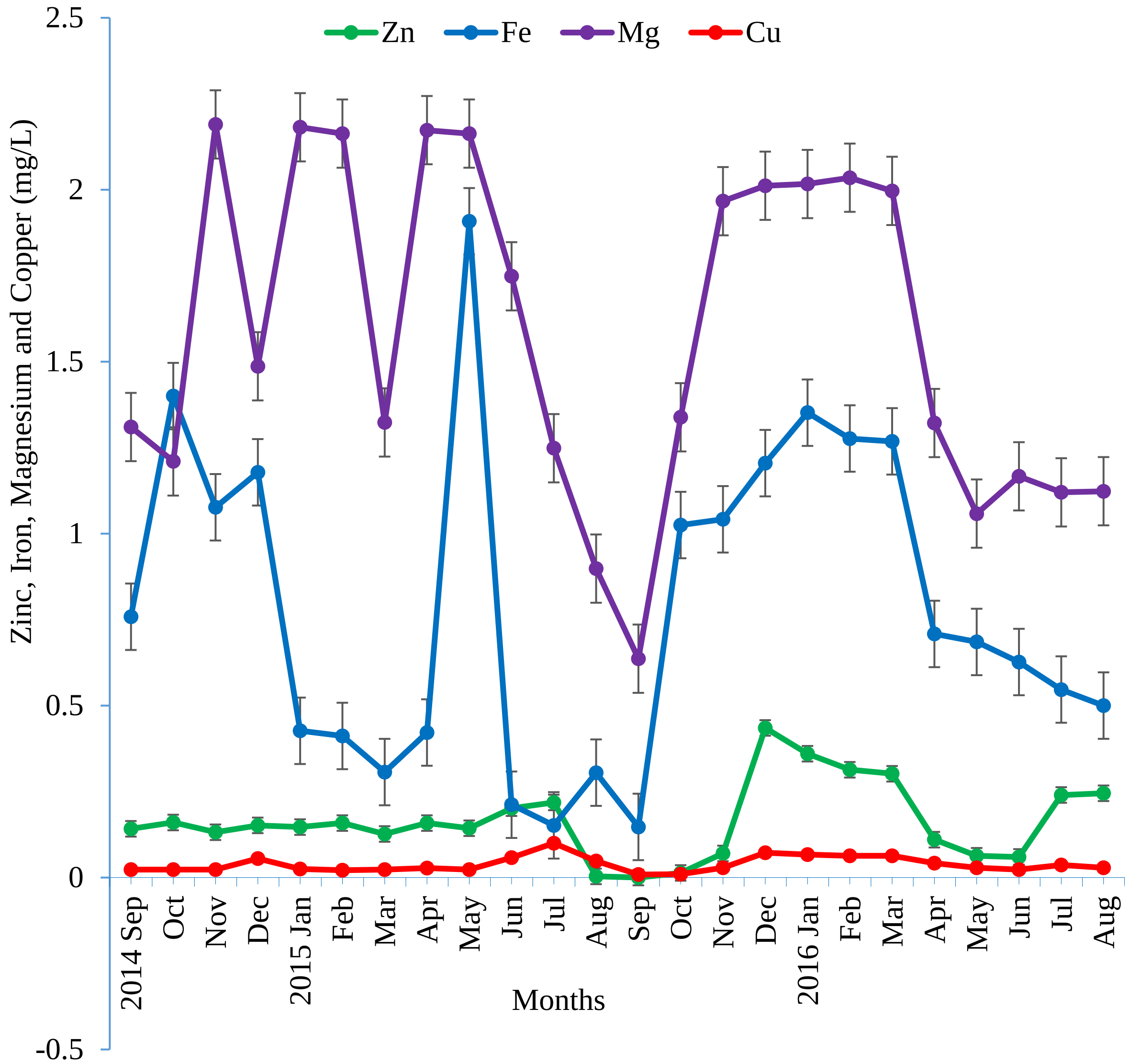


Figure 4.8. Temporal variations in zinc, iron and magnesium of Calabar River at Okomita at the time of the study

4.1.15.3 Magnesium

Magnesium (Mg) concentration ranged from 0.09 to 2.85 mg/L with a mean concentration value of 1.58±0.03 mg/L during the period of study (Table 4.1). The concentration, 1.94±0.11 mg/L in the dry season was higher than the concentration, 1.32±0.09 mg/L) in the wet season and the values were significantly different (Table 4.2). Spatial variation (Table 4.3) showed that the concentration, 1.83±0.12 mg/L at Station Five varied significantly from the concentrations at Stations One, 1.40±0.96 mg/L and Three, 1.43±0.70 mg/L. The dry season months had higher Mg values than the wet season months. Magnesium concentrations varied monthly, with the greatest value, 2.19 mg/L recorded in November 2014 and the lowest value, 0.64 mg/L recorded in September 2015 (Figure 4.8). Temporal variations of magnesium did not show any significant difference ($p>0.05$). The mean value of Mg was below WHO (2004) recommended limit of 150 mg/L for aquatic life and domestic uses.

4.1.15.4 Copper

Copper (Cu) concentrations ranged from 0.00 to 0.04 mg/L with a mean value of 0.04±002 mg/L during the study period (Table 4.1). Seasonal variation was not significantly different ($P>0.05$) since Cu concentration had equal values, 0.04 mg/L in both seasons (Table 4.2). Similarly, there were no significant variations in the concentration of copper along the stations (Table 4.3). The highest concentration, 0.10 mg/L was recorded in July, 2015, while the lowest value, 0.0 mg/L was recorded in September and October, 2015 each (Figure 4.8). There were no significant differences in temporal fluctuations of Cu. The mean value of Cu was below NESREA (2011), WHO (2004) and USEPA (2010) recommended limits of 2-4 mg/L, 1.0 mg/L, and 1.3 mg/L respectively for aquatic life and domestic uses.

4.1.15.5 Manganese

With a mean value of 0.04±0.002 mg/L, manganese (Mn) concentrations ranged from 0.00 to 0.39 mg/L (Table 4.1). The concentration was higher in the dry season (0.05±0.004 mg/L) than the wet season (0.04±0.005 mg/L). Seasonal variations did not show significant difference (see Table 4.2). Spatial variations (Table 4.3) showed that the value, 0.03±0.00 mg/L of Mn at Station Four was significantly different from the concentration, 0.06±0.03 mg/L at Station Six. Monthly variations revealed that the highest concentration, 0.10 mg/L was in July, 2015,

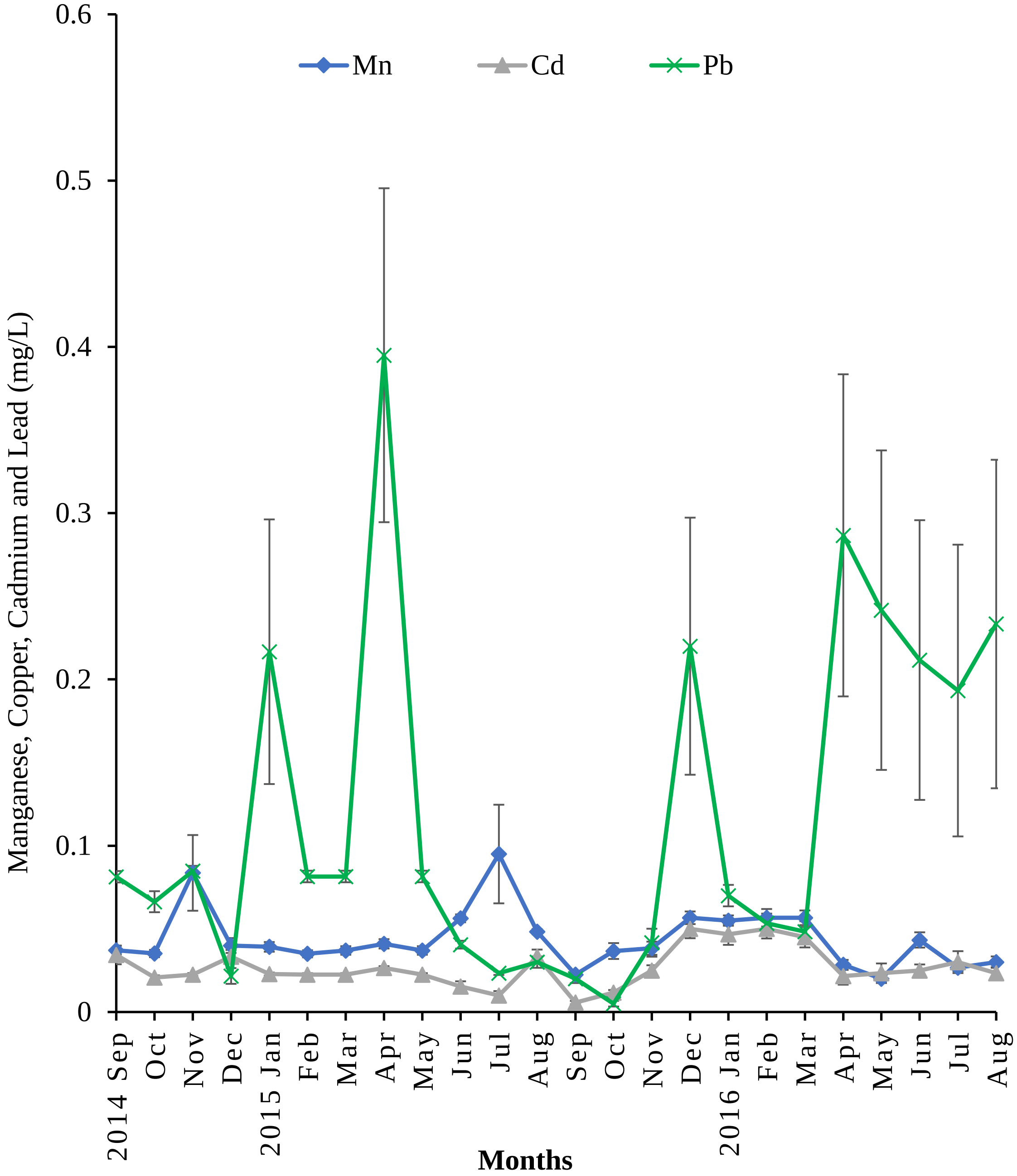


Figure 4.9. Temporal variations in manganese, copper, cadmium and lead of Calabar River at Okomita at the time of the study

while the lowest concentration, 0.02 mg/L was in September, 2015 and May, 2016 (Figure 4.9). There were no significant differences (P>0.05) in temporal fluctuations of Mn. The mean value of Mn was below WHO (2004) recommended limit of 0.4 mg/L for aquatic life and domestic uses.

4.1.15.6 Cadmium

Cadmium (Cd) concentrations ranged from 0.00 to 0.09 mg/L with a mean value of 0.03±0.002 mg/L (Table 4.1). The concentration, 0.04±0.005 mg/L was higher in the dry season compared to the wet season, 0.02±0.004 mg/L (Table 4.2). Seasonal variation was not significant (P>0.05). Cadmium varied spatially within the sampling stations. The concentration at Station One, 0.01±0.00 mg/L differed significantly from the concentrations at the other stations (Table 4.3). The concentrations, 0.04±0.01 mg/L) at Station Two was significantly different from the concentrations at Stations Four, 0.02±0.00 mg/L and Five, 0.03±0.00 mg/L. Highest Cd concentration of 0.05 mg/L was recorded in December, 2015 and January, February and March, 2016, while the lowest concentration of 0.01 mg/L was recorded in July, September and October, 2015 (Figure 4.9). Temporal variations of Cd were not significant (p>0.05). The mean value of Cd was below NESREA (2011) recommended limit of 0.20-1.80 mg/L for aquatic life and domestic uses.

4.1.15.7 Lead

Lead (Pb) concentration ranged from 0.00 to 1.22 mg/L with a mean value of 0.12±0.03 mg/L (Table 4.1). The concentration was higher in the wet season, 0.14±0.08 mg/L than in the dry season, 0.09±0.02 mg/L (Table 4.2); the seasonal difference was not significant. Spatial variations showed that the highest concentration, 0.37±0.10 mg/L was in Station Six and the lowest concentration, 0.04±0.01 mg/L in Station One (Table 4.3). The concentration in Station Six varied significantly with all the other stations. Highest concentration of Pb were recorded in the wet than dry months. Highest Pb concentration, 0.40 mg/L was recorded in April, 2015, while the lowest concentration, 0.01 mg/L was recorded in October, 2015 (Figure 4.9). Temporal variations of Pb were not significant (p>0.05). The mean value of Pb was above NESREA (2011) and WHO (2004) recommended limit of 0.07 mg/L and USEPA (2010) recommended limit of 0.015 mg/L for aquatic life and domestic uses.

4.1.16 Nutrients

4.1.16.1 Chloride

Chloride (Cl^-) concentration ranged from 1.23 to 11.20 mg/L with a mean value of 6.09±0.17 mg/L (Table 4.1). A higher mean concentration was recorded in the dry season, 7.00±0.44 mg/L than the wet season, 5.45±0.37 mg/L (Table 4.2). Chloride varied significantly ($p<0.05$) seasonally at the time of the study. Spatial variations showed that the concentration, 7.42±0.48 mg/L of Cl^- at Station One was significantly different from the concentrations at Stations Four, 5.09±0.37 mg/L; Five, 5.80±0.52 mg/L and Six, 5.45±0.56 mg/L (Table 4.3). The dry months had higher values than the wet months. Monthly variations showed that the highest concentration, 9.04 mg/L was in December, 2015, while the lowest concentration, 1.34 mg/L was in November, 2014 (Figure 4.10). Temporal variations were significantly different ($p<0.05$). The mean value of Cl^- was below NESREA (2011) and WHO (2004) recommended limits of 300 mg/L and 250 mg/L respectively for aquatic life and domestic uses.

4.1.16.2 Sulphate

Sulphate (SO_4^-) concentration ranged from 0.15 to 8.00 mg/L with a mean concentration of 2.09±0.10 mg/L (Table 4.1). A higher mean concentration, 2.40±0.28 mg/L was recorded in the wet season than dry season, 1.87±0.17 mg/L (Table 4.2), though the variation was not significantly different. The SO_4^- concentration, 2.47±0.30 mg/L in Station One was significantly different ($p<0.05$) from the concentration, 1.32±0.09 mg/L in Station Four (Table 4.3). The highest SO_4^- concentration, 2.75±0.37 was recorded at Station Two while the lowest was recorded at Station Six, 1.88±0.17 mg/L (Table 4.3). Higher values of SO_4^- were recorded in the wet than dry months. Monthly variations showed that the highest concentration, 3.07 mg/L of SO_4^- was recorded in June, 2015, while the lowest concentration, 0.02 mg/L was recorded in December, 2014 (Figure 4.10). Temporal variations of SO_4^- did not show any significant difference ($P>0.05$). The mean value of SO_4^- was below WHO (2004) and USEPA (2010) recommended limits of 400 mg/L and 250 mg/L respectively for aquatic life and domestic uses.

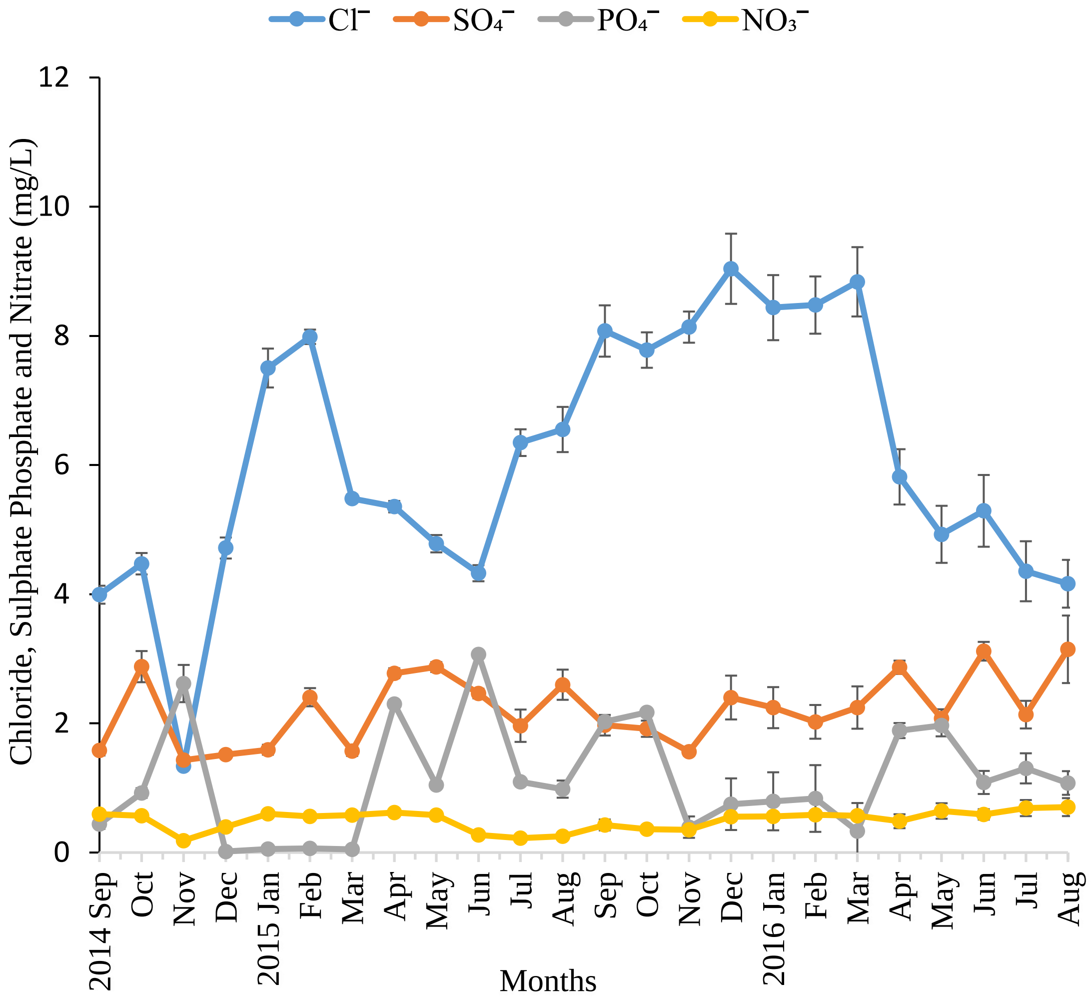


Figure 4.10. Temporal variations in chloride, sulphate, phosphate and nitrate of Calabar River at Okomita at the time of the study

4.1.16.3 Phosphate

Phosphate ($PO4^{-}$) concentration ranged from 0.00 to 7.30 mg/L with a mean value of 0.96±0.11 mg/L (Table 4.1). A higher concentration, 1.60±0.40 mg/L was recorded in the dry season than the concentration, 0.51±0.13 mg/L in the wet season (Table 4.2), and these seasonal values were significantly different ($p<0.05$). The highest concentration, 1.61±0.33 mg/L in terms of spatial variations was recorded at Station One, while the lowest concentration, 0.36±0.14 mg/L was recorded at Station Three (Table 4.3).The concentration in Station One varied significantly ($p<0.05$) from the concentrations in Stations Three and Four, 0.43±0.15 mg/L (Table 4.3). Higher values of PO_4^- were recorded in the wet than dry months. Monthly variations showed that the highest concentration, 3.15 mg/L of PO_4^- was recorded in August, 2016, while the lowest concentration, 1.45 mg/L was recorded in November, 2014 (Figure 4.10). Temporal variations of PO_4^- did not show any significant difference ($p>0.05$). The mean value of PO_4^- was below NESREA (2011) recommended limit of 3.50 mg/L for aquatic life and domestic uses.

4.1.16.4 Nitrate

Nitrate (NO_3^-) concentration (Table 4.1) ranged from 0.10 to 2.02 mg/L with a mean of 0.50±0.03 mg/L. The concentration of nitrate was equal in both seasons, 0.50 mg/L and did not vary significantly ($p>0.05$) at the time of this study (Table 4.2). The highest concentration in terms of spatial variations was recorded at Station One, 0.77±0.12 mg/L, while the lowest was recorded at Stations Three, 0.33±0.04 and Four, 0.33±0.02 (Table 4.3). The concentration of NO_3^- in Station One was significantly different ($p<0.05$) from the concentration in all the other stations (Table 4.3). The concentration at Station Three varied significantly ($p<0.05$) with the concentrations at Stations Five, 0.52±0.06 mg/L and Six, 0.57±0.05 mg/L. Nitrate had low values throughout the study period. The highest concentration, 0.70 mg/L for monthly variations was recorded in August, 2016, while the lowest value, 0.19 mg/L was recorded in November, 2014 (Figure 4.10). Temporal variations were not significantly different ($p>0.05$). The mean value of NO_3^- was below NESREA (2011), WHO (2004) and USEPA (2010) recommended limits of 9.10 mg/L, 50 mg/L and 10 mg/L respectively for aquatic life and domestic uses.

Table 4.4. Checklist of phytoplankton taxa encountered showing pollution indicators in Calabar River at Okomita at the time of the study

Phylum Class Order Family	Species
BACILLARIOPHYTA	
Bacillariophyceae (Diatoms)	
Bacillariales	
Bacillariaceae	*Bacillaria aurita* (Gmelin, 1788)
	Bacillaria paradoxa (Gmelin, 1788)
Coscinodiscales	
Coscinodiscaceae	*Coscinodiscus radiatus* (Ehrenberg, 1840)
	Coscinodiscus excentricus (Ehrenberg, 1840)
	Coscinodiscus lineatus (Ehrenberg, 1840)
Cymbellales	
Cymbellaceae	*Cymbella affinis** (Agardh, 1830)
Fragilariales	
Fragilariaceae	*Fragilaria striatula* (Lyngbye, 1819)
	Fragilaria capucina (Desmazières, 1830)
	*Synedra affinis** (Kützing, 1844)
	*Synedra acus** (Kützing, 1844)
Surirellales	
Surirellaceae	*Surirella ovalis** (Brébisson, 1838)
	*Surirella oblonga** (Ehrenberg, 1843)
	*Navicula petersenii** (Hustedt, 1937)
Naviculales	
Pinnulariaceae	*Pinnularia major** **(**Rabenhorst, 1853)
Pleurosigmataceae	*Gyrosigma sp.* (Reid, 2003)
Melosirales	
Melosiraceae	*Melosira granulata** (Ralfs, 1861)
Bacillariales	
Bacillariaceae	*Nitzschia paradoxa* (Grunow, 1880)
	Nitzschia sp. (Hassall, 1845)
Tabellarialles	
Tabellariaceae	*Asterionella formosa* (Hassall, 1850)
	Tabellaria sp. (Kützing, 1844)

*** = Pollution indicators**

Table 4.4. Contd. Checklist of phytoplankton taxa encountered showing pollution indicators in Calabar River at Okomita at the time of the study

Phylum Class Order Family	Species
CHAROPHYTA	
Chlorophyceae (Green Algae)	
Desmidiales	
Closteriaceae	*Closterium leibleinii** (Ralfs 1848)
	*Closterium lunula** (Ralfs 1848)
Gonatozygaceae	*Genicularia spirotaenia* (De Bary, 1858)
Zygnematales	
Zygnemataceae	*Spirogyra grassa*
Ulotrichales	
Ulotrichaceae	*Ulothrix sp.*
Desmidiales	
Desmidiaceae	*Euastrum sp.*
	Cosmarium granatum (Ralfs, 1848)
	Micrasterias sp.
CYANOBACTERIA	
Cyanophyceae (Blue-Green Algae)	
Chroococcales	
Microcystaceae	*Merismopedia elegans** (Kützing, 1849)
Oscillatoriales	
Oscillatoriaceae	*Oscillatoria tenuis** (Gomont 1892)
Spirulinales	
Spirulinaceae	*Spirulina sp** (Gomont, 1892)
Chrysophyceae (Golden Algae)	
Nostocales	
Aphanizomenonaceae	*Aphanizomenon sp.* (Flahault, 1888)
Chromulinales	
Dinobryaceae	*Dinobryon sp.*
Chromulinaceae	*Ochromonas sp.*
DINOFLAGELLATA	
Dinophyceae (Dinoflagellates)	
Gonyaulacales	
Ceratiaceae	*Ceratium hirundinella* (Dujardin, 1841)
Peridiniales	
Peridiniaceae	*Peridinium sp.*
EUGLENOZOA	
Euglenophyceae (Euglenoids)	
Euglenales	
Euglenaceae	*Euglena acus** (Ehrenberg, 1830)
Phacaceae	*Phacus caudata** (Hübner, 1886)

*** = Pollution indicators**

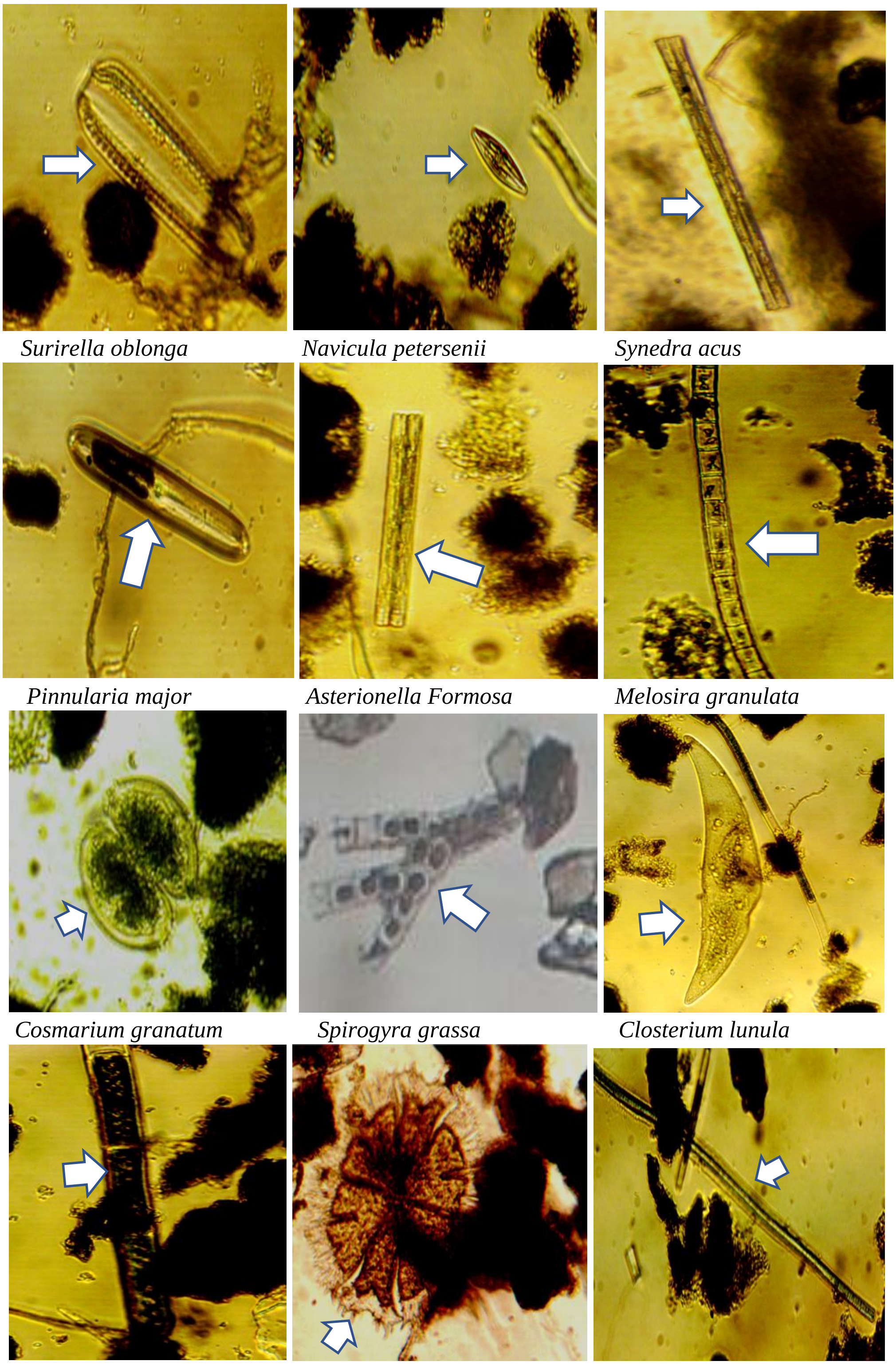
4.2 Phytoplankton

4.2.1 Phytoplankton composition and abundance

The checklist of the identified phytoplankton of Calabar River at Okomita at the time of this study is presented in Table 4.4. Twenty-Four (24) families and thirty-nine (39) species of phytoplankton were identified. Some of the phytoplankton encountered are shown in Plates 4.1. Bacillariophyceae had the highest number of identified species (20 species) and accounted for 70.49% of the phytoplankton abundance (Figure 4.11). The most abundant species of Bacillariophyceae were *Navicula petersenii* (9.69%), *Synedra acus* (8.63%), *Coscinodiscus radiatus* (5.70%) and *Coscinodiscus excentricus* (5.26%) (Table 4.5). Chlorophyceae was next to Bacillariophyceae in terms of number of species (9) and abundance (15.30%) of individuals (see Figure 4.11). Chlorophyceae was dominated by *Spirogyra grassa* with 2.44% followed by *Ulotrix* sp. and *Euastrum* sp. with 1.92% abundance each (Table 4.5). Cyanophyceae accounted for 6.03% of the phytoplankton. *Oscillatoria tenuis* dominated the blue-green algae with 2.37% followed by *Spirulina species* with 2.06%. Bio-indicator genera of phytoplankton recorded were: *Cymbella*, *Synedra*, *Surirella*, *Pinnularia*, *Melosira*, *Navicula*, *Closterium*, *Merismopedia*, *Oscillatoria*, *Spirulina*, *Euglena and Phacus* (Table 4.5).

4.2.2 Temporal abundance of phytoplankton

In the wet season, Bacillariophyceae had the highest percentage abundance (69.35%) while Dinophyceae had the lowest (1.51%) (Figure 4.12). Bacillariophyceae and Chrysophyceae were significantly higher ($p<0.05$) in the wet season than dry season. The percentage abundance of Cyanophyceae was significantly ($p<0.05$) higher in the dry season than wet season. Higher seasonal abundance of the total phytoplankton was recorded in the wet season (67.49%) than dry season (32.51%) and the variation was significant ($p<0.05$) (Figure 4.12). The highest monthly percentage abundance for Bacillariophyceae, 11.63% was recorded in April, 2015 and the lowest, 1.68% was recorded in December, 2015 (Figure 4.13). The highest temporal percentage abundance of Chlorophyceae (7.72%) was in September, 2014, while the lowest (2.04%) was in February, 2015. Percentage abundance of Cyanophyceae was highest (8.39%) in September, 2014 and the lowest (1.68%) in December, 2014. Bacillariophyceae, Chrysophyceae, Dinophyceae and Euglenophyceae had higher temporal percentage abundance in the wet season (Figure 4.13).



Surirella oblonga | *Navicula petersenii* | *Synedra acus*

Pinnularia major | *Asterionella Formosa* | *Melosira granulata*

Cosmarium granatum | *Spirogyra grassa* | *Closterium lunula*

Genicularia spirataenia | *Micrasterias* sp. | *Oscillatoria tenuis*

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Plate 4.1. Some phytoplankton encountered in Calabar River at Okomita at the time of the study

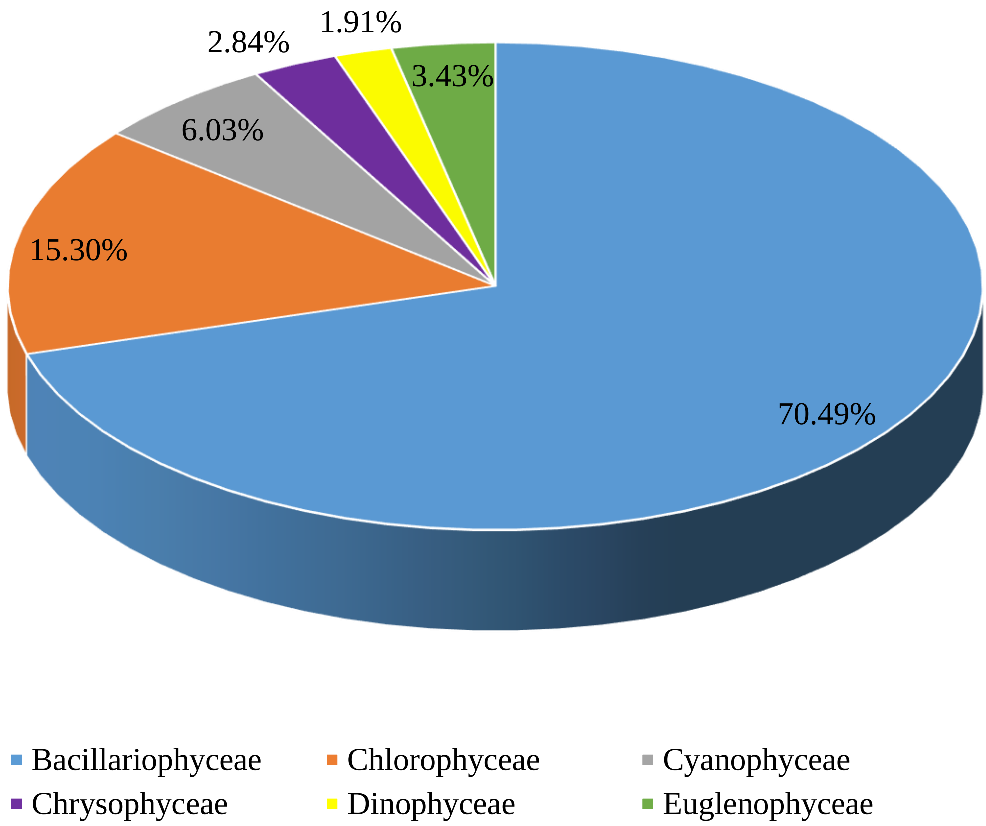


Figure 4.11. Percentage abundance of phytoplankton of Calabar River at Okomita at the time of the study

Table 4.5. Relative abundance of phytoplankton composition of Calabar River at Okomita at the time of the study

Phytoplankton Class	Species	Number of cells/mL	% Number
Bacillariophyceae			
	Navicula petersenii	1148	9.69
	Synedra acus	1022	8.63
	Coscinodiscus radiatus	675	5.70
	Coscinodiscus excentricus	623	5.26
	Asterionella formosa	574	4.84
	Bacillaria aurita	535	4.52
	Coscinodiscus lineatus	446	3.76
	Fragilaria striatula	380	3.21
	Bacillaria paradoxa	373	3.15
	Surirella oblonga	278	2.35
	Pinnularia major	265	2.24
	Melosira granulata	256	2.16
	Cymbella affinis	251	2.12
	Gyrosigma sp.	251	2.12
	Surirella ovalis	247	2.08
	Fragilaria capucina	236	2.00
	Synedra affinis	206	1.74
	Tabellaria sp.	206	1.74
	Nitzschia paradoxa	196	1.65
	Nitzschia sp.	184	1.55
	Sub Total	**8,352**	**70.49**
Chlorophyceae			
	Spirogyra grassa	289	2.44
	Euastrum sp.	228	1.92
	Ulothrix sp.	228	1.92
	Closterium lunula	222	1.87
	Trachelomonas volvocina	191	1.61
	Closterium leibleinii	160	1.35
	Micrasterias sp.	156	1.32
	Cosmarium granatum	192	1.26
	Genicularia spirotaenia	147	1.24
	Sub Total	**1,813**	**15.30**
Cyanophyceae			
	Oscillatoria tenuis	281	2.37
	Spirulina sp.	244	2.06
	Merismopedia elegans	190	1.60
	Sub Total	**715**	**6.03**

Table 4.5 contd. Relative abundance of phytoplankton composition of Calabar River at Okomita at the time of the study

Phytoplankton Class	Species	Number of cells/mL	% Number
Chrysophyceae			
	Dinobryon sp.	146	1.23
	Aphanizomenon sp.	118	1.00
	Ochromonas sp.	72	0.61
	Sub Total	**336**	**2.84**
Dinophyceae			
	Ceratium hirundinella	120	1.01
	Peridinium sp.	106	0.89
	Sub Total	**226**	**1.91**
Euglenophyceae			
	Euglena acus	295	2.49
	Phacus caudata	112	0.95
	Sub Total	**407**	**3.43**
Grand Total		**11,849**	**100**

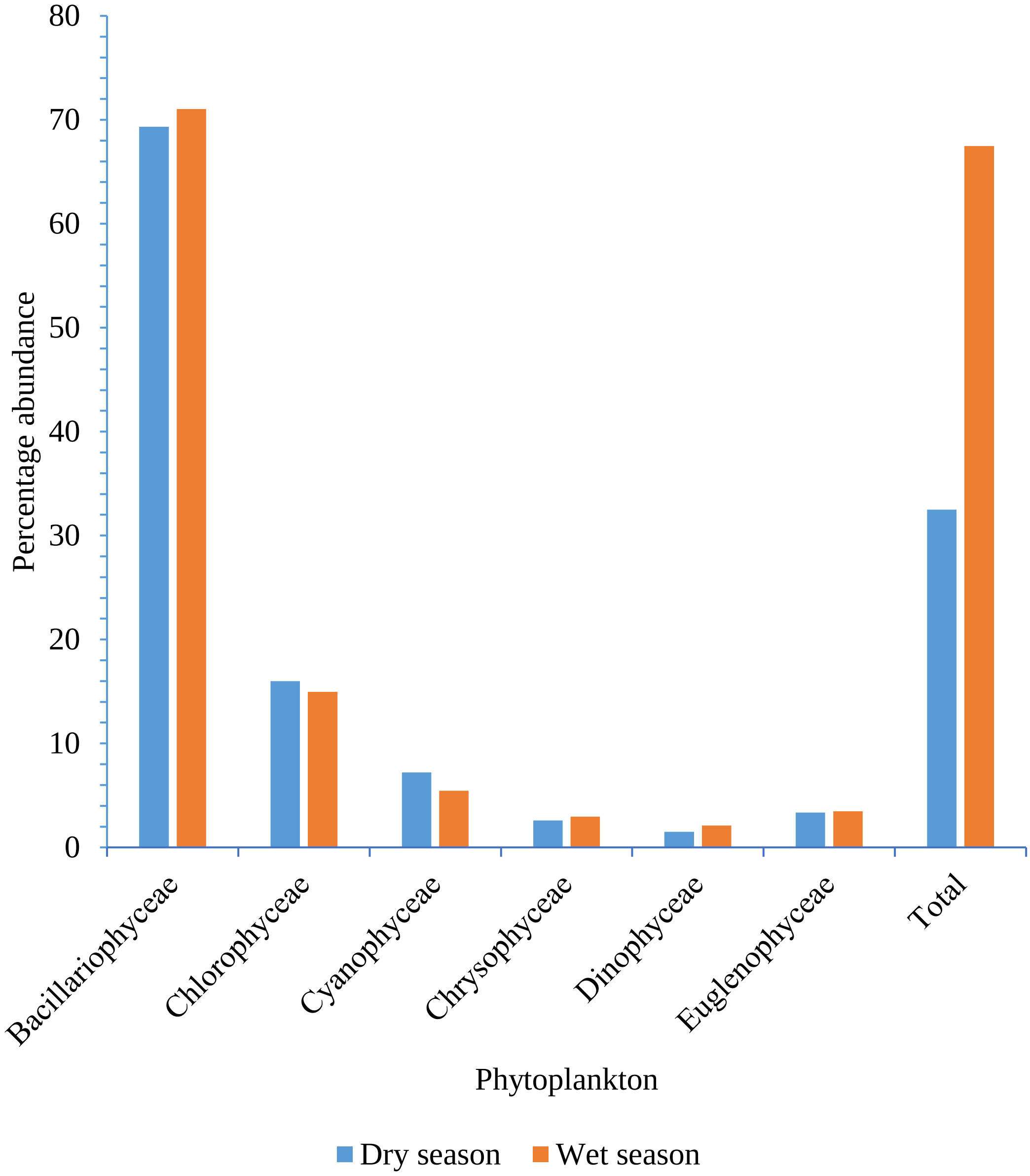


Figure 4.12. Seasonal percentage abundance of phytoplankton of Calabar River at Okomita at the time of the study

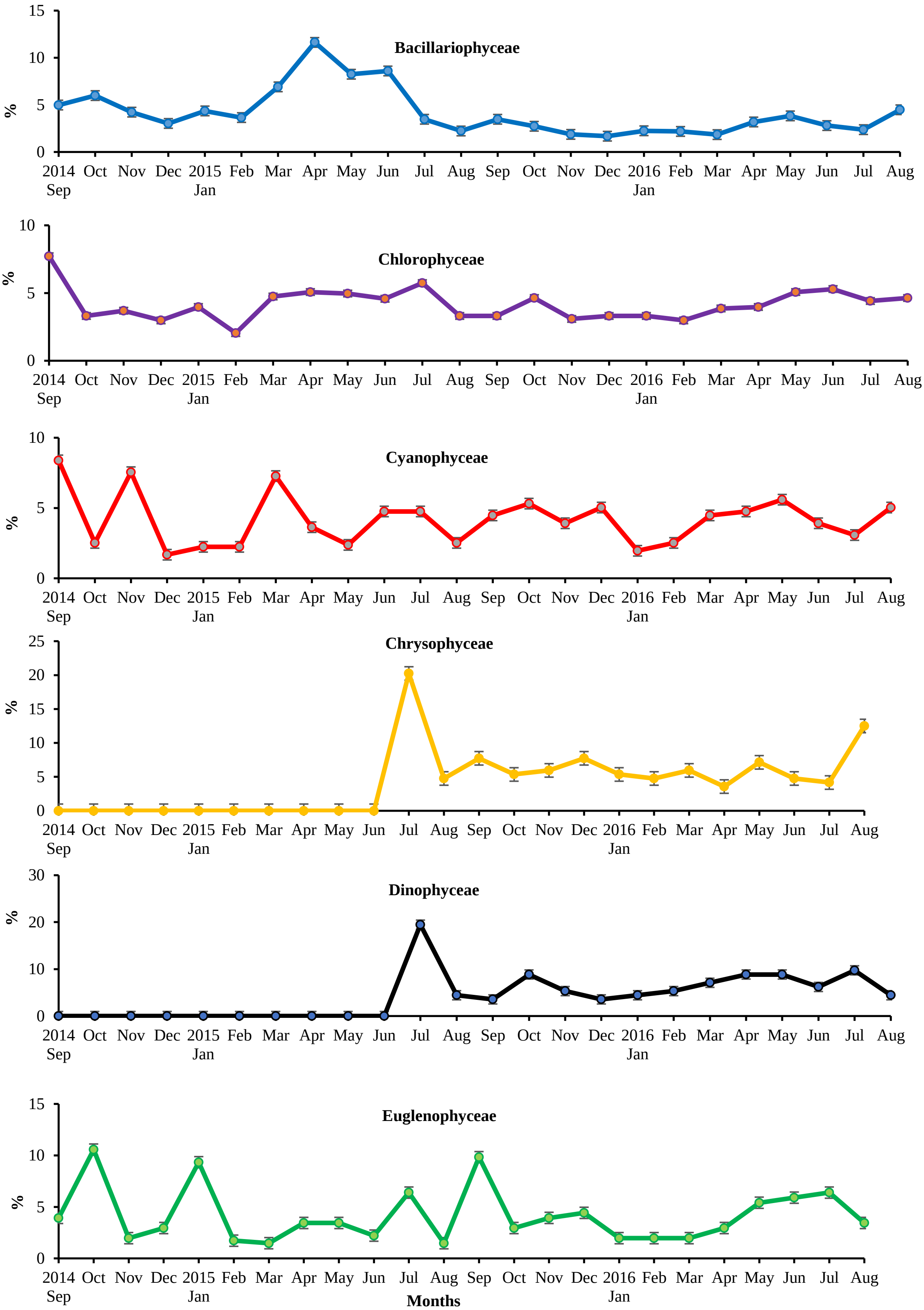


Figure 4.13. Temporal percentage abundance of phytoplankton of Calabar River at Okomita at the time of the study

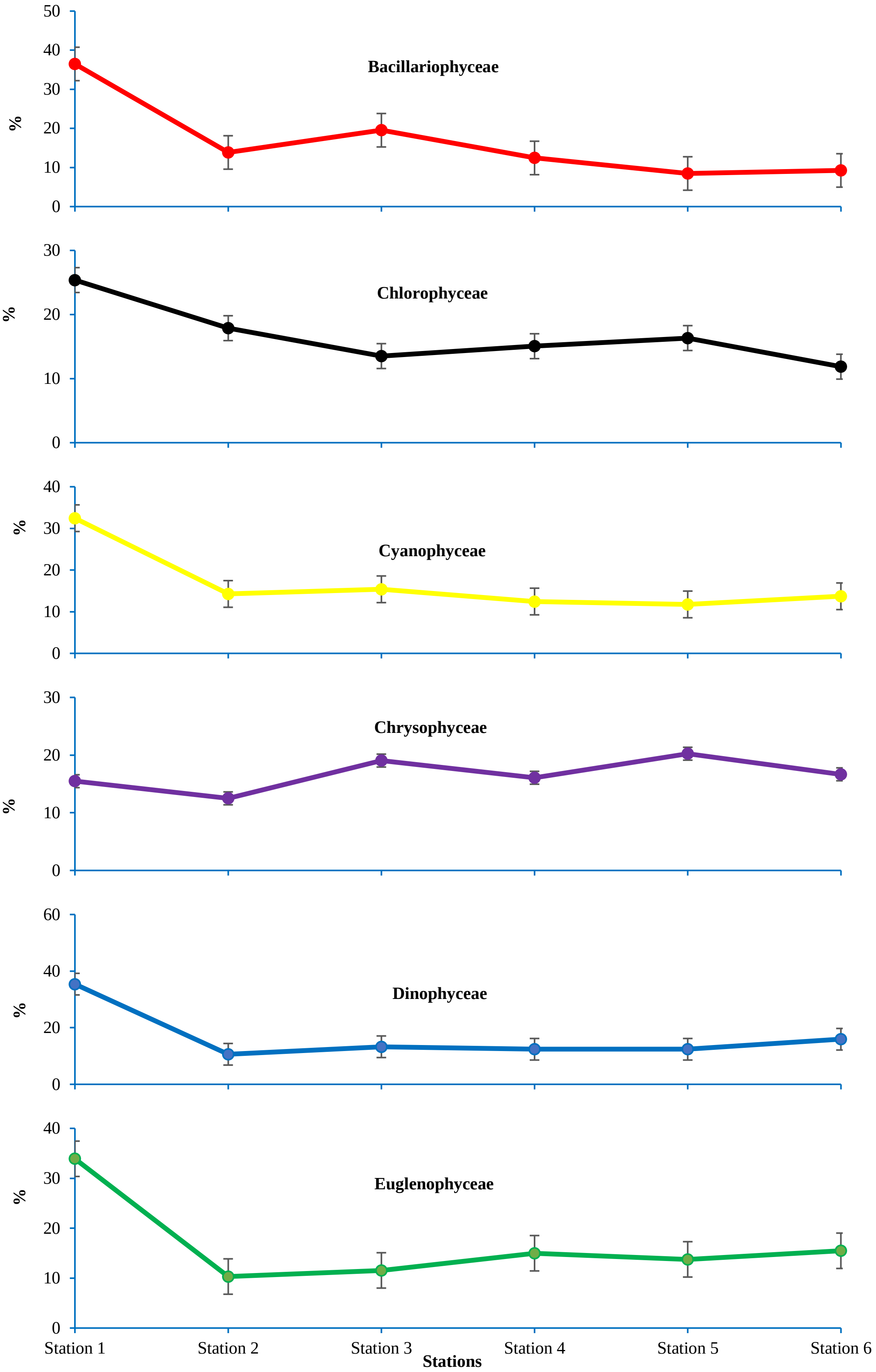


Figure 4.14. Spatial percentage abundance of phytoplankton of Calabar River at Okomita at the time of the study

4.2.3 Spatial abundance of phytoplankton

Station One had the highest percentage abundance for all the phytoplankton groups except Chrysophyceae (Figure 4.14). Percentage abundance of Chrysophyceae was highest (20.24%) in Station Five, while the lowest was in Station Two (12.20%). Percentage abundance of Bacillariophyceae, Chlorophyceae, Cyanophyceae and Dinophyceae varied significantly ($p<0.05$) between stations. Station One (33.83%) had the highest percentage abundance of all the phytoplankton, while Station Five (10.46%) had the lowest value (Figure 4.15). The total percentage abundance of phytoplankton at Station One was significantly higher than the other stations.

4.2.4 Diversity indices of phytoplankton

The results of phytoplankton taxa diversity indices are presented in Figure 4.16. Bacillariophyceae constituted the most diverse family (H = 2.823) while Euglenophyceae was the least diverse (H = 0.588) during the study period. Equitability was high (0.94-0.99) for all the phytoplankton groups except Euglenophyceae. Dinophyceae and Chlorophyceae had the highest equitability (J = 0.997) and (J = 0.990) respectively, while Euglenophyceae had the least equitability (J = 0.849).

4.2.4.1 Seasonal diversity indices of phytoplankton

Phytoplankton seasonal diversity indices is presented in Table 4.6. The overall mean seasonal diversity for all the phytoplankton was higher in the wet (H = 1.356±0.349) than dry (H = 1.285±0.36) season. The mean equitability value was also higher in the wet (J = 0.927±0.020) than dry (J = 0.861±0.029) season.

4.2.4.2 Spatial diversity indices of phytoplankton

The highest spatial diversity index of all the phytoplankton taxa (Figure 4.17) was recorded at Station Four (H = 1.410±0.350), while Station One (H = 1.262±0.369) had the lowest value. The spatial diversity indices for the various phytoplankton groups recorded in the six sampling stations at the time of the study are presented in Table 4.7. Bacillarophyceae accounted for the highest diversity in all the stations, 2.618, 2.893, 2.499, 2.794, 2.854 and 2.809 for Stations One, Two, Three, Four, Five and Six respectively. Chlorophyceae diversity indices was highest at Station Five (H = 2.173) and lowest at Station Two (H = 2.113). The total mean equitability value was highest (J = 0.976±0.010) at Station Four, while the lowest value (J = 0.833±0.078) was recorded at Station One.

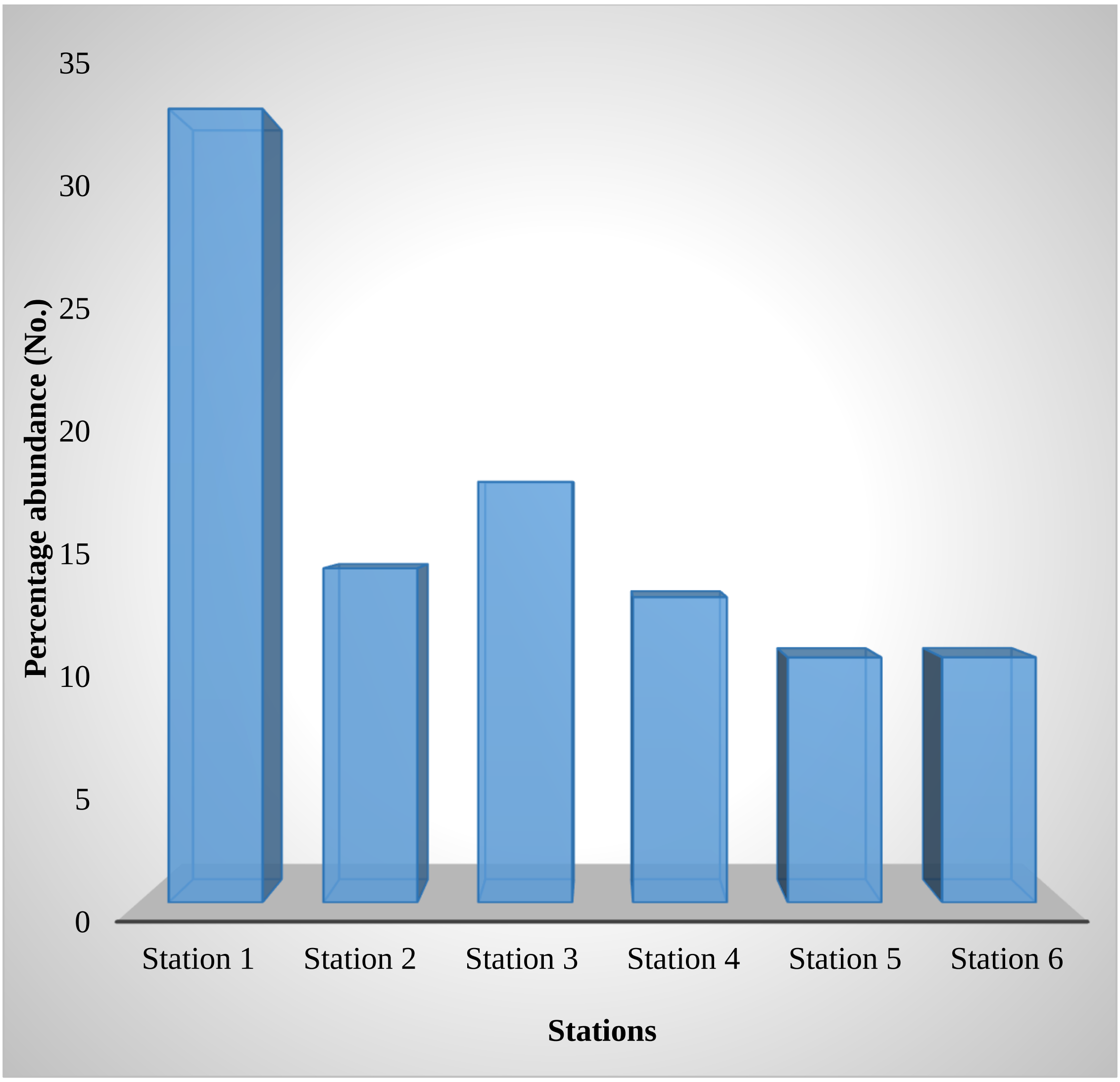
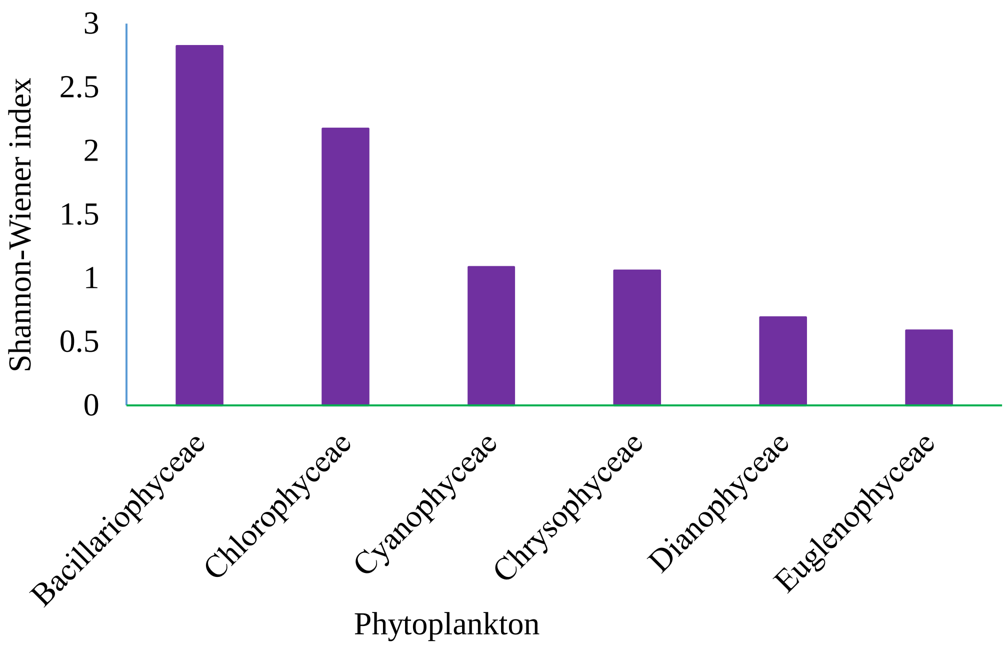


Figure 4.15. Spatial percentage abundance of total phytoplankton of Calabar River at Okomita at the time of the study



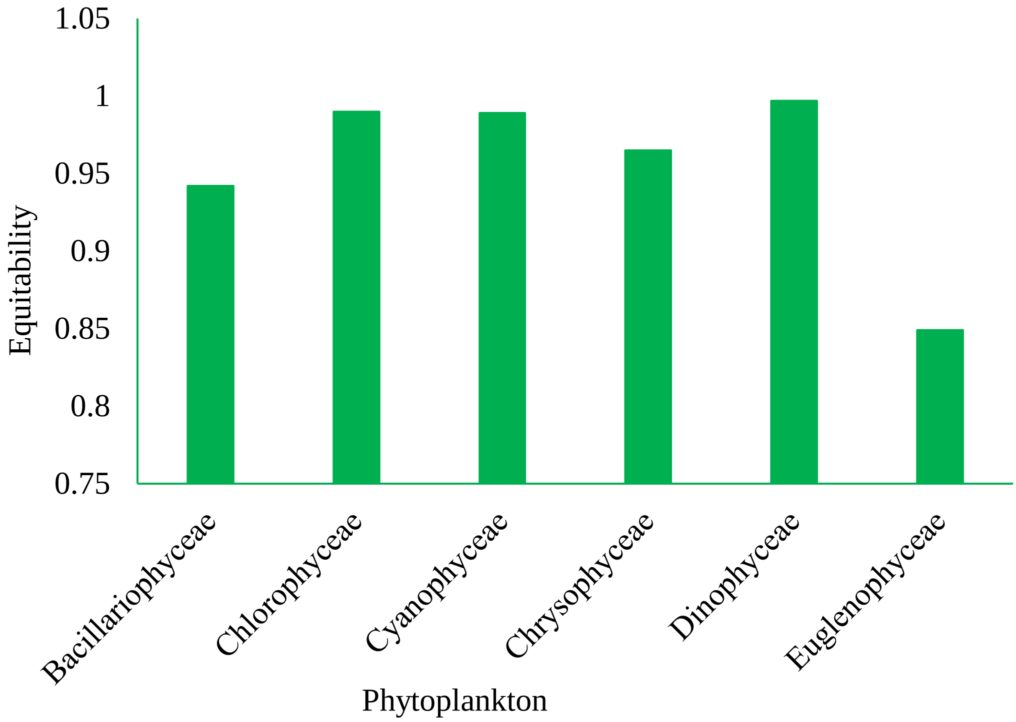


Figure 4.16. Diversity indices (Shannon-Wiener index ■ and Equitability ■) of phytoplankton of Calabar River at Okomita at the time of the study

Table 4.6. Seasonal diversity and equitability indices of phytoplankton of Calabar River at Okomita at the time of the study

Phytoplankton	Wet season H	Dry season H
Bacillariophyceae	2.702	2.787
Chlorophyceae	2.114	1.894
Cyanophyceae	1.054	1.011
Chrysophyceae	0.993	0.846
Dinophyceae	0.681	0.626
Euglenophyceae	0.591	0.544
Mean±SEM	**1.356±0.349**	**1.285±0.360**

SEM = Standard Error of Mean, H = Shannon-Wiener index

Phytoplankton	Wet season J	Dry season J
Bacillariophyceae	0.902	0.930
Chlorophyceae	0.962	0.862
Cyanophyceae	0.959	0.921
Chrysophyceae	0.904	0.770
Dinophyceae	0.982	0.904
Euglenophyceae	0.853	0.784
Mean±SEM	**0.927±0.020**	**0.861±0.029**

SEM = Standard Error of Mean, J = Equitability

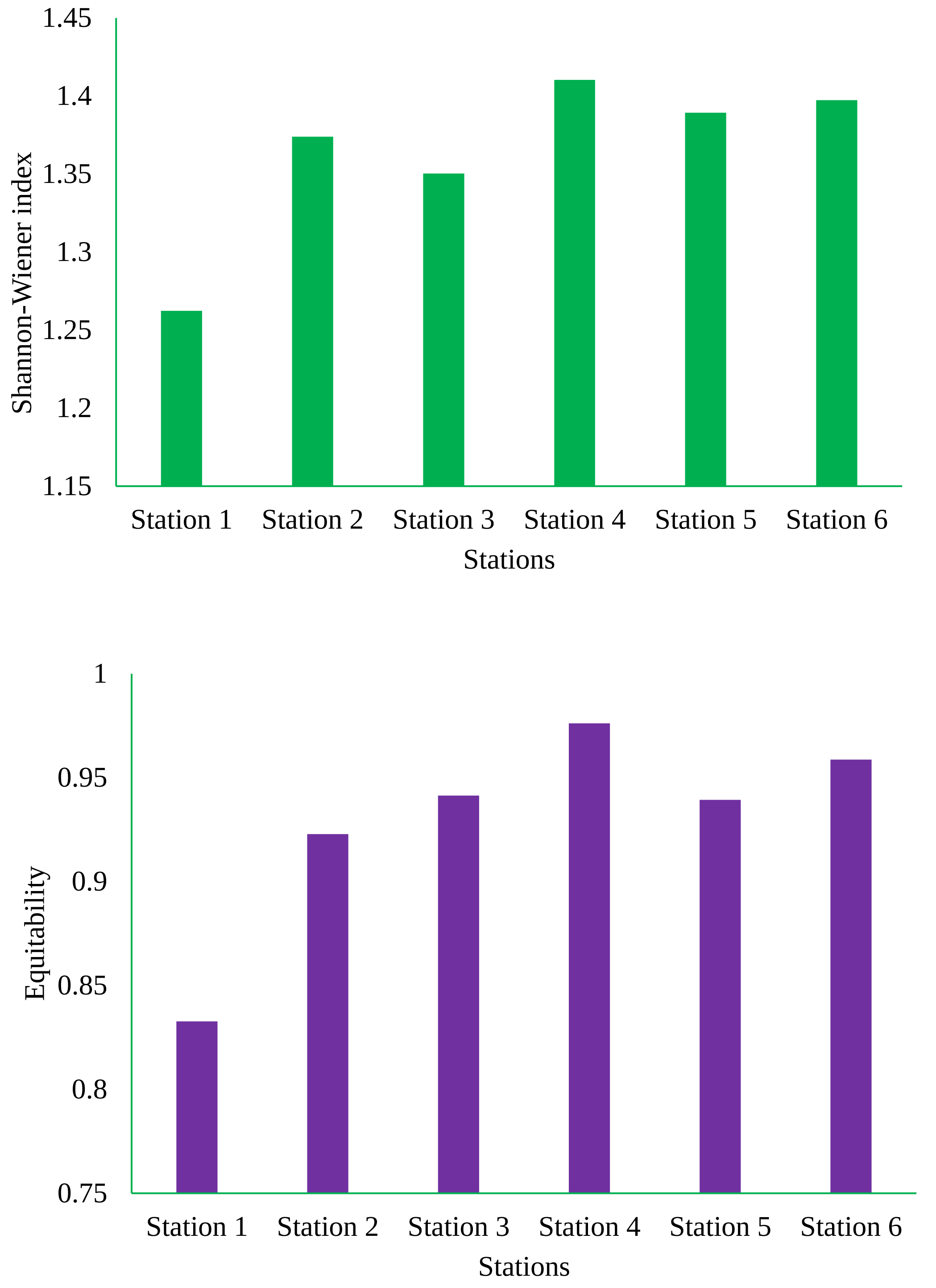


Figure 4.17. Spatial diversity (■) and equitability (■) indices of total phytoplankton abundance of Calabar River at Okomita at the time of the study

Table 4.7. Spatial diversity and equitability indices of phytoplankton abundance of Calabar River at Okomita at the time of the study

Phytoplankton	S1 H	S2 H	S3 H	S4 H	S5 H	S6 H
Bacillariophyceae	2.618	2.893	2.499	2.794	2.854	2.809
Chlorophyceae	2.137	2.113	2.167	2.115	2.173	2.163
Cyanophyceae	1.078	1.013	1.061	1.094	1.061	0.957
Chrysophyceae	0.645	0.983	1.061	1.094	0.967	1.097
Dinophyceae	0.682	0.693	0.673	0.683	0.683	0.693
Euglenophyceae	0.414	0.549	0.641	0.682	0.598	0.665

Phytoplankton	S1 J	S2 J	S3 J	S4 J	S5 J	S6 J
Bacillariophyceae	0.874	0.966	0.834	0.933	0.953	0.938
Chlorophyceae	0.973	0.962	0.986	0.963	0.989	0.985
Cyanophyceae	0.981	0.922	0.966	0.996	0.966	0.871
Chrysophyceae	0.587	0.895	0.966	0.996	0.880	0.999
Dinophyceae	0.984	1.000	0.971	0.985	0.985	1.000
Euglenophyceae	0.597	0.792	0.925	0.984	0.863	0.959

S1 is Station One; S2 is Station Two; S3 is Station Three; S4 is Station Four; S5 is Station Five and S6 is Station Six, H is Shannon-Wiener's Index, J is Equitability.

Equitability value for Bacillariophyceae was highest (J = 0.966) at Station Two, while the lowest value (J = 0.834) was recorded at Station Three. Highest equitability value for Cyanophyceae (J = 0.996) was recorded at Station Four and the lowest value (J = 0.871) was recorded at Station Six.

4.3 Zooplankton

4.3.1 Zooplankton composition and abundance

The checklist of the identified zooplankton is presented in Table 4.8. Zooplankton consisted of five groups and 21 species. Some of the zooplankton encountered are shown in Plate 4.2. Rotifera encountered were five species, Cladocera four species, while Copepoda were six species. Rotifera was the most abundant (33.02%), followed by Copepoda (29.70%), while the least abundant was Protozoa which accounted for 2.57% of the zooplankton population (Figure 4.18). The dominant species of Rotifera were *Keratella cochlearis* (7.65%); Cladocera, *Daphnia pulex* (6.43%); Copepoda, *Oithona halgolandica* (7.97%) and Insecta, *Sialis lutaria* (3.54%) (Table 4.9).

4.3.2 Temporal abundance of zooplankton

Higher seasonal abundance was recorded in the wet season for Cladocera (21.84%) and the difference was significant ($p<0.05$) (Figure 4.19). Copepoda (31.24%) and Insecta (16.44%) had higher percentage abundance in the dry season. The difference was insignificant ($p>0.05$). A total abundance of 52.71% of zooplankton was recorded in the wet season, while a total of 47.29% was recorded in the dry season (Figure 4.19), the difference was insignificant ($p>0.05$). Rotifera had the highest abundance (10.72%) in March, 2015, while the lowest (2.11% each) was recorded in July and August, 2015 (Figure 4.20). Cladocera had the highest abundance (8.61%) in October, 2014, while the lowest (2.57%) was in August, 2015 and February, 2016. The highest abundance (7.98%) of Insecta was recorded in March, 2015, while the lowest value (1.63%) was in April, 2015.

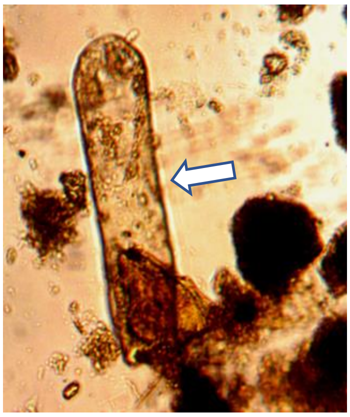
4.3.3 Spatial abundance of zooplankton

All the groups had highest abundance in Station One (Figure 4.21). Rotifera (8.98%), Copepoda (10.40%), and Insecta (10.10%) had their lowest percentage abundance at Station Five while Cladocera (10.01%) had lowest abundance in Station Three. Station Five had the lowest abundance of total zooplankton (Figure 4.22).

Table 4.8. Checklist of zooplankton taxa encountered showing pollution indicators in Calabar River at Okomita at the time of the study

Phylum Class Order Family	Species
CILIOPHORA	
Protozoa	
Choreotrichida	
Tintinnidiidae	*Tintinnidium fluviatile* (Stein, 1863)
ROTIFERA	
Monogononta	
Ploima	
Brachionidae	*Keratella cochlearis* (Gosse, 1851)
	Keratella quadrata (Müller, 1786)
Lecanidae	*Lecane lunaris** (Ehrenberg, 1832)
Brachionidae	*Brachionus forticula** (Wierzejski, 1891)
Bdelloida	
Philodinidae	*Philodina* sp.* (Ehrenberg, 1830)
ARTHROPODA	
Cladocera	
Anomopoda	
Daphniidae	*Daphnia pulex* (Leydig, 1860)
	Daphnia magna (Straus, 1820)
	Daphnia aspinosum (Müller, 1785)
Diplostraca	
Moinidae	*Moinodaphnia macleayi* (King, 1853)
Copepoda	
Calanoida	
Calanidae	*Calanus finmarchicus* (Gunnerus, 1770)
Paracalanidae	*Paracalanus parvus** (Claus, 1863)
Oithonida	
Oithonidae	*Oithona halgolandica* (Claus, 1863)
Harpacticoida	
Canthocamptidae	*Canthocamptus carinetus* (Sung, 1973)
Cyclopoida	
Cyclopidae	*Cyclops* sp. (Müller, 1785)
Harpacticoida	
Ameiridae	*Nitocra lacustris* (Schmankevitsch, 1875)
Insecta	
Megaloptera	
Sialidae	*Sialis lutaria (larva)* (Linnaeus, 1758)
Coleoptera	
Hydrophilidae	*Tropisternus lateralis* (Fabricius, 1775)
Diptera	
Culicidae	*Anopheles gambiae (larva)* (Giles, 1902)
Plecoptera	
Pteronarcyidae	*Pteronarcys* sp. *(larva)* (Newport, 1848)
Odonata	
Aeshnidae	*Anax imperator* (larva) (Leach, 1815)

* = Pollution indicators



Tintinnidium fluviatile

Lecane lunaris

Brachionus forticula

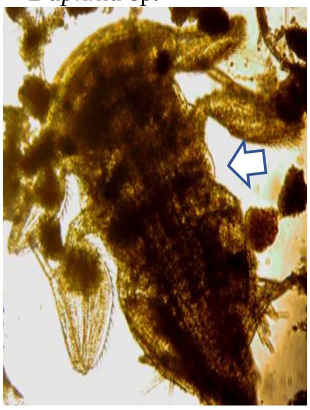
Philodina sp.

Daphnia pulex

Daphnia sp.

Paracalanus parvus (larva)

Pteronarcys sp. (larva)



Anax imperator (larva)

Magnification = X200

Plate 4.2. Some zooplankton encountered in Calabar River at Okomita at the time of the study

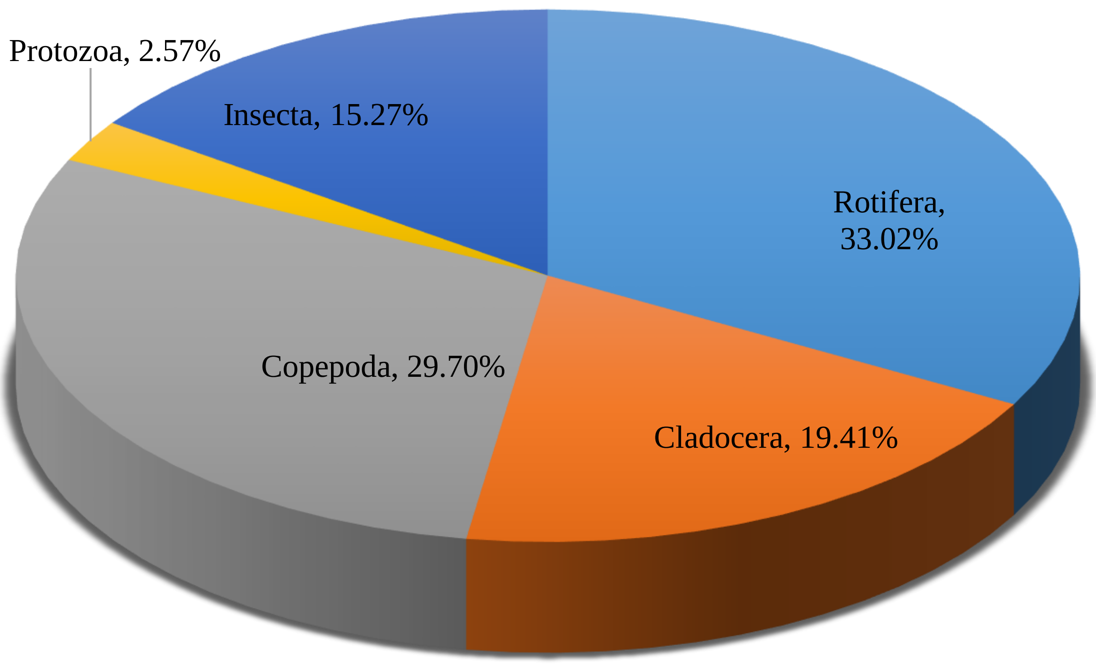


Figure 4.18. Percentage abundance of zooplankton of Calabar River at Okomita at the time of the study

Table 4.9. Relative abundance of zooplankton composition of Calabar River at Okomita at the time of the study

Zooplankton Classes	Species	Number of organisms/mL	% Number
Protozoa			
	Tintinnidium fluviatile	103	2.57
	Sub Total	**103**	**2.57**
Rotifera			
	Keratella cochlearis	307	7.65
	Philodina sp.	280	6.98
	Branchionus forticula	262	6.53
	Keratella quadrata	253	6.30
	Lecane lunaris	223	5.56
	Sub Total	**1,325**	**33.02**
Cladocera			
	Daphnia pulex	258	6.43
	Daphnia magna	210	5.23
	Moinodaphnia macleayii	180	4.49
	Daphnia aspinosum	131	3.26
	Sub Total	**779**	**19.41**
Copepoda			
	Oithona halgolandica	320	7.97
	Canthocamptus carinetus	227	5.66
	Cyclops sp.	194	4.83
	Calanus finmarchicus	192	4.78
	Nitocra lacustris	180	4.49
	Paracalanus parvus	79	1.97
	Sub Total	**1,192**	**29.70**
Insecta			
	Sialis lutaria (larva)	142	3.54
	Tropisternus lateralis (larva)	139	3.43
	Anopheles gambiae (larva)	130	3.24
	Pteronarcys sp. (larva)	103	2.57
	Anax imperator (larva)	100	2.49
	Sub Total	**614**	**15.27**
Grand Total		**4,013**	**100**

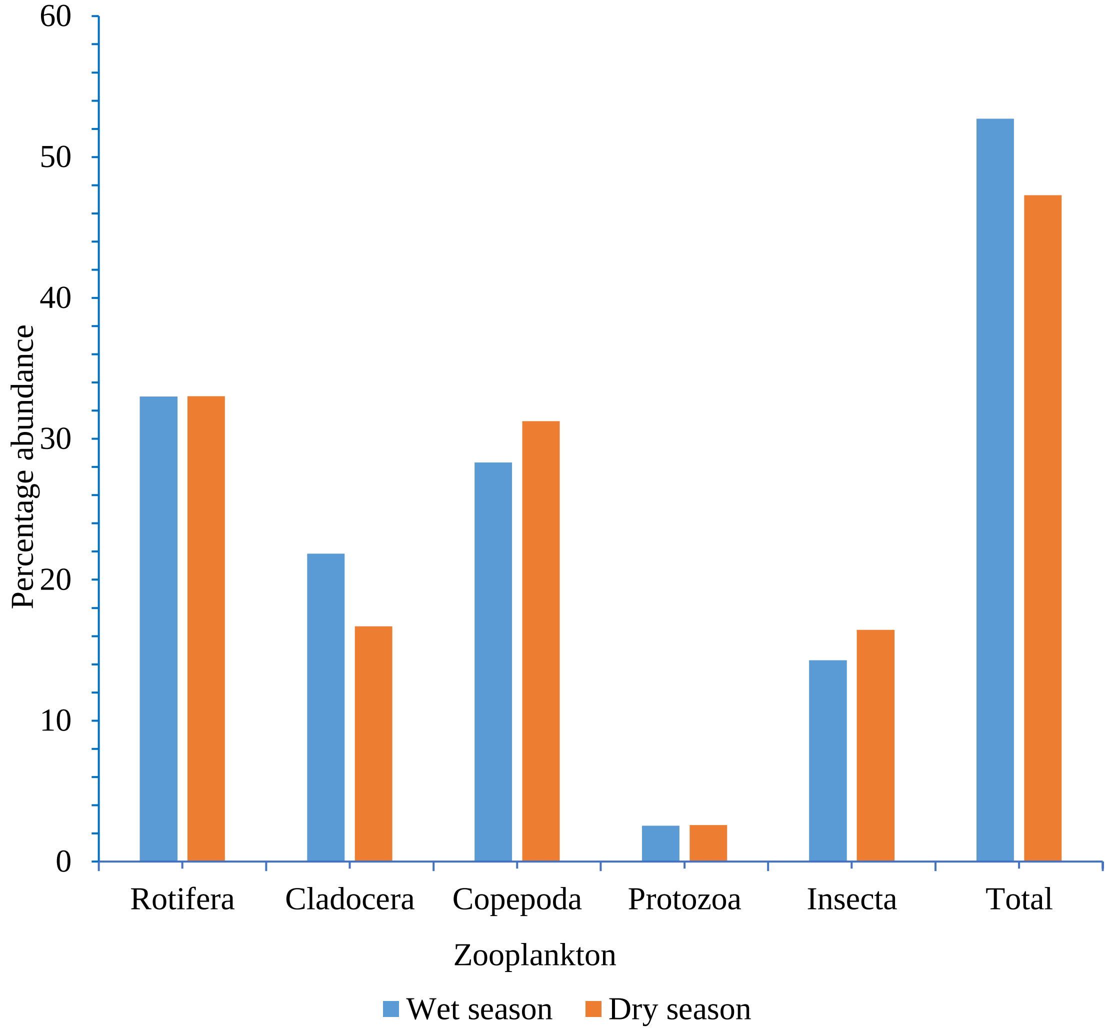


Figure 4.19. Seasonal percentage abundance of zooplankton of Calabar River at Okomita at the time of the study

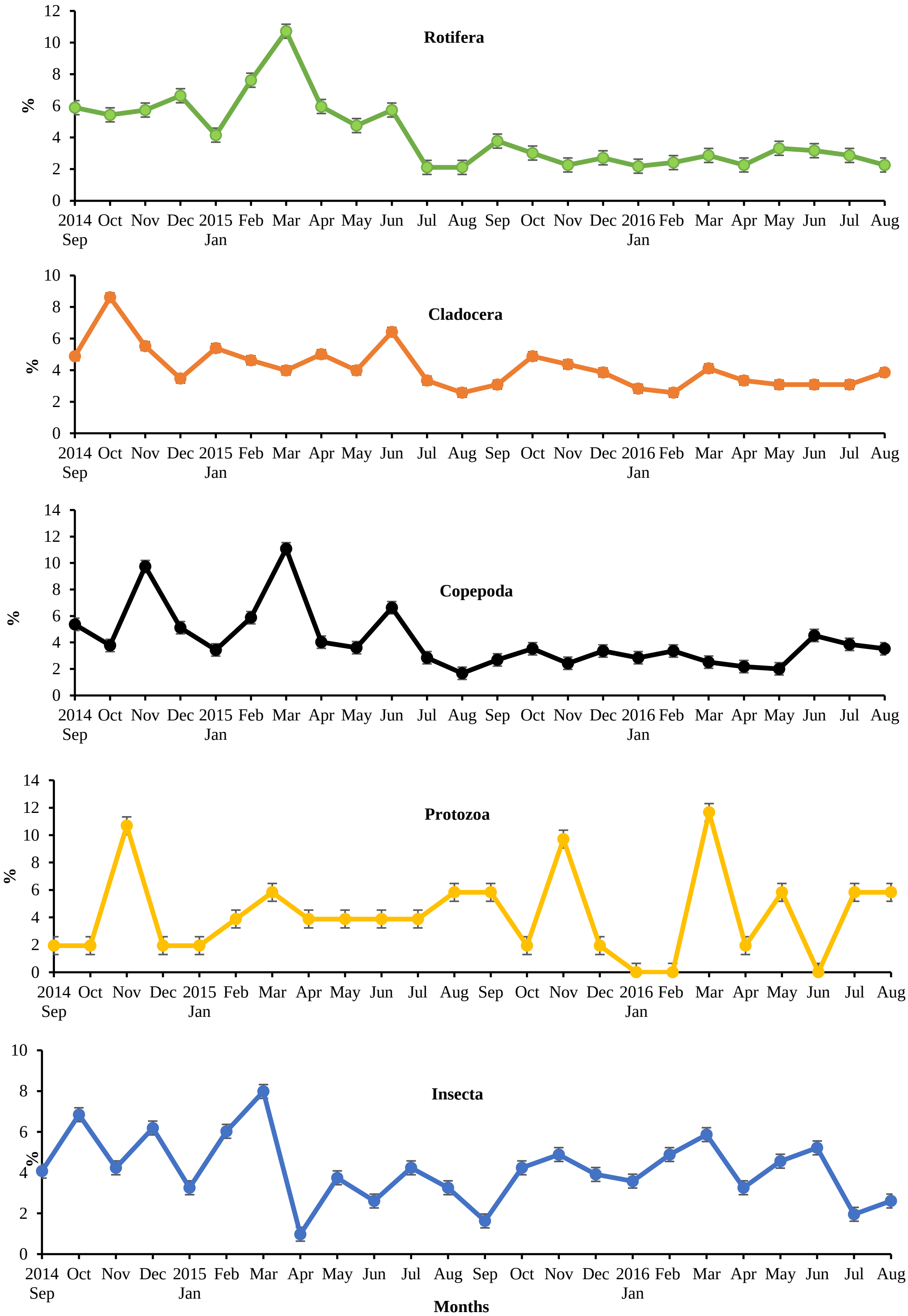


Figure 4.20. Temporal percentage abundance of zooplankton of Calabar River at Okomita at the time of study

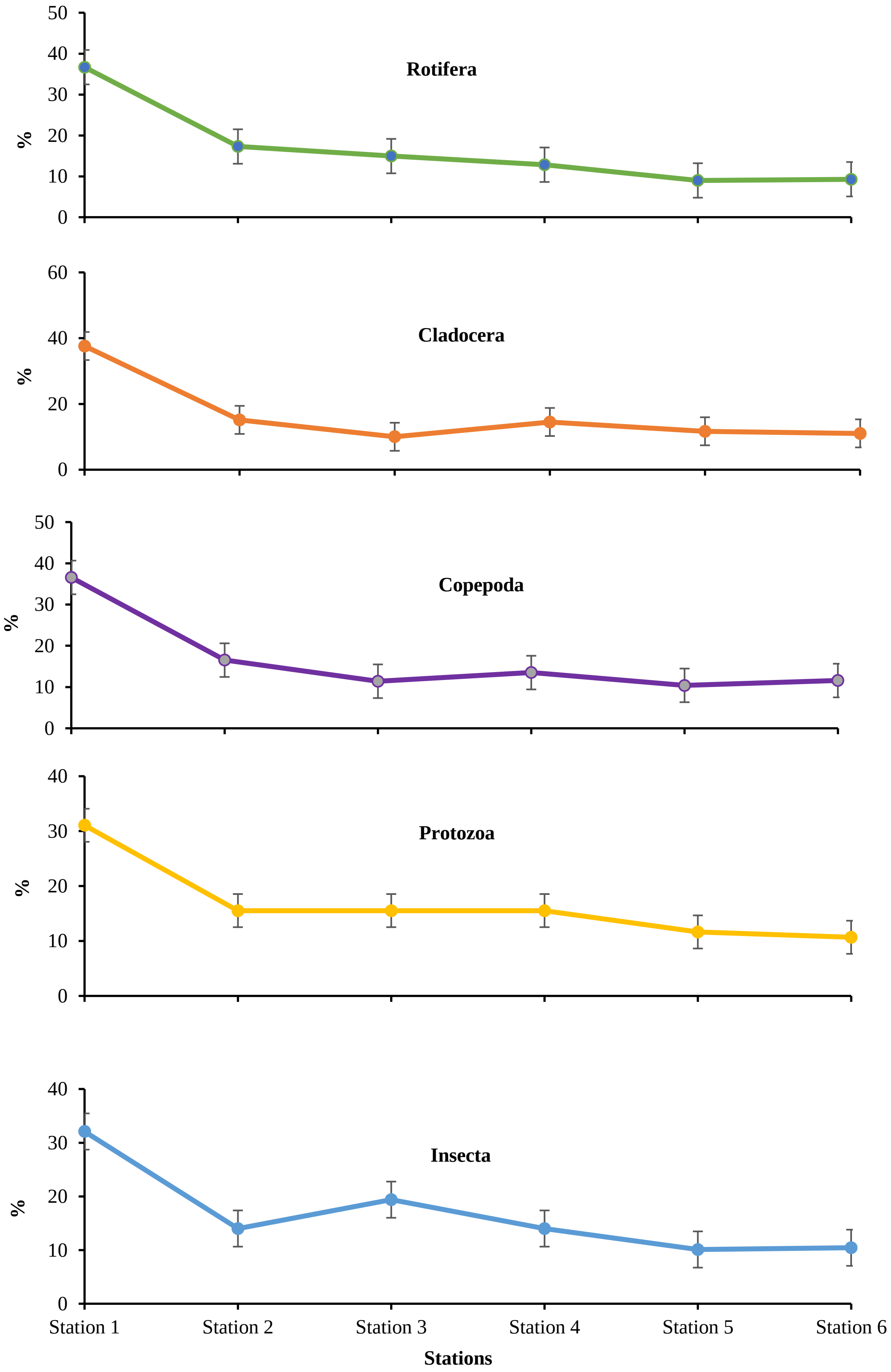


Figure 4.21. Spatial percentage abundance of zooplankton of Calabar River at Okomita at the time of the study

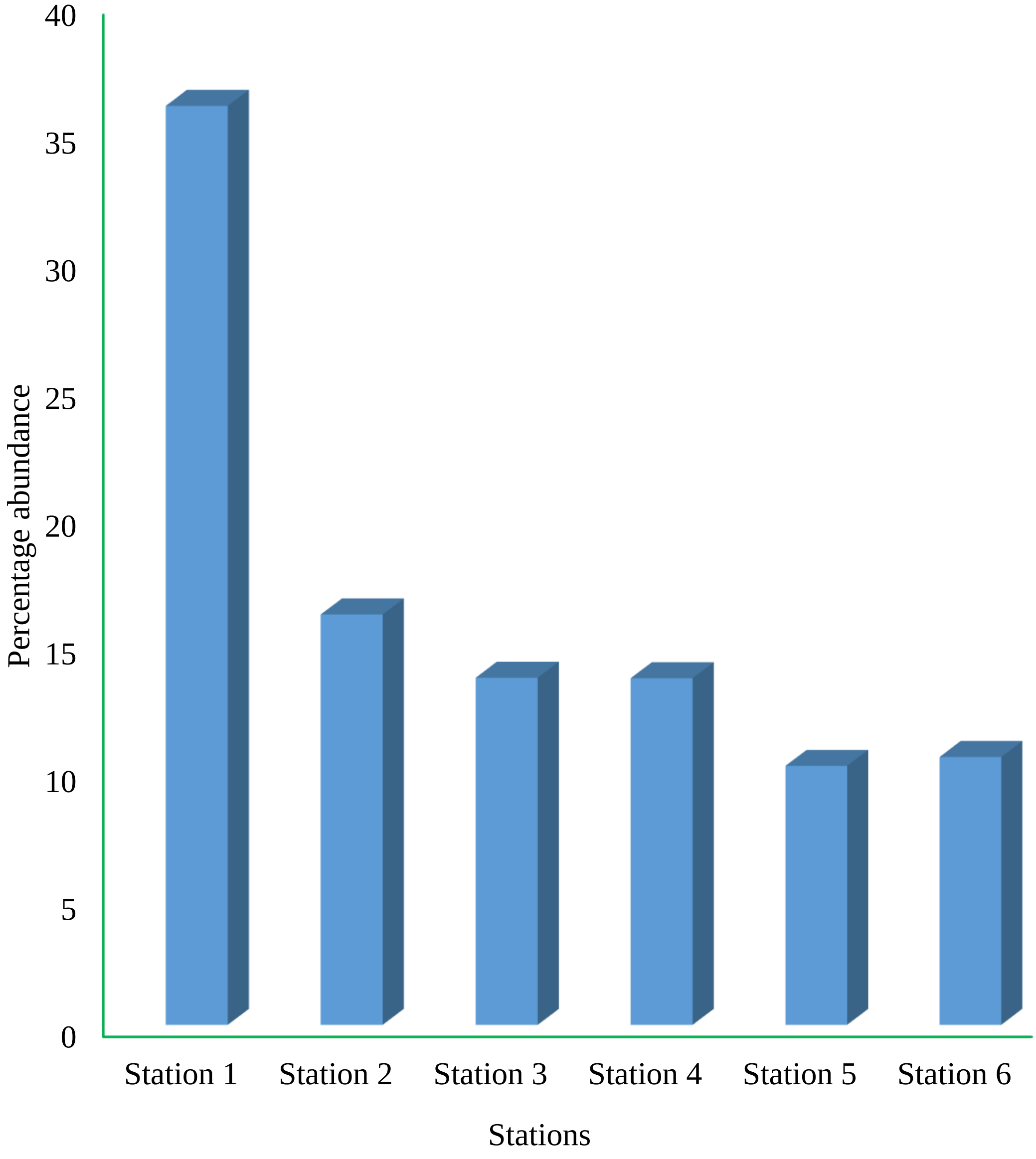


Figure 4.22. Spatial percentage abundance of total zooplankton of Calabar River at Okomita at the time of the study

The total zooplankton abundance at Station One was significantly higher ($p<0.05$) than the other stations.

4.3.4 Diversity indices of zooplankton

The results of zooplankton diversity indices are presented in Figure 4.23. Copepoda had the highest diversity (H = 1.724) while Cladocera had the lowest diversity (H = 1.358). Rotifera had the highest equitability (J = 0.997) while Copepoda had the lowest value (J = 0.962).

4.3.4.1 Seasonal diversity indices of zooplankton

The seasonal diversity indices of zooplankton is presented in Table 4.10. The mean diversity value for all zooplankton was higher in the wet (H = 1.541±0.084) than dry (H = 1.489±0.074) season. Higher diversity values were recorded in the wet season for all the zooplankton groups than the dry season. The mean equitability was also higher in the wet (J = 0.963±0.004) than dry (0.932±0.007) season. Equitability values for Rotifera, Cladocera, Copepoda and Insecta were higher in the wet than dry season. Diversity indicecs were not significantly different between seasons, likewise equitability ($p>0.05$).

4.3.4.2 Spatial diversity indices of zooplankton

The diversity indices for the various zooplankton groups recorded in the six sampling stations at the time of the study are presented in Table 4.11. The mean diversity value of all the zooplankton (Figure 4.24) was highest in Station Four (H = 1.561±0.004) and lowest at Station Three (H = 1.518±0.085). However, Rotifera accounted for the highest diversity (H = 1.599) in Station One and it was lowest (H = 1.516) in Station Three. The highest spatial diversity of Copepoda (H = 1.750) was recorded at Station Six while the lowest (H = 1.596) was recorded in Station One. Insecta recorded the highest diversity (H = 1.601) at Station One and the lowest (H = 1.515) at Station Three.

The mean equitability (Figure 4.24) of zooplankton of Calabar River, Okomita during the study period was highest in Station Four (J = 0.976±0.004) and lowest in Station Three (J = 0.948±0.005). Equitability of Rotifera (see Table 4.11) was highest in Station One (J=0.994) and lowest in Station Six (J=0.973). Cladocera had highest equitability (J = 0.978) in Station Two and the lowest value (J = 0.946) in Station Three.

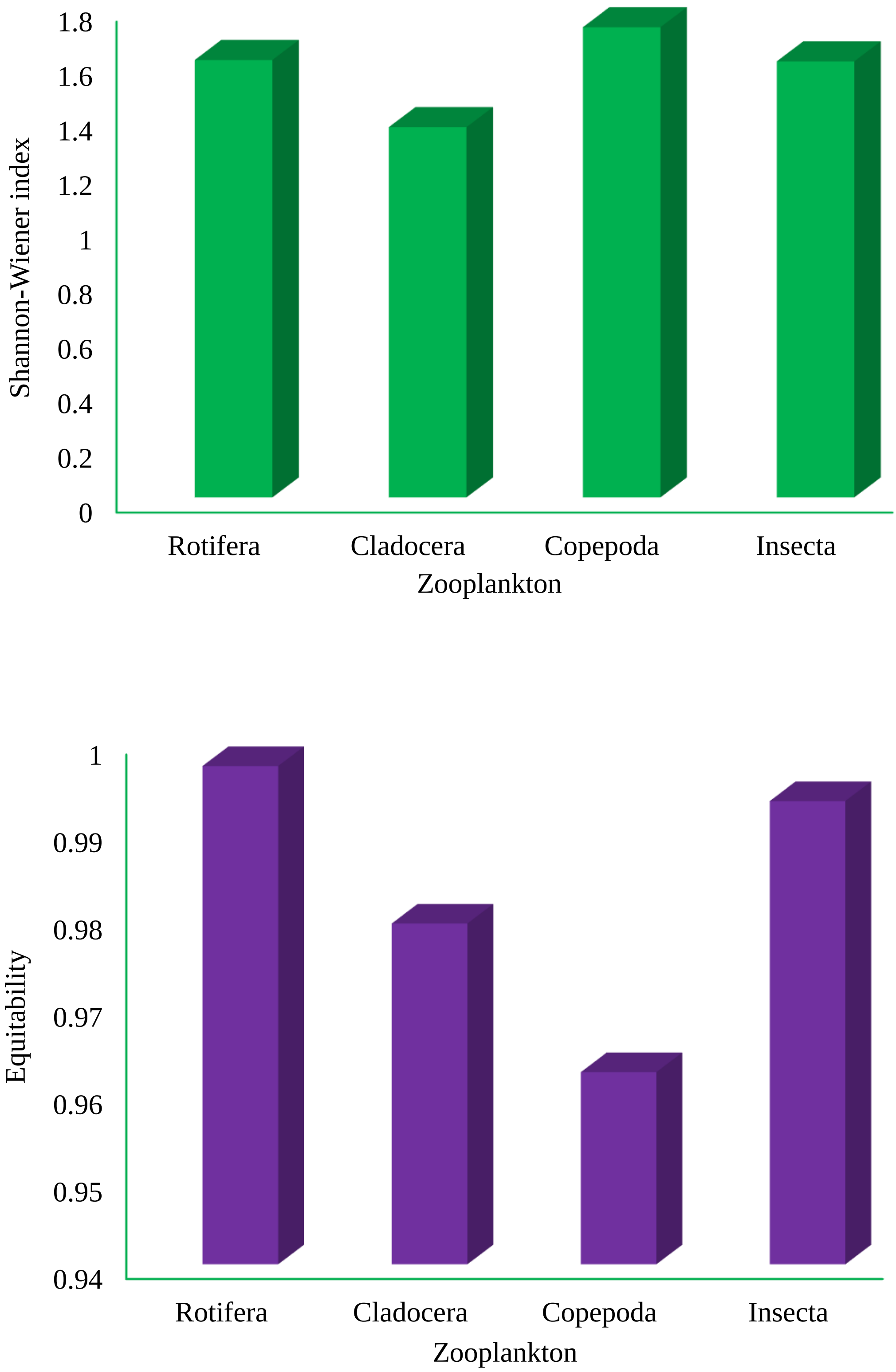


Figure 4.23. Diversity indices (Shannon-Wiener index ■ and Equitability ■) of zooplankton of Calabar River at Okomita at the time of the study

Table 4.10. Seasonal diversity and equitability indices of zooplankton of Calabar River at Okomita at the time of the study

Zooplankton	wet season H	Dry season H	Wet season J	Dry season J
Rotifera	1.566	1.514	0.973	0.941
Cladocera	1.322	1.284	0.954	0.926
Copepoda	1.729	1.637	0.965	0.914
Insecta	1.545	1.522	0.960	0.946
Mean±SEM	**1.541±0.084**	**1.489±0.074**	**0.963±0.004**	**0.932±0.007**

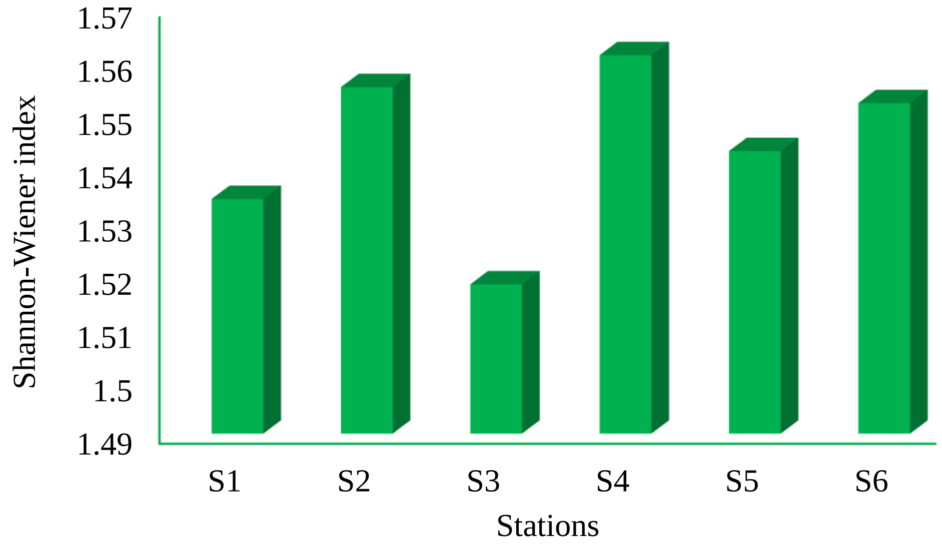
H is Shannon-Wiener’s Index, J is Equitabilty Measure, SEM is Standard Error of Mean

Table 4.11. Spatial diversity and equitability indices of zooplankton abundance of Calabar River at Okomita at the time of the study

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
Zooplankton	**H**	**H**	**H**	**H**	**H**	**H**
Rotifera	1.599	1.585	1.516	1.577	1.534	1.566
Cladocera	1.340	1.355	1.311	1.343	1.325	1.320
Copepoda	1.596	1.730	1.728	1.737	1.727	1.750
Insecta	1.601	1.549	1.515	1.586	1.585	1.573

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
Zooplankton	**J**	**J**	**J**	**J**	**J**	**J**
Rotifera	0.994	0.985	0.942	0.980	0.953	0.973
Cladocera	0.967	0.978	0.946	0.969	0.956	0.952
Copepoda	0.891	0.965	0.964	0.970	0.964	0.977
Insecta	0.995	0.962	0.941	0.985	0.985	0.978

S1 is Station One; S2 is Station Two; S3 is Station Three; S4 is Station Four; S5 is Station Five and S6 is Station Six, H is Shannon-Wiener's Diversity Index, J is Equitability



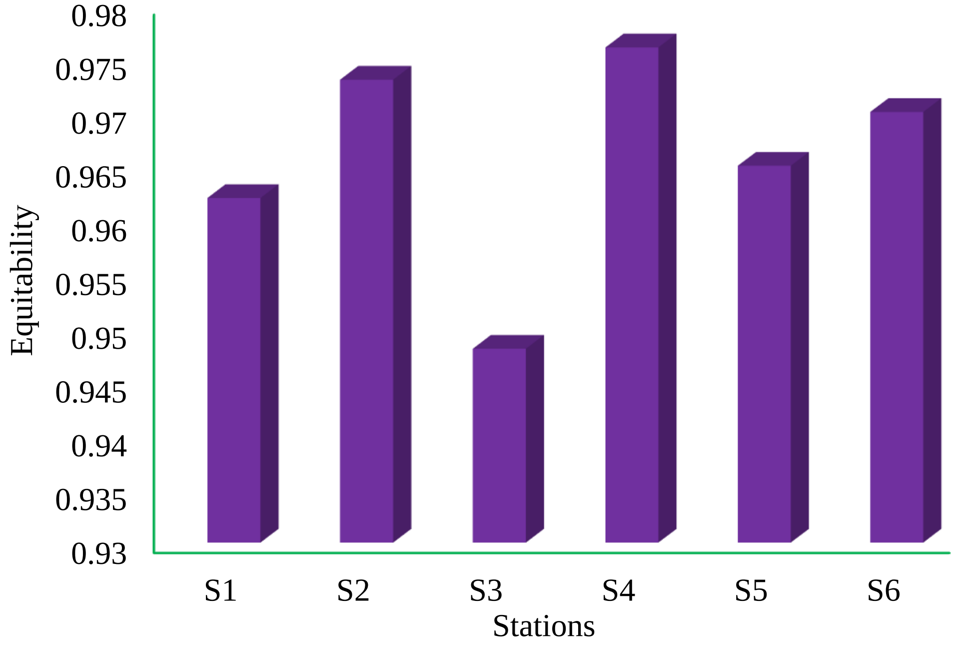


Figure 4.24. Spatial diversity (■) and equitability (■) indices of total zooplankton of Calabar River at Okomita at the time of the study

4.4 Macro-invertebrates

4.4.1 Macro-invertebrates composition and abundance

The checklist of the macro-invertebrates encountered is presented in Table 4.12 and pictures of some are shown in Plates 4.3. Forty species belonging to twenty-eight families, thirteen orders, five classes and three phyla were encountered. Class Insecta had the highest number of species (27 species) and dominated the macro-invertebrate fauna accounting for 87.81%, while Bivalvia (1.37%) was the least abundant (Figure 4.25). The insect *Enithares* sp. was the most abundant constituting 34.18% of the entire macro-invertebrate population, while another insect, *Glossosoma caddis* was least in abundance constituting 0.36% (Table 4.13). The phylum Arthropoda had a percentage abundance of 91.23%; Mollusca, 7.35% and Annelida, 1.40%. Arthropoda had the highest percentage abundance while Annelida had the least.

4.4.2 Temporal abundance of macro-invertebrates

In the wet season, Inecta had the highest abundance (85.66%) while Bivalvia had the lowest (1.28%) (Figure 4.26). Malacostraca (4.13%), Gastropoda (7.08%), Bivalvia (1.28%) and Clitellata (1.85%) had higher seasonal abundance in the wet than dry season. Higher seasonal abundance was recorded in the dry season for Insecta (88.84%) and the difference was significant ($p<0.05$). Higher seasonal abundance of the total macro-invertebrates (Figure 4.26) was recorded in the dry season (69.26%) than wet season (30.74%) and the difference was significant ($p<0.05$). The results of monthly abundance of macro-invertebrates of Calabar River at Okomita recorded in the time of study is presented in Figure 4.27. The months of the dry season had the highest abundance of all macro-invertebrate groups especially between November, 2015 and March, 2016. Insecta (9.70%), Bivaivia (16.80%) and Gastropoda (13.20%) had highest abundance in January, 2016. Gastropoda, Bivalvia and Clitellata were not encountered in October, November and December, 2014 as well as January, 2015.

4.4.3 Spatial abundance of macro-invertebrates

On the overall, Station Five had the least abundance (4.95%) of macro-invertebrate fauna during the period of study (Figure 4.28). Malacostraca (Figure 4.29) had the highest spatial abundance at Station Three (32.91%) and the lowest at Station Five (4.15%). The highest spatial abundance of Insecta was recorded at Station Four (32.04%), while the lowest was at Station Five (4.23%). Bivalvia had the highest spatial

Table 4.12. Checklist of macro-invertebrates taxa encountered showing pollution indicators in Calabar River at Okomita at the time of the study

Phylum	Class	Order	Family	Species
ARTHROPODA				
	Malacostraca			
		Decapoda		
			Palaemonidae	*Macrobrachium vollenhovenii* ** (Herklots, 1857
				Macrobrachium macrobrachion ** (Kingsley, 1892)
			Potamonautidae	*Sudanonautes africanus* (Edwards, 1869)
	Insecta			
		Hemiptera		
			Gerridae	*Gerris* sp. ** (Fabricius, 1794)
			Mesoveliidae	*Mesovelia furcata* ** (Mulsant & Rey, 1852)
				Mesovelia Vittigera ** (Horváth, 1895)
			Nepidae	*Ranatra* sp. *(larva)* *** (Linnaeus, 1758)
			Notonectidae	*Enithares* sp. ** (Leach, 1815)
			Micronectidae	*Micronecta* sp. (Kirkaldy, 1897)
			Hydrometridae	*Hydrometra* sp. (Linnaeus, 1758)
				Hydrometra stagnorum (Linnaeus, 1758)
		Coleoptera		
			Gyrinidae	*Gyrinus* sp. (Geoffroy, 1762)
				Orectochilus orbisonorum (Miller *et al.*, 2008)
			Chrysomelidae	*Donacia* sp. (Fabricius, 1775)
			Dytiscidae	*Hydaticus flavolineatus* (Leach, 1817)
				Dytiscus dauricus (Gebler, 1832)
			Gyrininae	*Dineutus americanus* (Linnaeus, 1767)
				Dineutus discolour (Aube, 1838)
		Odonata		
			Corduliidae	*Epicordulia* sp. ** (Burmeister, 1839)
			Libellulinae	*Libellula* sp. (Linnaeus, 1758)
			Aeshnidae	*Anax imperator* ** (Leach, 1815)
			Calopterygidae	*Phaon iridipennis* (Burmeister, 1839)
			Coenagrionidae	*Enallagma* sp. ** (Charpentier, 1840)
			Calopterygidae	*Calopteryx* sp. (Leach, 1815)
		Diptera		
			Chironomidae	*Ablabesmyia* sp. *(larva)* (Johannsen, 1905)
			Tipulidae	*Tipula sp. (larva)* ** (Linnaeus, 1758)
			Chironomidae	*Chironomus* sp. *(Larva)* **** (Meigen, 1803)
		Trichoptera		
			Glossosomatidae	*Glossosoma caddis (larva)* *** (Curtis, 1834)
				Glossosoma anale * (Martynov, 1931)
		Placoptera		
			Pteronarcyidae	*Pteronarcys* sp. *(larva)* * (Newman, 1838)

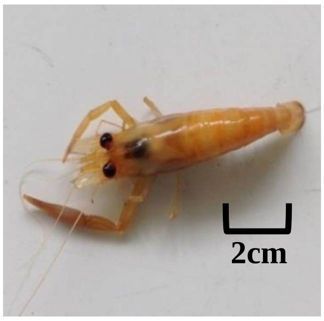
*= Sensitive, **= moderately intolerant, *** = fairly tolerant, **** = Very tolerant.
Species without superscript are pollution intolerant species

Table 4.12. Contd. Checklist of macro-invertebrates taxa encountered showing pollution indicators in Calabar River at Okomita at the time of the study

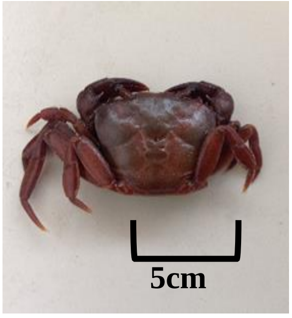
Phylum	Class	Order	Family	Species
MOLLUSCA				
	Gastropoda			
		Hydrophila		
			Lymnaeidae	*Lymnaea natalensis* ***** (Krauss, 1848)
		Architaenioglossa		
			Ampullariidae	*Pila wernei* (Philipi, 1851)
				Pila ovata (Olivier, 1804)
				Lanistes libycus (Morelet 1848)
		Littorinimorpha		
			Eulimidae	*Eulima fischeri* (Dautzenberg, 1912)
			Naticinae	*Natica flammulata* (Requien, 1848)
	Bivalvia			
		Unionida		
			Iridininae	*Mutula rostrata* ****** (Rang, 1835)
		Sphaeriida		
			Sphaeriidae	*Eupera parasitica* (Deshayes, 1854)
ANNELIDA				
	Clitellata			
		Tubificida		
			Naididae	*Limnodrilus hoffmeisteri* ******** (Claparède, 1862)
		Rhynchobdellida		
			Glossiphoniidae	*Placobdella pediculata* ******* (Hemingway 1908)

*****= Sensitive, ******= moderately intolerant, ******* = fairly tolerant, ******** = Very tolerant**.**

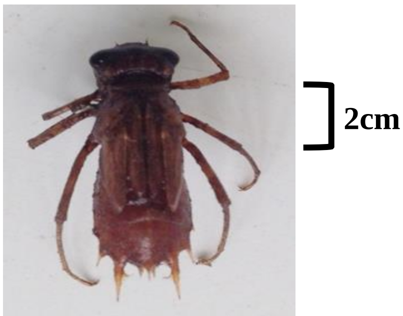
Species without superscript are pollution intolerant species



Macrobrachium vollenovenii

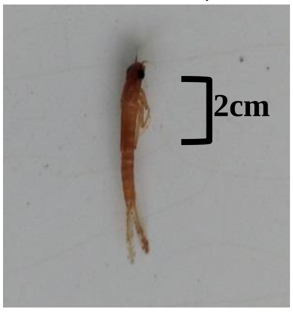


Sudanonautes africanus

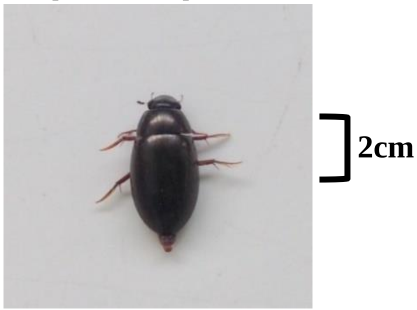


Epicordulia sp.

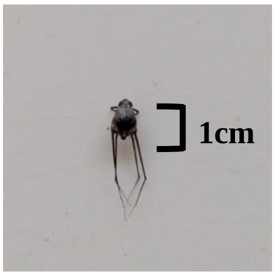
Glossosoma caddis



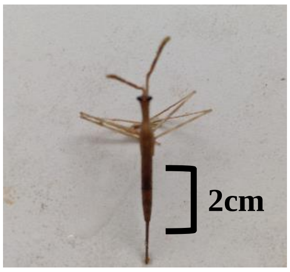
Enallegma sp.



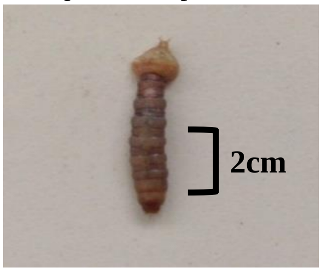
Tropisternus sp.



Enithares Sp.



Renatra sp.



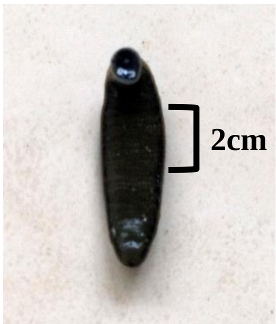
Tipulla sp.

Libellula sp.

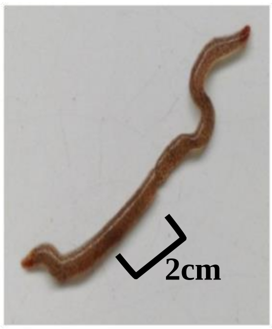
Limnaea natalensis

Natica flammulata

Mutela rostrata



Placobdella pedicullata



Limnodrilus sp.

Plate 4.3. Some macro-invertebrates of Calabar River at Okomita at the time of the study

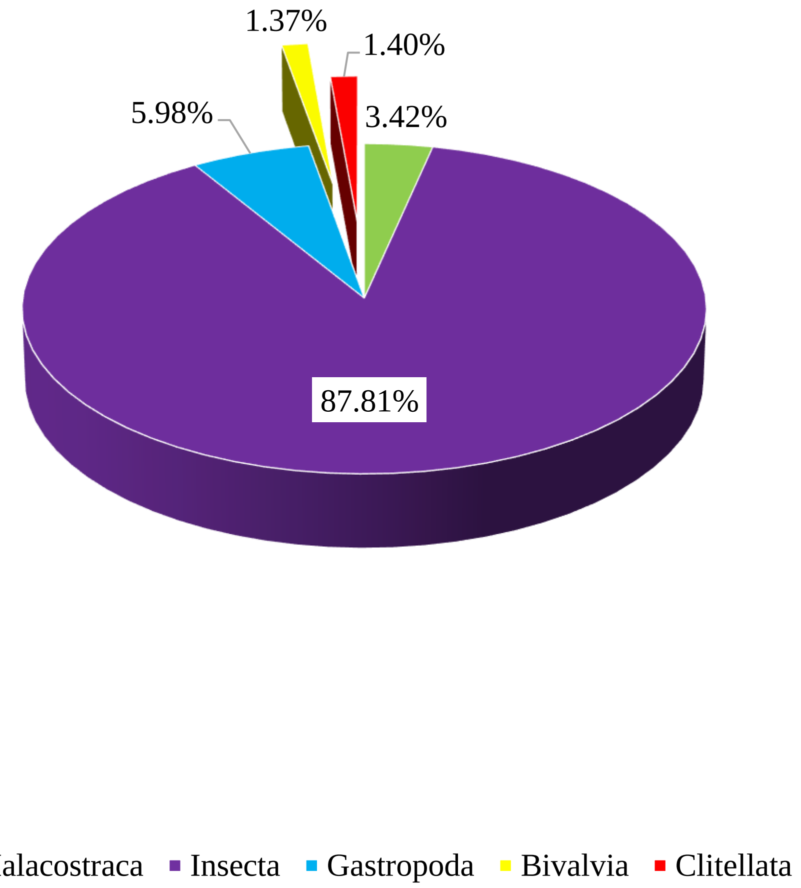


Figure 4.25. Percentage abundance of macro-invertebrates of Calabar River at Okomita at the time of the study

Table 4.13. Relative abundance of macro-invertebrates composition of Calabar River at Okomita at the time of the study

Class/Order	Species	Abundance (No)	Percentage (%)
MALACOSTRACA			
Decapoda	*Macrobrachium vollenhovenii*	121	1.32
	Macrobrachium macrobrachion	106	1.16
	Sudanonautes africanus	86	0.94
	Sub Total	**313**	**3.42**
INSECTA			
Hemiptera	*Gerris* sp.	654	7.15
	Mesovelia furcata	820	8.97
	Mesovelia Vittigera	820	8.97
	Ranatra sp *(larva)*	84	0.92
	Enithares sp.	3125	34.18
	Micronecta sp.	86	0.94
	Hydrometra sp.	68	0.74
	Hydrometra stagnorum	166	1.81
Coleoptera	*Gyrinus* sp.	303	3.31
	Orectochilus orbisonorum	306	3.35
	Donacia sp.	73	0.8
	Hydaticus flavolineatus	69	0.75
	Dytiscus dauricus	119	1.3
	Dineutus americanus	276	3.02
	Dineutus discolour	226	2.47
Odonata	*Epicordulia* sp.	12	1.39
	libellula sp.	63	0.69
	Anax imperator	67	0.73
	Phaon iridipennis	65	0.71
	Enallagma sp.	89	0.97
	Calopteryx sp.	62	0.68
Diptera	*Ablabesmyia* sp. *(larva)*	65	0.71
	Tipula sp. (larva)	68	0.74
	Chironomus sp. *(Larva)*	62	0.68
Trichoptera	*Glossosoma caddis (larva)*	33	0.36
	Tropisternus sp.	69	0.75
Placoptera	*Pteronarcys* sp. *(larva)*	66	0.72
	Sub Total	**8,031**	**87.81**
GASTROPODA			
Hydrophila	*Lymnaea natalensis*	104	1.14
Architaenioglossa	*Pila wernei*	81	0.89
	Pila ovata	99	1.08
	Lanistes libycus	85	0.93
	Eulima fischeri	85	0.93
Littorinimorpha	*Natica flammulata*	92	1.01
	Sub Total	**546**	**5.98**
BIVALVIA			
Unionida	*Mutula rostrata*	91	1.00
	Eupera parasitica	34	0.37
	Sub Total	**125**	**1.37**
CLITELLATA			
Tubificida	*Limnodrilus hoffmeisteri*	73	0.8
Rhynchobdellida	*Placobdella pediculata*	55	0.6
	Sub Total	**128**	**1.4**
	Grand Total	**9,143**	**100**

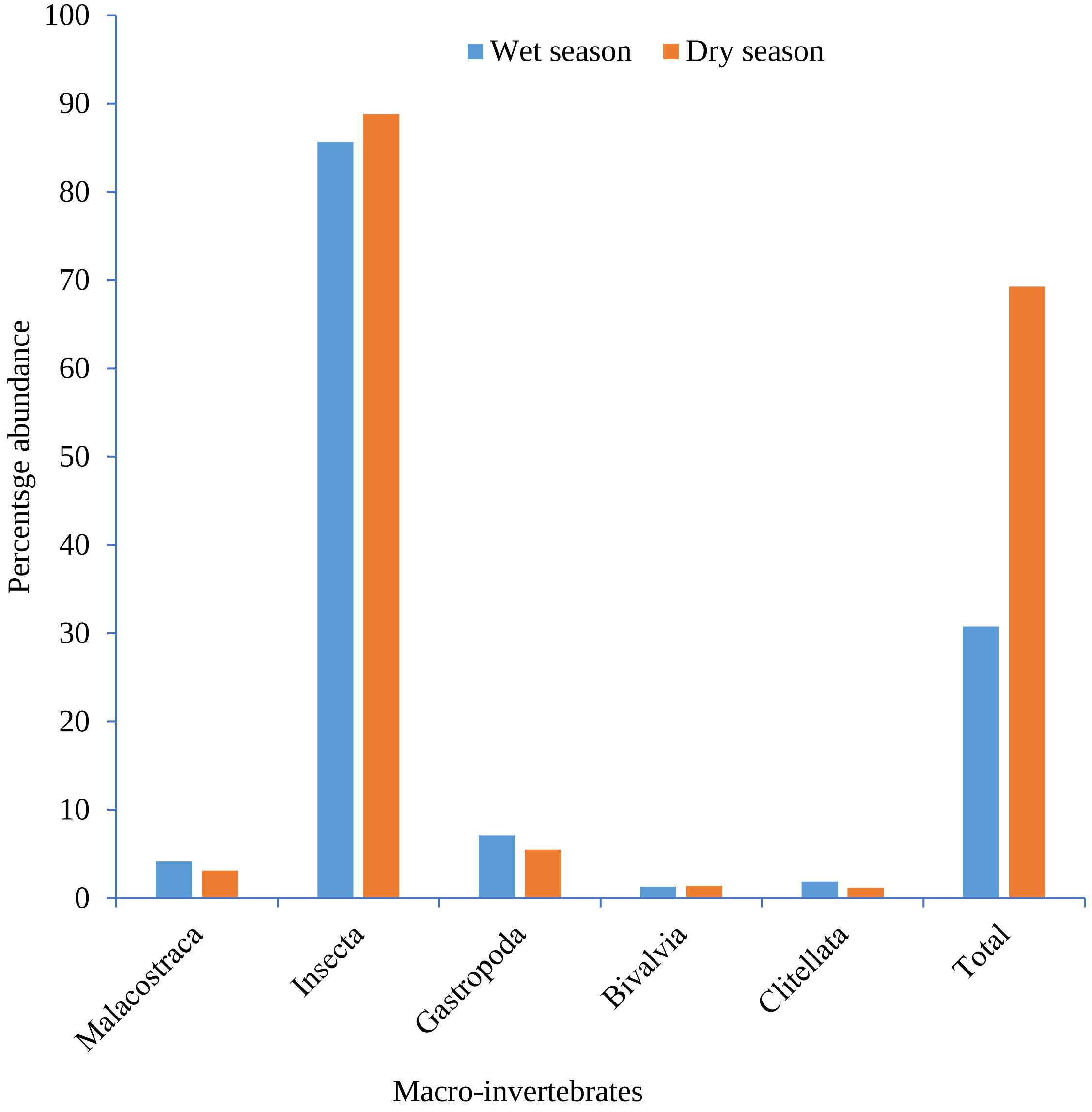


Figure 4.26. Seasonal percentage abundance of macro-invertebrates of Calabar River at Okomita at the time of the study

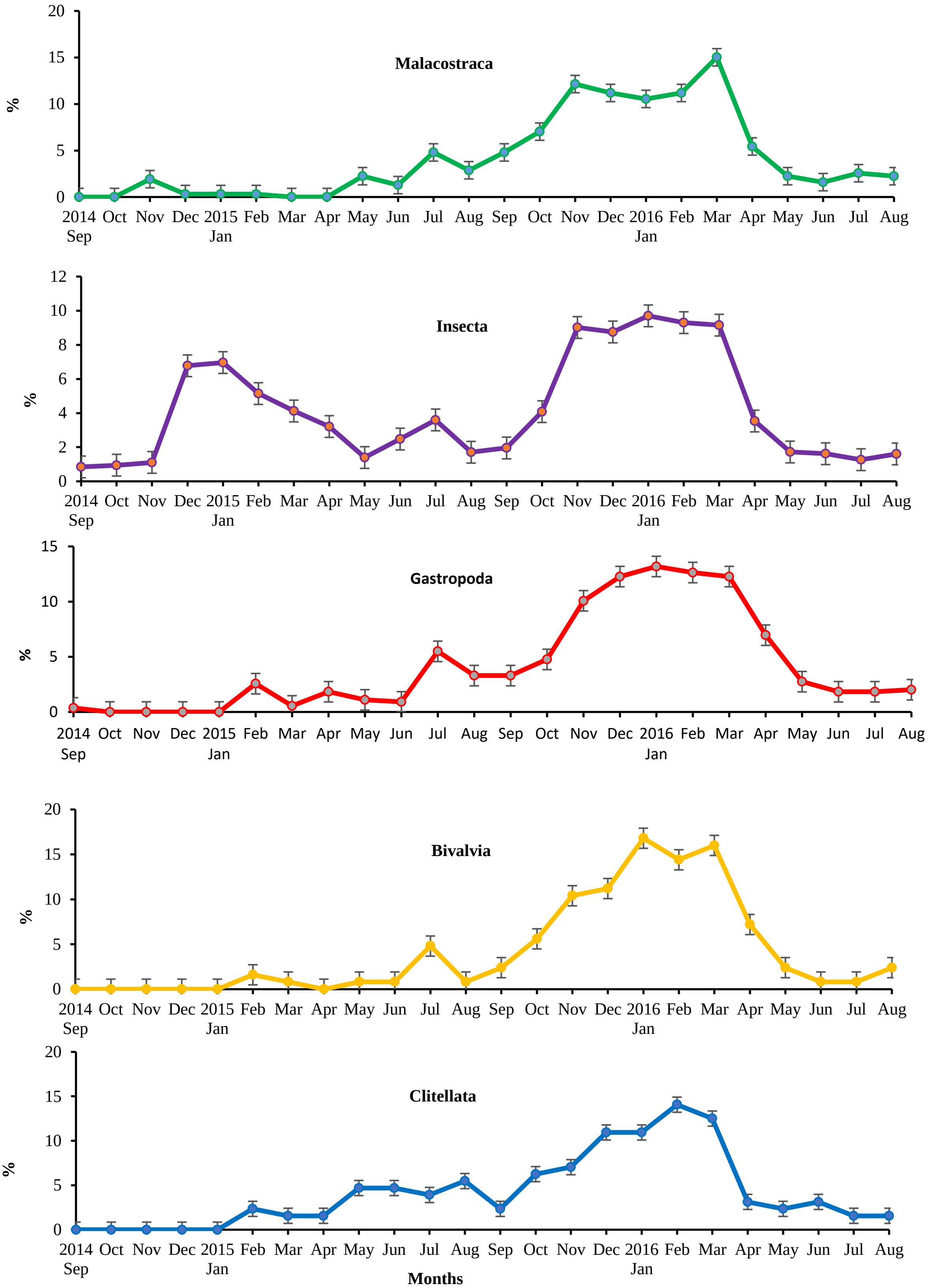


Figure 4.27. Temporal percentage abundance of macro-invertebrates of Calabr River at Okomita at the time of the study

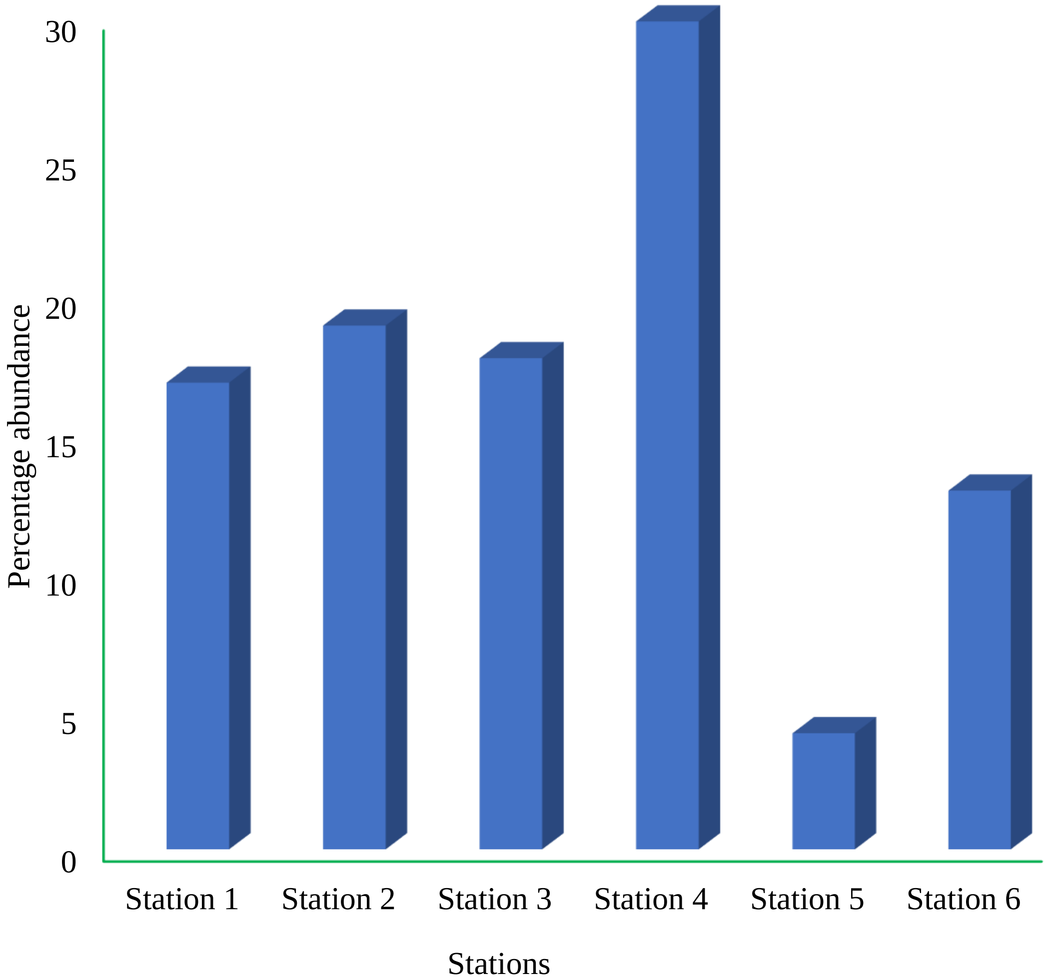


Figure 4.28. Spatial abundance of total macro-invertebrates of Calabar River at Okomita at the time of the study

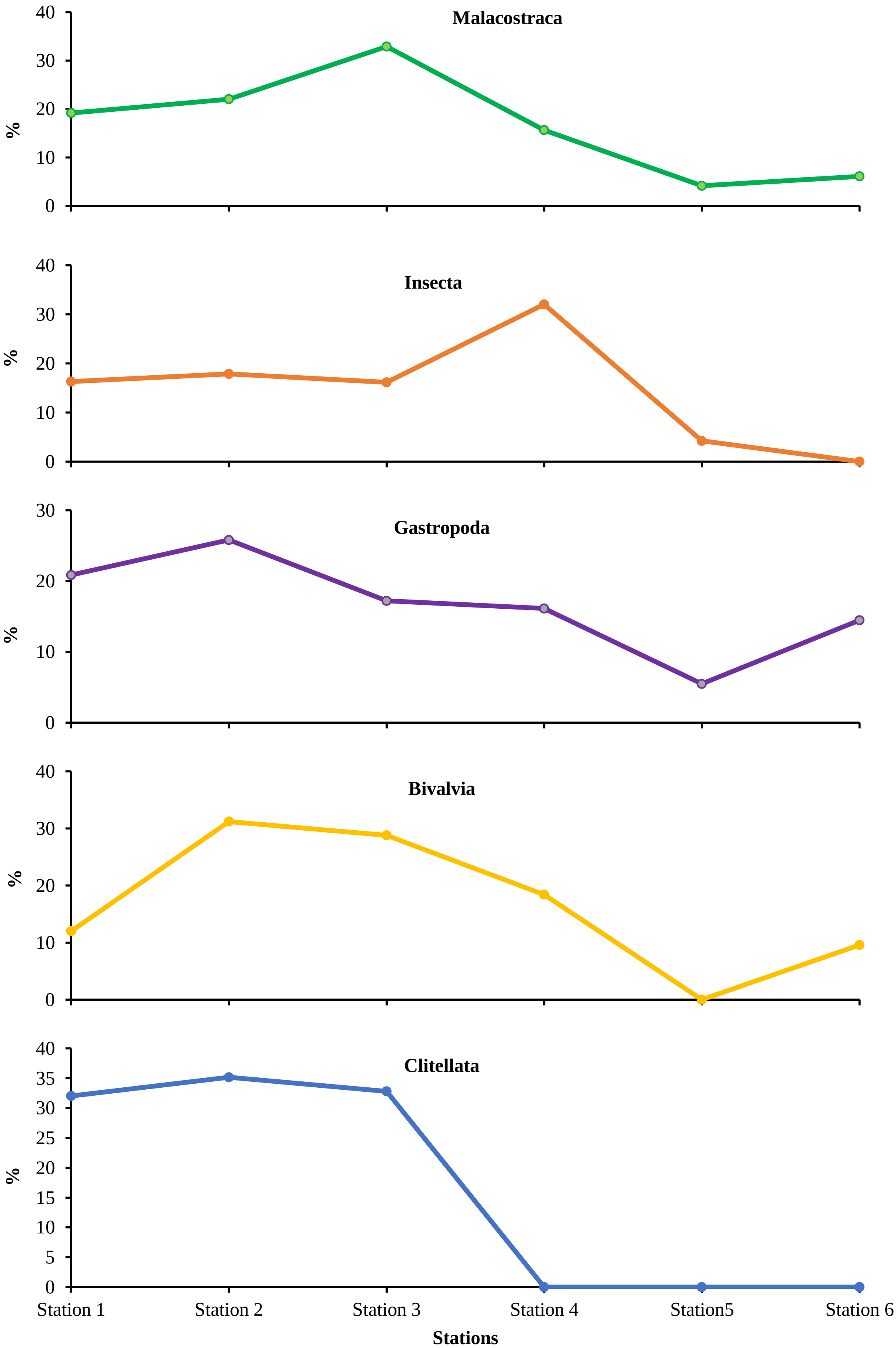


Figure 4.29. Spatial percentage abundance of macro-invertebrates of Calabar River at Okomita at the time of the study

abundance at Station Two (31.20%), while there was no bivalve encountered at Station Five. The spatial variations of Malacostraca, Bivalvia and Clitellata showed significant differences ($p<0.05$).

4.4.4 Diversity indices of macro-invertebrates

The results on the diversity indices are presented in Figure 4.30. Insecta had the highest diversity value (H = 2.355), while Bivalvia had the least (H = 0.585). Equitability of Gastropoda was highest (J = 0.998), while Insecta had the least value (J = 0.714) during the period of study.

4.4.4.1. Seasonal diversity indices of macro-invertebrates

The seasonal diversity indices of macro-invertebrates is presented in Figure 4.31. Higher diversity values were recorded in the dry season for Malacostraca (H = 0.994), Gastropoda (H = 1.709) and Bivalvia (H = 0.317). Insecta and Clitellata had higher diversity in the wet season i.e. H = 2.355 and H = 0.325 respectively. The total mean diversity value of macro-invertebrates was higher in the wet season (H = 1.119±0.398) than dry season (H = 1.105±0.382) though the difference was not significant ($p>0.05$). Equitability of Malacostraca (J = 0.905), Gastropoda (J = 0.954) and Bivalvia (J = 0.457) were higher in the dry season. The overall mean equitability values were equal in both seasons (see Figure 4.31).

4.4.4.2 Spatial diversity indices of macro-invertebrates

The highest mean total spatial diversity (H = 1.354±0.349) of macro-invertebrates was recorded in Station Three, while the lowest mean value (H = 0.894±0.452) was recorded in Station Five (Figure 4.32). The highest diversity of Malacostraca (H= 1.099) was recorded in Station Three while the lowest (H = 0.690) was recorded in Station Five (Table 4.14). Highest spatial diversity (H = 2.502) for Insecta was recorded in Station Three, while the lowest (H = 1.931) was recorded in Station Four. The highest spatial diversity (H = 1.781) was recorded at Station Three for Gastropoda, while the lowest (H = 1.414) was recorded at Station Five. The highest mean total spatial equitability value (J = 0.951±0.04) was recorded at Station Three (see Figure 4.32), while the lowest value (J = 0.501±020) was recorded at Station Five.

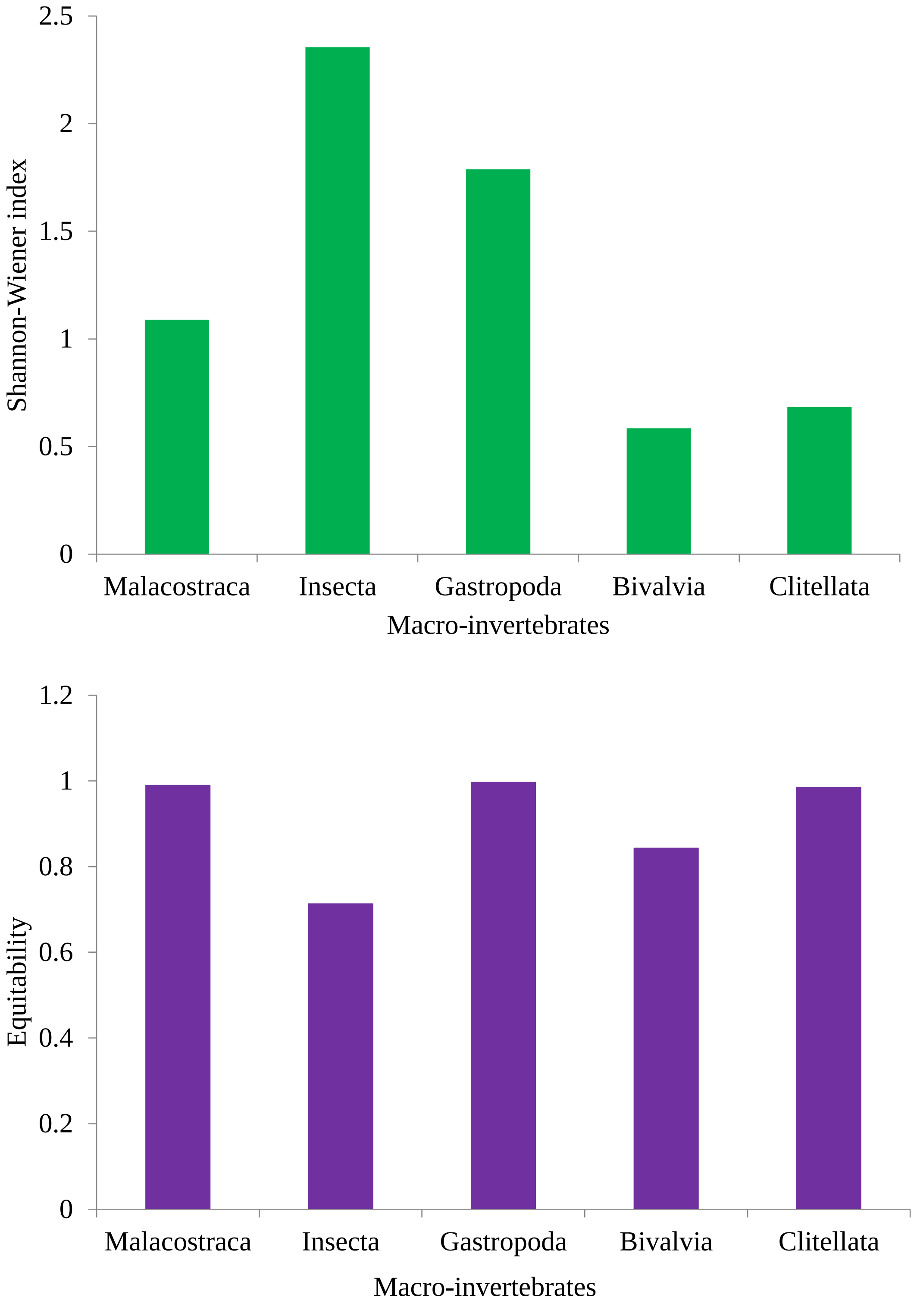
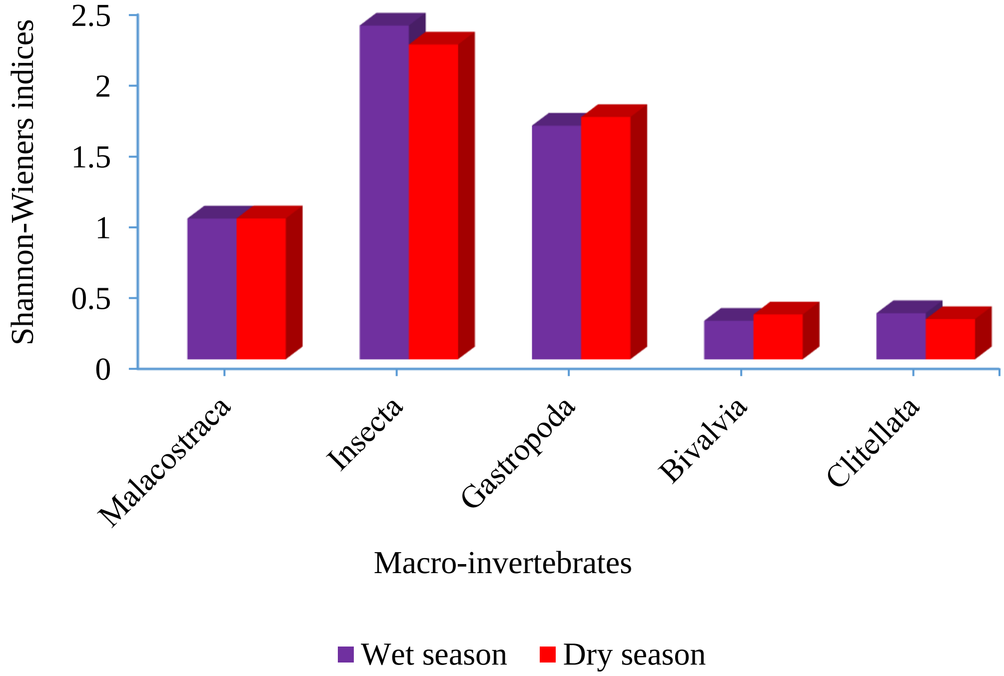


Figure 4.30. Diversity indices (Shannon-Wiener index ■ and Equitability ■) of macro-invertebrates of Calabar River at Okomita at the time of the study



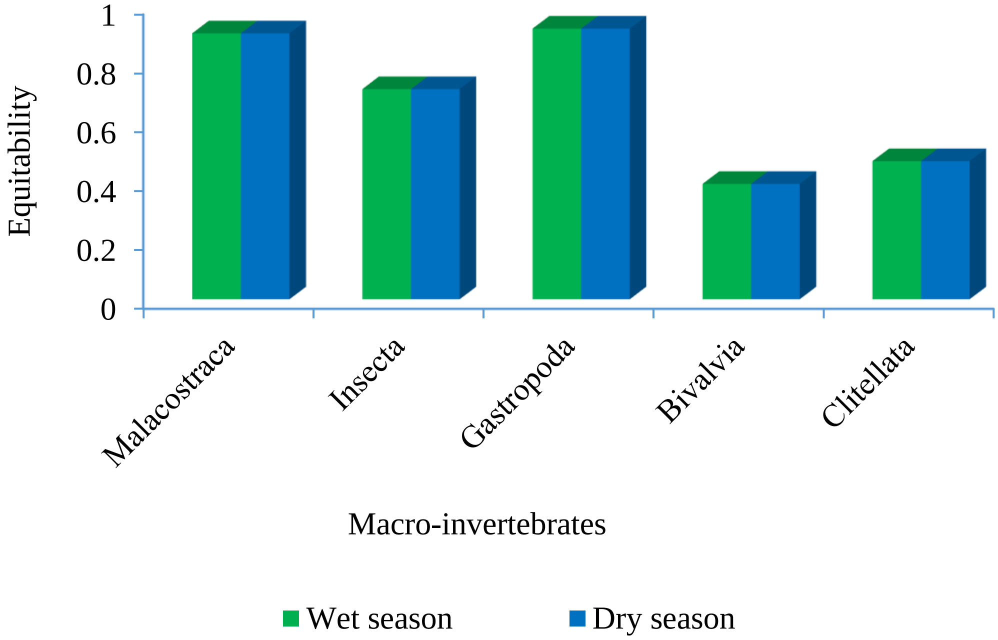
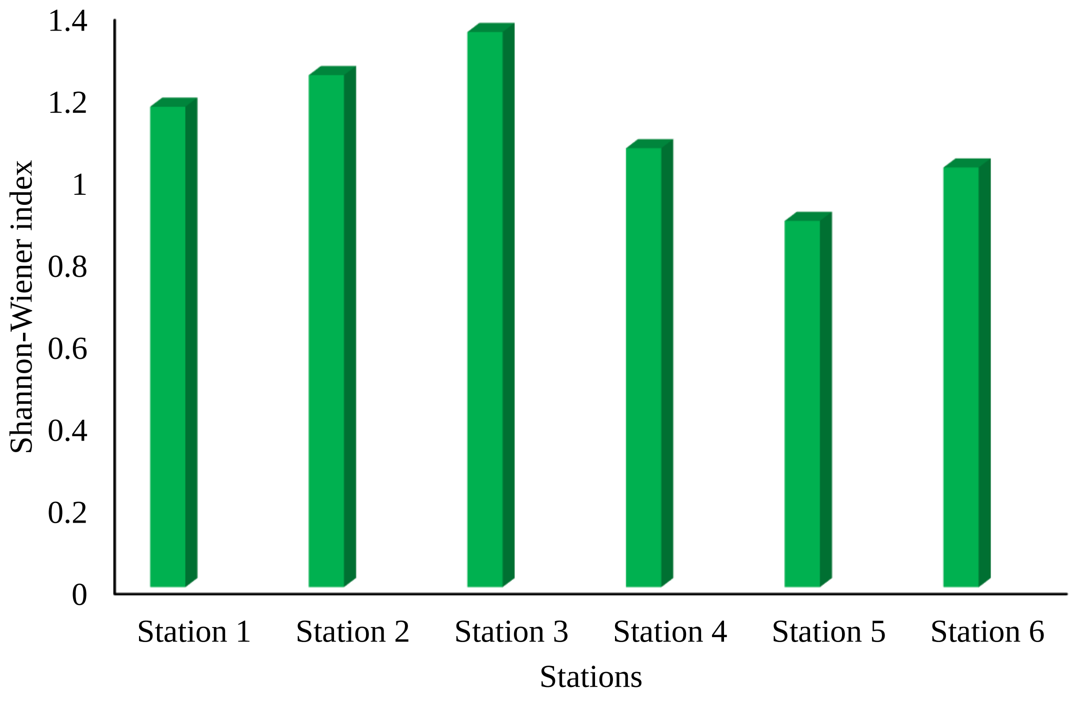


Figure 4.31. Seasonal diversity indices of macro-invertebrates of Calabar River at Okomita at the time of the study



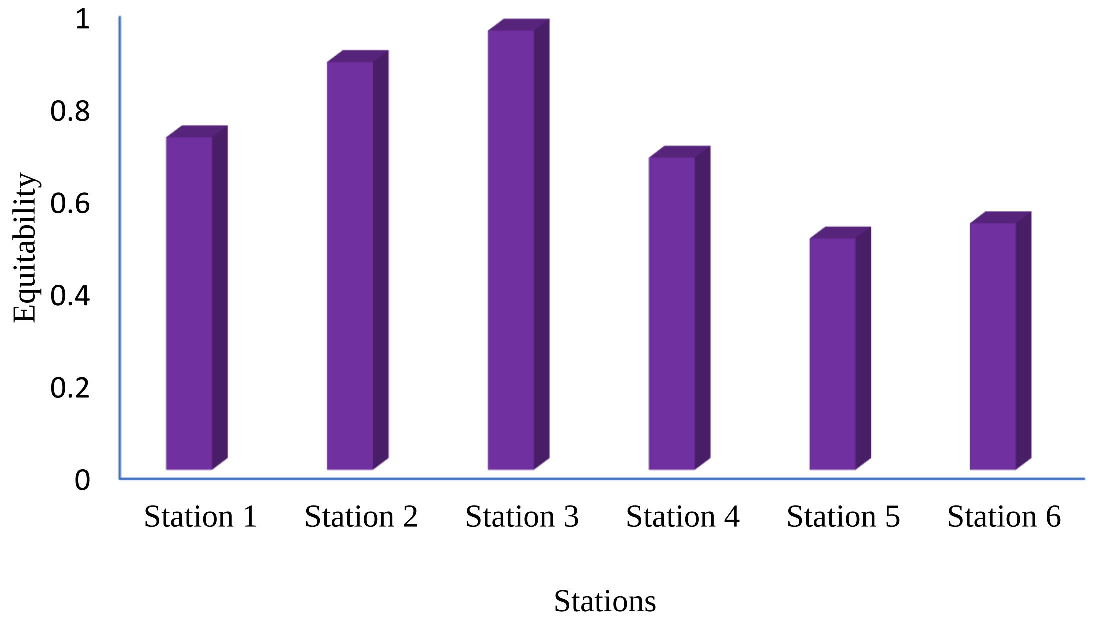


Figure 4.32. Spatial diversity indices (Shannon-Wiener index ■ and Equitability ■) of total macro-invertebrates of Calabar River at Okomita at the time of the study

Table 4.14. Spatial diversity indices of macro-invertebrates of Calabar River at Okomita at the time of the study

PHYLUM/Class	S1 H	S2 H	S3 H	S4 H	S5 H	S6 H
ARTHROPODA						
Malacostraca	1.011	1.098	1.099	1.073	0.690	1.096
Insecta	2.463	2.142	2.502	1.931	2.366	2.257
MOLLUSCA						
Gastropoda	1.709	1.773	1.781	1.776	1.414	1.768
Bivalvia	0.000	0.569	0.693	0.574	0.000	0.000
ANNELIDA						
Clitellata	0.679	0.663	0.693	0.000	0.000	0.000

Phylum/Class	S1 J	S2 J	S3 J	S4 J	S5 J	S6 J
ARTHROPODA						
Malacostraca	0.921	0.999	0.999	0.977	0.996	0.998
Insecta	0.747	0.650	0.759	0.586	0.718	0.685
MOLLUSCA						
Gastropoda	0.954	0.989	0.994	0.991	0.789	0.987
Bivalvia	0.000	0.821	1.000	0.828	0.000	0.000
ANNELIDA						
Clitellata	0.979	0.956	1.000	0.000	0.000	0.000

S1 is Station One, S2 is Station Two, S3 is Station Three, S4 is Station Four, S5 is Station Five and S6 is Station Six, H is Shannon Wiener's Index, J is Equitability Measure

4.5 Principal components of relationships between physico-chemical parameters with plankton and macro-invertebrates abundance

The principal components of physico-chemical parameters and the biota abundance are presented in Table 4.15, while the biplots are presented in Figures 4.33 to 4.35. In the first component, DO (0.67), BOD (0.69) and hardness (0.66) had the highest positive association with Insecta (0.65) and Bivalvia (0.65) abundance. Water pH (-0.65), TSS (-0.53) and turbidity (-0.69) had significant negative association with Insecta (0.65) and Bivalvia (0.65) abundance. Disolved oxygen (0.67), biochemical oxygen demand (0.69), hardness (0.66), alkalinity (0.59), transparency (0.54) and magnesium (0.54) had significant negative association with Cyanophyceae (-0.38) abundance. Total suspended solids (-0.53), pH (-0.65) and turbidity (-0.69) had significant negative association with the abundance of Inescta (0.65), Bivalvia (0.65) and Rotifera (0.39) abundance in the first component. Water depth (-0.48), conductivity (-0.60) and transparency (-0.48) had significant positive associated with Rotifera (-0.50), Cladocera (-0.60), Copepoda (-0.64), Protozoa (-0.52), Bacillariophyceae (-0.59), Cyanophyceae (-0.49) and Chrysophyceae (-0.51) abundance in the second component.

Season was important factor affecting the abundance of species in PC one to four. Principal Components 1 to 4 accounted for 50.06% variations in physico-chemical parameters and biota abundance. Dry season (0.80) had significant positive association with physico-chemical parameters (hardness, 0.66; DO, 0.67; BOD, 0.69), plankton (blue-green algae, 0.49) and macro-invertebrate (insects, 0.65 and bivalves, 0.65) abundance. Wet season (-0.80) had significant positive association with physico-chemical parameters (turbidity, -0.69 and pH, -0.65) and plankton (diatoms, -0.59; rotifers, -0.50; cladocerans, -0.60 and protozoans, -0.52) abundance but significant negative association with macro-invertebrates (insects, 0.65 and bivalves, 0.65) abundance. Dry season showed strong positive association with metals (Cu, Cd, Fe, Zn and Mg), nutrients (PO_4^- and SO_4^-) and biota (insects, bivalves, and rotifers) abundance.

Ordination plot of multidimensional scaling distances within stations is presented in Figure 4.36. Stations One and Two were far from each other and also far from Stations Three, Four, Five and Six. Stations Three to Six were close to each other within the ordinate plot.

Table 4.15. Principal Components (PC) relationships between physico-chemical parameters with plankton and macro-invertebrates abundance of Calabar River at Okomita at the time of the study

	PC 1	PC 2	PC 3	PC 4	PC 5
Water depth	-0.44	-0.48	0.42	0.40	-0.32
Air temp	-0.02	-0.12	0.54	-0.36	0.12
Water temp	0.03	0.08	0.61	-0.10	-0.02
pH	-0.65	-0.17	-0.03	0.33	0.10
DO	0.67	-0.17	-0.34	0.34	0.07
BOD	0.69	0.08	-0.06	-0.16	-0.08
COD	-0.18	0.08	0.50	-0.31	0.12
Conductivity	0.21	-0.60	-0.19	-0.19	-0.03
TDS	-0.46	-0.25	0.33	-0.02	0.05
TSS	-0.53	-0.17	0.07	-0.07	-0.09
Hardness	0.66	0.12	0.07	-0.27	-0.17
Alkalinity	0.59	-0.24	0.14	-0.30	-0.14
Transparency	0.54	-0.58	0.42	0.40	-0.32
Turbidity	-0.69	0.05	0.35	0.04	-0.08
Zn	0.41	-0.22	0.21	0.20	-0.40
Fe	0.43	0.34	-0.09	-0.07	-0.13
Mg	0.54	0.20	-0.41	0.08	-0.22
Mn	0.18	0.01	0.04	-0.23	-0.01
Cu	0.31	0.05	0.22	-0.21	0.11
Cd	0.43	0.14	0.10	0.25	-0.25
Pb	-0.01	0.33	-0.01	-0.24	-0.29
Cl^-	0.44	-0.39	0.28	-0.03	0.10
SO_4^-	0.34	-0.35	0.31	-0.06	-0.36
PO_4^-	0.44	-0.25	0.11	-0.26	-0.43
NO_3^-	0.05	-0.27	0.01	-0.42	-0.32
Arthropoda	0.58	-0.32	0.50	0.14	0.31
Insecta	0.65	-0.14	0.04	0.22	0.38
Mollusca	0.65	-0.35	0.46	0.06	0.13
Bivalvia	0.65	-0.26	0.45	0.24	0.18
Annelidar	-0.19	-0.21	-0.09	-0.23	0.09
Rotifera	0.39	-0.50	0.36	0.24	0.08
Cladocera	-0.18	-0.60	-0.59	0.06	0.05
Copepoda	-0.13	-0.64	-0.36	-0.16	0.00
Protozoa	-0.07	-0.52	-0.51	-0.08	-0.09
insectar	-0.04	-0.30	-0.11	-0.09	0.03
Bacillariophyceae	0.09	-0.59	-0.25	-0.11	0.22
Chlorophyceae	-0.26	-0.41	-0.40	0.05	0.08
Cyanophyceae	-0.38	-0.49	-0.08	-0.12	-0.06
Chrysophyceae	-0.17	-0.51	-0.18	-0.25	0.02
Dianophyceae	-0.01	-0.04	0.55	-0.31	0.21
Euglenophyceae	-0.06	-0.26	0.49	-0.53	0.17
Season {wet}	-0.80	0.09	0.34	-0.09	0.05
Season {dry}	0.80	-0.09	-0.34	0.09	-0.05
Site {site 1}	-0.11	-0.79	-0.24	-0.38	0.06
Site {site 2}	-0.06	-0.26	0.31	0.63	-0.47
Site {site 3}	0.05	0.08	0.08	0.26	0.43
Site {site 4}	0.05	0.23	-0.10	0.10	0.51
Site {site 5}	-0.01	0.36	-0.03	-0.25	-0.28
Site {site 6}	0.07	0.37	-0.02	-0.35	-0.25
Eigenvalues	**8.44**	**5.68**	**4.90**	**3.11**	**2.40**
% Total variance	**17.22**	**11.58**	**10.01**	**6.36**	**4.89**
Cumulative eigenvalue	**8.44**	**14.11**	**19.02**	**22.13**	**24.53**
Cumulative %	**17.22**	**28.80**	**38.81**	**45.17**	**50.06**

Temp is Temperature, DO is Dissolved Oxygen, BOD is Biochemical Oxygen Domand, COD is Chemical Oxygen Demand, TDS is Total Dissolved Solids, TSS is Total Suspended Solids, Zn is Zinc, Fe is Iron, Mg is Magnesium, Mn is Manganese, Cu is Copper, Cd is Cadmium, Pb is Lead, CL^- is Chloride, SO_4^- is Sulphate, PO_4^- is phosphate, NO_3^- is Nitrate

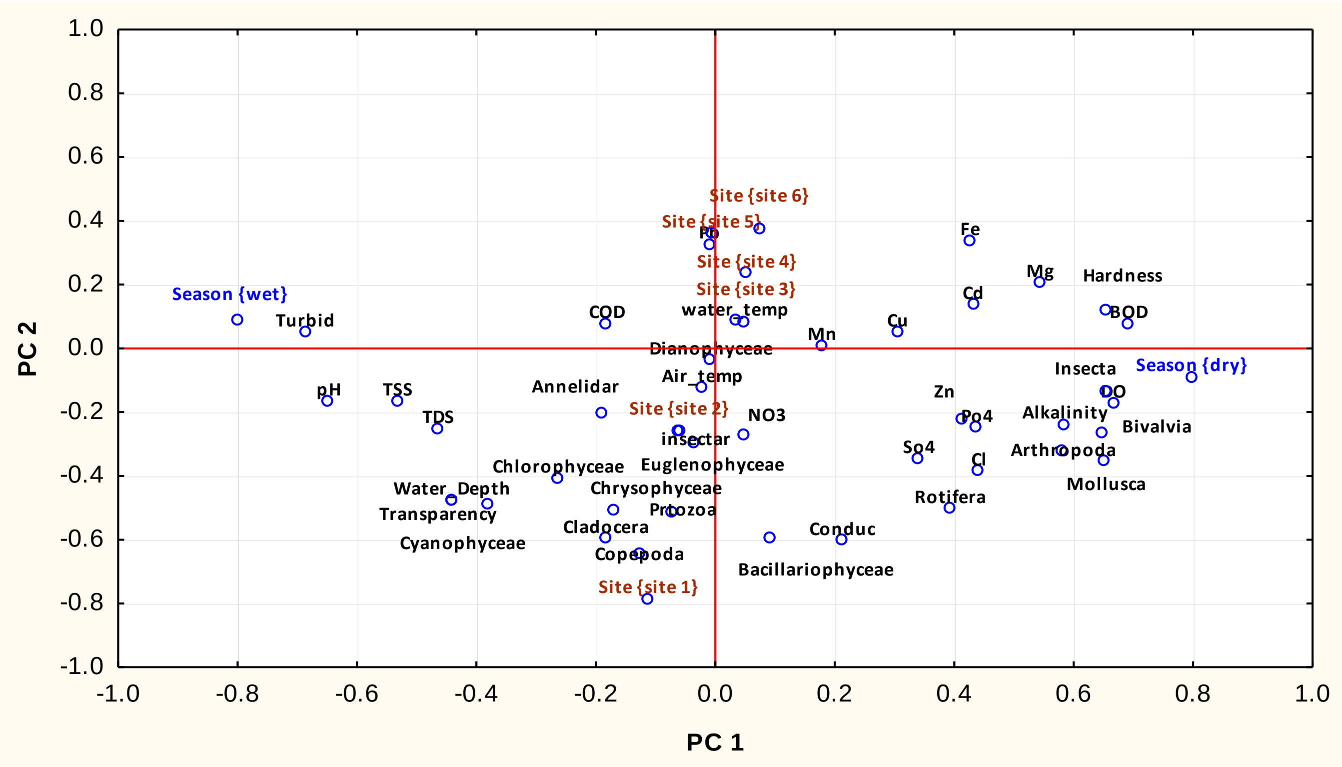


Figure 4.33. Biplot of Principal Components (PC) one and two of physico-chemical parameters and plankton and macro-invertebrates abundance of Calabar River at Okomita at the time of the study

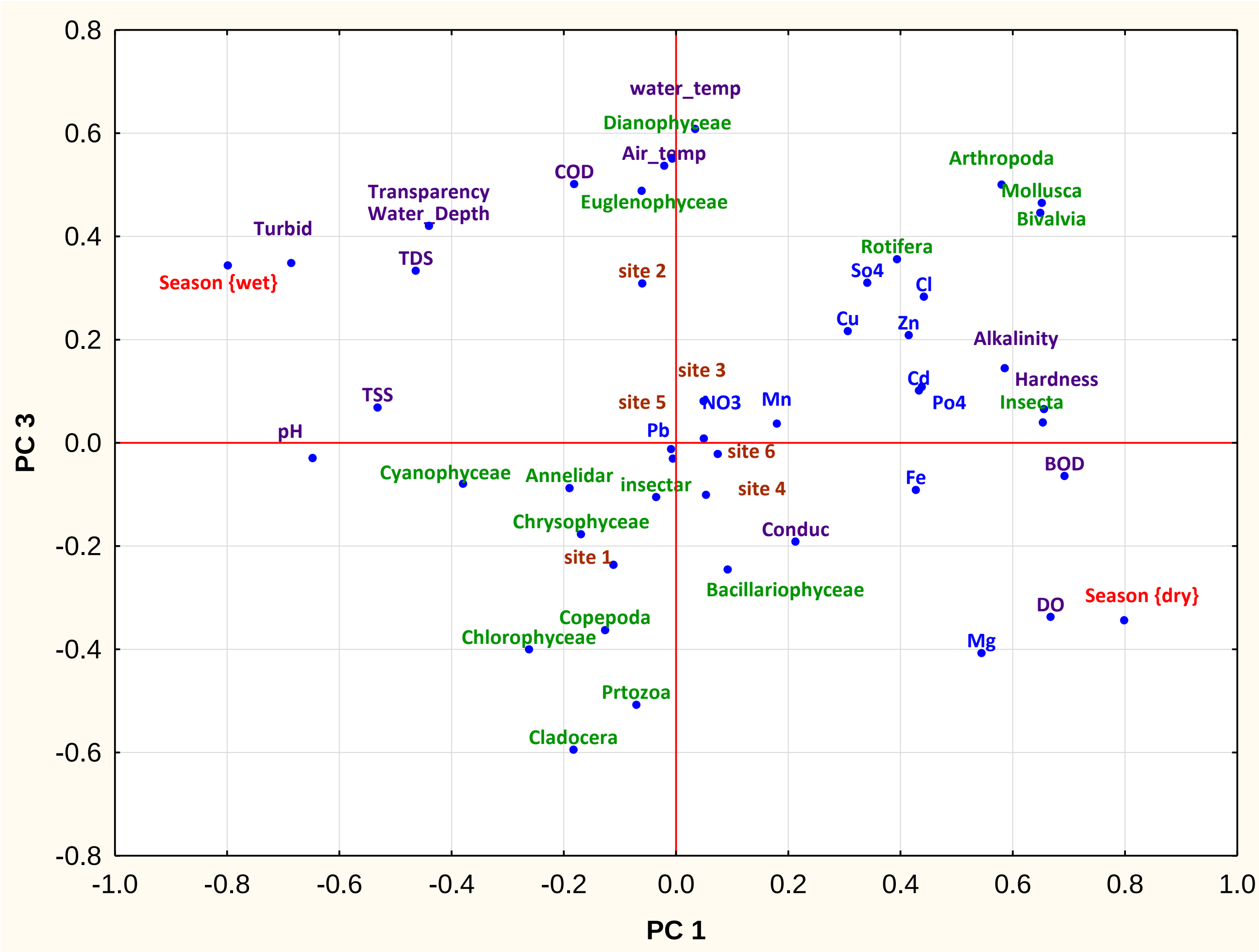


Figure 4.34. Biplot of Principal Components (PC) one and three of physico-chemical parameters and plankton and macro-invertebrates abundance of Calabar River at Okomita at the time of the study

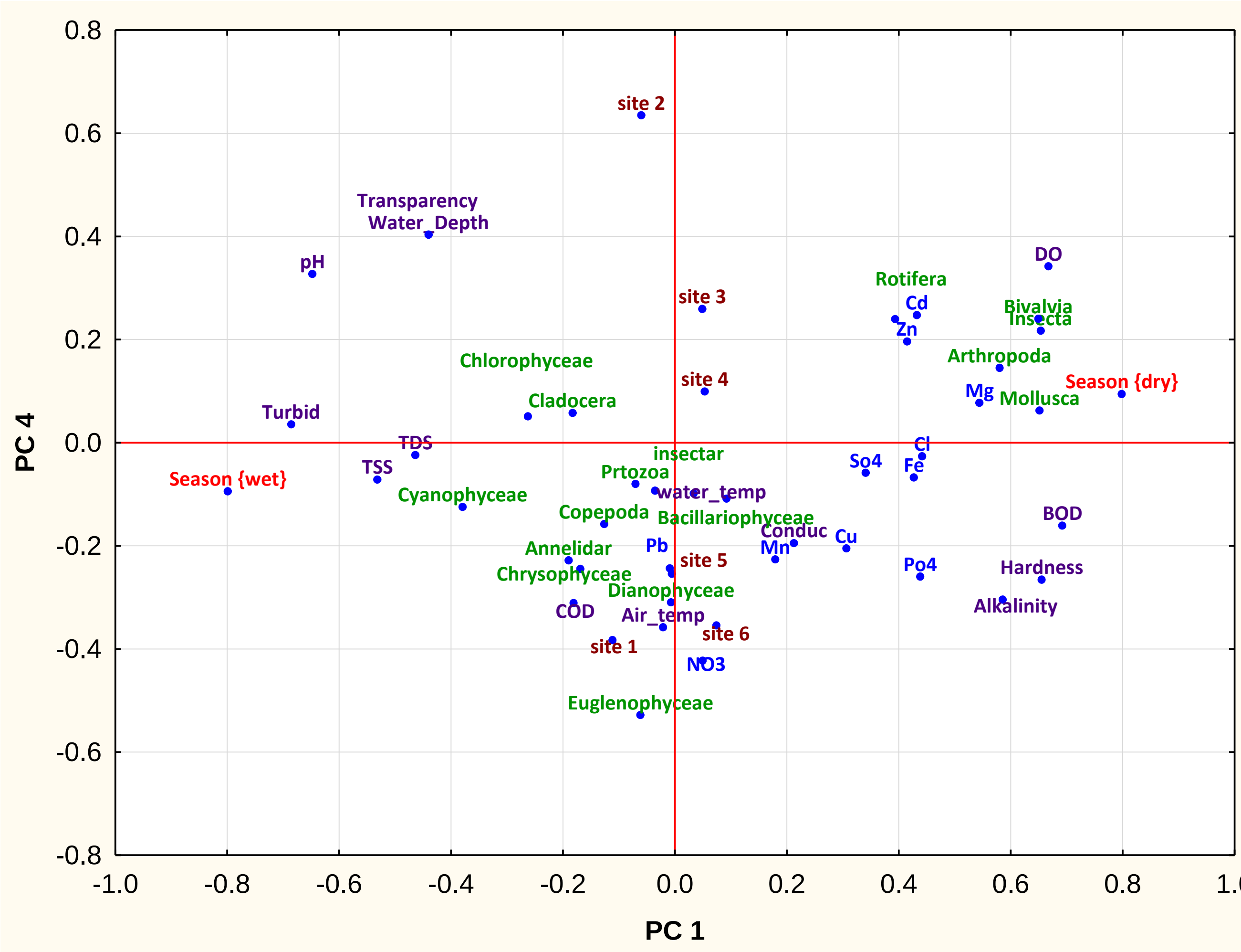


Figure 4.35. Biplot of Principal Components (PC) one and four of physico-chemical parameters and plankton and macro-invertebrates abundance of Calabar River at Okomita at the time of the study

Station 1

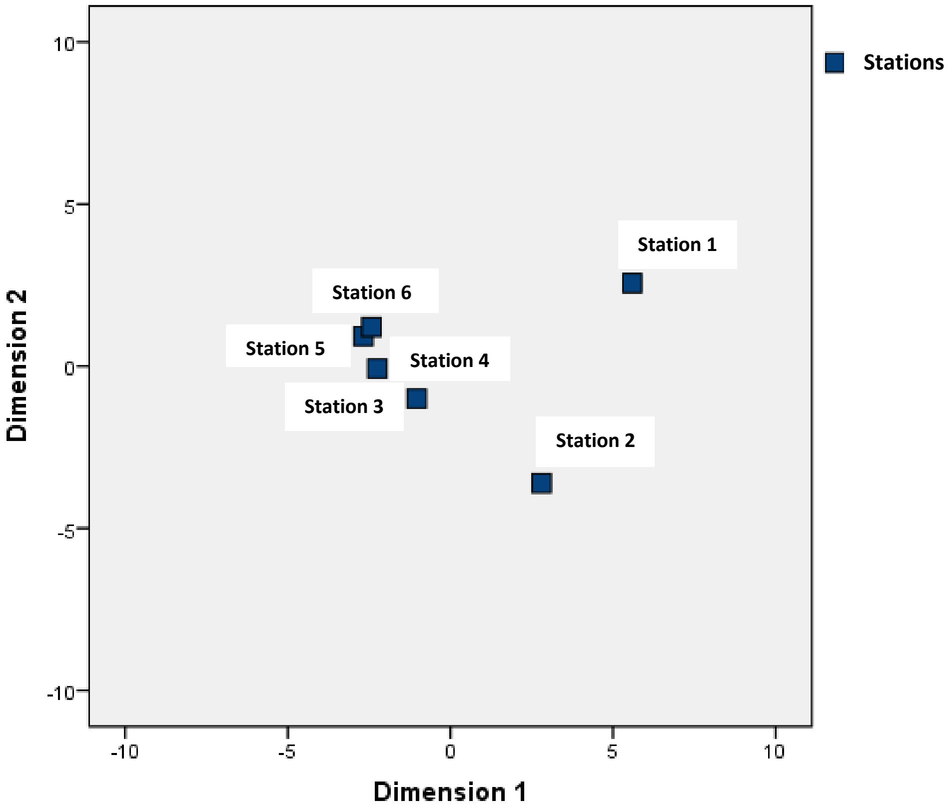


Figure 4.36. Ordination plot of multidimensional scaling distances based on physico-chemical parameters and abundance of plankton and macro-invertebrates between Stations One and Six

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical parameters

The water depth varied in each station. Station Two had significant higher deopth. This can be attributed to sand mining, an intensive activity in this station which occurred regularly throughout the year and this implies that sand mining influenced the depth of the river at Station Two. The range of water depth in Calabar River at Okomita is close to the report of Nwinyimagu *et al*. (2018) on the water depth (0.29-1.20) m of River Asu, south-south Nigeria. On the other hand, the range of water depth in Calabar River, Okomita exceeded the reports of Taiwo *et al*. (2017) on the water depth (0.11-1.67) m of Opa Reservouir in Ile-Ife, southwest Nigeria but lower than the report of Idowu *et al*. (2020) on the water depth (3.8-6.3) m of Ogbese River, Ado-Ekiti, Ekiti State.

Calabar River at Okomita was transparent down to the river bottom during the study period. The low turbidity, low total dissolved solids and low total suspended solids of the river could also have influenced the high water transparency. The river water being transparent to the bottom shows that light penetration reached the bottom of the river during the study period. This favours all aquatic plants in the river since they need sunlight for photosynthesis. The insignificant seasonal variation in transparency of the study area was an indication that seasonal changes in total suspended solids, turbidity, and total dissolved solids did not significantly alter transparency.

Values obtained for TSS (0.00–2.68) mg/L in the present study were less than the recommended limit (≤5.0 mg/L) by WHO (2004) for aquatic life, the low TSS can give rise to increase in entry of light into the river which may lead to increased photosynthesis with consequent increase in the population of phytoplankton and zooplankton. Higher TSS was recorded by Oluyemi *et al*. (2014) in Ethche River, Niger Delta, Akaahan *et al*. (2015) in River Benue, Makurdi and Tesi *et al*. (2019) in Warri River, Niger Delta. The authors attributed the high TSS to sand mining and discharge of wastes from industrial and domestic sources. The lowest value of TSS at Station Four showed that sand mining activities did not impact TSS at this station. The significantly higher TSS in the wet season than in the dry season in the present study could be attributed to possible higher quantity of suspended solid materials washed into the river by run-offs during rainfall.

The average water temperature of Calabar River, Okomita during the period of study fell within the range of acceptable temperatures (20-33^{o}C) of National Environmental Standard Regulation and Enforcement Agency, NESREA (2011) for aquatic life. The month of lowest temperature (February) corresponds with the months (November to February) of cool weather in the study area which may have been caused by harmattan. The harmattan period is characterised by cool dry north-east trade wind, hence the low temperature. The lowest water temperature recorded during the harmattan period in this work is similar to the works of Mustapha (2009) in Oyun Reservior, Offa, Nigeria, Usoro *et al*. (2013) in Ikoli River, Niger Delta; Akindele and Liadi (2014) in Aiba Stream, Iwo, south-west Nigeria; Nwabunike (2016) in Ebonyi River System, Ebonyi State; Apollos *et al*. (2016) in Zobe Reservoir, Dutsinma, Katsina State; Seiyaboh *et al*. (2016) in Ikoli Creek, Niger Delta and Taiwo *et al*. (2017) in Opa Reservoir, Ile-ife, southwest Nigeria who recorded the lowest temperature during harmattan months.

Significantly higher water temperature in Stations Two, Three and Five could be due to bathing, washing of clothes, dumping of wastes and sand mining activities. Idowu and Gadzama (2011) in Lake Alau, north-east Nigeria and Amadi *et al*. (2020) in Krakrama (Brackish) water, Rivers State reported higher temperatures at stations where there were influence of human activities such as bathing, sand mining, dumping of refuse and farming.

The mean pH (7.84±0.06) obtained in this study reveals that the water is close to neutral and so it is safe for aquatic organisms. Furthermore, it is within the recommended range (6.5-8.5) of NESREA (2011) for aquatic life. The mean pH is similar to the pH reported in other rivers in Nigeria such as River Ogun, Abeokuta (Odulate *et al*., 2017) and Ajali River, Enugu State (Eboh *et al*., 2020). The variation of pH with season noticed in the present study could be due to dilution from rain water (freshwater input) during the wet season as also reported by Adefemi *et al*. (2007); Ogbu *et al*. (2016); Atalawei and Gobo (2020) and Eboh *et al*. (2020). The higher pH of Calabar River, Okomita in the wet season agreed with the findings of Izonfuo and Bariwari (2001) in Epie Creek, Niger Delta; Seiyaboh *et al*. (2013) in Igbedi Creek, Upper Nun River, Niger Delta;

Aghoghovwia and Ohimain (2014) in Lower Kolo Creek, Otuogidi, Bayelsa State; Ogamba *et al*. (2015) in River Nun, Amassoma Axis, Nigeria; Seiyaboh *et al*. (2016) in Ikoli Creek, Niger Delta and Eboh *et al*. (2020) in Ajali River, Enugu State.

The mean DO (4.72±0.07) mg/L was lower than the acceptable limit (6-8) mg/L for aquatic life by WHO (2004) and NESREA (2011). Chemicals such as pesticides, herbicides and fertilizers from farms, domestic wastes and human faeces from dumpsites along the banks of Calabar River at Okomita may be responsible for the low dissolved oxygen. Similar observations of low DO as a result of organic pollution was reported by Yakub and Ugwumba (2010) in lower Ogun River, Ishasi-Olafin, Ogun State; Lawson (2011) in Lagos Lagoon, Lagos; Andem *et al*. (2013) in the intertidal regions of Calabar River at Calabar and Ogwueleka and Christopher (2020) in Usuma River, north-central, Nigeria. The higher concentration of DO in the dry season could be attributed to increase in photosynthetic activity, while the lower dissolved oxygen in the wet season could be attributed to decrease in photoperiod and photosynthetic activities as well as increase in turbidity of the water possibly caused by run-offs into the river during the wet season. Talabi *et al*. (2017) in river Oluwa, Agbabil, Ondo State; Taiwo *et al*. (2017) in Opa Reservoir at Ile-Ife, South-western Nigeria and Atalawei *et al*. (2020) in Olugbobiri and Ogboinbiri Creek, Bayelsa State also observed lower DO in the wet season. The authors attributed the lower DO during the wet season to increased amount of organic matter washed into the river by surface run-offs from the surroundings areas.

The BOD range (0.78-3.88) mg/L was less than 4 mg/L suitable for aquatic life as recommended by NESREA (2011). Any water body with BOD level lower than 4 mg/L is considered clean and water bodies with BOD levels higher than 10 mg/L is regarded as polluted since such water body contains degradable organic compounds in abundance (Boyd, 1982; NESREA, 2011; Tesi *et al*., 2019). According to Bamuwamye *et al*. (2017) and Ogwueleka and Christopher (2020), high BOD concentrations suggest a decline in dissolved oxygen concentration because the bacteria that threaten fish and other aquatic life survival are consuming the oxygen that is already accessible. The low DO recorded in this study area in the present study is possibly not cuased by BOD levels implying that other factors such as high turbidity which reduces photosynthesis could be responsible for the low DO. The higher BOD level (2.46±0.14) in the dry season could be due to higher putrefaction of substances deposited in the river from the surrounding areas, while the lower values in the wet season could be attributed to dilution effects of rain. Higher BOD recorded at Stations Three, Four, Five and Six where there were activities such as harvesting of palm fruits, dumping of refuse, milling of palm oil, harvesting and processing of rubber, butchering of animals and automobile repair might be due to the several organic wastes from dumpsites, abattoir and mechanic workshop, and chemicals such as herbicides, pesticides and fertilizers from the rubber and oil palm plantations along the river banks.

Direct discharge of untreated agricultural wastes from pesticides, herbicides and fertilizers through run-offs into Calabar River at Okomita may have contributed to the higher COD concentrations seen during the wet season compared to the dry season. The discharges (metals, commercial solvents, herbicides, pesticides, plant nutrients and sediments) from the catchment areas of the river could present some levels of danger to the aquatic biota. The COD value reported in this study was lower compared to the values reported by Amah-Jerry *et al*. (2017) in Aba River, Nnamonu *et al*. (2018) in River Ebenyi in Eha-Amufu and environs, Enugu State, both in southeast Nigeria and Tesi *et al*. (2019) in Warri River, Niger Delta.

The mean value of conductivity (22.11±0.77 µS/cm) for Calabar River at Okomita during this study was lower than the acceptable limit (1000 µS/cm) by WHO (2004) for aquatic life. The mean conductivity value can be regarded as low according to Sawyer (1996) who classified conductivity levels as follows: lower than 50 µS/cm as low; between 50-60 µS/cm as medium, and above 60 µS/cm as high levels. The conductivity value obtained in this study was less than the values recorded in some surface waters in Nigeria (Ogamba *et al*., 2015 in Kolo Creek, Niger Delta; Taiwo *et al*., 2017 in Opa River, Ile-Ife, southwest Nigeria; Olaniyan and Oguntimehin, 2017 in Owena River and Reservoir, Ondo State; Talabi *et al*., 2017 in Oluwa River, Agbabil, Ondo State and Baba *et al*., 2020 in Abba River, Gombe State). Using electrical conductivity as a measure of water quality, Calabar River at Okomita has low water quality. Dilution of ions by rain water may be the cause of the decline in conductivity levels during the wet season.

Higher TDS during the wet season might be as a result of run-offs from land into the river. Similar observation was reported by Mustapha (2009) in Oyun Reservoir, Offa, Kwara State; Seiyaboh *et al.* (2016) in Ikoli Creek, Niger Delta and Eboh *et al*. (2020) in Ajali River, Enugu State. Some researchers have observed higher TDS in different freshwater bodies in Nigeria, examples are: Izonfuo and Bariwani (2001) in Epie Creek, Niger Delta; Seiyaboh *et al*. (2013) in Igbedi Creek, Niger Delta; Aghoghovwia and Ohimaim (2014) in Kolo Creek, Otuogidi, Bayelsa State and Nwinyimagu *et al*. (2018) in River Asu, a tributary of Cross River, southeast Nigeria. The authors attributed the high TDS to regular discharge of wastes from industrial and domestic sources. The mean TDS value (16.88±0.28 mg/L) during the study period was below NESREA (2011) recommended limit of 300 mg/L and WHO (2004) recommended limited of 500 mg/L for aquatic life. So TDS values in Calabar River at Okomita fell within tolerable limit for aquatic life and domestic uses.

The higher level of hardness throughout the dry season, recorded during the present study compared with the wet season may be attributed to high level of alkalinity due to lower water level in the dry season. The study of Salisu *et al*. (2020) in River Saye, Zaria, Kaduna State; Eboh *et al*. (2020) in Ajali River, Enugu State and Atalawei and Gobo (2020) in Olugbobiri and Ogboinbiri Creek, Bayelsa State who recorded higher values of hardness in the wet season, disagrees with this investigation. The authors attributed their observation to increase in the amount of solid substances due to run-offs into the water body in the wet season. The low water hardness during the wet season could be due to dilution caused by increased rainfall. This finding agrees with the results of Ufodike *et al*. (2001) in Dokowa Mine Lake, Plateau State; Kolo and Oladimeji (2004) in Shiroro Lake, Niger State; Taiwo *et al*. (2017) in Opa Reservoir, Ile-Ife and Onuora *et al*. (2020) in Iyifeyi Stream, Ugwobi Abbi, Enugu State who also recorded higher concentrations of hardness in the dry season. The authors attributed their findings to dilution effects of precipitation.

Total hardness did not go beyond the maximum allowable limit (150 mg/L) by WHO (2004) for aquatic life. Hunter (1997) and Hanna (2003) classified hard water as having concentration greater than 200 mg/L while soft water usually has hardness concentration level lower than 75 mg/L. This shows that Calabar River, Okomita water was soft during the period of study. The desirable range of total hardness for fish production falls within 20-300 mg/L (Boyd and Lichtkoppler, 1979). Fish can grow to a desirable size with water hardness values of 15 mg/L or more, but those with values below 15 mg/L may experience delayed growth, distress, or even death (Gupta and Gupta, 2006). Therefore, total hardness obtained in Calabar River at Okomita during the present study can favour the growth of various aquatic life, including fish.

The higher value of alkalinity in the dry season could be credited to increased concentration of alkaline earth ions due to evaporation while The low level during the wet season could be caused by dilution from rain water. The higher alkalinity values recorded during the dry season months agreed with studies conducted by Tyokumbor *et al*. (2002) and Idowu and Ugwumba (2005) in Awba Stream and Reservior, Ibadan, Oyo State; Ayandiran *et al.* (2018) in Oluwa River, south-west Nigeria and Salisu *et al*. (2020) in River Saye, Zaria, Kaduna State but differs with results of Edward and Ugwumba (2010) in Egbe Reservior, Ekiti State; Ogbuagu *et al*. (2011) in Imo River, Etchie, south-eastern Nigeria; Eboh *et al*. (2020) in Ajali River, Enugu State. The mean alkalinity was lower than the standard limit (20 mg/L) by USEPA (2010) for aquatic life.

The higher value of turbidity obtained during the wet season compared to the dry season might have resulted from higher quantity of suspended solid materials washed into the river by surface run-offs during the wet season. Higher turbidity of Calabar River at Okomita in the wet season agreed with the work of Jaji *et al*. (2007) in Ogun River, south-west Nigeria; Eneji *et al*. (2012) and Akaahan *et al*. (2015) in River Benue, Benue State; Apollos *et al*. (2016) in Zobe Reservoir, Katsina State and Edori (2020) in Ede Onyima Creek, Okarki-Engenni, Rivers State who also recorded higher turbidity levels throughout the wet season. The mean turbidity (2.38±0.05 NTU) of Calabar River at Okomita during the 24 months study period was lower than the permissible limit (5 NTU) by WHO (2004), USEPA (2010) and NESREA (2011) for aquatic life. The highest mean value of turbidity obtained at Station Two may be attributed to quarrying and sand mining activities which could enhance the level of suspended solid materials as observed at this station.

The recorded mean concentrations of zinc (0.16±0.02), manganese (0.04±0.002), copper (0.04±0.002) and cadmium (0.03±0.002) did not exceed the recommended limits by WHO (2004) and NESREA (2011). The concentration of iron (0.79±0.05) and lead (1.12±0.03) exceeded the permissible limits by WHO (2004), USEPA (2010) and NESREA (2011) for aquatic life. The high concentrations of iron and lead could be attributed to run-offs from mechanic workshops and wastes dumpsites which carry pesticides and heavy metals at the bank into the river. Chen (1996), Adebanjo and Adedeji (2019) and Odoemelam *et al*. (2019) linked external sources of heavy metals into water bodies to irrigation, solid wastes, pesticides, fertilizers and atmospheric depositions.

The highest levels of lead recorded in Stations Five and Six (dumpsite, Okomita Market and mechanic workshop stations) could be attributed to discharges of lead from waste batteries in the dumpsite. Opeyemi and Olatunde (2020) attributed the high concentration of lead in River Ofin, Ado-Ekiti to the direct disposal into the river of household wastes containing lead from human activities at the bank of the river and vehicle exhausts. The values of heavy metals were lower than those reported by Anyanwu and Nwachukwu (2020) in Ossah River, Umuahia, Abia State and Opeyemi and Olatunde (2020) in River Ofin, Ado-Ekiti.

Average concentration of magnesium (0.04±0.002 mg/L) during the study was below WHO (2004) recommended level for aquatic life. Magnesium is used by phytoplankton and aquatic macrophytes for chlorophyll formation (Pereira *et al*., 2012). The mean magnesium concentration in Calabar River at Okomita suggests that it can support plankton growth and population increase in the river. The significantly lower magnesium concentration in the wet than dry season could be due to dilution by rain during the wet season. Usoro *et al*. (2013) in Ikoli River, Bayelsa State; Atojunere and Ogedengbe (2019) in some water sources in Ondo State also recorded high values of magnesium in the dry season than in the wet season. These findings are in disagreement with the findings of Ekhator *et al.* (2015) and Seiyaboh *et al.* (2016) who reported higher magnesium concentration in the wet than dry season in Osse River, Edo State and Ikoli Creek, Niger Delta respectively. The authors attributed their findings to influx of cations-rich flood water during the wet season. The highest magnesium concentration recorded at Station Five could be linked to run-offs of organic wastes from dumpsite, abattoir and Okomita Market.

The range of chloride concentration (1.23-11.20 mg/L) in Calabar River, Okomita fell below the recommended maximum level (300 mg/L) for aquatic life by NESREA (2011). The significantly lower chloride concentration in the wet than dry season may be linked to dilution effects from rainfall. This observation is in agreement with the finding of Chindah and Braide (2005) in a tropical estuary in the Niger Delta and Salisu *et al*. (2020) in River Saye, Zaria, Kaduna State but disagrees with the findings of Ogbuagu *et al*. (2001) in Imo River, Etche and Eboh *et al*. (2020) in Ajali River, Enugu State who attributed their higher concentration in the wet season to flow of sewage into the river.

The higher concentration of sulphate recorded in the dry season could be due to reduced water level that could lead to rise in concentration of SO_4^- during the dry season. The highest concentration of sulphate recorded at Station Two could be due to sand mining that may possibly release any trapped sulphate in the sand and also from fertilizers applied in the farms at the western side of the river bank at this station which may have been washed into the river through run-offs. The concentrations of sulphate in all stations fell within the permissible limits of 250 mg/L recommended by USEPA (2010) for aquatic life. The mean value of sulphate reported in this research is close to the mean values reported by Ikomi *et al*. (2003) in River Adofi, Delta State; Egereonu and Emeziem (2006) in some ground waters in Rivers State; Akubuenyi *et al*. (2013) in major water sources (rivers and streams) for domestic purposes in Calabar and Atalawei and Gobo (2020) in Olugbobiri and Ogboinbiri Creeks, Bayelsa State.

The average phosphate concentration in this investigation was lower than the recommended limit (3.50 mg/L) by NESREA (2011) for aquatic life. The significantly higher concentration of phosphate during the dry season than in the wet season could be due to reduced water level that could lead to rise in concentration of phosphate during the dry season. The mean value (0.96±0.11 mg/L) of phosphate is in accordance with the mean value reported by Atobatele *et al*. (2005) in River Ogunpa, Ibadan; Akubuenyi *et al*. (2013) in major water sources (rivers and streams) for domestic purposes in Calabar; Akaahan *et al*. (2015) in River Benue, Makurdi; Isaiah *et al*. (2015) in Lekki Lagoon, Lagos; Akinfolarin *et al*. (2020) in Mgbuodohia River, Port Harcourt; Kpee *et al*. (2020) in Nta-Wogba Stream, Port Harcourt and Ilechukwu *et al*. (2020) in Usuma Dam, Abuja.

The insignificantly seasonal variation of nitrate concentration in Calabar River at Okomita is an indication that changes in season did not significantly alter nitrate concentration at the time of the study. The mean concentration of nitrate in this study is lower than the permissible limits, 9.10 mg/L and 10 mg/L by NESREA (2011) and

USEPA (2010) respectively for aquatic life. The lowest values of nitrate obtained at Station Three (secondary forest station) and Station Four (sand mining station) may be attributed to absence of human and animal wastes dumpsites and farmlands which may give rise to low influx of nutrients into the river at these stations. Eyo *et al*. (2008) recorded low concentration of nitrate in a tropical rainforest lake, Agulu, Anambra State, likewise Ogamba *et al*. (2015) in Amassoma axis of Nun River in Bayelsa State; Seiyaboh *et al*. (2016) in Ikoli Creek, Niger Delta and Akinfolarin *et al*. (2020) in Mgbuodohia River, Port Harcourt. Nitrate concentrations recorded by Edori and Nna (2018) in New Calabar River, Niger Delta; Tesi *et al*. (2019) in Warri River, Niger Delta and Edori *et al*, (2019) in Siliver River, southern Ijaw, Bayelsa State were higher than the concentrations recorded in Calabar River at Okomita. The authors attributed their findings to decay of organic materials such as plants and animals and those that might have been carried through run-offs from adjoining farmlands.

5.2 Phytoplankton

The 39 species of phytoplankton encountered during the study period is low when compared with rivers in the region such as findings of Eyo *et al*. (2013) in the Great Kwa River, Calabar and Adeniyi and Akinwole (2017) in Lower River Niger, Agenebode, Edo State where 89 and 147 species respectively were encountered. However, Agouru and Audu (2012) in River Benue, Benue State; Antai and Joseph (2015) in Great Kwa River, Calabar and Andem *et al*. (2019) in Idundu River, south-eastern Nigeria reported lower number (than in the present study) of species, 19, 26 and 23 respectively. The composition and abundance of the diatoms: *Navicula, Synedra* and *Nitzschia* species as well as the euglenoid: *Euglena acus* and *Phacus caudata* indicate organic pollution in Calabar River at Okomita. It has been known that these genera can withstand organic pollution (Ugouru and Audu, 2012; Iloba and Ikomi, 2018). The existence of other pollution indicator species such as the diatoms: *Cymbella affinis*, *Surirella ovalis*, *Surirella oblonga* and *Melosira granulata,* dinoflagelates: *Closterum lunula* and the blue-green alga: *Oscillatoria tenuis* further shows that Calabar River at Okomita was under pollution stress during the study period. Esenowo *et al*. (2018) earlier reported these species as pollution indicators in Nwaniba River, south-south Nigeria.

The abundance of phytoplankton in Calabar River at Okomita in the present study was relatively high compared with the reports in freshwater bodies in the region such as Ogbuagu and Ayoade (2012) in freshwater bodies in Etche, Rivers State and Eyo *et al*. (2013) in Calabar area of Great Kwa River in Cross River State and in other region such as Bwala (2019) in Ngganga and Ngadda-Bul Rivers, Maidugiri, Borno State. The higher abundance of phytoplankton during the wet season could be attributed to the influx of nutrient-rich floodwater from abattoir, farmlands and Okomita Market which could result in the proliferation of phytoplankton. The higher phytoplankton abundance recorded during the wet season agrees with Davies *et al*. (2009) in Minichinda Stream, Rumukwurushi, Rivers State; Kiman *et al*. (2020) in River Shinga, Gombe State; Ayoade and Aderogba (2020) in a tropical reservoir, south-western Nigeria and Lawal *et al*. (2020) in Gwaigwaye Reservoir, Katsina State. On the contrary, the finding is not in tandem with the findings of Ajuonu *et al*. (2011) in Bonny Estuary, Niger Delta; Ogbuagu and Ayoade (2012) in Imo River, Etche and Akpan (2015) in Calabar Estuary, Calabar, southeast Nigeria. The authors attributed the lower abundance during the wet season to dilution of essential growth nutrients.

Stations Five and Six, the areas of waste dumps, bathing, swimming, washing and mechanic workshop had lower abundance of phytoplankton. The low abundance of plankton in these stations could be attributed influx of pollutants such as heavy metals, oil and petroleum products from mechanic workshop, market and dumpsite. Ogbuagu and Ayoade (2012) in Imo River, Etche; Asiegbu *et al*. (2019) in Ivo River Basin, South-eastern Nigeria and Andem *et al*. (2019) in Idundu River, south-eastern Nigeria attributed the observed significant differences in the spatial abundance of phytoplankton to perturbation-induced impacts such as fishing activities, dredging, washing and bathing on the habitat. The significantly low abundance of phytoplankton at Stations Two and Four (sand mining stations) indicates that sand mining impacted the abundance of phytoplankton.

Dominance of diatoms in freshwaters as observed in the present study has also been reported in different studies (Essien-Ibok, 2013; Akpan, 2015 and Andem *et al*., 2019). In this present study, dominance of diatoms is not surprising because they have been reported as one of the most noticeable representatives of phytoplankton population in lakes and rivers (Onyema, 2007; Esenowo and Ugwumba, 2010; Esenowo *et al*., 2018;

Ugwumba and Esenowo, 2020). On the contrary, Adeniyi and Akinwole (2017) and Barau *et al*. (2020) reported dominance of green algae in Lower River Niger in Agenebode, Edo State and Upper Benue River, Taraba State respectively. Dominance of blue-green algae and absence of diatoms was reported by Dimowo (2013b) in River Ogun, Abeokuta. Antai and Joseph (2015) related the high abundance of diatoms noticed in their study in Great Kwa River, Calabar to high silicate concentrations in the water system of Cross River. Least abundance of dinoflagellates observed in this present study could be due to the fact that they are mostly marine and estuarine (Tait, 1981; Hickman *et al*., 2001) hence, their low abundance in a freshwater body is expected. Wetzel and Weigl (1994) reported that (90%) of dinoflagellates live in marine ecosystems while 10% live in freshwater bodies.

The range of Shannon-Wiener's diversity indices (0.4 – 2.89) of phytoplankton in Calabar River from the present study indicates that Calabar River at Okomita was moderately polluted in all the stations. Shannon-Weiner diversity index values above three indicate clean water while values lower than one show heavy pollution and middle values (1 -3) show moderate pollution (Jhinggran *et al*., 1989). Phytoplankton of Calabar River, Okomita can be said to be evenly distributed in all the study stations during the study period since Pielou's evenness index values were close to one in all the stations (Pielau, 1966).

5.3 Zooplankton

Following a decreasing sequence, the relative abundance of zooplankton was as follows: rotifers > copepods > cladocerans > insects > protozoa. The dominance of the rotifers over the other zooplankton was probably due to their high reproductive rate. Adedeji *et al*. (2019) in River Shasha, southwestern Nigeria attributed the high abundance of rotifers to their ability to feed on many food types, their reproductive habits, and their parthenogenetic quick developmental time under favourable conditions.

In the present study, the dominance of rotifers is similar to the findings of Antai and Joseph (2015) in the Great Kwa River, Calabar and Olaniyan *et al*. (2018) in Oluwa River Ilaje, Ondo State. Agouru and Audu (2012) in River Benue, Benue State and Andem et al. (2019) in Idundu River, South-eastern Nigeria also reported rotifers as the most abundant zooplankton. The authors attributed the abundance of rotifers to the fact that they evolved from fresh water and are prevalent in tropical water bodies with high temperatures and are adapted to warm water. On the contrary, Uttah *et al*. (2013) in Bonny Estuary, Rivers State; Erhenhi and Omoigberale (2019) in Ethiope River, Delta State and Job *et al*. (2019) in Tinapa Lake, Calabar reported copepods as the most dominant members of the zooplankton population. According to them, copepods dominate most aquatic ecosystems because of their resilience and adaptability to changing environmental conditions and ability to withstand varying environmental stresses.

The higher relative abundance of rotifers observed during the wet season may have resulted from influx of nutrient-rich floodwater from abattoir and Okomita Market that likely accelerated primary production and consequently rotifer abundance due to proliferation of phytoplankton, their food. The relatively lower abundance of zooplankton at Stations Five and Six could be attributed to influx of metals through effluents from refuse dumpsite, Okomita Market and mechanic workshop which may have resulted in low primary productivity and in turn low secondary productivity. Ikhouriah *et al*. (2015) attributed spatial alterations of zooplankton abundance to prevailing physico-chemical conditions of water in different stations. The overall diversity indices suggest that the river is prone to pollution. Zooplankton species were evenly distributed across the five stations, since Pielou's evenness index values were closer to one in all the stations (Pielou, 1966). Considering the values of zooplankton abundance in the present study, the pollution status of Calabar River at Okomita was observed to follow increasing sequence within the stations as follows: S1 < S2 < S3 < S4 < S6 < S5; Station Five (S5) (mechanic workshop, Okomita Market, abattoir and waste dump station) being the most polluted while Station One (S1) (station with no anthropogenic activity) the least polluted.

5.4 Macro-invertebrates

The generally low macro-invertebrates composition and abundance might have been influenced by sand mining activities which destroyed their habitat, and also pollution by run-offs from dumpsites, quarry, Okomita Market, farms and mechanic workshop which carry pollutants into Calabar River. The low abundance of macro-invertebrates during the period of study may also be connected to the deterioration in some parameters of water observed in the area of study such as dissolved oxygen, lead, zinc and iron which were not within NESREA recommended limits for aquatic life.

Macro-invertebrates composition in Calabar River, Okomita characterised by three phyla and five classes in this research are less than those reported by Edema *et. al.* (2002) in Okhuo River, Edo State; Adakole and Annune (2003) in Urban Stream, Zaria; Iyagbaye *et al*. (2017) in Ovia River, Iguoriakhi, Edo State and Amusan *et al*. (2018) in Opa and Ona Rivers, Ibadan. However, the results obtained from this study agrees with the reports of some studies that recorded low macro-invertebrates populations in waterbodies such as Sharma *et al*. (2013) in Kaduna River, Kaduna; Akaahan *et al*. (2016) in River Benue, Makurdi; Anyanwu *et al*. (2019) in Ossah River, Umuahia and George *et al*. (2020) in Etim Ekpo River, Akwa Ibom State. The high relative abundance of insects recorded in this research could be as a result of the observed presence of macrophytes which serve as microhabitat to species of insects in Stations One (station of no anthropogenic activity), Three (oil palm (*Elaeis guineensis*) plantation and secondary forest station) and Four (rubber (*Ficus elastica*) plantation and sand mining station). The high relative abundance at Station Four indicates that sand mining did not influence the abundance of insects at this station. Heaps of sand were seen all year round at this station (see Plate 3.2). Household wastes were dumped directly into the river at this station). The rocky and sandy nature of the river bottom at Station Three may have accounted for low abundance of bivalves, clitellates, malacostracans and gastropods in this station because they are mainly mud dwellers as reported by Iyagbaye *et al*. (2017) and Marc (2020).

A marked seasonal difference in the macro-invertebrate fauna of Calabar River, Okomita was noticed during the study period. A larger macro-invertebrates abundance was observed during the dry season because the river water level was lower and cleaner, resulting in the substratum getting more stabilized for invertebrates attachment. In addition, flood could flush off macro-invertebrates such as insects attached to the macrophytes during rainstorm resulting in the lower abundance of mocro-invertebrates during the wet season. This result agrees with the findings of Ezekiel *et al*. (2011) in Sombreiro River, Niger Delta; Adadu *et al*. (2019) in River Okpokwu, Benue State and Mohammed *et al*. (2020) in Moussa Stream, Bida, Niger State who reported higher populations of macro-invertebrates during dry months as compared to the wet months.

The authors ascribed the changes to rain-induced instability of the bottom substrata that results in the displacement of the macro-invertebrate fauna. Akaahan *et al*. (2016) reported that prevailing environmental conditions such as flooding and unstable bottom sediment may be responsible for the seasonal variations observed in River Benue at Makurdi.

Macro-invertebrates spatial distribution pattern across all stations in Calabar River at Okomita showed significant differences. The low abundance of macro-invertebrates at Stations Five and Six is attributable to the observed high velocity of water and the perturbed state of these stations with activities such as refuse dumping, swimming, bathing, washing of clothes in them as well as butchering of animals and repair of automobiles around them during the period of study. It is therefore not surprising that, fewer macro-invertebrate species that cannot tolerate pollution (malacostracan: *Sudanonautes africanus*; insects: *Orectochilus orbisonorum; Dineutus discolour* and *Phaon iridipennis*; gastropods: *Pila ovata, Natica flammulata* and *Eulima fischeri*) were recorded in these stations. The low abundance of macro-invertbrates in these stations is therefore not without relation to the drop in water quality seen at these stations such as low dissolved oxygen and high level of iron. Organic pollution tolerant species such as the insect, *Chironomus* sp., and clitellate, *Limnodrilus hoffmeisteri* abundance in these stations could be that they were adapted to survive physiologically and morphologically in poor water quality. These adaptations include possession of haemoglobin pigment in *Chironomus* which gives affinity for oxygen even at very low concentrations, thereby giving them the advantage to survive in areas of high organic pollution (Akaahan *et al*., 2016). Stations Five and Six having the least diversity and equitability measures also showed that the stations have been subjected to high degree of anthropogenic activities. The overall diversity indices of macro-invertebrates in this study shows that all the stations were moderately polluted.

5.5 Principal components of relationships between physico-chemical parameters with abundance of plankton and macro-invertebrates

The results of Principal Components Analyses (PCA) indicated that biochemical oxygen demand, hardness, dissolved oxygen, conductivity, pH and transparency were the most significant environmental factors that affects phytoplankton abundance in Calabar River at Okomita during the study period. Solar radiation could have reached the bottom of Calabar River at Okomita during the study period since the river was transparent down to the bottom, hence increasing photosynthesis and other metabolic activities with a corresponding increase in population density of phytoplankton. Oxygen produced during photosynthesis may have resulted to increase in dissolved oxygen concentration which promoted phytoplankton abundance during the study period. The report of Yusuf (2020) who observed that dissolved oxygen was an important environmental variable that influenced the abundance of some phytoplankton species in Nasarawa Reservoir, Katsina State agrees with the present study.

Factors with the most significant impact on the abundance of zooplankton in this present study were hardness, alkalinity, total suspended solids, pH, dissolved oxygen, biochemical oxygen demand, conductivity, transparency and magnesium. This report agrees with Iloba and Akpoyibo (2019) findings who reported that environmental factors such as temperature, total dissolved solids, conductivity, pH, alkalinity, dissolved oxygen, phosphate, carbon dioxide, transparency, turbidity, chloride and potassium significantly influenced the abundance of plankton in Agbarho-ogbe-ijoh stretch, Warri River, Nigeria. Meanwhile, Mohammed *et al*. (2020) reported turbidity, biochemical oxygen demand, nitrate, phosphate, dissolved oxygen, air temperature, water temperature, pH, and total dissolved solids were the variables that influenced the abundance of Cladocera in river Gombe Abba River in Dukku Local Government Area, Gombe State, Nigeria.

Increase in dissolved oxygen, hardness, alkalinity, biochemical oxygen demand, transparency and magnesium caused increase in insect and bivalves abundance in the present study. The decrease in water temperature which gave rise to increase in abundance of insects in the second component could be attributed to influence of harmattan during the dry season, hence the abundance of insects during the dry season in contrast to the wet season.

The results of the PCA revealed that turbidity, total suspended solids, water depth and pH were the primary factors affecting the abundance of macro-invertebrates in the Calabar River at Okomita. This is because the macro-invertebrates abundance reduced as the concentrations of these parameters increased during the period of study. This report is similar to the reports of Iloba and Adamu (2020) who reported pH, total dissolved solids, alkalinity, depth, air and water temperatures as the major parameters influencing the abundance of macro-invertebrates in a rural-urban freshwater body in Delta State. Arimoro and Keke (2017) reported temperature, conductivity, alkalinity, depth, pH, biochemical oxygen demand, nitrate, dissolved oxygen, and phosphate as the key variables affecting macro-invertebrates abundance in Gbako River, north-central, Nigeria. The authors attributed the increase in these physico-chemical parameters to anthropogenic activities such as dredging, clothes and dishes washing and bathing in the river.

Alkalinity, biochemical oxygen demand, hardness and magnesium enhanced the abundance of insects and bivalves in the dry season. Dry season had positive correlation with insects and bivalves indicating that dry season influenced the abundance of these biota. This could be attributed to the observed stability of substrata, low water velocity, high water clarity in the drier months that could enhance the abundance of the biota. The wet season had positive correlation with the blue-green algae indicating that wet season enhanced the abundance of blue-green algae. Principal Components 1 to 4 which accounted for 50.06% variations in physico-chemical parameters and biota abundance, indicated that season modulated physico-chemical parameters and biota abundance.

Dissolved oxygen, pH, biochemical oxygen demand, hardness, alkalinity, conductivity, total suspended solids and magnesium were principal determinants of plankton and macro-invertebrate abundance in Calabar River at Okomita during the period of study. The concentrations of these parameters in Calabar River at Okomita could be attributed to influx of organic and inorganic materials from dumpsites, Okomita market and farmlands along the river banks. Okonofua *et al*. (2019) reported chloride, chemical oxygen demand, copper, carbonate, sulphate and sodium as the factors that have the greatest influence on the quality of the surface water of Ikpoba, Oregbeni, Benin City, Edo State. The authors linked their input to untreated effluents from breweries around the area which carried heavy organic and inorganic loads into the river. Mohammed *et al*. (2020) also reported that dissolved oxygen, nitrate, turbidity and phosphate influenced the abundance of phytoplankton in river Gombe Abba, Dukku Local Government Area, Gombe State.

Multidimensional scaling distances based on physico-chemical parameters and abundance of biota indicated that stations close to each other within the ordination plot were similar to each other. In other words, Station One (station of no anthropogenic activity) is very different from Station Two (quarry and sand mining station) regarding water quality and biota abundance. The cluster of Stations Three (bathing, washing of clothes and harvesting of palm fruits station), Four (sand mining stations), Five (mechanic workshop, Okomita Market, dumpsite and abattoir station) and Six (swimming, bathing and washing of clothes station) within the ordination space indicates that water quality and biota abundance pattern are very similar in these stations. The multidimensional scaling distances revealed a gradient of degradation of water quality across the six stations in Calabar River at Okomita. From the ordinate plots, Station One was the least polluted, followed by Station Two, while Stations Three, Four, Five and Six which clustered around each other showed similar level of pollution i.e. higher level of degradation of quality. This result is in tandem with the results of diversity indices that revealed the pollution status of Calabar River at Okokmita to follow increasing sequence within the stations as follows: S1 < S2 < S3 < S4 < S6 and S5.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

Most of the water quality parameters of Calabar River, Okomita at the time of the study fell within the allowable range by WHO (2004) and NESREA (2011) except dissolved oxygen (4.72±0.07), conductivity (22.11±0.77) and biochemical oxygen demand (1.86±0.03) which were lower than the acceptable limits, while iron (0.79±0.05) and lead (1.12±0.03) were higher than acceptable limits for aquatic life and domestic uses. The surface water showed seasonality for most of the parameters suggesting that run-offs from the adjourning farmlands and dumpsites, domestic wastes from the neighbouring communities and run-offs from Okomita market and mechanic workshop along the river bank might be responsible for their seasonal variations in Calabar River at Okomita.

The diverse phytoplankton population present within Calabar River at Okomita during the study period is in the following hierarchy of dominance: Bacillariophyceae > Chlorophyceae > Cyanophyceae > Euglenophyceae > Chrysophyceae > Dinophyceae. Phytoplankton species abundance and diversity were highest in Station One (area of no anthropogenic activity) of the study area; this station also had the highest phytoplankton abundance while Station Five (Okomita Market, dumpsite and mechanic workshop area) had the least. All the phytoplankton taxa were significantly influenced by seasons in terms of composition and abundance. Relatively higher abundance and diversity were recorded for the total phytoplankton during the wet season. The existence of pollutant-indicator species such as *Oscillatoria tenuis*, *Surirella oblonga*, *Melosira granulate*, *Closterium lunula*, and *Cymbella affinis* reflects that the river is undergoing some degree of perturbation. The low zooplankton species diversity (1.31–1.75) also shows that the Calabar River at Okomita is under pollution stress.

Environmental conditions such as possible substrate instability due to sand mining activities may have contributed to the low abundance of macro-invertebrates at Stations

Two and Four (stations of sand mining). The recorded low diversity and evenness of macro-invertebrates at Stations Five (Okomita Market, mechanic workshop and waste dumpsite station) and Six (bathing, swimming and washing of clothes station) indicate a polluted environment possibly due to inflow of pollutants from the market, abattoir, mechanic workshop and waste dumpsite at these stations. The perturbed state of Station Five probably due to refuse dumping, butchering of animals and repair of automobiles and wastes from Okomita Market during the present study and the observed high water velocity that could wash off macro-invertebrates may have contributed to the low macro-invertebrates abundance at this station.

The principal component analysis showed that parameter such as biochemical oxygen demand, hardness, cadmium, alkalinity, dissolved oxygen, chemical oxygen demand, zinc, total dissolved solids, pH and turbidity were the most important environmental factors influencing plankton and macro-invertebrates abundance in Calabar River at Okomita during the study period.

6.2 Conclusion

Anthropogenic activities such as farming, harvesting and processing of rubber and palm fruits, automobile repair, butchering of animals, timber logging and transportation, sand mining, dumping of refuse, bathing and washing of clothes adversely affected the quality of the river water causing some physico-chemical parameters to be outside recommended range for aquatic life and domestic uses. Seasonal variations affected some of the investigated physico-chemical parameters, and biota abundance in Calabar River at Okomita during the study period. Run-offs from the adjourning farm land, domestic wastes from the neighbouring communities and run-offs from the spilled wastes from the automobile workshop, dumpsite, abattoir and market were adduced for the seasonal changes.

The environment at Stations Five and Six, the areas of waste dumps, bathing, swimming, washing and mechanic workshop were not conducive for the proliferation of plankton due to pollutants such as heavy metals, soaps, detergents, oil and petroleum products which came from these wastes. Sand mining impacted the abundance of plankton at Stations Two and Four (sand mining stations) as there was significantly low abundance of plankton at these stations.

Decline in some water quality parameters observed in the study area such as dissolved oxygen, lead, zinc and iron which were not within NESREA recommended limits for aquatic life gave rise to low abundance of macro-invertebrates during the study period. Presence of macrophytes which serve as microhabitat to species of insects in Stations One (station of no anthropogenic activity), Three (oil palm (*Elaeis guineensis*) plantation and secondary forest station) and Four (rubber (*Ficus elastica*) plantation and sand mining station) was the cause of the high relative abundance of insects recorded in these stations. Sand mining did not influence the abundance of insects at Station Four since there was high relative abundance of insects at this station.

The relative dominance of the moderately pollution intolerant species (*Gerris* sp, *Mesovelia furcata, Enitthares* sp, *Epicodulia* sp *and Mutula rostrata*), followed by fairly tolerant macro-invertebrate species (*Ranatra* sp, *Glossosoma caddis and Placobdella pediculata*) and the least abundance of the sensitive species (*Tropisternus* sp *and Lymnaea natalensis*) confirmed that Calabar River at Okomita is perturbed. The abundance of pollution indicator biota, low Shannon-Weiner diversity values (0-2.50) and deviations of some physico-chemical parameters from the standard recommended levels for aquatic life and domestic uses suggest that Calabar River, Okomita is under pollution stress and not suitable for aquatic life and domestic uses.

6.3 Recommendations

To ensure proper management and sustainable conservation of biodiversity in Calabar River at Okomita, the following remedies are needed:

- There is the need to provide adequate waste disposal facilities to the inhabitants of the area, especially people living near the river banks. This will prevent the uncontrolled disposal of wastes into the river.
- Enlightenment of the public is necessary to raise the level of awareness that will change the people's attitudes, both large- and small-scale industries with respect to problems of environmental pollution resulting from release of untreated wastes or effluents into the river.
- Farmers should be educated on the right ways of fertilizer application and cautious use of pesticides and herbicides in their farms.

- There should be adequate regulation of sand mining operations in the Calabar River at Okomita since sand mining can lead to destruction of aquatic habitat and loss of aquatic life particularly macro-invertebrates.

6.4 Contributions to knowledge

- The investigation revealed that Calabar River, Okomita is under pollution stress due to anthropogenic activities within and around Okomita.
- The river is stressed with high levels of iron and lead and low levels of conductivity and dissolved oxygen.
- Sand mining, swimming, bathing, inorganic wastes from dumpsites in Okomita Market, mechanic workshop and quarry adversely affected abundance of resident biota in the river.
- The principal components analysis revealed that the main physico-chemical factors affecting the abundance of plankton and macro-invertebrates in the Calabar River at Okomita were pH, dissolved oxygen, conductivity, biochemical oxygen demand, total suspended solids, alkalinity, hardness, turbidity, transparency, and magnesium. The deviations of some physico-chemical parameters from the recommended limits of aquatic life impacted on the abundance and diversities of the plankton and maro-invertebrates.
- The study showed that the water of Calabar River at Okomita is not safe for aquatic life and domestic uses because dissolved oxygen, biochemical oxygen demand, conductivity, iron, and lead deviated from the recommended limits of NESREA (2011) and WHO (2004).

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