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Spatial Patterns of Plankton Diversity and Abundance in the Calabar River, Okomita Axis, Cross River State, Nigeria

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ABSTRACT

Calabar River is an important water body in south-eastern Nigeria that supports a thriving fishery to the surrounding communities. Effluents, run-offs and solid wastes from industries, farmlands, markets, slaughter houses, dumpsites and human settlements around Okomita area are discharged into the river causing pollutants that could adversely affect water quality and resident biota. This study evaluated the spatial dynamics in the diversity and abundance of plankton in connection to some physico-chemical factors in Calabar River at Okomita. Surface water and plankton sampling were carried out monthly from September, 2014 to August, 2016 at six sampling stations along the river. Physico-chemical parameters were measured following standard methods. Plankton net with a mesh size of 55µm was used to gather plankton samples. The biota were identified using standard identification guides. Descriptive statistics, ANOVA, student's t-test, PCA and Shannon-Wiener's species diversity and evenness were used to analyze the data. Significant differences **(***P*<0.05**)** were observed in all physico-chemical parameters due to spatial variability, except biochemical oxygen demand. Station one had the highest overall percentage abundance of all the phytoplankton **(**33.83%**)** and zooplankton **(**35.97%**)** while Station five had the lowest **(**phytoplankton, 10.46%; zooplankton, 10.17%**)**. Pollution-indicators were, phytoplankton: *Oscillatoria tenuis* **(**2.37%**)**, *Surirella oblonga* **(**2.35%**)** and *Melosira granulat*a **(**2.16%**)**; zooplankton: *Philodina* species. **(**6.98 %**)**, *Brachionus forticula* **(**6.53%**)** and *Lecane lunaris* **(**5.56 %**)**. The range of Shannon-Wiener's diversity indices **(**0.4 – 2.89**)** of plankton indicates that Calabar River at Okomita was moderately to highly polluted in all the stations. The principal component analysis revealed that parameters such as biochemical oxygen demand, dissolved oxygen, chemical oxygen demand, pH, total dissolved solids, and turbidity were the most important environmental factors influencing the plankton abundance in the river. Calabar River at Okomita is under pollution stress and may not be suitable for aquatic life.

INTRODUCTION

Rivers are among the planet's most productive ecosystems since they support a variety of plants and animals under favorable conditions **(Appolos *et al.*, 2016; Verla *et al.*, 2020).** The majority of freshwater bodies worldwide are becoming more polluted,

which reduces the water's portability and productivity **(Amah-Jerry *et al.*, 2017; Idowu *et al.*, 2020)**. Rivers are utilized in various regions of Nigeria to dispose of wastes from factories, residential areas, and slaughterhouses as well as human excrement **(Yakub & Ugwumba, 2009; Amusan *et al.*, 2018)**. Our ecology suffers from the direct and indirect repercussions of rapid industrialization **(Yinka *et al.*, 2019; Iyama *et al.*, 2020)**. This could increase industrial effluents, which, if released untreated, could contaminate water, soil, and sediment **(Edori *et al.*, 2019; Ugwumba & Esenowo, 2020)**. Deterioration and degradation of aquatic environments are major environmental concerns both at national and international levels **(Alinnor & Obiji, 2010; Vincent *et al.*, 2020)**.

Pollutants reduce the quality of the environment by rendering water bodies unsuitable for aquatic life and domestic uses **(Agboghovwia *et al.*, 2018; Ayandiran *et al.*, 2018)**. Raw or treated home sewage, urban runoff, effluents from industry, and farm wastes are all potential sources of pollution. Among the pollutants are metals such as lead, cadmium, mercury, which are toxic even at low concentrations **(Akintujoye *et al.*, 2013; Iyama *et al.*, 2020)**. All these modify water and sediment compositions, thus affecting aquatic organisms.

Plankton is an essential food source for bigger aquatic creatures, including mollusks, fish, and crabs **(Ugwumba & Ugwumba, 2007; Odulate *et al.*, 2017)**. Since they have a quick turnover rate and are sensitive to environmental stresses, phytoplankton are excellent indicators of the quality of water **(Effiong *et al.*, 2018; Bwala, 2019)**. The study on abundance and diversity of phytoplankton helps reveal the trophic status and the organic pollution in the aquatic ecosystems. Zooplankton is the primary food source for higher animals, such as fish, especially their larvae, as they feed on phytoplankton and help transform plant resources into animal tissues **(Akpan, 2015; Kwen *et al.*, 2019; Oluwale & Ugwumba, 2019)**. Their population is able to reflect the nature and potential of any aquatic ecosystem **(Okogwu, 2010; Ikhuoriah *et al.*, 2015; Enerosisor *et al.*, 2020)**.

Various activities- including farming, waste dumping, quarrying, rubber tapping, palm oil processing, auto repair, timber logging, and animal butchering—occur along the Calabar River and its banks at Okomita, posing significant risks to environmental and water quality. Effluents and solid wastes from industries, Okomita Market, slaughter houses, dumpsites, rubber and oil palm processing 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 water quality and diversity and abundance of biota in the river.

Despite previous studies on plankton and water quality in other parts of the Calabar River, there is a lack of data specific to the Okomita segment, an area facing intense anthropogenic activities such as quarrying, palm oil processing, waste dumping, and sand mining. Existing research has largely overlooked the spatial dynamics of plankton in relation to localized pollution sources in this area. Moreover, the potential of plankton—particularly phytoplankton and zooplankton—as sensitive bioindicators of water quality remains underutilized in this region.

This study is innovative in its spatially-resolved assessment of plankton diversity and abundance, linking ecological responses directly to site-specific land-use impacts. It provides the first ecological baseline for plankton communities in Okomita, offering valuable insights into pollution hotspots along the river. The findings will support sustainable water resource management, inform environmental regulations, and contribute to public health protection by revealing how human activities affect the base of the aquatic food web.

MATERIALS AND METHODS

Study area

Calabar River is located in Cross River State, southeast Nigeria and lies geographically between latitude 04°54'N and 04°56'N and longitude 08°16'E and 08°18'E (Fig. 1). Calabar River originates from the Oban Hills in Akamkpa Local Government Area of Cross River State, Nigeria and flows southward 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 characterized by a long rainy season between April and October with peak rainfall in June and a relatively short dry season from November to March **(Eze & Effiong, 2010; Ojo, 2014)**. Average annual rainfall of the area is 1,830mm, average temperatures is 27°C while the relative humidity is between 61 - 93% **(Osang *et al.*, 2016)**.

The coastal shoreline is characterized by thick vegetation, changing from freshwater to mangrove swamp. Okomita is located in Akamkpa Local Government Area of Cross River State, Nigeria. The area is semi-urban and lies within the high rainforest belt of southern Nigeria. Effluents and solid wastes from industries, markets, slaughter houses, rubber and oil palm plantations and settlements around the area 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. The vegetation in the area is characterized by secondary forest, farmlands, oil

palm (*Elaeis guineensis*) plantation, rubber (*Ficus elastica*) plantation. The major occupations of the villagers.

Six sampling stations (S1-S6) were selected based on visual observations of anthropogenic activities along the length of Okomita area of Calabar River and also on the accessibility to the stations. The entire sampling area is characterized by rocky and sandy substrata with scanty muddy areas. Some of the rocks are exposed to the surface of the water. The sampling stations covered a total distance of 4,800m 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.

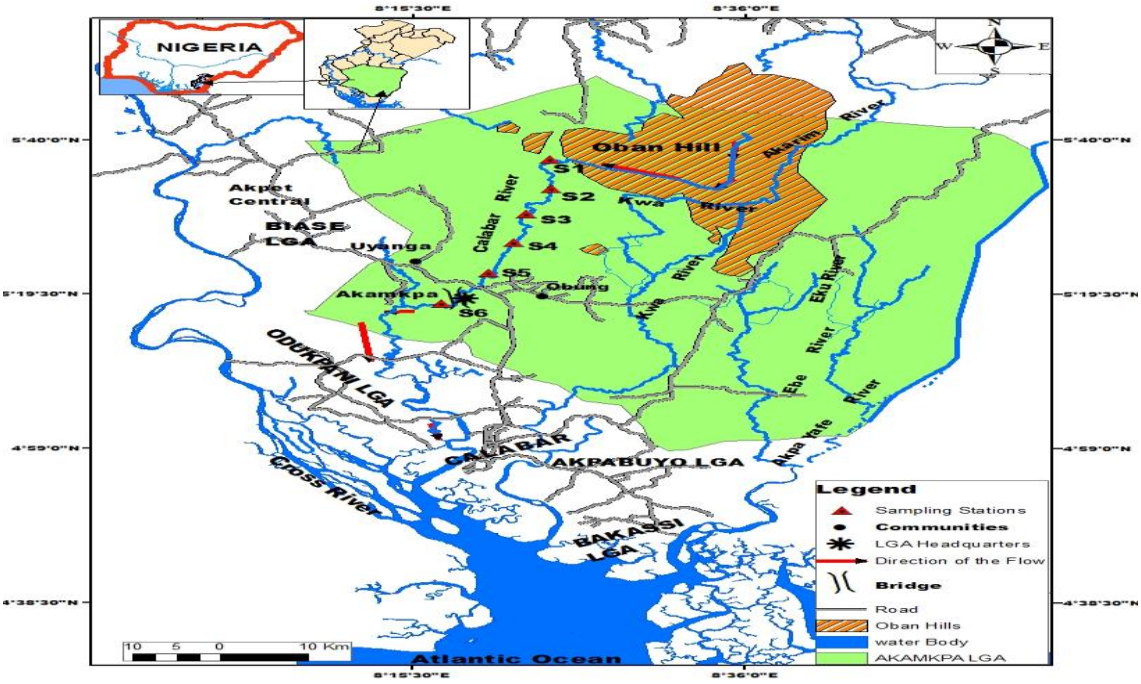

Fig. 1. Map of Akamkpa local government area indicating sampling stations (S1-S6) in Calabar River at Okomita (Map of Nigeria and Cross River State inserted)

Physico-chemical parameters

Samples collection, preparation and analysis

Two-liter polypropylene sampling vials were used to collect surface water samples. At every sampling station, the bottles were cleaned with distilled water, submerged in the river approximately 3cm below the surface, filled to the brim, and

securely closed. Three surface water samples were collected from each sampling station during each sampling occasion. The water samples were transported to the University of Calabar's Department of Chemistry Laboratory for analysis. The physico-chemical parameters investigated included surface water temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), conductivity, transparency, turbidity, total dissolved solids (TDS), total suspended solids (TSS), nitrate, phosphate, and heavy metals such as manganese, cadmium, and lead. Sampling involved both *in situ* measurements and the collection of water samples from designated stations for laboratory analysis using standard methods **(APHA/AWWA/WPCF, 2005)**.

Plankton sampling

One hundred liters of water samples were collected at each station from the water surface and filtered using a pour-through plankton net with a mesh size of 55µm, following standard methods **(APHA, 2005)**. To prevent bacterial action and autolysis, plankton samples were immediately preserved in 4% formalin within five minutes of collection, stored in labelled wide-mouth plastic bottles, and transported to the laboratory for identification and enumeration.

Identification and counting of plankton

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 concentrated to 10mL **(Bellinger & Sigee, 2015)**. Using a pipette, one milliliter of each sample was taken, and it was examined under a Zeiss binocular microscope to identify and count each individual taxon present. 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. The samples were stained with Lugos's iodine solution to improve accurate identification of the morphological characteristics of plankton species and proper identification **(APHA/AWWA/WPCF, 2005)**. Phytoplankton counts were expressed as number of cells/mL while zooplankton counts were expressed as number of organism/ mL.

Data analyses

For every sampling station and the whole study region, the means of the physico-chemical parameters were determined, together with their standard errors. Variations in the plankton abundance as well as the physico-chemical parameters values 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 correlations existing between the physico-chemical characteristics of the water and abundance of plankton. This was performed using IBM SPSS statistics version 23 for windows. 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)**.

RESULTS

Physico-chemical parameters

The detailed data obtained on spatial variations in the physico-chemical parameters are presented in Table (1). Water temperature varied from 17.00 to 31.95^{o}C. Water temperature showed significant spatial differences between stations one and two only, while stations three to six did not show any significant difference. Station one reported the lowest water temperature, 24.99±0.65^{o}C, while Station two recorded the highest, 26.52±0.31^{o}C. The pH ranged from 6.02 to 9.98. The pH varied significantly within stations, with the least value, 7.52±0.12, recorded at Station five and the highest value (8.21±0.16) recorded at Station two. 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 at Station Five, 4.41±0.20 mg/L was not significantly different from the other stations. Biochemical oxygen demand (BOD) concentration ranged from 0.78 to 3.88 mg/L. Stations three (0.97±0.14mg/ L) and four (1.37±0.19mg/ L) showed significant spatial variations while other stations did not.

Conductivity concentrations ranged from 12.80 to 60.20µS/ cm. Mean spatial concentrations of conductivity differed significantly across stations. 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 $P<0.05$ (Table 1). Spatial variations of total dissolved solids 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, 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. The TSS, 1.10±0.13 mg/L at Station one varied spatially with the concentration at stations three, 0.72±0.11 mg/L, four, 0.55±0.10 mg/L and six, 0.65±0.12 mg/L. The river was transparent down to the bottom. Transparency ranged from 0.51±0.05 m (Station six) to 1.66±0.06 m (Station two). Spatial variations in transparency showed significant differences ($P<0.05$). The concentrations of turbidity ranged from 0.00 to 5.85 NTU with a mean value of

2.38±0.05 NTU. Turbidity in stations two, 2.76±0.33 NTU and four, 2.04±0.22 NTU varied significantly.

Spatial variations revealed that the concentration, 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. The concentration, 0.01±0.00 mg/L at Station one was significantly different from the concentrations at other stations. The concentration, 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. Spatial variations of Pb showed that the highest concentration, 0.37±0.10 mg/L was recorded at Station six and the lowest concentration, 0.04±0.01 mg/L was registered for Station one. The concentration at Station six varied significantly with all the other stations.

Phosphate (PO_4^{-}) concentration ranged from 0.00 to 7.30 mg/L. Station one recorded the highest concentration, 1.61±0.33 mg/L, while Station three recorded the lowest concentration, 0.36±0.14 mg/L. The concentration at Station one varied significantly ($P<0.05$) from the concentrations at stations three and four, 0.43±0.15 mg/L. Station one had the highest concentration, measuring 0.77±0.12 mg/L, while stations three and four had the lowest concentrations, measuring 0.33±0.04 and 0.33±0.02, respectively. Compared to the concentrations at every other station, the NO_3^- concentration at Station one differed considerably ($P<0.05$). 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.

Spatial abundance of phytoplankton

Six (6) families and thirty-nine (39) species of phytoplankton were identified. Station one had the highest spatial percentage abundance for all the phytoplankton groups, except Chrysophyceae (Fig. 2). Percentage abundance of Chrysophyceae was at its highest (20.24%) at Station five, while the lowest was at 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 total percentage abundance of all the phytoplankton while Station five (10.46%) had the lowest. The total percentage abundance of phytoplankton at Station one was significantly higher than the other stations.

Spatial abundance of zooplankton

Zooplankton consisted of five taxonomic groups and 21 species. All the groups had the highest abundance at Station one (Fig. 3). 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 at Station Three. Station one (35.97) showed

the greatest abundance among all the zooplankton, while Station five had the lowest (10.17). Compared to the other sites, Station one had a noticeably greater zooplankton total percentage abundance.

Spatial diversity indices of phytoplankton

The spatial diversity indices for the various phytoplankton groups recorded at the six sampling stations during the study period are presented in Table (2). Bacillarophyceae accounted for the highest diversity at 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 were recorded with the highest values at Station five (H = 2.173) and the lowest at Station two (H = 2.113). The total mean equitability value was the highest (J = 0.976±0.010) at Station four, while the lowest value (J = 0.833±0.078) was recorded at Station one. Equitability value for Bacillariophyceae was the highest (J = 0.966) at Station two, whereas the lowest value (J = 0.834) was recorded at Station three. The 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.

Spatial diversity indices of zooplankton

The diversity indices for the various zooplankton groups recorded at the six sampling stations during the period of study are presented in Table (3). However, Rotifera accounted for the highest diversity (H = 1.599) at Station one, and it was the lowest (H= 1.516) at Station three. The highest spatial diversity of Copepoda (H = 1.750) was recorded at Station six, while the lowest (H = 1.596) was recorded at Station one. Insecta recorded the highest diversity (H = 1.601) at Station one and the lowest (H = 1.515) at Station three. Equitability of Rotifera was the highest at Station one (J=0.994) and the lowest at Station six (J=0.973). Cladocera had the highest equitability (J = 0.978) at Station two and the lowest value (J = 0.946) at Station three.

Table 1. Spatial variations of physico-chemical parameters of Calabar River at Okomita during the study period

Parameter	Range	S1 Mean±SEM	S2 Mean±SEM	S3 Mean±SEM	S4 Mean±SEM	S5 Mean±SEM	S6 Mean±SEM
Temp. **(**ºC**)**	17.00-31.95	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	6.02-9.98	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**)**	2.09-6.74	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**)**	0.78-3.88	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)	0.00-3.05	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)	12.80-60.20	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)	10.60-27.02	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}
TSS (mg/L)	0.00-2.68	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}
Trans. (mg/L)	0.12-2.15	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}
Turbidity (NTU)	0.00-5.85	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
Mn (mg/L)	0.00-0.39	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}
Cd (mg/L)	0.00-0.09	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)	0.00-1.22	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}
PO_4^- (mg/L)	0.00-7.30	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)	0.10-2.02	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}

At $P<0.05$, groups that share any of the superscripts are considered significant. Superscript-free groupings do not differ significantly from any other group. Station One is represented by S1, Station Two by S2, Station Three by S4, Station Five by S5, and Station Six by S6. Temperature = Temp., Standard Error of Mean = SEM, Mn is manganese, Cd is cadmium, Pb is lead, $PO4^-$ is phosphate, $NO3^-$ is nitrate, DO is Dissolved Oxygen, BOD is Biochemical Oxygen Demand, COD is Chemical Oxygen Demand, and TDS is Total Dissolved Solids.

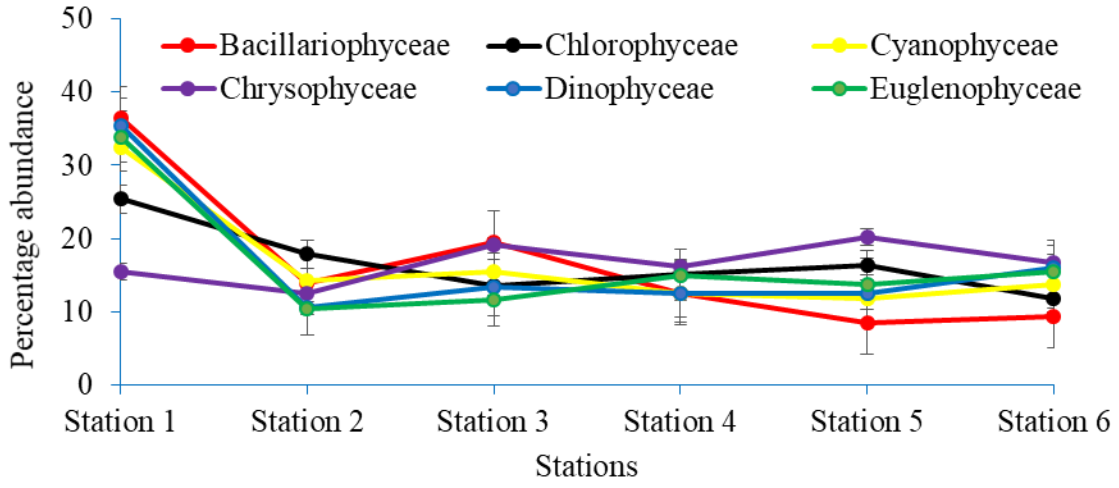

Fig. 2. Spatial percentage abundance of phytoplankton of Calabar River at Okomita at the time of the study

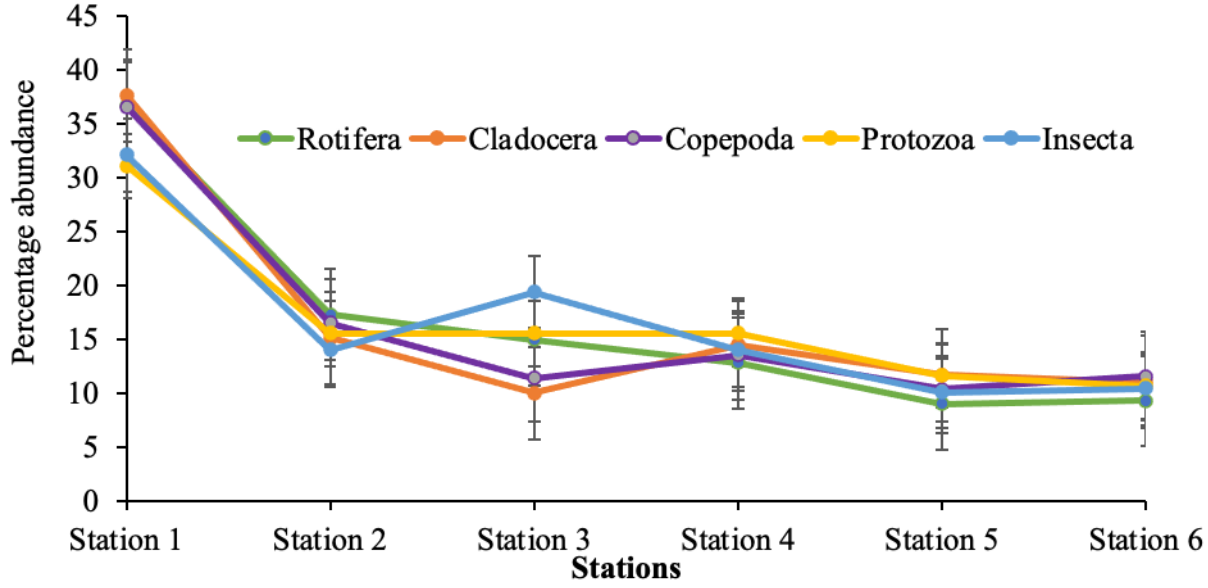

Fig. 3. Spatial percentage abundance of zooplankton of Calabar River at Okomita at the time of the study

Table 2. Spatial diversity indices of phytoplankton abundance of Calabar River at Okomita at the time of the study

	S1	S2	S3	S4	S5	S6
Phytoplankton	**H**	**H**	**H**	**H**	**H**	**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
Dianophyceae	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

S1 denotes the first station, S2 the second, S3 the third, S4 the fourth, S5 the fifth, and S6 the sixth, The Shannon-Wiener index is H.

	S1	S2	S3	S4	S5	S6
Phytoplankton	**J**	**J**	**J**	**J**	**J**	**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
Dianophyceae	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 = Station one; S2 = Station two; S3 = Station three; S4 = Station four; S5 = Station five and S6 = Station six, J = Equitability measure.

Table 3. Spatial diversity 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

Station One is represented by S1, Station Two by S2, Station Three by S4, Station Five by S5, and Station Six by S6. H stands for Shannon-Wiener diversity index.

	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

Station One is represented by S1, Station Two by S2, Station Three by S4, Station Five by S5, and Station Six by S6. H stands for Shannon-Wiener diversity index., J stands for Equitability Measure.

Principal components of physico-chemical parameters and plankton abundance

The principal components of physico-chemical parameters and the biota abundance are presented in Table (4). In the first component, five parameters were significantly positively associated with DO (0.69) and BOD (0.69) having the highest association. Dissolved oxygen (DO) (0.67) and DOD (0.69) associated significantly negatively with Cyanophyceae (-0.38) abundance. The first component had negative loadings on pH (-0.65), total suspended solids (-0.53) and turbidity (-0.69). In the second component, conductivity (-0.60) and transparency (-0.48) were significantly negatively associated. Conductivity (-0.60) and transparency (-0.48) associated significantly positively with rotifer (-0.50), Cladocera (-0.60), Copepoda (-0.64), Protozoa (-0.52), Bacillariophyceae (-0.59), Cyanophyceae (-0.49) and Chrysophyceae (-0.51) abundance. The PCA also revealed that parameters such as DO (0.67), BOD (0.69), turbidity (-0.69) and pH (-0.65) were principal determinants of plankton (blue-green algae, 0.49; diatoms, -0.59; rotifers, -0.50; cladocerans, -0.60 and protozoans, -0.52) abundance.

Table 4. Principal components (PC) of physico-chemical parameters and plankton abundance of Calabar River at Okomita, at the time of the study

	PC 1	PC 2	PC 3	PC 4	PC 5
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
Transparency	0.54	-0.58	0.42	0.40	-0.32
Turbidity	-0.69	0.05	0.35	0.04	-0.08
Mn	0.18	0.01	0.04	-0.23	-0.01
Cd	0.43	0.14	0.10	0.25	-0.25
Pb	-0.01	0.33	-0.01	-0.24	-0.29
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
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 refers to temperature, DO stands for dissolved oxygen. COD stands for chemical oxygen demand, whereas BOD stands for biochemical oxygen demand. TDS stands for total dissolved solids, TSS for total suspended solids, Mn for manganese, Cd for cadmium, Pb for lead, PO4 for phosphate, and NO3 for nitrate.

DISCUSSION

Physico-chemical parameters

Significantly ($P< 0.05$) higher water temperature at stations two, three and five could be due to bathing, washing of clothes, dumping of waste and sand mining activities. **Onojake *et al*. (2017)** and **Amadi *et al.* (2020)** reported higher temperatures at stations where there were influence of environmental factors and human activities such as bathing, sand mining, farming and dumping of refuse. The mean pH **(**7.84±0.06) obtained in this study is within the recommended range for optimal survival and growth of most aquatic organisms. The mean pH is similar to the pH reported by **Taiwo *et al.* (2017)** in Opa reservoir, Ile-Ife, **Odulate *et al.* (2017)** in River Ogun, and **Abeokuta 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 (6-8mg/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 could be the cause of the low dissolved oxygen recorded at all the stations. 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; **Andem *et al.* (2013)** in the intertidal regions of Calabar River in Calabar, and **Ogwueleka and Christopher (2020)** in Usuma River, north-central, Nigeria.

A water body is deemed clean if its BOD level is less than 4 mg/L, and polluted if it is more than 10 mg/L since it contains a lot of organic compounds that degrade easily **(Boyd, 1982; NESREA, 2011; Tesi *et al.*, 2019)**. According to **Bamuwamye *et al.* (2017)** and **Ogwueleka and Christopher (2020)**, high BOD levels indicate a decrease in dissolved oxygen concentration because bacteria are using the oxygen that is available, endangering fish and other aquatic life. Higher BOD recorded at Stations Three, Four, Five and Six may be related to the various organic wastes from dumpsites and chemicals such as fertilizers, pesticides and herbicides from farmlands along the river banks. The discharges (metals, commercial solvents, herbicides, pesticides, plant nutrients and sediments) from the river's catchment areas may present some degree of risk to aquatic life. The COD value reported in this study was lower than 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 conductivity value can be regarded as low according to **Sawyer (1996)**, who classified conductivity levels as follows: below 50 µS/cm as low; those between 50-60 µS/cm as medium, while those above 60 µS/cm as high levels. The conductivity value obtained in this study is less than those stated for several surface waters in Nigeria, for instance the study of **Ogamba *et al.* (2015)** in Kolo Creek, Niger Delta; that of **Taiwo *et***

***al.* (2017)** in Opa River, Ile-Ife, Southwest Nigeria and **Baba *et al.* (2020)** in Abba River, Gombe State. Calabar River, Okomita has a low water quality using electrical conductivity as water quality index. The mean TDS value (16.88±0.28 mg/L) during the study period was below the **WHO (2004)** recommended level of 500mg/ L for aquatic life and the **NESREA (2011)** recommended value of 300mg/ L. Hence, TDS values in Calabar River at Okomita fell within tolerable limit for domestic water and aquatic life at all stations.

Calabar River at Okomita was transparent down to the bottom of the river at all the stations during the study period. The low turbidity, low total dissolved solids and low total suspended solids of the river could also have contributed to the high water clarity. The river water being transparent to the bottom shows that light penetration reached the bottom of the river during the study period. This favors all aquatic plants in the river since they need sunlight for photosynthesis. The variations at stations two and four of TSS could be attributed to quarrying and sand mining activities going on at those stations. The turbidity **(**2.38±0.05 NTU**)** of Calabar River at Okomita during the 24 months study period is less than the allowed threshold (5 NTU) by **WHO (2004)**, **USEPA (2010)** and **NESREA (2011)** for aquatic life. The highest mean value of turbidity obtained at Station two could be linked to sand mining and quarrying activities which could increase the level of suspended solid materials at this station.

In the present study in Calabar River at Okomita, sources of cadmium and lead could be connected to run-offs along the river banks from refuse dumps, abattoir, discharges from domestic activities and Okomita Market which may contain materials such as waste batteries, insecticides, paints, rubber and lubricating oil into the river. **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 reason for the elevated lead concentration could be runoffs from mechanic workshop and wastes dumpsites which carry pesticides and heavy metals at the bank into the river. The highest concentrations 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 domestic wastes containing lead from human activities at the river bank and vehicle exhausts. The values of heavy metals are 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.

The mean value of phosphate concentration recorded in the present study is within the recommended value (3.50 mg/L) by NESREA (2011) for aquatic life. The mean values (0.96±0.11 mg/L) of phosphate agrees with the mean value reported by

Akubuenyi *et al.* (2013) in major sources of water **(**rivers and streams**)** for household uses in Calabar and **Akinfolarin *et al.* (2020)** in Mgbuodohia River, Port Harcourt. The lowest values of nitrate obtained at Stations Three **(**secondary forest station**)** and Station Four **(**sand mining station**)** may be attributed to absence of human and animal wastes dumpsites and farmlands at these stations. Indiscriminate disposal of human and animal wastes that contribute to nitrate pollution is one of the greatest challenges of urbanization in developing nations **(Adesuyi *et al.*, 2015; Edori *et al.*, 2019)**.

Plankton

The most frequently occurring phytoplankton species encountered throughout present study in Calabar River at Okomita were *Navicula petersenii* and *Synedra acus*. The presence 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. These genera are known to be resistant to organic pollution **(Ugouru & Audu, 2012; Iloba & Ikomi, 2018)**. The existence of species that are indicators of pollution, including *Cymbella affinis*, *Surirella ovalis*, *Surirella oblonga*, *Melosira granulata, Closterum lunula, Oscillatoria tenuis* and *Phacus caudata* shows that Calabar River at Okomita is under pollution stress. **Esenewo *et al.* (2018)** reported these species as pollution indicators in Nwaniba River, South-South Nigeria.

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 parthenogenetic reproductive patterns, short developmental period under favorable conditions and their ability to feed on different food types. The dominance of rotifer in this study 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 who reported rotifers as the most abundant zooplankton. **Agouru and Audu (2012)** in River Benue, Benue State and **Andem *et al.* (2019)** in Idundu River, southeastern 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 suited for warm water; they are primarily found in tropical bodies of water that have high temperatures.

Stations Five and Six, the areas of waste dump, bathing, swimming, washing and mechanic workshop had lower abundance of plankton indicating that the environment in these stations was probably not conducive for the proliferation of plankton due to pollutants such as heavy metals, soaps, detergents, oil and petroleum products and swimming activity**. 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-South, Nigeria attributed the observed significant differences in the spatial abundance of plankton to perturbation-induced impacts such as fishing activities,

dredging, washing and bathing on the habitat. The relatively low values of the nutrients such as sulphate, phosphate and nitrate could be responsible for the relatively low plankton composition, diversity and abundance in Calabar River, Okomita.

Dominance of diatoms in freshwaters as observed in the present study has also been reported **(Akpan, 2015; Andem *et al.*, 2019)**. The dominance of diatoms in the present study is not surprising. They have been reported as one of the most obvious representatives of the phytoplankton in rivers and lakes **(Onyema, 2007; Esenowo & Ugwumba, 2010; Esenowo *et al.*, 2018; Ugwumba & Esenowo, 2020)**. **Antai and Joseph (2015)** related the high abundance of diatoms noticed in their study in Great Kwa River, Calabar to high concentrations of silicate in the Cross River Water System. The least abundance of dinoflagellates observed in this present study could be attributed 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) for spatial diversity indices of plankton of Calabar River, Okomita indicates that Calabar River at Okomita was moderately to heavily polluted at all the stations. Shannon-Weiner diversity index values above three indicate clean water while values less than one indicate heavy pollution and intermediate values (1-3) indicate moderate pollution **(Jhinggran *et al.*, 1989)**. Plankton of Calabar River, Okomita can be said to be evenly distributed at all the stations during the study period since Pielou's evenness index values were close to one at all the stations **(Pielau, 1966)**.

CONCLUSION

Various human activities—such as rubber and palm fruit harvesting and processing, automobile repairs, farming, animal butchering, timber logging and transportation, sand mining, refuse dumping, as well as bathing and laundry—may have negatively impacted the quality of the river water, resulting in some physico-chemical parameters exceeding the recommended limits for aquatic life and domestic use. 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 elevated levels of 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. Phytoplankton species abundance and diversity were the highest at Station one (area of no anthropogenic activity) of the study area; this station also had the highest zooplankton abundance while Station five (Okomita Market, dumpsite and mechanic

workshop area) had the least. The existence of pollution-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 also shows that the Calabar River at Okomita is under pollution stress.

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