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ZOOPLANKTON COMMUNITY SHIFTS IN RESPONSE TO ENVIRONMENTAL VARIABLES IN QUA IBOE RIVER, NIGER DELTA, NIGERIA

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ABSTRACT

The study was conducted in the Qua Iboe River system between January 2020 and June 2021 in five sampling locations to investigate zooplankton composition and its relation with environmental variables. Water samples were collected using sterilised plastic bottles, while samples for biochemical oxygen demand were collected using 250 mL reagent bottles and analysed following the standard examination methods. Water temperature, hydrogen ion (pH), dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solids (TDS) were measured *in situ* while water samples were collected for determination of sulphate (SO_4^-), nitrate (NO_3^-), ammonia (NH_3), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), chloride (Cl^-), total suspended solids (TSS), total alkalinity (TA) and phosphate (PO_4) in the laboratory. Zooplankton samples were collected by towing 55µm mesh size of plankton net for ten minutes. The concentrated zooplankton samples on the towing net were filtered into one-litre sampling bottles and preserved with two drops of 4% formalin solution, and identified using standard keys. The results showed that mean values for pH, DO, BOD_5, COD, TSS and PO_4 in some locations, deviated from the permissible limits. The zooplankton recorded was dominated by Rotifera (38.93 %), while Protozoa (9.2 %) was the lowest. The maximum species (905, 27.42 %) were obtained in location 1, while the minimum (550, 16.66 %) was in location 5. The study revealed that all the investigated water parameters except temperature, TSS and COD were negatively influenced the abundance of zooplankton owing to anthropogenic activities. Thus, the river should be protected by regulating the level of economic activities within the watershed, in order to improve water quality, maintaining the ecological integrity, and the socio-economic services they provide.

KEYWORDS: Zooplankton, Environmental variables, Qua Iboe River, Niger Delta, Nigeria

INTRODUCTION

The interactions between ecosystem components contribute to its stability and reproductive success. According to Michael (2020), an ecosystem is a natural unit, made up of living and non-living components, interacting together to produce a stable community structure. In aquatic ecosystems, zooplanktons are among the living components, with significant roles in the aquatic food chain, recycling of nutrients, and occupy a central position in the trophic link between primary producers and higher trophic levels (Jonah *et al.,* 2020a; Nwinyimagu *et al*., 2021). A shift in zooplankton community structure in lotic systems could be influenced by a number of factors; commonly grouped into biotic and abiotic factors (Chandrasekhar and Kodarkar, 1997). However, the abiotic factors include temperature, precipitation, flood, dissolved oxygen, nutrients materials and water quality, etc. while biotic factors include feeding ecology and predator pressure (Egborge, 1994). Variations in the physicochemical conditions of aquatic environments can cause changes in the qualitative and quantitative composition of zooplankton and influence their densities (Qin *et al*., 2003; Nwinyimagu *et al*., 2021). Studies attributed the spatiotemporal dynamics of zooplankton to changes in environmental variables, resulting from anthropogenic activities including sand mining, agricultural runoff, domestic and industrial effluents (Jonah *et al*., 2020b**;** Anyanwu *et al*., 2021).

In the Qua Iboe River, indiscriminate sand mining and agricultural activities dominate, with minor contributions from waste disposal, coupled with surface runoff from the nearby communities into the water. As a consequence, the zooplankton community of the river may be impacted negatively. These activities have been reported as potential threats to aquatic ecosystem and the inhabitant organisms by various researchers including Jonah and George (2019), Anyanwu *et al*. (2021), Jabbi and Isah (2022), Ibienebo *et al*. (2024), through increased turbidity, excessive nutrients, high organic and inorganic pollutants, and loss of breeding and spawning grounds (Sheeba, 2009). Studies have shown that the diversity and abundance of zooplankton are sensitive to changes in environmental variables such as dissolved oxygen, electrical connectivity, flood pulses, lake morphometry, and pH (Okogwu *et al* 2010). Therefore, the study seeks to investigate the composition of zooplankton community structure concerning environmental variables of Qua Iboe River, Niger delta, Nigeria.

MATERIALS AND METHODS

The Study Area

Qua Iboe River is among the major rivers in Niger delta, Nigeria. It's a vital economic resource and one of the longest rivers in the Niger Delta region, which traversed over 150 communities in 5 and 13 Local Government Areas in Abia and Akwa Ibom States respectively (Ituen and Johnson, 2015; Jonah *et al*., 2025). The studied sections covered Obot Akara and Ukanafun local government area; lies between Latitude 04º53' and 05º09' North and from Longitude 07º39' to 07º47' East (Fig.1). The river flows in southeastern direction towards the Atlantic Ocean from Ikwuano Local Government Area of Abia State into Usaka community in Akwa Ibom State. The river receives waste from point and non-point sources, and serves as the source of water for irrigation, industrial and domestic use. The region is characterised by having two climatic seasons (April - September) and dry season (October - March).

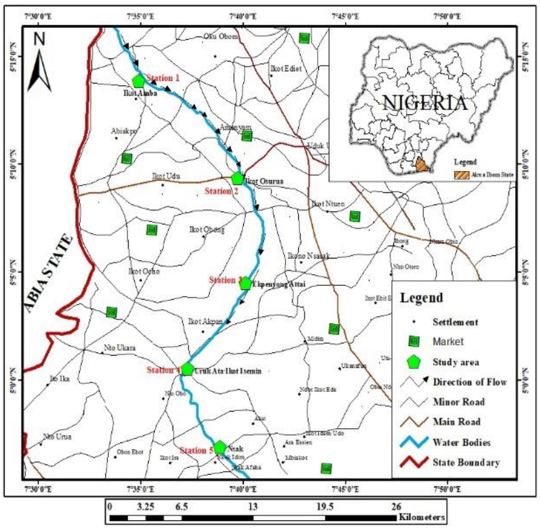

Fig. 1: A map showing the stretch of Qua Iboe River and sampling locations

Location of Sampling Sites

For the purpose of this study, five locations were selected along the stretch of the river based on the ecological setting, geological features, land use, nearest to the communities, and human activities. The 1st location is upstream (Ikot Amba); 3km from Obot Akara L.G. Headquarters. The location is characterised by slow water current, higher penetration of sunlight intensity, the substrate is sandy and muddy at the right-hand side of the river, and human activities (bathing, laundry and farming) are minimal. The 2nd location (Head Bridge at Ikot Osurua) is 6km from location 1. The location is characterised by higher human activities, ranging from extensive farming, intense sand dredging, bathing, laundry, sand loading, stone mining and other domestic activities. The river receives wastes from nearby communities, markets, municipal run-off, direct dumping, and from road construction. Plants like *Pseudosasa japonica*, *Raphia vinifera*, *Nipa fruticans* and other tropical forest trees were observed at the location, which prevents the intensity of sunlight penetration into the water. The 3rd location (Ekpenyon Attai 1) is 5km from location 2; anthropogenic activities are high, which include extensive farming, sand dredging, bathing, laundry, and sand loading. The location is near human habitations and shaded by the overhanging canopy of riparian vegetations (*Pandanus*, *Raphia hookeri*, *R. vinifera*, and *N. fruticans*), and other tropical forest trees. The 4th location (Uruk Ata Ikot Isemin) is 5km from location 3; it is shaded by the *Raphia* sp and *N. fruticans*. Macrophytes were abundant along the riverbank. The human activities were farming at the wetland behind the river, fishing and laundry. The 5th location (Head Bridge at Nkek Idim) is 4km downstream from location four. The abundant plants were *Pandanus, N. fruticans* and *R. vinifera* and other riparian vegetations. The location is characterised by the intense human activities such as sand dredging, farming, bathing, and laundry and frequently received wastes from nearby community through runoff.

Samples Collection

Water samples and methods of analysis

The water samples were collected monthly in five sampling locations, between January 2020 and June 2021 for physicochemical analysis, using sterilized one-litre plastic bottles. Samples collected were placed in an ice chest and transferred to the Laboratory Unit of Akwa Ibom State Ministry of Science and Technology, Uyo, and kept frozen at 4ºC before analysis. Parameters (temperature, hydrogen ion, dissolved oxygen, electrical conductivity and total dissolved solids were determined *in situ,* while others were analysed *ex-situ* using standard methods described by APHA (2017). Temperature was measured using mercury-in-class, hydrogen ion concentration (pH) by using pH meter (Jenway 550 Model), electrical conductivity (EC) and total dissolved solids (TDS) by portable TDS/EC meter (HACH CO.150 model), dissolved oxygen (DO) was with DO meter (Hanna H 19146 – 04 Model), sulphate (SO_4^-) by turbidimetric method, nitrate (NO_3^-) by cadmium reduction method, ammonia (NH_3**)** by Nessler colorimetric method, biochemical oxygen demand (BOD_5) by acid modification method, chemical oxygen demand (COD) by open reflux method, chloride (Cl^-) by Argentometric method; total suspended solids (TSS) by gravitation method, total alkalinity (TA) by titration method while phosphate (PO^-_4) was determined using molybdenum blue method.

Zooplankton collection, enumeration and identification

Zooplankton was collected by towing a 55µm mesh size plankton net in the water column for ten minutes. The net was towed horizontally against the water current in each sampling location. The concentrated water samples containing zooplankton on the towing net were filtered into one-litre sampling bottles and filtered fixed with two drops of 4% formalin solution before being taken to the laboratory for further analysis. In the laboratory, the samples were allowed to stand for 30 minutes for the planktons in the river water to settle at the beneath of the sample bottles. The settled samples were further filtered into 100 mL of sampling bottles, from which a sub-sample (1 mL) from each sample was taken and transferred into a Sedgewick-Rafter counting chamber fitted on a microscope for enumeration. The counting and enumeration were done using a compound microscope at various magnifications (x20, x40, x100, x200, and x400). The zooplankton were identified to genus level by using standard keys of Boxshall and Braide (1991), Korinek (1999), Altaff (2004), Dang *et al.* (2015), and Dhanasekaran *et al.* (2017). Three replicate observations were made and the average count was recorded, and the zooplankton enumerated was expressed as individuals per ml of sample.

Data Analysis

The data obtained were grouped by sampling locations; One-way ANOVA was performed using SPSS, while Fisher's LSD was applied to compare the means of environmental variables with s significant difference set at $P < 0.05$. The zooplankton community structure was measured using ecological indices (Shannon-Weiner, Margalef, Equitability, and Simpson's index). PAST Statistical Software Package (version 3.24) was used to determine the ecological indices (Hammer *et al*., 2001), while Pearson correlation analysis was carried out to ascertain the relationship of environmental variables with zooplankton groups per study location. The relative abundance (%) of zooplankton species was calculated according to George *et al*. (2020) and Jonah and Akpan (2024) as follows:

$$R.A\ (\%) = n/N \times 100$$

Where;
n = the total number of individuals zooplankton species.
N = the total number of individuals of the entire zooplankton species.

RESULTS

Environmental variables

The summary of environmental variables is presented in Table 1. The water temperature ranged between 22.0 and 31.6 ºC; the mean values varied slightly across the study locations with the maximum value (26.68 ºC) obtained in location 3, while the lowest value (24.97 ºC) was in location 1. There was no significant difference (ANOVA, $P > 0.05$) between the locations. The pH value obtained ranged from 5.2 to 8.6; the maximum mean level (7.41) was obtained in location 2, while the lowest (6.43) was recorded in locations 4 and 5. There was no significant difference (ANOVA, $P > 0.05$) between the study locations, while the mean level obtained in locations 4 and 5 dropped below the permissible limit (6.5 - 8.5). The EC ranged from 72.5 to 195.0 (uS/cm); with the maximum mean levels of 147.99 and 147.44 uS/cm obtained in locations 3 and 5 respectively, while the minimum of 115.46 uS/cm was recorded in location 4. There was no significant difference (ANOVA, $P > 0.05$) between the locations.

Table 1: Summary of environmental variables from upper segment of Qua Iboe River

Environmental variables	Location 1	Location 2	Location 3	Location 4	Location 5	NESREA, 2011
Temp. (ºC)	24.97±0.43^a	26.44±0.42^a	26.68±0.44^a	25.89±0.44^a	26.01±0.48^a	NI
pH	6.71±0.07^a	7.41±0.06^a	6.63±0.16^a	6.43±0.11^a	6.43±0.11^a	6.5-8.5
EC (uS/cm)	123.08±1.72^a	133.75±1.74	147.99±2.39^a	115.46±2.36^a	147.44±2.69^a	NI
TDS (mg/L)	82.46±3.93^a	89.61±0.84^a	98.76±1.85^a	77.35±1.54^a	98.53±1.76^a	NI
DO (mg/L)	4.83±0.30^a	3.17±0.22^a	2.47±0.21^b	3.96±0.27^a	2.66±0.18^b	> 6
SO_4^- (mg/L)	59.97±5.28^a	92.53±8.03^b	95.64±6.38^b	73.46±3.50^a	83.09±6.18^a	100
NO_3^- (mg/L)	3.25±0.27^a	5.92±0.49^b	6.10±0.35^b	3.68±0.47^a	5.34±0.46^b	9.1
NH_3 (mg/L)	0.24±0.23^a	0.42±0.04^b	0.64±0.54^c	0.46±0.04^b	0.58±0.55^c	NI
BOD_5 (mg/L)	2.42±0.39^a	4.08±0.26^b	5.94±0.20^b	2.86±0.15^a	5.38±0.16^b	< 3
COD (mg/L)	109.47±7.05^a	129.77±9.75	121.04±9.81^c	116.83±8.36^a	140.54±11.08^d	30
Cl^- (mg/L)	39.44±2.32^a	42.91±3.55^a	46.88±3.82^a	50.16±2.87^a	35.32±3.32^a	300
TSS (mg/L)	45.74±5.05^a	54.11±4.20^a	61.13±4.34^b	41.77±4.38^a	64.04±3.84^b	0.25
TA (mg/L)	31.78±3.21^a	88.59±2.88^b	67.70±3.60^b	54.87±3.71^b	44.17±3.13^a	NI
PO^-_4 (mg/L)	2.49±0.36^a	5.15±0.39^c	5.89±0.46^b	4.43±0.43^d	5.95±0.41^b	3.5

±= Standard error; Means with different superscripts along the same row are significantly different ($P < 0.05$), NI = Not indicated.

The concentration of TDS ranged from 48.6 to 130.6 mg/L; the maximum mean values (98.76 and 98.53) mg/L were recorded in locations 3 and 5, while the minimum (77.35) mg/L was in location 4. There was no significant difference (ANOVA, $P > 0.05$) between the locations. The DO contents ranged between 1.5 and 7.4 mg/L; the maximum mean value (4.83) mg/L was obtained in location 1, while the minimum values were obtained in locations 3 (2.47) and 5 (2.66) mg/L. The mean contents in locations 3 and 5 were significantly (ANOVA, $P < 0.05$) lower than the others, while values across the locations were below the permissible limit (> 6.0 mg/L). The SO_4^- content ranged from 42.8 to 158.3 mg/L; the maximum mean value (95.64) mg/L was recorded in location 3, while the minimum (59.97) mg/L was in location 1. The mean value in locations 2 and 3 was significantly higher (ANOVA, $P < 0.05$) than the other locations; the mean values across the locations were within the permissible limit (100 mg/L). The NO_3^- levels obtained ranged between 1.76 and 17.48 mg/L; the mean value recorded for the five locations was 3.25 mg/L (location 1), 5.92 mg/L (location 2), 6.10 mg/L (location 3), 3.68 mg/L (location 4), and 5.34 mg/L (location 5). ANOVA test showed that locations 1 and 4 were significantly ($P < 0.05$) lower than the other locations. In all the studied locations, the mean contents were within the acceptable limit (9.1) mg/L. The NH_3 level ranged from 0.11 to 0.92 mg/L; the mean value recorded for the five locations was 0.24 mg/L (location 1), 0.42 mg/L (location 2), 0.64 mg/L (location 3), 0.46 mg/L (location 4), and 0.58 mg/L (location 5). ANOVA, when applied, showed that location 1 was significantly lower ($P < 0.05$) than the other locations.

The BOD_5 content ranged from 0.62 to 6.51 mg/L; the mean value for the five locations was 2.42 mg/L (location 1), 4.08 mg/L (location 2), 5.94 mg/L (location 3), 2.86 mg/L (location 4), and 5.38 mg/L (location 5). It was observed that the mean levels in locations 1 and 4 were significantly (ANOVA, $P < 0.05$) lower than the other studied locations, and were within the permissible limit (> 3.0 mg/L), while the mean values obtained in locations 2, 3 and 5 were above the recommended limit. The concentration of COD ranged between 69.8 and 233.6 mg/L; the mean value for the five locations was 109.47 mg/L (location 1), 129.77 mg/L (location 2), 121.04 mg/L (location 3), 116.83 mg/L (location 4), and 140.54 mg/L (location 5). The mean value recorded in location 5 was significantly (ANOVA, $P < 0.05$) higher than the other locations; all values were above the permissible limit (30 mg/L). The Cl^- contents ranged from 22.29 and 80.36 mg/L; the mean value obtained for the five locations was 39.44 mg/L (location 1), 42.91 mg/L (location 2), 46.88 mg/L (location 3), 50.16 mg/L (location 4), and 35.32 mg/L (location 5). ANOVA test showed no significant difference ($P > 0.05$) between the mean values, and all the values were exceeded in the permissible limit (300 mg/L).

The level of TSS obtained ranged from 22.1 to 91.5 mg/L; with the maximum mean value (64.04) mg/L obtained in location 5, while the minimum (41.77) mg/L was in location 4. The TSS values across the locations were above 0.25 mg/L, which is the acceptable limit. ANOVA revealed that the mean value in locations 3 and 5 was significantly ($P < 0.05$) higher than the others. The concentration of TA obtained ranged from 17.5 to 98.8 mg/L; with the maximum mean value (88.59) mg/L obtained in location 2, while the minimum (31.78) mg/L was obtained in location 1. The mean value in locations 1 and 5 was significantly ($P < 0.05$) lower than the others. The PO_4^- content ranged between 1.85 and 17.95 mg/L; the mean value obtained for the five studied locations was 2.49 mg/L (location 1), 5.15 mg/L (location 2), 5.89 mg/L (location 3), 4.43 mg/L (location 4), and 5.95 mg/L (location 5). ANOVA test showed significant difference ($P < 0.05$) in locations 3 and 5 when compared to others. All the mean values except in location 1 exceeded in the permissible limit (3.5) mg/L.

Variation in zooplankton composition

A total of 3301 individual zooplankton species from 35 taxa that belong to 4 taxonomic groups were recorded as shown in Table 2. A total of 11 species of Rotifera were represented, Copepoda 10, Cladocera 9, while protozoa were 5 respectively. The most abundant was Rotifera, with 1285 individuals (38.93 %), followed by Cladocera with 864 (26.17 %) ind. /L, while the minimum was Protozoa with 304 ind. /L (9.2 %) respectively. In respect to studied locations, 32 species and 905 (27.42 %) zooplankton ind. /L were obtained in location 1, while location 2 had 35 species and 554 (16.78 %.) zooplankton ind. /L. Location 3 was also recorded 35 species with 605 (18.33 %) zooplankton ind. /L; location 4 had 25 species and 687 (20.81 %) individuals' zooplankton, while 27 species and 550 zooplankton ind. /L with relative abundant of 16.66% were obtained in location 5. There is no significant difference between the study locations (ANOVA, $P > 0.05$), while significant variations (ANOVA, $P < 0.05$) were obtained in locations 1, 3 and 5. The Cladocera recorded in location 1 was a significantly (ANOVA, $P < 0.05$) higher than the other locations. The maximum number (244 ind./L) was obtained in location 1, while the lowest of Cladocera (125 ind./L) was in location 5. The maximum number (202 ind. /L) of Copepoda was obtained in location 3; followed by location 5 (186 ind./L), while the minimum (139 ind./L) was obtained in location 4. ANOVA, when applied, showed significant difference ($P < 0.05$) in locations 1, 3 and 5. Protozoa were significantly higher in location 1 ($P < 0.05$) than the others with 123 ind. /L; followed by location 3 (76 ind. /L), while the lowest was obtained in location 4 (13 ind./L). The Rotifera were higher (362 ind. / L) in location 1; followed by location 4 (353 ind. /L), while 174 ind. /L was obtained in location 5. ANOVA test showed significant difference ($P < 0.05$) in Rotifera obtained between the studied locations. However, the most abundant species in location 1 was *Filinia longiseta* (51 individuals), while *Moina micrura*, *Microcyclops rubellus* and *Microcyclops varicans* were not recorded at all in location 1. In location 2, *Brachionus calyciflorus* (46 ind. /L) was the abundant species, while *Eucyclops speratus* (52 ind./L) was in location 3. In location 4, *Filinia longiseta* was the most abundant species with 83 ind. /L, while species (*Daphnia magna*, *Cyclops strenuous*, *Diaptomus gracilis*, *Eucyclops speratus*, *Assulina muscorum*, *Arcella vugaris*, *centropyxis*, *Lecane bulla* and *Platyias quadricornis*) were not recorded.

In location 5, species (*Diaphanosoma sarsi*, *D. brachyurum*, *Daphnia pulex*, *D. magna*, *Eucyclops speratus*, *Mesocyclops leuckarti*, *M. rubellus* and *Platyias quadricornis*) were not recorded, while *Cyclops strenuous* and *Calanoides carinatus* were the most abundant species (41 ind. /L) and (40 ind. /L) respectively.

Correlation Coefficient (r) Matrix of Environmental Variables and Zooplankton

The values of correlation analysis between environmental variables and zooplanktons are presented in Tables 3a, b and c. The values showed significant either at $P < 0.05$ or $P < 0.01$. The study revealed that DO, pH, and TSS established positive correlation with Cladocera in location 1 at $P < 0.05$; Temperature and DO correlate positively with Copepoda at $P < 0.05$.

Protozoa was negatively correlate with TA, and inverse correlation with temperature and DO $P < 0.05$, while the Rotifera had a strong positive correlation with BOD_5 ($P < 0.01$) and pH ($P < 0.05$). Hydrogen ion and PO_4^- established a negative correlation with Cladocera ($P < 0.05$) and NH_3 ($P < 0.01$) in location 2. Copepoda showed a negative correlation with NH_3 ($P < 0.05$); Protozoa had positive relationship with DO and inverse correlation with NO_3^-, NH_3, and PO_4^- ($P < 0.05$), while pH, TDS, NH_3 ($P < 0.05$), and NO_3^- ($P < 0.01$) (Table 3a). In location 3, DO and BOD_5 were correlated negatively with Cladocera ($P < 0.01$); Copepod was positively correlated with temperature and PO_4^- ($P < 0.05$) and negatively with BOD_5 ($P < 0.05$), while Protozoa correlate positively with pH and EC ($P < 0.05$), while inverse correlation was with SO_4^- ($P < 0.01$). Cladocera in location 4 had a significant positive relationship with pH and Cl^- ($P <$

0.05); Protozoa correlate negatively with TSS, SO_4^-, PO_4^- (P < 0.05), while Rotifera correlate positively with temperature and DO (P < 0.05) (Table 3b). On the other hand, Cladocera obtained in location 5 were correlated with NO_3^- (P < 0.01) and negatively with Cl^- (P < 0.05); Copepoda relate negatively with EC (P < 0.05); Protozoa negatively correlated with NO_3^- (P < 0.01), while pH and COD were correlated negatively with Rotifera (P < 0.05) (Table 3c).

Community structure of zooplankton species

The species diversity of zooplankton species obtained is shown in Table 4. The Shannon-Weiner diversity index ranged from 3.067 to 3.381; location 4 recorded the least value (3.067), while the highest value (3.381) was recorded in location 1. The Margalef's index values ranged between 3.674 and 5.382, with the highest value in location 2, while the lowest value (3.674) was obtained in location 4. The equitability index values obtained had their highest value in recorded in location 1 (0.975), and the least value was in locations 2 and 3 (0.939) respectively. Simpson's index values ranged from 0.946 to 0.964; the highest value was recorded in location 1, and the lowest value was recorded in location 4.

Table 2: Checklist of zooplankton species and relative abundance obtained from the upper segment of Qua Iboe River water

Zooplankton	Location 1	Location 2	Location 3	Location 4	Location 5	Total	R.A (%)
CLADOCERA							
Alona rectangular	26	15	7	29	20	97	2.94
Ceriodaphnia cornuta	49	16	24	27	11	127	3.85
Chydorus sphaericus	26	23	23	29	28	129	3.90
Diaphanosoma sarsi	32	15	7	9	0	63	1.90
D. brachyurum	34	33	13	25	0	105	3.18
Daphnia pulex	13	18	14	26	0	71	2.15
Daphnia magna	28	28	28	0	0	84	2.54
Moina brachiata	36	14	12	16	32	110	3.33
Moina micrura	0	10	13	21	34	78	2.36
Total	**244**[a]	**172**[b]	**141**[c]	**182**[b]	**125**[c]	**864**	**26.17**
COPEPODA							
Bryocamptus minitus	39	16	9	43	30	137	4.15
Calanoides carinatus	9	14	24	20	40	107	3.24
Cyclops strenuous	33	19	24	0	41	117	3.54
Diaptomus gracilis	14	28	37	0	38	117	3.54
Eucyclops speratus	24	10	52	0	0	86	2.60
Heliodiaptomus viduus	24	30	14	26	27	121	3.66
Mesocyclops leuckarti	0	13	10	14	0	37	1.12
Microcyclops rubellus	0	4	22	16	0	42	1.27
Microcyclops varicans	21	7	5	10	5	48	1.45
Thermocyclops hyalinus	12	4	5	10	5	36	1.09
Total	**176**[a]	**145**[b]	**202**[c]	**139**[b]	**186**[d]	**848**	**25.69**
PROTOZOA							
Arcella vulgaris	31	3	13	13	11	71	2.15
Arcella hemispherica	28	6	6	0	14	54	1.64
Assulina muscorium	26	2	7	0	14	49	1.48
Centropyxis aculeate	8	9	20	0	11	48	1.45
Centropyxis spinosa	30	7	30	0	15	82	2.48
Total	**123**[a]	**27**[b]	**76**[c]	**13**[b]	**65**[e]	**304**	**9.2**
ROTIFERA							
Asplanchna brightwellii	28	13	25	54	5	125	3.78
Brachionus falcatus	57	39	23	34	16	169	5.12
Brachionus caudatus	26	15	21	45	23	130	3.94
Brachionus budapestinesis	42	15	19	26	13	115	3.48
Brachionus calyciflorus	15	46	30	14	15	120	3.64
Brachionus rubens	19	6	2	30	19	76	2.30
Filinia longiseta	51	33	39	83	22	228	6.90
Keretella cochlearis	28	10	2	22	25	87	2.64
Keretella quadrata	34	20	13	45	18	130	3.94
Lecane bulla	38	3	10	0	18	69	2.09
Platyias quadricornis	24	10	2	0	0	36	1.09
Total	**362**[a]	**210**[b]	**186**[c]	**353**[d]	**174**[e]	**1285**	**38.93**

Number of species	**32[a]**	**35 [a]**	**35 [a]**	**25 [a]**	**27 [a]**	**35 [a]**
Number of individuals	**905[a]**	**554[d]**	**605[c]**	**687[b]**	**550[d]**	**3301**
Relative abundance (%)	**27.42**	**16.78**	**18.33**	**20.81**	**16.66**	**100.0**

Values with different superscripts along the same row are significantly different (P < 0.05); R.A = Relative Abundance.

Table 3a: Correlation coefficient (r) matrix of environmental variables and zooplankton in locations 1 and 2.

Environmental Variables	**Zooplankton Groups**							
	Location 1				**Location 2**			
	Cladoc.	**Copep.**	**Protoz.**	**Rotif.**	**Cladoc.**	**Copep.**	**Protoz.**	**Rotif.**
Temp.	-.715	**.915***	**.932***	-.731	-.428	-.581	-.100	.539
pH	**.987***	-.678	.087	**.896***	**-.907***	-.654	-.294	**.910***
EC	-.638	-.745	-.261	-.426	-.664	.683	.537	.336
DO	**.916***	**.987***	**.914***	-.235	.694	-.638	**.911***	.774
TDS	-.162	-.085	-.002	-.110	-.762	-.102	-.674	**.879***
SO_4^-	-.631	-.102	-.461	-.735	-.426	-.030	-.358	.482
NO_3^-	-.365	-.194	-.579	.701	-.708	-.037	**-.933***	**.968****
NH_3	-.574	-.316	-.136	.538	**-.983****	**-.914***	**-.946***	**.943***
BOD_5	-.148	-.113	.574	**.919****	-.094	-.146	-.264	-.164
COD	-.621	-.792	-.029	-.043	-.753	-.142	-.251	-.613
Cl^-	-.711	-.634	-.210	-.624	-.246	.113	-.653	-.625
TSS	**.952***	-.364	-.235	-.215	-.121	.349	-.725	-.125
TA	-.321	-.003	**-.861***	-.735	-.635	-.502	-.636	-.635
PO_4^-	-.220	-.525	-.015	-.293	**-.884***	-.719	**-.878***	.374

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 3b: Correlation coefficient (r) matrix of environmental variables and zooplankton in locations 3 and 4.

Environmental Variables	**Zooplankton Groups**							
	Location 3				**Location 4**			
	Cladoc.	**Copep.**	**Protoz.**	**Rotif.**	**Cladoc.**	**Copep.**	**Protoz.**	**Rotif.**
Temp.	-.738	**.976***	-.012	.846	-.645	-.315	-.548	**.976***
pH	-.154	-.479	**.892***	.742	**.871***	-.249	-100	-.126
EC	-.124	-.647	**.971***	-.303	-.751	.002	.636	-.608
DO	**-.979****	.463	-.100	-.472	-.461	-.390	-724	**.994***
TDS	-.653	-.358	-.541	-.479	-524	-.286	**-.897***	.016
SO_4^-	.026	-.782	**-.857****	-.245	-263	-.008	**-.942***	-.079
NO_3^-	037	-.678	-.381	-.363	-.796	-.333	-643	-.823
NH_3	.283	.692	-.092	-.482	.345	-.215	-.581	-.375
BOD_5	**-.960****	**-.894***	-.471	-.162	-.179	-.814	.648	-.017
COD	-.725	-.773	-.509	-.448	-.334	-.064	-.479	-.594
Cl^-	-.064	-.764	-.759	-.564	**.852***	..736	-.109	..016
TSS	.336	-.405	-.676	-.072	.794	.602	-.471	-.779
TA	.501	-.624	-.485	-.689	-.734	.539	-.005	-.121
PO_4^-	.103	**.928***	-.648	-.357	-.209	.002	**-.902***	-.216

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 3c: Correlation coefficient (r) matrix of environmental variables and zooplankton in location 5

Environmental Variables	**Zooplankton Groups**			
	Cladocera	**Copepoda**	**Protozoa**	**Rotifera**
Temp.	-.464	.545	.065	-.159
pH	-.178	-.141	.643	**.872***
EC	.364	**-.863***	-.023	.082
DO	-.316	.230	-.713	-.658
TDS	-.705	-.237	-.625	.801
SO_4^-	-.094	.082	.003	.082

NO_3^-	**.962****	.078	**-.977****	-.139
NH_3	.078	-.815	-.646	-.548
BOD_5	-.547	-.110	-.796	-.332
COD	.815	.027	-034	**.939***
Cl^-	**-.911***	.772	-.735	.364
TSS	.082	-.513	.816	.821
TA	.822	-.735	.014	-.202
PO_4^-	-.792	-.483	-.054	-.641

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 4: Diversity indices of zooplankton species across the studied locations

Indices	Location 1	Location 2	Location 3	Location 4	Location 5
Number of species	32	35	35	25	27
Number of individuals	905	554	605	687	550
Shannon-Weiner (H)	3.381	3.339	3.338	3.067	3.165
Margalef's index (d)	4.554	5.382	5.308	3.674	4.12
Equitability index (J)	0.975	0.939	0.939	0.952	0.960
Simpson index (C)	0.963	0.958	0.959	0.946	0.935

DISCUSSION

All the investigated parameters were within acceptable limits except pH, DO, BOD_5, COD, TSS, and PO_4^- in some sampling points. The concentrations of physicochemical parameters in water are mostly varied determined by the inherent environmental condition, anthropogenic activities, and probable source of pollution (Akhtar *et al.*, 2021). The mean values of water temperature recorded were slightly varied between the locations; all the values were within the ambient range (24 –30 ºC) that supports the growth of aquatic biota (George *et al*., 2020; Jonah and Akpan, 2021). The mean values are consistent with previous reports by Esenowo *et al.* (2017) and Jonah *et al.* (2020a) in the same region. The slight variation between the locations could be linked to the period of investigation, water level, air temperatures and canopy cover in each location.

The lower mean pH levels recorded in locations 4 and 5 could be attributed to anthropogenic activities, and they were below than the acceptable limits (6.5 – 8.5) set by NESREA (2011). The mean values of electrical conductivity and total dissolved solids recorded were varied across the locations; the maximum mean values were recorded in locations 3 and 5 when compared with other locations. These could be suggesting leaching of agricultural wastes, higher dissolved salts and ionic contents, sand mining activities and other allochthonous inputs into these locations during the study period. Dissolved oxygen is a critical parameter for aquatic biodiversity; the impact of human activities in the aquatic environment can be identified by the dissolved oxygen contents (Anyanwu *et al.*, 2022), and values greater than 5 mg/L have been reported to be essential in supporting aquatic life and good fish production (Saloom and Duncan, 2005; Jacob *et al*., 2023). The mean values across the sampling locations were below the acceptable limit of 6.0 mg/L (NESREA, 2011). The mean values corroborate the findings earlier reported by George *et al.* (2020) from this region. The low mean values recorded in locations 3 and 5 suggests to higher accumulative effects of pollutants released into the water at these points from the human activities within the watershed (Jonah *et al*. 2022).

The mean values of sulphate in locations 2 and 3 were high compared to other locations; the values recorded suggest geogenic influence, coupled with human activities such as washing of motor cycles, laundering and bathing. The mean values across the sampling locations were within the acceptable limit (< 100 mg/L). The mean values of nitrate and ammonia were higher in location 3; these could be associated with the severe land use for farming within the catchment area and surface runoff (Zhang *et al.*, 2019; Jonah *et al.*, 2020c). The mean values for nitrate were within the acceptable limit (< 9.1 mg/L) set by NESREA (2011). However, the high biochemical oxygen demand in location 3 could be connected to the consistent deposition of organic wastes from varying anthropogenic sources (Akpan *et al.*, 2023). The mean values in locations 2, 3 and 5 exceeded the acceptable limit (< 3 mg/L) set by NESREA (2011). The maximum mean value of chemical oxygen demand recorded in location 5 may suggest accumulation of organic-rich wastes, which might have been oxidised chemically rather than biochemically. The mean value in all the locations exceeded the acceptable limit (30 mg/L) set by NESREA (2011). The maximum mean value of chloride recorded in location 4 could be associated with the domestic activities such as laundering and washing of motorcycle. Ganiyu *et al*. (2018) affirmed that the concentration of chlorine in water is associated with domestic sewage disposal, and other related human activities. The mean values recorded were within the acceptable limit (300 mg/L) set by NESREA (2011).

The mean values of total suspended solids exceeded the acceptable limit (0.25 mg/L); the higher value in location 5 could be associated with the indiscriminate discarding of solid wastes, sand dredging, and other allocthtonus input into the water. Higher content of alkalinity have adverse physiological stress on aquatic organisms, with subsequent loss of biodiversity. The maximum mean value of total alkalinity was obtained in location 2; this suggests geogenic source of alkaline pollutants, and carbonate rock bearing in the environment (Etim *et al.,* 2013), while the maximum concentration of phosphate recorded in location 5 suggests increase of organic wastes owing to human activities at the left and right banks of the river. The means value of phosphate across the locations except 1 exceeded the acceptable limit (3.5 mg/L) by NESREA (2011).

The zooplankton composition varied among sampling locations. Water quality impacted on abundance and distribution of aquatic biota including zooplankton (Essien-Ibok and Ekpo, 2015; Jonah *et al*., 2020b). Related studies (Anyanwu *et al*., 2021; Bozkurt, 2022) reported that the parameters - pH, conductivity, temperature, nutrients (nitrate and phosphate), and food availability regulate zooplankton assemblages; which have reflected in the dominance of different taxonomic groups between the sampling locations. However, the 35 taxa recorded were low when compared with the 53 reported by Essien-Ibok and Ekpo (2015) in the Ikpa River. The low taxa could be attributed to the effect of sand dredging, and organic pollutants exacerbated other anthropogenic activities (Xiong *et al*., 2016). The zooplankton recorded showed spatial variation; the highest abundance was recorded in sampling locations 1 and 4, while the least was in location 5. The observed trend could be attributed to the prevailing conditions of each location, food availability, stress imposed on the water body associated with sand dredging, and domestic effluents (Rehman *et al*., 2016; Jonah *et al.* 2022). These factors probably might have disrupted life and reproductive cycles of the zooplankton, and subsequently migrations as observed in locations 2, 3, and 5.

The abundance of Rotifera, Protozoa and Cladocera in location 1 could be attributed to less anthropogenic perturbation. On the other hand, the abundance of Copepoda in location 3 could be linked to their resilience and tolerance to degradable conditions in the aquatic system (Akin-Oriola, 2003; Uttah *et al*., 2008). The occurrence of Rotifera and Cladocera in locations 2, 3 and 5, despite the observed level of anthropogenic activities, is an indication that the groups were dominated by pollution-tolerant species. The dominance of *Brachionus calyciflorus* in location 2, *Eucyclops speratus* in 3, *Filinia longiseta* in 4, and *Calanoides carinatus* in 5 could be ascribed to their ability to adapt to environmental variability and regarded as biological indicators of pollution (Rehman *et al*., 2016).

Correlation analysis showed that specific environmental variables influenced zooplankton abundance and distribution in each location. The existing positive correlations of environmental variables with zooplankton imply that the increase in these parameters thus favours their abundance, while the negative correlations indicate that the parameters have negative influence on the plankton group. The negative influence of water parameters with zooplankton could be linked to anthropogenic perturbation in the river system which in turn impaired their abundance.

The diversity indices are useful tools for comparing community stability in aquatic ecosystems. An increase in the index reflects stability, while the low value is an indication of environmental stress with impact on the biota (Leinster and Cobbold, 2012). The values for Shannon-Weiner diversity index were > 3, indicating that river water was stable for zooplankton distribution (Mason, 2002). The higher values of Margalef's index obtained in locations 2 and 3, despite the human perturbation could be ascribed to the fact that the index is focuses on the richness and taxonomic composition rather than community abundance (Meng *et al*., 2020). The values for Equitability and Simpson index were closer to 1, indicating that no dominant group among the zooplankton was recorded.

CONCLUSION

Water quality characteristics were varied across the locations. The mean values of hydrogen ion, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total suspended solids and phosphate in some sampling points exceeded the limit. Parameters such as hydrogen ion, ammonia, phosphate, nitrate, dissolved oxygen, biochemical oxygen demand, sulphate, total dissolved solids, chloride and electrical conductivity in some locations influences the abundant of zooplankton. Human activities in the watershed warrant attention from relevant authorities; regulation of these activities should be enforced to minimize the situation of water deterioration, and to restore natural water quality to support aquatic life and health, and make it suitable for domestic usage.

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