JOURNAL OF SCIENCE AND TECHNOLOGY
ISSN: 2229-8460 e-ISSN: 2600-7924

JST

Vol. 17 No. 1 (2025) 143-155
https://publisher.uthm.edu.my/ojs/index.php/jst

Water Quality and Plankton Assemblages in Eniong Creek: Implications for Biodiversity and Anthropogenic Influence

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DOI: https://doi.org/10.30880/jst.2025.17.01.014

Article Info

Received: 23 August 2024
Accepted: 9 June 2025
Available online: 30 June 2025

Keywords

Water quality, plankton, diversity, Eniong Creek

Abstract

The water quality and plankton assemblages of Eniong Creek were studied between August 2022 and January 2023 in three sampling points. Plankton and water samples were collected monthly using plankton net and water sampler. The water and plankton samples were analyzed using standard laboratory techniques. The results showed that some values of pH, PO^{-}_{4}, BOD_5 and all TSS, and DO did not conform to the acceptable limits. A total of 33 species of phytoplankton from three taxonomic classes were recorded: dominated by Baccillariophyceae with 17 species and 401 individuals (59.8%). A total of 26 zooplankton species from four taxonomic classes were recorded. Monogononta (Rotifar) was the most dominant and abundant class with 12 species and 357 individuals (47.1%). *Melosira granulata* was the most abundant phytoplankton species (36, 5.4%), while *Lecane bulla* was the most abundant zooplankton species (62, 8.2%). The biodiversity- Margalef's index: 4.769-4.963 (Phytoplankton) and 3.711- 4.109 (Zooplankton), Shannon-Weiner index: 3.075 (Phytoplankton) and 2.85-2.99 (Zooplankton), and Pielou Evenness index: 0.802-0.874 (phytoplankton) and 0.799-0.842 (Zooplankton) suggest moderate. It can be concluded that the composition, abundance and distribution of plankton in was influenced by the physicochemical conditions of the Creek, which in turn was influenced by human activities.

1. Introduction

Eniong Creek is among the most productive ecosystems, providing conducive environment that supports a wide range of aquatic organisms. Over the years, the system has been experiencing a remarkable rate of qualitative and quantitative degradation, closely linked to anthropogenic activities such as lumbering, transportation, fishing, indiscriminate dumping of waste, and other economic activities within the watershed, coupled with the rapid population growth of the area [1].

Water quality status plays a crucial role in aquatic life sustainability; its community structure and polluted water pose physiological stress on aquatic biota [2-4]. It determined the suitability of aquatic environment for the growth and development of aquatic biota [5, 6]. Physicochemical parameters give an insight into water chemistry and quality, which alone does not give a clear picture of the ecological condition of the water body [7]. The plankton community in the aquatic ecosystems have been found in relation to physicochemical characteristics to be the base approach to check the ecological integrity of aquatic system due to their speedy response to ecological changes in their natural habitat [8-11].

Recent studies showed that the ecological effects of human activities coupled with the impact of climate change on aquatic ecosystem can be predicted by the assessment of its biological communities [12-13]. In the same natural aquatic ecosystem, different habitats often exhibit differences in plankton community structure partly due to different nutrient concentrations [14].

More so, Jonah et al. [15], described plankton as aquatic micro-plants (phytoplankton) and animals (zooplankton), floating in the water column, with a low capacity to counteract the movement of water current during swimming. The phytoplankton forms the basis of aquatic productivity; they are the ultimate source of food for diverse aquatic organisms, while the zooplanktons are valuable protein materials in fishes [16]. In addition, plankton is an important part of the aquatic ecosystems; their stability and structure are affected by the combined effects of biotic and abiotic factors [17]. The alteration of the optimal physicochemical parameter levels of aquatic systems such as water temperature, turbidity, pH level, dissolved oxygen, nutrients, suspended and dissolved solids; majorly attributed to human activities poses negative impact on aquatic biota [18,19]. According to Anyanwu et al. [20], dissolved oxygen and nutrients are important for the composition and distribution of zooplankton. Low dissolved oxygen in water would limit their development; nutrients enhance their growth, while pH and total suspended solids are essential for their distribution [21].

In addition, prior studies have shown that total phosphorus, total nitrogen, water temperature, and dissolved oxygen have also been confirmed to relate to plankton community stability [22, 23]. The efficiency of trophic transfer through zooplankton to fish depends largely on the composition of zooplankton in an aquatic ecosystem [24]. A decline in zooplankton diversity in aquatic ecosystems will ultimately affect higher trophic levels, loss of fish species and ecosystem services if there is no control [25]. Location of residential settlements, markets and other economic activities within the downstream watershed of the creek could result in the introduction of allochthonous materials into the water body which in turn could have a substantial effect on the autochthonous plankton composition, abundance and distribution. Therefore, objective of this study was to assess the of water quality status and plankton community structure of Eniong Creek, Akwa Ibom State, Nigeria.

2. Materials and Methodology

2.1 Materials

2.1.1 Study Area and Sampling Points

The section of Eniong Creek studied is in Itu Local Government Area, Akwa Ibom State, Nigeria, within Latitude 5° 12'20 North and Longitude 7°58'27 (Fig. 1). The water body took its source from Nkana Ikpe in Ini Local Government Area, transverse through Ikpanya community in Ibiono Ibom Local Government, Obot Akpabio to Asang Eniong and empties into the Cross River as a confluence. The study area was characterized by a tropical climate change of long wet season between March and October and short dry season (November - February). The water body is commonly called black water, due to its color, receives pollutants from point and non-point sources within the watershed and the nearby settlements.

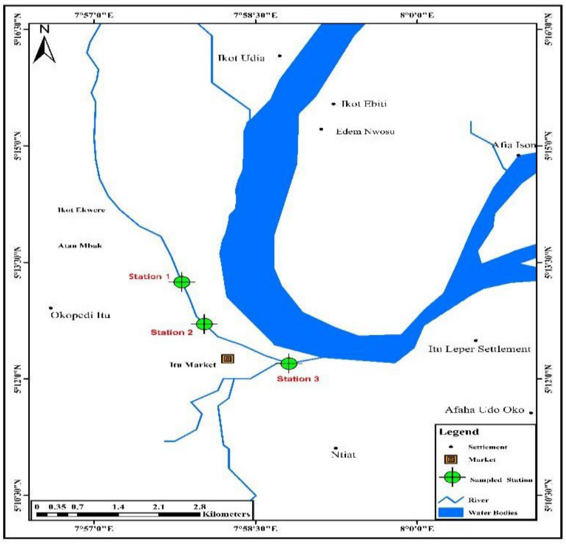

Fig. 1 *Map of Eniong Creek with sampling stations*

The anthropogenic activities observed include road construction, indiscriminate dumping of domestic waste, fishing, farming, boat building, logging, selling of foodstuff (miscellaneous items) and transportation of goods. For this study, three sampling points were selected along the study stretch, based on accessibility and nature of anthropogenic activities. Point I is upstream after the uncompleted bridge and close to residential settlement with higher anthropogenic activities such as indiscriminate dumping of domestic wastes, fishing, farming and lumbering. The location receives storm water from the community. Point II is in the middle, beside the local market and residential settlement, 2 km downstream of point I, with higher anthropogenic activities which include road construction, indiscriminate dumping of domestic wastes, fishing, farming, boat building, logging, selling of foodstuff (miscellaneous items) and transportation of goods. Point III is downstream, about 2 km away from point II and close to the discharge point into Cross River with minimal human activities such as road construction, fishing, bathing and transportation of goods.

2.2 Methods

2.2.1 Water Samples Collection and Analysis

The water samples were collected monthly in three sampling points, between August 2022 and January 2023 for physicochemical analysis using one-litre water sampler. Samples for biochemical oxygen demand (BOD_5) determination were collected using 250 mL amber colour reagent bottles and wrapped immediately with aluminum foil. The physicochemical parameters were analyzed using standard method of America Public Health Association (APHA 2005). Parameters like temperature, dissolved oxygen (DO), water transparency (TR), total dissolved solids (TDS), electrical conductivity (EC), and pH level were determined *in-situ* while others - phosphate (PO_4^-), nitrate (NO_3^-), sulphate (SO_4^-), total suspended solids and biochemical oxygen demand (BOD_5) were determined *ex-situ*. A mercury-in-glass thermometer (0-100 ^oC) was used to determine water temperature, dissolved oxygen (DO) was determined using portable DO Meter (Hanna H 19146 - 04 Model), water transparency was determined using Secchi disk, total dissolved solids (TDS) was derived using TDS=Ke × EC (Ke) is correlation factor = 0.64), hydrogen ion (pH) was determined using portable pH meter (JENWAY 3505), electrical conductivity (EC) was determined using HANNA instruments (Model HI 98303), phosphate (PO^-_4) and sulphate (SO_4) by UV spectrophotometric, nitrate (NO^-_3) by turbidimetric method, total suspended solids (TSS) were determined by gravimetric method while biochemical oxygen demand (BOD_5) was determined after 5 days using Azide modification of Winklers' method.

2.2.2 Plankton Sample Collection and Identification

The plankton samples were collected using the filtration method. A composite sample of 100 litres of water was filtered through 55μm Hydro-Bios plankton net. The net content was washed out into plankton bottles of 100 ml size and preserved in 4% formalin solution. In the laboratory, 1 mL of the preserved sample was taken as a sub-sample using a pipette. The collected sample was put on the Sedgwick-Rafter counting chamber and viewed under a light binocular microscope (Nikon 400 binocular microscope) using a low magnification (x10, x20 and x40). The plankton was sorted into different taxonomic groups and the cells per ml were counted. The identification was made to the lowest practicable taxonomic level using recommended key literatures of [27-31].

2.2.3 Data Analysis

All data were summarized in Microsoft Excel and subjected to statistical analysis using One-way Analysis of Variance (ANOVA) on Statistical Package for Social Sciences (SPSS), version 20. The source of significant difference at $P < 0.05$ was determined with the Tukey pairwise posthoc test. Bivariate correlation analysis was applied to establish the relationship between the environmental variables and planktons. The Margalef (D), Shannon-Weiner (H), and Pielou's Evenness (J) indices were used to determine species richness and diversity using the PAST statistical package.

3. Results

3.1 Environmental Variables

The summary of environmental variables is summarized in Table 1. The pH value ranged between 4.2 and 8.9; with the highest mean value recorded in point III (7.28), while the lowest was recorded in point II (5.32). Some of the values were within the acceptable limit (6.5 – 8.5) set by NESREA (2011). The mean value in point III was significantly higher than in sampling points I and II ($F = 26.14$; $P < 0.05$). The WT ranged between 22.5 and 28.3^oC; with the highest average value (26.85^oC) obtained in point II, while the lowest was in point I (25.64^oC) with no significant differences. The DO values ranged between 2.10 and 5.61 mg/L; the highest average value (5.23 mg/L) was obtained in point III, while the lowest was in point II (2.88 mg/L). All the DO values did not conform to 6 mg/L set by NESREA (2011). There were significant (F = 15.4; $P < 0.05$) variations between the mean values. The TR ranged from 34.0 to 82.0 cm; with the maximum mean value (67.0 cm) in point III, while the minimum (40.0 cm) was obtained in point II. Point III was significantly higher than points I and II (F= 19.0; $P < 0.05$). The EC values ranged between 88.4 and 195.73 µS/cm; the highest mean value (127.65µS/cm) was recorded in point I, while the lowest was in point III (104.52 µS/cm). Point III was significantly lower (F = 41.35; $P < 0.05$).

Table 1 *The summary of physicochemical parameters recorded in Eniong Creek*

Parameters	Point I X±S.E.M	Point II X±S.E.M	Point III X±S.E.M	Statistical significance	Standard limit **
pH*	5.63±0.04^{a} (4.8–6.2)	5.32±0.08^{a} (4.5–6.5)	7.28±0.09^{b} (4.2– 8.9)	*P* <0.05	6.5–8.5
Temp. °C	25.64±0.34 (22.5–27.6)	26.85±0.57 (23.2–28.1)	26.13±0.52 (24.0– 28.3)	*P* >0.05	Ambient
DO (mg/L)*	3.16±0.32^{a} (2.24–5.61)	2.88±0.52^{b} (2.10–4.35)	5.23±0.19^{c} (3.15–5.33)	*P* <0.05	>6.0
TR (cm)	41.0±0.23^{a} (34.0–78.0)	40.0±0.31^{a} (35.0–55.0)	67.0±0.33^{b} (49.0–82.0)	*P* <0.05	NI
EC (µS/cm)	127.65±2.34^{a} (88.4–164.53)	126.23±2.14^{a} (120.4–195.73)	104.52±2.23^{b} (92.8 - 148)	*P* <0.05	NI
TDS (mg/L)	63.85±3.43^{a} (45.2–82.4)	68.23±2.21^{a} (61.2–95.9)	52.6±2.31^{b} (45.4–75.5)	*P* >0.05	NI
PO_4^- (mg/L)*	5.16±2.12^{a} (3.45–6.53)	5.75±3.43^{a} (4.66–6.25)	3.75±2.51^{b} (2.13–4.51)	*P* <0.05	<3.5
NO_3^- (mg/L)	5.53±0.63^{a} (3.42–7.25)	5.26±0.54^{a} (3.64–9.62)	3.34±0.34^{b} (2.42–3.85)	*P* <0.05	<9.1
SO_4^- (mg/L)	65.82±0.42^{a} (33.6–76.4)	54.31±0.80^{b} (46.2–66.2)	48.42±0.35^{c} (25.9– 56.4)	*P* <0.05	<100
TSS (mg/L)*	18.73±4.44^{a} (10.7–32.74)	11.82±5.65^{bc} (10.4–32.5)	9.55±6.34^{c} (6.82–25.5)	*P* <0.05	<0.25
BOD_5 (mg/L)*	4.25±0.56^{a} (3.5–5.22)	4.63±0.46^{a} (2.32–5.18)	2.12±0.64^{b} (2.53–4.72)	*P* <0.05	<3.0

**Parameter with mean value either exceeded or below the acceptable limits; **Guidelines and Standards for Environmental pollution control in Nigeria, Nigeria Environmental Standard and Regulatory Enforcement Agency [32]; NI = Note indicated.*

The values for TDS ranged between 45.2 and 95.9 mg/L; with the highest mean value (68.23 mg/L) recorded in point II, while the lowest in point III (52.6 mg/L). The mean values in points I and II were significantly higher than in sampling point III (F = 12.73; $P < 0.05$). The PO_4 values ranged between 2.13 and 6.53 mg/L; the highest mean value (5.75 mg/L) was recorded in point II, while the lowest (3.75 mg/L) was in point III. Some of the values exceeded the acceptable limit (3.5 mg/L) set by NESREA (2011). Point III was significantly (F= 13.8; $P < 0.05$) lower than points I and II. The NO_3 ranged between 2.42 and 7.25 mg/L; the highest mean value (5.53 mg/L) recorded in point I, and the lowest (3.34 mg/L) in point III. All the values were lower than the acceptable limit (9.1 mg/L) set by NESREA (2011). The mean value in point III was significantly lower than in sampling points I and II (F = 5.53; $P < 0.05$). The SO_4 value ranged between 25.9 and 76.4 mg/L; the highest mean value (65.82 mg/L) was recorded in point I, while the lowest (48.42 mg/L) in point III. All the values were lower than the acceptable limit (100 mg/L) set by NESREA (2011). There were significant variations between the mean values (F= 12.3; $P < 0.05$). The TSS values ranged between 6.82 and 32.74 mg/L; the highest mean value (18.73 mg/L) was recorded in point I, while the lowest (9.55 mg/L) in point III. All the values highly exceeded the acceptable limit (0.25 mg/L) set by NESREA (2011). There were significant variations between the mean values (F= 53.6; $P < 0.05$). The BOD_5 ranged between 2.32 and 5.22 mg/L; the highest mean value (4.63 mg/L) was recorded in point II, while the lowest (2.12 mg/L) in point III. Point III was significantly lower than points I and II (F = 11.36; $P < 0.05$).

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3.2 Phytoplankton Composition

The study recorded a total abundance of 670 phytoplankton individuals from the three sampling points (Table 2). A total of 33 species from three taxonomic classes (Bacillariophyceae, Cyanophyceae and Zygnematophyceae) was recorded. The highest abundance (282 individuals, 42.0 %) was recorded in sampling point II, followed by point I (199 individuals, 29.7 %), while the lowest (189 individuals, 28.3 %) was recorded in point III. The sampling point II was significantly higher than points I and III (F = 41.15; $P < 0.05$). The dominant class was Bacillariophyceae with 17 species and 401 individuals (59.8 %). The highest abundance of Bacillariophyceae (148 individuals) was recorded in sampling point II, while the lowest (122 individuals) was recorded in point III. There were significant (F= 26.1; $P < 0.05$) variations in the composition of Bacillariophyceae recorded in the sampling points. The most abundant species was *Melosira granulata* (36; 5.4 %), followed by *M. moniliformis* and *Fragilaria acus* (35; 5.3 %) while the lowest was *Synedra crystalline* (7; 1.0 %). The Cyanophyceae had an abundance of 126 individuals (18.8%) from 10 species; the highest (50 individuals) was recorded in point II, while the lowest (34 individuals) in point I. Sampling point II was significantly (F= 27.6; $P < 0.05$) higher than the other sampling points. The *Microcystis wesenbergii* was the most abundant of Cyanophyta (24; 3.6 %), while the lowest was *Oscillatoria curviceps* (3; 0.4 %). Zygnematophyceae had 143 individuals (21.4 %) from 6 species; the highest abundance (86 individuals) was recorded in point II, while the lowest (25 individuals) was recorded in point III. The composition of Zygnematophyceae among the sampling points were significantly difference (F= 16.24; $P < 0.05$). The most abundant species was *Cosmarium amoenum* with 41 individuals (6.2%), while the lowest was *Spondylosium panduriforme* with 5 individuals (0.7 %).

Table2 *Composition, abundance and distribution of phytoplankton in Eniong Creek*

Species	Point I	Point II	Point III	Total	R.A (%)
Bacillariophyta / Baccillariophyceae					
Asterionella japonica	-	8	5	**13**	**1.9**
Amphora ovalis	6	8	13	**27**	**4.0**
Bacillaria paradoxa	-	11	-	**11**	**1.6**
Cyclotella striata	23	5	4	**32**	**4.8**
Cyclotella stelligera	15	-	7	**22**	**3.3**
Coscinodiscus concinnus	10	8	3	**21**	**3.2**
Fragilaria dibolos	4	6	9	**19**	**2.8**
Fragilaria acus	2	11	22	**35**	**5.3**
Gyrosigma distortum	8	-	-	**8**	**1.2**
Gyrosigma acuminatum	16	7	11	**34**	**5.0**
Melosira moniliformis	14	9	12	**35**	**5.3**
Melosira granulata	7	18	11	**36**	**5.4**
Melosira varians	13	14	3	**30**	**4.5**
Nitzschia closterium	7	13	4	**24**	**3.6**
Nitzschia palea	5	12	10	**27**	**4.0**
Synedra crystalline	3	4	-	**7**	**1.0**
Synedra pulchella	-	12	8	**20**	**2.9**
Sub-total	**133[b]**	**146[c]**	**122[a]**	**401**	**59.8**
Cyanophyta / Cyanophyceae					
Anacystis marginata	2	3	1	**6**	**0.9**
Anabaena spiroides	6	7	6	**19**	**2.8**
Anabaena constricta	9	5	9	**23**	**3.4**
Chroococcus minor	4	-	-	**4**	**0.6**
Microcystis aeruginosa	-	4	5	**9**	**1.4**
Microcystis wesenbergii	2	14	8	**24**	**3.6**
Oscillatoria subbrevis	5	7	-	**12**	**1.8**
Oscillatoria chlorine	-	8	4	**12**	**1.8**
Oscillatoria tenuis	6	-	8	**14**	**2.0**
Oscillatoria curviceps	-	2	1	**3**	**0.4**
Sub-total	**34[a]**	**50[b]**	**42[a]**	**126**	**18.8**

		Charophyta / Zygnematophyceae			
Arthrodesmus incus	8	15	6	**29**	**4.3**
Cosmarium amoenum	11	18	12	**41**	**6.2**
Cosmarium humile	3	24	-	**27**	**4.0**
Hyalotheca mucosa	6	11	4	**21**	**3.2**
Micrasterias radiate	3	14	3	**20**	**2.9**
Spondylosium panduriforme	1	4	-	**5**	**0.7**
Sub-total	**32a**	**86[b]**	**25[a]**	**143**	**21.4**
Total Number of Individuals	**199**	**282**	**189**	**670**	**100**

R.A = Relative abundance

3.3 Zooplankton Composition

The study recorded a total abundance of 759 zooplankton individuals from the three sampling points (Table 3). A total of 26 species from four taxonomic classes (Monogononta, Copepoda, Branchiopoda, Tubulinea) were recorded. The highest abundance (344 individuals, 45.3 %) was recorded in sampling point II, followed by point III (219 individuals, 28.9 %), while the lowest (196 individuals, 25.8 %) was recorded in point I. There were significant differences in the composition among the sampling points (F= 54.2; $P < 0.05$). The dominant and most abundant class was Monogononta with 12 species and 357 individuals (47.1 %). The highest number individual (137) was recorded in the sampling point II, while the lowest (104 individuals) was recorded in point III. Among the Rotifer, *Lecane bulla* was the most abundant (62; 8.2 %), followed by *Notholca labis* (46; 6.0 %), while the lowest was *Lecane scutata* (3; 0.4 %). The class Copepoda had an abundance of 140 individuals (18.4%) from 5 species. The highest abundance (73 individuals) was recorded in point II, while the lowest (28 individuals) was recorded in point I. The most abundant Copepoda species was *Mesocyclops hyalinus* (41; 5.4 %), followed by *M. leuckarti* (39; 5.2 %). There were significant differences in the composition of copepod among the sampling points (F= 37.0; $P < 0.05$), while the class Branchiopoda had 254 individuals (33.4 %) from 8 species. The highest abundance (126 individuals) was recorded in point II, while the lowest (52 individuals) was recorded in point I.

Table 3 *Composition, abundance and distribution of zooplankton in Eniong Creek*

Species	Point I	Point II	Point III	Total	RA (%)
		Rotifera / Monogononta			
Brachionus falcatus	13	7	9	29	3.8
B. caudatus	6	3	8	17	2.3
B. calyciflorus	-	6	-	6	0.8
Filinia longiseta	13	7	8	28	3.7
F. limnetica	15	11	13	39	5.2
Keratella tropica	3	13	-	16	2.1
Lecane scutata	3	-	-	3	0.4
L. bulla	21	9	32	62	8.2
L. curvicornis	4	33	5	42	5.5
Notholca labis	17	21	8	46	6.0
Polyarthra vulgaris	13	14	12	39	5.2
Trichocerca similis	8	13	9	30	3.9
Sub-total	**116[a]**	**137[b]**	**104[a]**	**357**	**47.1**
		Arthropoda/ Copepoda			
Cyclopoid nauplii	4	11	5	20	2.6
Eucyclops speratus	5	5	9	19	2.5
Mesocyclops hyalinus	3	34	4	41	5.4
M. leuckarti	5	19	15	39	5.2
Microcyclops rubellus	11	4	6	21	2.7
Sub-total	**28[b]**	**73[a]**	**39[c]**	**140**	**18.4**
		Branchiopoda			
Bosmina longirostris	-	12	12	24	3.2
Ceriodaphnia cornuta	12	23	-	35	4.6

Chydorus aphaericus	-	43	15	58	7.6
Daphnia pulex	6	8	22	36	4.7
D. longispina	14	17	5	36	4.7
D. rosea	5	7	2	14	1.8
Moina dubia	12	6	16	34	4.5
M. micrura	3	10	4	17	2.3
Sub-total	**52b**	**126a**	**76b**	**254**	**33.4**
		Amoebozoa / Tubulinea			
Centropyxis spinosa	-	8	-	8	1.1
Sub-total	**0a**	**8b**	**0a**	**8**	**1.1**
Total Number of individuals	**196**	**344**	**219**	**759**	**100**

RA = Relative abundance

Among the Branchiopoda, *Chydorus* sp was the most abundant (58; 7.7%), followed by *Daphnia pulex* and *D. longispina* (36; 4.6%) each, while the least was *D. rosea (14).* There were significant differences between the sampling points (F= 13.7; $P < 0.05$). The class Tubulinea represented 1 species *Centropyxis spinosa* recorded in sampling point II with 8 individuals (1.1%). In the study, *Lecane bulla* is the most abundant species with 62 individuals accounting for 8.2%, while the lowest species was *Lecane scutata* with 3 (0.4 %) individuals recorded only in point I.

3.4 Correlation Analysis Between Environmental Variables and Plankton Community

The correlation between environmental variables and plankton (phytoplankton and zooplankton) community are shown in Table 4. For the phytoplankton, Baccillariophyceae had a negative correlation with pH (r = - .916; $P < 0.05$), WT (r = - .954; $P < 0.05$) and inverse correlation with TR (r = .971; $P < 0.05$), PO_4 (r = .845; $P < 0.05$), NO_3 (r = 962; $P < 0.05$), and BOD_5 (r = .895; $P < 0.05$). The Cyanophyceae established a positive relationship with DO (r = .876; $P < 0.05$), NO_3 (r = .905; $P < 0.01$), TSS (r = .842; $P < 0.05$), and BOD_5 (r = .931; $P < 0.05$), while inverse relationship was with EC (r = -.884; $P < 0.05$). The class Monogononta of zooplankton had positive correlation with TDS (r=.966; P<0.05), PO_4 (r=.942; $P < 0.05$), and SO_4 (r = .857; $P < 0.05$), while negative relationship of this class was with DOD_5 (r = -.913; $P < 0.05$). Branchiopoda correlate positively with PO_4 (r = .845; $P < 0.05$) and strong negative (r = -.946; $P < 0.01$) with BOD_5, while the class Tubulinea had a strong negative relationship (r = -.986; $P < 0.01$) with DO, TR (r = -.957; $P < 0.05$), PO_4 (r = -.842; $P < 0.05$) and NO_3 (r = -.915; $P < 0.01$).

Table 4 *Correlation analysis between environmental variables and plankton community in Eniong Creek*

Environmental Variables	Phytoplankton			Zooplankton			
	Bacil.	Cyano.	Zygn.	Mono.	Copep.	Branch.	Tubul.
pH	-.916*	-.514	-.343	-.345	-.643	-.753	-.421
WT	-.954*	.345	.118	-.206	-.345	-.356	-.546
DO	-.571	.876*	-.361	-.537	-.456	.736	-.986**
TR	.971*	-.623	.128	.864	-.189	-.123	-.957*
EC	-.425	-.884*	-.765	-.264	-.023	-.546	-.325
TDS	-.514	.574	.572	.966*	-.457	.754	-.642
PO_4	.845*	.653	-.468	.942*	-.136	.845*	-.842*
NO_3	.962*	.905**	-.473	-.685	-.087	-.104	-.915**
SO_4	-.426	-.571	-.207	.857*	-.463	-.005	-.746
TSS	-.454	.842*	-.476	-.616	-.063	-.446	-.174
BOD_5	.895*	.931*	-.333	-.913*	-.467	-.946**	-.246

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

3.5 Plankton Biodiversity Indices

The biodiversity indices (Shannon-Weiner index, Margalef's index, and Pielou's Evenness index) of phytoplankton and zooplankton are shown in Table 5. The species diversity indices of phytoplankton revealed that the highest value of Margalef's index (4.963) was recorded in point II, while the lowest value (4.769) was recorded in point

III. ANOVA showed significant differences between the sampling points ($F = 31.9$; $P < 0.05$). The Shannon-Weiner index ranged between 3.075 and 3.233 with the highest value in point II, while the lowest is in point III. There was significant difference in sampling point II ($F = 14.1$; $P < 0.05$), while Pielou's Evenness index ranged between 0.802 (point I) and 0.874 (point II) with significant differences between the values ($F = 57.0$; $P < 0.05$).

Table 5 *Biodiversity indices of phytoplankton and zooplankton of Eniong Creek*

Biodiversity Indices	Phytoplankton			Zooplankton		
	Point I	Point II	Point III	Point I	Point II	Point III
Number of taxa	27[a]	29[a]	26[a]	22[a]	25[a]	21a
Number of individuals	199[a]	282[b]	189[a]	196[a]	344[b]	219[c]
Percentage composition (%)	29.7[a]	42.0[b]	28.3a	25.8[a]	45.3[b]	28.9[c]
Margalef's Index	4.912[a]	4.963[b]	4.769[c]	3.979[a]	4.109[a]	3.711[b]
Shannon-Weiner Index	3.076[a]	3.233[b]	3.075[a]	2.92[a]	2.99[a]	2.85[b]
Pielou Evenness Index	0.802[a]	0.874[b]	0.832[c]	0.842[a]	0.799[b]	0.830[a]

Values with different superscripts (a, b, c) across the rows indicate significant at p<0.05

For the zooplankton, Margalef's index values ranged between 3.711 and 4.109; with the highest value in point II, while the lowest was in point III. The value in point III was significantly lower ($F = 8.24$; $P < 0.05$) than the other points. The Shannon-Weiner index ranged between 2.85 (point III) and 2.99 (point II). Pielou's Evenness index ranged between 0.799 (point II) and 0.842 (point I). The values recorded in points I and II were significantly higher than point III ($F = 19.5$; $P < 0.05$).

4. Discussion

All the parameters were within acceptable limits except pH, DO, PO_4^-, TSS, and BOD_5 in some sampling points. The concentrations of physicochemical parameters in water are varied mostly determined by the inherent environmental condition, anthropogenic activities and probable source of pollution [33]. The lower pH levels obtained in points I and II could be attributed to anthropogenic activities, while the slight alkaline pH recorded in point III could be due to minimal human activities [34]. The average value obtained in points I and II were below the limits (6.5 - 8.5). Most aquatic organisms thrive best within an optimum pH level (6.5 – 8.5), and a small change is harmful to sensitive species [35]. Kale [36] reported that aquatic biota is sensitive to pH level lower than 5 which could lead to drastic death.

Water temperature is a critical factor in some biotic and abiotic processes in the aquatic environment [37]. The values recorded were slightly varied between the points. All the mean values obtained were within the ambient range (24 - 30 °C) that supports the growth of aquatic biota. The findings contradicted with the previous study by Oribhabor et al. [38] from Lower Cross River water. The variation could be linked to the period of investigation, water level, water turbulence and air temperatures. Dissolved oxygen is critical for aquatic organisms; the impact of pollution in aquatic environment can be identified by DO levels [39]; values greater than 5mg/L have been reported to be essential for growth and reproduction of aquatic organisms [40]. The average values across the locations were below the limit (6.0 mg/L); although the mean value in point III was > 5 mg/L. The extremely low values in points I and II suggest accumulative effects of pollutants released into the water from the human activities within the watershed [41].

The transparency of water body determines the solubility of DO as well as the primary productivity of such water bodies. Low transparency impairs the efficacy of conversion heat energy by aquatic plants for photosynthetic activities. Poor water transparency declined the process of food production by autotrophic plankton to heterotrophic aquatic organisms. The low levels of transparency in sampling points I and II could be attributed to the impact of direct inputs of non-dissolvable domestic waste into the water body. Flooding and surface runoff from various tributaries and the surroundings accompanied by high precipitation could also contribute to the low transparency observed in points I and II. The EC and TDS are important water quality parameters; they give a good idea of the level of dissolved materials in aquatic ecosystems [42]. The parameters showed significant fluctuations across the three points; with the highest mean values in points I and II which could be attributed to the impact of surface runoff, transporting toxic substances into the water body at these points [43].

The PO_4^- and NO_3^- mean values recorded in points I and II may be linked to the combined effects of precipitation and anthropogenic inputs, ranging from laundering, discharge of contaminated sewage, and runoffs laden with fertilizers and pesticides [44]. The mean values of PO_4^- across the points exceeded limit (3.5mg/L), while NO_3^- values were within the limit (9.0 mg/L). The average value across the stations for PO_4^- obtained is higher than 2.17 mg/L reported by Egbomuche *et al*. [45], indicating higher shift of pollutants from point and non-point sources. The level of SO_4^- was high in point I; although the values obtained were within the limit (< 100 mg/L). The higher value in point 1 ascribed to geogenic influence, coupled with the human activities. All the total suspended solids values exceeded the acceptable limit (0.25 mg/L) by NESREA (2011). The higher value in point I could be associated with the low flow velocity and input of particles from tributaries and indiscriminate discarding of waste and macro-plastics into the water. The BOD_5 contents in water used to assess its pollution load; the values obtained in points I and II exceeded the acceptable limit (3.0 mg/L), suggesting high levels of organic and inorganic pollutants, and reflected in the values of dissolved oxygen. The mean value in sampling points I and II were significantly higher than station III. Unpolluted water bodies have BOD_5 values of 2.0 mg/L or less, while values from 3.0 to 10 mg/L or more indicate moderate to severe pollution [46]. The processes of wastes degradation by aerobic bacteria required a lot of DO which resulted in increased BOD_5 level [47].

Biological parameters have been extensively used to assess the health status of aquatic ecosystems. The biota of an aquatic system directly reflects conditions existing in the environment and their changes in composition depend on the prevailing physiochemical characteristics [48]. The Eniong creek watershed has been plagued with some anthropogenic activities that could impair the system quality. The most common was road construction during the study, indiscriminate domestic wastes disposal, selling of miscellaneous items at the bank, transportation of goods, fishing, farming, logging, lumbering, sand mining, dredging and human settlement. These activities and more have adversely affected the aquatic biota in the area. The compositions of plankton recorded were varied between the sampling points. The most abundant species of phytoplankton was recorded in point II despite the observed level of anthropogenic activities. The study revealed that most plankton species proliferate intensively in nutrient-rich water. Among the phytoplankton, Bacillariophyceae was the most dominant group, followed by Cyanophyceae suggests accumulation of organic matters and nutrients. It could also ascribe to their sustainable capacity to dwell in polluted environment [49]. The occurrence of pollution tolerant species such as *Coscinodiscus, Melosira*, *Nitzschia*, *Synedra*, *Anacystis, Anabaena, Microcystis and Oscillatoria* is an indication that the water body was enriched with organic pollutants from combined effect of anthropogenic activities in the watershed [50 - 52], which evidence is from the positive relationships established with phosphate and nitrate. The Cyanophyceae recorded was favoured by dissolved oxygen, nitrate, total suspended solids and the level of biochemical oxygen demand, judging from the correlation test results.

The zooplankton record showed spatial variation; the highest abundance was recorded in point II, while the least was in point I. The observed trend could be attributed to food availability and primary producers supported by adequate and quality nutrients and favorable environmental variables [53]. Studies [54, 55] documented that parameters such as water temperature, pH, EC, nutrients, and food availability regulate zooplankton assemblage, which have reflected in the dominance of different taxonomic groups recorded in this study. The abundance of Monogononta (Rotifera) could link to their capacity to tolerate wide range of physicochemical parameters [56]. The correlation test further explains that the concentration of total dissolved solids, phosphate and sulphate contributed to the abundance of Rotifera. The dominant rotifera genera – *Brachionus* and *Lecane* have been reported as bioindicator of pollution [57], Copepods and Branchiopoda predominantly inhabit freshwater bodies; their abundance in sampling point II with high level of anthropogenic activities indicate their resilience and adaptability to changing environmental conditions and ability to withstand varying environmental stresses [58]. The low species of Tubulinea suggest low dissolved oxygen, phosphate, higher transparency and nitrate contents. However, the correlation test indicates that the level of biochemical oxygen demand influence negatively on the abundance of Branchiopoda. The values of biodiversity indices for phytoplankton showed that Shannon-Weiner index ranged between 3.075 (point III) and 3.233 (point II), while Margalef index ranged from 4.769 (point III) to 4.963 (point II). For the zooplankton, the Shannon-Weiner index ranged between 2.85 (point III) and 2.99 (point II), while Margalef index ranged from 3.711(pointIII) to 4.109 (point II). The Shannon-Weiner index classified water bodies as clean when the value is > 4.5, slight pollution (3 - 4.5), moderate pollution (2 - 3), heavy pollution (1 – 2) and high pollution (< 1). In this study, the Shannon-Weiner values recorded for both phytoplankton and zooplankton indicating that the water body is slightly to moderately polluted. These believed to have emanated from severe stress imposed by anthropogenic activities [59]. The Margalef index measures diversity in relation to total number of individuals and the total sample size. Margalef Index values were all greater > 3 for both phytoplankton and zooplankton with higher values recorded among the phytoplankton. LATUMAHINA et al. [60] classified Margalef index value (R) as R < 2.5 (Low species richness), 2.5 > R < 4 (Medium species richness) and R > 4 (High species richness). Higher Margalef index value is an indication of better species richness or diversity, when considering the total number of individuals involved [61]. The higher values recorded for phytoplankton in points I and II could be attributed to the fact that the index focuses on the richness and taxonomic composition rather than community abundance [62, 63]. The Evenness index values were moderate; ranging between 0.7 and 0.8 in both phytoplankton and zooplankton; suggesting uneven distribution of the organisms. Evenness value ranges between 0 and 1; with 1 indicating that all species have equal distribution or complete evenness. Since the Evenness Index indicates the degree of uniformity of species, low value indicates that one or a few species dominate, while high value indicates the relatively equal distribution of each species.

5. Conclusion

The study revealed that the levels of pH, dissolved oxygen, biochemical oxygen demand in points I and II, phosphate and total suspended solids in all the sampling points did not conform to standard limits. The variation in these parameters could be linked to anthropogenic and seasonal driven factors which could significantly influence the plankton community structure and its stability. The biodiversity indices indicate that the water body was moderately polluted thus favored the abundance and the stability of phytoplankton over zooplankton. It can be concluded that the composition, abundance and distribution of the phytoplankton in the water was influenced by the environmental variables and the general environmental conditions of the creek.

Acknowledgement

The authors would like to acknowledge Mr. Utibe Usanga of the Department of Geography, University of Uyo, Uyo, Nigeria, for producing the map inserted in this manuscript.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the article.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Imaobong E. Ekpo.* ***Data collection****: Udeme E. Jonah;* ***analysis and interpretation of results****: Udeme E. Jonah;* ***draft manuscript preparation****: Udeme E. Jonah, Emeka D. Anyanwu. All authors reviewed the results and approved the final version of the manuscript.*

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