Water Quality and Plankton Assessment of Eme River, Umuahia, Southeast Nigeria

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Research

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Abstract

Certain anthropogenic activities have negative impacts on the aquatic ecosystems. Plankton are sensitive to their environment and are used to monitor anthropogenic impacts. A South-eastern Nigeria River was studied from December 2017 to November 2018 in 6 stations; to assess the plankton community, water quality and anthropogenic impacts. The river was subjected to intense sand mining activities among other activities. The plankton was sampled with filtration method while water was collected and analysed using standard methods. A total of 36 phytoplankton species and 27 zooplankton species were recorded with Chlorophyceae and Rotifers being the most abundant groups. The most abundant species - Melosira granulata (phytoplankton) and Daphnia pulex (zooplankton) are pollution indicators. Some of the physicochemical parameters showed that the river was perturbed by the anthropogenic activities in the watershed. However, the plankton assemblage and community structure gave an indication of a stable environment; though the zooplankton fauna showed some level of stress. The impacts of sand mining activities on water quality and plankton were more in the downstream stations (4–6) where sand mining was intense while perturbation from swimming children and related activities were observed in station 1 especially during the dry season. The presence of eutrophic indicators and tolerant species showed that the river was tending towards eutrophication. Sand mining activities contributed to the nutrient enrichment of the river. CCA showed the major water quality parameters that influenced the plankton community structure. There is need to regulate illegal sand mining activities in the river.

Introduction

Rivers support diverse and large number of flora and fauna; making some of them the most productive ecosystems on the earth and biodiversity hotspots. Freshwater bodies across the world are subjected to intense human activities which has degraded the quality and utility of the water [1]. Researchers have predicted the quality of the aquatic ecosystem and ecological effects of human activities by the assessment of its biological communities [2, 3]. Planktons are one of the essential biological communities found in lotic freshwater ecosystems [4, 5]. Regular monitoring of planktons is the cheapest and easy method of assessing the quality of water in developing countries [6]. Planktons (phytoplankton and zooplankton) are essentially microscopic, non-motile or weak swimming organisms floating in the water column and drift with it; making them susceptible to changes in the water [7].

Mathivanan et al [8] reported that due the sensitivity of planktons to their environments, changes in the environment will affect the tolerance, abundance, diversity and dominance of the plankton communities in the habitat. They are highly sensitive to fluctuations in nutrient levels, temperature, pollution, levels of light and increase in predation [9, 10]. Plankton directly or indirectly controls all the secondary productions in the aquatic ecosystems [11, 12].

According to Bellinger and Sigee [13], phytoplankton are the micro-plant organisms without distinct roots, stems and leaves. The phytoplankton community plays a key role in aquatic ecosystems as bioindicators and primary producers; providing for carbon fixation, oxygen and food production [14]. Phytoplankton species are able to survive and develop in diverse aquatic habitats but each species is restricted to a defined niche based on their physiological requirements and environmental limitations [15].

Zooplankton are microscopic animals that are essential components of aquatic food webs; an important link in the conversion of energy from producers to consumers [16, 17]. Schmidt et al [18] described zooplankton as a key biological group that is very important to the function of the ecosystem. They respond strongly to environmental changes and are used to assess the conditions in aquatic ecosystems [18, 19]. Temporal and spatial variations of physico-chemical environmental conditions often result in dramatic and rapid changes in zooplankton because of their short life span and fast regeneration [20].
The trophic transfer efficiencies from phytoplankton to zooplankton and from zooplankton to fish are largely dependent on the taxa of zooplankton available in an aquatic ecosystem [21, 22]. The composition of macroinvertebrate predator and fish species can be influenced by the pattern of changes in the zooplankton species composition within the same space [23]. In aquatic ecosystems, decline in zooplankton diversity will ultimately affect higher trophic levels; resulting in loss of species, habitat or even ecosystems and ecosystem services, if the trend was not abated [24]. Eme River was subjected to a number of anthropogenic activities, of which illegal and indiscriminate sand mining was the major one. The objective of this study was therefore to assess the water quality and plankton diversity in relation to anthropogenic activities.

**Study Area**

Eme River took its source from Uzoakoli in Abia State, Nigeria; flowing through many communities before discharging into Imo River at Onuimo. The section of Eme River studied was between Ofeme and Umudiawa across the Port Harcourt - Enugu expressway in Umuahia, Abia State; about 3.25km in length (Fig. 1). It lies between latitude 5°38’ and 5°37’N and Longitude 7°25’ and 7°26’E. The study area falls within the sub-equatorial zone with mean annual rainfall of about 4000mm per annum. It is characterized by high relative humidity of over 70% and high temperature of about 29-31°C. It is also characterized by two seasons - wet (June to November) and dry (December to May) and double maxima rainfall peaks in July and September with a short period of dryness between the peaks known as the August break. The river was divided into six stations, which were within the dredged section except station 1. Station 1, located within Ofeme community at Mbato, was upstream and the control station. The major human activities observed were including laundry and extraction of drinking water in the dry season. Large number of children was also observed swimming during the dry season up to early rains because easy accessibility and low water depths. The substrate is muddy. Station 2, located on the out sketch at Eme - Ihite, about 1.84km downstream of Station 1. It was a less active sand mining site and minimal laundry, swimming and extraction of drinking water were observed during the dry season. The substrate is mixture of sand and stones. Station 3, also located in Eme - Ihite, by the expressway, about 419.67m downstream of Station 2. No activities were observed except periodic boat movements. The substrate is made up of large clayey boulders. Station 4, located in Umudiawa Community across the expressway, about 490.26m downstream of Station 3. It was also downstream to an intensive sand mining and two sand landing sites. The substrate was sandy. Station 5, within Umudiawa Community was about 200.22m downstream of Station 4. The substrate was sandy and sand mining activities was also observed. Station 6, within Umudiawa Community was about 300.14m downstream of Station 5. The substrate was sandy and sand mining activities occur within the water channel and around the shores.

**Samples collection and analyses**

**Water Samples**

Water samples were collected from Eme River, Umuahia, monthly between December 2017 and November 2018. The samples were collected with 1-litre water sampler, stored in sterilized 1litre plastic bottles and then taken to the laboratory for analysis. Some physicochemical parameters (Water Temperature, Flow Velocity, Turbidity, pH, Electrical Conductivity and Total Dissolved Solids) were determined in-situ while Dissolved Oxygen, Biochemical Oxygen Demand, Nitrate and Phosphate were determined in the laboratory using standards methods described by American Public Health Association (APHA) [25].

**Plankton Samples**

Plankton samples were collected from undisturbed areas of the River as the water samples. The sampling was carried out using the quantitative method. A composite sample of 100 litres of water was filtered through 55um Hydro-Bios plankton net (with the aid of a 10 litres of bucket drawn 10 times at each station). The net content was washed out into plankton bottles of 250ml size and preserved in 4% formalin solution after a proper labelling. In the laboratory, one 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 of x10. Planktons were sorted into different groups and the cells per ml were counted. Identification work was done using key literatures by Jeje and Fernando [26]; Janse van Vuuren et al [27] and Dang et al [28]. The identification was made to lowest practicable taxonomic.

**Statistical Analysis**

The data were summarised using Descriptive Statistic Package of Microsoft Excel while one-way ANOVA was used to test for statistical differences among the stations and Tukey's pairwise comparisons test was performed to determine the location of significant difference (P<0.05). The community structures of the plankton were determined using Margalef (D), Shannon-weiner (H) Evenness (E) indices. Canonical correspondence analysis (CCA) was used to evaluate relationships between the plankton groups and environmental variables with PAST statistical package [29].

**Results**

**Water Quality**

Aspects of the physicochemical parameters of Eme River are presented in Table 1. Surface water temperature ranged from 22.0°C to 28.5°C. The lowest value was recorded in station 1 in May 2018 while the highest was recorded in station 6 in April 2018. The temperature values were within acceptable limits. Flow velocity values were moderate; ranging between 0.21 and 0.85 m/s. The lowest flow velocity was recorded in station 1 in April 2018 while the highest was recorded in station 3 in December 2017. Stations 2 and 3 were significantly higher (F = 31.59; P< 0.05) than the other stations. Turbidity ranged between 0.5 and 9.4 NTU. The lowest and highest values were recorded in station 4 in March and February 2018 respectively. Stations 4–6 recorded relatively higher turbidity values especially between May and October, 2018. Some of the values exceeded the 5 NTU limit set by FMEnv [30] in all the stations. All the pH values recorded were acidic and lower than the acceptable limit (6.5–8.5); ranging from 4.3 to 6.3. The lowest pH was recorded in station 2 in June 2018 while the highest value was recorded in station 1 in September 2018. The electrical conductivity (EC) values ranged between 45.2 and 168.4 µS/cm. The lowest and values highest were recorded in stations 2 and 5 in March and January 2018 respectively. The downstream stations (4–6) were significantly higher (F = 29.59; p < 0.05) than the upstream stations (1–3). The dissolved oxygen (DO) values ranged from 1.6 to 6.1 mg/L; all the DO values except two were below the acceptable limit (> 6mg/L) set by FMEnv [30]. The lowest value was recorded in station 4 in November 2018 while highest was recorded in stations 3 (January 2018) and 4 (February 2018). Biochemical oxygen demand (BOD) values ranged between 0.8 and 4.3 mg/L. The lowest and highest values were recorded in November 2018 and February 2018 respectively in station 4. Some of the values exceeded the acceptable limit (3 mg/L) especially in Stations 4–6. Station 4 was significantly higher than stations 2 and 3 (F = 3.43; p < 0.05). Nitrate values were all within acceptable limit and ranged from 1.1 to 5.6 mg/L; though station 4 was significantly (F = 14.62; p < 0.05) higher than the other stations. The lowest value was recorded in station 3 (June 2018) while the highest was recorded in station 4 (February 2018). Phosphate values ranged between 0.4 and 4.6 mg/L. The lowest value was recorded in station 3 (June and July 2018) while the highest was recorded in station 4 (September 2018). Stations 4–6 recorded values that exceeded the acceptable limit and were significantly different (F = 56.71; p < 0.05) from stations 1–3.
Table 1
Summary of Physico-chemical Parameters of Eme River, Umuahia, Abia State.

| Parameter                        | Stn 1 X ± SEM | Stn 2 X ± SEM | Stn 3 X ± SEM | Stn 4 X ± SEM | Stn 5 X ± SEM | Stn 6 X ± SEM | P-value | FMEnv. |
|----------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------|--------|
| **Water Temperature (°C)**       | 24.8 ± 0.59   | 24.9 ± 0.54   | 24.8 ± 0.53   | 24.9 ± 0.51   | 24.4 ± 0.53   | 24.8 ± 0.53   | P > 0.05 | < 40   |
|                                  | (22.0–28.0)   | (22.5–28.2)   | (23.0–28.2)   | (23.2–28.4)   | (23.0–28.3)   | (22.9–28.5)   |
| **Turbidity (NTU)**              | 4.2 ± 0.61    | 3.5 ± 0.52    | 3.0 ± 0.48    | 5.0 ± 0.72    | 3.9 ± 0.61    | 4.1 ± 0.56    | P > 0.05 | 5      |
|                                  | (1.3–8.1)     | (0.6–5.4)     | (0.5–9.4)     | (0.5–7.8)     | (0.7–6.9)     |               |
| **Flow Velocity (m/s)**          | 0.35 ± 0.02a  | 0.56 ± 0.04b  | 0.71 ± 0.02c  | 0.36 ± 0.02a  | 0.37 ± 0.02a  | 0.45 ± 0.0a   | P < 0.05 | -      |
|                                  | (0.21–0.49)   | (0.37–0.80)   | (0.63–0.85)   | (0.24–0.46)   | (0.28–0.50)   | (0.26–0.58)   |
| **pH**                           | 5.69 ± 0.11   | 5.43 ± 0.13   | 5.42 ± 0.10   | 5.53 ± 0.10   | 5.49 ± 0.10   | 5.55 ± 0.10   | P > 0.05 | 6.5–8.5|
|                                  | (5.0–6.3)     | (4.3–5.9)     | (4.9–6.1)     | (5.0–6.1)     | (5.1–6.2)     | (5.1–6.1)     |
| **Electrical Conductivity (µS/cm)** | 86.0 ± 4.40a | 71.3 ± 4.43a  | 65.7 ± 3.50a  | 130.4 ± 5.86b | 115.4 ± 6.04b | 119.6 ± 5.38b | P < 0.05 | -      |
|                                  | (55.6–115.8)  | (45.2–95.4)   | (49.6–88.7)   | (90.3–160.2)  | (88.5–168.4)  | (87.1–148.4)  |
| **Total Dissolved Solids (Mg/l)**| 43.0 ± 2.17a  | 35.8 ± 2.25a  | 33.1 ± 1.86a  | 65.3 ± 2.81b  | 57.9 ± 3.03b  | 60.0 ± 2.69b  | P < 0.05 | -      |
|                                  | (27.5–56.9)   | (22.6–47.7)   | (24.8–46.5)   | (46.9–80.1)   | (44.7–85.2)   | (43.2–74.2)   |
| **Dissolved Oxygen (Mg/l)**      | 3.7 ± 0.38    | 3.6 ± 0.34    | 3.7 ± 0.40    | 3.9 ± 0.46    | 3.6 ± 0.37    | 3.8 ± 0.42    | P > 0.05 | 6      |
|                                  | (2.3–5.7)     | (2.2–5.9)     | (1.8–6.1)     | (1.6–6.1)     | (2.0–5.5)     | (1.8–5.8)     |
| **Biochemical Oxygen Demand (Mg/l)** | 1.7 ± 0.14ab | 1.5 ± 0.08b   | 1.7 ± 0.12b   | 2.6 ± 0.37ac  | 1.9 ± 0.20ab  | 2.1 ± 0.25ab  | P < 0.05 | 3      |
|                                  | (1.0–2.5)     | (1.1–1.9)     | (1.1–2.4)     | (0.8–4.3)     | (1.0–3.2)     | (0.9–3.9)     |
| **Nitrate (Mg/l)**               | 2.9 ± 0.30b   | 2.2 ± 0.17b   | 1.6 ± 0.12a   | 4.5 ± 0.20c   | 2.6 ± 0.37ab  | 2.9 ± 0.27b   | P < 0.05 | 9.1    |
|                                  | (1.8–4.9)     | (1.3–3.2)     | (1.1–2.4)     | (3.4–5.6)     | (1.2–5.3)     | (1.9–5.2)     |

a, b, c, d, e = Means with different superscripts across the rows are significantly different at p < 0.05; SEM = Standard Error of Mean; FMEnv. National Environmental (Surface and Groundwater Quality Control) Regulations (2011).
| Parameter       | Stn 1       | Stn 2       | Stn 3       | Stn 4       | Stn 5       | Stn 6       | P-value | FMEnv. |
|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|---------|--------|
|                 | X ± SEM     | X ± SEM     | X ± SEM     | X ± SEM     | X ± SEM     | X ± SEM     |         |        |
| Phosphate (Mg/l)| 1.3 ± 0.08a | 0.8 ± 0.10a | 0.7 ± 0.07a | 3.4 ± 0.18b| 2.8 ± 0.22bc| 2.9 ± 0.21bc| P < 0.05| 3.5    |
|                 | (1.0–1.9)   | (0.5–1.7)   | (0.4–1.2)   | (2.8–4.6)   | (1.9–4.3)   | (2.0–4.5)   |         |        |

a, b, c, d, e = Means with different superscripts across the rows are significantly different at p < 0.05; SEM = Standard Error of Mean; FMEnv. National Environmental (Surface and Groundwater Quality Control) Regulations (2011).

**Plankton composition, abundance and distribution**

**Phytoplankton**

The species composition of phytoplankton in the stations of Eme River, Umuahia was presented in Table 2. A total of 5213 phytoplankton individuals were recorded, out of which the most abundant group was Chlorophyceae (1776 or 34.1%), followed by Bacillariophyceae (1234 or 23.7%). Other phytoplankton taxa recorded were Cyanophyceae (838 or 16.1%), Euglenophyceae (835 or 16.0%) and Pyrrophyceae (530 or 10.2%). One-way ANOVA showed that Cyanophyceae, Euglenophyceae and Pyrrophyceae were significantly (F = 18.0, p < 0.05) lower than Chlorophyceae and Bacillariophyceae in terms of abundance. Spatially, station 3 recorded the most abundant individuals (1108 individuals/L or 21.3%), followed by station 2 (1007 individuals/L or 19.3%) while station 1 (748 individuals/L or 14.3%) was the least. One-way ANOVA showed that stations 2 and 3 were significantly (F = 10.3, p < 0.05) higher than stations 1, 4–6 in terms of abundance. The most abundant phytoplankton species recorded was *Melosira granulata* (Bacillariophyceae) with 190 individuals (3.64% of the total phytoplankton abundance), followed by *Planktosphaeria gelatinosa* (Chlorophyceae) with 180 individuals/L (3.45% of the total phytoplankton abundance) and the least was *Peridinium depressum* (Pyrophyceae) with 101 individuals/L (1.94% of the total phytoplankton abundance).
Table 2
Species composition, abundance and distribution of phytoplankton in Eme River, Umuahia, Nigeria.

| Group          | Taxa                  | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 | Total | RA (%) |
|----------------|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-------|--------|
| Cyanophyceae   | Anabaena affinis      | 14        | 29        | 26        | 30        | 36        | 35        | 170   | 3.26   |
|                | A. spiroides          | 12        | 36        | 31        | 14        | 21        | 19        | 133   | 2.55   |
|                | Oscillatoria laccustris| 14        | 21        | 35        | 21        | 30        | 30        | 151   | 2.90   |
|                | Spirulina substilissinia| 18        | 24        | 29        | 26        | 14        | 14        | 125   | 2.40   |
|                | Microcystis weswenbergii| 11        | 23        | 24        | 25        | 18        | 32        | 133   | 2.55   |
|                | Coelosphaerium pallidum| 10        | 27        | 20        | 24        | 22        | 23        | 126   | 2.41   |
| Euglenophyceae | Euglena candata       | 13        | 35        | 20        | 15        | 42        | 32        | 157   | 3.01   |
|                | E. acus               | 20        | 24        | 25        | 15        | 12        | 34        | 130   | 2.59   |
|                | E. proxima            | 27        | 20        | 28        | 25        | 26        | 12        | 138   | 2.65   |
|                | Phacus longicanda     | 23        | 29        | 37        | 31        | 20        | 19        | 159   | 3.05   |
|                | P. caudata            | 24        | 30        | 23        | 15        | 24        | 10        | 126   | 2.42   |
|                | Trachelomonas aramata | 33        | 14        | 30        | 20        | 28        | 0         | 125   | 2.40   |
| Bacillariophyceae| Amphoria ovaris       | 24        | 28        | 32        | 40        | 21        | 16        | 161   | 3.09   |
|                | Melosira granulata    | 25        | 30        | 32        | 42        | 22        | 39        | 190   | 3.64   |
|                | M varians             | 25        | 29        | 23        | 15        | 19        | 20        | 131   | 2.51   |
|                | Synedra acus          | 32        | 28        | 23        | 19        | 19        | 13        | 134   | 2.57   |
|                | S. ulna               | 25        | 29        | 19        | 35        | 18        | 25        | 151   | 2.90   |
|                | S. affins             | 20        | 31        | 28        | 39        | 28        | 30        | 176   | 3.38   |
|                | Cyclotella glomerata  | 33        | 30        | 27        | 23        | 20        | 13        | 146   | 2.80   |
|                | Tragilaria crotonesis | 15        | 22        | 32        | 21        | 33        | 22        | 145   | 2.78   |
| Chlorophyceae  | Pediastrum clathratum | 19        | 27        | 28        | 31        | 20        | 20        | 145   | 2.78   |
|                | P. simplex            | 26        | 21        | 43        | 15        | 24        | 31        | 160   | 3.07   |
|                | P. dublex             | 4         | 39        | 28        | 21        | 26        | 27        | 145   | 2.78   |
|                | Closterium moniliferum| 31        | 32        | 38        | 17        | 14        | 21        | 153   | 2.93   |
|                | C. parvulum           | 20        | 26        | 29        | 22        | 22        | 21        | 140   | 2.69   |
|                | C. macilentum         | 1         | 25        | 34        | 16        | 19        | 23        | 118   | 2.26   |
Phytoplankton Community Structure

The number of taxa (species) recorded were 36 in all the station except station 6 with 35 (Table 3). The number of individuals ranged from 748 (station 1) to 1108 (station 3). Shannon-weiner diversity index (H) varied from 3.477 (station 1) to 3.562 (station 2). Margalef Species Richness, on the hand was highest in station 1 (5.289) and station 3 had the least (4.993). The Evenness Index (E) was highest in station 2 (0.9785) and least in station 1 (0.8987).

| Group               | Taxa                           | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 | Total | RA (%) |
|---------------------|--------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-------|--------|
|                     | Cosmarium amoerum              | 2         | 29        | 42        | 11        | 30        | 25        | 139   | 2.67   |
|                     | Mougeotia scalaris             | 32        | 29        | 34        | 17        | 18        | 16        | 146   | 2.80   |
|                     | Volvox aureus                  | 26        | 21        | 38        | 17        | 22        | 30        | 154   | 2.95   |
|                     | Chlamydomonas Atactogam        | 26        | 31        | 40        | 9         | 21        | 16        | 143   | 2.74   |
|                     | Planktosphaeria Gelatinosa     | 28        | 43        | 48        | 19        | 24        | 18        | 180   | 3.45   |
|                     | Scenedesmus quadriacauda       | 11        | 34        | 29        | 17        | 26        | 36        | 153   | 2.93   |
| Pyrophycceae        | Ceratium candelabum            | 30        | 31        | 45        | 16        | 6         | 19        | 147   | 2.82   |
|                     | C. hirudenella                 | 23        | 29        | 34        | 25        | 9         | 25        | 145   | 2.78   |
|                     | Peridinium depressum           | 23        | 18        | 31        | 8         | 9         | 12        | 101   | 1.94   |
|                     | P. latum                       | 28        | 33        | 23        | 25        | 20        | 8         | 137   | 2.63   |
| Total               |                                | 748       | 1007      | 1108      | 781       | 783       | 786       | 5213  |         |

Relationship between Phytoplankton Groups and Environmental Variables

The Canonical Correspondence Analysis (CCA) showed that electrical conductivity and phosphate exerted a greater positive influence on the relative abundance of the phytoplankton groups compared to the higher negative influence.
exerted by pH and temperature (Fig. 2). Biochemical oxygen demand, electrical conductivity and phosphate exerted positive influence on cyanophyceae and flow velocity on euglenophyceae and chlorophyceae. On the other hand, turbidity and nitrate exerted negative influence on bacillariophyceae and temperature on Pyrrophyceae. Spatially, pH and flow velocity exerted negative influence respectively in stations 1 and 3 while turbidity and nitrate exerted negative influence in station 4.

Zooplankton

The overall species composition, abundance and distribution of zooplankton in the stations of Eme River, Umuahia are presented in Table 4. A total of 3382 zooplankton individuals were recorded in this study. Of these, the most abundant group was Rotifer (1064 individuals/L or 31.5%) followed by Cladocera (961 individuals/L or 28.4%), Protozoa (741 individuals/L or 21.9%) and Copepod (616 individuals/L or 18.2%). Spatially, Station 2 recorded the most abundant individuals (619 individuals/L or 18.3%), followed by Station 6 (614 individuals/L or 18.2%), Station 3 (577 individuals/L or 17.1%), Station 5 (511 individuals/L or 15.1%) and station 4 (498 individuals/L or 14.7%). The most abundant zooplankton recorded was *Daphnia pulex* (Cladocera) with 175 individuals/L (5.17% of the total zooplankton abundance).
Table 4
Species composition, abundance and distribution of phytoplankton in Eme River, Umuahia, Nigeria.

| Group       | Taxa                        | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 | Total | RA (%) |
|-------------|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-------|--------|
| Copepoda    | *Campthocamptus staphylinus*| 26        | 21        | 14        | 33        | 22        | 22        | 138   | 4.08   |
|             | *Eucyclops speratus*        | 10        | 22        | 39        | 29        | 12        | 32        | 144   | 4.26   |
|             | *Microcyclops varicans*     | 21        | 27        | 22        | 11        | 16        | 21        | 118   | 3.49   |
|             | *Sinodiatomus sarsi*        | 23        | 20        | 20        | 0         | 3         | 22        | 88    | 2.6    |
|             | *Mesochra suifunensis*      | 24        | 18        | 26        | 16        | 10        | 34        | 128   | 3.78   |
| Cladocera   | *Alona affinis*             | 12        | 19        | 25        | 27        | 34        | 13        | 130   | 3.84   |
|             | *Daphnia longis*            | 20        | 26        | 23        | 10        | 20        | 35        | 134   | 3.96   |
|             | *D. pulex*                  | 25        | 25        | 35        | 27        | 37        | 26        | 175   | 5.17   |
|             | *D. magna*                  | 26        | 26        | 25        | 12        | 22        | 28        | 139   | 4.11   |
|             | *Moina dubia*               | 44        | 22        | 19        | 20        | 26        | 35        | 166   | 4.91   |
|             | *M. micrura*                | 11        | 18        | 22        | 20        | 22        | 15        | 108   | 3.19   |
|             | *Diaphanosoma Brachyurum*   | 21        | 15        | 19        | 27        | 20        | 7         | 109   | 3.22   |
| Rotifera    | *Keratella cochlearis*      | 20        | 20        | 21        | 14        | 15        | 14        | 104   | 3.08   |
|             | *Brachionus capsuliflorus*  | 20        | 26        | 12        | 25        | 23        | 35        | 141   | 4.17   |
|             | *Asplanchna priodontra*     | 27        | 19        | 25        | 27        | 31        | 22        | 151   | 4.47   |
|             | *Notholca labis*            | 15        | 36        | 14        | 11        | 33        | 22        | 131   | 3.87   |
|             | *Synchaeta pectinata*       | 26        | 23        | 30        | 23        | 21        | 29        | 152   | 4.49   |
|             | *Conochilus umcormis*       | 25        | 23        | 25        | 21        | 6         | 28        | 128   | 3.79   |
|             | *Ascomorpha ecaudis*        | 29        | 30        | 20        | 13        | 17        | 18        | 127   | 3.76   |
|             | *B. plicatilis*             | 16        | 24        | 18        | 25        | 17        | 30        | 130   | 3.84   |
| Protozoa    | *Paramecium candatum*       | 15        | 21        | 13        | 12        | 24        | 20        | 105   | 3.11   |
|             | *Diffuglia candatum*        | 14        | 18        | 22        | 15        | 17        | 7         | 93    | 2.75   |
|             | *Didinium bolbanic*         | 26        | 25        | 22        | 8         | 8         | 14        | 103   | 3.05   |
|             | *Tintinnopsis lacustris*    | 17        | 27        | 12        | 20        | 23        | 25        | 124   | 3.67   |
|             | *Amoeba radiosa*            | 11        | 17        | 12        | 13        | 11        | 23        | 87    | 2.57   |
|             | *Vorticella radians*        | 20        | 30        | 17        | 24        | 18        | 32        | 141   | 4.17   |
|             | *Arcella nitrata*           | 19        | 21        | 25        | 15        | 3         | 5         | 88    | 2.60   |
| **Total**   |                             | 563       | 619       | 577       | 498       | 511       | 614       | 3382  |        |
Zooplankton Community Structure

The number of taxa (species) recorded were 27 in all the station except station 4 with 26 (Table 5). The number of individuals ranged from 498 (station 4) to 619 (station 2). Shannon-weiner diversity index (H) varied from 3.178 (station 5) to 3.276 (station 2). Margalef Species Richness, on the hand was highest in station 5 (4.169) and station 4 had the least (4.025). The Evenness Index (E) was highest in station 2 (0.9806) and least in station 5 (0.8885).

Table 5
Community Structure of Zooplankton in Eme River, Umuahia.

| Biodiversity Indices | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Taxa (S)             | 27        | 27        | 27        | 26        | 27        | 27        |
| Individuals          | 563       | 619       | 577       | 498       | 511       | 614       |
| Shannon-weiner (H)   | 3.241     | 3.276     | 3.250     | 3.192     | 3.178     | 3.212     |
| Evenness (E)         | 0.9464    | 0.9806    | 0.9554    | 0.936     | 0.8885    | 0.9197    |
| Margalef             | 4.105     | 4.045     | 4.089     | 4.025     | 4.169     | 4.050     |

Relationship between Zooplankton Groups and Environmental Variables

The Canonical Correspondence Analysis (CCA) showed that water temperature, flow velocity and dissolved oxygen exerted a greater positive influence on the relative abundance of the zooplankton groups compared to the higher negative influence exerted by electrical conductivity, phosphate and turbidity (Fig. 3). Flow velocity exerted positive influence on copepod while Biochemical oxygen demand exerted negative influence on rotifer and cladocera. Spatially, dissolved oxygen exerted positive influence on stations 3 and 6 while electrical conductivity, phosphate and turbidity exerted negative influence in stations 1 and 4.

Discussion

Rivers are natural resources that offer a wide range of ecosystem services from drinking to water utilities in industry, agriculture, transportation and recreation [31, 32]. Rivers need have a healthy ecosystem and a good water quality in order to provide these services. The surface water temperatures were within acceptable limits and were influenced by season and sampling times. The lowest value was recorded after an early rain in May 2018 while the highest was during the dry season in April 2018. Surface water temperatures are strongly influenced by air temperatures [33]. Dugdale et al [34] reported water temperature as a critical factor in biotic and abiotic processes; capable of affecting the amount of dissolved matter, organic/inorganic pollutants, nutrients, microbacterial concentrations, the behavior of fish and invertebrates in the aquatic environment.

Flow velocity values were moderate though Stations 2 and 3 were significantly higher. The ability of a waterbody to assimilate and transport pollutants can be significantly affected by flow velocity [35]. It can also affect the composition, abundance and distribution of aquatic biota. Low algal population may be associated with high water velocity while algal population growth is stimulated by low velocity among other things [36]. This study was different; the highest phytoplankton and zooplankton abundance were recorded respectively in Stations 3 and 2 with high flow velocities but little or no human activities. CCA also showed that flow velocity was a strong negative factor especially in Station 3; increased river discharge and flow velocity, especially during the wet season, has been reported to be responsible for low species composition and abundance in rivers due to low time of residency [37, 38].
The standard limit for turbidity was exceeded by some values recorded in all the stations especially between December 2017 and March 2018, which could be attributed to cumulative effect of receding flood and anthropogenic activities. Swimming by large number of children, bathing, washing and extraction of water for drinking were high during the dry season and affected turbidity in Station 1. However, Stations 4–6 had relatively higher values between May and November 2018; attributed to the effect of sand mining activities which increased with the rains [31, 39, 40]. This was more remarkable in Station 4 that was immediately downstream of sand mining and landing sites and steadily declined further downstream [41, 42]. CCA also showed that turbidity had negative effect in station 4 for both phytoplankton and zooplankton. Aquatic lives are affected by high turbidity [43, 44].

All the pH values did not comply with acceptable limit because of acidity. This is attributed to both geogenic [45] and anthropogenic influences [46, 47]. Sand mining lowers the pH of water bodies [42]. Extremes of pH are unsuitable for most aquatic organisms. Kale [44] reported the extreme sensitivity of aquatic organisms to pH levels below 5 and death may arise at these low pH values. CCA showed a strong negative influence of pH on phytoplankton.

The total dissolved solids (TDS) and electrical conductivity (EC) values of the water were moderate though downstream stations (4–6) were significantly higher than the upstream stations (1–3). This could be attributed to effects of sand mining activities. Sand mining activities can increase the levels of TDS and EC in surface water [46, 48] and water pollution usually increase with increasing EC [49]. The TDS and EC values recorded in Station 1 were relatively higher compared to Stations 2 and 3; this could be attributed to perturbation from large number of children swimming during the dry season and allochthonous input from increased runoff during the wet season. The TDS levels recorded were below 600mg/l and cannot reduce light penetration to inhibit phytoplankton growth [50].

Most of the Dissolved Oxygen values were not up to the acceptable limit especially in station 4; which could be attributed to anthropogenic impact. Rao et al [51] reported that some consequences of sand mining activities like addition of nutrients, changing the flow of water, raising the water temperature and the addition of chemicals can contribute to oxygen depletion in water. Dissolved oxygen (DO) is one of the major parameters used in the determination of water quality [32] and the level is critical to support aquatic biodiversity. CCA showed that dissolved oxygen was one of the major positive factors influencing the zooplankton community. Dissolved oxygen levels > 5 mg/L is essential to support aquatic life and good fish production [52].

Biochemical Oxygen Demand (BOD) is an important parameter of water indicating the health and self-purification status of freshwater bodies. Some of the BOD values; especially in Stations 4–6 were higher than the acceptable limit. This could be attributed to sand mining activities. Akankali et al [46] observed that sand mining activities considerably enhance the release and circulation of organic matters from the sediments into the water column which can increase the BOD levels. High BOD level is a pointer to potential pollution problems because it is capable of adversely depleting dissolved oxygen to the detriment of aquatic biota [53].

Nitrate, a common form of nitrogen occurs naturally in many environments in moderate levels [54]. The nitrate values were all within acceptable limit though higher values were recorded in Stations 4–6; attributable to sand mining activities. In Okoro Nsit stream South-south Nigeria; subjected to intense sand mining activities, Akankali et al [46] recorded a range of 10.7 to 12.4 mg/l. The relatively higher values recorded in Station 1 compared to Stations 2 and 3 could be attributed to the effect of large number of children swimming during the dry season and rain during the wet season. Water with nitrate values higher than 5.0 mg/L is considered poor because naturally the range is often between 0.01 and 3.0 mg/L [55]. Nitrates have negative impact on the environment; noted for contamination of ground and surface waters due to its high solubility [54].

The nutrient levels and eutrophication of the river system can be identified by the concentrations of phosphate in the river [56]. Some of the phosphate values exceeded acceptable limit especially in Stations 4–6 and could be attributable to sand
mining activities. Akankali et al [46] recorded a range of 2.5 to 3.6 mg/l in Okoro Nsit stream in Akwa Ibom State in Nigeria. Relatively higher values were also recorded in Station 1 attributed to perturbation from large number of children swimming during the dry season and increased allochthonous input during the wet season. Phosphate values are usually 0.005 to 0.020 mg/L in most natural surface waters; high concentrations can pollution and are mainly responsible for eutrophication [35]. Nutrients such as nitrogen and phosphates compounds in water stimulate the growth of algae and other photosynthetic aquatic life [57].

Biomonitoring provides for temporal integration of all impacts and allows the integrated analysis of different factors and their complex interactions in a reliable and cost-effective way. This is because aquatic organisms spend most part of their life under the specific conditions of the site [58]. Studies have documented the use of plankton as bioindicators of water quality [59, 60]. The composition and abundance of phytoplankton and zooplankton of the water body is a clear indication of the health status of the water body [61].

The high phytoplankton abundance in this study could be attributed to nutrient enrichment and low zooplankton abundance. Lehman [62] reported that zooplankton are major recyclers of nitrogen and phosphorus which frequently limit phytoplankton growth rate, therefore low zooplankton abundance contribute to increased enrichment and phytoplankton development. The phytoplankton was dominated by Chlorophyceae followed by Bacillariophyceae as reported by Kshirsagar et al [63] and Bwala [64]. Chlorophyceae was also reported as the dominant in Odot Stream by Ekpo et al [65] while the dominance of Bacillariophyceae was reported in Ikpa River by Ekwu and Udo [38], Idumayo River by Nwonumara [66] both in Southeast Nigeria, River Kaduna in North Central Nigeria by Arimoro et al [9] and Orashi River, South-South Nigeria by Davies et al [67]. The growth and development of Chlorophyceae is controlled by parameters like transparency, water temperature, dissolved oxygen, pH and nutrients [68, 69, 70] while low level of DO and high BOD, nitrate and phosphate, favor the growth of diatoms [63]. High abundance of diatoms is attributed to high levels of silicates in the water, resulting from sand mining activities [38] and also suggests perturbation and organic pollution [67].

The composition of the phytoplankton was dominated cosmopolitan and pollution tolerant species [64, 66, 67, 71]. The most abundant species were Melosira granulata and Planktosphaeria gelatinosa. Other common tolerant species include Anabaena affins (Cyanophyceae), Euglena canda, Phacus longicauda (Euglenophyceae), Amphoria ovaris, Synedra affins (Bacillariophyceae) and Pediastrum simplex (Chlorophyceae). Phytoplankton species have been used as indicators of organic pollution [66, 72, 73] Some of the taxa recorded like Euglena, Ceratium, Peridinium, Anabaena, Closterium, Scenedesmus and Pediastrum were indicative of eutrophic condition [72].

Spatially, stations 2 and 3 had the highest number of individuals despite their high velocities; this could be due to little or human activities in the stations [74]. Stations 1, 4–6 were significantly lower with station 1 being the lowest. Stations 4–6 were subjected to intense sand mining activities. Sand mining adversely affects both physical and biological environments, often extending beyond the mining sites [43]. Apart from constant agitation of the water, it increases turbidity levels and reduces light penetration which hinders the photosynthetic activity, productivity and growth of plankton [75]. The low abundance recorded in station 1 could be attributed to perturbation from large number of children swimming in the station. This was observed throughout the dry season sampling period, which also reflected in the levels of some physicochemical parameters. The effect of rains also could be responsible during the wet season. Plankton abundance usually decrease as the amount of rainfall increase; attributed to high turbidity and high flow velocity [9, 66, 72].

The composition of the zooplankton group was dominated by Rotifer followed by Cladocera, Protozoa and Copepod as observed by Kamboj and Kamboj [76] in the mining-impacted stretch of Ganga River, India. Rotifer was also reported as the dominant group in Ikpa and Odot Streams in South-South Nigeria that is subjected to intense sand mining [38, 65]. Rotifers especially Keratella, Brachionus, Asplanchna and Notcholca have been reported to dominate freshwater zooplankton in Nigeria [38, 77, 78]. Small size, parthenogenesis and rapid reproduction of rotifers under favourable conditions (nutrient-enriched water) could be responsible for their high abundance [79]. Other factors include their
morphological variations and adaptations [80] as well as their diverse feeding habits [78]. Rotifers minimize competition through niche exploitation and food utilization because of their ability to migrate vertically, which could also be responsible for their dominance [65].

The relatively low zooplankton abundance could be attributed to anthropogenic and seasonal influences. The most abundant zooplankton species was *Daphnia pulex* (Cladocera). *Daphnia pulex* is the most common cladoceran found almost in all permanent and eutrophic freshwater environments [81]. The large body sizes of *Daphnia* makes it possible for them to graze on large quantities and diverse forms of phytoplankton; contributing to their predominance of among the cladocerans [78] and their composition and abundance is also dependent on food supply [81].

Spatially, little or no human activities was responsible for the high zooplankton abundance in Station 2 while sand mining activities was responsible the low abundance in Station 4. Station 6 showed signs of recovery after the impacts. Ko et al [82] reported a significant recovery in the number of species and individuals after dredging operations. High flow velocity could be responsible for the relatively lower abundance in Station 3. Plankton development is usually affected by flowing water because they are continually washed downstream [83].

Diversity indices have an important application in plankton studies especially in relation to assessment of pollution and waterbody productivity. The ShannonWeiner diversity indices for phytoplankton and zooplankton were all greater than 3 indicating ecosystem stability. Stations 2 and 3 were relatively higher for the phytoplankton while upstream stations (1–3) were relatively higher for the zooplankton. According to Wilm and Dorris [84], water bodies with algal ShannonWeiner diversity Index < 1 are classified as being heavily polluted while 1–3 is for moderately polluted and > 3 for clean water and stable environment. Margalef indices were high for both phytoplankton and zooplankton. In aquatic community, It is generally accepted that species diversity and richness decrease when under stress conditions; though some tolerant species usually break out [85]. Evenness values were relatively higher in stations 2 and 3 in both phytoplankton and zooplankton indicating the effect of the anthropogenic activities in the other stations. Evenness index is an indication of whether all species are equally abundant in a sample [86]. This means that species evenness will decrease as the plankton population size increase. Among the phytoplankton, the evenness of Station 3 with more abundance was lower than that of Station 2.

**Conclusion**

Some of the physicochemical parameters showed that the river was perturbed by the anthropogenic activities in the watershed especially in the downstream stations where sand mining was intense. However, the plankton assemblage and community structure gave an indication of a stable environment; though the zooplankton fauna showed some level of stress from the anthropogenic activities. The presence of eutrophic indicators and tolerant species showed that the river was tending towards eutrophication. Sand mining activities contributed to the nutrient enrichment of the river. There is need to regulate illegal sand mining activities in the river.

**Abbreviations**

FMEnv
Federal Ministry of Environment

**Declarations**

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Authors’ contributions

EDA and SNU designed the research. EDA and OGA conducted the field research, analyzed the data, and interpreted the results. All the authors contributed in writing the manuscript, reading and approving the final manuscript.

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