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Anyanwu Emeka Donald
Department of Zoology and Environmental Biology, Michael Okpara University of Agriculture, Umuahia – Ikot Ekpene Road, Umudike, Nigeria

Ukaegbu Amarachi Blessing
Department of Zoology and Environmental Biology, Michael Okpara University of Agriculture, Umuahia – Ikot Ekpene Road, Umudike, Nigeria

Correspondence
Anyanwu Emeka Donald
Department of Zoology and Environmental Biology, Michael Okpara University of Agriculture, Umuahia – Ikot Ekpene Road, Umudike, Nigeria

Index approach to water quality assessment of a south eastern Nigerian river

Anyanwu Emeka Donald and Ukaegbu Amarachi Blessing

Abstract
Water quality of natural water bodies is on a rapid decline due to activities and discharges arising from population growth, urbanisation and industrialisation. The water quality of a south eastern Nigerian river was studied between January and June 2018 in 3 stations in relation to anthropogenic impacts and suitability to support aquatic biodiversity using water quality indices. Thirteen parameters were evaluated using standard methods and compared with national standard. Some parameters did not meet the standards; pH and dissolved oxygen in all the stations and biochemical oxygen demand in Station 1. The indices in the three stations effectively captured the effect of the anthropogenic activities in the river and showed that the water quality was suitable to sustain biodiversity. It can be concluded that human activities including effluent discharge did not give negative impact on the water quality. However, the activities need to monitored and regulated.

Keywords: WQI, NPI, anthropogenic, geogenic, water quality, limits

1. Introduction

Rivers have always been the most important freshwater resources, along the banks of which ancient civilizations have flourished, and most developmental activities are still dependent upon them [1]. According to Effendi [2], "a rapid interpretation of river water quality is a compulsory since river is a dynamic ecosystem, influenced by various activities in the river bank". The physical and chemical characteristics of water bodies affect the species composition, abundance, productivity and physiological conditions of aquatic organisms [3]. Water is a scarce and fading resource and its management can have an impact on the flow and biological quality of rivers and streams [4]. The availability and quality of water either surface or ground, have been deteriorated due to some important factors such as increasing population, industrialization, urbanization, etc [5]. Anthropogenic activities have resulted in significant decrease of water quality of aquatic systems in watersheds [6]. Rivers play a major role in receiving and dispersal of municipal and industrial wastewater and runoff from agricultural land [7]. This is a major concern because rivers are main water resources for domestic, industrial, and irrigation purposes in a watershed [8]. The pollution of surface water bodies as a result of anthropogenic activities is a growing concern worldwide [9, 10]. Consequently, it is imperative to prevent and control river pollution and to have reliable data on the quality of water for effective management [7]. A number of indices have already been developed for the evaluation of water quality. Water Quality Index (WQI) and Nemerow's Pollution Index (NPI) were used in this study. Water quality index is an approach which minimizes the data volume to a great extent and simplifies the expression of water quality status [2, 11]. It also provides a single number that expresses the overall water quality at a certain location and time based on several water quality parameters [12]. Nemerow pollution index (NPI), on the other hand, refers to the pollution calculation which was developed by Nemerow and Sumitomo [13]. The use of NPI is advantageous for offering quick and simple assessment result of the status of water quality [14]. In Nigeria, many urban and semi urban streams and rivers are polluted as a result of the discharge of untreated wastewater and other organic wastes directly into them [15 -17]. Thus, river pollution is becoming a central issue in water management in Nigeria [18]. Further studies have shown the extent and impact of human activities and the implications for our aquatic resources [19 – 21]. Ossah River is an urban river that receives industrial effluent from a vegetable oil processing factory and also subjected to other anthropogenic impacts. The objective of this study was to evaluate aspects of physico-chemical parameters of Ossah River, Umuahia, Nigeria in relation to anthropogenic impacts and suitability to support aquatic biodiversity using water quality indices.

2. Materials and Methods
2.1 Study area and sampling stations
The study was carried out in Ossah River located in Umuahia, Southeast Nigeria. The section of the river studied lies within Latitude 05º29̍20.00" - 05º31̍40.00"N and Longitude 07º27'50.40" - 07º28'548.00"E (Fig 1). Station 1 is upstream and control station, located in Ahi Amanso, Ossah community. There is a lot of building and road construction activities going on in the watershed; stormwater from the sites discharge into the river. The station is relatively deep and the substrate is sandy. Other activities observed in the station include sand mining, bathing, swimming, washing of clothes, extraction of water for drinking. Occasional human defections were also observed around the river. Station 2 is located at Eziama Ossah, 510m down stream of station 1 and 410m downstream of the effluent discharge point (EDP). It is shallow and sandy with minimal activities like washing, bathing, and periodic watering of cattle. This station was abandoned as a drinking water source because of the effluent discharge. Station 3 is located at Umuchime Ossah, 610m downstream of station 2. The station is by a bridge along an abandoned road construction site. The station was deep with a sandy substrate. Storm water also discharge into this station during the rains; depositing sand on the edge of the river. Human activities were observed during the study include fishing, bathing, swimming, washing of motorcycles, tricycle (keke) and clothes.

2.2 Samples collection and analyses
Water samples were collected from Ossah River monthly from January to June 2018. Samples were collected with 1 litre water sampler and stored in sterilized 1litre plastic bottles and then taken to the laboratory for analysis. The physicochemical parameters were analyzed using standards methods described by American Public Health Association (APHA) [22]. All the results were statistically analysed using ANOVA and Tukey Pairwise test was performed to determine the location of significant difference.

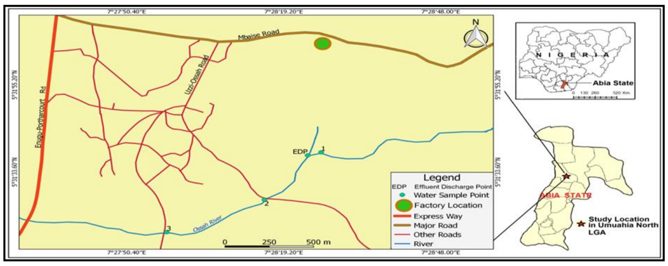

Fig 1: Map of Umuahia, Abia State, Nigeria showing the sampling Stations of Ossah River.

2.3 Calculation of water quality indices
2.3.1 Water quality index
Water quality index method as described by Al-Othman [23] was used in this study. Thirteen (13) parameters (turbidity, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrate, phosphate, sulphate, chloride, calcium, potassium, sodium and magnesium) were evaluated and Fisheries and Recreation Quality Criteria Standard [24] was used as the recommended standard. The method has been widely used by the various scientists [12, 25].

The WQI was calculated as follows:

$$\text{WQI} = \frac{\sum q_i \ x \ W_i}{\sum W_i} \quad (1)$$

The quality rating scale for each parameter *qi* was calculated by using this expression

$$qi = 100 \ x \ \frac{V_n}{V_i} \quad (2)$$

where, V_n is actual amount of nth parameter and V_s is the Federal Ministry of Environment (FMEnv) standards for corresponding parameter as listed in Table 1. Relative weight (W_i) was calculated by a value inversely proportional to the standards for corresponding parameter as follows:

$$W_i = \frac{1}{V_i} \quad (3)$$

Generally, WQI is applicable to different uses. If all measured water quality parameters have permissible limits, the excellent WQI will equal 100.

2.3.2 Nemerow pollution index
The Nemerow pollution index (NPI) refers to the pollution calculation which developed by Nemerow and Sumitomo [13]. This index has been extensively used by researchers [2, 26–29] for different purposes and standards.
The index was calculated by the following measures.

- Selection of parameters that exist in the FMEnv standards.
- Calculation of C_i/L_i for each parameter for each sampling location. C_i is measured water quality parameter and L_i is standard water quality for each parameter.
- The usage of value $(C_i/L_i)_{\text{measurement}}$ if the value is smaller than 1.0, and the use of $(C_i/L_i)_{\text{new}}$ if the value of $(C_i/L_i)_{\text{measurement}}$ greater than 1.0. $(C_i/L_i)_{\text{new}} = 1.0 + P \log (C_i/L_i)_{\text{measurement}}$.
- Determination of the average value and the maximum value of the overall C_i/L_i [(C_i/L_i) R and (C_i/L_i) M].
- Determination of water pollution index:

$$\text{NPI} = \sqrt{\frac{\left(\frac{C_i}{L_1}\right)_M^2 + \left(\frac{C_i}{L_i}\right)_R^2}{2}} \quad (4)$$

Where, NPI is the pollution index for a specified water quality purpose, C_i is measured water quality parameters, L_i is the standard water quality parameter for each parameter at specified water quality purpose, (C_i/L_i) M is C_i/L_i maximum, (C_i/L_i) R is C_i/L_i average.

3. Results
3.1 Physicochemical Parameters
The physicochemical parameters of the studied river were as presented in Table. 1. Turbidity values followed the same trend as colour. The values ranged from 0.5 to 14.7 NTU; the mean values also decreased spatially. Some of the turbidity values exceeded limit (5 NTU) set by FMEnv. [24]. All the pH values were acidic ranging from 4.60 to 6.30 and outside acceptable limits (6.5-8.5). Station 1 recorded the lowest mean value (5.38). The dissolved oxygen (DO) values ranged from 3.2 to 6.4 mg/l; all but one were below the acceptable

limit (>6mg/l) while biochemical oxygen demand values ranged from 1.50 to 4.20 mg/l. All but one was within the acceptable limit (3mg/l). Station 1 was significantly different from Stations 2 and 3(P<0.05). Station 1 was also significantly different (*P*<0.05) in Chemical Oxygen Demand (COD) ranging from 7.8 to 21.5 mg/l. The mean values decreased spatially. The nutrient values were generally low. Nitrate values ranged from 0.93 to 3.42mg/l; station 1 was significantly different (P <0.05) from station 3. The mean values decreased spatially. Phosphate ranged from 0.47 to 2.65 mg/l; stations 1 and 2 were significantly different (P <0.05) from station 3. The mean values also decreased spatially as in nitrate. Sulphate on the other hand, ranged between 0.31 and 0.88 mg/l; station 1 was significantly different (P <0.05) from station 3. The mean values followed the same trends observed in nitrate and phosphate. The chloride values ranged from 30.5 to 91.3 mg/l; station 1 was also significantly different from stations 2 and 3. The mean values also decreased spatially. The anions were generally low though relatively higher values were recorded in stations 1 and 2. Calcium ranged from 1.17 to 3.64 mg/l, Magnesium ranged from 0.42 to 1.38 mg/l, Potassium and sodium values ranged from 0.05 to 0.25 mg/l and 0.24 to 1.13 mg/l respectively. Stations 1 and 2 were significantly different ($p < 0.05$) and the mean values also decreased spatially in both of them.

Table 1: Summary of Physico-chemical Parameters of Ossah River (with range in parenthesis)

Parameter	Station 1 x±SEM	Station 2 x±SEM	Station 3 x±SEM	P-value	FMEnv. 2011
Turbidity (NTU)	4.77±2.12 1.3-14.7	2.15±0.91 0.8-6.6	1.98±0.91 0.5-5.7	P>0.05	5
pH	5.38±0.22 4.6-6.0	5.60±0.21 4.8-6.3	5.55±0.19 4.8-6.2	P>0.05	6.5-8.5
Dissolved Oxygen (mg/l)	5.10±0.29 3.8-5.7	5.65±0.26 4.7-6.4	4.83±0.35 3.2-5.5	P>0.05	6
Biochemical Oxygen Demand (mg/l)	3.25±0.33^{a} 2.10-4.20	2.08±0.20^{b} 1.60-3.00	2.10±0.15^{b} 1.50-2.50	P<0.05	3
Chemical Oxygen Demand(mg/l)	17.2±33^{a} 12.0-21.5	10.53±0.94^{b} 7.80-13.6	9.78±0.49^{b} 7.80-11.2	P<0.05	30
Nitrate (mg/l)	2.64±0.27^{a} 1.65-3.42	2.04±0.21^{ab} 1.12-2.61	1.67±0.28^{b} 0.93-2.50	P<0.05	50
Phosphate (mg/l)	2.00±0.25^{a} 0.85-2.65	1.80±0.20^{a} 0.91-2.31	0.71±0.08^{b} 0.47-1.01	P<0.05	3.5
Sulphate (mg/l)	0.65±0.07^{a} 0.39-0.88	0.49±0.03^{ab} 0.37-0.61	0.37±0.03^{b} 0.31-0.47	P<0.05	100
Chloride (mg/l)	73.59±6.13^{a} 47.8-91.3	56.31±3.77^{b} 41.1-68.3	41.03±2.90^{b} 30.5-50.3	P<0.05	300
Calcium (mg/l)	2.62±0.23^{a} 1.90-3.25	2.25±0.30^{a} 1.68-3.64	1.37±0.08^{b} 1.17-1.70	P<0.05	180
Potassium (mg/l)	0.19±0.01^{a} 0.12-0.25	0.14±0.02^{a} 0.09-0.20	0.08±0.01^{b} 0.05-0.11	P<0.05	50
Sodium (mg/l)	0.70±0.04^{a} 0.59-0.80	0.61±0.11^{a} 0.42-1.13	0.39±0.04^{b} 0.24-0.54	P<0.05	120
Magnesium (mg/l)	1.06±0.08^{a} 0.81-1.35	0.86±0.12^{a} 0.54-1.38	0.53±0.04^{b} 0.42-0.71	P<0.05	40

a, b = Means with different superscripts across the rows are significantly different at p<0.05; SEM= Standard Error of Mean; Fisheries and Recreation Quality Criteria Standard (FMEnv) [24].

3.2 Water Quality Indices

The results obtained for the WQI and NPI from the sampling stations are presented in Table 3. The WQI results were found to be varied from 49.2 to 77.7; decreasing spatially. The results indicated that only station 3 with WQI of 49.2 was of excellent water quality and suitable to support aquatic biodiversity while stations 1 and 2 with WQI of 77.7 and 58.6 respectively were considered of good water quality and also suitable to support aquatic biodiversity based on the WQI standards (Table 3). The NPI results followed the same trend as the WQI. It varied from 0.58 to 0.81; decreasing spatially. The results indicated that the 3 stations had values less than 1 (good water quality) and suitable to support aquatic biodiversity based on the NPI standards (Table 4).

Table 2: The results of WQI and NPI calculated for sampling stations.

Parameters		Station 1		Station 2		Station 3	
	W*i**	q*i*	q*i* x w*i*	q*i*	q*i* x w*i*	q*i*	q*i* x w*i*
Turbidity (NTU)	0.2	95.4	19.08	43	8.6	39.6	7.92
pH	0.13	71.2	9.256	75	9.75	74	9.62
Dissolved Oxygen	0.17	85	14.45	94	15.98	80.5	13.685
BOD5	0.33	108	35.64	69	22.77	70	23.1
COD	0.033	57	1.881	35	1.155	32.6	1.0758
Nitrate	0.02	5.3	0.106	4.1	0.082	3.34	0.0668
Phosphate	0.29	57	16.53	51	14.79	20.29	5.8841
Sulphate	0.01	0.65	0.0065	0.49	0.0049	0.37	0.0037
Chloride	0.0033	25	0.0825	19	0.0627	41.03	0.135399
Calcium	0.0056	1.5	0.0084	1.3	0.00728	0.76	0.004256

Potassium	0.02	0.38	0.0076	0.28	0.0056	0.16	0.0032
Sodium	0.0083	0.58	0.004814	0.51	0.004233	0.33	0.002739
Magnesium	0.025	2.7	0.0675	2.2	0.055	1.33	0.03325
∑	1.25		97.1		73.3		61.5
WQI		77.7		58.6		49.2	
NPI		0.81		0.70		0.58	

* Same for all the stations

Table 3: Water quality classification based on WQI value [30]

WQI	Water quality Status
<50	Excellent
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable

Table 4: Water quality classification based on NPI value [31]

NPI Value	Water quality status
0≤NPI≤1.0	Good quality standard
1.0≤ NPI ≤5.0	Slightly polluted
5.0≤NPI≤10	Moderately polluted
NPI ≥10	Water heavily polluted

4. Discussion

Turbidity is derived from suspended materials such as mud, sand, organic and inorganic materials, plankton and other microscopic organisms [27], which interferes with light penetration in the water column. Turbidity limits light penetration, thereby limiting photosynthesis in the bottom layer; higher turbidity can cause temperature and DO stratification and generally aesthetically unpleasing [31, 32]. Some of the turbidity values exceeded standard especially in stations 1 and 2 that are subjected to cumulative anthropogenic impacts and effluent discharges respectively. High turbidity affects aquatic life [31, 33, 34].

pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water or how acidic or basic the water is [31]. Chemicals in the water can affect pH; therefore, pH is an important indicator of water that is changing chemically. The solubility and biological availability of chemical constituents such as nutrients and heavy metals are determined by the pH of the water [31, 35]. All the pH values recorded in this study were acidic and below acceptable limit; attributable to both geogenic [36] and anthropogenic influences. Radojevic and Bashkin [37] observed that extremes of pH are associated with polluted waters.

Dissolved oxygen (DO) is the measure of oxygen dissolved in the water. DO is necessary to maintain variety of biological life forms in water and the effect of waste discharge in a water body is largely determined by oxygen balance of the system [40]. It is used in aerobic decomposition of organic matter, respiration of aquatic organism and chemical oxidation of mineral [31]. Most of the Dissolved Oxygen values were lower than acceptable limits especially stations 1 and 3 which could be attributed to anthropogenic impact. Concentrations below 5mg/l may adversely affect the functioning and survival of biological communities and below 2mg/l may lead to the death of most fish [39].

Biochemical Oxygen Demand (BOD) is an important parameter of water indicating the health scenario of freshwater bodies [40]. Some of the BOD values were close or higher than the acceptable limit; especially in stations 1 and 2 and could be attributed to anthropogenic activities. BOD is an indication of organic pollutant in the river and therefore affects water quality [41]. Unpolluted waters typically have BOD values of 2 mg/l [39] while Radojevic and Bashkin [37] reported that a river can self – purify itself if the BOD is below 4, but not if it is greater than 4 mg/l.

Chemical oxygen demand (COD) gives us a reliable parameter for judging the extent of pollution in water [42]. High oxygen consumption in the chemical process showed contamination by organic pollutants [43]. Some COD values recorded in this study were relatively high though within acceptable limit. Station 1 was significantly different and could be attributed to cumulative and diverse anthropogenic influences. Water bodies that contained high COD is undesirable for fisheries and agriculture [27]. The concentrations of COD observed in surface waters range from 20 mg/l O_2 or less in unpolluted waters to greater than 200 mg/l O_2 in waters receiving effluents [39].

Nitrate levels when influenced by human activities, surface waters can have nitrate concentrations up to 5 mg/l, but often less than 1 mg/l and concentrations in excess of 5 mg/l usually indicate pollution by human or animal waste, or fertilizer run-off [39]. The recorded values were well within acceptable though station 1 was higher due to anthropogenic impact. Major source of river water pollution comes from domestic sewage, animal waste, agricultural waste, soil erosion and runoff from the settlement [44].

Phosphate concentration gives an indication of the nutrient levels and eutrophication of the river system [45]. Phosphate contamination comes from disposal of detergent contaminated sewage and direct washing of clothes in water and also use of fertilizer, pesticides [46]. Phosphate values recorded in this study were within acceptable limit but stations 1 and 2 were relatively higher due anthropogenic impacts. In most natural surface waters, phosphate ranges from 0.005 to 0.020 mg/l and high concentrations can indicate the presence of pollution and are largely responsible for eutrophic conditions [39].

Sulphate is one of the major anions in natural waters and is contributed by industrial and household discharges. These discharges decreases pH of river water and increases bacterial load in the form of sulphate reducing bacteria [47]. The values of sulphate recorded in this study were very low and did not reflect any anthropogenic impact. Sulphate concentrations in natural waters are usually between 2 and 80 mg/l [39].

Chloride values within acceptable limit, though higher in station 1 and could indicate anthropogenic influence. High concentrations of chloride can make waters unpalatable and, therefore, unfit for drinking or livestock watering [39] as well as inhibit plant growth, impair reproduction and reduce the diversity of organisms in streams [48].

The cations did not reflect any anthropogenic influences, though stations 1 and 2 generally recorded higher values but all are within acceptable limits. Calcium is an important component of plant cell walls and shells and bones of many aquatic organisms [39, 49]. Low calcium levels can cause osmotic problem and affect shell or cuticle secretion in invertebrates (such as crayfish and snails) [49].

Magnesium occurs in many organometallic compounds and in organic matter, since it is an essential element for living organisms [39, 49]. The value of magnesium recorded in this study were low and within acceptable limits. Natural concentrations of magnesium in freshwaters may range from 1 to > 100 mg/l, depending on the rock types within the catchment [39]. Magnesium can be toxic at concentrations approaching natural background levels, but it is dependent on calcium concentrations; very low ionic mg concentration in Ca-deficient waters pose the greatest risk to aquatic life [50].

Potassium (as K^+) is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering [39]. Potassium content was equally low; Lenntech [51] reported that potassium tends to settle, and consequently ends up in sediment mostly and rivers generally contain about 2 – 3 mg/l. All organisms require K for several metabolic processes. In freshwater, K could limit growth because low external concentrations can increase the energetic costs of accumulating K [52]. Besides the potential for growth limitation at low concentrations, potassium and many other ions can be toxic at sufficiently high concentrations [53].

All natural waters contain some sodium since sodium salts are highly water soluble and it is one of the most abundant elements on earth [31]. The values of sodium recorded in this study were equally low and within acceptable limits. Freitas and Rocha [54] studied the effect of sublethal concentrations of sodium on the life history parameters of the tropical cladoceran *Pseudosida ramose*. The concentrations of the sodium that affected the reproduction of *P. ramosa* were lower than those that resulted in other endpoints.

The classification of Ossah River at each station was obtained through index analysis. The WQI and NPI at the three stations showed that the water quality was almost same and of the quality to sustain diverse biodiversity. The indices were a good reflection of the water quality status and effectively captured the effect of the anthropogenic activities in the river. Poonam *et al* [55] observed that water quality indices play major roles in water quality assessments of given sources as a function of time and other influencing factors.

5. Conclusion

Generally, water quality conditions of Ossah River based on the water quality indices can be classified as good. However, there are some parameters that did not meet the standard. Those parameters were pH and DO in all the stations and BOD in Station 1. The study has shown that human activities including effluent discharge did not give negative impact on the water quality. However, the activities need to monitored and regulated.

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7. Conflict of Interest

The authors declare that no conflict of interest exists. No writing assistance was utilized in the production of this research article.

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