GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(Research Article)

Assessment of surface water quality of Onuiyieke river in Imo State, Nigeria

Eze Chinwe Catherine [1,*], Ahmad Ahmad Danmama [1], Anaebonam Emeka [2], Frank–Ogu Ngozi [1], Nweze Kenneth Emeka [2] and Onyemeka Regland Michael [3]

[1] *Department of Microbiology, Federal University of Technology, Owerri, Nigeria.*
[2] *Department of Biological Sciences, Chukwuemeka Odumegwu Ojukwu University, Anambra, Nigeria.*
[3] *Department of Botany, Lagos State University, Lagos, Nigeria.*

GSC Biological and Pharmaceutical Sciences, 2021, 16(03), 071–084

Publication history: Received on 03 August 2021; revised on 06 September 2021; accepted on 08 September 2021

Article DOI: https://doi.org/10.30574/gscbps.2021.16.3.0264

Abstract

This research aimed to assess the surface water of Onuiyieke River to ascertain its quality status. Measurements were made on samples collected from seven locations with 500ml sample bottles according to standard methods. Samples for heavy metals were collected in 250ml bottle and fixed with concentrated $HN0_3$. Descriptive analysis, variation plots, ANOVA, Duncan Multiple Range tests, Principal Components Analysis (PCA), Pearson Correlation (r) and Water Quality Index (WQI) were used to analyze data. Mean values of the parameters obtained were: Total Suspended Solids (TSS) 198.19 ± 80.93mg/L; Electrical Conductivity (EC) 331.81 ± 59.78µ; Turbidity 18.84 ± 2.22 NTU; Nitrate ions 14.77 ± 0.92mg/L; Dissolved Oxygen (DO) 6.58 ± 0.22mg/L and Biological Oxygen Demand (BOD) 1.77 ± 0.10mg/L. Mean values of the Trace Metals obtained were: Iron (Fe) 1.93 ± 0.23mg/L; Magnesium (Mg)0.22 ± 0.02mg/L and Calcium (Ca) 15.15 ± 1.87mg/L while the mean value of Faecal Coliform was 1.91 ± 0.10MPN/100. pH, EC, TSS, BOD, turbidity, $N0_3$-, Ammonia, Fe and Faecal coliforms exceeded the NESREA and WHO maximum permissible limits. There were significant spatial differences in levels of TDS, EC, NO_3, NH_3, DO and Faecal coliforms (Sig F=0.000 to 0.039) and significant temporal differences in levels of PO_4^{3-} (Sig F= 0.078 to 1000) between the control and other locations at $p<0.05$. Four Principal Components (PCs) formed the extraction solution with a cumulative percentage variability of about 77.67%. The Water Quality Index revealed that the rating for the water quality across the sampling locations was between excellent and unsuitable. Appropriate monitoring procedures for the sustainable development of the river should also be put in place.

Keywords: Water indicators; Water Quality Index; Principal Components Analysis; Pollution; Physicochemical

1. Introduction

Water is necessary to live, essential for socio-economic development and maintenance of healthy ecosystems and is useful for industrial, domestic and recreational purposes [1]. Plants and animals require water and cannot survive if their water is loaded with toxic chemicals or harmful microorganisms [2]. Polluted water can kill large numbers of fish, birds, and in some cases, all members of a species in an affected area. Water quality is evaluated relative to its intended use [3].

The term "water pollution" can be defined as the deterioration in the chemical, physical and biological properties of water resulting from humans and their activities [4]. Increasing the human population, industrialization, intensive agricultural practices and discharges of wastewater into rivers and streams have also resulted in deterioration of water quality [5].

* Corresponding author: Eze Chinwe Catherine

Department of Microbiology, Federal University of Technology, Owerri, Nigeria.

The impact of these anthropogenic activities has been so extensive that some water bodies have lost their self-purification capacity to a large extent [6]. The Onuiyieke river is one of the largest rivers flowing across Obowo to Ihitte-Uboma Local Government Area of Imo State. The river drains from its source, the Imo River, passing through many rural communities such as Ogwogoroanya, Umulogho, Umoke, Amanze, Amainyi, etc. With a drainage area of about 150000 hectares. The watershed of the river serves as the water source for the population of the bordering communities, from the source downstream. According to [7] as societies throughout the world become more aware of the issues involved in water pollution, there has been a considerable public debate about the environmental effects of effluents discharged into aquatic environments. It is based on these concerns that the present study was conducted to assess the surface water quality Of Onuiyieke River in Imo State, Nigeria.

2. Material and methods

2.1. Study Area

The study area lies within a humid tropical rainforest region characterized by depleted rainforest vegetation and the Imo River Basin hydrological province of Nigeria. The State experiences heavy rainfall, with an average annual rainfall of 2000-2400 mm/year with mean temperatures of 27^{0}C throughout the year.

2.2. Research

The research was conducted in two phases: field sampling and laboratory analysis. A systematic point sampling design was adopted by selecting sampling locations at regular intervals as they are encountered. This approach often provides greater information because the sample is distributed uniformly over the entire study area and because of its ease of use in field studies. One sample was collected at a time from each of the seven sampling locations. One of the locations was upstream of the river which served as the control point while six other locations served as downstream of the river.

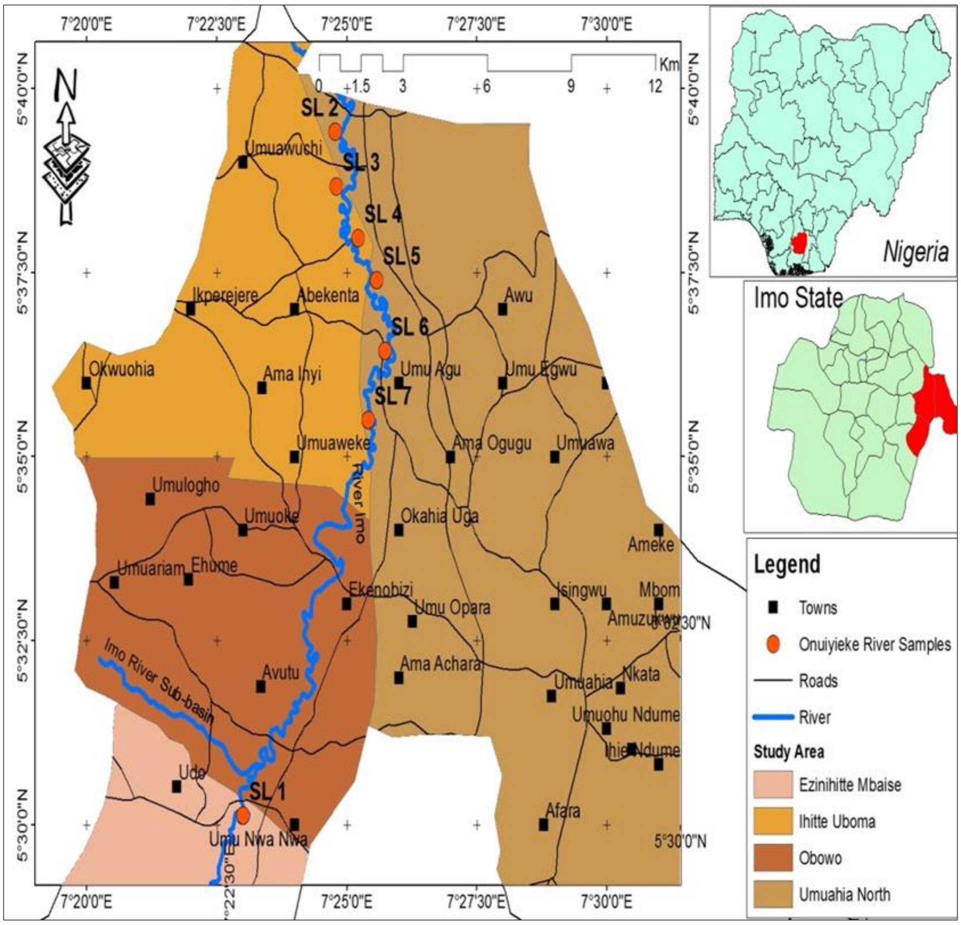

Figure 1 Map showing sampling points in the study area

2.3. Sample Collection

Surface water temperature, conductivity, pH, Dissolved Oxygen (DO), Turbidity and Total Dissolved Solids (TDS) were determined electromagnetically with the HANNAH HI 9828 VI PH/OR/EC/DO meter. The metre was pre-calibrated with the standard HI 9828-25 calibration solution. The desired physicochemical parameters were read off the LCD. Water samples were collected from the early hours of the day under aseptic conditions using disposable sterile hand gloves. Bottles were rinsed with the river water before sampling. The containers were unscrewed at a depth of 15-30cm below the surface of the water, facing the upstream direction and corked when filled while still under water to prevent oxidation. A small air space of 2 to 3cm above the sample was left in the container for proper mixing of the sample before analysis. Collected water samples were subjected to filtration after collection. All the different dilutions were properly labelled and used for total plate count.

2.4. Preparation of reagents

The standards reagents used in the analysis were prepared using double distilled water. Water samples for trace metals were collected in 250mls plastic bottles and fixed with concentrated H_2SO_4 in the ratio of 2:500. Water samples for other parameters were collected in 500mls sterile plastic containers. It was tightly closed and labelled. These were stored in the icebox to retard the biochemical activities and promptly transported to the laboratory. Water samples were taken to the laboratory as soon as possible to maintain their integrity. A total of 129 samples were collected from the seven sampling locations in triplicates for six months from September 2017 to February 2018.

2.5. Laboratory Analyses

Nitrate was determined by the spectrophotometric method. *Temperature* was determined at the point of sample collection by dipping the bulb of mercury-in-glass thermometer into the soil suspension and recording the readings. *Conductivity* was measured using the suntex conductivity meter (DD 193). *Total Solids (TS)* was determined gravimetrically. *Total Suspended Solids (TSS)* was determined by subtracting Total Dissolved Solids from Total Solids. *Total Hardness* was determined by the titrimetric method. *Dissolved Oxygen (DO)* was determined using the audiometric method and its aside modification as described by Prescott *et al.*, (2002). *Chloride* is determined by mercuric nitrate titration. *Chemical Oxygen Demand (COD)* was determined by Oxidation reaction method.

2.6. Faecal Coliform Bacteria Count

About 100ml of the water samples were filtered through a membrane filter with the aid of a vacuum pump. The filter membrane was placed on a MacConkey agar plate. This was then incubated using an incubator pre-set to 44.5 ± 2^0C for 24hrs. Observation was made for colony development on the filter membrane. The colonies were then counted as colony-forming units per 100ml.

2.7. Calculation of Water Quality Index

The calculation of the water quality index (WQI) was calculated using the standards of drinking water quality recommended by the National Environmental Standards and Regulatory Agency (NESREA), [8] and World Health Organization (WHO), [9].

2.8. Statistical analyses

Statistical analyses were performed with SPSS v 22.0 and MS Excel version 2010 was utilized in the analyses of data. Descriptive statistics were used to explore minimum and maximum values of the Data Set. The test of homogeneity in mean-variance of the quality parameters was explored with a one-way Analysis of Variance (ANOVA). The factor analysis procedure, using the Principal Components Analysis (PCA) method of extraction for data reduction was used to remove highly correlated (redundant) variables. Factor rotations for the transformation of extracted factors to a new position for interpretation were achieved with the Varimax method. The Pearson correlation was used to determine possible relationships between the physical and chemical attributes of the river.

3. Results and discussion

The result for the physical, chemical and biological parameters is captured in Table 1 below.

3.1. Physical parameters

These are Total Suspended Solids (TSS) (Range =3006.00). Electrical Conductivity (EC) (Range =1361.00), Total Dissolved Solids (TDS) (Range= 826.00), Total Solids (TS) (Range=3660.00), this value far exceeds NESREA, [8] regulatory standard value of 500mg/l. These parameters have comparatively wider variations than the other parameters however pH, Turbidity and Dissolved Oxygen varied from 5.40- 7.00 (6.18 ± 0.06), 4.50 – 53.00 (18.84 ± 2.22) and 3.00- 8.30 (6.58 ± 0.22) mg/l respectively. Temperature was at 26.00 – 29.00 (27.67 ± 0.14) ^{0}C. The values for Turbidity and Dissolved Oxygen also exceeded the WHO standards of 10mg/l and 6.00mg/l respectively.

3.2. Chemical parameters

Calcium ion concentration ranged from 3.00 to 39.00 mg/l with a mean value of 15.15 ± 1.87 mg/l, Magnesium ion concentration 0.09 -0.46 (0.22 ± 0.02) mg/l, nitrate 4.50 – 28.10mg/l (14.77 ± 0.92) mg/l, phosphate ion concentration 0.17 - 4.00 (2.08 ± 0.18)mg/l, biochemical oxygen demand (BOD) values 0.70 – 3.30 (1.77 ± 0.10) mg/l., Ammonia (NH_3)chloride ion concentration (Range = 118.00) exceeding the NESREA standard of 0.05mg/l. Iron ion concentration and chemical Oxygen demand ranged from 0.15 -5.80 (1.94 ± 0.23) mg/l and 1.40- 5.60 (3.03 ± 0.18) mg/l respectively. The value for iron ion concentration exceeded the NESREA standard of 0.30mg/l while COD values fell below the permissible NESREA standard of 30mg/l.

3.3. Biological parameter

Faecal coliform count range between 0.70 and 3.30 with a mean value of (2.60 ± 1.91MPN/100ml). This value exceeded the WHO, [9] regulatory standard of 0.5 MPN/100ml.

Table 1 Descriptive statistics of the Physical, Chemical and Biological parameters of Onuiyieke River

Parameters	Min	Max	Range	Mean	SE	WHO, 2011	NESREA, 2011
Total hardness(mg/L)	4.20	200.00	195.80	73.08	9.85		300
Water Temperature(^{0}C)	26.00	29.00	3.00	27.6738	0.14	20-30	20-30
TSS(mg/l)	6.00	3012.00	3006.00	198.19	80.93	30	0.25
EC (μS/cm)	7.00	1368.00	1361.00	331.81	59.78	40	-
TDS(mg/l)	4.00	830.00	826.00	219.70	39.30	50	<1000
TS(mg/L)	56.00	3722.00	3666.00	417.72	105.33	259-500	500
Turbidity(NTU)	4.50	53.00	48.50	18.84	2.22	6	10
DO(mg/L)	3.00	8.30	5.30	6.58	0.22	7.5	6.00
BOD_5(mg/L)	0.70	3.30	2.60	1.77	0.10	6-9	-
Chloride(mg/L)	3.00	121.00	118.00	41.90	5.51		300
Calcium(mg/L)	3.00	39.00	36.00	15.15	1.87	50	
Magnesium(mg/L)	0.09	0.46	0.37	0.22	0.02		0.20
Phosphate(mg/L)	0.17	4.00	3.83	2.0843	0.18		3.50
Nitrate(mg/L)	4.50	28.10	23.60	14.7695	0.92	20	50
Ammonia(mg/L)	5.13	25.50	20.37	14.6179	0.89	<1.50	0.05
Iron(mg/l))	0.15	5.80	5.65	1.9352	0.23	-	0.30
COD(mg/l)	1.40	5.60	4.20	3.0340	0.18	45	30
Faecal/Coliform(MPN/100ml)	0.70	3.30	2.60	1.9114	0.10	0.5	

SE= standard error of the mean, TSS=Total Suspended Solids, EC=Electrical Conductivity, TDS= Total Dissolved Solids, Do=Dissolved Oxygen, BOD= Biological Oxygen Demand, COD= Chemical Oxygen Demand. Sources: WHO, [9] and NESREA, [8].

3.4. Spatial variations in physical, chemical and biological parameters

The physical, chemical and biological parameters measured in the river varied across the seven sampling Locations studied (see Table 2). Mean pH varied from 5.40 (±0.16) in SL 2 to 7.00 (± 0.13) in SL 3. Mean Total hardness varied from 11.83 (±1.29) mg/line SL 1 to 182.67(± 7.51) mg/l in SL 3. Temperature varied from 27.00^{0}C (±0.45^{0}C) in SL 4 to

28.17^{0}C (± 0.25^{0}C) in SL 6.Mean TSS varied from, 63.96 (± 6.14) mg/l in SL1, to 894.17 (± 509.5) mg/l in SL 3.Mean EC varied from, 21.50 (± 6.00)µS/cm in SL1, to 1065.00 (± 192.30) µS/cm in SL 3. Mean TDS varied from, 12.53 (± 3.63) mg/l in SL1, to 778.167 (± 19.46) mg/l, in SL 3. Iron ion concentration varied from 0.61 (± 0.20) mg/l in SL 4 to 4.13 (±0.42) mg/l in SL 6. Mean TS varied from 76.55 (± 6.80) mg/l in SL1 to 1680.67 (± 492.96) mg/l in SL 3. Mean Turbidity varied from 6.73 (± 0.88) NTU in SL 1 to 43.20 (± 5.73) NTU in SL 3. However, mean DO varied from, 4.28 (± 0.48) mg/l in SL 3, to 8.07 (± 7.91) mg/l in SL 1. Mean BOD varied from 1.03(± 0.27) mg/l in SL 1 to 2.68 (± 0.17) in SL 3. Mean Chloride ion concentration varied from 5.33 (± 1.28) mg/l in SL 1, to 82.00 (±2.14) mg/l in SL 6. Mean Calcium ion concentration varied from 3.67(± 3.12) mg/l in SL 1 to 34.00(± 1.70) mg/l in SL 3. Total Magnesium ion concentration varied from 0.11(± 0.01) mg/l in SL 1 to 0.38(± 0.03) mg/l in SL 3. Total Phosphate ion concentration varied from 1.04 (±0.27) mg/l in SL 1 to 2.72 (± 0.54) mg/l in SL 5. Nitrate ion concentration varied from 5.48(± 0.41) mg/l in SL1 to 22.57 (±0.64) mg/l in SL 5. Ammonium ion concentration varied from 6.21 (± 0.29) mg/l in SL1 to 23.52 (± 0.54) mg/l in S 5. Fe ion concentration varied from 0.43(± 0.08) mg/l in SL1 to 4.14(± 0.42) mg/l in SL 3. COD varied from 1.93(± 0.18) mg/l in SL 1 to 4.88(± 0.24) mg/l in SL 3. Faecal Coliforms varied from 1.15(± 0.179) MPN/100ml SL to 2.52 (± 0.27) MPN/100ml in SL 3.

The One-Way Analysis of Variance (ANOVA) revealed that all the parameters measured, except phosphate ion concentration (Sig F value 0.190) and water temperature (Sig F value = 0.095), differed significantly in their mean concentrations (Sig F values =0.000 to 0.039) across the sampling locations at $p<0.05$.

Table 2 Mean Separation in the physical, chemical and biological Parameters using Multiple Range test (P<0.05)

	Sampling locations						
Parameters	**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**	**SL 6**	**SL7**
pH	5.7500^a	6.2867^{bc}	6.5550^c	5.990^{ab}	6.1633^{bc}	6.3633^{bc}	6.1067^{ab}
T-Hardness	11.8333^a	31.0000^a	182.6667^d	29.0333^a	31.2167^a	133.950^c	91.8333^b
Temperature (^{0}C)	27.8500^{ab}	27.1667^{ab}	27.6500^{ab}	27.0000^a	27.9167^a	28.1667^b	27.9667^{ab}
TSS	63.9633^a	81.6667^a	894.1667^b	71.8333^a	92.0000^a	109.3333^a	74.3333^a
EC	21.5000^a	37.3333^a	1065.0000^c	66.500^{ab}	302.000^b	428.667^{ab}	401.667^{ab}
TDS	12.53^a	28.00^b	778.17^d	38.67^a	177.83^b	285.00^c	222.67^c
TS	76.56^a	115.50^a	1680.67^b	110.50^a	269.83^a	401.00^a	270.00^a
Turbidity	6.733^a	11.283^{ab}	43.20^c	16.50^{ab}	22.17^b	17.25^{bc}	14.77^{ab}
DO	8.0667^d	7.0333^c	4.2833^a	7.4833^{cd}	5.2333^{bb}	6.8500^c	7.1000^c
BOD	1.0333^a	1.4883^{ab}	2.6750^c	1.7250^b	2.4083^c	1.6833^b	1.3467^{ab}
Chloride	5.3333^a	11.7500^a	78.0000^c	16.6667^a	51.8333^b	82.0000^c	47.7500^b
Ca	3.6667^a	6.0000^a	34.0000^c	6.3333^a	6.6667^a	26.000^b	23.3500^b
Mg	0.1133^a	0.1467^{ab}	0.3767^c	0.1400^{ab}	0.1883^b	0.3100^c	0.2633^c
PO_4^{3-}	1.0400^a	1.6733^{ab}	2.5233^b	1.7217^{ab}	2.7150^b	2.7033^b	2.2133^{ab}
NO_3	5.4800^a	11.7633^b	15.3083^{bc}	17.4583^c	22.5650^d	17.6450^c	13.1667^b
NH_3	6.2133^a	11.2067^b	18.0117^c	17.2000^c	23.5150^d	16.3783^c	9.8000^b
Fe	0.4250^a	1.4200^{ab}	4.1383^c	0.6133^a	2.3933^b	2.3733^b	2.1833^b
COD	1.9283^a	2.8217^b	4.8800^c	2.3750^{ab}	4.3000^c	2.5450^{ab}	2.3883^{ab}
Faecal Coliforms	1.1467^a	2.2833^b	2.5167^b	2.3667^b	2.0667^b	1.6000^a	1.4000^a

SE= standard error of the mean, TSS=Total Suspended Solids, EC=Electrical Conductivity, TDS= Total Dissolved Solids, Do=Dissolved Oxygen, BOD= Biological Oxygen Demand, COD= Chemical Oxygen Demand. Source: Author's Fieldwork, (2018).

A post-hoc mean separation using Duncan Multiple Range Test revealed that the observed significant differences in pH were between SL 1, SL 2 and SL 3. For EC, SLs 1, 3 and 5. For Total hardness, SLs 1, 3, 6 and 7. For Temperature, SLs 4 and 6, SLs 5 and 6. For TSS, there are no observed significant differences between Sample locations except SL 3. For TDS SLs 1, 2, 3, and 6. And also SLs 4, 5 and 7. For TS, SL 3 and all the other site locations. For turbidity, SLs 1, 3 and 5. For DO, SLs 1, 2, 3 and 5. For BOD, SL 1, 3, and 4. For Cl^- observed significant differences between SLs 1, 3 and 5; SLs, 4, 6 and 7; SLs 2, 3, 6 and 7. For Ca, SLs 1, 3 and 6; SLs 2, 3 and 7. For Mg, SLs 1, 3 and 5. For PO_4^{3-}, SLs 1 and 3. For NO_3, SLs 1, 2, 4 and 5, as well as between SLs 4 and 7. For NH_3, SLs 1, 2, 3 and 5, were observed between SLs 5, 6 and 7. For Fe, SLs 1, 3 and 5, SLs 3, 4 and 5. For COD, SLs 1, 2 and 3. For faecal coliforms, there were observed significant differences between SLs 1 and 2, also between SLs 1 and 3, also between SLs 1 and 4, and between SLs 2 and 7.

3.5. Principal Component Analysis (PCA)

PCA analysis was carried out to investigate the parameters that contributed to the highest variabilities in the water quality. The physical, chemical and biological parameters that were subjected to the PCA procedures produced high Initial and Extraction Communalities (See Table 3&4). This indicates that the extracted components represent the variables well. The first four Principal Components, (PCA) formed the Extraction solution, with a cumulative percentage Variability of about 77.67% in the original 19 variables. This reduces the complexity of the data set by using these components with only about 22.33% loss of information. The rotation maintained the cumulative percentage of variation explained by the extracted components (77.67%) The Scree plot represents the Eigenvalue of each component in the initial solution. The extracted components are on the steep slope, while the components on the shallow slope contributed little (22.33%) to the solution. The last big drop occurred between the 4^{th} and 5^{th} components. With this rotation, the first component contributed almost 48.333% to the total variability, while the second, third and fourth contributed 12.534%, 10.592% and 6.212% respectively total variability The first PC (PC1) was most highly related with Mg ions concentration (0.925) and also had high loading for electrical Conductivity (EC)(0.733), Total Dissolved Solids (TDS) (0.810), Chloride ions (0.787), Total Hardness (0.894), Calcium ions (0.917) and Fe ions concentration (0.646). The first factor (PC1) seemed to be associated with the earth's crust and the geological formation of the area.

PC2 was most highly correlated with NH_3 (0.903) and also had high loadings for Turbidity (0.510). Biological Oxygen Demand (BOD) (0.739), Faecal Coliforms (0.659), Nitrate ions concentration (0.835) and Chemical Oxygen Demand (COD) (0.670). This factor can be attributed to mining activities, agro products processing, and anthropogenic sources.

PC3 was most highly correlated with Total Suspended Solids (TSS) (0.903) and also had high loadings for Total Solids (TS) (0.867), Turbidity (0.531), and COD (0.517). However, PC4 was most highly correlated with water temperature (0.840) and also had high loadings for PO_4^{3-} (0.623). The Component plot in rotated space revealed that all of the parameters measured except TSS were closely related (Figure 2).

Table 3 Extraction Sums of Squared Loadings of physical, chemical and biological parameters of Onuiyieke River in Imo State, Nigeria

Components	Total	% of Variance	Cumulative %
1	9.183	48.333	48.333
2	2.381	12.534	60.867
3	2.012	10.592	71.458
4	1.180	6.212	77.670

Table 4 Rotation Sums of Squared Loadings of physical, chemical and biological parameters of Onuiyieke River in Imo State, Nigeria

Components	Total	% of Variance	Cumulative %
1	5.804	30.546	30.546
2	4.070	21.419	51.964
3	3.439	18.098	70.062
4	1.446	7.608	77.670

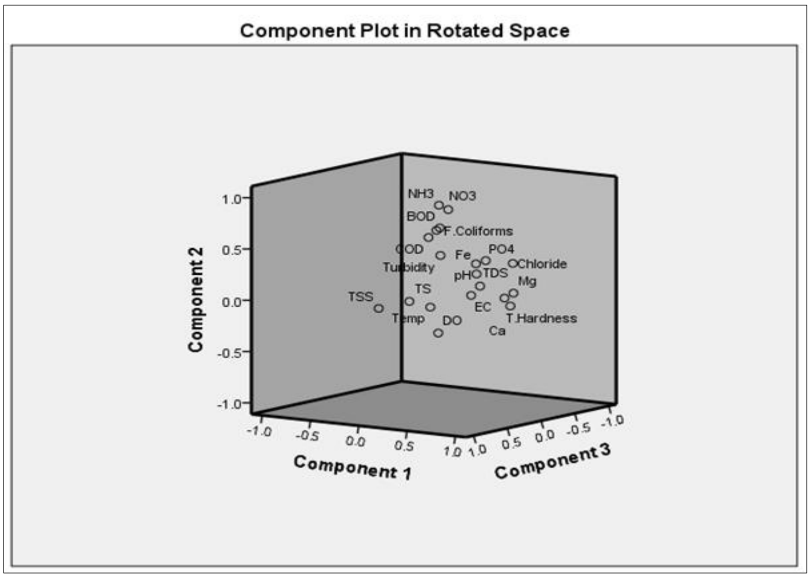

Figure 2 Component Plot in Rotated Space of the Physical, Chemical and Biological Parameters of the Onuiyieke River

3.6. Relationships between physical, chemical and biological Parameters

The Pearson correlations between the parameters are shown in Table 5. At $p<0.05$, pH correlated positively with EC(r = 0.315), TS (r =0.329), Turbidity (r =0.376), BOD(r = 0.364), Mg(r = 0.389), Faecal Coliforms (r =0.367), Fe (r = 0.351), NO_3 (r = 0.332), NH_3 (r = 0.320) and correlated negatively with DO(r = -0.389). TSS correlated positively with Total Hardness(r = 0.316) showing the impact of TSS on Total hardness of the water sample. EC correlated positively with PO_4^{3-} (r = 0.341), NH_3 (r = 0.317) TDS correlated positively with PO_4^{3-} (r = 0.350).TS correlated positively with Chloride ion concentration (r = 0.312), Turbidity correlated positively with NO_3 (r = 0. (r = 355).

DO correlated negatively with Chloride(r = -0.384), Faecal Coliforms (r = -0.349).BOD correlated positively with Total Hardness (r = 0.372) and Ca (r = 0.320).Ca correlated positively with BOD (r =0 .309) Phosphates correlated positively with NH_3 (r = 0.363) and Temperature (r = 0.331). NH_3 correlated positively with Fe (r = 0.341). At $P<0.01$, pH correlated positively with TDS (r = 0.459), Chloride (r = 0.393), Total Hardness (r = 0.543), Ca(r = 0.502) and COD (r = 0.472).

TSS correlated positively and strongly with EC (r = 0.462) indicating that increase in one affects the other, TDS (r = 0.469), TS (r = 0.943), COD (r = 0.442) but had negative correlation with Turbidity (r = -0.510). EC correlated positively with TDS (r = 0.889), TS (r = 0.687), Turbidity (r = 0.632), DO (r = 0.716), BOD (r = 0.582), Total Hardness (r = 0.742), Cl(r =0.584), Ca(r = 0.773), Mg (r = 0.773), Fe (r = 0.666) and COD (r = 0.59). TDS correlated positively with TS(r = 0.735), Turbidity (r =0.726), BOD (r = 0.615), Cl(r = 0.695), Total Hardness (0.852), Ca (0.803), Mg (0.855), Fe (r = 0.788), COD (r =0.665) but correlated negatively with DO (r =-0.726).

TS correlated positively with Turbidity (r =0.650), BOD (r =0. 429), Cl(r =0.312), Total Hardness (r =0. 562) but correlated negatively with DO (r =0. -667) Turbidity Correlated negatively with DO (r = -0.590) but correlated positively with BOD (r =0.839), Cl(r =0.585), Total Hardness (r =0.518), Ca(r =0.464), and Mg (r =0.547). DO correlated positively with BOD (r =0.647) but correlated negatively with Total Hardness (r = -0.529), Ca(r = -0.474), Mg (r = -0.523), NO3 (r = -0.574), Temp (r = -0.574), Fe (r = -0.527) and COD (r -0.800).

BOD correlated positively with Cl (r = 0.532), Mg (r = 0.454), Faecal Coliforms (r =0.429). NO_3 (r = 0.521), NH_3 (r = 683), Fe (r = 600), and COD (r = 0.784). Chloride ion concentration correlated positively with Total Hardness (r = 0.690), Ca(r = 0.685), Mg (r =0.832), PO_4^{3-} (r =0.481), NO_3 (r = 0.443), NH_3 (r = 0.442), Fe (r = 0.677) and COD(r = 0.477). Total Hardness correlated positively with Ca(r = 0.959), Mg (r = 0.821), Fe (r = 0.561) and COD (r =0.428). Ca correlated with Mg (r = 0.823) and Fe (r =0.530). Mg correlated positively with PO_4^{3-} (r = 0.422), Fe (r = 0.725) and COD (r = 0.411). PO_4^{3-} correlated positively with Fe (r = 0.504). Faecal Coliforms correlated positively with NO_3 (r = 0.440), NH_3 (r = 0.486) and COD (r = 0.486). NO_3 correlated positively with NH_3 (r =0.84) and COD (r = 0.467). NH_3 correlated positively with COD (r = 0.623). Fe correlated positively with COD (r = 0.596) thus high correlations show that the parameters are derived from the same source. Therefore the correlation matrix of the Onuiyieke River can be checked very effectively by controlling the PH, EC,TS, DO and the ionic concentrations.

Table 5 Correlation (r) Matrix between the physical, chemical and biological Parameters of Onuiyieke River

	pH	**TSS**	**EC**	**TDS**	**TS**	**Turbidity**	**DO**	**BOD**	**Cl-**	**T-Hardness**	**Ca**	**Mg**	**PO_4^{3-}**	**Faecal coli**	**NO_3**	**NH_4**	**Temp**	**Fe**	**COD**
pH																			
TSS	0.192																		
EC	0.315*	0.462**																	
TDS	0.459**	0.469**	0.889**																
TS	0.329*	0.943**	0.687**	0.735**															
Turbidity	0.376*	0.499**	0.632**	0.726**	0.650**														
DO	-0.389*	-0.510**	-0.716**	-0.705**	-0.657**	-0.590**													
BOD	0.364*	0.263	0.582**	0.615**	0.429**	0.839**	-0.647**												
Cl-	0.393**	0.066	0.584**	0.695**	0.312*	0.586**	-0.384*	0.532**											
T-Hardness	0.543**	0.316*	0.742**	0.852**	0562**	0.518**	-0.529**	0.372*	0.690**										
Ca	0.502**	0.262	0.737**	0.803**	0.503**	0.464**	-0.474**	0.309*	0.685**	0.477**									
Mg	0.389*	0.212	0.737**	0.855***	0.486**	0.547**	-0.523**	0.454**	0.832**	0.821**	0.828**								
PO_4^{3-}	0.258	-.0132	0.341*	0.350*	0.030	0.172	-0.198	0.320*	0.481**	0.263	0.240	0.422**							
Faecal coliforms	0.367*	.0170	0.112	0.285	0.246	0.406**	-0.349*	0.429**	0.228	0.208	0.102	0.163	0.106						
NO_3	0.332*	0.040	0.142	0.216	0.115	0.355*	-0.400**	0.521**	0.443**	0.249	0.208	0.206	0.301	0.440**					
NH_3	0.320*	0.130	0.317*	0.350*	0.236	0.490**	-0.574**	0.683**	0.442**	0.259	0.177	0.261	0.363*	0.486**	0.840**				

Temp	0.055	0.097	0.104	0.121	0.105	0.004	-0.078	0.037	0.144	0.185	0.155	0.080	0.331*	-0.217	0.081	-0.028			
Fe	0.351*	0.288	0.666**	0.788**	0.509**	0.649**	-0.527**	0.600**	0.677**	0.561**	0.530**	0.725**	0.504**	0.203	0.211	0.341*	.*		
COD	0.472**	0.442**	0.539**	0.665**	0.590**	0.718**	-0.800**	0.784**	0.477**	0.428**	0.366*	0.411**	0.142	0.486**	0.467**	0.623**	596*		

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

Table 6 Spatial parameters used in the calculation of the Water Quality Index of Onuiyieke River

s/no	Parameters	SL1	SL2	SL3	SL4	SL5	SL6	SL7
1	pH	5.99	6.29	6.56	5.99	6.16	6.36	6.11
2	EC	21.50	37.33	1065.00	66.50	302.17	428.67	401.67
3	DO	8.07	7.03	4.28	7.48	5.23	6.85	47.75
4	Chloride	5.33	11.75	78.00	16.67	51.83	82.00	13.17
5	Nitrate	5.48	11.77	18.01	17.46	22.57	17.65	1.35
6	BOD	1.03	1.49	2.68	1.75	2.41	1.68	6.11
7	TSS	63.96	81.67	894.17	71.83	92.00	109.33	91.83
8	Total hardness	11.83	31.00	182.67	29.03	31.22	133.95	222.67
9	Total dissolved solids	12.53	28.00	778.17	38.67	177.83	285.00	7.10
Water Quality Index		16.24	34.46	123.05	45.14	87.70	68.98	58.05

Source: Author's Fieldwork, (2018).

3.7. Water Quality Index (WQI) of Onuiyieke River

The Water Quality Index of the present water body is established from important various physical, chemical and biological parameters in different site locations. Table 6 & 7 shows the result of the Water Quality Index across the sampling locations of the Onuiyieke River. The Water Quality for SL 1 gave a WQI of 16.24 showing that the control had excellent water quality while SL 2 gave a WQI of 36.46 indicating good water quality. However, SL3 gave a WQI of 123.04 indicating that the water from that location was unsuitable for drinking. SL 4 had a WQI of 58.05 classified as medium, while SL 5 graded very poor water having a WQI of 87.70 showing that the water from the location is of medium quality. SL 7 had a WQI of 58.05, indicating the self-cleansing characteristic of the river, thus it is graded medium water quality according to the Weighted Arithmetic Water Quality Index Method (WAWQI).

The water quality report showing the quality index for the nine parameters for each of the sampling locations can be seen in Tables 5 & 6. In SL 1, Dissolved Oxygen and BOD gave the quality rating of (2.66) and (20.6) while pH and EC gave the quality rating of (57.77) and (7.17) Nitrate and Chloride gave quality ratings of (12.18) and (2.13) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (12.79), (3.94) and (2.51) respectively.

In SL 2, Dissolved Oxygen and BOD gave the quality rating of (78.85) and (29.80) while pH and EC gave the quality rating of (47.33) and (7.17) Nitrate and Chloride gave quality ratings of (26.16) and (4.7) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (16.33), (10.33) and (5.60) respectively.

In SL 3, Dissolved Oxygen and BOD gave the quality rating of (107.50) and (53.60) while pH and EC gave the quality rating of (29.00) and (355.00) Nitrate and Chloride gave quality ratings of (40.02) and (173.33) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (178.83), (60.89) and (155.634) respectively.

In SL 4, Dissolved Oxygen and BOD gave the quality rating of (74.167) and (35.00) while pH and EC gave the quality rating of (67.33) and (22.16) Nitrate and Chloride gave quality ratings of (38.80) and (6.67) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (14.37), (9.68) and (7.73) respectively. In SL 5, Dissolved Oxygen and BOD gave the quality rating of (97.60) and (48.20) while pH and EC gave the quality rating of (56.00) and (100.72) Nitrate and Chloride gave quality ratings of (50.16) and (20.73) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (18.40), (10.41) and (35.57) respectively.

Table 7 Summary of water quality index (WQI) by site location along the course of Onuiyieke River

S/N	Site locations	0-25 Excellent	25 -50 Good	50 -70 Medium	70 -90 Very poor	90-100 Unsuitable
1	SL 1	16.24				
2	SL 2		34.46			
3	SL 3					123.05
4	SL 4		45.14			
5	SL 5				87.70	
6	SL 6			68.98		
7	SL 7			58.05		

Source: Author's Fieldwork, (2018)

In SL 6, Dissolved Oxygen and BOD gave the quality rating of (80.83) and (33.6) while pH and EC gave the quality rating of (42.67) and (142.89) Nitrate and Chloride gave quality ratings of (39.22) and (32.80) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (21.87), (44.65) and (57.00) respectively. In SL 7, Dissolved Oxygen and BOD gave the quality rating of (46.59) and (27.00) while pH and EC gave the quality rating of (59.33) and (133.89) Nitrate and Chloride gave quality ratings of (29.27) and (19.10) TSS, Total Hardness and Total Dissolved Solids gave the quality ratings of (1.22), (30.61) and (44.53) respectively. These values fall within the classification of water quality based on the weighted arithmetic WQI method as given in Table 5. SL3 had significant bad water quality this may be as a result of industrial and agro effluent, refuse dump disposal, runoff into the river at those locations. It follows that untreated water from site locations having water quality status of 51 and above is must, therefore, be treated before use to avoid water-related diseases. The water quality index of Onuiyieke River varies from excellent to unsuitable for drinking status suggesting impact of anthropogenic activities in the water body like the inflow of direct sewerage from residential and commercial establishments, lack of proper sanitation system, agricultural run-off, direct disposal of untreated effluents and unabated dumping of solid wastes by the communities residing in the area, etc.

4. Discussion

From the analysis of available data, the major findings of this research are as follows: The physical, chemical and biological characteristics of a water body are important in the determination of its productive capacity and effect on the biota.

Consumption of low pH water could lead to acidosis, which results in peptic ulcer. The low pH observed in all sampling points except SL 2 could be a result of human activities. These activities may have caused the death of some aquatic life forms. These aquatic life forms release proteins including ammonia upon death and decay. Comparing the mean pH of the water samples showed that their pH level was between 6.12- 7.00, within the range of standard limits for safe drinking water by WHO. The mean pH indicates slightly acidic water according to NESREA, [8] standards. The high temperature recorded in SL 5 and 6 when compared to the control location SL 1 might be as a result of agricultural inputs from downstream nearby. PC 4 was most highly correlated with water temperature which according to [10] might be a result of industrial and agricultural discharges, including runoffs into the river. The Total hardness range (4.20 – 200.00 mg/l) of the studied river falls within the degree of water hardness indicated. Though Total Hardness was within permissible limits with SL3 being the highest at 200.00mg/l in December 2017, The water is hard and is thus largely unsuitable for direct use by communities that use it for laundry work and bathing. Calcium and Magnesium hardness range from 3.00mg/l to 39.00mg/l and from 0.09 to 0.46 mg/l respectively. However, the mean concentration of calcium and magnesium is 15.15mg/l and 0.22mg/l which are below the recommended permissible limit of 200.00mg/l for both calcium and magnesium [11].

Some of these observed solids existed as un-dissolved suspended solids as observed in the present study and most dissolved to form dissolved solids as the case with Onuiyieke River. TSS, according to Andem *et al.* [3], can be defined as the portion of total solids in a water sample retained by a filter. Mean TSS in the present study when compared to the Control Location (SL 1) showed very high pollution in the Onuiyike River according to NESREA permissible limits of 0.25mg/l. PC 3 had the highest loading of TSS which can be attributed to discharges from agro-industries, dumping of solid wastes at the banks of the river, agricultural runoff and domestic sewage. The high conductivity values observed in SL 3, 5 and 6 could be attributed to high dissolved solids observed at the points. The progression of water conductivity level that increased from 7.00microhms/cm, in October 2017, at control point SL1, to 1368.00 microhms/cm at SL3 in February 2018 (an increase of about 52 per cent) reflects the status of inorganic pollution and is a measure of TDS in water thus far exceeding the WHO maximum permissible limit. The high value of the mean EC observed in the present study may be due to an increase in concentrations of salts, organic and inorganic materials as a result of discharges from industries, runoff from domestic and other human activities into the river. TDS in the present study also showed a similar trend with EC with the highest values being observed at SL 3. High values of EC and TDS recorded in SL 3 can be attributed to the nature of effluents discharged nearby. These discharges can contain high amounts of ions that exceed the recommended standard of [8]. This differs from the Control Location (SL 1) where the value is very low due to the absence of industries around that area. The wide range observed in the EC of the Onuiyike River indicates varying levels of conducting ions being discharged into the river. This may also be the reason for the positive correlations between the EC and the trace metals at $P<0.01$ in this study. Also, the high positive correlations between EC and TDS in this study indicate that as TDS increases, the EC of the river also increases.

Dissolved oxygen levels of Onuiyieke River were lower than that of the WHO standard, [9]. SL 3 recorded the least value of DO which according to [8] can pose a threat to fish and other higher forms of aquatic organisms. This low DO can be attributed to increased industrial effluents that may carry a high concentration of oxygen demanding materials from nearby farmlands. The lower level of DO noted at site SL 3 may be attributed to increased growth of aerobic bacteria in the presence of large organic matter, due to anaerobiosis. SL1 (upstream) had DO mean values within the acceptable (8.01mg/l). This indicates less organic waste input which provides enabling environment for aquatic life. The midstream, SL 3 and SL 5, however, had relatively lower DO values. This could be attributed to the impact of municipal wastes dumped in the river directly or through runoff. The mean BOD and COD indicate that the Onuiyieke River was relatively poor for aquatic growth according to NESREA Standards [8]. The values of COD recorded in the present study according to [12] who also recorded similar values of BOD and COD can be caused by the inflow of domestic, agricultural and growth of iron bacteria that hasten the rusting process of ferrous metals that come in contact with the water. The mean value of turbidity from the present study exceeded the desired limit of 10NTU according to NESREA standards, thereby making the river unfit for aquatic life. Also, the mean value of turbidity (18.84 NTU) exceeded that of SL 1 [8] The greater the amount of suspended solids in water, the murkier it appears and the higher the measured turbidity also, higher turbidity increases water temperatures and in turn reduces the concentration of Dissolved Oxygen (DO) [13].

This can be the reason for the inverse correlations between turbidity and DO in the present study. The high level of turbidity observed in this study can be attributed to runoff and anthropogenic activities. Turbidity of the water increased greatly from 4.5 NTU at SL1 to 48.70 NTU at SL 3 all in November 2017 showing an increase in the concentration of suspended matters in the water sample and soil particles transported by runoff to the river but highest at the point SL 3 after input of wastes from effluents. Reduction at the point of leaving in SL 7 is indicative of self-purification by the river. The mean total hardness in the present study showed a similar trend with EC at SL 3 recording the highest values (73.08mg/l). Total Hardness according to Cosmas & Samuel [14], is the sum of the Calcium and Magnesium concentration both expressed as calcium carbonate in milligrams per litre. This may be the reason for the positive correlations between calcium and magnesium as against Total Hardness in the present study. The mean Chloride ions in this study suggest that the river is suitable for the growth of organic organisms (41.9mg/l) when compared to the NESREA standards of 300mg/l. The existence of considerable amount of Cl^- ions in river water may be attributed to the discharge of agro and industrial effluents into the river as seen at SL 3 which is relatively high compared to the values of the control (SL1). The high correlations between Cl^- and conductivity shows that when Chlorine is introduced into the water, the quantity of electrolytes of total dissolved solids in the water rises which in turn raise the conductivity of water. The high mean ammonium and mean nitrate ions concentration recorded in SL 3 might be attributed to nitrogenous input indicating their heavy impact on the river. Nitrates find their way into water bodies through agricultural fertilizers, industrial wastewaters, landfills and garbage dumps [15]. Mean Nitrate levels across the sampling locations were progressively high, the highest located at SL 5 (22.57mg/l). This may explain the rich growth of water weeds and plankton around the site location. Farming and dumping of animal waste along the river course might be responsible for these high readings. Mean phosphate levels varied along with the sampling locations, the highest recorded at SL5 (2.72 mg/l). The mean phosphate from the present study according to [8] indicates that the river is relatively good for aquatic life but higher than the value of the Control Location SL1. Organisms such as *Escherichia coli*, *Klebsiella sp., Vibro sp*, *Proteus sp*., *Shigella sp., Salmonella sp., Staphylococcus epidermidis*, *Bacillus sp., Pseudomonas aeruginosa*, and *Citrobacter sp.,* were among the wide range of organisms isolated from Onuiyieke River water. The presence of these microorganisms has practical significance in terms of human activities [16] For instance, *Escherichia coli* signifies faecal coliform contamination of a water body [11]. *Escherichia coli, Klebsiella sp., Proteus sp., Shigella sp., and Salmonella sp.*, belong to the family known as *Enterobacteriaceae* [17]. Their presence in water indicates faecal waste contamination.

On average about 70% of the total coliforms are of faecal origin. The total bacterial count ranged from 3.0 ×104 to 7.5 ×104 CFU/ml. Faecal indicators are microbes whose presence indicates that the water may be contaminated with human or animal wastes. Results of bacteriological analyses including total heterotrophic count, total coliform and thermotolerant coliform counts revealed a high level of faecal pollution of the river. This range is higher than WHO standards. Some genera could be of soil origin while others are of intestinal and hence faecal origin. Vibro sp, Pseudomonas sp, and Citrobacter sp., identified in the present study further indicate the presence of more pathogens in Onuiyieke River. The differences observed in concentrations of these organisms could be as a result of human activities. The presence of these organisms in Onuiyieke River may be an indication of possible water-borne diseases such as typhoid fever, cholera, dysentery, etc. on the consumption of water from the river by humans.

There are major sources of pollutants in Onuiyieke River. Wide variations were observed in the values of the nineteen parameters studied which includes water temperature, pH, TSS, EC, TDS, TS, Turbidity, DO, BOD_5, Cl^- ion concentration, total hardness, Ca^+ ion concentration, Mg^+ ion concentration, NO_3^-, NH_3 and Fe ion concentration, Faecal coliforms and PO_4^{3-} ion concentration. This variation indicates various levels of inputs across the various locations.

TSS contributed the greatest variability among the physical, chemical and biological parameters studied.

All the parameters measured except PO_4^{3-} ion concentration and water temperature differed significantly in their mean concentrations across the sampling locations. PO_4^{3-} ion concentration differed significantly during the study period (Sept 2017- Feb 2018)

Several parameters correlated positively indicating similar anthropogenic sources of pollution into the river ranging from industrial discharges, agricultural activities, nearby waste dump, and runoff.

The mean values of pH, EC, turbidity, BOD_5, faecal coliforms$^-$, NH_3, and Fe ion concentration exceeded the maximum permissible limits of NESREA and WHO for aquatic life and potability.

The water quality index showed that sample location 3 and 5 were badly polluted while the rest were moderately polluted. The overall water quality of the river is of medium quality indicating various stages of eutrophication.

5. Conclusion

The water quality of the water body is a significant technique for a complete assessment of the water body. The physical, chemical and biological parameters such as pH, turbidity, Electrical Conductivity, Ammonia, Iron, BOD, Magnesium and faecal coliforms exceeded the maximum permissible limits of NESREA and WHO. Also, the result of the water quality index across the sampling locations indicates bad water quality in some locations while for others, it is average, it can, therefore, be concluded that water from Onuiyieke River is not potable but may be used for other purposes. Human activities along the course of the river should be monitored for the sustainability of the ecosystem. Onuiyieke river demands appropriate monitoring procedures for pollution control and mitigation for sustainable development of the resource. This study tried to examine the surface water quality of the Onuiyieke River. Further studies should dwell more on heavy metal concentrations such as lead, cadmium, arsenic, etc. as well as sediment chemistry to properly assess the current status of the river. This is as a result of increasing anthropogenic activities going on at the banks of the river.

Compliance with ethical standards

Acknowledgements

The authors will like to appreciate everyone who participated in the study and publication of this article.

Disclosure of conflict of interest

The authors acknowledge that there is no conflict of interest during the publication of this article.

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