RESEARCH ARTICLE

Physicochemical Assessment of Omambala and Ezu Rivers in Anambra State, Nigeria, Using Artificial Neural Networks and Fuzzy Logic

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Abstract: This study analytically assesses the water quality of the Omambala and Ezu Rivers, both of which are subject to significant anthropogenic influences and surface runoff, resulting in pronounced pollution. The primary objective was to assess the water quality using the Water Quality Index (WQI) methodology, focusing on both physicochemical parameters and toxic elements. A total of thirty water samples were collected, fifteen from each river, at three strategically selected sampling locations. Physicochemical analyses were conducted following the American Public Health Association (APHA) standard methods, and the findings were evaluated against the permissible limits established by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). Results revealed that both rivers are heavily polluted, with WQI values indicating severe degradation: 568.269 for River Omambala and 672.99 for River Ezu, the latter demonstrating a higher level of pollution. Conversely, the assessment of potentially toxic elements yielded WQI values of 423.67 for River Omambala and 289.93 for River Ezu, suggesting greater contamination in River Omambala regarding these elements. Notably, parameters such as pH, temperature, dissolved oxygen, total dissolved solids, total hardness, chlorides, and sulfates fell below NSDWQ permissible limits, while electrical conductivity, biochemical oxygen demand, turbidity, and nitrates exceeded recommended thresholds for both rivers. Elevated concentrations of Arsenic and Iron were observed, posing additional health risks. These findings underscore the critical influence of anthropogenic activities on water quality. Comprehensive management strategies, including pollution mitigation measures and community engagement, are urgently recommended to restore the ecological integrity of these rivers. Further research is warranted to explore the long-term impacts of observed pollution and the effectiveness of implemented interventions.

Keywords: Water Quality Index, anthropogenic pollution, physicochemical parameters, toxic elements, environmental management

1 Introduction

Water is an essential natural resource for the ecosystem and living things which is utilized for drinking and general well-being [1,2]. Surface water includes rivers, lakes, dams, reservoirs, etc and the general populace depends on surface water for domestic purposes, irrigation purposes, economic development and industrial activities. Unfortunately, surface water is no longer safe as a result of anthropogenic activities such as agricultural wastes, industrial effluents, dumping of solid wastes into water bodies, contamination by potentially toxic elements pollutants and increase population, which has greatly contaminated the surface water and hence affects the quality of such surface water [3]. Thus, making accessibility and availability of clean and uncontaminated water difficult. As a result, heavy metals is considered one of the most dangerous pollutants of all these activities as they alter the chemical composition of surface water thereby resulting to consequences detrimental to humans, other animals, vegetation and soil pollution [4]. Thus, considered a worldwide environmental problem [5,6] and causing death of about 3 million people annually [7].

Potentially toxic elements and metalloids are non-biodegradable elements that occur in the earth's crust with high density, significant concentrations of these toxic elements such as Cobalt, Iron, Lead, Copper, Cadmium, Nickel, Chromium, Arsenic and Zn has high risk on human health and negative tendency towards the environment [8,9]. Potentially toxic elements enter the environment through natural and anthropogenic activities such as mining, industrial processes and waste disposal [10, 11]. Potentially toxic elements such as lead can be present in municipal solid waste incinerators, fuel, plumbing systems, industrial activities and motor vehicles (i.e. tetraethyl lead) [12]. Cadmium may be found in automobile tyres, industrial production and inappropriate disposal of batteries and release of spent oils from automobile workshops while zinc can contaminate natural waters through roofing sheets, galvanized pipes, metal oxidation enter the water bodies through surface run-off, sewage, effluent discharge, mine drains and release of spent oils from automobile workshops etc. Iron can be present in surface water through oxidation of metals (rusting of metals) [13, 14]. Potentially toxic elements tend to accumulate in food chains [15], thus they cause serious human health issues, such as neurological disorders, nervous system damage, multiple organ damage such as the kidney, Alzheimer's disease, cancer, fragile bones and even death in case of large amount of the potentially toxic elements [16–18]. However, human beings need some trace metals such as iron, zinc and copper for intracellular and DNA-binding processes, but these metals are toxic even in trace amount [19].

Surface water monitoring is essential, especially when the water is normally used for industrial, agricultural and domestic purposes [20, 21]. Apart from the use of surface water as domestic purposes, irrigation purposes, economic development and industrial activities, the Rivers, Omambala and Ezu, are known to be rich in natural resources such as fisheries, readily available protein. With the increasing human population, there is need for sustainable exploitation of these fisheries resources [22].

The importance of this river to the local population is that it serves as a fish ground and above all as a source of water for domestic purposes, especially when public water supply fails. This work is therefore, an attempt to examine the selected potentially toxic elements sampled locations of Rivers Omambala and Ezu, in Anambra State and compared with the WHO and NSDWQ standard for conformity to physicochemical standards for drinking water quality.

The information obtained from this research work makes recommendations where necessary, providing knowledge of physicochemical parameters, potentially toxic elements pollutant, Water Quality Index (WQI) and other reliable information that could be useful to the relevant government, water treatment agencies, research institutes and the general public health and safety.

2 Materials and Methods

2.1 Study Area

The description of the study areas are Omambala River, Anambra East L.G.A and Ezu River, Awka North L.G.A of Anambra State, Nigeria were investigated (Figure 1 and 2). The two rivers are located at longitude $6^o36^o.0^1$E and $7^o12.0^1$E and latitude $5^o42^o.0^1$N and $6^o36^o0^{'}$N within the tropical rain forest belt [22]. Omambala is a tributary of River Niger (North), Ezu River (South), Omor and Umuerum communities (East). The area is located within the tropical climate of the rainforest vegetation with distinct dry and wet seasons. The dry season lasts from November to March while the rainy season from April to October with mean annual rainfall of about 1805 mm. River omambala flows 210 kilometres (130 miles) into the Niger River before finally being released into the Atlantic ocean through various outlets [23].

2.2 Sample Collection and Pretreatment

Three sampling points were selected along the length of River Omambala (labelled ROWS1, ROWS2 and ROWS3) and along River Ezu (labelled REWS1, REWS2 and REWS3). Plastic bottles were used for sample collection; they were washed with detergent, rinsed with distilled water and dried in an oven overnight 105^oC. The marked sterilized bottles were dipped into the river at a depth of 25cm below the water surface. The samples were collected between 9.00am and 11.00am, sealed and covered with black polythene bag to prevent reaction with sunlight. A total of thirty (30) water samples; fifteen (15) water samples each were collected for the study from the three different points in Omambala River and River Ezu.

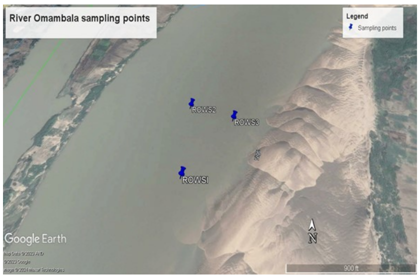


Figure 1 Map showing River Omambala

Figure 2 Map showing River Ezu

2.3 Digestion of water sample

The water samples were shaken thoroughly in their various plastic containers before the commencement of the analysis. 100 ml of water sample was measure into a 100 ml conical flask, 5ml of concentrated nitric acid was added and heated on a hot plate to evaporated about 20 ml in order to ensure that the water did not boil. A further 5ml of concentrated nitric acid (65% purity) was added and the beaker was covered with a watch glass while heating continued. Concentrated nitric acid was added at an interval until the solution appeared coloured and cleared. Few drops of hydrogen peroxide were then added to ensure complete digestion. The solution was filtered and the filtrate was transferred to a 100 ml volumetric flask to cool and then made up to the mark with distilled water [24].

2.3.1 Determination of Physicochemical Properties of River Omambala and River Ezu

The physical parameters such as temperature, pH, electrical conductivity and total dissolved solid were measured and recorded at the time of collection of water samples. The physico-chemical analysis was carried out using the American Public Health Association (APHA) [25] standard methods for water analysis as follows [APHA]:

(1) Determination of pH: The pH was determined using a pH meter (Hanna Instrument, Model: HI991300). The pH meter was calibrated using buffer standards at pH 4, pH 7 and pH 9. After the calibration, the pH electrode was rinsed with distilled water, cleaned dry and then rinsed with the water sample. The electrode was then dipped into each of the water samples in turn and the respective pH readings were obtained from the digital readout.

(2) Determination of Temperature: This was determined using the mercury-in-glass thermometer, calibrated in degree Celsius with a range of 0–100°C. The thermometer was immersed into the can containing the water sample for five minutes to ensure a complete stabilization before taking the readings.

(3) Determination of Electrical Conductivity: The conductivity meter used was HANNA EC 215 conductivity meter. The conductivity meter probe was rinsed with deionized water, cleaned dry and then rinsed with the water sample. The probe was then dipped into the water samples in turn to obtain the respective conductivity reading from the digital readout.

(4) Determination of Dissolved oxygen: This was determined using the Winkler method.

(5) Determination of Biochemical oxygen Demand: This was determined using the Winkler method.

(6) Determination of Turbidity: Turbidity was determined using a turbidity meter (Thermo Fisher Scientific, Model: AQ4500).

(7) Determination of Total Hardness: This was determined by titrimetric method using Solochrome Black-T as indicator and 0.01EDTA as titrant. The titre values were recorded and the total hardness of the water sample was calculated thus:

$$\text{Total hardness } (\mathrm{mg/CaCO_3}) = \frac{\text{Volume of Titrate } \times \ 1000}{\text{Volume of samples } (\mathrm{cm^3})} \tag{1}$$

(8) Determination of Chloride: This was done by the Argentometric titration method using potassium chromate as indicator and 0.01M silver nitrate as titrant. The titre values were recorded and chloride concentration of the water sample was calculated thus:

$$\text{Chloride concentration} = \text{titre value} \times 10 = 10 \times \mathrm{mg/l} \tag{2}$$

(9) Determination of Nitrate and Sulphate: Nitrate and Sulphate were measured using a UV–visible spectrophotometer (Bioevo-peak, Model: 721G-100).

2.3.2 Potentially Toxic Elements Analysis

Potentially toxic elements analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer (AAS) according to the method of APHA (American Public Health Association) [26, 27]. The wavelength (energy) absorbed in the flame is proportional to the concentration of the element in the sample. The standard solution for each tested element was prepared according to its concentration and the calibration curve for each metal was prepared by plotting the absorbance of standards versus their concentrations [23, 28].

2.4 Data Analysis

The data obtained from this study was analyzed using statistics (mean) for the three sampling points on Omambala River and Ezu River and compared with the recommended limits set by the Nigeria Standard for Drinking Water (NSDWQ) [29] and World Health Organization (WHO) [30].

2.5 Water Quality Index

Water quality index is a tool used to determine status of water quality by integrating all the parameters while comparing with the standards recommended by the government authorities to safe guard human health [31, 32]. The WQI was calculated using the standards recommended by World Health Organization (WHO) and the Nigeria Standard for Drinking Water (NSDWQ). The WQI was calculated by averaging the individual index values of some or all of the parameters within five water quality parameter categories that depicts the pollution level or status of the water: turbidity biochemical oxygen demand, dissolved oxygen, nutrients (total nitrogen (mg/l), and/or total phosphorus (mg/l)) and total solids. The standard value of the ith parameter is inversely proportional to the relative weight. Relative weight (w_i) is calculated by:

$$\mathrm{Wi} \; \alpha \; 1/\mathrm{Si} \tag{3}$$

The unit weight for each water quality parameter is calculated by using the following parameter:

$$\mathrm{Wi} = \mathrm{k}/\mathrm{Si} \tag{4}$$

$$\mathrm{K} = 1/\sum 1/\mathrm{Si} \tag{5}$$

Where:
Wi = relative weight
Si = Recommended NSDWQ/WHO standard value of i parameter
K = Proportionality constant

The Quality rating scale is calculated as [31–33]:

$$\mathrm{Qi} = 100 \times \frac{(\mathrm{Vi} - \mathrm{Vi}_0)}{(\mathrm{Si} - \mathrm{Vi}_0)} \tag{6}$$

$$\mathrm{Qi} = \mathrm{Vi}/\mathrm{Si} \times 100 \tag{7}$$

where,
Q_i = sub index of the ith parameter.
V_i = concentration of the ith parameter.
S_i = Recommended WHO standard value of the ith parameter.
Vi_0 = the ideal value of the nth parameter in pure water. The ideal value used for all parameters was zero, except pH =7 and DO = 14mgL^{-1} [33].

The sub-index Si and WQI are computed using the relationship in Equations (3) and (4), respectively.

$$\mathrm{SIi} = \mathrm{wi} \times \mathrm{qi} \tag{8}$$

$$\mathrm{WQI} = \sum \mathrm{SIi} \tag{9}$$

Where: SI_i is the sub-index of the ith parameter and q_i is the rating based on the concentration of the ith parameter.

Finally, overall WQI was calculated using the WQI [34, 35] according to the following expression:

$$\mathrm{WQI} = \frac{\sum{}^{\mathrm{n}}\mathrm{iQiWi}}{\sum \mathrm{Wi}} \tag{10}$$

The water quality ratings are 0–25 (excellent), 26–50 (good), 51–75 (poor), 76–100 (very poor) and > 100 (heavily polluted) [36].

3 Results and Discussion

Table 1 Physicochemical Properties of Rivers Omambala and Ezu in Anambra State

Parameter	ROWS-1	ROWS-2	ROWS-3	REWS-1	REWS-2	REWS3	NSDWQ standards
pH	5.51	5.91	5.99	5.09	6.43	4.99	6.5–8.5
Temp. (^{o}C)	27.74	28.97	29.25	27.71	28.53	30.40	25–35
E.C (μs cm^{-1})	1469.70	1530.65	1623.82	1731.18	1361.52	1830.51	1000
Dissolved oxygen (mg L^{-1})	6.12	5.48	5.64	4.41	6.84	4.53	10.00
Biochemical oxygen demand (mg L^{-1})	16.73	18.61	15.45	20.02	26.43	19.70	2.00
Total dissolved solid (mg L^{-1})	27.54	32.09	38.62	19.75	21.12	24.86	500
Turbidity (NTU)	35.19	29.30	30.36	27.14	21.74	29.50	5.00
Total hardness (mg L^{-1})	20.27	17.96	17.95	22.26	29.19	22.26	150.00
Chloride (mg L^{-1})	73.08	93.57	100.58	105.69	84.26	98.33	250.00
Nitrate (mg L^{-1})	53.85	60.95	63.25	76.89	50.15	80.39	50.00
Sulphate (mg L^{-1})	49.04	53.77	56.33	50.20	43.51	57.05	250.00

Table 2 Potentially toxic elements in surface water from Rivers Omambala and Ezu in Anambra State

Parameter	ROWS-1 (mg/L)	ROWS-2 (mg/L)	ROWS-3 (mg/L)	REWS-1 (mg/L)	REWS-2 (mg/L)	REWS-3 (mg/L)	NSDWQ Standards	WHO limits
As	0.095	0.114	0.130	0.080	0.093	0.056	0.01	0.01
Cd	0.008	0.004	0.005	0.004	0.002	0.002	0.03	0.01
Cu	0.010	0.008	0.012	0.09	0.006	0.008	1.00	2.00
Fe	2.004	1.900	1.769	2.533	1.989	2.164	0.30	0.30
Pb	0.007	0.009	0.008	0.008	0.007	0.005	0.01	0.01
Zn	0.305	0.287	0.299	0.456	0.376	0.311	3.00	5.00

Note: * NSDWQ: Nigerian Standard for Drinking Water Quality; * WHO: World Health Organization; * ROWS: River Omambala Water Sample; * REWS: River Ezu Water Sample.

Table 3 Computation of Water Quality Index from River Omambala

Parameter	VI	SI	1/SI	WI	QI	QIWI
pH	5.80	7.5	0.1333	0.1324	**77**.33	10.24
Temp. (^{o}C)	28.65	27.5	0.03636	0.03610	104.18	3.76
E.C (μs cm^{-1})	1541.39	1000	0.001	0.0009927	154.14	0.15
Dissolved Oxygen (mgL^{-1})	5.75	10.0	0.1	0.09927	57.50	5.71
Biochemical Oxygen Demand (mgL^{-1})	16.93	2.0	0.5	0.4964	846.5	420.20
Total Dissolved Oxygen (mgL^{-1})	32.75	500	0.002	0.001985	6.55	0.013
Turbidity (NTU)	31.62	5.0	0.2	0.1985	632.4	125.53
Total Hardness (mgL^{-1})	18.73	150	0.00667	0.006605	12.49	0.082
Chloride (mgL^{-1})	89.08	250	0.004	0.003971	35.63	0.14
Nitrate (mgL^{-1})	59.35	50	0.02	0.01985	118.7	2.36
Sulphate (mgL^{-1})	53.05	250	0.004	0.003971	21.22	0.084
			$\sum$ (1/Si) = 1.00733	1.0000447		$\sum$ Qiwi = 568.269

Table 4 Computation of Water Quality Index from River Ezu

Parameter	VI	SI	1/SI	WI	QI	QIWI
pH	5.50	7.5	0.1333	0.1324	73.33	9.71
Temp. (^{o}C)	28.88	27.5	0.03636	0.03610	105.02	3.79
E.C (μs cm^{-1})	1641.07	1000	0.001	0.0009927	164.11	0.16
Dissolved Oxygen (mgL^{-1})	5.26	10.0	0.1	0.09927	52.60	5.22
Biochemical Oxygen Demand (mgL^{-1})	22.05	2.0	0.5	0.4964	1102.50	547.28
Total Dissolved Oxygen (mgL^{-1})	21.91	500	0.002	0.001985	4.38	0.0087
Turbidity (NTU)	26.13	5.0	0.2	0.1985	522.6	103.74
Total Hardness (mgL^{-1})	24.57	150	0.00667	0.006605	16.38	0.11
Chloride (mgL^{-1})	96.09	250	0.004	0.003971	38.44	0.15
Nitrate (mgL^{-1})	69.14	50	0.02	0.01985	138.28	2.74
Sulphate (mgL^{-1})	50.25	250	0.004	0.003971	20.1	0.080
			$\sum$ (1/Si) = 1.00733	1.0000447		$\sum$ Qiwi = 672.99

Note: K=1/$\sum$ (1/Si); wi = k/Si; K = 1/1.00733; K = 0.9927; The Quality rating scale is calculated as CCME WQI [31]: Qi =Vi / Si x100

Table 5 Computation of Water Quality Index of Potentially Toxic Elements in Surface water from River Omambala in Anambra State

Parameter	Vi	Si	1/Si	Wi	Qi	Qiwi
Arsenic	0.113	0.01	100.00	0.329	1130.0	371.77
Cadmium	0.00567	0.01	100.00	0.329	56.7	18.65
Copper	0.01	2.00	0.50	0.00165	0.5	0.000825
Iron	1.891	0.30	3.33	0.0110	630.33	6.93
Lead	0.008	0.01	100.0	0.329	80.0	26.32
Zinc	0.297	5.00	0.20	0.000658	5.94	0.00391
			$\sum$(1/Si) = 304.03	1.000308		$\sum$Qiwi = 423.67

Table 6 Computation of Water Quality Index of Potentially Toxic Elements in surface water from River Ezu in Anambra State

Parameter	Vi	Si	1/Si	Wi	Qi	Qiwi
Arsenic	0.0763	0.01	100.00	0.329	763.0	251.03
Cadmium	0.00267	0.01	100.00	0.329	26.7	8.78
Copper	0.0347	2.00	0.50	0.00165	1.735	0.0029
Iron	2.229	0.30	3.33	0.0110	743.0	8.17
Lead	0.00667	0.01	100.0	0.329	66.7	21.94
Zinc	0.381	5.00	0.20	0.000658	7.62	0.00501
			$\sum$(1/Si) = 304.03	1.000308		$\sum$Qiwi = 289.93

Note: K = 1/$\sum$(1/Si); wi = k/Si; K = 1/304.03; K = 0.00329; The Quality rating scale is calculated as CCME WQI [31]: Qi = Vi/Si $\times$ 100

Table 7 Water Quality Assessment

Physicochemical Parameters	WQI Values	Grade
River Omambala	568.269	E
River Ezu	672.99	E
Potentially Toxic Elements	WQI Values	Grade
River Omambala	423.67	E
River Ezu	289.93	E

Note: Total WQI $>$ 100, CLASS E

3.1 Plots of the actual data

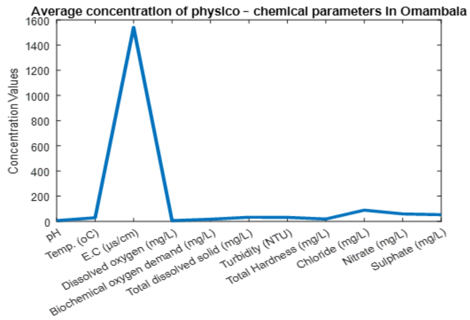


Figure 3 Actual plot for River Omambala

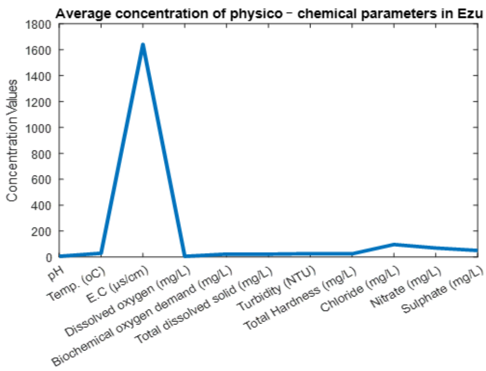
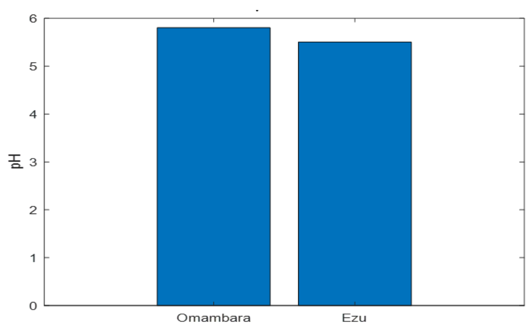


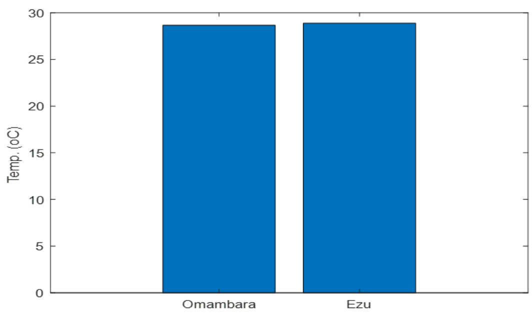
Figure 4 Actual plot for River Ezu



ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	0.7569	1	0.7569	6.78	0.1213
Error	0.2234	2	0.1117		
Total	0.9803	3			

Figure 5 pH plots



ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	1.05063	1	1.05063	21.61	0.0433
Error	0.09725	2	0.04862		
Total	1.14787	3			

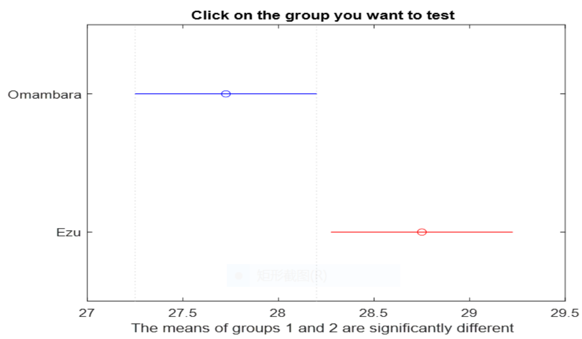


Figure 6 Temperature plots

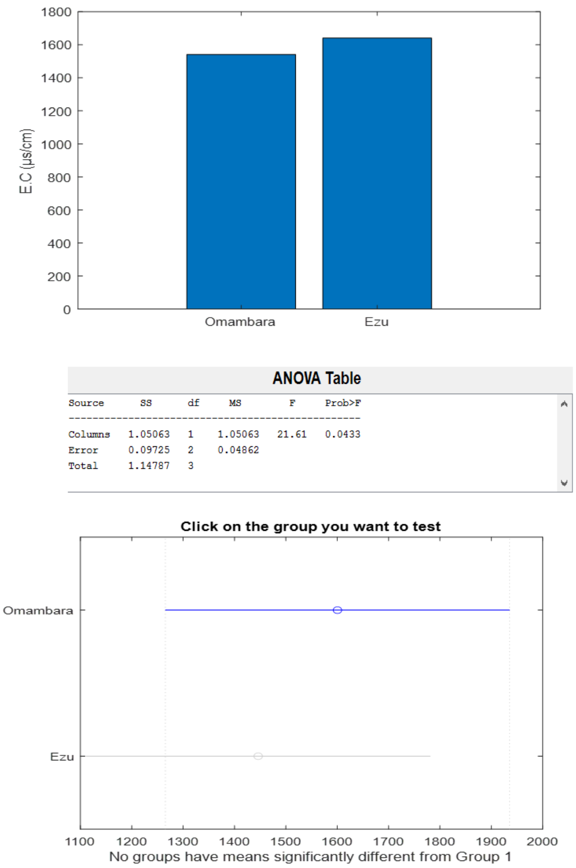


Figure 7 E.C (μs/cm) plots

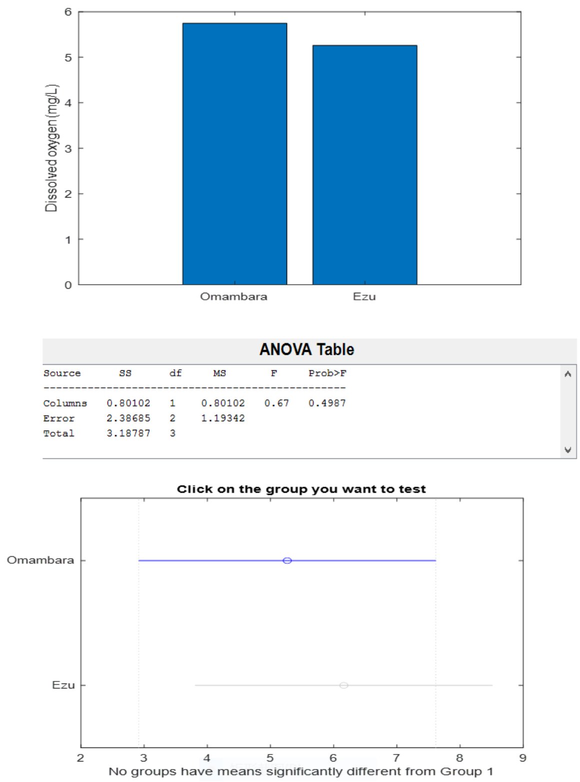
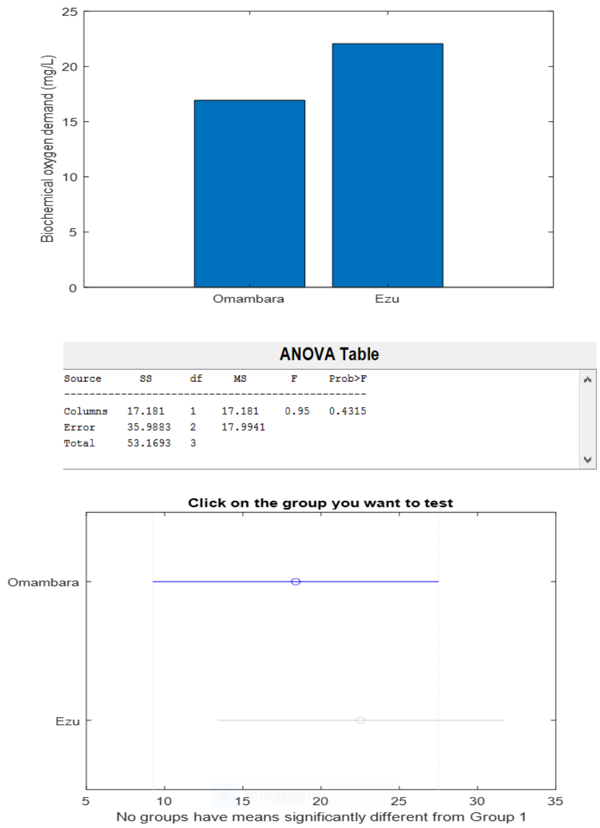
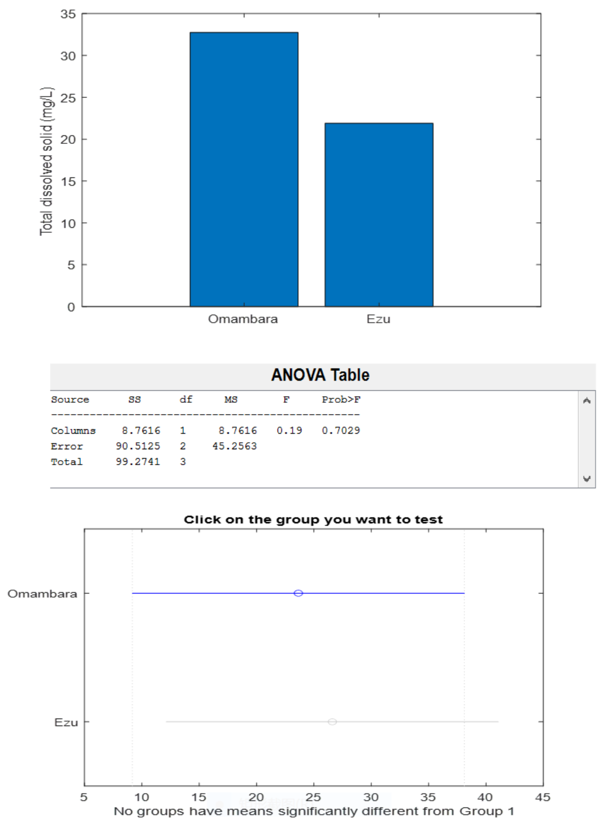


Figure 8 Dissolved oxygen (mg/L) plots



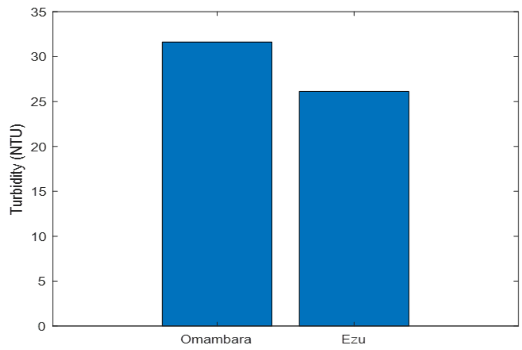
Source	SS	df	MS	F	Prob>F
Columns	17.181	1	17.181	0.95	0.4315
Error	35.9883	2	17.9941		
Total	53.1693	3			

Figure 9 Biochemical oxygen demand (mg/L) plots



Source	SS	df	MS	F	Prob>F
Columns	8.7616	1	8.7616	0.19	0.7029
Error	90.5125	2	45.2563		
Total	99.2741	3			

Figure 10 Total dissolved solid (mg/L) plots



ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	31.866	1	31.866	1.05	0.4141
Error	60.978	2	30.489		
Total	92.8441	3			

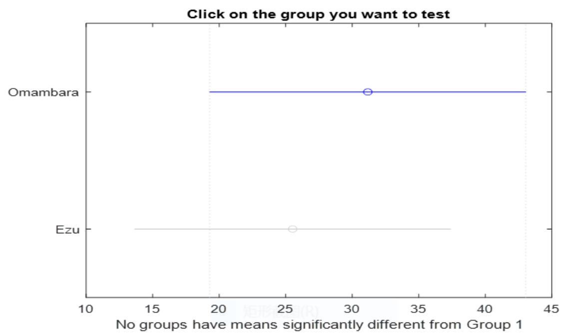
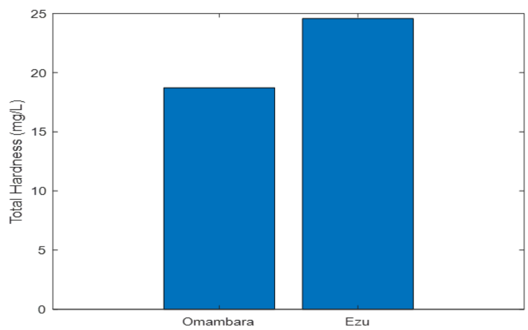


Figure 11 Turbidity (NTU) plots



ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	5.3361	1	5.3361	0.16	0.7246
Error	65.0365	2	32.5183		
Total	70.3726	3			

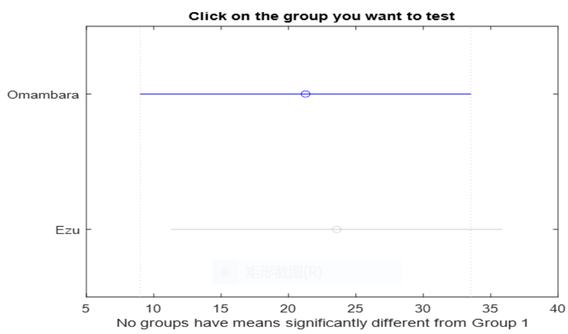


Figure 12 Total Hardness (mg/L) plots

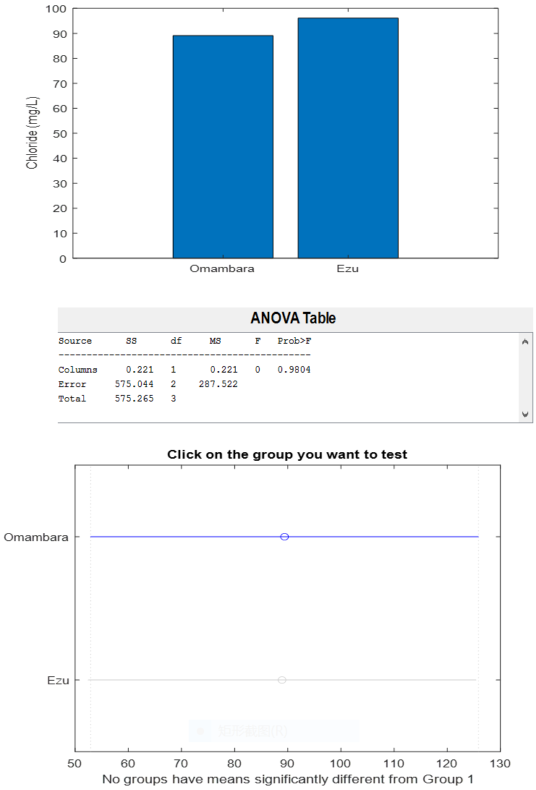


Figure 13 Chloride (mg/L) plots

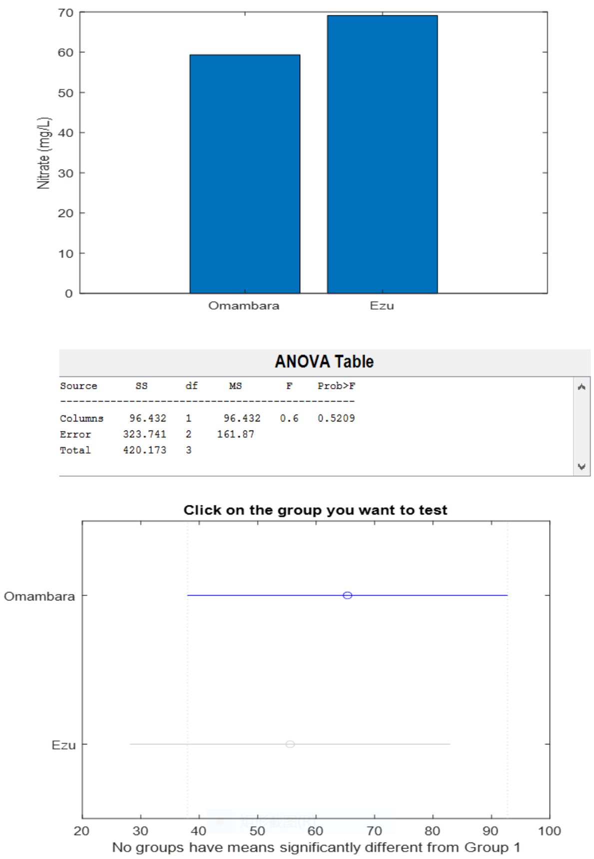
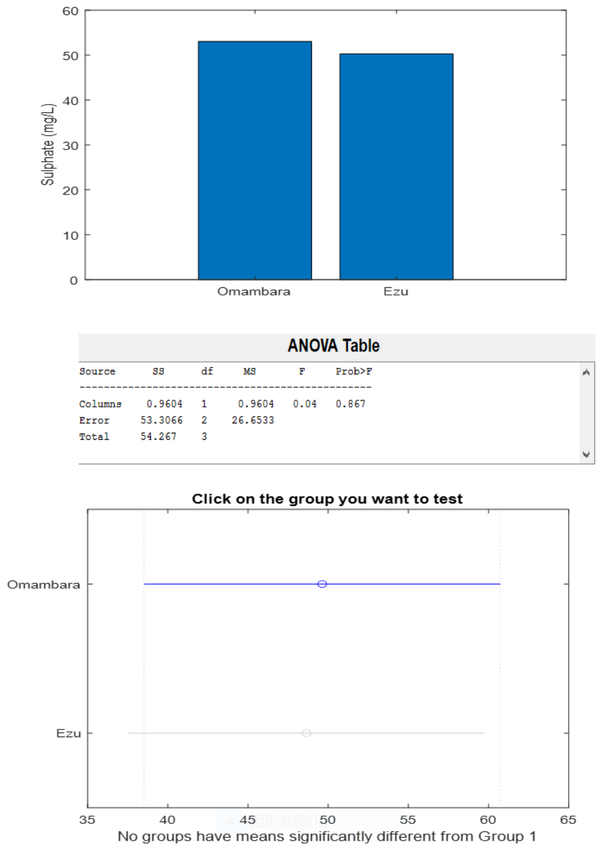


Figure 14 Nitrate (mg/L) plots



Source	SS	df	MS	F	Prob>F
Columns	0.9604	1	0.9604	0.04	0.867
Error	53.3066	2	26.6533		
Total	54.267	3			

Figure 15 Sulphate (mg/L) plots

3.2 Plot with ANN

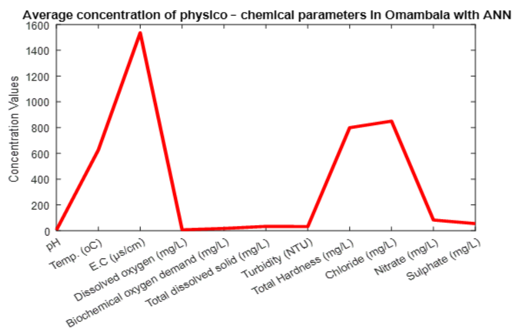


Figure 16 ANN for River Omambala

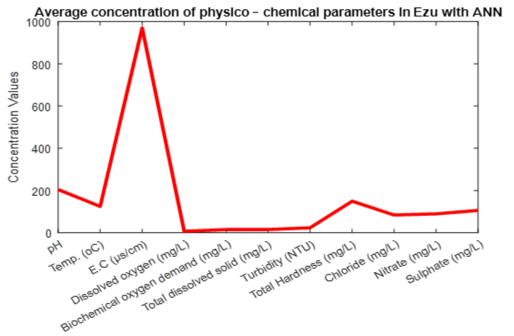


Figure 17 ANN for River Ezu

3.3 Plot with Fuzzy logic

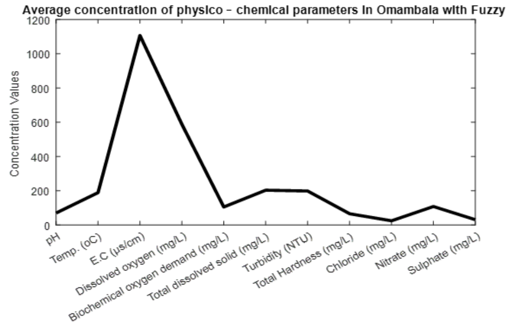


Figure 18 Fuzzy logic for River Omambala

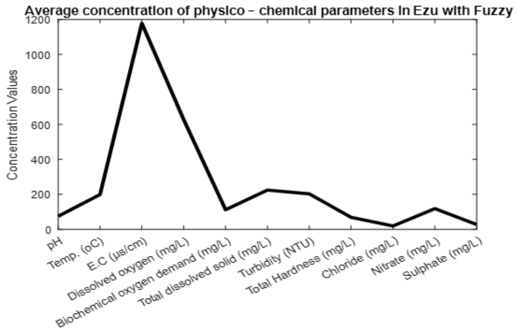


Figure 19 Fuzzy logic for River Ezu

3.4 Comparative analysis

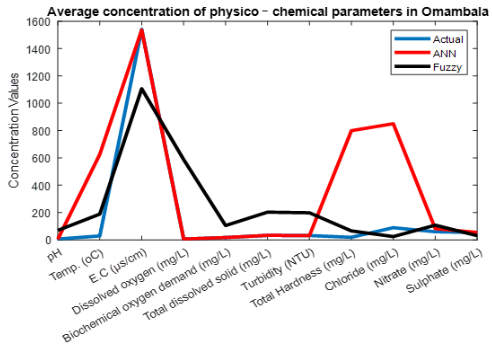


Figure 20 Comparative plot for River Omambala

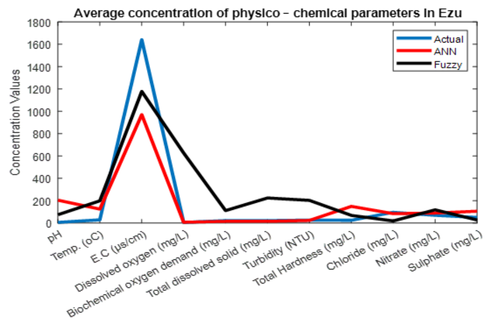


Figure 21 Comparative plot for River Ezu

pH: The mean concentration of River Omambala is 5.80 and ranged from 5.51-5.99 while the mean concentration of River Ezu is 5.50 and ranged from 4.99-6.43. These values are below the acceptable limit of the Nigerian Standard for Drinking Water Quality (NSDWQ). This implies that the mean pH values for both rivers are slightly acidic.

Temperature: The mean concentration of River Omambala is 28.65 and ranged from 27.74-29.25 while the mean concentration of River Ezu is 28.88 and ranged from 27.71-30.40. These values are within the ambient temperature range stipulated by the Nigerian Standard for Drinking Water Quality (NSDWQ).

Electrical conductivity: The mean concentration of River Omambala is 1541.39 and ranged from 1469.70-1530.65 while the mean concentration of River Ezu is 1641.07 and ranged from1361.52-1830.51. It can be seen that these values are higher than the acceptable Nigerian Standard for Drinking Water Quality limit. The high electrical conductivity values were attributed to the impact of dissolved ions in the surface water [37].

Dissolved oxygen: The mean concentration of River Omambala is 5.75 and ranged from 5.48-6.12 while the mean concentration of River Ezu is 5.26 and the ranged from 4.41-6.84.The dissolved oxygen values are below the recommended limit stipulated by the Nigerian Standard for Drinking Water Quality, this is in agreement to the earlier work done by Ikeogu et al. [23] in River Omambala. Dissolved oxygen is one of the most important indicators of good water quality and it is required for the survival of fish and other aquatic organisms [38].

Biochemical oxygen demand: The mean concentration of River Omambala is 16.93 and ranged from 15.45-16.73 while the mean concentration of River Ezu is 22.05 and ranged from 19.70-26.43. The values are much higher than the recommended Nigerian Standard for Drinking Water Quality, which conforms to the earlier work done by Okeke et al. [22]. This implies that the water contains biodegradable organic matter, indicating that the water is highly polluted, therefore High BOD indicates low DO [39].

Total dissolved solid: The mean concentration of River Omambala is 32.75 and ranged from 27.54-38.62 while the mean concentration of River Ezu is 21.91and ranged from 19.75-24.86. These values are far below the recommended limit stipulated by the Nigerian Standard for Drinking Water Quality. This is in line with earlier work done by Okeke et al. [22] in River Omambala and Mor et al. [40] in River Ezu.

Turbidity: The mean concentration of River Omambala is 31.62 and ranged from 29.30-35.19 while the mean concentration of River Ezu is 26.13 and ranged from 21.74-29.50. It can be seen that the turbidity values are significantly higher than the stipulated limit recommended by the Nigerian Standard for Drinking Water Quality, this conforms to the earlier work done by Okeke et al. [22] in River Omambala. According to Kabari et al. [33], high turbidity values in surface waters can harbor microbial pathogens and result to health risks when consumed directly or indirectly.

Total hardness: The mean concentration of River Omambala is 18.73 and ranged from 17.95-20.27 while the mean concentration of River Ezu is 24.57 and ranges from 22.26-29.19, this is in line with Okeke et al. [22] and Wakawa et al. [40] in River Ezu. It can be seen that the total hardness values reported in this study are far below the recommended limit stipulated by the Nigerian Standard for Drinking Water Quality. This means that the water is not hard, but may lack some essential minerals like Ca^{2+} and Mg^{2+} ions needed for proper body functioning.

Chloride: The mean concentration of River Omambala is 89.08 and the ranged from 73.08-100.58 while the mean concentration of River Ezu is 96.09 and ranged from 84.26-105.69 , this conforms to the earlier work done by Wakawa et al. [40] in River Ezu. These chloride values are much lower than the stipulated limit by the Nigerian Standard for Drinking Water Quality.

Nitrate: The mean concentration of River Omambala is 59.35 and ranges between 53.85-63.25 while the mean concentration of River Ezu is 69.14 and ranges between 50.15-80.39. The values are higher than the recommended limit by the Nigerian Standard for Drinking Water Quality, which conforms to the earlier work done by Ikeogu et al. [23] in River Omambala. Nitrate in occurs mainly from fertilizers, waste dumps, and manure storage pollution [41].

Sulphate: The mean concentration of River Omambala is 53.05 and ranged from 49.04-56.33 while the mean concentration of River Ezu is 50.25 and ranged from 43.51-57.05. This conforms to the earlier work done by Wakawa et al. [40] in River Ezu. The sulphate values are far below the recommended limit by the Nigerian Standard for Drinking Water Quality. Sulphate in the water can occur through the oxidation of sulphide in soils, mineral dissolution and runoff of fertilizers in the soil [42].

3.5 Potentially toxic elements of River Omambala

Arsenic: The mean concentration of River Omambala is 0.113 and ranged from 0.095-0.130 while the mean concentration of River Ezu is 0.0763 and ranged from 0.056-0.093. The values are higher than the recommended limit by the World Health Organization (WHO), this conforms to earlier work done by Tabugbo et al. [43] in River Omambala. Surface run-offs, refuse dumps and agricultural activities may have contributed to the high concentration of iron. Arsenic is a potent carcinogen. Excessive exposure to high arsenic levels in water can cause skin lesions, cancers and other health problems [44–48].

Cadmium: The mean concentration of River Omambala is 0.00567 and ranged from 0.004-0.005 while the mean concentration of River Ezu is 0.00267 and ranged from 0.002-0.004. The values are lower than the recommended limit by the World Health Organization (WHO), this conforms to similar work done by Tabugbo et al. [43] in River Omambala. However, high concentration of cadmium from batteries, electronic wastes, paints and hydrocarbon exploration and extraction in surface waters is considered toxic to aquatic organisms and humans [44, 49, 50]. In fishes, it affects the endocrine function thereby reducing breeding and fish population. For children, it affects their bone formation. Cadmium is highly toxic. Long-term exposure to cadmium in water or food can lead to kidney damage, lung cancer, and bone disorders [44, 51–58].

Copper: The mean concentration is 0.01 and ranged from 0.008-0.012 while the mean concentration of River Ezu is 0.0347 and ranged from 0.006-0.09. The values are lower than the recommended limit by the World Health Organization (WHO), this conforms to earlier work done by Tabugbo et al. [43] in River Omambala and Wakawa et al. [40] in River Ezu.

Iron: The mean concentration of River Omambala is 1.891 and ranged from 1.769-2.004 while the mean concentration of River Ezu is 2.229 and ranged from 1.989-2.533. The values are higher than the recommended limit by the World Health Organization (WHO), this conforms to earlier work done by Tabugbo et al. [43] and Ikeogu et al. [23] in River Omambala. Surface run-offs, refuse dumps and agricultural activities may have contributed to the high concentration of iron.

Lead: The mean concentration River Omambala is 0.008 and ranged from 0.007-0.009 while the mean concentration of River Ezu is 0.00667 and ranged from 0.005-0.008. The values are lower than the recommended limit by the World Health Organization (WHO), this conforms to earlier work done by Tabugbo et al. [43] in River Omambala.

Zinc: The mean concentration is 0.297 and ranged from0.287-0.305 while the mean concentration of River Ezu is 0.381 and ranged from 0.311-0.456. The values are lower than the recommended limit by the World Health Organization (WHO), this conforms to earlier works done by Tabugbo et al. [43] and Ikeogu et al. [23] in River Omambala.

Water Quality Index

The WQI revealed that all the water samples from both River Omambala and River Ezu were heavily polluted both for the physicochemical parameters and toxic elements. For the physicochemical parameters; WQI for River Omambala is 568.269, while that of River Ezu is 672.99. The values show that River Ezu is more polluted than River Omambala. For the potentially toxic elements; WQI for River Omambala is 423.67, while that of River Ezu is 289.93. The values show that River Omambala is more polluted than River Ezu. This could be as a result of anthropogenic activities such as the chemicals employed during fishing and natural factors.

The WQI values from this study when compared to other regions showed that the WQI values were higher than the values found in Lagos, Nigeria [21], and (174.49) for Otamiri and Orimiriukwa, Owerri [48]. However, WQI values higher than the study area results which ranged from (138.62-44412.16) Niger Delta [33], (1243.9–3034.5) Uyo, Nigeria [46], 752.4–752.8 Rivers, Nigeria [47]. Therefore, river water must be well treated for drinking, domestic purposes and to effectively harness the natural resources such as fishes due to the heavy pollution of the environment.

4 Conclusion

The physicochemical examination of both River Omambala and River Ezu revealed that the water samples were polluted with different concentrations of pollutants. The pH, DO,TDS, total hardness, chloride, sulphate values were below the recommended limit according to the

National Standard for Drinking Water Quality (NSDWQ), while the electrical conductivity, BOD, turbidity and nitrate values were above the recommended limit according to the National Standard for Drinking Water Quality (NSDWQ). For potentially toxic elements, only Arsenic and Iron values were above the World Health Organization (WHO) drinking water limits for both River Omambala and River Ezu. Water with high electrical conductivity, turbidity, nitrate, Arsenic and Iron values is unfit for consumption and hence requires treatment. Apart from providing economic development and domestic purposes, River Omambala and River Ezu is known to a provide source of food (proteins), through fishing in the community hence it is suitable for aquaculture purposes when properly treated to reduce high concentrations of heavy metals

The WQI showed that both rivers were heavily polluted both for the physicochemical examination and potentially toxic elements. Therefore, there is a need for regular quality monitoring of both River Omambala and River Ezu. Also, the government and water treatment agencies, research institutes should ensure quality water is made available for the general public health and safety.

Authors' contributions

VCE & UUE: visualization, conceptualization and methodology; NJO: writing- original draft preparation; CHE & CCA: reviewing and supervision; BLA & CCI: editing and data curation; MNN & FAE: investigation and software; SKE: methodology and validation; AOE: visualization.

Data availability

All data discussed in this study are available in the current tables and figures.

Conflict of interest

The authors declare no competing interests.

References

[1] Harun HH, Roslan MKM, Nurhidayu S, et al. Physicochemical analysis of groundwater and suitability for domestic utilization in Kuala Langat, Selangor. IOP Conference Series: Earth and Environmental Science. IOP Publishing. 2021, 646(1): 012025.
https://doi.org/10.1088/1755-1315/646/1/012025

[2] Adimalla N, Qian H. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicology and Environmental Safety. 2019, 176: 153-161.
https://doi.org/10.1016/j.ecoenv.2019.03.066

[3] Cousins I, Sha B, Johansson J, et al. How safe is it to drink water? 2022.
https://theconversation.com

[4] Adepoju-Bello A A, Ojomolade O O, Ayoola G A, et al. Quantitative analysis of some toxic metals in domestic water obtained from Lagos metropolis. The Nig. J. Pharm. 2009, 42(1): 57-60.

[5] Muhammad S, Shah MT, Khan S. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchemical Journal. 2011, 98(2): 334-343.
https://doi.org/10.1016/j.microc.2011.03.003

[6] Pejakov T, Tepic I, Vidikant P, et al. Reducing harmful effects of metals in water. Metalurgija. 2014, 53(4): 677-680.

[7] Olawale AF, Oluwagbayide SD, Akinyika A. Assessment of rainwater quality obtained from a suburban area of Nigeria based on the physico-chemical properties. Techno-Science. 2020, 3(2): 50-58.

[8] Amos IA, Edward BA, Maryam I. Quality Assessment of the Physicochemical Properties of Soils from AutomobileWorkshops and Transformer Installations Site in Lafia, Nasarawa State. Science World Journal. 2023, 18(1).
https://www.scienceworldjournal.org

[9] Rahman Z, Singh VP. The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. Environmental Monitoring and Assessment. 2019, 191(7).
https://doi.org/10.1007/s10661-019-7528-7

[10] Chen X, Zeng XC, Kawa YK, et al. Microbial reactions and environmental factors affecting the dissolution and release of arsenic in the severely contaminated soils under anaerobic or aerobic conditions. Ecotoxicology and Environmental Safety. 2020, 189: 109946.
https://doi.org/10.1016/j.ecoenv.2019.109946

[11] Nawab J, Din ZU, Ahmad R, et al. Occurrence, distribution, and pollution indices of potentially toxic elements within the bed sediments of the riverine system in Pakistan. Environmental Science and Pollution Research. 2021, 28(39): 54986-55002.
https://doi.org/10.1007/s11356-021-14783-9

[12] Hassan NE, Mohammed SJ. Assessment of Ground Water Pollution by Heavy Metals in SomeResidential Areas in Kurdistan Region of Iraq. Environ Sci Arch. 2023, 2: 35-44.
https://doi.org/10.5281/zenodo.7625078

[13] Agbi GG, Akpokodje OI, Uguru H. Evaluating the impact of traffic activities on the heavy metals concentrations along a major highway in Delta State, Nigeria. Direct Research Journal of Public Health and Environmental Technology. 2021, 6: 45-51.
https://doi.org/10.26765/drjphet70711801

[14] Briffa J, Sinagra E, Blundell R. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon. 2020, 6(9): e04691.
https://doi.org/10.1016/j.heliyon.2020.e04691

[15] Zakir HM, Sharmin S, Akter A, et al. Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. Environmental Advances. 2020, 2: 100005.
https://doi.org/10.1016/j.envadv.2020.100005

[16] Azeh Engwa G, Udoka Ferdinand P, Nweke Nwalo F, et al. Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the Modern World-New Tricks for an Old Dog? IntechOpen. 2019.
https://www.intechopen.com

[17] Badeenezhad A, Radfard M, Abbasi F, et al. Effect of land use changes on non-carcinogenic health risks due to nitrate exposure to drinking groundwater. Environmental Science and Pollution Research. 2021, 28(31): 41937-41947.
https://doi.org/10.1007/s11356-021-13753-5

[18] Mohammadpour A, Motamed-Jahromi M, Soleimani H, et al. Trace elements human health risk assessment by Monte Carlo probabilistic method in drinking water of Shiraz, Iran. International Journal of Environmental Science and Technology. 2023, 20(4): 3775-3788.
https://doi.org/10.1007/s13762-023-04815-x

[19] Pandey S, Kumari N. Impact assessment of heavy metal pollution in surface water bodies. Metals in Water. Published online 2023: 129-154.
https://doi.org/10.1016/b978-0-323-95919-3.00004-5

[20] Brazilian Journal of Analytical Chemistry.
https://doi.org/10.30744/brjac.2179-3425

[21] Adeyi AA, Majolagbe AO. Assessment of groundwater quality around two major active dumpsites in Lagos, Nigeria. Global Journal of Science Frontier Research: B Chemistry. 2014, 14(7): 15-23.

[22] Okeke JJ, Okoye CO, Ayadiuno RU, et al. Evaluation of the ichthyofaunal diversity of some sections of Omambala, Ezu and Ahommiri Rivers in Anambra State, Nigeria. Int J Forest Animal Fisheries Res. 2012, 2(1): 18-27.
https://doi.org/10.22161/ijfaf.2.1.3

[23] Ikeogu CF, Uzoma OS, Okpala-Ezennia KP, et al. Evaluation of Suitability of Omambala River in Anaku Community for Aquaculture Production. International Journal of Environmental & Agriculture Research (IJOEAR). 2022.

[24] Radojevic M, Bashkin VN. Practical environmental analysis. Royal society of chemistry, 2007.

[25] APHA, American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 19th ed. Washington, DC: American Public Health Association (APHA), 2005.

[26] American Public Health Association, American Water Works Association and Water Environment Federation (APHA, AWWA and WEF). Standard Methods for the Examination of Water and Wastewater, 20th edn. Washington, DC; 2001. (London, England: F and FN Spon 1996). California, Division of Agriculture and Natural Resources.

[27] Ogoko EC. Water Quality Assessment of Dug Wells in Lagos Island, Southwestern Nigeria. Communication in Physical Sciences. 2019, 4(2): 110-117.

[28] Ogoko EC, Mgbemana N, Ijeoma K H. Heavy metals contamination of Anambra River. Communication in Physical Sciences. 2020, 6(1): 714-721.

[29] WHO, World Health Organization. Guidelines for drinking-water quality. 4th ed. Geneva: WHO Press, 2017.

[30] Nigerian Standard for Drinking Water Quality 2007.

[31] Canadian Council of Ministers of the Environment (CCME) WQI.

[32] Shrestha S, Bista S, Byanjankar N, et al. Groundwater quality evaluation for drinking purpose using water quality index in Kathmandu Valley, Nepal. Water Science. 2023, 37(1): 239-250.
https://doi.org/10.1080/23570008.2023.2237278

[33] Sam KS, Onyena AP, Erieegha OJ, et al. Water quality evaluation using water quality index and pollution model in selected communities in Gbaramatu Kingdom, Niger Delta, Nigeria. African Journal of Environmental Science and Technology. 2023, 17(6): 118-134.

[34] Noori MD. Comparative analysis of weighted arithmetic and CCME Water Quality Index estimation methods, accuracy and representation. IOP Conference Series: Materials Science and Engineering. 2020, 737(1): 012174.
https://doi.org/10.1088/1757-899x/737/1/012174

[35] Olubukola Ajoke Adelagun R, Edet Etim E, Emmanuel Godwin O. Application of Water Quality Index for the Assessment of Water from Different Sources in Nigeria. Promising Techniques for Wastewater Treatment and Water Quality Assessment. Published online December 1, 2021.
https://doi.org/10.5772/intechopen.98696

[36] Alum OL, Okoye CO, Abugu HO. Quality assessment of groundwater in an agricultural belt in eastern Nigeria using a Water Quality Index. African Journal of Aquatic Science. 2021, 46(3): 304-318.
https://doi.org/10.2989/16085914.2021.1882375

[37] Eze VC, Onwukeme VI, Ogbuagu JO, et al. Evaluation of selected physicochemical properties of River Otamiri, Imo State. Health and Environment. 2024, 4(1): 209-216.
https://doi.org/10.25082/he.2023.01.003

[38] Amakiri KT, Ogolo NA, Angelis-Dimakis A, et al. Physicochemical assessment and treatment of produced water: A case study in Niger delta Nigeria. Petroleum Research. 2023, 8(1): 87-95.
https://doi.org/10.1016/j.ptlrs.2022.05.003

[39] Adesakin TA, Oyewale AT, Bayero U, et al. Assessment of bacteriological quality and physicochemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. Heliyon. 2020, 6(8): e04773.
https://doi.org/10.1016/j.heliyon.2020.e04773

[40] Wakawa YM, Nwaiwu NE. (2019). Physicochemical and Bacteriological Assessment of EZU River. American Journal of Engineering Research. 2019, 8(3): 239-244.

[41] Mor S, Ravindra K, Dahiya RP, et al. Leachate Characterization and Assessment of Groundwater Pollution Near Municipal Solid Waste Landfill Site. Environmental Monitoring and Assessment. 2006, 118(1-3): 435-456.
https://doi.org/10.1007/s10661-006-1505-7

[42] Akinbile CO, Yusoff. MS. Environmental Impact of Leachate Pollution on Groundwater Supplies in Akure, Nigeria. International Journal of Environmental Science and Development. Published online 2011: 81-86.
https://doi.org/10.7763/ijesd.2011.v2.101

[43] Tabugbo BI, Ogbuagu OJ, Ekpunobi UE, et al. Heavy metal pollution in the marine environment: A study contribution of three rivers to the pollution at the upper of the River Niger. Nigeria. Progress Chem and Biochem Res. 2024, 7(1): 51-64.
https://doi.org/10.48309/pcbr.2024.421932.1300

[44] Akinterinwa A, Oladele E, Adebayo A, et al. Synthesis of cross-linked carboxymethyl legume starch for adsorption of selected heavy metals from aqueous solutions. Adv. J. Chem.-Sect. A. 2020, 3: 594-611.

[45] Hu Z, Li J, Wang H, et al. Soil Contamination with Heavy Metals and Its Impact on Food Security in China. Journal of Geoscience and Environment Protection. 2019, 07(05): 168-183.
https://doi.org/10.4236/gep.2019.75015

[46] Determination of Water Quality Index for the Assessment of Groundwater Quality Around Uyo Refuse Dumpsite. Umudike Journal of Engineering and Technology. Published online June 1, 2020: 49-54.
https://doi.org/10.33922/j.ujet_v6i1_5

[47] Effects of Open Dumpsite Leachate on Groundwater Quality: a Case Study of Alakahia Dumpsite in Port Harcourt, Nigeria. Journal of Environmental Studies. 2015, 1(1).
https://doi.org/10.13188/2471-4879.1000002

[48] Amadi AN, Olasehinde PI, Okosun EA, et al. Assessment of the water quality index of Otamiri and Oramiriukwa Rivers. 2010.

[49] Aralu CC, Okoye PAC, Abugu HO, et al. Toxicity and distribution of polycyclic aromatic hydrocarbons in leachates from an unlined dumpsite in Nnewi, Nigeria. International Journal of Environmental Analytical Chemistry. 2022, 104(18): 6220-6231.
https://doi.org/10.1080/03067319.2022.2140415

[50] Aralu CC, Okoye PAC, Abugu HO, et al. Pollution and water quality index of boreholes within unlined waste dumpsite in Nnewi, Nigeria. Discover Water. 2022, 2(1).
https://doi.org/10.1007/s43832-022-00023-9

[51] Eze VC, Onwukeme VI, Ogbuagu JO, et al. Toxicity and risk evaluation of polychlorinated biphenyls in River Otamiri, Imo State. Scientific African. 2023, 22: e01983.
https://doi.org/10.1016/j.sciaf.2023.e01983

[52] Eze VC, Onwukeme VI, Ogbuagu JO, et al. Source apportionment of polychlorinated biphenyls in surface water and sediments from River Otamiri, Imo State. Scientific African. 2023, 22: e01957.
https://doi.org/10.1016/j.sciaf.2023.e01957

[53] Aralu CC, Okoye PAC, Eze VC, et al. Seasonality of environmental health risks and soil pollution from an unsanitary landfill in Nigeria: Implications for water security, agriculture, and climate adaptation. Journal of Hazardous Materials Advances. 2025, 17: 100597.
https://doi.org/10.1016/j.hazadv.2025.100597

[54] Agbasi JC, Egbueri JC, Alghamdi AA, et al. Analytical Examination of the Nutritional Status of Drinking Water Resources: A First Case Application in Africa. Analytical Letters. Published online November 12, 2024: 1-17.
https://doi.org/10.1080/00032719.2024.2426041

[55] Ononogbo C, Ohwofadjeke PO, Chukwu MM, et al. Agricultural and environmental sustainability in nigeria: a review of challenges and possible eco-friendly remedies. Environment, Development and Sustainability. Published online September 26, 2024.
https://doi.org/10.1007/s10668-024-05435-2

[56] Aralu CC, Okoye PAC, Abugu HO, et al. Potentially toxic element contamination and risk assessment of borehole water within a landfill in the Nnewi metropolis. Health and Environment. 2023, 4(1): 186-197.
https://doi.org/10.25082/he.2023.01.001

[57] Onwukeme VI, Eze VC. Identification of heavy metals source within selected active dumpsites in southeastern Nigeria. Environmental Analysis Health and Toxicology. 2021, 36(2): e2021008.
https://doi.org/10.5620/eaht.2021008

[58] Eze VC, et al. Assessment of vanadium pollution and ecological risk in some selected waste dumpsites in Southeastern Nigeria. Health and Environment. 2022, 3(1): 169-175.
https://doi.org/10.25082/he.2022.01.004