WATER POLLUTION

Assessment of Surface Water Quality along Rumuodogo/Osogu Market Creek of Sombrero River, Rivers State, South-South Nigeria

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Abstract

Surface water bodies play an important role in sustaining aquatic ecosystems and supporting the domestic and economic activities of communities. However, increasing human activities around rivers and creeks can introduce pollutants that compromise water quality and threaten aquatic life and public health. This study assessed the physicochemical (pH, EC, DO, BOD, COD, TDS and TSS) and selected metal (Pb, Cd, Mg and Mn) concentrations of surface water along Rumuodogo/Osogu Market Creek, a tributary of the Sombrero River in Rivers State, Nigeria. Water samples for quasi-experiment were collected from three sampling points, designated SP1, SP2, and SP3, to examine spatial variations in selected water quality parameters. The results showed that the water was acidic across all three sampling points, with pH values ranging from 4.98 to 5.53. EC ranged from 683 to 708 µS/cm, while DO ranged from 6.83 to 7.68 mg/L. BOD values varied between 1.43 and 1.60 mg/L, whereas COD ranged from 5.25 to 8.40 mg/L. TDS concentrations ranged from 342 to 354 mg/L, while TSS varied between 9 and 12 mg/L. Turbidity ranged from 19 to 22 NTU. The metal results also revealed spatial variations. Pb concentrations ranged from 0.1573 to 1.2100 mg/L, with the highest concentration recorded at SP1. Cd increased progressively across the sampling points, from 0.0079 mg/L at SP1 to 0.1069 mg/L at SP3. Mn and Mg also increased from SP1 to SP3, reaching 2.3421 mg/L and 3.1724 mg/L, respectively, at SP3. The findings demonstrate variations in water quality across the study area, particularly in acidity and selected metal concentrations. The acidic nature of the water and the observed Pb and Cd concentrations warrant further investigation and comparison with applicable water quality standards.

Keywords: Surface water quality; physicochemical parameters; heavy metals; lead; cadmium; Rumuodogo/Osogu Market Creek; Sombrero River; Rivers State

1 Introduction

Water is a substance with two atoms of hydrogen and an atom of oxygen chemical bounded together (Bibiye et al., 2022). It is a free-gift of nature that supports human survival, ecological stability, economic development, and the continued functioning of aquatic ecosystems. Surface water bodies, including rivers, streams, creeks, and estuaries, provide habitats for aquatic organisms and may serve as sources of water for domestic activities, fishing, agriculture, transportation, and other livelihood activities (WHO, 2021; UNEP, 2021; UNEP, 2018). In many developing regions, these water bodies are particularly important to communities where access to reliable treated water is limited. Though, the quality of surface water can deteriorate when natural processes interact with human activities that introduce pollutants into the aquatic environment.

According to Bawa-Allah (2023) and World Health Organization (WHO) (2022), water quality refers to the physical, chemical, and biological characteristics of water that determine its suitability for a particular use. These characteristics are influenced by geological formations, rainfall, soil composition, tidal movements, drainage patterns, and human activities within the surrounding catchment. Domestic wastewater, market refuse, agricultural runoff, industrial effluents, petroleum-related activities, and poorly managed waste disposal can introduce contaminants into rivers and creeks. Consequently, the assessment of surface water quality requires the measurement of relevant physicochemical parameters and potentially harmful chemical substances, including heavy metals (WHO, 2022).

The assessment of water quality is particularly important in the Niger Delta region of Nigeria, where an extensive network of rivers, creeks, wetlands, and estuarine environments supports human settlements, fisheries, transportation, and commercial activities. Rivers State forms part of this environmentally sensitive region. Its aquatic ecosystems are exposed to varying pressures associated with urban development, population growth, waste disposal, oil and gas activities, and other land-use changes. These activities do not necessarily affect every water body to the same degree, making location-specific investigations important for understanding the condition of individual creeks. Where wastewater, solid waste, runoff, illegal bunker activities or other pollutant sources enter a water body, changes may occur in its physicochemical characteristics and the concentrations of potentially harmful substances. Heavy metals are of particular concern because some can persist in aquatic environments, interact with suspended particles and sediments, and pose risks to aquatic organisms or human populations when exposure is sufficient. Unlike many visible forms of pollution, metal contamination may not produce an obvious change in the appearance or smell of water. Reliable laboratory analysis is therefore necessary to determine whether selected metals are present at concentrations of environmental or public-health concern (Bawa-Allah, 2023; Hamza- Hama Aziz et al., 2023; Ajala et al., 2022; WHO, 2022; Adams et al., 2020; Miranda et al., 2021; Basti et al., 2024). Physicochemical measurements are equally important because they provide information about the condition of the water and help explain factors that may influence the behaviour of metals. Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), and oxygen-demand indicators can reveal variations in water chemistry and identify conditions requiring further investigation (Chapman, 2021).

Surface water quality is an important environmental concern because rivers and creeks receive materials transported from their surrounding catchments and may be affected by both natural processes and human activities. Studies conducted in Rivers State have demonstrated the relevance of examining physicochemical characteristics and heavy-metal concentrations together when evaluating aquatic pollution. For example, Ogan (2023) investigated water and sediment characteristics in Oginigba/Woji Creek, Port Harcourt, and reported measurable variations in physicochemical parameters and selected metals across sampling stations. This type of research illustrates the value of assessing both general water chemistry and potentially toxic elements when investigating the environmental condition of a creek. However, findings from one water body cannot automatically be applied to another because pollutant concentrations depend on local hydrology, surrounding activities, sediment characteristics, and the timing of sampling. Even though studies have examined water quality in other aquatic environments in Rivers State, results from those locations cannot establish the current condition of Rumuodogo/Osogu Market Creek. A separate investigation is needed to determine the concentrations of selected heavy metals and the physicochemical characteristics of water collected from the creek. The central research problem is therefore the need for

reliable, site-specific evidence on the heavy-metal concentrations and physicochemical characteristics of surface water along Rumuodogo/Osogu Market Creek. Without such measurements, it would be difficult to establish baseline water quality conditions, identify spatial differences, or determine whether measured parameters exceed relevant environmental or drinking-water guideline values, where those values are applicable. The resulting data will provide an evidence-based assessment of the creek's water quality and identify parameters that may require further environmental investigation. Such information would provide a scientific basis for evaluating observed water quality conditions, identifying parameters that require further investigation, and supporting environmental monitoring and management. To achieving this, the following specific objectives were set out: 1. 1. Determination of some physicochemicals (pH, EC, DO, TDS, TSS, Turbidity, BOD, COD & Mg) and selected heavy metals (Pb, Cd & Mn) characteristics of surface water along Rumuodogo/Osogu Market Creek. 2. Examine spatial variations in physicochemical characteristics and heavy-metal concentrations within sampling stations of the river. 3. Determine the relationships between selected physicochemical parameters and heavy-metal concentrations and 4. Compare the measured concentrations with applicable Nigerian environmental standards and relevant international guideline values, while distinguishing drinking-water criteria from standards intended for other environmental uses.

2 Materials and methods

2.1 Study design

Analytic descriptive study design was utilized. The design was relevant to this study because it provides a picture of the situation as it naturally happens (Ogomaka, 1992; Nwankwo, 2016).

2.2 Study area

Emohua is dominated with agrarian farming than fishing in terms of occupation. It has an Area estimation of 832km2 (321 sq.ml.) and a population of 201, 901(NPC, 2006) (Wikipedia.org). Its latitude and longitude are 50100N and 60540E, with a tropical rainforest and having characteristics of 8 months rainy and 4 months dry seasons. Average temperature is between 220C and 290C.The Emohua are part of the Ikwerre speaking community with distinctive qualities in terms of culture, tradition, and socio-economic activities. They have vast land with little marsh land, highly suitable for agricultural purpose; the East-West Road transverses through the Local Government Area, to the west of Nigeria. However, the Rumuodogo/Osogu market creek transverses from Degema (Sombrero River) downstream and River Niger upstream (Figure 1). This route serves as one of the major sea net-work of the Kalabari people to trade with their Ikwerre (Inland/Northern) neighbours. The coastal/southern of it lies Iyibo kiri (George-Douglas kiri) and Harrison Kiri of Degema Local Government Area respectively while at far North-west lies Abua, Local Government Area and north-est lies Obuama (Delga) and Ilelema (Asalga) respectively. The creek serves as natural boundary between Delga and Emuoha Local Government Area respectively. The adjacent communities (Iyibo kiri and Harrison kiri of Degema local Government Area) are deeply rooted in agrarian farming. The rainfall patter of the study area is influenced by highly seasonal, heavy, and dictated by their locations within the humid, tropical Niger Delta region of Rivers State. Emuoha has lowland (~5.1°N) rainforest zone. Both Emuoha and Delga LGAs (lower latitude ~4.5°N) exhibit a "double maxima" rainfall pattern (meaning they experience two distinct peak periods of high rainfall separated by a short dry spell). Geographically, the River (Rumuodogo/Osogu creek) falls within the marine/coastal

mangrove zone (coastal/estuarine ecosystem) receiving immediate convective and orographic rainfall from ocean winds. The annual rainfall pattern in Emuoha is moderately-high; ranges between 1,700mm and 2,100mm with peak rainfall months as July and September with an average under 45mm at December recording High (~180 to 200 days) rainy days per year.

Osogu Creek (mostly known as Fe-okolo by the kalabaris) is part of the interconnected network of creeks and waterways within the Niger Delta region of Rivers State, Nigeria. It is associated with the Sombreiro River drainage system (tributaries), which forms an important component of the hydrological network of the eastern Niger Delta. The creek is situated within a low-lying deltaic environment characterized by extensive wetlands, swampy terrain, interconnected waterways and alluvial deposits. Its hydrological characteristics are influenced by seasonal rainfall, surface runoff, groundwater contributions, tidal fluctuations and the movement of water through adjoining river channels (Figure 1)

2.3 Sampling locations

Three (3) sampling location were identified and named SP1 (Upstream i.e., entry point), SP2 (Middle-stream Market influenced location also known as Fepoku were intense anthropogenic activities takes place), and SP3 (Downstream), respectively along the Rumuodogo/Osogu market creek (a tributary to the Sombrero River). The HANNA HI 9828 PH/ORD/EC/DO meter was used to measure surface water, pH, Dissolved Oxygen (DO), Electrical conductivity, BOD, and Total Dissolved Solids (TDS) in situ. Measurements were made in triplicates and the average taken. No tidal disturbances for sample collection.

Again, water sample from these locations were collected during the second quarter (early rainy season of 2022) using water sampler to about 30cm below the surface water and stoppered. The sample for the physicochemical parameters were placed in a 2 liters plastic container which was previously rinsed with the water sample to be collected. Addition of 2 drops of concentrated Nitric acid (HNO3) was made to the sample of the heavy metal which was placed in 150ml plastic container to retain their integrity. A 250ml brown reagent bottle was used to collect the BOD and in situ measurement was carried out. All the samples were preserved in a cool ice- packed-box and were transported to the laboratory for analysis.

2.4 Laboratory analysis

All the water quality parameter measured were expressed in mg/L, except pH, turbidity (NTU) and EC (µS/cm). Samples were analyzed for 12 (DO, pH, EC, TDS, TSS, Turbidity, BOD, COD, Cd, Mn, Mg and Pb) parameters using Standard Methods for Examination of Water and Wastewater in line with the experimental procedure of the APHA/AWWA/ WEF (2023). Details of the experimental methods and equipment used are given elsewhere (Baird et al., 2017; Chounlamany, 2015; Chapman, 2021).

2.4.1 pH, electrical conductivity, total dissolved solids, total suspended solids and turbidity

The above parameters were measured using Horriba Water Checker (Model U-10) after calibrating the instrument with the standard Hinbu Solution. The units of measurement are µS/cm mg/L, mg/L and NTU respectively for conductivity, TDS, TSS and turbidity.

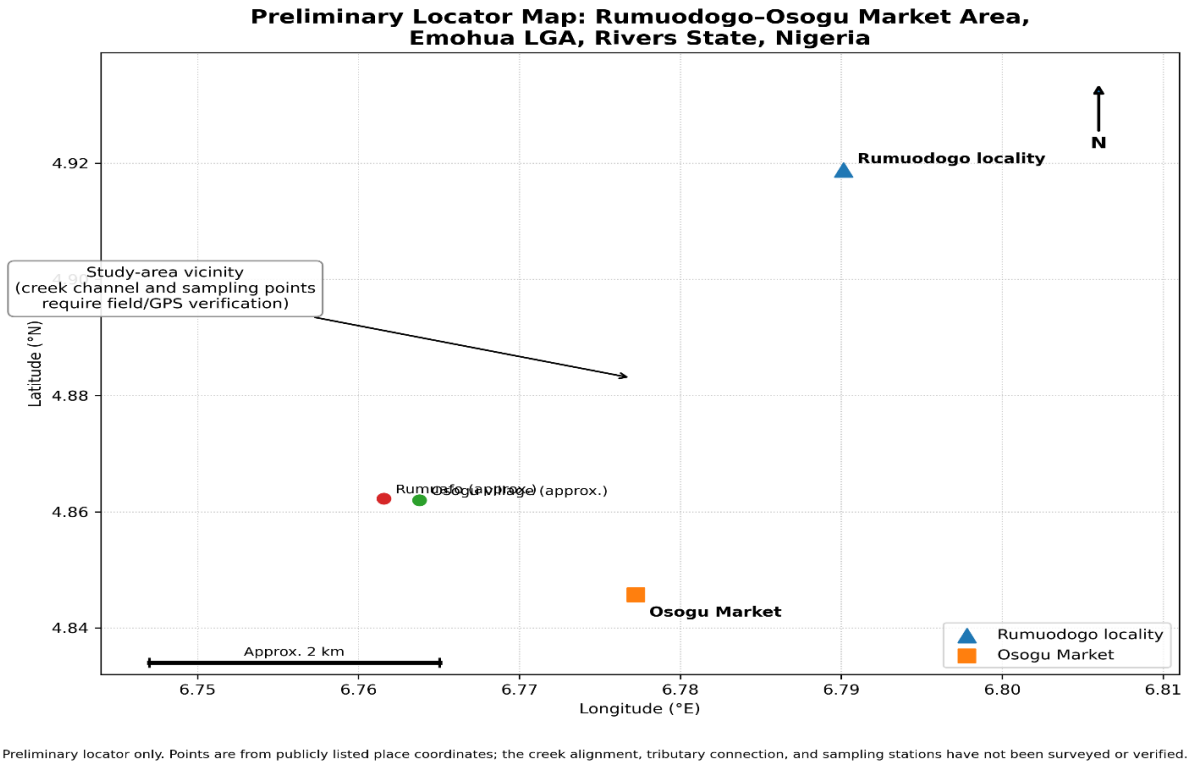


Figure 1. Locator map showing the Rumuodogo/Osogu market area.

2.4.2 Dissolved oxygen (APHA 4500-C)

The dissolved oxygen (DO) was determined by the modified Azide or Winkler's method (APHA, 2023). In a 70ml BOD bottle filled with sample water, 0.5ml MgSO4 (Winkler I) solution and 0.5ml alkaline-iodide-azide reagents (Winkler II) were added, stopper (excluding air bubbles) and well mixed for about 10 minutes, 0.5ml concentration of H2SO4 is added, re-stopped and mixed for complete dissolution of the precipitate. The fixed sample is taken for analysis.

2.4.3 Biochemical oxygen demand (APHA 5210-B)

A known portion of the water sample collected was diluted with oxygenated water and incubated at 200C for 5 days. At the end of the incubation period, the samples were treated in same manner as the Dissolved Oxygen (DO) samples Stated above. Detection limit is 1.0mg/L.

2.4.4 Chemical oxygen demand (APHA 5220)

Chemical Oxygen Demand (COD) was determined using the closed-reflux dichromate method in accordance with the procedures described in APHA (2023), Standard Methods for the Examination of Water and Wastewater, Method 5220. The analysis involved the oxidation of chemically oxidizable substances in the water samples using potassium dichromate in a strongly acidic medium, with silver sulphate serving as a catalyst. Mercuric sulphate was used where necessary to minimize chloride interference. Measured portions of the water samples were transferred into appropriate COD digestion tubes containing the prescribed digestion reagents. The tubes were securely closed, mixed and heated at 150°C for two hours. Following digestion, the tubes were allowed to cool to room temperature. The residual dichromate was determined by titration with standardized ferrous ammonium sulphate solution using ferroin as an indicator. A reagent blank was prepared and subjected to the same analytical procedure. The COD concentration was calculated and expressed in milligrams per litre (mg/L) using Equation 1:

$$\text{COD (mg/L)} = \frac{(A - B) \times M \times 8000}{V} \quad (1)$$

Where A represents the volume of ferrous ammonium sulphate (FAS) used for the blank (mL), B represents the volume used for the sample (mL), M is the molarity of the ferrous ammonium sulphate (FAS) solution, and V is the volume of the water sample analyzed or used (mL) and 8000 = oxygen equivalent conversion (OEC) factor.

2.4.5 Determination of total recoverable heavy metals (Pb, Cd and Mn)

The determination of heavy metals in the surface water samples was carried out to establish the concentrations of selected metallic contaminants present in the study area. Total recoverable metal concentrations were determined using an appropriate acid digestion procedure, following the principles of USEPA Method 200.8. The collected water samples were not filtered before preservation to ensure that both dissolved metals and metals associated with suspended particulate materials were represented in the analysis. The samples were preserved with nitric acid (HNO_3) to maintain a pH below 2 before laboratory preparation. An appropriate volume of each sample was subjected to acid digestion using the prescribed analytical procedure. Following digestion, the samples were cooled and prepared for instrumental determination. The concentrations of the selected heavy metals were subsequently determined using Atomic Absorption Spectrophotometry (AAS). The results were expressed in milligrams per litre (mg/L) and used to evaluate the distribution and potential contamination of the surface water by heavy metals across the sampling locations.

2.4.6 Magnesium (APHA 3111-B, AAS)

For dissolved magnesium determination, the samples were filtered through a 0.45 µm membrane filter before acidification. The concentration was calculated using Equation 2:

$$\text{Mg (mg/L)} = C \times \text{DF} \quad (2)$$

Where: C = Magnesium concentration obtained from the AAS (mg/L); DF = Dilution factor.

2.5 Statistical analysis

The statistical analyses as provided by MS Excel version 2007 and SPSS mean and standard version 17.0 were used for the organization of data. Minimum and maximum data-sets, range, errors of the physicochemical properties were conducted with single factor analysis of variance (ANOVA) while the Duncan Multiple Range was detected with the post-Hoc mean separation. The influence on the physicochemical proportion of the river was determined with the Pearson Correlation Coefficient (r).

3 Results

3.1 Levels of physicochemical and heavy-metal characteristics of surface water

There were wide range of variation in levels of pH (Range = 0.56), EC (Range = 27.00µS/m), DO (Range = 0.87mg/L), BOD (Range = 0.28mg/L) and COD (Range = 3.17mg/L) of the river (Table 1), and Mg (Range = 2.72mg/L). TDS, TSS and Turbidity varied from 341.00 – 355.00 (348.000±1.7555mg/L), 8.00-13.00 (10.3333±0.5271) mg/L and 18.00–23.00 (20.3333±0.5271) mg/L respectively. Pb, Cd, and Mn varied from 0.16 – 1.21 (0.5594±0.1651) mg/L, 0.01 – 0.11 (0.0507±0.447) mg/L, and 0.62 – 2.34 (1.5005±0.2492) mg/L, respectively (Table 1; Figure 2).

3.2 Spatial variations in physicochemical characteristics and heavy-metal concentrations

The physicochemical parameters showed variations across the sampling points. The minimum value of pH (4.98) was recorded in sample point one (SP1) while the maximum value (5.53) was recorded in sample point three (SP3). The minimum value of DO (6.83) mg/L was recorded in SP 1 while its maximum value (7.69) mg/L was recorded in SP 2. The minimum value of BOD (1.43) mg/L was recorded in SP3 while the maximum value of BOD (1.60) mg/L was recorded in SP 2. The minimum value of COD (5.25) was recorded in SP3 while its maximum value (8.4) mg/L was recorded I SP1, respectively (Figure 3).

Table 1. Descriptive statistics of physicochemical parameters of the river samples.

Parameters	Minimum	Maximum	Range	Mean	SE
pH	4.97	5.33	0.56	5.300	0.0819
EC (µS/cm)	682.00	709.00	27.00	696.333	3.6439
DO (mg/L)	6.82	7.69	0.87	7.153	0.1328
BOD (mg/L)	1.42	1.70	0.28	1.497	0.3114
COD (mg/L)	5.24	8.41	3.17	6.343	0.5145
TDS (mg/L)	341.00	355.00	14.00	348.00	1.7559
TSS (mg/L)	8.00	13.00	5.00	10.333	0.5271
Turb. (NTU)	18.00	23.00	5.00	20.3333	0.5271
Pb (mg/L)	0.16	1.21	1.05	0.5594	0.1651
Cd (mg/L)	0.01	0.11	0.10	0.0507	0.0147
Mg (mg/L)	0.45	3.17	2.72	1.7208	0.3958
Mn (mg/L)	0.62	2.34	1.72	1.5005	0.2492

EC = electrical conductivity; DO = dissolved oxygen; TDS = total dissolved solids; TSS = total suspended solids; Turb. = turbidity; NTU = nephelometric turbidity unit.

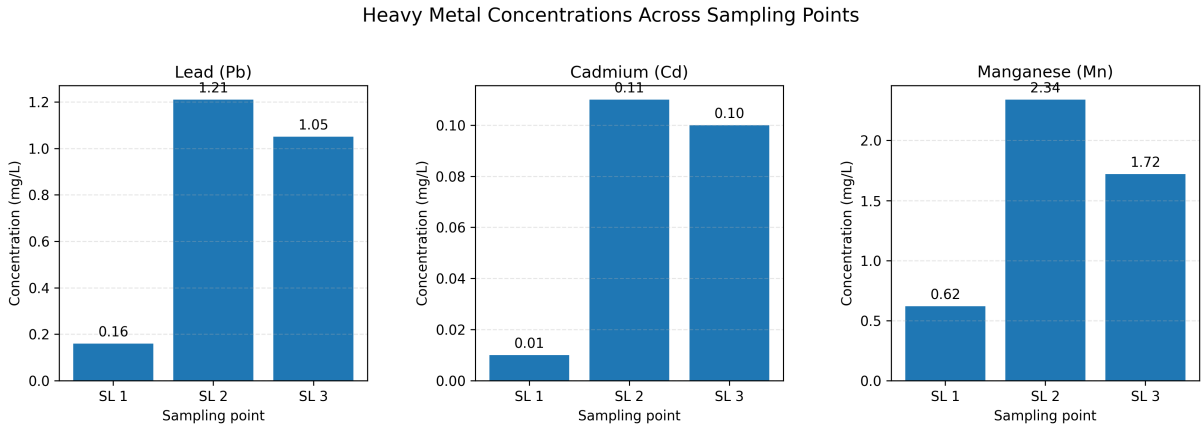


Figure 2. Heavy-metal concentrations across sampling points.

The minimum value of EC (683) mg/L was recorded in SP1 while its maximum value (708) mg/L was recorded in SP2. TDS has a minimum value of 342mg/L at SP1 whereas its maximum value of

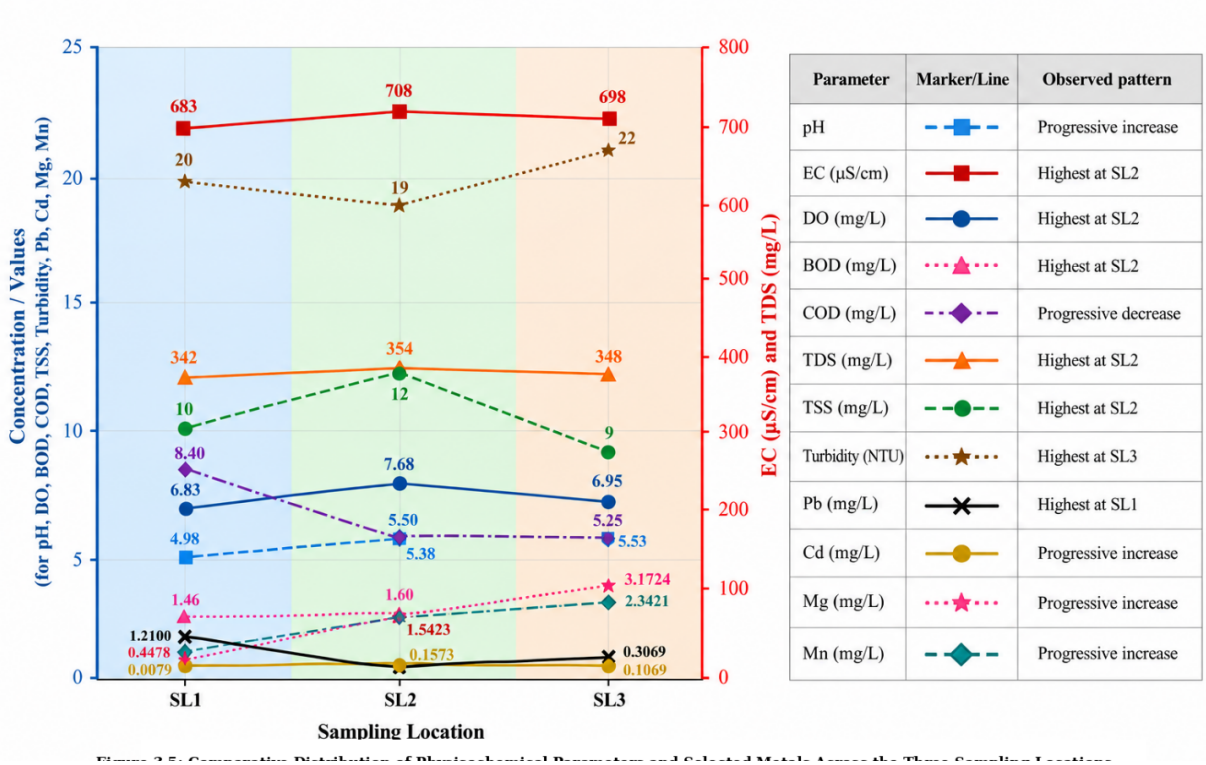
355mg/L was recorded in SP2. Also, the minimum value of TSS (8mg/L) was recorded in SP3 while its maximum value of 12mg/L was recorded in SP2 and the minimum value of Turbidity (18mg/L) was recorded in SP2 while its maximum value of 23mg/L was recorded in SP3 respectively (Figure 3).

Furthermore, the minimum value of Pb (0.1mg/L) was recorded in SP2 while its maximum value of 1.21 mg/L was recorded in SP1. The minimum value of Cd (0.01mg/L) was recorded in SP1 while its maximum value of 0.11mg/L was recorded in SP3.

The value of Mg (0.45mg/L) was recorded in SP1 while its maximum value of 3.17mg/L was recorded in SP3. The minimum value of Mn (0.62mg/L) was recorded in SP1 while its maximum value of 2.34mg/L was recorded in SP3 (Figure 3).

3.3 Relationships between physicochemical parameters and heavy-metal concentrations

pH exercised a progressive increase from sampling point (SP1) to (SP3) while COD exhibited a progressive decrease from sample point (SP1) to (SP3). The physicochemical properties of EC, DO, BOD, TDS and TSS has the highest concentration at sample point (SP2) whereas turbidity has the highest concentration of 22.00NTU at sampling point (SP3), and Lead (Pb) has the highest concentration of 1.2100mg/L in sampling point (SP1). Cadmium (Cd), Magnesium (Mg), and Manganese (Mn) exercised a progressive increase from sampling point (SP1) to (SP3) respectively (Figure 3).



Parameter	Marker/Line	Observed pattern
pH		Progressive increase
EC (µS/cm)		Highest at SL2
DO (mg/L)		Highest at SL2
BOD (mg/L)		Highest at SL2
COD (mg/L)		Progressive decrease
TDS (mg/L)		Highest at SL2
TSS (mg/L)		Highest at SL2
Turbidity (NTU)		Highest at SL3
Pb (mg/L)		Highest at SL1
Cd (mg/L)		Progressive increase
Mg (mg/L)		Progressive increase
Mn (mg/L)		Progressive increase

Figure 3. Comparative distribution of physicochemical parameters and selected metals across the three sampling locations.

A post-hoc mean separation with Duncan Multiple Range test revealed that the observed difference in pH was between all the sample locations, whereas in EC and DO, it is within sampling points 1 and 3 respectively. In BOD, the observation was found with sampling points 1 and 2 while in COD, it is found in all the sampling points. Furthermore, in TSS, it is found in sampling points 1 and 2 whereas in

Turbidity, it is found in sampling point 1. Again, in Pb, Cd, Mg and Mn; the observed difference is found across sampling points (Table 3).

The test of homogeneity in mean variance of the physicochemical parameters across sampling point using the Simple Factor ANOVA revealed that at $p<0.05$, the physicochemical parameter differs significantly (Table 2).

Table 2. Analysis of variance (ANOVA) of the physicochemical parameters across sampling points.

Source of variation	SS	df	MS	*F*	*p*
Between groups	0.482	2	0.241	2412.00	0.000
Within groups	0.001	6	0.000		
Total	0.483	8			

Table 3. Mean separation of the physicochemical parameters using Duncan's multiple range test ($p < 0.05$).

Parameters	SP1	SP2	SP3
pH	4.9800a	5.4000b	5.5200c
EC (µS/cm)	683.0000a	708.0000c	698.0000c
DO (mg/L)	6.8300a	7.6800c	6.9500c
BOD (mg/L)	1.4600a	1.6000b	1.4300a
COD (mg/L)	8.4000c	5.3800b	5.2500a
TDS (mg/L)	342.0000a	354.0000c	348.0000b
TSS (mg/L)	10.0000a	12.0000b	
Turb. (NTU)	20.0000a	19.0000a	
Pb (mg/L)	1.214100c	0.157300a	0.306900b
Cd (mg/L)	0.007900a	0.037200b	0.106900c
Mg (mg/L)	0.4475607a	1.542300b	3.172400c
Mn (mg/L)	0.617200a	1.542900b	2.342100c

EC = electrical conductivity; DO = dissolved oxygen; TDS = total dissolved solids; TSS = total suspended solids; Turb. = turbidity; NTU = nephelometric turbidity unit. Means with different letters in a row differ significantly ($p < 0.05$).

3.4 Comparison of physicochemical and heavy-metal concentrations with benchmarks

The pH, DO, TDS, and TSS comparison values are reported in a Nigerian study of Lagos coastal waters. The comparison with applicable Nigerian Environmental Standards and relevant International Guideline Values of the physicochemical and heavy metal properties of the river across sampling points revealed that pH is below reported range at all locations, EC has no universal marine EC limit thus requires salinity investigation for appropriate interpretation. DO meets the Nigerian benchmark at all locations (>5 mg/L), as reported in Nigerian coastal-water studies. BOD has no single universal marine BOD criterion applicable to all receiving waters. COD has no universal marine COD criterion applicable to every water body. TDS is below the benchmark of 1,000 mg/L, albeit, sanity specific assessment is required. The TSS reported is below the reported benchmark (600 mg/L) in a Nigerian

coastal-water study. Turbidity has no universal turbidity limit applicable to every ecosystem. Also, Mg has no directly applicable universal marine-water threshold (Table 4).

The Pb and Cd values are US EPA saltwater aquatic-life criteria. The EPA metal criteria are expressed for dissolved metals. Pb US EPA saltwater criteria: 0.210 mg/L acute; 0.0081 mg/L chronic indicates that all exceed the chronic criterion and that SP1 and SP3 exceed the acute criterion. Cd of 0.0079 mg/L (SP1), 0.0372 mg/L (SP 2), and 0.1069 mg/L (SP 3) respectively exceed US EPA saltwater criteria: 0.033 mg/L acute and 0.0079 mg/L chronic criteria. Mn has no directly applicable universal marine-water threshold used here and thus requires an appropriate aquatic-life benchmark (Table 4).

4 Discussion

The study highlights the importance of regular water quality monitoring, pollution prevention, and effective management of activities around the creek to protect aquatic ecosystems and safeguard community health. pH is an important physicochemical parameter used to determine the degree of acidity or alkalinity of water.

Table 4. Comparison of measured water quality parameters with selected Nigerian and international benchmarks.

Parameter	SP1	SP2	SP3	Selected reference benchmark	Assessment
pH	4.98	5.50	5.53	Nigerian coastal-water studies report 6.5–9.0 as a comparison range	Below the reported range at all locations
EC (µS/cm)	683.00	708.00	698.00	No universal marine EC limit; interpretation requires salinity and site classification	Requires further assessment
DO (mg/L)	6.83	7.68	6.95	>5 mg/L, as reported in Nigerian coastal-water studies	Meets this benchmark at all locations
BOD (mg/L)	1.46	1.60	1.43	No single universal marine BOD criterion applicable to all receiving waters	Requires site-specific assessment
COD (mg/L)	8.40	5.38	5.25	No universal marine COD criterion applicable to every water body	Requires site-specific assessment
TDS (mg/L)	342.00	354.00	348.00	1,000 mg/L reported in a Nigerian coastal-water study as a comparison benchmark	Below this benchmark; salinity must also be assessed
TSS (mg/L)	10.00	12.00	9.00	600 mg/L reported in the same Nigerian study	Below this reported benchmark
Turbidity (NTU)	20.00	19.00	22.00	No universal marine turbidity limit applicable to every ecosystem	Requires an appropriate site-specific benchmark
Pb (mg/L)	1.2100	0.1573	0.3069	US EPA saltwater criteria: 0.210 mg/L acute; 0.0081 mg/L chronic	All exceed the chronic criterion; SP1 and SP3 exceed the acute criterion
Cd (mg/L)	0.0079	0.0372	0.1069	US EPA saltwater criteria: 0.033 mg/L acute; 0.0079 mg/L chronic	SP1 is approximately at the chronic criterion; SP2 and SP3 exceed both criteria

Parameter	SP1	SP2	SP3	Selected reference benchmark	Assessment
Mg (mg/L)	0.4478	1.5423	3.1724	No directly applicable universal marine-water threshold used here	Requires assessment against appropriate background or site-specific data
Mn (mg/L)	0.6172	1.5423	2.3421	No directly applicable universal marine-water threshold used here	Requires an appropriate aquatic-life benchmark

Scientifically, it expresses the activity of hydrogen ions (H+) in an aqueous solution and is calculated as the negative logarithm of hydrogen-ion {pH = -log[H^+]} activity. On the conventional pH scale, a value of 7 indicates neutrality, values below 7 indicate acidic conditions, and values above 7 indicate alkaline conditions. Because the pH scale is logarithmic, a change of one pH unit represents an approximately tenfold change in hydrogen-ion activity according to the U.S. Environmental Protection Agency (EPA) (2021).

In water quality assessment, pH is useful because it provides information about the chemical condition of a water body and helps explain how environmental processes and pollutants may affect aquatic life. pH is also useful in understanding the behaviour and potential toxicity of heavy metals in water. Water acidity can influence the solubility, chemical forms, and biological availability of metals such as lead and cadmium according to US Geological Survey (USGS) (n.d.); EPA (2021) respectively. Under many environmental conditions, lower pH can increase the solubility of certain metals, potentially making them more available for uptake by aquatic organisms. The current study reveals that the river water is acidic at all three sampling locations, with pH values ranging from 4.98 to 5.53. These values were below the pH range of 6.5–9.0 reported in Nigerian coastal-water literature as a comparison benchmark (Oyatola, 2021). The lowest pH occurred at SP1, while SP3 had the highest pH. These results indicate consistently acidic conditions that may affect aquatic organisms and the chemical mobility of certain metals. The pH of surface water can be influenced by natural factors, including the geology of the surrounding area, soil composition, rainfall, dissolved carbon dioxide, and the decomposition of organic matter. The observed acidity values of the pH across sampling points could be due to human activities such as agricultural runoff, industrial discharges, and the release of untreated or inadequately treated wastewater from cassava fermentation. Consequently, changes in pH may indicate alterations in the chemical characteristics of a river, creek, or other surface water body (Ajani et al., 2021; US EPA, 2021; USGS, n.d.).

DO is one of the most important physicochemical parameters used to assess the quality and ecological health of marine water bodies. DO is the amount of oxygen gas dissolved in water and available for use by aquatic organisms. In marine environments, dissolved oxygen plays a vital role in sustaining fish, crabs, shrimps, mollusks, plankton and other organisms that depend on oxygen for respiration. Its concentration is therefore an important indicator of the ability of marine and estuarine ecosystems to support aquatic life (US EPA, n.d.; NOAA, n.d.). DO concentrations in the current study ranged from 6.83 to 7.68 mg/L, exceeding the 5 mg/L comparison benchmark reported in the same Nigerian coastal-water study (Oyatola, 2021; FRN, 2011; NESREA, 2011). This indicates that the sampled water was reasonably oxygenated at the time of measurement. Nevertheless, the results represent measurements at the sampling locations and do not establish that adequate oxygen conditions are maintained throughout daily and seasonal cycles (Senn et al., 2016). DO enters marine water through the exchange of gases between the atmosphere and the water surface, as well as through photosynthesis by phytoplankton, algae and aquatic plants. However, its concentration is

influenced by several environmental factors, including water temperature, salinity, tidal. For instance, increasing water temperature and salinity generally reduce the amount of oxygen that can dissolve in water. Similarly, the decomposition of organic wastes by microorganisms consumes oxygen and may cause its concentration to decline to levels that are harmful to aquatic organisms (NOAA, n.d.; USGS, 2024)

EC ranged from 683 to 708 µS/cm. The highest value was recorded at SP2, followed by SP3 and SP1. Electrical conductivity depends on the concentrations and types of dissolved ions. However, a universal EC threshold cannot be applied indiscriminately to freshwater, brackish water, and seawater. TDS ranged from 342 to 354 mg/L. The TDS and TSS values were below the respective comparison values of 1,000 mg/L and 600 mg/L reported in the Nigerian coastal-water study. Although these parameters varied relatively little across the sampling locations, their interpretation requires consideration of the ionic composition and salinity of the water. However, these comparisons require caution because the reported values are not necessarily the most appropriate criteria for every marine habitat. In particular, the conductivity values appear low for ordinary seawater.

BOD and COD are important physicochemical parameters used to evaluate water quality and investigate the effects of pollution on marine and estuarine environments. Both parameters provide information about the oxygen demand associated with substances present in water, particularly organic matter and certain chemically oxidizable compounds. However, they measure different aspects of water quality and should not be interpreted as interchangeable indicators (APHA, 2023; EPA, 2023). BOD measures the amount of dissolved oxygen consumed by microorganisms as they decompose biodegradable organic matter under specified test conditions, usually over five days at 20°C (BOD_5). COD, on the other hand, measures the oxygen equivalent of substances that can be chemically oxidized using a strong oxidizing agent under standardized laboratory conditions. COD can therefore account for a broader range of oxidizable substances than BOD, including some that are not readily biodegradable (U.S. EPA, n.d.; APHA, 2023). BOD ranged from 1.43 to 1.60 mg/L, whereas chemical oxygen demand ranged from 5.25 to 8.40 mg/L. The highest COD concentration occurred at SP1, which also recorded the highest lead concentration. Although this coincidence may justify further investigation into possible interactions between organic matter and lead distribution, it does not establish a causal relationship.

The most significant concern arose from the measured concentrations of Pb and Cd. Pb concentrations ranged from 0.1573 to 1.2100 mg/L, while Cd concentrations ranged from 0.0079 to 0.1069 mg/L. Compared with the United States Environmental Protection Agency's saltwater aquatic-life criteria, Pb exceeded the chronic criterion at all three sampling points, while SP1 and SP3 also exceeded the acute criterion. Cd at SP2 and SP3 exceeded both the acute and chronic saltwater criteria, whereas the SP1 concentration was approximately equal to the chronic criterion (US EPA, n.d.). These comparisons indicate that the measured Pb and Cd concentrations warrant careful investigation because of their potential ecological significance (Jolaosho et al., 2025; Adams et al., 2020; UNEP, n.d.). The comparison also assumes that saltwater criteria are appropriate for the sampled environment. Again, magnesium Mg and Mn concentrations increased progressively from SP1 to SP3. These patterns indicate spatial differences in the distribution of the measured elements, but they do not independently establish their sources or demonstrate a statistically significant relationship with the physicochemical parameters. Mg is an essential major ion in natural waters and is not conventionally classified as a heavy metal. Mn is a trace metal whose environmental significance depends on its concentration, chemical form, and exposure conditions

5 Summary of findings

1. Magnesium increased from 0.4478 mg/L at SP1 to 3.1724 mg/L at SP3. Manganese increased from 0.6172 mg/L to 2.3421 mg/L over the same locations.
2. The progressive increases indicate that the two elements exhibit similar spatial patterns. However, these observations do not establish that they originate from the same source.
3. A reliable assessment of Mg and Mn requires an appropriate environmental background or applicable aquatic-life criterion. It would be scientifically inappropriate to label these concentrations compliant or non-compliant without identifying a suitable reference value.
4. The combined results indicate that the water samples exhibit acidic conditions and elevated concentrations of Pb and Cd relative to the selected international saltwater aquatic-life criteria.
5. Dissolved oxygen was above the comparison benchmark reported in the Nigerian coastal-water literature.
6. TDS and TSS were also below the respective comparison values used in this assessment. However, these favourable results for selected parameters do not eliminate the environmental concerns associated with the measured metals.
7. The elevated Pb and Cd concentrations warrant confirmation through repeat laboratory analysis, quality-control checks, and assessment of dissolved and total metal fractions.
8. Pb was highest at SP1, whereas Cd and Mn increased progressively toward SP3. These contrasting distributions suggest that the factors influencing the measured concentrations may vary by metal and location.
9. The low pH may also affect metal mobility and bioavailability.
10. Turbidity was highest at SP3 (22 NTU). However, turbidity alone does not establish the concentration or source of heavy metals.
11. Elevated turbidity may reduce light penetration and may be associated with suspended particles that transport adsorbed contaminants.

6 Conclusion

This study assessed the physicochemical characteristics and selected metal concentrations of surface water along Rumuodogo/Osogu Market Creek of the Sombrero River in Rivers State, Nigeria. The results revealed variations in water quality across the three sampling points, indicating that the creek should not be assumed to have uniform water quality throughout the study area. One of the major findings was the acidic nature of the water, with pH values ranging from 4.98 to 5.53. This condition may affect the chemical behaviour and availability of metals in the aquatic environment and may also influence the survival and distribution of sensitive aquatic organisms. Although dissolved oxygen concentrations ranged from 6.83 to 7.68 mg/L, the BOD and COD results showed that oxygen-demanding substances were present in the water. These parameters should be considered together when evaluating the creek's ecological condition.

The metal analysis revealed notable spatial differences in the concentrations of Pb, Cd, Mg, and Mn. Pb recorded its highest concentration at SP1, while Cd and Mn increased progressively across the three sampling points. Mg also showed an increasing pattern, with its highest concentration recorded at SP3. These variations indicate that the distribution of the measured constituents differs across the sampling points and deserves further investigation. However, the observed patterns alone cannot establish the sources of the metals or demonstrate a direct relationship with specific human

activities. Of particular concern are the reported Pb and Cd concentrations, which require careful comparison with applicable water quality standards and further verification through appropriate quality assurance procedures. Elevated concentrations of these metals could present risks to aquatic organisms and could affect human health where the water is used for drinking, food preparation, fishing-related activities, or other exposure pathways. The actual level of risk, however, depends on the reliability of the measurements, the nature and extent of exposure, and the intended use of the water.

Overall, the study provides useful baseline information on the physicochemical properties and selected metal concentrations of Rumuodogo/Osogu Market Creek. The findings suggest that water quality management in the area should give particular attention to acidity, spatial variations in metal concentrations, and the prevention of potential pollution. Nevertheless, the assessment of the creek's overall suitability for domestic, recreational, agricultural, or ecological purposes requires a more comprehensive comparison with relevant standards and, where necessary, additional chemical, microbiological, and seasonal investigations. The study therefore concludes that sustained water quality monitoring, appropriate pollution control measures, and responsible management of activities within the creek's catchment are necessary to support the protection and long-term sustainability of this aquatic resource.

7 Recommendations

Based on the outcomes of this study, the following recommendations are proposed to improve water quality management and protect the aquatic environment along Rumuodogo/Osogu Market Creek of the Sombrero River.

- Relevant environmental authorities should establish a routine water quality monitoring programme for the creek to assess changes in physicochemical parameters and metal concentrations over time.
- Monitoring should cover the existing sampling locations and additional points where necessary to provide a more representative picture of water quality.
- Sampling should also be conducted during different seasons, particularly the wet and dry seasons, to determine whether rainfall, flooding, and changes in water flow influence pollutant concentrations.
- There should be a follow-up analysis for Pb and Cd as their concentrations warrant priority attention. The results should be compared with relevant Nigerian environmental requirements and applicable international guidelines, taking account of the intended use of the water. This step is necessary to establish the reliability of the measurements and determine whether further pollution-control measures are required.
- Environmental authorities and researchers should investigate potential sources of Pb, Cd, and Mn within and around the creek.
- The investigation should consider relevant activities such as waste disposal, market-related activities, runoff, wastewater discharge, and other locally plausible sources.
- Local authorities, community leaders, market operators, and residents should work together to prevent the uncontrolled disposal of solid waste, wastewater, and potentially hazardous materials into the creek.

- Adequate waste collection facilities, appropriate disposal arrangements, public sanitation facilities, and enforcement of environmental regulations should be provided or strengthened.
- Particular attention should be given to preventing waste accumulation and direct discharge of untreated wastewater into the water body.
- Further investigations should examine the factors responsible for the observed pH values, which ranged from 4.98 to 5.53. The assessment should consider natural characteristics of the catchment as well as possible anthropogenic influences.
- The relationship between acidity and metal mobility should also be investigated to improve understanding of the potential ecological implications. Any proposal to adjust the pH should be based on a detailed assessment of the water chemistry and the ecological characteristics of the creek.
- Environmental management measures should be introduced to minimize pollution and protect aquatic habitats.
- Where the creek supports fisheries or other important aquatic resources, periodic assessment of the condition of aquatic organisms and, where justified, contaminant accumulation in edible species should be considered. This would help determine whether the measured water quality conditions have implications for aquatic organisms and people who depend on them.
- Community-based environmental education should be organized to inform residents, market operators, fishers, and other creek users about the importance of maintaining water quality.
- Awareness programmes should address appropriate waste disposal, prevention of pollution, the potential implications of exposure to contaminated water, and the need to report activities that may threaten the aquatic environment. Involving community members in monitoring and pollution-prevention initiatives may also improve local ownership and compliance.
- Relevant environmental protection agencies, local government authorities, public health officials, and community representatives should coordinate their efforts to protect the creek.
- Their responsibilities should include routine inspection, water quality surveillance, public education, pollution reporting, and enforcement of applicable environmental regulations. Clear responsibilities and effective communication among these stakeholders would help ensure that identified water quality concerns receive appropriate attention.
- A broad base experimentation of major heavy metals and physicochemical parameters to include ions of phosphate, nitrate, sulphate among others be encouraged in a bid to ascertain the levels of nutrients which possibly may cause eutrification of the river.

Conflict of interest

Authors declare no conflict of interest.

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