



Multivariate Assessment of Physicochemical Parameters and Heavy Metal Contamination in Surface Waters of Oil-Producing Communities, Delta State, Nigeria

¹Biose E.*, ²Ogwo, P. A.

¹Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Edo State, Nigeria <https://orcid.org/0000-0002-6776-8001>

²Department of Environmental Management and Toxicology, College of Natural Resources and Environmental Management, Michael Okpara University of Agriculture, Umudike

*Corresponding author, Email address: ekene.biose@uniben.edu

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Abstract: This study evaluated the physicochemical characteristics and heavy metal contamination in surface water from of an oil-producing community, Delta State, Nigeria. The aim was to assess the influence of oil exploration and related anthropogenic activities on water quality using descriptive statistics and multivariate analyses. Four sampling stations were analyzed for physicochemical parameters and heavy metals using standard methods. The results showed that while pH (6.45–7.22) and DO (4.8–6.1 mg/L) were within acceptable limits, turbidity (13.2–42.6 NTU), EC (210–526 $\mu\text{S}/\text{cm}$), TDS (142–352 mg/L), TSS (105–288 mg/L), COD (44.5–93.6 mg/L), hardness (65–184 mg/L), and chloride (78–210 mg/L) exceeded national and international standards. Elevated heavy metals included Pb (0.12–0.37 mg/L), Cd (0.04–0.11 mg/L), Fe (0.56–1.38 mg/L), and total hydrocarbons (0.18–0.63 mg/L). Cluster Analysis (CA) grouped the stations into two clusters, reflecting spatial variation in pollution levels. Principal Component Analysis (PCA) extracted seven components explaining 86.96% of the total variance; Dimension 1 (32.54%) was strongly associated with EC, TDS, TSS, COD, alkalinity, hardness, Cl^- , Na, K, and Ca, while Dimension 2 (16.85%) was dominated by BOD, NO_3^- , Cr, Cu, Mn, and THC, indicating contributions from both ionic load and hydrocarbon-related contamination. Correlation analysis confirmed these patterns, revealing strong positive relationships among physicochemical parameters and among heavy metals, suggesting common anthropogenic sources such as oil spills, dredging, and industrial effluents. This study demonstrate that the Okpare Olomu River is significantly impacted by oil-related activities, posing ecological and public health risks. Strengthened environmental monitoring, regulatory enforcement, remediation, and provision of safe alternative water sources are recommended.

Keywords: Surface water quality, Physicochemical parameters, Heavy metal contamination, Principal component analysis (PCA), Oil producing communities

1. Introduction

Crude oil is one of the world's most economically valuable natural resources, comprising a complex mixture of hydrocarbons and non-hydrocarbon compounds, including toxic heavy metals (Speight 2014). Despite its economic importance, crude oil exploration and production have been

widely associated with environmental degradation. Oil spills, equipment failures, pipeline vandalism, and inadequate waste management contribute to large-scale contamination of soil, surface water, and groundwater in oil-producing regions (UNEP 2011; Nriagu *et al.*, 2016). These risks are particularly evident in Nigeria's Niger Delta, which has been the hub of hydrocarbon exploitation for more than six decades. The Niger Delta is one of the most ecologically significant ecosystems globally, hosting Africa's largest wetland and the world's third-largest mangrove forest (Davies and Abowei, 2009). It provides critical ecosystem services such as fisheries, fertile farmlands, forest resources, and freshwater supply that sustain millions of people. However, intensive oil exploration has severely disrupted these ecological functions, leading to biodiversity loss, habitat destruction, and widespread environmental pollution. Of particular concern is the release of heavy metals such as arsenic, cadmium, lead, and mercury into surface waters. These metals are non-biodegradable, persistent in aquatic systems, and capable of bioaccumulating in fish and other organisms, thereby posing serious ecological and public health risks (Nduka and Orisakwe, 2011; Karim *et al.*, 2016; Orajiaka-Uchegbu *et al.*, 2020; El Hammari *et al.*, 2022).

The health consequences of chronic exposure to heavy metals are well documented. Arsenic exposure is linked to skin and lung cancers, cadmium to kidney dysfunction, lead to neurological and developmental disorders, and mercury to cardiovascular and reproductive health problems (Ite *et al.*, 2013), (WHO 2017) (Hassan *et al.*, 2021). Communities in the Niger Delta, whose livelihoods rely heavily on fishing and farming, are particularly vulnerable because contamination directly affects water resources and food chains. In addition, pollution undermines agricultural productivity, reduces fish populations, and deepens economic hardship. Ironically, while the Niger Delta contributes more than 80% of Nigeria's national revenue (NNPC 2021), it remains economically marginalized, facing poverty, unemployment, and widespread environmental injustice (Idemudia 2009). Traditional livelihoods such as farming and fishing have been devastated by recurrent oil spills, habitat loss, and gas flaring, which elevates ambient temperatures and reduces crop yields (Ebegbulem *et al.*, 2013) (Dung *et al.*, 2018). These cumulative environmental pressures not only weaken community resilience but also contribute to recurring militancy, sabotage of oil infrastructure, and social unrest (Ojajorotu 2008). Although several studies have reported hydrocarbon pollution and heavy metal contamination in parts of the Niger Delta (Osuji and Onojake, 2006), (Nduka and Orisakwe, 2011), (Orajiaka-Uchegbu *et al.*, 2020), most assessments have been fragmented either localized to specific spill sites, restricted to selected metals, or lacking integration of physicochemical and toxicological parameters. Few studies have systematically examined spatio-temporal variations in water quality and heavy metal concentrations across oil-producing communities in Delta State. Consequently, reliable baseline data remain scarce, hindering effective evaluation of ecological risks, compliance with water quality standards, and evidence-based policy interventions.

This study seeks to bridge this gap by assessing the variations in physicochemical parameters and heavy metal contamination in surface water from of an oil-producing community, Delta State, Nigeria. The evaluating water quality against national and international standards, the research provides baseline data essential for environmental monitoring, community health protection, and sustainable water resource management.

2. Materials and Methods

2.1 Study Area

This research was conducted in Delta State, South-South Nigeria, located between latitude 5°30'N and longitude 6°00'E. Sampling locations were selected based on criteria such as population activity and proximity to past oil spill incidents. Surface water samples were collected from four stations along the Okpare Olomu River in Ughelli South Local Government Area. Delta State, with a land area of 16,842 km², is classified as part of the tropical rainforest zone and is recognized as one of the most ecologically sensitive regions in Nigeria (NDES 1997), (Uyigüe and Agho, 2007), (Ekpo *et al.*, 2018). The region harbors diverse aquatic and terrestrial species, making it an important biodiversity hotspot (Ebewore 2020). Ecologically, the state is endowed with diverse aquatic and terrestrial ecosystems that sustain numerous plant and animal species, while also providing essential ecosystem services such as fishing, farming, and potable water supply for host communities (Ebewore 2020). Despite these ecological assets, the state has been subjected to long-standing environmental pressures from oil exploration and production, which have heightened concerns about surface water quality and community health.

2.2 Climate

Delta State lies within the tropical rainforest zone of Nigeria and is characterized by an equatorial climate with alternating wet and dry seasons (UNDP 2006). The wet season extends from April to October, with peak rainfall occurring between April and September, and is typically associated with high relative humidity and relatively mild atmospheric temperatures. In contrast, the dry season lasts from November to March and is marked by reduced rainfall, low humidity, and higher temperatures (Agbaire and Emoyan, 2012). The state records an average annual rainfall of about 3000 mm, much of which is heavy and torrential. Mean annual temperature is approximately 30°C, with only slight variations throughout the year. The average monthly temperature during the warmest months ranges from 28–33°C, while the coolest months record 22–26°C (Okumagba and Ozabor, 2014). These climatic conditions not only sustain the dense rainforest vegetation but also influence hydrological dynamics, water quality, and ecological processes in the study area.

2.3 Sampling and Sample Collection

Surface water samples were collected from selected locations along the Okpare Olomu River. The sampling sites were chosen to capture spatial variations in water quality in relation to oil exploration and production activities as well as community use of the river. At each site, water samples were collected in pre-cleaned polyethylene bottles, which were rinsed with the river water before sampling to minimize contamination. Samples for heavy metal analysis were preserved with a few drops of concentrated nitric acid to prevent metal precipitation and adsorption onto container walls, while those for physicochemical analysis were stored in ice chests and transported to the laboratory for immediate analysis.

The surface water samples were collected at four sampled stations from Okpare Olomu River from the following stations as follows:

Station 1 / Ejeba Okpare

N 05° 27. 795' E 005° 54. 409'

Station 2 / Uhrovwodo Okpare

N 05° 27. 600' E 005° 53. 980'

Station 3 / Ogbe Okpare

N 05° 27. 115' E 005° 53. 742'

Station 4 / Arovie Okpare

N 05° 25. 859' E 005° 53. 569'

Sampling was done for twelve (12) months. See [Figure 1](#) showing maps of the study area.

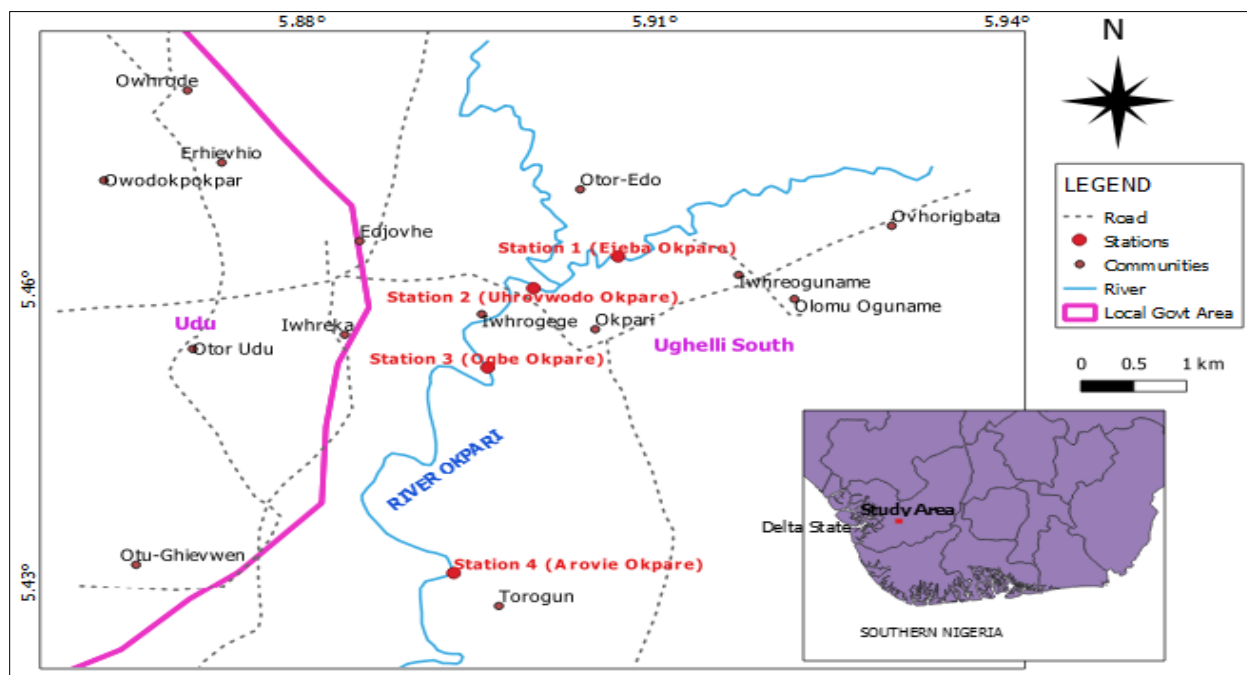


Figure 1. Map of Ughelli South showing surface water sampling stations

2.4 Laboratory Analysis

True colour (Pt-Co Unit) was determined using a HACH colorimeter DR 2000 Model spectrophotometer at a wavelength of 455 nm. In situ measurements were carried out for water temperature using a Gilson mercury-in-glass thermometer; water pH and electrical conductivity were measured using a digital electronic pH meter (Hanna instrument: HI 1922 model) and conductivity meter (Hanna instrument: HI96107 model) respectively. Surface water samples for physico chemical analyses were collected in clean and sterilised 1-litre polyethylene bottles and tightly closed, placed in a cooler box. Physico-chemical analyses followed appropriate quality assurance and quality control standard protocols ([APHA 2012](#)) in Quality Analytical Laboratory Services. Turbidity measured in NTU (Nephelometric Turbidity Units) was determined using the HACH colorimeter (DR/ 920) by absorptometric method in the laboratory with a visible spectrophotometer Vs72IG. The samples were read at a wavelength of 420nm. Total solids was determined by the evaporation method using the gravimetric Method: 10ml of the samples was measured into a pre weighed evaporating dish which was oven dried at a temperature of 103°C to 105°C for 2 ½ hours. The dish was allowed to cool in a desiccator at room temperature and weighed. The total solid was represented by the increase in the weight of the evaporating dish. Total dissolved solids was determined using the conductivity meter (HACH 44600-00) while Total suspended solids was obtained by subtracting the amount calculated from the TDS from the TS. Samples for dissolved oxygen (DO) determination were collected in plain

amber bottles, fixed in the field using 0.1 ml each of Winkler solutions A and B, and determined titrimetrically in the laboratory using the Azide modification technique of the Winkler method. Samples for biochemical oxygen demand (BOD) were collected in amber 250 ml reagent bottles and incubated for five days before analysis using the Winkler's method (APHA 2012). Chemical oxygen demand (COD) (mg/L) was analysed using the dichromate method where fifty (50ml) milliliters of the sample was pipetted into a conical flask, 10 ml of 0.00833 K₂Cr₂O₇ solution was added and 1ml of H₂SO₄ and 10 ml of AgSO₄ was also added and heated gently to boiling for exactly 10 minutes on a hot plate with plastic funnel on the mouth of the conical flask. Total alkalinity was estimated by titrimetric (APHA 1998) using methyl orange as indicator and 0.02 N H₂SO₄ as titrant. Total hardness was measured by adding 1 ml of ammonium buffer solution to 50 ml of the sample followed immediately by the addition of a pinch of ManVer 2 hardness indicator. The resulting mixture was titrated against 0.8 M EDTA solution till a blue coloured end point was observed. Calculated total hardness values will be obtained by multiplying the number of digits on the digital titrator with the digit multiplier (2.0). Chloride content was determined by MOHR's titration method. Two drops of potassium chromate (K₂CrO₄) indicator were added to 50 ml of water sample and titrated against a 0.01M silver nitrate (AgNO₃) solution to give a brick red end point, and compared to the end point of the blank titration (Ademoroti 1996). Flame photometric method was adopted in the determination of the exchangeable bases (potassium, sodium, calcium and magnesium) concentration in the water samples. This was determined using the Technicon auto analyzer flame photometer IV, pre-calibrated using known concentrations of K, Na, Ca and Mg with lithium as internal standards (APHA 2012). Sulphate, nitrate and phosphate were determined using the HACH colorimeter (DR/ 890). The respective reagent powder was added to 10 ml of water sample in a beaker and thoroughly mixed, then allowed to stand for 5 minutes. Sample water was then poured into the cell bottle and placed in the colourimeter, and the concentration read from the display screen in mg L⁻¹. Total hydrocarbon content in water samples was determined as described by ASTM (2003). Triple extraction was carried out on water samples using extraction solvent toluene; and concentrations of total hydrocarbon were determined spectrophotometrically at a wavelength of 420 nm. The concentrations of the hydrocarbon content were obtained from a standardised calibration.

2.5 Digestion and analysis of heavy metals

Water samples were digested using a mixed acid procedure (HNO₃–H₂SO₄–HClO₄) following the standard method of the Association of Official Analytical Chemists (AOAC 2000). The digested extracts were analysed for copper (Cu), iron (Fe), zinc (Zn), cadmium (Cd), lead (Pb), manganese (Mn), and chromium (Cr) using an Atomic Absorption Spectrophotometer (AAS; Solar 969 Unicam Series). Appropriate blanks, calibration standards, and certified reference materials were included for quality assurance and quality control (QA/QC).

2.6 Multivariate Analysis: Cluster analysis: Euclidean similarity and distance indices

To explore spatial and compositional relationships among heavy metals, a hierarchical cluster analysis (HCA) was applied to the normalized dataset. The analysis was based on Euclidean distance as a measure of similarity and the Ward's linkage method, which minimizes the total within-cluster

variance (Simeonov *et al.*, 2003), (Singh *et al.*, 2004). This approach allowed the grouping of sampling sites with similar heavy metal profiles, highlighting patterns of contamination and possible common sources (Vega *et al.*, 1998), (Omo-Irabor *et al.*, 2008). The results were visualized using a dendrogram, which provides a graphical representation of the degree of similarity among clusters. HCA is widely applied in environmental studies to reduce dimensionality and uncover underlying structure in complex water quality datasets (Kazi *et al.*, 2009), (Fan *et al.*, 2010), (Wu *et al.*, 2010).

2.7 *Principal Component Analysis (PCA)*

Principal Component Analysis (PCA) was applied to the standardized dataset to reduce dimensionality and identify the key factors influencing heavy metal concentrations in water samples. PCA transforms correlated variables into a smaller set of uncorrelated components, thereby enhancing the interpretation of pollution sources and underlying patterns (Shrestha and Kazama, 2007), (Fan *et al.*, 2010). The analysis was performed using R software (version 4.0.2) with the factoMineR package, while visualization and interpretation were aided by the factoextra package (R Development Core Team, 2020). The eigenvalues and loading matrix were examined to determine the proportion of variance explained by each component and to identify parameters with the highest contributions. This approach enabled the assessment of correlations among metals and highlighted the principal factors controlling water quality in the study area. PCA is increasingly applied in environmental studies due to advances in computational tools, which facilitate the handling of complex, multidimensional data (Anazawa *et al.*, 2004). In this study, it provided insights into the major pollution sources and their influence on the aquatic environment.

2.8 *Statistical Analysis*

All statistical analyses were performed using Microsoft Excel, SPSS (version 20.0), PAST4, and R (version 4.0.2). Descriptive statistics were first applied to summarize the physicochemical and heavy metal data. Differences among sampling locations were tested using one-way analysis of variance (ANOVA). Where significant differences were observed ($p < 0.05$), Duncan's Multiple Range (DMR) test was applied to identify the specific locations contributing to the variation. Multivariate analyses were conducted to explore relationships among parameters and to identify potential pollution sources. Cluster Analysis (CA) was performed in PAST4 based on Euclidean distances, while Principal Component Analysis (PCA) was carried out in R (R Development Core Team, 2020) using the varimax rotation method to maximize interpretability. In addition, correlation analysis was employed to determine the strength and direction of associations between physicochemical parameters and heavy metals.

3. **Results and Discussion**

3.1 *Physicochemical characteristics of surface water samples*

The results of the physico-chemical characteristics and heavy metal content of water samples obtained at Okpare Olomu River from four sampled stations are summarized in Table 1 and Table 2. The river system is the major source of fresh water. It carries along its course and tributaries a reasonable quantity or load of matter which are either in dissolved or particulate form (Edori *et al.*,

2019). The hydrogen ion concentration of an aquatic ecosystem is a measure of hydrogen ions in a given sample and can be altered by biological activities due to a narrow change which can be a threat to aquatic life (Tebbutt 1992).

Table 1. Summary of physico-chemical characteristics of the water from Okpare Olomu River

Parameters	Station 1	Station 2	Station 3	Station 4	p-Value	NESREA 2015	USEPA/WHO 2004/2011
	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)			
Colour	Pale yellow	Pale yellow	Pale yellow	Pale yellow			
pH	5.71±0.30 (5.47-6.20)	5.71±0.19 (5.40-5.93)	5.86±0.48 (5.37-6.65)	5.85±0.61 (5.36-6.92)	p>0.05	6.5 - 8.5	6.5 - 8.5
EC (us/cm)	22.54±5.09 (16.00-26.80)	17.23±6.47 (10.80-24.20)	17.28±4.26 (12.40-21.60)	24.23±4.01 (17.14-27.00)	p>0.05	1000	500 1000
Turbidity (NTU)	8.03 ^a ±0.11 (7.95-8.15)	7.03 ^b ±0.48 (6.50-7.51)	7.71 ^a ±0.33 (7.35-7.96)	7.09 ^b ±0.31 (6.75-7.32)	p<0.01	< 5.0	0.5 – 1.0 < 5.0
TDS (mg/L)	8.00 ^b ±0.71 (7.00-9.00)	6.46 ^c ±0.48 (6.10-7.30)	6.18 ^c ±0.46 (5.90-7.01)	13.46 ^a ±0.42 (13.20-14.22)	p<0.01	500	500
TSS (mg/L)	74.00 ^b ±0.71 (73.00-75.00)	71.20 ^d ±1.10 (70.00-72.00)	72.60 ^c ±0.89 (71.00-73.00)	75.20 ^a ±0.45 (75.00-76.00)	p<0.01	500	500
TS (mg/L)	82.00 ^b ±0.71 (81.00-83.00)	77.66 ^d ±0.86 (76.30-78.30)	78.78 ^c ±0.43 (78.01-79.00)	88.66 ^a ±0.55 (88.20-89.30)	p<0.01	500	500 1000
DO (mg/L)	5.54±0.58 (5.00-6.40)	5.12±1.07 (4.30-7.00)	5.46±2.44 (4.11-9.80)	6.24±0.90 (4.70-6.80)	p>0.05		7.5-10
BOD (mg/L)	6.70±2.90 (4.50-11.35)	6.46±2.90 (4.20-10.90)	3.34±0.83 (2.18-4.40)	7.43±4.97 (3.60-16.15)	p>0.05	30	4.0-7.5
COD (mg/L)	40.20 ^a ±15.01 (32.00-67.00)	30.80 ^a ±7.43 (26.00-44.00)	25.20 ^b ±1.79 (22.00-26.00)	42.40 ^a ±6.39 (34.00-52.00)	p<0.01		10.0
Alkalinity (mg/L)	8.37 ^b ±1.47 (6.20-10.20)	7.42 ^b ±2.13 (6.10-11.00)	6.92 ^b ±0.68 (6.00-7.90)	11.12 ^a ±1.50 (9.20-12.40)	p<0.01		100 100
Hardness (mgCaCO ₃ /L)	9.16 ^b ±2.49 (7.01-12.40)	7.16 ^b ±0.83 (5.82-8.01)	8.02 ^b ±1.61 (7.01-10.80)	15.49 ^a ±2.10 (14.27-19.22)	p<0.01	100	150 75
Chloride (mg/L)	6.92 ^b ±1.50 (5.80-9.45)	4.77 ^c ±0.90 (3.90-6.30)	3.54 ^d ±1.28 (2.70-5.65)	9.35 ^a ±1.33 (7.22-10.65)	p<0.01	250	250 100
Potassium (mg/L)	1.61 ^b ±0.23 (1.26-1.92)	1.35 ^b ±0.26 (1.14-1.65)	1.32 ^b ±0.29 (0.98-1.67)	2.49 ^a ±0.39 (2.15-3.11)	p<0.01	10	10
Sodium (mg/L)	1.20 ^a ±0.11 (1.14-1.40)	0.83 ^c ±0.17 (0.60-0.99)	1.03 ^b ±0.11 (0.86-1.16)	1.29 ^a ±0.15 (1.12-1.51)	p<0.01	200	200 200
Calcium (mg/L)	1.87 ^b ±0.74 (0.98-2.98)	1.27 ^b ±0.02 (1.26-1.30)	1.75 ^b ±0.34 (1.17-1.96)	3.76 ^a ±0.87 (3.12-5.13)	p<0.01		7.50
Magnesium (mg/L)	0.46 ^c ±0.24 (0.17-0.78)	1.06 ^a ±0.47 (0.24-1.38)	0.55 ^b ±0.21 (0.27-0.78)	1.19 ^a ±0.61 (0.14-1.56)	p<0.01		200 250
Sulphate (mg/L)	3.05±0.88 (2.45-4.58)	3.55±1.77 (2.28-6.50)	2.64±0.30 (2.16-2.86)	2.43±0.45 (2.02-3.19)	p>0.05	100	250 200
Phosphate (mg/L)	0.66±0.71 (0.05-1.80)	0.22±0.16 (0.02-0.36)	0.39±0.37 (0.03-0.98)	0.40±0.54 (0.01-1.34)	p>0.05	5.0	3.5 10.0
Nitrate (mg/L)	1.94±0.73 (1.22-2.83)	1.91±0.70 (1.37-2.88)	2.46±0.82 (1.32-3.61)	2.87±0.93 (1.49-3.86)	p>0.05	50	10 11
Nitrogen (mg/L)	0.58 ^{bc} ±0.21 (0.33-0.79)	0.33 ^c ±0.11 (0.19-0.49)	1.28 ^a ±0.06 (1.20-1.33)	0.55 ^{bc} ±0.22 (0.19-0.77)	p<0.01		

$\bar{x} \pm SD$ = average mean generated from values across the months per station, \pm standard deviation; min-max = minimum and maximum values for each parameter per station; post hoc = values with different superscripts (a > b > c > d) are significantly different (p < 0.05 or 0.01) while values with same superscript are not significantly different (p > 0.05). *p < 0.05 (significant difference), **p < 0.01 (highly significant difference)

NESREA, National Environmental Standard, regulation and Enforcement Agency Guidelines and standards for water quality in Nigeria (2015); WHO, World Health Organization Guidelines for Drinking Water Quality (2011);

USEPA, United State Environmental Protection Agency National recommended water quality criteria (2004).

The pH values obtained from Okpare Olomu River were relatively similar and were moderately acidic to slightly acidic with an average mean of 5.71, 5.71, 5.86 and 5.85 at stations 1, 2, 3 and 4 respectively. There was no significant difference ($p>0.05$) in pH values across the study stations. The acidic nature of rivers in Nigeria had earlier been reported by different aquatic ecologist ([Iwegbue et al., 2007](#)), ([Puyate et al., 2007](#)), ([Wogu and Okaka, 2011](#)) ([Omoigberale et al., 2013](#)), ([Omoruyi 2014](#)). pH values give information on the amount of heavy metals that are likely present in either water or sediment media. [Nnoli et al. \(2021\)](#) recorded higher pH value of 6.55 in Goi Creek in Ogoni land. At average, the pH nature of Okpare Olomu River was slightly acidic and similar to the values recorded by [Iyama et al. \(2019\)](#) in Sagbama Creeks. Acidic condition is typical of the tropical forest stream within this ecozone ([Ogbeibu and Anagboso, 2003](#)). The mean pH values between the sampled stations had no much difference, suggesting the uniform pH recorded in Okpare Olomu River.

The electrical conductivity (EC) values obtained from Okpare Olomu River were higher in station 4 than other sampled stations. The average mean values of EC were 22.54, 17.23, 17.28 and 24.23 ($\mu\text{S}/\text{cm}$) at station 1, 2, 3 and 4 respectively. This shows that the level of anthropogenic activity were lower in station 4 followed by station 1 which were relatively similar but different from stations 2 and 3 which had more activities going on in both stations. [Okorafor et al. \(2014\)](#) obtained a lower EC values of 12.15 and 11.65 $\mu\text{S}/\text{cm}$ upstream and downstream of the Lower Qua Iboe River in Akwa Ibom State, while [Edori et al. \(2019\)](#) and [Anweting et al., \(2024\)](#) recorded higher values of (26,567 $\mu\text{S}/\text{cm}$) and (73.70 $\mu\text{S}/\text{cm}$) in surface water of Silver River in Bayelsa and Idim Idaang Stream in Ibiono Ibom, Akwa Ibom State, Nigeria. [Linden and Palsson \(2013\)](#) opined that Electrical conductivity were predictably low in their study which was directly influenced by the tides. There was no significant difference ($p>0.05$) in EC values across the sampled stations in this study. The level of suspended and dissolved particles in any water environment give high turbidity to the environment ([Edori et al., 2019](#)). The results show the turbidity values obtained from Okpare Olomu River was higher in station 1 than other sampled stations. The high value of turbidity in station 1 from Okpare Olomu River would have been as a result of the influx of particulate matters with runoffs during the rainy season as this station was assessed from a slope by the indigenes of Okpare and assumed to cause an increase in number of suspended solids as turbidity is associated with suspended solid concentrations ([Okorafor et al., 2014](#)). The average mean values of turbidity were 8.03, 7.03, 7.71 and 7.09 (NTU) at station 1, 2, 3 and 4 respectively. [Edori et al. \(2019\)](#) recorded higher values of (15.57 NTU) in surface water of Silver River in Bayelsa State and attributed it to the amount of dissolved solids (organic or inorganic Materials) present in the river Silver in Bayelsa State. The values of turbidity observed in this work is similar than those of [Edori and Nna \(2018\)](#), in the New Calabar and those of [Yapo et al. \(2012\)](#), in a river in Abidjan City. Effects of high turbidity include prevention of light penetration, hindrance to photosynthetic activities and destruction of the normal aquatic life and also reduce the value and appearance of surface water ([Gupta et al., 2017](#)). The observed values of turbidity in Okpare Olomu River is higher than the value of <5.0 NTU for portable water accepted by [NESREA \(2015\)](#), and also the recommended values of <5.0 NTU by [WHO \(2008\)](#) and 0.5-1.0 NTU by [USEPA \(2008\)](#) for drinking water quality.

Total dissolved solids (TDS) in water measures the presence of both inorganic an organic material which are in solution ([Rahmanian et al., 2015](#)), ([Edori et al., 2019](#)). The TDS values of water samples from Okpare Olomu River were different and showed a highly significant difference ($p<0.01$)

in the sampled stations. The average mean values of TDS were 8.00, 6.46, 6.18 and 13.46 (mg/L) station 1, 2, 3 and 4 respectively. [Edori et al. \(2019\)](#) recorded higher values of (13,250 mg/L) in surface water of Silver River in Bayelsa State and obtained values which varied from 13,050 - 13,500 mg/L. The increased value in [Edori et al. \(2019\)](#) may be a consequence of salt water intrusion, human input through bunkering activities and the redox potential of the water system ([Iyama and Edori, 2016](#)). Total Suspended Solids (TSS) is the material in water that affects the transparency or light scattering of the water and is typically composed of fine clay or silt particles, plankton, organic compounds or other microorganisms ([Edori and Kpee, 2016](#)). The average mean concentration values of TSS and TS in this study were 74.00, 71.20, 72.60 and 75.20 (mg/L) and 82.00, 77.66, 78.78 and 88.66 (mg/L) at stations 1, 2, 3 and 4 respectively. However the TSS value at station 4 (75.20 mg/L) and TS value at station 4 (88.66 mg/L) were higher than the TSS and TS values at other sampled stations. However, there was a highly significant difference ($p < 0.01$) in the concentration of TSS and TS across the sampled stations. [Edori and Nna \(2018\)](#) recorded lower range values of (20.53-31.31 mg/L) for TSS in effluents at discharge points into the New Calabar River along Rumuolumeni Axis, Rivers State while [Nnoli et al. \(2021\)](#) also recorded lower TSS of 17.56 mg/L in Goi Creek in Ogoni land. The observed values of TSS and TS in this study are lower than the recommended value of 500 mg/L for drinking water quality by [NESREA \(2015\)](#), [WHO \(2004\)](#) and [USEPA \(2008\)](#).

Dissolved oxygen (DO) concentration in natural waters depends on the physical, chemical and biochemical activities in the water body. The average mean concentration of DO in this study were 5.54, 5.12, 5.46 and 6.24 (mg/L) at stations 1, 2, 3 and 4 respectively. [Linden and Palsson \(2013\)](#) recorded DO values which varied between 1.5 and 6.9 mg/L for the different sites and averaged 4.2 mg/L, and attributed their values to flow rate of the river and aquatic flora. Oxygen depends on temperature, depth, flow rate, salinity and pressure of the water body ([Linden and Palsson, 2013](#)). The trends observed for DO in the following stations were relatively similar except for station 4 and but showed no significant difference ($p > 0.05$) across the sampled stations. [Edori and Nna \(2018\)](#) recorded lower range values of (2.62-3.72) for DO in effluents at discharge points into the New Calabar River along Rumuolumeni Axis, Rivers State while [Nnoli et al. \(2021\)](#) recorded a similar DO of 9.82 mg/L in Goi Creek in Ogoni land. However, the DO values recorded in this study were lower than WHO permissible limit of 7.5 mg/L and higher than FNEMN permissible limit of 5.0 mg/L. The variability of biological oxygen demand (BOD) in water samples obtained from Okpare Olomu River reflects the amount of oxygen essential for an organism to breakdown or utilize the organics present in a water body over a period of time at a specific temperature ([Sawyer 1994](#)), ([Edori et al., 2019](#)). This factor is important for determining the safety and cleanliness of any water. The BOD values of water samples from Okpare Olomu River were relatively similar except for station 3 which had the least value and showed no significant difference ($p > 0.05$) across the sampled station. The average mean values of BOD were 6.70, 6.46, 3.34 and 7.43 (mg/L) at station 1, 2, 3 and 4 respectively. According to WHO (2005), water is considered clean when the BOD level is between 1.0 and 2.0 mg/L; fairly clean at 3.0 mg/L, doubtful at 5.0 mg/L and unclean - polluted at levels of 10.0 mg/L. [Ayobahan et al. \(2014\)](#) recorded BOD values of 2.78-3.58 mg/l which was lower than the BOD values in this study except for station 3 which had similar values. The possible reason for difference observed between the ranges obtained in this study is increase in anthropogenic activities in the river and its shed which in turn can

directly or indirectly increase use of the river as waste receptacle. Films of oil were observed at the water surface especially at stations 2 and 4 during the sampling. These hindered re-aeration at water surface thus reduced dissolved oxygen concentration while increasing the biochemical oxygen demand because it is organic in nature. The DO and BOD levels across the stations did not maintain specific patterns in this study, which probably was due to input of organic substances and subsequently their decomposition effects.

The COD values of water samples from Okpare Olomu River were different across the sampled stations with an average mean concentration of 40.20, 30.80, 25.20 and 42.40 (mg/L) at station 1, 2, 3 and 4 respectively. However the COD concentration of station 4 was higher than other sampled stations and showed a highly significant difference ($p < 0.01$) across the sampled stations. [Ayobahan et al. \(2014\)](#) obtained the least and highest mean concentration of COD in Benin River. The high level of chemical substances observed in this study is an evidence of the intense anthropogenic activities going on in the upstream and downstream of Okpare Olomu River. High COD has been linked with pollution ([UNEP 2011](#)). Lesser value was observed at station 3 when compared to station 2 and probably resulted from the flowing current which increased downstream. [Edori et al. \(2019\)](#) recorded relatively higher COD values of (50.13 mg/L) in surface water of Silver River in Bayelsa State when compared to this study. The COD values in this study were higher than the recommended value of 10 mg/L for drinking water quality by [WHO \(2011\)](#).

The average mean concentration of alkalinity and hardness from Okpare Olomu river at stations 1, 2, 3 and 4 were 8.37, 7.42, 6.92 and 11.12 (mg/L) and 9.16, 7.16, 8.02 and 15.49 (mg/L) respectively. The trends observed across the stations were different for alkalinity and hardness which showed a highly significant difference ($p < 0.01$) across the sampled stations. The highest alkalinity and hardness values were obtained at station 4 while the lowest values were obtained at stations 3 and 2 respectively. Similar hardness value at station 4 of this study was recorded by [Okorafor et al. \(2014\)](#) upstream of the Lower Qua Iboe River in Akwa Ibom State, but total hardness values at stations 1, 2 and 3 were also similar to the values of [Okorafor et al. \(2014\)](#), which was 10.00 mg/L downstream of the Lower Qua Iboe River in Akwa Ibom State. [Nnoli et al. \(2021\)](#) recorded higher Alkalinity value of 31.94 mg/L in Goi Creek in Ogoni land. However, the alkalinity and harness values were far lower than the recommended value of 100 mg/L for drinking water by [WHO \(2008\)](#). The variability of chloride (Cl^{-1}) in water samples obtained from Okpare Olomu River were different in all the samples stations. However, Cl^{-1} content at station 4 (9.35 mg/L) was higher than the Cl^{-1} content of other sampled stations followed by station 1 (6.92 mg/L). There was a highly significant difference ($p < 0.01$) in the concentration of Cl^{-1} across the sampled stations. [Oghenenyoreme and Njoku \(2014\)](#) obtained higher values of 21.6 mg/L for hardness in selected part of Oji River and its environs, Enugu State. [Edori and Nna \(2018\)](#) recorded similar range values of (6.067-9.411 mg/L) for Cl^{-1} in effluents at discharge points into the New Calabar River along Rumuolumeni Axis, Rivers State. The Cl^{-1} values in this study were lower than the recommended values of 250 mgCaCO₃/L for drinking water by [NESREA \(2015\)](#), [USEPA \(2008\)](#) and 100 mg/L by [WHO \(2008\)](#).

The variability of K, Na, Ca and Mg in water samples obtained from Okpare Olomu River were relatively similar in all the samples stations. However, the K content at station 4 (2.49 mg/L) was higher than the K content of other sampled stations followed by station 1 with (1.61 mg/L). The Na

content at station 4 (1.29 mg/L) was higher than the Na content of other sampled stations followed by station 1 with (1.20 mg/L). The Ca content at station 4 (3.76 mg/L) was higher than the Ca content of other sampled stations followed by station 1 with (1.87 mg/L). Excess amount of calcium (Ca^{2+}) can damage the kidney and impact hardness to water (Nnoli *et al.*, 2021). The Mg content at station 4 (1.19 mg/L) was higher than the K content of other sampled stations followed by station 2 with (1.06 mg/L). Excess concentration of magnesium in water causes water hardness which may further cause cardiovascular mortality (Nnoli *et al.*, 2021). The trends observed in K, Na, Ca and Mg content in the Okpare Olomu River was seen to accumulate the following minerals in station 4 followed by station 1 except for Mg content in station 2. Oghenenyoreme and Njoku (2014) obtained similar values of 4.2 mg/L for Ca, higher values of 3.5 mg/L for Mg and as well as similar values of 2.1 mg/L for K in selected part of Oji River and its environs, Enugu State.

Sulphate occurs naturally in water and it is an essential primary productivity nutrient. The SO_4 content at station 2 (3.55 mg/L) was higher than the SO_4 content of other sampled stations followed by station 1 with (3.05 mg/L). Edori *et al.* (2019) recorded a higher SO_4 range between 1956 – 2455 mg/L in surface water of Silver River in Bayelsa State which was higher than the values observed in this study. Nnoli *et al.* (2021) also recorded higher SO_4 value of 22.15 mg/L in Goi Creek in Ogoni land. The values of sulphate in this study were also lower than those of a previous researchers in the water system (Dirican 2015), (Okoro *et al.*, 2017), in different aquatic environments in Nigeria and elsewhere in the world. The phosphate (PO_4) content at station 1 (0.66 mg/L) was higher than the PO_4 content of other sampled stations followed by station 4 with (0.40 mg/L). Okorafor *et al.* (2014) obtained a higher PO_4 values of 12.34 and 9.20 mg/L upstream and downstream of the Lower Qua Iboe River in Akwa Ibom State and attributed the high PO_4 levels in the water to the leaching of fertilizer residues from agricultural farms along the river. The orthophosphates are the most predominant species of phosphate in most aquatic environments (Edori *et al.*, 2019). Phosphate sources in the water samples may have originated from degeneration of organic matter, runoffs from agricultural lands where PO_4 based fertilizers have been applied, animal dungs (piggery and poultry farms) and other sources. The consequence of phosphate increase in water or aquatic environment (water or sediment) is algal bloom (excessive growth of algae), which results in eutrophication especially in lakes and stationary water (Edori and Kpee, 2016). This will eventually lead to shallowness of the river, thus causing withdrawal of most bottom dwelling species that require certain level of depth to inhabit or dwell in any aquatic environment (Edori *et al.*, 2019). Phosphate values in this study were lower than the maximum permissible level of 10 mg/L by (WHO 2011). The PO_4 values in this study were far lower than the recommended value of 10 mg/L for drinking water by NESREA (2015), USEPA (2008) and WHO (2008). Nitrate (NO_3) content at station 4 (2.87 mg/L) was higher than the NO_3 content of other sampled stations followed by station 3 with (2.46 mg/L). Okorafor *et al.* (2014) obtained a lower nitrate values of 0.35 and 0.22 mg/L upstream and downstream of the Lower Qua Iboe River in Akwa Ibom State and attributed the source of NO_3 from oxidation of other forms of nitrogen compounds like ammonia and nitrite into nitrate. Oghenenyoreme and Njoku (2014) obtained an average value of 26.0 mg/L for NO_3 which was higher than the NO_3 values in this study. Edori and Nna (2018) recorded lower range values of (0.34-0.53 mg/L) for NO_3 in effluents at discharge points into the New Calabar River along Rumuolumeni Axis, Rivers State while Nnoli *et al.* (2021) recorded

a similar NO₃ value of 3.56 mg/L in Goi Creek. This study reveals that the effect of oil spill pollution, associated runoffs from the watershed and other anthropogenic activities that have occurred in these areas are the major determinants of the variations in the water quality parameters. The values recorded for nutrients in Okpare Olomu River were moderate and acceptable for a fresh water body and did not exceed the standard permissible limits of NESREA, USEPA and WHO. The low values of SO₄, PO₄, NO₃ and N values in Okpare Olomu River were observed to follow a trend. SO₄ was highest in station 2 and this could be as a result of oil spill pollution. PO₄, was highest in station 1 as this could be as a result of domestic activities by indigenes of Okpare Olomu such as washing and bathing. NO₃ was highest in station 4 as this could be as a result of plants and other inorganic pollutants that's settled downstream of the river. Agricultural activities in Okpare Olomu River is minimal as they barely have fertile soils for agricultural practices. Therefore, the nutrients recorded in Okpare Olomu River could still be attributed to the land use practices around the river.

3.2 *Heavy metals in surface water samples*

The concentration of heavy metals in water samples from the Okpare Olomu River followed the order: Fe > Pb > Zn > Cr > Cu > Cd > Mn (Table 2). This trend is consistent with reports from other Niger Delta rivers, though with some variation in the order of occurrence. For instance, [Oribhabor and Ogbeibu \(2009\)](#) reported Mg > Ca > Fe > Zn > Ni > Cr > Pb > Cd in a Niger Delta mangrove creek, while [Wogu and Okaka \(2011\)](#) found Fe > Mn > Zn > Cu > Ni > V > Cr > Cd > Pb in Warri River. Similarly, [Adewuyi and Olowu \(2012\)](#) observed Cu > Zn > Pb > Cd > Ni > Cr in surface waters near the NNPC oil depot in Ibadan and [Anweting et al., \(2024\)](#) observed Zn > Fe > Cu > Mn > Cd > Pb > Cr > Ni > Co > Hg = As in surface water from Idim Idaang Stream in Ibiono Ibom, Akwa Ibom State, Nigeria.

Iron (Fe) concentration level in the environment had continued to maintain its top position in relation to the concentration levels of other heavy metals in the surface water in almost all investigations carried out to date. This could be attributable largely to effluents the river receives from many iron based industries located along its banks as well as Fe found everywhere in our environment ([Iwegbue et al., 2007](#)), ([Puyate et al., 2007](#)), ([Wogu and Okaka, 2011](#)), ([Omoigberale et al., 2013](#)), ([Omoruyi 2014](#)), ([Enuneku et al., 2017](#)). The dominance of Fe may also have originated from the bedrock as it is the fourth most abundant element in the earth's crust ([Wright and Welbourn 2002](#)). The average mean concentration of Fe in water samples from Okpare Olomu River were 1.56, 2.35, 0.86 and 1.83 (mg/L) at station 1, 2, 3 and 4 respectively. [Oribhabor and Ogbeibu \(2009\)](#) obtained a lower concentration of Fe value of 0.712 mg/L in surface water in Niger Delta mangrove creek. Similar values of 1.930 mg/L were obtained by [Wogu and Okaka \(2011\)](#) in surface water samples from Warri River and attributed the high concentration level of Fe to the iron and steel industry at Aladja, which discharges its effluents into the river. [Dibofori-Orji et al. \(2019\)](#) recorded a lower value of 0.419 and 0.545 mg/L for Fe in water samples from Woji Creek and attributed this to the degradation of the abandoned boats which can also account for the high concentration of other heavy metals, such as Fe in the sample station. Overall, Fe concentration in water samples from Okpare Olomu River were above the maximum permissible limit of 0.3 mg/L by [NESREA \(2015\)](#), [USEPA \(2008\)](#) and [WHO \(2011\)](#).

Table 2. Heavy metal content of water samples from Okpare Olomu River

Parameter	Station 1	Station 2	Station 3	Station 4	p-Value	NESRE	USEPA/WH
	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)	$\bar{x}\pm SD$ (Min-Max)		A	O
Fe (mg/L)	1.56±0.37 (0.90-1.75)	2.35±2.28 (1.00-6.40)	0.86±0.61 (0.30-1.78)	1.83±0.59 (0.80-2.20)	p>0.05	0.3	0.3
Cr (mg/L)	0.06±0.04 (0.01-0.11)	0.07±0.07 (0.00-0.17)	0.12±0.14 (0.00-0.34)	0.09±0.09 (0.01-0.23)	p>0.05		0.1 0.05
Cd (mg/L)	0.05±0.04 (0.00-0.10)	0.07±0.04 (0.00-0.10)	0.05±0.04 (0.00-0.10)	0.02±0.01 (0.00-0.02)	p>0.05	0.003	0.005 0.003
Cu (mg/L)	0.07±0.06 (0.03-0.16)	0.06±0.06 (0.01-0.14)	0.06±0.04 (0.00-0.10)	0.09±0.07 (0.02-0.17)	p>0.05	1.0	1.0 2.0
Zn (mg/L)	0.15±0.06 (0.06-0.22)	0.14±0.09 (0.03-0.28)	0.13±0.05 (0.05-0.16)	0.16±0.12 (0.06-0.36)	p>0.05	3.0	3.0 3.0 – 5.0
Mn (mg/L)	0.01±0.01 (0.00-0.20)	0.02±0.02 (0.00-0.03)	0.01±0.01 (0.00-0.01)	0.02±0.02 (0.01-0.04)	p>0.05	0.05	0.05
Pb (mg/L)	0.18 ^b ±0.10 (0.00-0.20)	0.23 ^a ±0.06 (0.15-0.31)	0.10 ^b ±0.04 (0.00-0.10)	0.00 ^b ±0.00 (0.00-0.00)	p<0.01	0.01	0.01
THC(mg/L)	3.61±1.90 (2.06-6.67)	3.34±1.17 (2.23-5.29)	3.62±1.09 (2.32-5.29)	2.85±0.93 (1.53-3.97)	p>0.05		

NESREA, National Environmental Standard, regulation and Enforcement Agency Guidelines and standards for water quality in Nigeria (2015); WHO, World Health Organization Guidelines for Drinking Water Quality (2011); USEPA, United State Environmental Protection Agency National recommended water quality criteria (2004)

The average mean concentration of Cr in water samples from Okpare Olomu River were 0.06, 0.07, 0.12 and 0.09 (mg/L) at station 1, 2, 3 and 4 respectively. Higher concentrations were obtained at station 3 followed by station 4 while station 1 had the lowest concentration. However the concentration of Cr in Okpare Olomu River showed no significant difference (p>0.05) across the sampled stations. High chromium content in station 3 can be attributed to the continuous dredging of sediments using petroleum powered engines throughout the year and other industrial anthropogenic activities carried out by indigenes of Okpare Olomu. The average mean concentration of Cd in water samples from Okpare Olomu River were 0.05, 0.07, 0.05 and 0.02 (mg/L) at station 1, 2, 3 and 4 respectively. [Dibofori-Orji et al. \(2019\)](#) recorded a higher value of 0.197 mg/L for Cd in water samples from Woji Creek. Higher concentrations were obtained at station 2 while station 4 had the lowest concentration. [Oribhabor and Ogbeibu \(2009\)](#) obtained a similar concentration of Cd value of 0.04 mg/L in surface water in Niger Delta mangrove creek. However the concentration of Cd in Okpare Olomu River showed no significant difference (p>0.05). Long term exposure to cadmium is associated with renal dysfunction, anaemia, bone marrow disorder, cancer, bronchitis, liver and brain disorders ([Dara 2000](#)), ([Koji et al., 2004](#)). Overall, Cr and Cd concentration in water samples from Okpare Olomu River were above the maximum permissible limit of 0.05 mg/L and 0.003 mg/L ([NESREA 2015](#)), ([WHO 2004](#)).

The average mean concentration of Cu in water samples from Okpare Olomu River were 0.07, 0.06, 0.06 and 0.09 (mg/L) at station 1, 2, 3 and 4 respectively. Higher concentrations of Cu were obtained at station 4 while station 2 and 3 had the lowest concentrations. [Dibofori-Orji et al. \(2019\)](#) recorded a similar value of 0.036 mg/L for Cu in water samples from Woji Creek. Higher values of 0.26 mg/L were obtained by [Wogu and Okaka \(2011\)](#) in surface water samples from Warri River and attributed it to wastes from industrial, agricultural and domestic sources while [Nnoli et al. \(2021\)](#) also recorded higher Cu value of 1.93 mg/L in Goi Creek. However the concentration of Cu in Okpare Olomu River showed no significant difference ($p>0.05$) across the sampled stations. Copper can cause stomach and intestinal distress, liver and kidney damage. In high doses, it results in bad taste and significant staining in cloths fixtures ([Obasi and Akudinobi, 2013](#)), ([Oghenenyoreme and Njoku, 2014](#)). The average mean concentration of Zn in water samples from Okpare Olomu River were 0.15, 0.14, 0.13 and 0.16 (mg/L) at station 1, 2, 3 and 4 respectively. [Oribhabor and Ogbeibu \(2009\)](#) obtained a lower concentration of 0.087 mg/L for Zn in surface water from a Niger delta mangrove creek. Higher values of 0.63 mg/L were obtained by [Wogu and Okaka \(2011\)](#) in surface water samples from Warri River. The health implications of elevated levels of zinc (Zn^{2+}) are severe vomiting, diarrhoea, bloody urine, liver and kidney failure and anaemia ([Fosmire 1990](#)). [Ardeleanu et al. \(1999\)](#) attributed the level of Mn in his study to anthropogenic sources, especially from oil spill areas and industrial activities. The average mean concentration of Mn in water samples from Okpare Olomu River were 0.01, 0.02, 0.01 and 0.02 (mg/L) at station 1, 2, 3 and 4 respectively. Higher values of 0.68 mg/L were obtained by [Wogu and Okaka \(2011\)](#) in surface water samples from Warri River and attributed it to wastes from industrial, agricultural and domestic sources. The concentration of Mn in Okpare Olomu River showed no significant difference ($p>0.05$).

The average concentration of Pb in water samples from Okpare Olomu River were 0.18, 0.23, 0.10 and 0.00 (mg/L) at station 1, 2, 3 and 4 respectively. [Oribhabor and Ogbeibu \(2009\)](#) recorded similar concentration of 0.107 mg/L for Pb in surface water from a Niger Delta mangrove creek. Higher concentrations of Pb were obtained at station 2 while Pb content was not detected at station 4. [Dibofori-Orji et al. \(2019\)](#) recorded a higher value of 1.352 mg/L for Pb in water samples from Woji Creek and attributed the high Pb value to the visible presence of petroleum in the creek suggests that some of the heavy metals in the samples analysed come from petroleum sources. [Nnoli et al. \(2021\)](#) recorded higher Pb value of 1.62 mg/L in Goi Creek. The non-detected content of Pb at station 4 would arise due to volatilization as station 4 was the downstream of the study station. However the concentration of Pb in Okpare Olomu River showed a highly significant difference ($p<0.01$). Lead concentration in water samples from Okpare Olomu River were above the maximum permissible limit of 0.01 mg/L by [NESREA \(2015\)](#), [USEPA \(2008\)](#), [WHO \(2008 & 2011\)](#) at stations 1, 2 and 3. The average concentration of total hydrocarbon content (THC) in water samples from Okpare Olomu River were 3.61, 3.34, 3.62 and 2.85 (mg/L) at station 1, 2, 3 and 4 respectively. Higher concentrations of THC were obtained at station 3 probably due to the constant dredging of sand with petroleum driven engines while station 4 had the lowest concentration. However the concentration of THC in Okpare Olomu River showed no significant difference ($p>0.05$). THC obtained in this study were higher than the values obtained by [Howard et al. \(2009\)](#) in an oil-polluted mangrove wetland in the Niger Delta and lower than the values obtained by [Wokoma \(2014\)](#) in a polluted tidal creek of Bonny River. Elsewhere,

Tahir *et al.* (1997) also recorded a higher THC range of 1.4 – 21.8mg/L in the coastal waters of Malaysia. On the contrary the mean value of 149 mg/L recorded by Eja and Orji (2003) in the coastal areas of South Eastern Nigeria is significantly higher than the observed values of THC in the present study. The observed levels of THC in surface water in all sampling stations throughout the period of study was lower than the maximum permissible limit of 10 mg/L for inland waters set by EGASPIN (2002). However, higher levels of THC in water could cause oxygen deterioration by reduction in gaseous diffusion through the surface film of oil with far reaching implications for the flora and fauna of the affected area (Howard *et al.*, 2009), (Wokoma, 2014), (Edori *et al.*, 2019). Overall, the concentrations of Fe, Cd, and Pb exceeded recommended limits, highlighting potential ecological risks and implications for human health. Heavy metal contamination in aquatic systems has been associated with bioaccumulation in fish and other organisms (Adepoju-Bello and Alabi, 2005), (Ali *et al.*, 2019) leading to population declines, behavioural disruptions, and deformities (Sfakianakis *et al.*, 2015). The elevated levels observed in this study most likely reflect recurrent crude oil spills and industrial effluents in the region (FEI 2019).

3.3 Cluster analysis for physicochemical parameters and heavy metals in surface water

Table 3 presents the Euclidean similarity and distance indices among the sampled stations, while Figure 2 illustrates the dendrogram of cluster analysis based on physicochemical and heavy metal concentrations in water samples from Okpare Olomu River. The Euclidean dissimilarity values showed marked variation across stations, ranging from 7.233 between Stations 2 and 3 to 25.180 between Stations 3 and 4.

Table 3. Euclidean similarity and distance indices

	Station 1	Station 2	Station 3	Station 4
Station 1	0.000			
Station 2	12.589	0.000		
Station 3	17.208	7.233	0.000	
Station 4	12.049	22.054	25.180	0.000

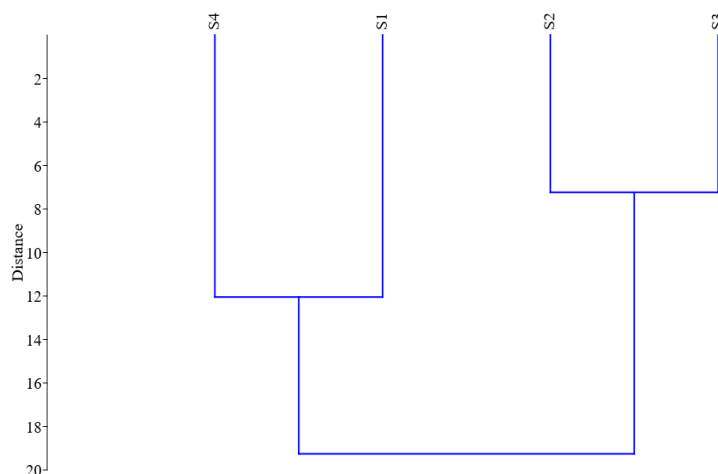


Figure 2: Dendrogram for cluster analysis

The dendrogram (**Figure 2**) revealed two main groupings. Stations 2 and 3 clustered closely together, reflecting their similar physicochemical and heavy metal characteristics and suggesting that both locations were influenced by comparable anthropogenic activities, most likely linked to dredging and oil-related operations observed during sampling. In contrast, Stations 1 and 4 formed a separate grouping, indicating that these sites shared more similar conditions with each other than with Stations 2 and 3. Their similarity may be attributed to a reduced direct influence of dredging activities and comparatively lower hydrocarbon inputs. This clustering pattern underscores spatial variation in water quality along the Okpare Olomu River, defined by Euclidean distance and Ward's linkage method. Comparable results have been reported in Nigerian inland waters, where differences in land use, effluent inputs, and other anthropogenic pressures shaped the distribution of cluster groups ([Ogbeibu *et al.*, 2014](#)), ([Akporido and Onianwa, 2015](#)). Overall, the analysis confirms that while Stations 2 and 3 share common pollution sources and water quality characteristics, Stations 1 and 4 are more alike, highlighting localized variations in pollution intensity across the river stretch.

3.4 *Principal components analyses in surface water samples*

Seven (7) dimensions (Dim) or principal components (PCs) with eigenvalues greater or equal to one were extracted from surface water samples of the Okpare Olomu River, accounting for a cumulative variation of 86.9587% in the dataset (**Table 4**). The individual contributions of Dims 1 to 7 were 32.542%, 16.854%, 11.793%, 9.139%, 6.795%, 5.499%, and 4.336%, respectively. Dim 1 showed high eigenvector loadings for EC, TDS, TSS, TS, COD, alkalinity, hardness, chloride, potassium, sodium, and calcium, indicating strong associations with ionic and mineral enrichment. Dim 2 was defined by high eigenvector values for EC (-0.517), BOD, nitrate, chromium, copper, manganese, and THC, suggesting influences from organic pollution and hydrocarbon-related inputs. Dim 3 showed high loadings for pH (-0.553), turbidity, sodium, magnesium, iron, and lead, reflecting geogenic and metal contamination factors. Dim 4 was dominated by total nitrogen, cadmium, and zinc, pointing to combined nutrient and trace metal influences. Dim 5 was characterized by sulphate,

phosphate, and nitrogen, consistent with nutrient enrichment from agricultural runoff and effluent discharge. Dim 6 was defined by dissolved oxygen, representing the oxygenation status of the river, while Dim 7 was dominated by turbidity, reflecting the role of suspended solids and dredging-related disturbances.

3.4.1 Principal components analyses (PCA) variables

Figure 3 shows the variable correlation plots for the principal component (PC) dimensions, while Figure 4 presents the bi-plots of the PCA after varimax rotation. The proximity of parameter vectors in these plots denotes the strength and nature of their relationships in water samples from Okpare Olomu River, in relation to cumulative variability across the dimensions.

The PCA analysis indicated that Dims 1 and 2 together accounted for 49.396% of the total dataset variability. Dim 1 loaded high eigenvector values for EC, TDS, TSS, TS, COD, alkalinity, hardness, chloride, potassium, sodium, and calcium, while Dim 2 loaded high eigenvector values for EC (-0.517), BOD, nitrate, chromium, copper, manganese, and THC. Notably, physico-chemical properties and water quality parameters in Dim 2 exhibited strong correlation with total hydrocarbon content (THC), reflecting the influence of hydrocarbon-related inputs on river water quality.

Table 4. Eigenvalues for Surface Water Samples

Parameter	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7
pH	-0.137	-0.261	-0.553*	0.147	0.380	0.029	-0.457
EC	0.608*	-0.517*	-0.065	-0.047	-0.248	0.034	-0.025
Turbidity	-0.207	0.429	-0.587*	0.087	0.020	-0.098	0.550*
TDS	0.951*	-0.014	-0.018	0.169	0.103	0.105	-0.148
TSS	0.779*	0.285	-0.333	-0.001	0.102	-0.272	0.023
TS	0.953*	0.113	-0.139	0.099	0.112	-0.058	-0.108
DO	0.393	-0.067	-0.056	-0.053	-0.215	0.774*	-0.280
BOD	0.365	-0.569*	0.267	0.487	0.013	-0.177	0.275
COD	0.690*	-0.469	0.002	0.379	-0.051	0.114	0.220
Alkalinity	0.846*	-0.400	0.067	-0.058	-0.112	0.041	-0.136
Hardness	0.917*	0.031	-0.131	-0.084	-0.016	0.136	-0.031
Chloride	0.754*	0.174	0.194	0.444	0.242	-0.073	0.056
Potassium	0.879*	0.274	0.085	0.132	0.053	-0.169	0.087
Sodium	0.648*	0.255	-0.586*	0.057	0.125	0.113	0.195
Calcium	0.896*	0.077	-0.141	-0.226	0.039	-0.090	-0.122
Magnesium	0.421	-0.011	0.775*	-0.240	-0.236	-0.097	-0.068

Sulphate	-0.464	-0.290	-0.115	0.355	0.583*	-0.065	-0.059
Phosphate	0.159	-0.278	-0.251	0.442	-0.678*	0.217	0.170
Nitrate	0.254	0.832*	0.118	-0.112	0.108	-0.129	-0.192
Nitrogen	-0.136	0.462	-0.349	-0.510*	-0.501*	-0.065	0.033
Fe	0.291	-0.089	0.692*	0.110	-0.126	-0.359	0.044
Cr	0.049	0.790*	0.222	0.163	-0.213	-0.182	-0.185
Cd	-0.450	0.349	0.005	0.705*	-0.100	0.125	-0.156
Cu	0.285	0.792*	0.363	0.075	0.074	0.259	0.173
Zn	0.235	-0.268	0.075	-0.597*	0.319	0.252	0.434
Mn	0.334	0.529*	0.304	-0.117	0.409	0.409	0.107
Pb	-0.495	-0.155	0.665*	0.035	0.188	0.328	0.089
THC	-0.310	0.630*	-0.008	0.512	-0.150	0.240	0.100
Eigenvalue	9.112	4.719	3.302	2.559	1.903	1.540	1.214
Variance percent	32.542	16.854	11.793	9.139	6.795	5.499	4.336
Cumulative variance	32.542	49.396	61.189	70.328	77.123	82.622	86.958

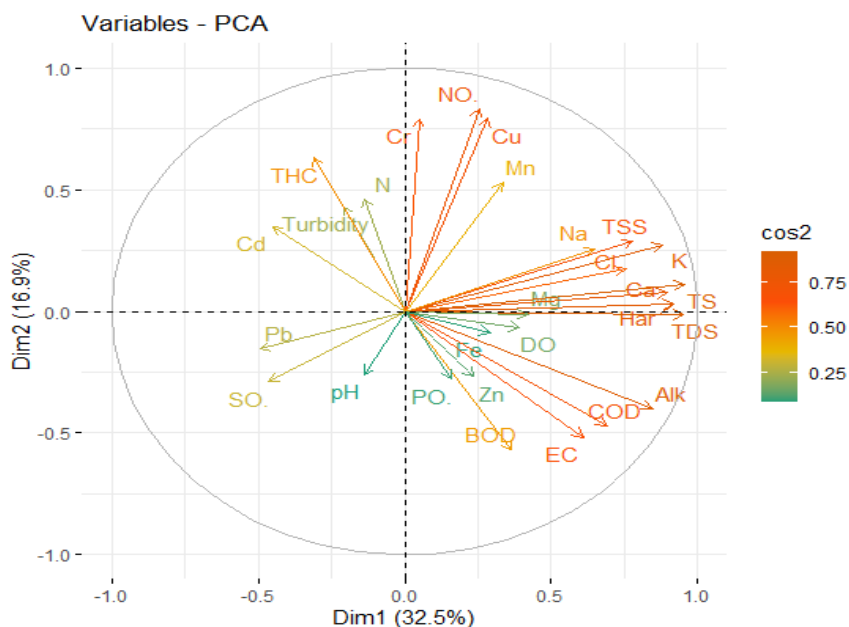


Figure 3. Principal component analysis loadings showing the eigenvectors, eigenvalues, and cumulative proportion - Variable correlation plot for soil. (OrgC - Organic C; MoistC - Moisture Content; AvaiP - Available P; TotN - Total N)

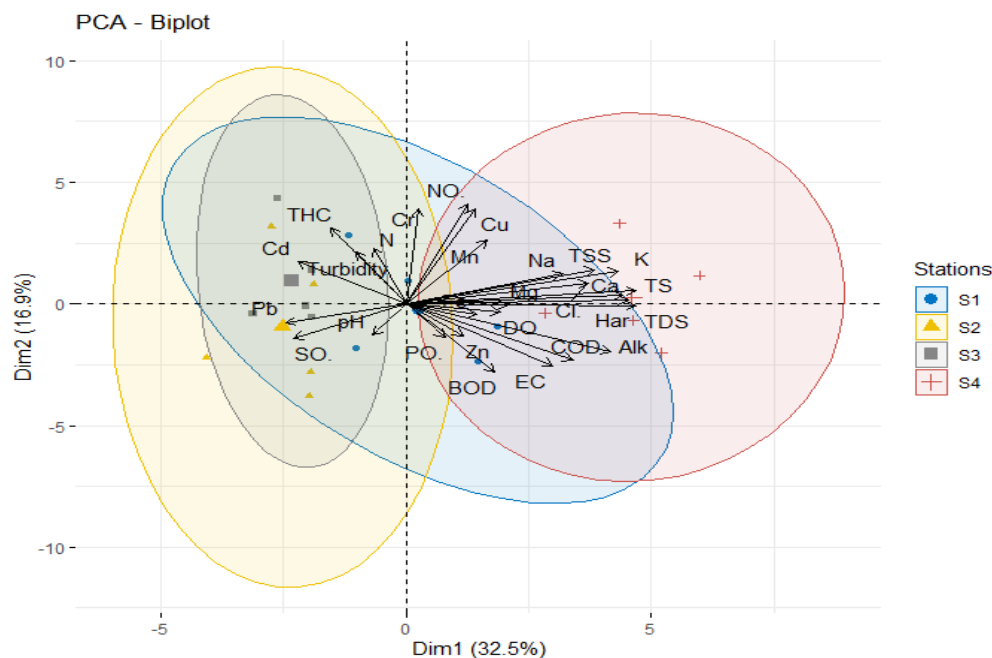


Figure 4. Varimax rotation of PCA biplot for Dim 1 and 2, OrgC - Organic C; MoistC - Moisture Content; AvaiP - Available P; TotN - Total N

3.4.2 Principal component analysis (PCA) biplot

The PCA bi-plot (**Figure 4**) further revealed variations of the analyzed parameters across the study stations in Dims 1 and 2. Water quality parameters, including heavy metal contents, were predominantly associated with Stations 1, 2, and 4, whereas other physicochemical parameters, including selected heavy metals, exhibited mixed variations and distributions across the sampled stations.

3.5 Relationship between cluster analysis (CA) and principal component analysis (PCA)

The results of cluster analysis (CA) and principal component analysis (PCA) showed a complementary interpretation of spatial and parameter-based variability in the Okpare Olomu River. CA grouped the stations into two main clusters: Stations 2 and 3 formed one group due to their similarity in physicochemical and heavy metal conditions, while Stations 1 and 4 formed another group, reflecting their shared but distinct water quality characteristics. This spatial clustering highlighted localized differences in pollution intensity along the river, largely influenced by dredging and oil-related activities at some sites.

PCA, on the other hand, explained the underlying structure of these variations by identifying the dominant parameters driving water quality differences. Dim 1 was strongly associated with ionic strength and general water chemistry (EC, TDS, TS, hardness, major cations and anions), while Dim 2 captured pollution signals related to organic loading, nutrients, heavy metals, and especially total hydrocarbon content (THC). These axes revealed that water quality at Stations 2 and 3 was largely influenced by anthropogenic inputs (oil-related activities and dredging), while the grouping of Stations 1 and 4 reflected relatively lower but comparable levels of such influences. When considered together, CA and PCA consistently emphasized that spatial variation in water quality was shaped by both

hydrocarbon contamination and general ionic composition. The CA confirmed the similarity between stations, while PCA clarified the specific parameters driving those similarities. Thus, both analyses complement each other: CA delineated where conditions were similar or different, while PCA explained why these similarities and differences occurred, identifying the pollutant sources and dominant processes influencing water quality in the Okpare Olomu River. This complementary interpretation strengthens the conclusion that spatial variation in the Okpare Olomu River is shaped by both natural geochemical processes and anthropogenic activities. Such integrated multivariate approaches have been widely applied in surface water studies (Shrestha and Kazama, 2007), (Ogbeibu *et al.*, 2014), (Akporido and Onianwa, 2015), as they enhance the reliability of identifying pollution sources and the factors controlling water quality dynamics.

3.6 Correlation matrix of surface water samples from okpare olomu river

Figure 5 presents the correlation matrix of physicochemical and heavy metal parameters in water samples obtained from the Okpare Olomu River. Correlation analysis was adopted to assess the degree of inter-parameter associations and to provide further evidence for the interactions revealed by CA and PCA. The critical levels of correlation coefficients were 0.444 ($p < 0.05$) and 0.561 ($p < 0.01$) at $df = 2$. The results revealed that pH exhibited a negative and significant correlation with Mg and Cu, indicating an inverse relationship between acidity and the mobility of these metals. Electrical conductivity (EC), a proxy for ionic strength, showed positive and significant correlations with TDS, TS, BOD, COD, alkalinity, and hardness, but a negative and significant correlation with Cd and THC. This implies that while EC is largely driven by dissolved ions and organic load, the presence of petroleum hydrocarbons and certain trace metals may alter its conductivity.

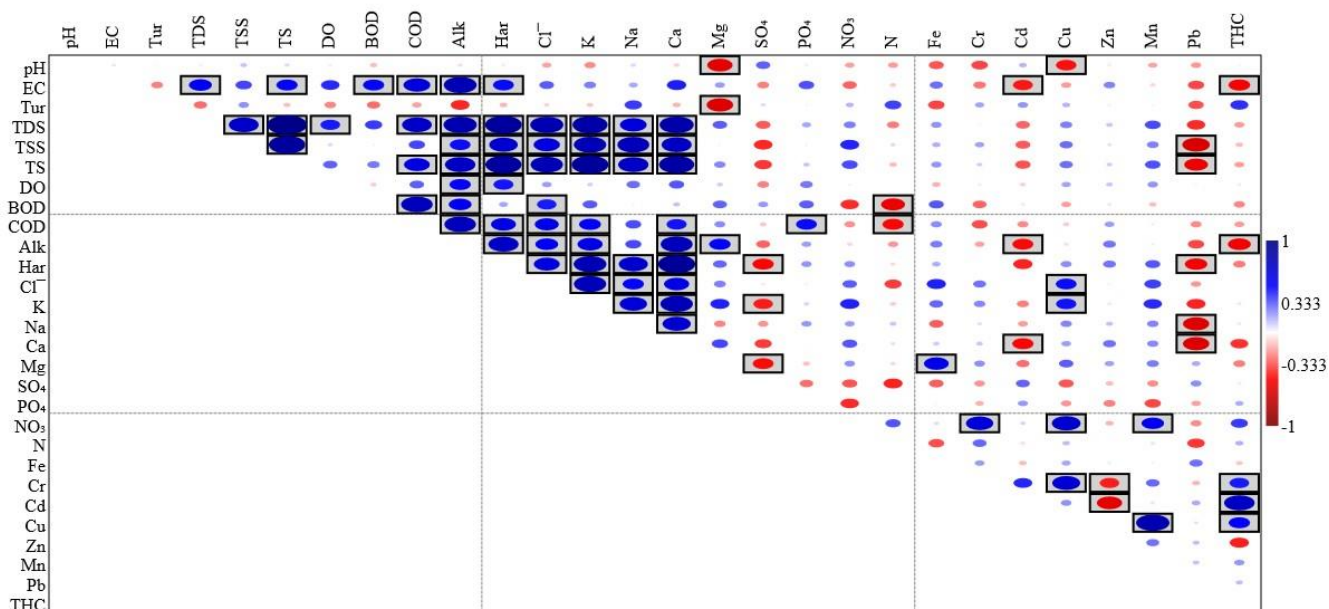


Figure 5. Correlation matrix for physicochemical parameters and heavy metals

Total dissolved solids and TSS both showed positive and significant correlations with TS, DO, COD, alkalinity, hardness, Cl^- , K, Na, and Ca, underscoring their shared geochemical and

anthropogenic sources. Pb, however, exhibited a negative and significant correlation with TSS and TS, suggesting that Pb may partition differently within the water column, potentially due to precipitation or sediment interactions. Organic pollution indicators were strongly interlinked: BOD and COD were positively correlated with alkalinity and Cl^- , while total nitrogen (TN) showed a negative correlation with BOD and COD, suggesting a possible dilution or nutrient transformation process. Dissolved oxygen (DO) correlated positively with alkalinity and hardness, further highlighting buffering effects within the aquatic system. Among the major ions, alkalinity correlated positively with hardness, Cl^- , K, Na, Ca, and Mg, but negatively with Cd and THC, suggesting that while the carbonate system supports ionic balance, petroleum-derived pollutants may disrupt natural buffering capacity. Similarly, Na, K, Ca, and Cl^- were strongly intercorrelated, reflecting their common origin from mineral weathering and anthropogenic discharges.

Heavy metals exhibited significant co-associations: Cr, Cu, Cd, Mn, and THC were positively correlated with one another, pointing to a shared source, most likely petroleum-related contamination and sediment dredging activities in the study area (Otari and Dabiri, 2015). These findings align with Adewuyi and Olowu (2012), who reported significant associations among Pb, Cd, Zn, Ni, Cu, and Cr in surface waters around petroleum depots in Nigeria. Such metals, often constituents of crude oil or fuel additives, can persist in aquatic systems, posing ecological and public health risks. The adverse health implications of these metals cannot be ignored. Pb, in particular, is known to disrupt metabolic processes by undergoing metathesis reactions with Zn^{2+} and Ca^{2+} metalloproteins, leading to loss of enzymatic function (Sebastian *et al.*, 2001). The significant correlations among Pb, Cd, Cu, Cr, and Mn in this study thus reinforce the concern that hydrocarbon pollution and industrial effluents are driving heavy metal enrichment in the Okpare Olomu River. Overall, the correlation matrix complements the CA and PCA findings by revealing strong parameter interlinkages. While PCA identified dimensions dominated by ionic strength (Dim 1) and hydrocarbon/metal pollution (Dim 2), the correlation matrix confirmed that these groups of parameters not only co-occur but also share strong linear relationships. This triangulation strengthens the conclusion that oil spillages, dredging, and industrial inputs are the dominant drivers of water quality variation in the river.

Conclusion

This study demonstrates that surface water in the Okpare Olomu River, a host community in Delta State, Nigeria, is significantly influenced by oil exploration activities and related anthropogenic pressures. While certain parameters, such as pH and dissolved oxygen, remained within acceptable regulatory limits, several key indicators including turbidity, TDS, TSS, COD, and major ions exceeded national and international water quality standards. The elevated concentrations of heavy metals such as Pb, Cd, and Fe, alongside the presence of total hydrocarbons, confirm ongoing hydrocarbon pollution and metal enrichment in the river. The strong interrelationships revealed by correlation analysis, PCA, and CA further suggest that these contaminants originate from common sources, predominantly oil spills, dredging activities, and industrial discharges. Such pollutant loads pose serious ecological risks, including habitat degradation and biodiversity loss, while also presenting direct public health concerns for communities that rely on the river for domestic and agricultural purposes. These findings underscore the urgent need for strengthened environmental monitoring,

enforcement of regulatory standards, and the implementation of effective remediation strategies in oil-producing regions. Prioritizing such interventions is essential not only for safeguarding aquatic ecosystems but also for protecting the health and livelihoods of vulnerable host communities.

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