Research Article

Assessment of Water Quality Parameters in the Lower Benue River, Makurdi: Implications for Ecological Health

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ABSTRACT

Assessment of water quality indicators in the lower Benue River, Makurdi with emphasis on ecological health was studied for a year. Water samples collected monthly using plastic bottles were analysed for physicochemical variables and heavy metals following standard methods. The data obtained were subjected to statistical tools for descriptive and inferential analysis using Statistical Packages for Social Sciences (SPSS) version 25.0. The mean values were used to ascertain the pollution status of the area. Some variables ranged as pH, 5.60-8.00, Dissolved oxygen (DO), 3.20mg/l-5.80mg/l, Electrical conductivity (EC), 210-1890μs/cm, Temperature, 25.00 - 30.50^{0}C. Total dissolved solute (TDS), 122-867. Nitrate, phosphate and sulphate ranged as, 30-70mg/l, 0.010-0.90mg/l and 20-34mg/l respectively. Heavy metals ranged as, Cd, 0.0050-0.550mg/l, Cr, 0.150-0.580mg/l, Fe, 0.005-2.880mg/l, Pb,0.010-0.950 mg/l) and Ni, 0.068-0.40 (0.219±0.10mg/l). Only EC, and TDS exhibited both spatial and seasonal variation significantly at P<0.05. Single factor pollution index (SFI) ranged from 0.055-256 (non-pollution-severe pollution). Some parameters in the stations met acceptable limits but Station 3 exhibited significant pollution, particularly in heavy metals and nitrates. Comprehensive pollution index (CPI) ranged between 143.36 (Station 2) and 280.32. Contamination factor (CF) ranged between 2.03-104.33(station 1 and station 3) but highest in wet season. Pollution load index (PLI) ranged from 4.45-9.25 (ST3 and ST2), heavy metal evaluation index (HEI), 58.02-180.03 (ST1 and ST3) while heavy metal pollution index (HPI) was 11.60-360.01. It was concluded that the Lower Benue River was slightly to severely polluted. Adequate measures should be put in place to monitor the levels of anthropogenic activities in the area.

Keywords: Assessment; Ecological Health; Lower Benue River; Makurdi; Pollution; Water quality Parameters

INTRODUCTION

Water quality is vital for river ecosystems that sustain biodiversity and human needs. The Lower Benue River in Nigeria provides drinking water, irrigation, and aquatic habitats but faces degradation from agriculture, industry, and urbanization. Physicochemical variables are essential for assessing ecosystem productivity, nutrient balance, and pollutant sources, thereby estimating ecological carrying capacity (Britto *et al*., 2018; Tyagi *et al.,* 2013). The Lower Benue River at Makurdi faces growing ecological stress from industrial effluents, abattoir waste, urban runoff, and seasonal flow variations, which drive physicochemical parameters

such as BOD, nutrients, and metals beyond safe limits. Alongside emerging pollutants like microplastics, these pressures degrade biodiversity, hinder aquaculture, and pose public health risks, highlighting the need for integrated water quality management (Apeh & Ekenta, 2012; Egesi *et al*., 2025; Ajegi *et al.,* 2025; Vangeryina *et al*., 2025; Idoko *et al*., 2025).

Ogedengbe and Akinbile (2010) noted that technological advances, though beneficial, often become threats to human existence. With growing anthropogenic activities, monitoring the Lower Benue River's water quality is urgent, as pollution risks endanger aquatic biodiversity and community health. Assessing water quality indicators is vital for guiding management strategies and policies to protect this resource. Findings will enrich knowledge of the river's ecological health and support interventions to reduce pollution and strengthen resilience, echoing earlier studies on the harmful impacts of contamination (Raphae *et al*., 2021).

Understanding the variation in water quality is critical, as it can reveal patterns linked to specific anthropogenic activities or natural processes. By systematically sampling different locations within the lower Benue River from Makurdi axis, this study aims to identify areas of concern, determine the extent of pollution, and evaluate how local practices influence water quality. Such insights are vital for informing stakeholders, including policy makers and community members, about the current status of their water resources. To effectively assess water quality in the lower Benue River along Makurdi axis, this study employs both a single factor pollution (SFI) and comprehensive factor pollution indices (CFI) along with other water quality indices. These approaches enable a more nuanced understanding of spatial variations in water quality and the potential sources of pollution with the potential risks involved.

MATERIALS AND MTHODS

Study Area

River Benue is a freshwater river in Nigeria and the second largest after River Niger. It originates from the Adamawa mountains in Cameroon, bordering the Nigerian frontier, and flows eastward through Nigerian territory before joining River Niger at Lokoja, Kogi State (Okayi *et al*., 2001). Makurdi (7.7319° N, 8.5250° E) is the capital of Benue State, Nigeria, located along the Benue River. Abinsi (7.6570° N, 8.5470° E) is a rural town to the west of Makurdi known for agriculture and fishing. Buruku (7.1955° N, 9.0795° E) is a local government area with rich agricultural lands near water bodies; and Katsina-Ala (7.2619° N, 9.0266° E) is a town near the Katsina-Ala River, noted for its vibrant agricultural and aquatic biodiversity (Iorchor, *et al*., 2020) (Figure 1).
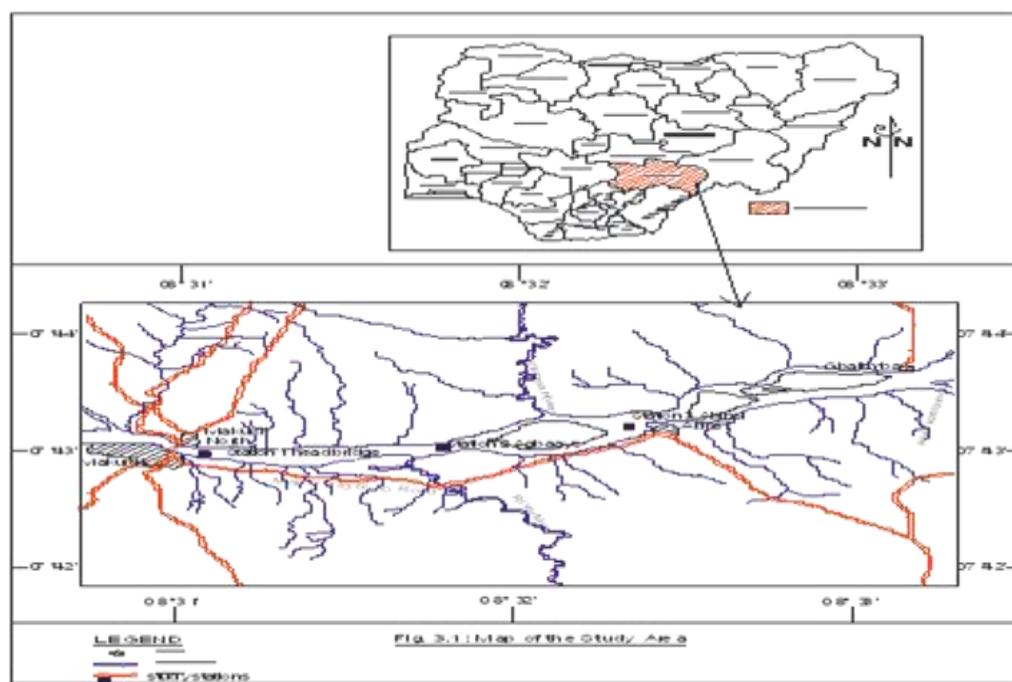

Figure 1. Map Showing the Sampling Points along River Benue

The main vegetation of the area consists of *Eichhornia crassipes, Elaeis guineensis, Nymphaea lotus, Salvinia nymphellula, and Pandanus candelabrum* while dredging, logging, fishing, boating, watercraft maintenance, transportation, washing, bathing, and swimming are some of the anthropogenic activities that take place within and near this river (Nigeria, 2011).

Benue State has a tropical climate with two seasons: a hot wet season (Nov–Mar) and a rainy dry season (Apr–Oct) (Banks et al., 1985). The Benue River, spanning 129,000 hectares (Welcomme, 1971), floods its plains during rains, creating breeding grounds for fish. Water levels can vary up to 25 meters (Okayi *et al*., 2001). Makurdi, the state capital, lies in North Central Nigeria at Latitude 7°44'N and Longitude 8°32'E, covering 820 km² with a population of 348,990 (National Population Commission, 2011).

Sampling and Analysis of Water Variables

Surface water temperature was measured in-situ with a mercury-in-glass thermometer, while pH, conductivity, and hydrogen ion concentration were determined using a HACH digital meter. Dissolved oxygen and biochemical oxygen demand (BOD) were assessed by Winkler's method (Boyd, 1979), with BOD measured after five days of incubation at 20°C. Salinity, nutrients (phosphate, nitrate, sulphate), and solids (total, suspended, dissolved) were analyzed titrimetrically. Heavy metals such as lead, cadmium, nickel, and chromium were identified using standard solutions and spectrophotometry at set wavelengths (APHA, 2015).

Data Analysis

Data were analyzed using SPSS v25.0 with descriptive statistics, ANOVA, and Duncan Multiple Range Test (DMRT). Mean values were compared with WHO and NESREA standards, and pollution status of the Lower Benue River at Makurdi was evaluated using single-factor and comprehensive indices.

Single Factor Analysis (SFI)

The Single Factor Index (SFI) simplifies pollutant identification by comparing water parameters to standards. It is calculated as $Pi = Ci/Si$, where Ci is the pollutant concentration and Si the acceptable limit (Yan *et al.,* 2015). The index is classified into five grades (Li *et al*., 2010).

Table 1: Standards for single-factor pollution index (*Pi*)

Pi Pollution grades

< 0.4	Non-pollution
0.4 - 1.0	Slight pollution
1.0 - 2.0	Medium polluted
2.0 - 5.0	Heavy polluted
>5.0	Serious polluted

Source: Yan *et al*. (2015)

Comprehensive Pollution Index (CPI)

This offers a more holistic view by integrating multiple parameters into a single index, reflecting the overall pollution status of the water body. It was calculated as follows:

$CPI = \frac{1}{n}\Sigma_{i=1} = \frac{Ci}{Si}$ (Tao *et al.,* 2011)

Where: CPI = the comprehensive pollution index, Ci = concentration of the pollution indicator *i* (mg/l), Si = permissible limit for the pollution indicator *i* in water, n = the number of analysed pollution indicators. CPI is classified according to Tao *et al.* (2011) into five water quality levels (Table 2).

Table 2: Classification of surface water quality based on CPI

Values	Water Quality Grades
< 0.2	Cleanness
0.21 - 0.4	Sub-cleanness
0.41 - 1.0	Slight pollution
1.01 - 2.0	Moderate pollution
> 2.01	Severe pollution

Source: Loto and Ajibare (2021)

Pollution Load Index (PLI)

The Pollution Load Index (PLI) is a quantitative tool for evaluating overall pollution levels in environments such as water bodies or sediments. It reflects the combined impact of multiple pollutants from different sources and serves as an indicator of an ecosystem's ecological health. It also represents a cumulative indicator for overall metal toxicity in a particular water and is calculated by using Eq.(4), the 5th root of the 5 number of multiplied CF value mathematically represented as:

$PLI = \sqrt[5]{CF1 \times CF2 \times CF3 \times CF4 \times CF5}$

$CF = \frac{Ci}{Cref}$

Where

Ci= Concentration of the pollutant in the water

Cref = Background concentration or the reference value for the pollutant/heavy metal in the water (Cd, Cr, Pb, Fe and Ni=0.003,0.05,0.01, 0.30 and 0.02

respectively). PLI is classified into five (5) levels (Table 3)

Contamination Factor (CF)

This is the ratio of concentration of each metal in the water by the baseline/background value represented by the formular:

$$CF = \frac{\text{Concentration of heavy metals in water}}{\text{Background value}}$$

Where

C heavy metal = concentration of heavy metal

C background = concentration of background/baseline value

Cf is classified into four grades for monitoring pollution of a single metal over a period of time (Hakanson,1980). Classification of contamination levels is based on their intensities on a scale ranging from 1- 6: low degree (Cf < 1), moderate degree (1< Cf < 3), considerable degree (1<Cf <3), considerable degree (3< Cf < 6) and very high degree (Cf > 6) (Luo *et al*.,2007)

Heavy Metal Pollution Index

The Heavy Metal Pollution Index (HPI) is used to assess water quality by evaluating multiple metals collectively. Each metal is assigned a weight based on toxicity and health risks, derived from scientific research and regulatory guidelines. These weights reflect their relative contribution to overall pollution and potential impacts on human health and the environment (Mohan et al., 1996; Itekere et al., 2024). This is represented mathematically as:

$$HPI = \frac{\sum (C_i X W_i)}{\sum W_i}$$

Where Ci =Concentration of the ith heavy metal in the water sample, Wi=weight assigned to the ith heavy metal based on its toxicity and environmental significance. It is classified into five (5) levels (Table 3)

Heavy Metal Evaluation Index (HEI)

The Heavy Metal Evaluation Index (HEI) quantifies heavy metal levels in water by summing ratios of measured concentration (Hc) to maximum allowable limits ($Hmax$). Hc is expressed in µg/l, while $Hmax$ represents threshold values for each metal (Reza and Singh, 2010). It is mathematically represented as follows:

$$HEI = \sum \left(\frac{C_i}{C_{maxi}} \right)$$

Where Ci =Concentration of the specific heavy metal in the water sample, Cmax represents the maximum allowable concentration of the specific heavy metal in the water as per regulatory standard. It is classified into five levels (Table 1).

Table 1: Classification of Water Quality based on the Indices (HPI, PLI and HEI)

Index	Class	HPI	PLI	HEI	Description
Heavy Metal	Class1 (Excellent)	0-20	N/A	N/A	Water is safe for drinking and Aquatic life
Evaluation	Class 11 (Good)	21-40	0-1	0-1	Water is acceptable but may require monitoring
Index	Class111(Moderate)	41-60	1-2	1-2	Water may pose health risks; treatment recommended
	Class IV (Poor)	61-80	2-3	2-3	Water is contaminated, not suitable for drinking
	Class V (Very Poor)	>80	>3	>3	Highly polluted, urgent attention required

Key: Pollution Load Index (PLI), Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI) (Reza & Singh,2010). **NA=Not available**

RESULTS

The ranges, overall mean and the permissible limits of the water variables are as shown in Table 2. pH ranged between 5.60 and 8.00 with the overall mean value of 6.765±0.55. The value was highest in Station 1 (6.842±O.60) but lowest in Station 4(6.642±0.60) without significant difference across the Stations at p<0.05. pH showed no seasonality with observed higher value in the dry season (6.767±0.156) than the wet season without significant difference at p<0.05. pH value showed no seasonality with observed higher value in the dry season (6.767±0.55) than the wet season. Dissolved oxygen (DO) ranged between 3.20mg/l and 5.80mg/l with the overall mean value of 4.20±0.77mg/l. Spatially, DO value was highest in Station 4(5.642±0.60mg/l) without significant difference across the Stations at p<0.05(Table 6). DO values exhibited seasonality with the dry season value (5.00±0.51mg/l) higher than the wet season value (3.841±0.49mg/l) (Table 7). Electrical conductivity (EC) ranged from 210-1890µs/cm with the mean value of 28.342±1.29 µs/cm (Table 4). EC values exhibited spatial and seasonal variations with the highest and lowest values observed in Stations 4(1402.83±241.27µs/cm) and Station 1(1303±414.37µs/ cm) and wet season

(1594.17±138.52µs/cm) and dry season (111.67±233.98µs/cm) respectively (Table 3 & 4). Temperature ranged between 25.00 and 30.50^{0}C with the mean value of 28.342±1.29^{0}C (Table 2). Spatially and seasonally, there was no significant variation at p<0.05 with the values highest and lowest in Station 2(28.808±7.48^{0}C) and Station 4(28.292±0.91^{0}C) and wet season (28.575± 1.17^{0}C) and dry season (28.108±1.39^{0}C) respectively (Table 4&5). Total dissolved solute (TDS) values ranged from 122-867 with the mean value of 298.48±183.52mg/l(Table 5). The values exhibited both spatial and seasonal variations with the highest values recorded in Station

2 and in the wet season respectively (Table 5&6). Biological oxygen demand (BOD) values ranged from 2-6mg/l with the mean value of 3.783±1.06mg/l (Table 3). There was no significant spatial variation but there was observed seasonality with the highest value observed in the wet season (4.625±0.81mg/l). The water nutrients, nitrate, phosphate and sulphate values ranged from 30-70mg/l, 0.010-0.90mg/l and 20-34mg/l(Table 4) but all with highest values in Station 4 with observed significant difference across the stations but only nitrate exhibited seasonality with higher dry season value (50.00±10.99mg/l) than the wet season value(45.00±11.17mg/l) (Table 3&4).

Table 2: Mean Values of Water Variables and their Standard Limits

S/N	Parameters	Mean	Mini	Maxi	(WHO, 2022)	NESREA,2011
1	pH	6.765±0.55	5.60	8.00	6.5-8.5	6.5–8.5
2	Dissolved Oxygen (DO) (mg/l)	4.420±0.77	3.20	5.80	≥5.0	≥ 5.0
3	Electrical Conductivity (EC)(µs/cm)	1352.92±309.22	210	1890	1000	1000
4	Temperature (0C)	28.342±1.29	25.00	30.50	25-30	25–30
5	Total Dissolved Solutes (TDS)(mg/l)	298.48±183.52	122	867	1500	1500
6	Biological Oxygen Demand (BOD)(mg/l)	3.783±1.06	2.00	6.00	5.0	5.0
7	Nitrate (N03) (mg/l)	47.500±11.26	30.00	70.00	5.0	10.0
8	Phosphate (P04) (mg/l)	0.19±0.23	0.010	0.90	≥0.30	0.5
9	Sulphate (S04) (mg/l)	28.21±3.20	20.00	34.00	500	100
10	Cadmium (Cd)(mg/l)	0.149±0.15	0.005	0.550	0.003	0.003
11	Chromium (Cr)(mg/l)	0.276±0.89	0.150	0.580	0.05	0.05
12	Iron (Fe)(mg/l)	1.754±0.80	0.005	2.880	0.30	0.30
13	Lead (Pb)(mg/l)	0.328±0.23	0.010	0.950	0.01	0.01
14	Nickel (Ni)(mg/l)	0.219±0.10	0.068	0.400	0.07	0.02

SL=Standard limits

Table 3: Spatial Mean Values of Water Variables from the Study Area

Parameters	ST 1	ST 2	ST 3	ST4	P-Value
pH	6.842±0.75[a]	6.775±0.49[a]	6.800±0.34[a]	6.642±0.60[a]	P>0.05
DO (mg/l)	4.600±0.781[a]	4.417±0.911[a]	4.500±0.777[a]	5.642±0.60[a]	P>0.05
Conductivity (µs/cm)	1303±414.37[b]	1328.33±340.9[b]	1376.67±236.16[b]	1402.83±241.27[a]	P<0.05
Temperature (0C)	28.525±140[a]	28.808±748[a]	28.74±1.62[a]	28.292±0.91[a]	P>0.05
Total Dissolved Solutes (mg/l	297.33±213[b]	336.17±244[a]	251.42±88.43[c]	289.00±104.41[b]	P<0.05
BOD(mg/l)	3.808±1.07[a]	3.875±0.96[a]	3.725±1.17[a]	3.725±1.17[a]	P>0.05
Nitrate (N03) (mg/l)	47.08±10.39[b]	46.50±10.81[b]	46.83±9.02[b]	49.58±5.11[a]	P<0.05
Phosphate (P04) (mg/l)	0.130±0.17[b]	0.255±0.267[a]	0.110±0.11[b]	0.284±0.311[a]	P<0.05
Sulphate (S04) (mg/l)	27.33±4.18[b]	28.75±3.137[a]	27.92±2.96[a]	28.83±2.44[a]	P>0.05
Cd(mg/l)	0.069±0.06C	0.129±0.06a	0.313±0.19a	.084±0.07C	P<0.05
Cr(mg/l)	0.269±0.04b	0.248±0.06b	0.361±0.13a	.226±0.04b	P<0.05
Fe (mg/l)	1.529±0.91b	1.241±0.70b	2.562±0.18a	1.685±0.67b	P<0.05
Pb (mg/l)	0.224±0.24b	0.242±0.10b	0.550±0.25a	0.297±0.16b	P<0.05
Ni (mg/l)	0.142±0.05b	0.221±0.06b	0.345±0.05a	0.167±0.09b	P<0.05

Key: Means with similar superscripts along the same row are not significantly different at P<0.05

Table 4: Seasonal Values of Water Variables in the Study Area

S/N	Parameters	Dry Season	Wet Season
1	pH	6.767±0.56[a]	6.762±0.56[a]
2	Dissolved Oxygen (DO) (mg/l)	5.00±0.508[a]	3.841±0.49[b]
3	Electrical Conductivity (EC) (µs/cm)	111.67±233.98[b]	1594.17±138.52[a]
4	Temperature (0C)	28.108±1.39[a]	28.575±1.17[a]
5	Total Dissolved Solutes (TDS) (mg/l)	167.33±23.860[b]	419.63±187.21[a]
6	Biological Oxygen Demand (BOD)(mg/l)	2.94±0.42[b]	4.625±0.810[a]
7	Nitrate (N03) (mg/l)	50.00±10.99[a]	45.00±11.17[b]
8	Phosphate (P04) (mg/l)	0.60±0.01[a]	0.239±0.289[a]
9	Sulphate (S04) (mg/l)	28.58±3.23[a]	27.83±3.199[a]
10	Cadmium (Cd)(mg/l)	0.084±0.068[a]	0.213±0.160[b]
11	Chromium (Cr)(mg/l)	0.266±0.081[a]	0.286±0.098[a]
12	Iron (Fe)(mg/l)	1.369±0.838[b]	2.139±0.560[a]
13	Lead (Pb)(mg/l)	0.210±0.116[a]	0.447±0.250[a]
14	Nickel (Ni) (mg/l)	0.184±0.105[a]	0.254±0.090[a]

Key: Means with similar superscripts along the same row are not significantly different at $P<0.05$

The heavy metals varied as follows: Cd, 0.0050-0.550(0.149±0.15mg/l), Cr, 0.150-0.580(0.276±0.89mg/l), Fe, 0.005-2.880(1.754±0.80mg/l), Pb,0.010-0.950(0.328±0.23mg/l) and Ni, 0.068-0.40 (0.219±0.10mg/l) (Table 5). All the values were highest in Station 3 and in the wet season except Fe which was highest in the dry season. Only Cd and Fe values showed significant difference seasonally at $p<0.05$ (Table 5 & 6).

The results of SFI and CPI are as shown in Table 5. The results showed that SFI ranged from 0.055(non-pollution) through 1.00 and above(medium) to 256 (high pollution) between sulphate, cadmium and iron (Fe). pH, temperature, TDS etc exhibited slight pollution across all the stations. Conductivity across all the stations and wet season exhibited slight pollution. Some stations met acceptable limits for various parameters, Station 3 exhibits significant pollution, particularly in heavy metals and nitrates. Spatially CPI value ranged between 143.36 (Station 2)

and 280.32 with the highest value (237.775) observed in the wet season. CPI value showed high level of pollution across the station.

Table 6 showed the contamination factor and pollution load index of heavy metals across the stations. Contamination factor ranged between 2.03(Nickel) in station 1 and 104.33(Cadmium) in station 3. Station 3 had the highest contamination factor while the lowest was in station 1 with wet season value recording the highest value across all the heavy metals. The order of heavy metal contamination was Cd>Pb>Cr>Fe>Ni. PLI ranged between 4.45 (ST3) and 9.25(ST2) with the highest value observed station 2 (9.25) and in the wet season. Table 7 showed the spatial and seasonal values of HEI and HPI. HEI ranged between 58.02 (St1) and 180.03(S3) with the highest value observed in the wet season. HPI ranged from 11.60(ST1) to 36.01(ST3) with the highest value observed in the wet season (13.63) all above unity.

Table 5: Spatio-temporal values of SFI and CPI of the Water Variables in the Study Area

Parameter	SFI ST1	SFI ST2	SFI ST3	SFI ST4	SFI DS	SFI WS
pH	0.804(sp)	0.796(sp)	0.794(sp)	0.780(sp)	0.796(sp)	0.795(sp)
DO (mg/l)	0.920(sp)	0.883(sp)	0.900(sp)	1.128(mp)	1.000(mp)	0.768(sp)
Conductivity (µs/cm)	1.303(mp)	1.328(mp)	1.377(mp)	1.403(mp)	0.112(sp)	1.594(mp)
Temperature (°C)	0.951(sp)	0.960(sp)	0.958(sp)	0.943(np)	0.937(np)	0.952(np)
TDS (mg/l)	0.198(sp)	0.224(sp)	0.168(sp)	0.193(sp)	0.112(sp)	0.280(sp)
BOD (mg/l)	0.762(sp)	0.775(sp)	0.745(sp)	0.745(sp)	0.588(sp)	0.925(sp)
Nitrate (NO3) (mg/l)	15.693(p)	15.500(p)	15.610(p)	16.527(p)	16.667(p)	15.000(p)
Phosphate (PO4) (mg/l)	0.433(sp)	0.850(sp)	0.367(sp)	0.947(sp)	2.000(p)	0.797(sp)
Sulphate (SO4) (mg/l)	0.055(np)	0.058(np)	0.056(np)	0.058(np)	0.057(np)	0.056(np)

Cd (mg/l)	0.069(np)	0.129(sp)	0.313(sp)	0.084(np)	0.084(np)	0.213(sp)
Cr (mg/l)	0.269(sp)	0.248(sp)	0.361(sp)	0.226(sp)	0.266(sp)	0.286(sp)
Fe (mg/l)	152.900(p)	124.100(p)	256.200(p)	168.500(p)	136.900(p)	213.900(p)
Pb (mg/l)	0.224(sp)	0.242(sp)	0.550(sp)	0.297(sp)	0.210(sp)	0.447(sp)
Ni (mg/l)	0.142(sp)	0.221(sp)	0.345(sp)	0.167(sp)	0.184(sp)	0.254(sp)
CPI	**171.47**	**143.36**	**280.32**	**189.41**	**159.806**	**237.775**

Key: SFI=Single factor pollution index, CPI=Compressive pollution index, DS= Dry season, WS= Wet season, mp=Moderate pollution, p=Pollution, np=No pollution

Table 6: Spatial and Seasonal Mean Values of CF and PLI from the Study Area

Heavy Metals	ST 1	ST 2	ST 3	ST4	Dry Season	Wet Season
Cd	23.30	43.00	104.33	28.00	28.00	71.00
Cr	5.38	4.96	7.22	4.52	5.32	5.72
Fe	5.10	4.14	8.54	5.62	4.56	7.13
Pb	22.40	24.20	55.00	29.70	21.00	44.70
Ni	2.03	3.16	4.93	2.39	2.63	3.63
PLI	**7.79**	**9.25**	**4.45**	**8.72**	**5.41**	**13.63**

ST1-4= Stations 1-4, CF=Contamination factor, PLI=Pollution load index

Table 7: Spatial and Seasonal Mean Values of Some Pollution Indices from the Study Area

Parameters	ST 1	ST 2	ST 3	ST4	Dry Season	Wet Season
HEI	58.02	79.46	180.03	70.23	61.51	132.18
HPI	11.60	15.89	36.01	14.05	12.30	26.44

Key: HEI=Heavy metal evaluation index, HPI=Heavy metal pollution index

DISCUSSION

Physicochemical variables are vital for assessing lake ecosystems, offering insights into productivity, nutrient balance, and resource cycling. They help estimate ecological carrying capacity and identify pollutant sources (Britto et al., 2018; Tyagi et al., 2013). Water quality indicators such as pH, temperature, dissolved oxygen, and turbidity affect aquatic life, while regular monitoring enables early detection of eutrophication, pollution, and habitat degradation, supporting effective management and conservation. The study recorded pH values between 5.60 and 8.00, with a mean of 6.765±0.55, aligning with the 4.50–6.80 range reported in Luumbara creek, Niger Delta (Otene and Iorchor, 2025). These values exceeded WHO's recommended 6.50–8.50 range (WHO, 2003, 2022). Elevated pH can impart bitterness and reduce water suitability for domestic and industrial use. Seasonal variation showed slightly higher wet season values, likely due to similar anthropogenic activities. As noted by Chandaluri et al. (2013), pH is a key water quality parameter influencing solubility, nutrient availability, and aquatic ecosystem health. The observed value of DO in this study is below the permissible limits (6.5-8.50)

of World Health organization (WHO,2003, 2022) and National Environmental Safety and Regulation Enforcement Agency (NESREA,2003). Dissolved oxygen supports aquatic life, facilitates pollutant breakdown, indicates water pollution levels, and helps maintain chemical balance in aquatic ecosystems.

The observed temperature range (25.00–30.50 °C) met NESREA (2003) and WHO (2003, 2022) standards and agreed with values reported for Niger Delta streams (Allison and Otene, 2012; Otene et al., 2023; Otene and Alfred-Ockiya, 2019). It also aligns with the optimal 28–30 °C range that supports fish growth, health, and pollutant tolerance (Ekubo and Abowei, 2011). Water temperature critically influences biotic and abiotic processes, including nutrient levels and microbial activity (Dugdale *et al.*, 2018). In contrast, Loto and Ajibare (2021) reported a lower mean of 25.33 ± 1.75 °C for Lagos Lagoon.
The observed range of TDS (122-867 mg/l) reflect the characteristic of a typical freshwater body. The observed spatial and seasonal variations with the highest values recorded in Station 2 and in the wet season respectively could be attributed to variations

in anthropogenic activities, especially in station 2 and during the wet season.

The highest nutrient levels (nitrate, phosphate, sulphate) recorded at Station 4 likely result from agricultural runoff, industrial discharge, and urban wastewater, influenced by local hydrology. Enyoh *et al*. (2020) confirmed that domestic nitrate pollution contributes to eutrophication, while sulphate often enters aquatic systems through industrial effluents from chemical, mining, and textile industries.

Heavy metal concentrations in this study exceeded WHO (2003, 2022) and NESREA (2003) limits. Elevated Cd, Cr, Pb, and Ni at Station 3 during the wet season likely resulted from runoff and leaching, while Fe peaked in the dry season due to sediment resuspension and reduced dilution. Idris and Abdullahi (2023) confirmed seasonal variations, with wet season runoff mobilizing contaminants, and dry season conditions concentrating metals. Similarly, Raji *et al*. (2016) reported higher lead levels in the rainy season.

The observed SFI ranged from non-pollution to severe pollution, consistent with reports from Mahin Lagoon (Loto *et al*., 2023) and the Lower Benue River (Otene and Iorchor, 2025), largely linked to anthropogenic activities. Parameters such as sulphate, cadmium, iron, pH, temperature, TDS, and conductivity showed slight pollution, while Station 3 exhibited significant contamination, especially in Fe and nitrates, suggesting inputs from agriculture, industry, and wastewater (Saifullah *et al.*, 2013). Elevated conductivity, Fe, nitrate, and DO indicate organic pollution, which reduces oxygen and harms aquatic habitats (Vigiak *et al*., 2019). Seasonal variations and sources such as runoff, effluents, and sediment resuspension explain these trends (Idris and Abdullahi, 2023; Raji *et al.*, 2016; WHO, 2022).

CPI values indicated severe pollution across stations, with Station 3 highest. This agrees with Yan et al. (2015) on polluted regions in the Honghe River, and with findings from Lagos Lagoon (Loto and Ajibare, 2021) and Mahin Lagoon (Loto *et al*., 2023, CPI > 2). In contrast, Yadav et al. (2018) reported CPI < 1 in the Chambal River. Comparisons show the Lower Benue River's CPI exceeded values from other rivers, including Henwal (1.25–8.52; Mishra et al., 2015) and Cau (0.50–1.57; Son *et al*., 2020).

The contamination factor (CF) in this study ranged from moderate (class 1) to very high (class 2)

(Ahamad *et al*., 2019). These values exceeded those reported for Niger Delta fish farms (0.01–4.16; Ehiemere et al., 2022), Kolo creek flow stations (0.67–3.50; Uzoekwe and Aigberua, 2019), and Elele-Alimini and Elechi creeks where CF < 1 was observed (Otene and Alfred-Ockiya, 2019, 2020). Higher CF values at Station 3 and during the wet season reflect intensified anthropogenic activities. The contamination order (Cd > Pb > Cr > Fe > Ni) contrasts with Cd > Cr > Ni > Pb reported for Elele-Alimini stream (Otene and Alfred-Ockiya, 2020).

The PLI value above 1 in this study indicates rising pollution. This contrasts with the lower range (0.132–0.360) reported in Niger Delta fish farms (Ehiemere *et al*., 2022) and the 0.022–0.038 observed in Anantigha sediments, which showed no pollution though some heavy metal presence (Aki et al., 2019). The result was lower than Bonny River estuary values (Onojake *et al*., 2015) but aligns with higher PLIs reported in River Benue sediments (Emmanuel *et al*., 2018), Namibia's Erongo coastline (Onjefu *et al*., 2016), and New Calabar River (Edori and Kpee, 2018), where severe pollution was noted.

The HPI values (11.60–36.01), highest in the wet season, were well below the critical limit of 100 for drinking water and aquatic life, likely due to sewage inputs and limited dilution. Balakrishnan & Ramu (2016) note that values above 100 indicate medium to very high pollution. In contrast, Oluwafemi *et al*. (2025) reported HPI >100 at all stations, classifying their reservoir as unsafe.The HEI range between 58.02 and 180.03 with the highest value observed in the wet season in this study classified this water into class V water (HEI >3) which is heavily polluted and need urgent attention as opined by Reza and Singh (2010). This result is in tandem with the range (20.3926-103.0056) reported by Egai and Paaru (2025) from a surface water in Enerhen River, Warri South, Delta, Nigeria.

CONCLUSION

Most physicochemical parameters, except DO and heavy metals (Cd, Cr, Fe, Pb, Ni), met WHO, and NESREA permissible limits. However, pollution indices (SFI, CPI, CF, PLI, HEI, HPI) indicated slight to severe pollution, with Station 3 showing the highest contamination, particularly Cd. Monitoring of

anthropogenic activities, especially at Station 3, is necessary to prevent further degradation.

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