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ASSESSMENT OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS IN OKPARE CREEK DRINKING WATERS, DELTA STATE, NIGERIA

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Abstract

Efficient and sustainable management of the environment requires periodic monitoring of the various ecosystem matrices therein. In this study, the physicochemical parameters and heavy metals in Okpare Creek water in Niger Delta, Nigeria were analyzed using *in-situ* measurement with the aid of a multimeter probe (6920 V2-1 Multiparameter Water Quality Sonde, Xylem Analytics, USA) and laboratory analysis. A total of 96 water samples were collected for four stations within the period of two years. The samples were analysed to highlight the spatiotemporal variability of the parameters, determine the health status and potential for ecological protection of the system. The average physicochemical parameters and heavy metals: Temperature, TDS, TSS, Turbidity, EC, pH, DO, BOD, Chloride, Bicarbonate, Sulphate, Phosphate, Nitrate, Total hardness, Calcium, Magnesium, Sodium, Potassium and WQI obtained results are 29.35, 33.17, 184.22, 129.76, 62.23, 5.95, 2.63, 3.61, 7.80, 1.74, 1.48, 0.03, 0.07, 9.05, 2.03, 2.14, 2.62, 4.01 mg/L and 564.41 respectively. The levels of turbidity, TSS, DO and pH at all the stations did not comply favourably with national and international surface water regulatory standards, but all other parameters are within the permissible limit. The data obtained were subjected to univalent and multivalent statistics as well as water quality index (WQI). Generally, the parameters showed more spatial than temporal differences, this condition was mostly attributed to anthropogenic activities. Except for TDS, electrical conductivity, pH, chloride, and sulphate, the concentrations of other parameters differ significantly ($p<0.05$) across the stations while only the concentration of calcium differs significantly ($p<0.05$) across the seasons. However, other parameters maintained some sort of variation across the seasons. With the aid of WQI, contamination that arose from organic matter decomposition was identified as a factor that is responsible for most variations on the water quality. The results from this research can serve as a basis for sustainable management of aquatic ecosystems within the region.

Keywords: Okpare, Creek, physicochemical, parameters, water.

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1.0 INTRODUCTION

Surface waters are important habitats for many organisms whose fate of survival is largely dependent on the physical and chemical components of the system. Periodic monitoring of the aquatic ecosystem is required to ensure the sustainability of the aquatic life forms therein and the various services the system provides to man (Uddin *et al.,* 2021; Idehen and Ezenwa, 2019). Globally, contamination and degradation of water quality have become important issues for sustainable development and this is in consideration that anthropogenic activities and climate change have emanated as major drivers of alterations in the hydrological cycle (Rahman *et al.,* 2021). Having access to safe water is important because human well-being is linked to the quality of water in the environment (Achieng *et al.,* 2014). Human activities such as improper disposal of domestic waste, waste amount, untreated industrial effluents and runoff from agricultural land are the main factors responsible for surface water quality deterioration and pollution (UN, 2016; Ofomola *et al.,* 2017; *Uddin et al.,* 2021; Jin *et al.,* 2020). It has been reported that variation in natural and anthropogenic activities such as precipitation and temperature ranges can affect the quality of water in the aquatic ecosystem and can contribute to different attributes across different seasons (Barakat *et al.,* 2016; Islam *et al.,* 2018; Rahman *et al.,* 2021).

Crude oil deposit in the Niger Delta area is the primary source of Nigeria's economy and many oil allied companies operate in the watershed and within the water bodies in the area. Effluent from the companies which in some cases is untreated is directly or indirectly discharged into aquatic bodies within the area thus causing deterioration of surface water quality (Eze *et al.,* 2019; Odukoya *et al.,* 2002). For the past few decades, municipal waste and industrial effluents have adversely impacted the surface water quality in Nigeria (Ololade *et al.,* 2009; Agbalagba *et al.,* 2013; Iwuoha *et al.,* 2013; Sowunmi 2019; Keke *et al.,* 2021). Okpare Creek located in Ughelli South area of Niger Delta, Nigeria provides important sources of livelihood including valuable fishery resources, water for domestic activities, means of water navigation, and sand resources for building and constructions for humans. Researcher have studied water samples obtained from similar environments and reported accordingly (Whitehead *et al.,* 2018; Islam *et al.,* 2019; Yuan *et al.,* 2014: Phung *et al.,* 2015; Patil *et al.,* 2012; Dirican, 2015; Andong *et al.,* 2019; Ayobahan *et al.,* 2014; Nnoli *et al.,* 2021). However, with the aid of multivariate analyses, useful information, correlations among parameters, and dimensions signifying water deterioration as well as recommended strategies for management and monitoring of water quality can be achieved (Kiymaz *et al.,* 2014; Ofomola *et al.,* 2017; Ogwueleka and Christopher, 2020). Considering the multiple human activities that take place in the study area, it is important to study physicochemical parameters and heavy metal concentrations of Okpare Creek. However, to the best of my knowledge, physicochemical parameters and heavy metals concentration of Okpare Creek has not been investigated. Therefore, this study aimed at evaluating the physicochemical parameters and heavy metal concentrations of surface water in the Okpare Creek and its health implications. This objective was achieved by conducting a general linear model, matrix correlation analysis, principal component analysis, and water quality index to determine the spatiotemporal variations of the water quality parameters, correlation among different parameters, the best fit among parameters with their sources, and the suitability of the water for aquatic organisms and general uses. Hence the study will be a baseline study.

Study area

This study was conducted along the course of the Okpare creek in Ughelli South Local Government Area of Delta State, Nigeria (Fig.

1). It is located between latitude 05°, 27 N and 05°, 33 N and longitude 005°, 53 E and 006°, 04 E. The freshwater creek runs North-West to South-East. The Okpare creek took its source from Umuaja in Umutu and River Niger and empty into the Atlantic Ocean at Forcados. This area is located within the equatorial region having two climatic regimes: the wet season, which begins in April and lasts till October, and the dry season from November to March. However, the incidence of climate change has resulted in fluctuation in the timing of the seasons from year to year. Four stations were distinguished along the study stretch. Station 1 was upstream from other stations; the vegetation is fringed and marginal. Fringed vegetation is mainly that of tropical rainforest comprising rubber trees, oil palm trees, Indian Bamboo, and cola trees while the floating macrophytes include ferns and water hyacinth. Human activities in this station include bathing, laundry, fishing, and sawmill. The second station was located 3km away from station 1. There are trees in the background with vegetation similar to station 1. Fishing is the major human activity in this station. Station 3 was located approximately 2km away from station 2, sand mining is the major activity therein. Runoff from the road enters into the creek via station 3. Station 4 was located in the jetty area which is 2km away from station 3. The observed human activities include swimming, washing clothes, motorcycles, and cars, and dumping municipal waste by the bank. Okpare Creek is a waterway to access many remote settlements at Ughelli and transport raw materials to petrochemical industries that operate in the hinterland.

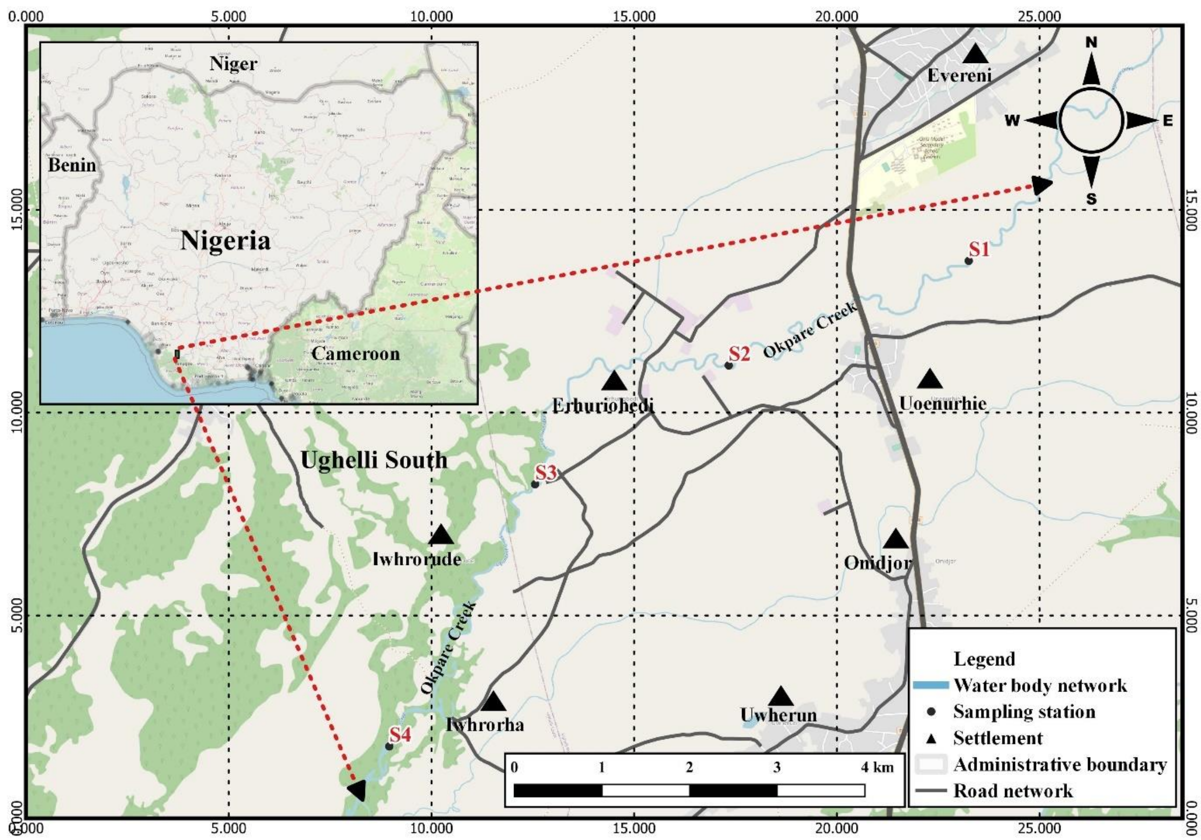


Figure 1: Map of study area showing sampling stations.

2.0 MATERIAL AND METHODS

Sample collection and analytical techniques

A total of 96 surface water samples were collected from Okpare Creek between March, 2022 to October, 2023 and physicochemical parameters were determined using *in-situ* with the aid of a multimeter probe (6920 V2-1 Multiparameter Water Quality Sonde, Xylem Analytics, USA). In the laboratory, some other physicochemical parameters and heavy metals were determined using standard methods (APHA, 2012; Allen, 1989).

Data analysis

The mean, standard deviation, and range, for each physicochemical parameters, were calculated per station. With the stations and the seasons as fixed factors, the general linear model was adopted to compare the variations of physicochemical parameters across the stations and seasons respectively. Tukey's post hoc HSD test was performed to compare the means between stations in the case when there are significant differences ($p<0.05$). The general linear model was performed using SPSS version 26.0 (IBM Corp., 2019) p values of the output were reported. The Shapiro–Wilk and Levene's test methods were used to performed normality and homogeneity of variance assumptions before the general linear model. The data were $\log(x+1)$ transformed in situations where the assumptions were violated. Pearson correlation was performed on the data to highlight the nature of the relationship among parameters. The Pearson correlation was computed using PAST version 3.2 statistical software (Hammer, 2018)

Principal component analysis (PCA) was performed using the psych package in R version 4.0.2 (R Core Team, 2020) to highlight the hypothetical variations in the physicochemical parameters. To ensure a reduction in the number of parameters with high eigenfactor for the various rotated components, the exploratory factor analysis was based on the varimax rotation method (Nnoli *et al.*, 2021; Vega *et al.*, 1998; Paca *et al.*, 2019). Without losing the information, the resulting RCs provide knowledge about the most significant variables that delineate the original dataset, as well as reduce its bulky nature (Kim *et al.*, 2019; Keke *et al.*, 2021). Eigenvalue ≥ 1 was adopted as the benchmark for the selection of the RCs, the selection was aided by the screen plot.

Water quality index (WQI)

Water quality index **(**WQI) is among the preferable technique to summarize a large aggregate of water quality parameters into simple terms in a consistent manner (Ashwani and Anish 2009). WQI was computed using the weighted arithmetic index method which was described by Cude (2001) (Eq. (1)). The parameters used for the WQI computation included pH, TSS, TDS, turbidity, DO, BOD_5, HCO^-_3, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Ca, Mg, K, and, Na.

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} \mathrm{WiQi}}{\sum_{i=1}^{n} \mathrm{Wi}} \tag{1}$$

Where, Qi = Quality rating of *n*th parameter, Wi = Relative weight of *n*th parameter.

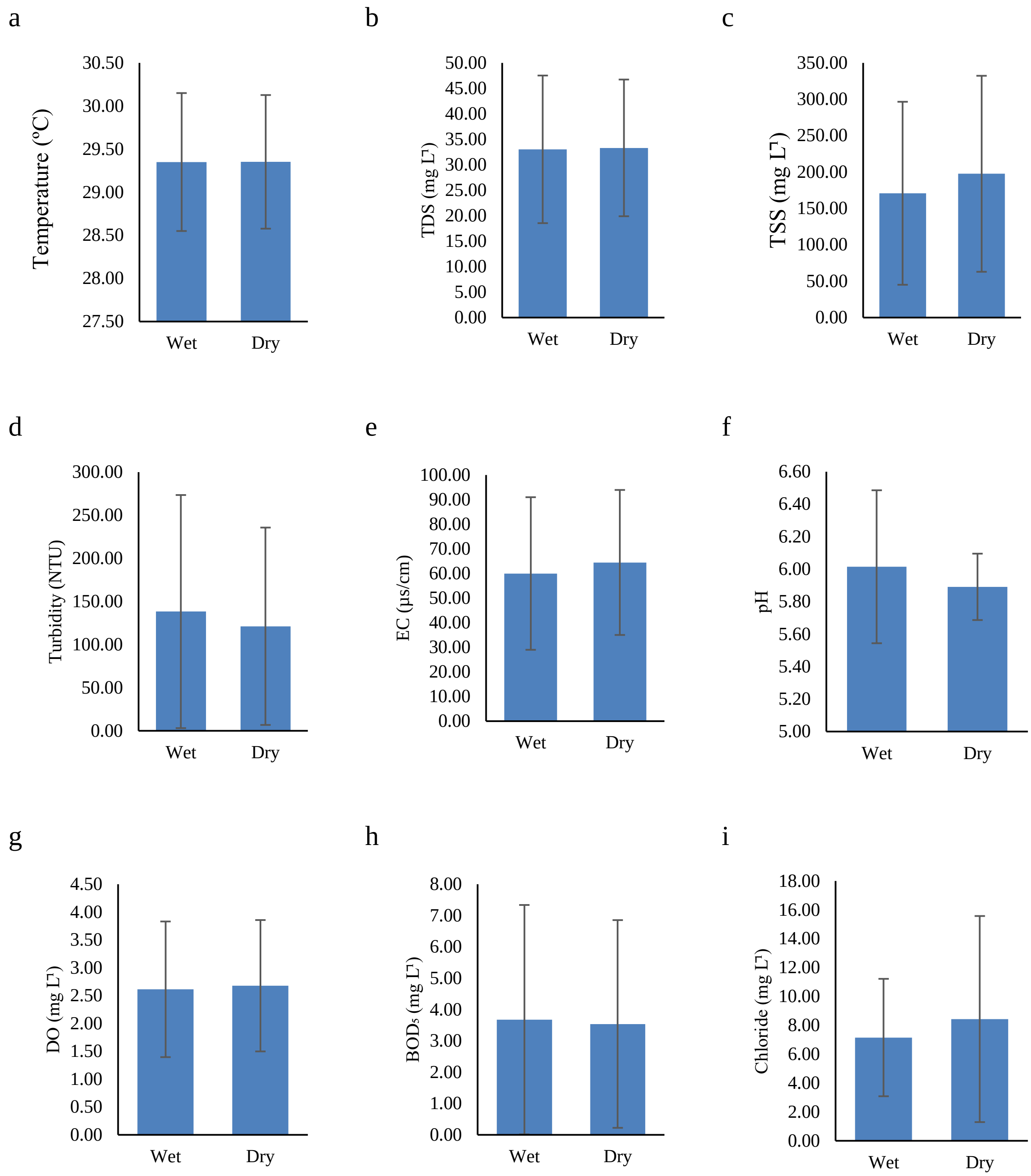
The quality rating and relative weight were calculated by standard procedure as described by Cude (2001). Water quality status can be described as excellent (< 50), good (50 – 100), poor (101-200), very poor (201 – 300), and unsuitable for domestic uses (> 300) (Ramakrishniah *et al.*, 2009).

3.0 RESULTS AND DISCUSSION

Table 1: Summary of the physicochemical variables characterised in the samples obtained from the four sampling stations at Okpare Creek (values are mean ± standard deviation with range in bracket; n=24)

Parameters	Station 1	Station 2	Station 3	Station 4	P values Spatial variation	Seasonal variation	Water quality guidelines
Temperature (ºC)	29.44 ^{b} ±0.85 (27.20-30.80)	29.28 ^{b} ±0.76 (28.00-30.50)	29.71^{a}±0.70 (28.50-30.80)	28.98^{b} ±0.66 (27.50-30.50)	0.011*	0.986	35 ^{A}
TDS (mgL^{-1})	32.74±10.21 (10.40-66.00)	31.30±12.92 (9.83-82.01)	34.87±19.66 (13.68-110.52)	33.77±11.51 (17.75-70.19)	0.804	0.980	500 ^{A}
TSS (mgL^{-1})	197.50 ^{a} ±51.35 (100.00-300.00)	142.92^{b} ±71.60 (40.00-300.00)	212.50 ^{a} ±166.01 (10.00-600.00)	183.96 ^{a} ±178.90 (10.00-700.00)	0.029*	0.493	<10 ^{A}
Turbidity (NTU)	119.71 ^{b} ±32.02 (25.36-178.23)	102.11 ^{b} ±51.06 (11.90-192.42)	175.63 ^{a} ±177.21 (14.50-695.72)	121.58 ^{b} ±161.91 (8.83-605.40)	0.015*	0.489	5 ^{A}
EC (µs/cm)	56.99±20.50 (19.74-116.20)	60.07±30.18 (18.16-185.26)	63.88±39.91 (25.64-202.00)	67.97±27.59 (34.20-142.32)	0.435	0.392	
Ph	5.95±0.28 (5.60-6.93)	5.89±0.41 (5.09-7.14)	5.97±0.37 (5.56-7.09)	6.00±0.41 (5.41-7.22)	0.771	0.107	6.5-8.5 $^{A, B, C}$; 6.5-9.0 ^{E}
DO (mgL^{-1})	3.38 ^{a} ±0.77 (1.92-4.68)	3.70 ^{a} ±0.64 (2.19-4.68)	1.14 ^{c} ±0.27 (1.00-1.44)	2.28 ^{b} ±0.99 (1.03-4.00)	0.000**	0.562	6 ^{B}
BOD_5 (mgL^{-1})	1.04 ^{c} ±0.41 (0.14-1.96)	0.95 ^{c} ±0.26 (0.46-1.31)	7.69 ^{a} ±2.52 (3.21-13.10)	4.75 ^{b} ±3.20 (1.15-13.78)	0.000**	0.670	3 ^{B}
Chloride (mgL^{-1})	6.11±2.34 (3.21-12.73)	6.20±1.62 (4.05-10.02)	10.43±9.35 (3.19-36.71)	8.44±5.56 (2.12-20.22)	0.132	0.611	300^{B}; 250 ^{CD}
Bicarbonate (mgL^{-1})	2.72 ^{a} ±1.25 (1.26-5.63)	2.81 ^{a} ±0.86 (1.62-4.62)	0.67 ^{b} ±0.80 (0.22-3.36)	0.77 ^{b} ±0.62 (0.25-2.09)	0.000**	0.535	200 ^{A}
Sulphate (mgL^{-1})	1.52±0.84 (0.48-3.56)	1.07±0.50 (0.12-2.04)	1.93±1.97 (0.11-8.11)	1.41±0.90 (0.01-3.14)	0.263	0.709	100 ^{B} ;250^{C} 500 ^{D}
Phosphate (mgL^{-1})	0.01 ^{b} ±0.01 (0.01-0.03)	0.01 ^{b} ±0.00 (0.01-0.02)	0.06 ^{a} ±0.06 (0.01-0.22)	0.03 ^{b} ±0.02 (0.00-0.08)	0.000**	0.290	3.5 ^{C}
Nitrate (mgL^{-1})	0.02 ^{b} ±0.02 (0.01-0.07)	0.01 ^{b} ±0.01 (0.01-0.03)	0.19 ^{a} ±0.20 (0.01-0.76)	0.04 ^{b} ±0.03 (0.01-0.10)	0.000**	0.662	10 $^{A C}$; 9.1 ^{B}
Total hardness (mgL^{-1})	5.74 ^{b} ±2.89 (3.11-14.05)	5.21 ^{b} ±1.30 (3.46-8.22)	16.85 ^{a} ±7.01 (6.99-31.50)	8.41 ^{b} ±5.81 (2.16-21.80)	0.000**	0.897	
Calcium (mgL^{-1})	1.42 ^{c} ±0.58 (0.43-2.96)	1.20 ^{c} ±0.61 (0.41-2.56)	3.44 ^{a} ±1.45 (1.45-7.11)	2.04 ^{b} ±1.07 (0.88-4.65)	0.000**	0.034*	180 ^{B}
Magnesium (mgL^{-1})	2.70 ^{a} ±1.36 (1.01-6.19)	2.42 ^{a} ±0.89 (1.24-4.32)	2.16 ^{a} ±1.08 (0.61-4.41)	1.26 ^{b} ±0.88 (0.25-3.40)	0.000**	0.646	40 ^{B}
Sodium (mgL^{-1})	2.12 ^{b} ±0.80 (1.01-4.01)	1.62 ^{c} ±0.71 (1.00-3.65)	4.03 ^{a} ±1.66 (1.18-7.05)	2.71 ^{b} ±1.29 (1.12-5.51)	0.000**	0.641	120 ^{A}; 200 ^{B}
Potassium (mg/L)	3.36 ^{b} ±1.77 (2.00-7.86)	2.66 ^{b} ±0.52 (2.02-3.62)	5.45 ^{a} ±1.88 (2.59-10.18)	4.55 ^{a} ±1.40 (2.43-7.48)	0.000**	0.496	50 ^{B}
WQI	523.99±98.82 (259.97-728.08)	435.09±183.72 (118.81-787.56)	749.07±594.75 (338.26-2340.12)	549.50±560.25 (81.77-2307.81)	0.743	0.075	100^{F}

Water quality guidelines: FMEnv. (2002), NER (2011), USEPA (2009),UNECE (1994), Ramakrishniah *et al.*, (2009).


a
Temperature (°C)
30.50
30.00
29.50
29.00
28.50
28.00
27.50
Wet
Dry
b
TDS (mg L-1)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Wet
Dry
c
TSS (mg L-1)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Wet
Dry
d
Turbidity (NTU)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Wet
Dry
e
EC (µs/cm)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Wet
Dry
f
pH
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
Wet
Dry
g
DO (mg L-1)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Wet
Dry
h
BOD5 (mg L-1)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Wet
Dry
i
Chloride (mg L-1)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
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0.00
Wet
Dry

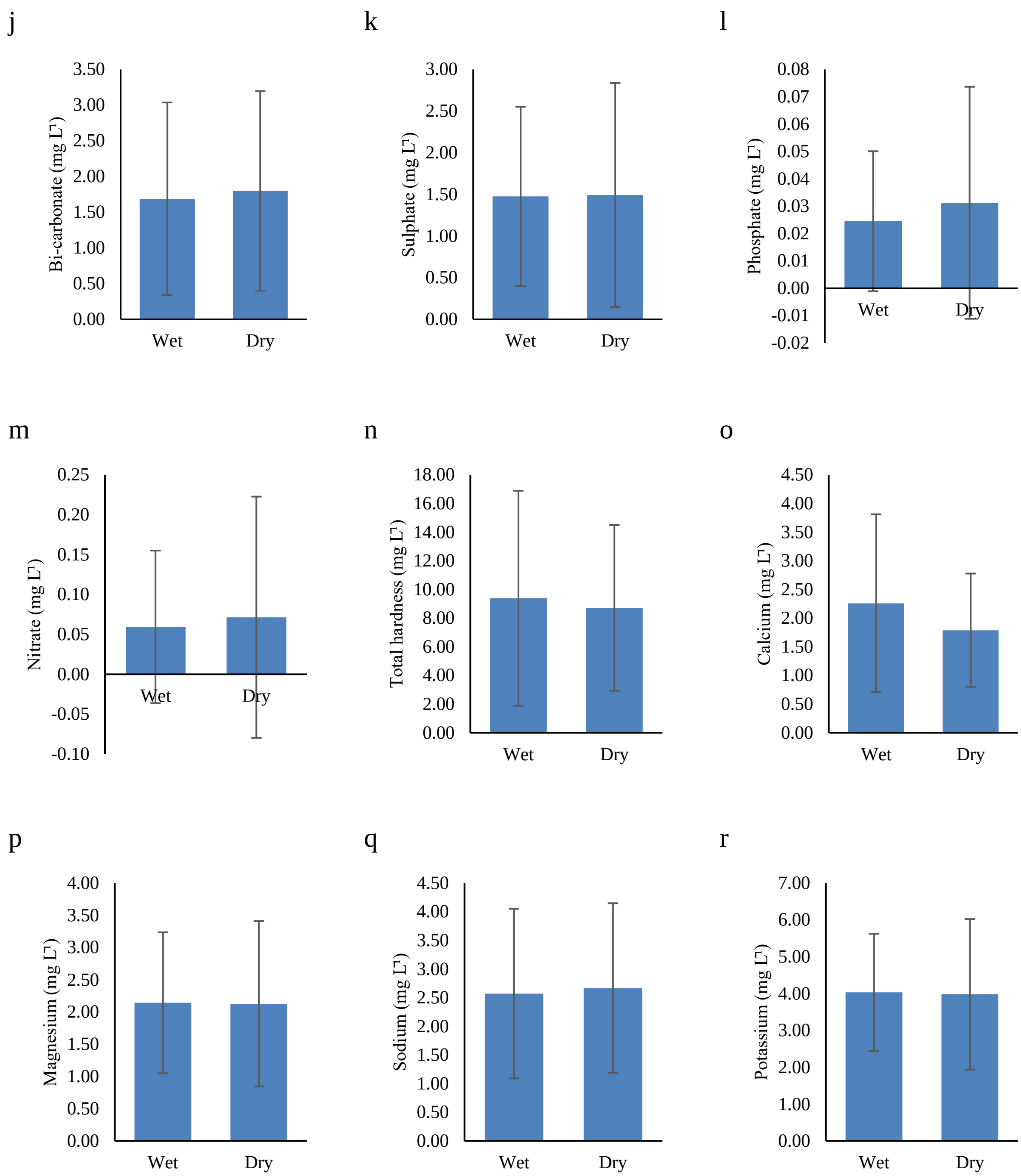

Figure 2: Seasonal variations of physicochemical properties of water in Okpare Creek (n = 48 for each of the seasons; error bar = standard deviation)

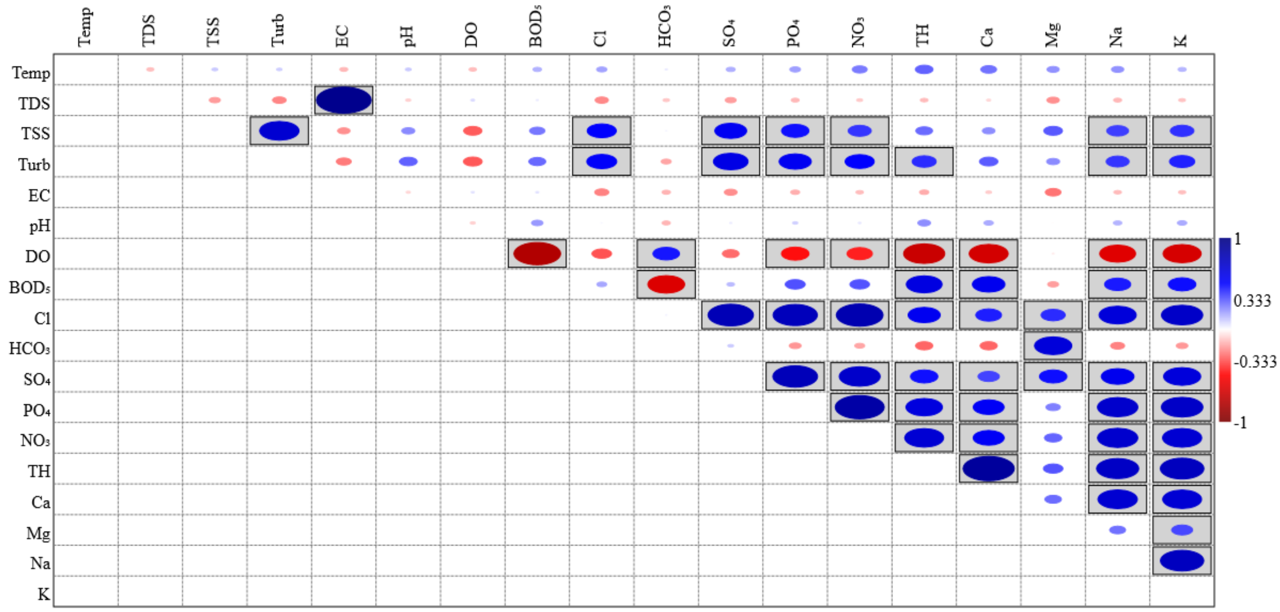

Figure 3: Pearson correlation plot of the physicochemical properties of water in Okpare Creek (n = 96; Temp = water temperature, Turb = turbidity, TH = total hardness)

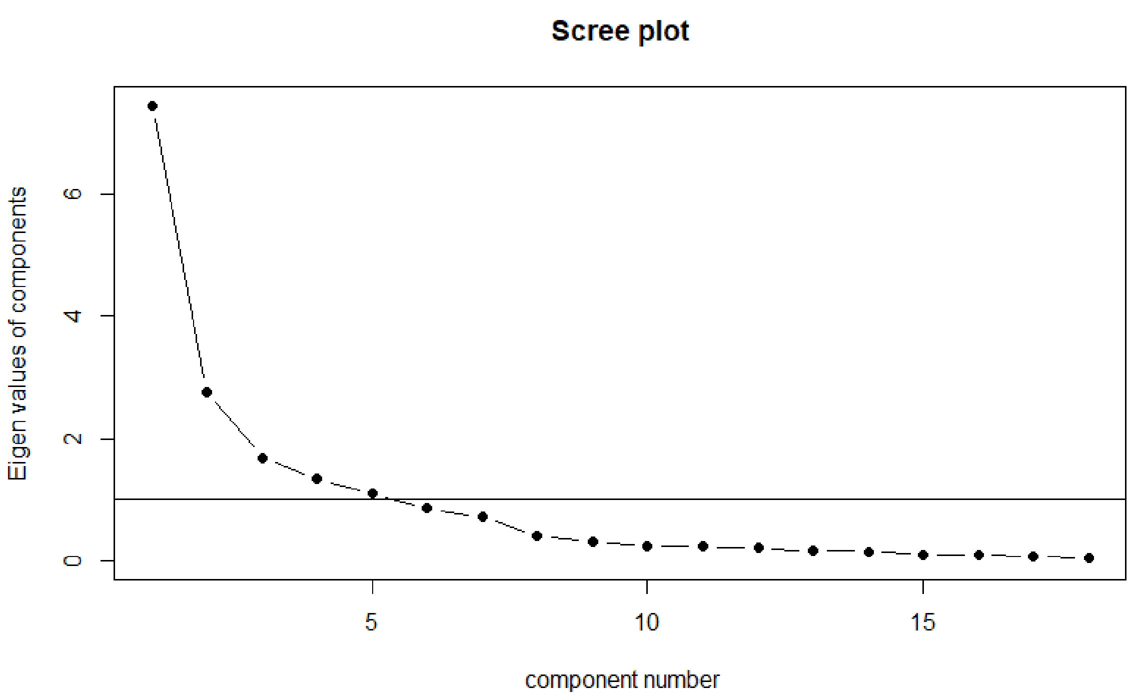

Figure 4. Screen plots of the eigenvalues showing extraction of rotated components of the PCA.

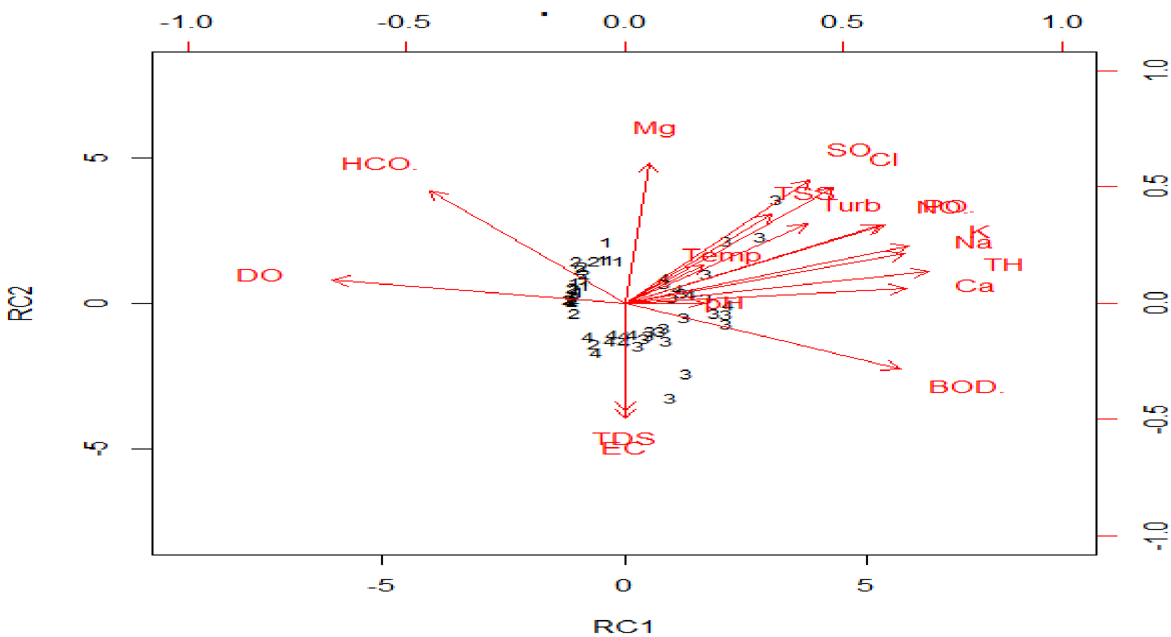

Figure 5: Biplot of the first and second varimax rotated component axes of 18 physicochemical parameters of water and the sampling stations. (Variance explained: RC 1 = 32%; RC 2 = 16%).

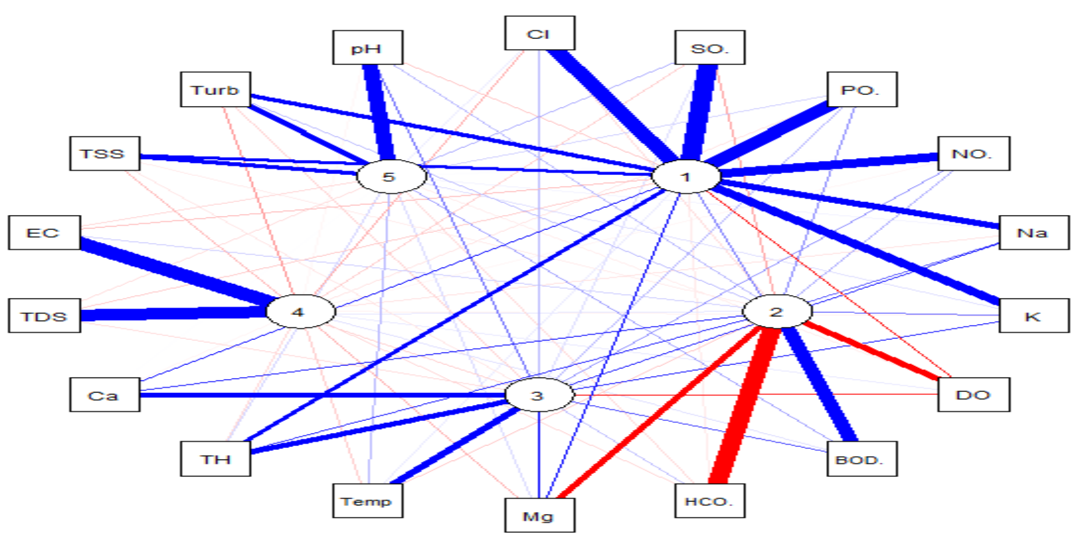

Figure 6. qgraph plot of the varimax rotated component loadings of the 18 physicochemical variables. Blue lines indicate positive loadings while the red lines indicate inverse loadings. Temp = water temperature, TH = total hardness, Tur = turbidity, EC = electrical conductivity.

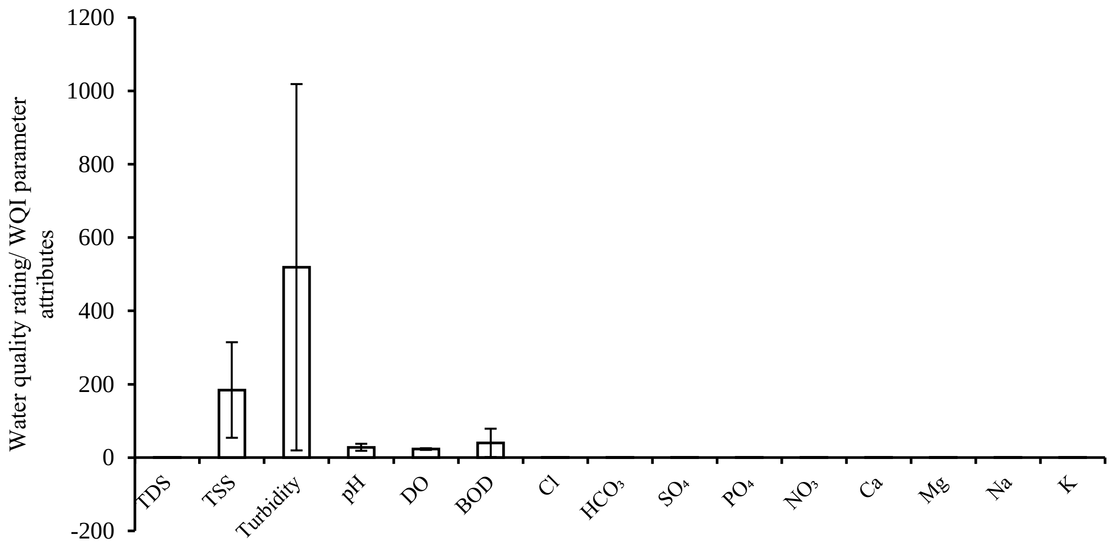

Figure 7: Bar chart for the quality rating for the water quality index (n = 96; error bar = standard deviation).

Spatial and temporal variabilities of the physicochemical properties of water

A summary of spatial variations of the characterised physicochemical variables in the water is presented in Table 1. Some of the variables including TDS, EC, pH, chloride, and sulphate did not differ significantly ($p>0.05$) across the stations. With the exception of EC., pH, DO, HCO_3, and Mg, the highest levels of other variables were recorded in water samples obtained from Station 3. Variations of the TSS and turbidity across the stations showed significance ($p<0.05$) which originated from low values of these variables at station 2. The water was slightly acidic and no significant difference ($p>0.05$) was observed in the pH across the stations. DO and BOD_5 exhibited an inverse pattern across the stations: as the low values of DO were recorded at Stations 3 and 4, the high values of BOD_5 were recorded at the same stations. Both alkali metals (Na and K) and alkali earth metals were significantly higher at stations 3 and 4 than at stations 1 and 2.

Figure 2 shows the variations of the variables across the two seasons at the study area. Among the variables, only the concentrations of calcium showed a significant difference ($p<0.05$) across the seasons while the variations for the other variables across the seasons were minimal ($p>0.05$) (second to the last column on Table 1). Mean values together with the standard deviations of the variables for wet and dry seasons were as follow (temperature = (29.35 ± 0.8) ºC and (29.35 ± 0.77) ºC; TDS = (33.03 ± 14.49) mg L^{-1} and (33.31 ± 13.41) mg L^{-1}; TSS = (170.83 ± 125.746) mg L^{-1} and (197.60 ± 134.68) mg L^{-1}; turbidity = (138.27 ± 135.19) mg L^{-1} and (121.24 ± 114.45) mg L^{-1}; EC = (59.98 ± 30.99) µs cm^{-1} and (64.47 ± 29.45) µs cm^{-1}; pH = (6.01 ± 0.47) and (5.89 ± 0.20); DO (2.61 ± 1.22) mg L^{-1} and (2.68 ± 1.18) mg L^{-1};BOD_5 = (3.68 ± 3.66) mg L^{-1} and (3.54 ± 3.32) mg L^{-1}; chloride = (7.15 ± 4.07) mg L^{-1} and (8.43 ± 7.14) mg L^{-1}; bi-carbonate = (1.69 ± 1.35) mg L^{-1} and (1.80 ± 1.40) mg L^{-1}; sulphate = (1.48 ± 1.08) mg L^{-1} and (1.49 ± 1.34) mg L^{-1}; phosphate = (o.02 ± 0.03) mg L^{-1} and (0.03 ± 0.04) mg L^{-1}; nitrate = (0.06 ±

0.10) mg L^{-1} and (0.07 ± 0.15) mg L^{-1}; total hardness = (9.39 ± 7.50) mg L^{-1} and (8.71 ± 8.71) mg L^{-1}; calcium = (2.26 ± 1.55) mg L^{-1} and (1.79 ± 0.99) mg L^{-1}; magnesium = (2.14 ± 1.09) mg L^{-1} and (2.13 ± 1.28) mg L^{-1}; sodium = (2.57 ± 1.48) mg L^{-1} and (2.67 ± 1.48) mg L^{-1}; potassium = (4.03 ± 1.59) mg L^{-1} and (3.89 ± 2.04) mg L^{-1}) respectively. With the exception of TSS, the other physical variables showed wider range of variations during the wet season than dry season. While for the chemical variables, the variations of pH, DO, BOD_5, total hardness and calcium were higher during the wet season than dry season.

Pearson correlations of the physicochemical properties of water

Figure 3 shows the Pearson correlation plot of the physicochemical properties of the water in Okpare Creek. No significant correlation ($p>0.05$) was observed between the water and other variable while the TDS had a strong positive correlation with EC ($r = 0.9447$, $p<0.01$) and did not correlate significantly with other variables. TSS had significant positive correlations with turbidity ($r = 0.678$, $p<0.01$), chloride ($r = 0.501$, $p<0.01$), sulphate ($r = 0.548$, $p<0.01$), phosphate ($r = 0.472$, $p<0.01$), nitrate ($r = 0.398$, $p<0.01$), sodium ($r = 0.377$, $p<0.05$) and potassium ($r = 0.406$, $p<0.01$). Turbidity of the water exhibited significant and positive correlations with chloride ($r = 0.516$, $p<0.01$), sulphate ($r = 0.598$, $p<0.01$), phosphate ($r = 0.554$, $p<0.01$), nitrate ($r = 0.502$, $p<0.01$), total hardness, ($r = 0.415$, $p<0.01$), sodium ($r = 0.395$, $p<0.05$) and potassium ($r = 0.435$, $p<0.01$). DO had significant negative correlations with BOD_5 ($r = -0.804$, $p<0.01$), phosphate ($r = -0.473$, $p<0.01$), nitrate ($r = -0.437$, $p<0.01$), total hardness ($r = -0.710$, $p<0.01$), calcium ($r = -0.671$, $p<0.01$), sodium ($r = -0.617$, $p<0.01$), and potassium ($r = -0.658$, $p<0.01$) and a positive correlation with the bicarbonate ($r = 0.457$, $p<0.01$). BOD_5 exhibited a strong inverse correlation with bicarbonate ($r = -0.634$, $p<0.01$). Chloride correlated positively with other anions including sulphate ($r = 0.783$, $p<0.01$),phosphate ($r = 0.764$, $p<0.01$), nitrate ($r = 0.806$, $p<0.01$), as well as the cations ($r = 0.443$, $p<0.01$), magnesium ($r = 0.415$, $p<0.01$), sodium ($r = 0.642$, $p<0.01$), and potassium ($r = 0.712$, $p<0.01$).With the exception of magnesium, the other metals showed significant correlations for one another.

Water quality assessment

Results of the water quality index (WQI) showed a degraded water condition for all the sampling stations as the values were significantly higher than the benchmark of 100 (Table 1). The ranges of WQI were 259.97 to 728.08, 118.81 to 787.56, 338.26 to 2340.12, and 81.77-2307.81 for stations 1, 2, 3, and 4 respectively. The values of the WQI across the stations did not differ significantly. The high values of WQI were most attributable to high levels of TSS, turbidity BOD_5 as well as the acidic water condition and low concentrations of dissolved oxygen (Fig. 7).

Discussion

In this study, the levels of physicochemical characteristics of Okpare Creek in Niger Delta determined showed that the water quality of this lotic system varied more spatially than seasonally. This condition could be attributed to anthropogenic activities in the study area which are dissimilar across the stations but relatively the same across the two seasons obtainable therein. The turbidity and TSS level of the water, DO concentration and pH at all the stations, and BOD_5 at stations 3 and 4 did not comply favourably with water regulatory standards including FMEnv. (2002), NER (2011), and USEPA (2009). The principal component analysis biplot showed that the influence of the natural, as well as anthropogenic activities as reflected by physicochemical parameters, did not maintain a particular pattern among the stations.

Although, the water temperature was relatively equal across the seasonal regimes in the study area, some sort of spatial variations which were substantial to cause significant difference were obtained across the stations. The variation was due to temperature rise at station 3 which could be attributed to low vegetation shading at the station compared to other stations. Bruce and Franz (2007) highlighted other factors including discharge of thermal effluent, water abstraction, damming, and forestry practices. The findings of this study is similar to that reported by Mkude *et al.* (2018) as similar temperature values were recorded through the seasons (rainy and dry) of their survey of Wami River in Tanzania.

Total Dissolve Solid (TDS) values were similar across the stations and seasons and were significantly lower when compared to the TSS counterpart. This is contrary to the observation made by Ayobahan *et al.* (2015), Nnoli *et al.* (2021), Omoigberale *et al.* (2021) at a lentic system within the Niger Delta. Also, Walter *et al.* (2019) and Rahman *et al.* (2021) recorded higher values of TDS than TSS in river systems in Uganda and Bangladesh respectively. The high levels of TSS are attributable to sand mining activity which was common at Okpare Creek which leaves the high level of solids in suspension; it is a tendency of pollution which needs to be curbed. The high level of TSS resulted in the high turbid nature of the water; this was further buttressed by the positive correlation ($p<0.01$) between the parameters. Water transparency is reduced by high levels of TSS which in turn inhibits photosynthesis, enhances sedimentation, and smothers the breeding bed for the aquatic organism (Ogbeibu and Anagboso, 2004). The levels of turbidity across the stations were pointedly higher than the values reported by Bhuiyan *et al.* (2011) and Rahman *et al.* (2021) in Turag River of Bangladesh. These differences are attributable to the anthropogenic activities operating in the different landscapes in these different places. Apart from the sand mining activity, the high turbid nature of the aquatic ecosystem can result from organic matter from the discharge of sewage as well as built-up stormwater overflow (Gikinju *et al.*, 2002; Pawełczyk, 2013). TSS and turbidity levels showed multiples of significant positive correlations with the ionic constituents, these showed that the suspended particles were composed of ionic bonded matters and thus could disassociate to individual components. The PCA revealed that TSS, TDS, and turbidity are among the important determinants of water quality in Okpare Creek.

The water is slightly acidic. This acidic condition is common within the study area (Kaizer and Osakwe, 2010; Ayobahan *et al.*, 2015; Anani *et al.*, 2020; Omoigberale *et al.*, 2021). Low pH indicates poor buffering capacity of the total alkalinity in the aquatic ecosystem which could be the resultant effects of the decomposition of organic matter (Ayobahan *et al.*, 2015). The condition responsible for the acidic nature of this lotic ecosystem was not chiefly driven by organic matter decomposition, this is in consideration of the weak positive correlation between BOD and pH. pH 6.5 - 8.5 is the normal range for surface water systems while the range of 6.5 to 8.0 is optimum for irrigation and aquaculture (Rahman et al., 2021). Based on this range and the high eigenvalue value of pH in reference to PCA, the ranges of pH recorded in this study could be considered an important variable that limits the distribution of biodiversity in Okpare Creek. The pH values were relatively higher during the wet season than in the dry season, this difference could be a result of the influx of alkaline substances during the rainy.

Dissolved oxygen (DO) and biochemical oxygen demand (BOD) are important determinants of oxygen concentration and consumption in the aquatic environment (Nnoli et al., 2021). The level of DO was low and was lower than the values recorded within Niger Delta ecozone by Ayobahan *et al.* (2015), Anani *et al.* (2020), Omoigberale *et al.* (2021) and Nnoli et al. (2021). The mean values of DO were < 4.0 mg L−1 across the four stations. However, Tibebea *et al.* (2019) reported that DO below the level of 4.0 mg L−1 can affect aquatic life adversely and as DO level decreases in the aquatic ecosystem, fish and other mobile aquatic organisms swing to other areas of the system. The concentrations of the DO and BOD exhibited a strong inverse correlation thus increase of one would lead to a decrease in the other. Previous studies including Kannel *et al.* (2008), Yuan *et al.* (2014), Assubaie *et al.* (2014) and Ogwueleka and Christopher (2020), reported that high BOD concentrations deplete DO concentrations. At high BOD levels, aquatic organisms that can tolerate low dissolved oxygen concentration might become plentiful. BOD values at station 3 were similar to the values obtained by Eneji et al. (2012) at a highly perturbed portion of River Benue. DO and BOD_5 fluctuated more widely during the wet season than during the dry season. This seasonal variation which aligns with the works of Izonfuo and Bariweni (2001) and Anani *et al.* (2020) could be related to the effects of urban run-off on DO concentrations during the rainy season.

Bicarbonate, phosphate, and nitrate showed defined spatial variations among the anions characterised. The concentrations of chloride and sulphate were relatively the same. A similar variation was recorded by Nnoli *et al.* (2021) at Goi Creek. Except for bicarbonate, higher concentrations of other anions were recorded at stations 3 and 4 than at stations 1 and 2. The concentration of chloride dominated the concentrations of other anions, Ayobahan *et al.* (2015) and Anani *et al.* (2020) maintained the same pattern of variation in their studies. The concentration of chloride obtained in this study was lower than the values recorded by Ayobahan *et al.* (2015) and Anani *et al.* (2020). This difference is traceable to the tidal action at the Benin and Ossiomo Rivers where the studies were conducted as it can enhance saltwater intrusion from the Atlantic Ocean which increases chloride levels. Chloride together with EC, TDS, bicarbonate, sulphate, total hardness, Ca, Mg, K, Na, Fe, and Sr constitute the variables of salinity factors (Bu *et al.*, 2010). The concentrations of nitrate and phosphate peaked at station 3, agricultural activities (and particularly the use of N and P) based fertilizer is an important source of these compounds (Kadiri, 2000; Ehaise and Anyasi, 2005). Phosphate concentrations within the range of 0.05 to 0.1 mg L−1 are measured to be thresholds for waters of natural sources (Tibebe *et al.*, 2019). Values above this threshold were in some instances recorded at station 3 thus there are chances for anthropogenic input of phosphate at this station. The average concentrations of nitrate in the sample obtained across the stations were higher when compared to the concentrations of phosphate. Nnoli et al. (2021) reported that this pattern is typical of phosphorus in shallow water and further explained that phosphate in its soluble state gets adsorbed at the surface of the muddy substrate and could re-enter the water column at possible agitation. The strong positive correlations between the pairs of the anion indicate that they are likely of the same source. The concentrations of bicarbonate and sulphate were relatively equal for the two seasons while phosphate and nitrate concentrations were higher during the dry season than the wet season this pattern of variation could be the resultant effect of dilution due to rain.

The results from the sample analyses showed that both alkaline earth and alkali metals maintained sorts of spatial variation as the peak of the concentrations for individual metals were recorded at station 3. The alkali metals (sodium and potassium) were important in explaining the variation of water quality in Okpare Creek. The inclusion of alkali metals together with anions at the first rotated component of PCA implied salinity variations due to saltwater intrusion (Bu *et al.,* 2010). The water samples obtained were richer in potassium than sodium across all stations; a similar variation was reported by Izonfuo and Bariweni (2001), Oghenenyoreme and Njoku (2014), Nnoli *et al.* (2021). Variations of the alkaline earth metals were dissimilar to the record of Omoigberale *et al.* (2021) in which calcium concentrations dominated the magnesium concentration in all stations. In this study, the concentration of magnesium dominated at stations 1 and 2 while that of calcium dominated at stations 3 and 4; this variation could be attributed to external inputs which alter the background pattern. Varying dominance of the alkaline earth metals as observed in this study is consistent with the records of Walter *et al.* (2019) in River Rwizi, Western Uganda. Except for calcium, the other metals were relatively the same across the wet and dry seasons. The concentration of calcium was higher during the wet season than in the dry season, this variation could be accounted to the mineralization of the element after weathering of rocks.

Potential factor(s) responsible for water quality variations can be identified from the cluster of parameters having high eigenvalues within the rotated component in PCA (Felipe-Sotelo *et al.*, 2007; Kannel *et al.*, 2008; Bu *et al.*, 2010). The qgraph plot of the PCA via the varimax rotated component parameters highlighted multiple activities infringing on the water quality in Okpare Creek. The first RC recorded high eigenvalues for parameters of salinity factors; thus, this RC represents water quality variation orchestrated by tidal action. The second RC associated high eigenvalue with negative and positive effects for DO and BOD respectively, this indicates an oxidation-related reaction and organic pollution. The level of BOD in water increases at the expense of oxygen as the organic matter gets oxidized (Kannel *et al.*, 2008). The inclusion of calcium, total hardness, and temperature with strong eigenvalues and magnesium with moderate eigenvalue in the third RC highlights the rock weathering action which was orchestrated by precipitation. The fourth RC which represented soluble salt concentrations gave an overview of chemical changes caused by the river discharge (Bu *et al.*, 2010) while the fifth RC with strong eigen values for turbidity, TSS, and pH represented the effects of the sand mining activities on the water quality and decomposition of organic matter (Kaizer and Osakwe, 2010).

The water quality index (WQI) was employed to assess the overall quality of the water concerning the characterised parameters with the requisite regulatory standard. Although, the values of WQI did not differ significantly ($p>0.05$), the worst water quality was obtained from station 3 which was followed by stations 5, 1, and 2 (in the order of reducing water quality). By adopting Ramakrishniah *et al.*, (2009) grading scale, the water quality of Okpare Creek was very poor and cannot be used for any domestic purpose without proper treatment. Also, the outcome of this assessment showed that the water would not support a high diversity of organisms due to the synergistic toxic effects of the parameters responsible for the poor quality. The plot for quality rating showed that the poor quality of this system was championed by the levels of turbidity, TSS, BOD, DO, and pH. In general, these parameters are potential for organic pollution.

4.0 CONCLUSION

This study characterised the levels of some physical and chemical parameters of Okpare Creek in the quest to understand the spatiotemporal variability of the parameters and the general health of the system. The results highlighted that the water varied more spatially than temporal which buttress impacts from anthropogenic activities. Generally, the poor condition of this ecosystem is traceable to pollution from poor organic waste management and sand mining activities therein. By identifying the factor(s) responsible for water quality variations of the system, the results of this system highlight a basis for ecological restoration protection of this ecosystem. This study concluded that the water from Okpare Creek was not suitable for drinking and other domestic uses, irrigation, and aquatic organisms. Proper management of wastes from domestic and industrial imposes is essential to reduce the contamination and possibly pollution in the Okpare Creek as it would minimise degradation of the system.

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