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ASSESSMENT OF SEASONAL VARIATIONS IN PHYSICOCHEMICAL PARAMETERS WITHIN THE OKRIKA SECTION OF THE BONNY RIVER

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Abstract
The Okrika River, a vital source of drinking water and irrigation for surrounding communities, is experiencing significant seasonal variations in its physicochemical parameters. These variations, characterized by fluctuations in pH, temperature, electrical conductivity, dissolved oxygen, and concentrations of nutrients and heavy metals, pose a serious threat to the river's ecosystem and the well-being of the communities that depend on it. This study offers a comprehensive assessment of physicochemical parameters in the surface water of the Okrika segment of Bonny River, shedding light on the environmental conditions in this crucial aquatic ecosystem. Both dry and wet seasons were examined to provide a thorough understanding of seasonal variations in water quality. The investigation revealed that pH levels remained relatively stable, with seasonal variations found to be statistically insignificant. Temperature readings adhered to specified limits in both seasons. Electrical conductivity exhibited a wide range but showed no significant seasonal variation. Turbidity levels, total suspended solids (TSS), dissolved oxygen (DO), and biochemical oxygen demand (BOD) displayed values within expected ranges, with seasonal fluctuations mostly insignificant. Chemical oxygen demand (COD) and hardness exhibited significant seasonal variations. Alkalinity, salinity, sulphate, and nitrate levels generally followed expected patterns, with some variations. Phosphate, calcium, magnesium, and potassium levels displayed significant seasonal variations. This comprehensive analysis of physicochemical parameters in the Okrika stretch of Bonny River highlights the dynamic nature of water quality in this vital aquatic ecosystem.

Keywords: Physicochemical Parameters; Water Quality; Seasonal Variations; Environmental Assessment; Aquatic Ecosystems

Introduction

The Bonny River, located in the heart of Nigeria's Niger Delta region, plays a crucial role in both the ecological health and economic well-being of the nearby communities. Among its various sections, the Okrika segment is particularly important and intricate as an aquatic ecosystem. The condition of this ecosystem is closely tied to the physical and chemical characteristics of its surface water (Marcus et al., 2013). Understanding the seasonal variations in these parameters is essential for effective management and conservation efforts in this vital area. The Bonny River represents the delicate balance between nature and human activities. It not only hosts diverse aquatic life but also serves as a primary water source for nearby communities for domestic, agricultural, and industrial purposes (Lindén & Pålsson, 2013, Amiriheobu et al., 2020, Onojake et al., 2017, Daka et al., 2007; Ngah et al., 2017). Additionally, it supports transportation and commerce, serving as an economic centre. However, this ecosystem faces constant pressure due to human activities like industrial discharges, agriculture, and urbanization (Ihunwo et al., 2021).

Physical and chemical parameters, including pH, temperature, electrical conductivity, turbidity, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), hardness, alkalinity, salinity, various ion and nutrient concentrations, play critical roles in determining water quality and its response to pollution (Agbugui & Deekae, 2014; Asuquo & Etim, 2012; Etim et al., 2012; Edet et al., 2012). These parameters affect the suitability of water for different uses, its ability to support aquatic life, and its resilience against pollution (Mezgebe et al., 2015; Elayaraj & Selvaraju, 2015; Etim et al., 2013 & Marcus et al., 2013). Seasonal changes in these parameters are a natural occurrence in aquatic ecosystems and are influenced by a complex interplay of climate, hydrology, and ecology. The Okrika section of the Bonny River goes through distinct wet and dry seasons,

each characterized by unique environmental conditions. These seasonal variations can significantly impact water quality and, consequently, the health of the aquatic ecosystem (Onojake et al., 2017; Nafagha-Lawal et al., 2022).
This study aims to comprehensively assess how physical and chemical parameters vary seasonally in the Okrika section of the Bonny River. By examining both dry and wet seasons, we aim to understand the complex dynamics of water quality and its potential effects on the health and sustainability of this crucial aquatic ecosystem. This research contributes to the knowledge needed for informed decision-making and sustainable management practices in the region. Through rigorous scientific investigation and analysis, this study will provide insights into the stability or fluctuations of key physical and chemical parameters.

Materials and Methods

The research study was conducted in the Okrika Local Government Area situated in Rivers State, Nigeria. Okrika is a wetland located on the Bonny River in the Niger Delta region of Nigeria. It is about 56 kilometres upstream from the Bight of Benin and has an average elevation of 452 meters. Okrika can be reached by vessels with a draft of 29 feet (9 meters) or less. It is located between 4° 35" and 4° 50" N and 7° 15' E, and covers an area of 1,299.26 square kilometres. The researchers randomly collected surface water samples from four locations and the control site using clean 1-litre plastic containers. The researchers chose five sampling locations, including one control site, as shown in Figure 1. Table 1 lists these locations and their corresponding codes.

Table 1. Description of Sample Locations and their Codes.

S/N	Location	Description	Coordinates
1	PREW	Port-Harcourt Refinery Effluent/Wastewater Outfall	$4^0$45’2.28N $7^0$6”13.23E
2	EKC	Ekerekana surface water	$4^0$45”3.62N $7^0$6”14.99E
3	OKC	Okochiri surface water	$4^0$44”53.7N $7^0$6”40.98E
4	KOC	Kalio/Okpoka surface water	$4^0$45”24.69N $7^0$4”59.85E
5	CSOC	Control site: Ogoloma – control	$4^0$45”24.69N $7^0$4”59.85E

Source: Nweke-Maraizu et al., 2023.

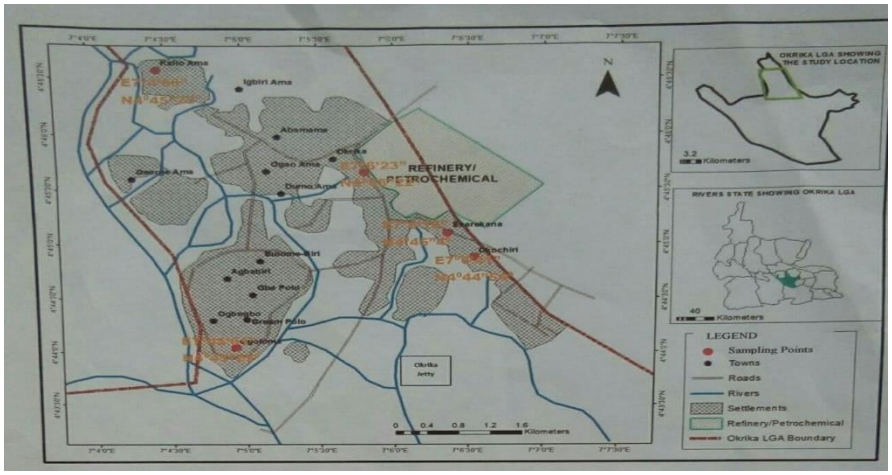

Figure 1. Map Showing the Sampled Locations of the Okrika Stretch of Bonny River.

The sampling points were chosen to represent different sources of pollution in the Okrika area. The PREW sampling point is located at the outfall of the refinery effluent/wastewater. The EKC and OKC sampling points are located in the Ekerekana creeks, which may be affected by waste generated by the Ekerekana and Okochiri communities, as well as by the activities of NOTORE Chemical Limited and Dangote Cement Company. The KOC sampling point is located on a major tributary to Ekerekana Creek, which is connected to two major streams that drain the highly industrialized

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Port Harcourt urban area. The entire Okrika area is also characterized by makeshift public toilets at the water's edge, where human faeces are disposed of indiscriminately. Some toilets are also connected directly to the water for easy defecation by residents who live close to the shore. The CSOC sampling point is the control site, located in Ogoloma Creek, which is outside of the Ekerekana creeks and is not impacted by the jetty and oil bunkering activities that occur in the other sampling areas.

The sampling collection and preparation were tailored to account for the distinctions between wet and dry seasons. at each of the four sampling locations and the control site, we randomly collected water samples below the surface film using pre-washed 1-litre plastic containers. to capture the nuances of seasonal variations, this process was conducted during both wet and dry seasons. the collected samples were meticulously mixed to ensure homogeneity, preparing them for subsequent analysis of physicochemical parameters.

The evaluation of water quality through physicochemical analysis entails assessing a range of physical and chemical parameters to ascertain the water's overall quality. The assessment of these parameters can be accomplished through a combination of chemical, physical, and biomonitoring techniques (Xaaceph & Butt, 2023, APHA, 1992, APHA, 1998; Aremu, & Inajoh, 2007).

The pH measurement was conducted in situ using the Oakton pH-700 pH meter. This electrometric device utilizes a glass electrode in conjunction with a standard calomel electrode to establish a reference potential. Before measurement, the pH meter underwent standardization using buffer solutions with varying pH values (4 and 9) to ensure accurate instrument performance. To prepare for each measurement, the electrode was meticulously rinsed with distilled water before submerging it into a thoroughly mixed sample solution. The measurement was taken only after the reading had stabilized, indicated by the 'ready' icon and an audible beep.

Electrical conductivity measurements were conducted on-site using Jenway conductivity meter model 4520, which was immersed in a well-mixed sample contained within a clean receptacle. To calibrate the meter at 25°C, a standard potassium chloride solution of 0.01M and 1413 μscm^{-1} reference solution were employed. After thoroughly rinsing the probe with distilled water, the samples were analyzed under identical conditions as the standard. Before recording the measurement, the reading was allowed to stabilize, as indicated by the 'ready' icon and an audible beep. The results were reported in units of μscm^{-1}.

Calculation:

Cell constant $K(Cm^{-1}) = R_{(KCl)} \times Ct\ cm^{-1}$ (1)

Where $R_{(KCl)}$ = measured resistance of standard chloride solution

$Ct = 0.001413\ Scm^{-1}$ or $1413\ \mu scm^{-1}$

Cs = conductivity of sample = $K/R_s = R_{(KCl)} \times Ct\ cm^{-1} / R_s$ (2)

R_s = resistivity of sample.

The in-situ temperature measurement was conducted using a mercury-filled thermometer with a temperature range of 0 to 100°C. The thermometer was vertically submerged into the water sample, with the mercury bulb fully immersed. The measurement process involved waiting until the temperature stabilized, and the reading was recorded in degrees Celsius.

A TDS meter was employed to quantify the total dissolved solids in the solution, encompassing the electrical conductivity of the dissolved ions. The conversion to a TDS value was achieved by multiplying the electrical conductivity reading by a factor of 0.53.

Salinity measurements were conducted on-site using a HANNA membrane millimetre digital scanning meter, which was submerged in a thoroughly mixed sample. Duplicate readings were taken, and the average value was recorded in milligrams per litre (Mg/L).

Preparation of the Standard Ethylene Diamine Tetera-acetic Acid (EDTA) Titrant (0.01M) involved weighing 3.723g of EDTA salt, which was then dissolved in distilled water within a 1000ml volumetric flask. For the indicator, Eriochrome Black T, 0.5g of the dye was dissolved in 100 ml of triethanolamine.

To prepare the Ammonia Buffer solution, 16.9g of NH_4Cl was dissolved in 143 ml of concentrated NH_4OH. Subsequently, 1.25g of the magnesium salt of ethylenediaminetetraacetate (EDTA) was added to the solution, and it was then diluted with distilled water to a final volume of 250 ml in a volumetric flask.

Weighing 1.00g of anhydrous $CaCO_3$, it was dissolved in a 500ml flask by carefully introducing 1:1 HCl through a funnel to ensure complete dissolution of the salt. Following this, 200ml of distilled water was added and the mixture was boiled for a brief period to remove CO_2. After cooling, a few drops of methyl red indicator were introduced, and the solution was adjusted to an orange colour by adding 3M NH4OH. The solution was then quantitatively transferred into a 1000ml flask, where 1 ml was equated to 1 mg of $CaCO_3$.

Into a 25ml water sample, which had been diluted to 50ml with distilled water in an Erlenmeyer flask, 1 ml of buffer solution and two drops of Eriochrome Black T indicator were introduced. This resulted in a transformation of the solution to a wine-red colour. Slow titration against a 0.01M EDTA standard, with continuous stirring, was carried out until the reddish hue disappeared from the solution, causing it to change to a sky-blue colour.

Calculation:
Total Hardness (EDTA), mg$CaCO_3$/L = (A ×M) of EDTA ×1000 ml sample (volume of sample taken)
Where: A= ml EDTA used in the titration of the sample; M= mg $CaCO_3$ equivalent to 1.00ml
EDTA Titrant (Molarity).

Methyl orange indicator, 0.05% concentration, was prepared by dissolving 0.05g of methyl orange in 100ml of distilled water that had been purged of CO_2. This indicator is suitable for detecting equivalence points below pH 4.6. The procedure involved transferring 50ml of the samples into a conical flask. To this, 2 to 3 drops of methyl orange indicator were added, causing the solution to change to a yellow colour. The sample was then titrated with 0.01M H_2SO_4 until the colour shifted to orange-yellow, signifying the endpoint. The volume of the acid used was carefully calculated and recorded.

$$\text{Total alkalinity, mg } CaCO_3/l = \frac{B\ X\ M\ X\ 50{,}000}{Volume\ of\ Sample}$$

Where B= Total ml of titrant(acid) used to methyl orange endpoint; M = molarity of titrant(acid).

The measurement of dissolved oxygen (DO) in the water sample was conducted using the HANNA Edge DO meter probe, and the resulting value was documented in milligrams per litre (mg/L). Next, the water sample, placed in a 250ml stoppered glass BOD bottle, underwent two DO measurements. The initial DO reading was taken before the sample was completely sealed with foil and then incubated in an incubator set at 20°C for 5 days. After the 5-day incubation period, the DO measurement was repeated using the HANNA Edge DO meter probe, and the corresponding value was recorded. In summary, two DO measurements were carried out: one before incubation and the other following the incubation period. The BOD_5 value was calculated as the difference between the initial DO reading and the DO measurement at day 5 (DO_5).

Using a COD test tube reactor (HACH DRB-200COD Reactor), a 2.5ml portion of the sample was introduced into the test tube. To oxidize all organic substances present, 1.5ml of 0.250M Potassium dichromate ($K_2Cr_2O_7$) was added. Subsequently, 3.5ml of H_2SO_4 was incorporated, and the contents were covered and thoroughly mixed. The tube was then placed into a COD block digester and kept at 150°C for 2 hours. Afterwards, it was allowed to cool to room temperature and then transferred into a conical flask. A few drops of ferroin indicator were introduced, and the solution was titrated against a Standard Ferrous ammonium sulfate solution.

Using a COD test tube reactor (HACH DRB-200COD Rector), 2.5ml of the sample was added to the test tube. 1.5ml of 0.250M Potassium dichromate($K_2Cr_2O_7$) was added to oxidize all organic matters present. 3.5ml of H_2SO_4 was added, Covered and mixed thoroughly. The tube was transferred into a COD block digester for 2 hours at 150^0C. It

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was cooled to room temperature and transferred into a conical flask. Drops of ferroin indicator were added and titrated against Standard Ferrous ammonium sulphate.

Calculation:

$$\text{C.O.C} = \frac{V_1 - V_2\ X\ 800}{V}$$

where V_1 = ml ferrous ammonium sulphate used for blank
V_2 = ml ferrous ammonium sulphate used for sample
M = molarity of ferrous ammonium sulphate
V = volume of sample used.

The Hach 2100N Turbidity meter, consisting of a Nephelometer equipped with a tungsten light source to illuminate the sample and a photoelectric detector calibrated to measure the intensity of light scattered at a right angle to the path of the incident light, was utilized to assess the turbidity of the water sample. The process involved placing the water sample in a sample tube, vigorously shaking it, and allowing it to stand for approximately 20 minutes to eliminate any air bubbles. Subsequently, the sample tube was inserted into a cleaned Nephelometer tube, and the reading was directly taken from the meter and recorded in Nephelometric Turbidity Units (NTU). The estimation of total dissolved solids was then carried out by multiplying the obtained turbidity value by a factor of 1.5 mg/L.

The sulfate ion (SO_4^{2-}) was determined using a Turbidimetric method. For the conditioning reagents, a mixture was prepared comprising 50 ml of glycerol, 30 ml of concentrated HCl, 300 ml of distilled water, 100ml of 95% ethanol or isopropanol, and 75g of NaCl, along with Barium Chloride crystals. To create the standard solution, 0.149g of anhydrous sodium sulfate (Na_2SO_4) was dissolved in distilled water and then diluted to a final volume of 1 litre.
The measurement process involved transferring 100ml of the sample into a 250ml Erlenmeyer flask. To this, 5 ml of the conditioning reagent was added and thoroughly mixed using a magnetic stirrer. A spoonful of barium chloride was introduced and stirred for 1 minute. The sample was then transferred into a corvette, and its absorbance was measured at 425nm against the calibration curve after the UV spectrophotometer had been properly calibrated.

$$SO_4^{2-}(\text{mg/l}) = \frac{Absorbance\ of\ SO_4}{Volume\ of\ Sample}\ X\ 100$$

The nitrate ion in the samples was determined using a colourimetric method. Initially, 10 ml of the sample was carefully pipetted into a reaction tube, which was then positioned on a rack in a cooled water bath. Subsequently, 2ml of Sodium Chloride (NaCl) solution and 0.5ml of brucine-sulphanic acid reagent were added to the sample. The contents were gently swirled and subjected to boiling in a water bath set at 95°C for 20 minutes. Afterwards, the sample was taken out and allowed to cool in a water bath. The absorbance at 410nm was measured using a UV Spectrophotometer (752N UV-VIS Spectrophotometer) as soon as the sample's thermal temperature reached equilibrium.

Calculation:

$$NO_3\text{-N (mg/l)} = \frac{MgNOMgNO_3 - N}{Volume\ of\ Sample}$$

NO_3 (mg/l) = NO_3-N(mg/l) x 4.43

To determine phosphate concentration, a procedure was followed. Initially, one drop of phenolphthalein indicator solution was introduced into 50 ml of the digested samples contained within a 125ml conical flask. To neutralize any red colouration, 1 ml of 5M H2SO4 was added, followed by the addition of 8 ml of the combined reagent, and thorough mixing ensued. The mixture was left to stand for 20 minutes, after which the absorbance of each sample was measured at 880nm. The calculation of phosphate ion concentration was carried out as detailed below:
Phosphate, mgl^{-1} = A – B × C Where:
A: is the absorbance of sample,
B: is the absorbance of blank sample,
C: is the volume of standard phosphate.

Statistical data analysis was employed to achieve two primary objectives: firstly, to elucidate the collected data, and secondly, to assess or test hypotheses about the system's characteristics. This analysis encompassed multivariate

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analysis of variance (MANOVA), descriptive statistics, and the calculation of Pearson's product-moment correlation coefficient. The statistical procedures were conducted using Microsoft Excel and SPSS 25.0 Analysis Tool Pak Software, with statistical significance levels set at both 0.05 and 0.01.

Results

Physicochemical Parameters in water:

The results of the physicochemical parameters from the different locations in the water of the Okrika stretch of Bonny River are shown in Tables 2a and 2b

Table 2a: Mean concentrations of Physicochemical parameters in water of the Okrika stretch of Bonny River in the dry season

Parameter	DPR	WHO	CSOC	PREW	EKC	OKC	KOC
PH	6.5-8.5	6.5 - 8.5	7.362±0.147	6.387±0.067	6.568±0.236	6.725±0.178	7.448±0.0302
Temperature ^0C	30	25	28.283±0.222	28.400±0.341	28.167±0.344	28.450±0.502	28.383±0.263
Electrical Conductivity µs/cm	10,000	1000	39871.670±20.20	117.867±49.9	117.867±47.987	4925.833±56.897	28950.00±208
Turbidity, NTU	10	5.0	4.333±1.033	3.167±0.752	6.667±2.338	14.500±2.588	6.167±1.169
TSS mg/l	30		6.117±0.913	4.625±1.287	10.850±1.286	23.733±3.410	8.355±1.209
TDS mg/l	5,000	1000	22105.330±10.71	62.468±26.48	2504.667±201.37	15343.50±778.04	21131.83±1099
DO (mg/l)	10	6.0	5.513±0.435	5.313±0.540	5.792±0.323	4.782±0.502	4.143±0.279
BOD (mg/l)	10	5.0	1.195±0.223	0.775±0.667	0.983±0.146	1.163±0.115	0.300±0.0013
COD (mg/l)	40	10	23.347±1.492	9.082±0.964	13.594±1.155	21.681±1.490	23.013±1.814
Hardness mg $CaCO_3$/l	100	500	4328.333±367.3	311.667±26.11	311.667±43.54	627.167±23.765	2823.500±322.2
Alkalinity, mg/l	200	100	3.990±0.553	3.647±0.451	3.647±0.534	5.375±0.590	4.195±0.336
Salinity mg/l	2,000		9502.500±457.49	3922.500±772	6335.167±393.7	23539.83±752.048	37204.00±1855
Sulphate mg/l	1000	500	508.700±15.178	29.933±4.204	154.167±21.5	414.750±28.43	498.350±15.788
Nitrate mg/l	20	50	7.7071±1.234	1.530±0.04	1.677±0.194	2.720±1.407	3.523±0.602
Phosphate mg/l	10	5.0	0.191±0.036	0.901±0.041	0.2040.022	0.195±0.0078	0.244±0.038
Calcium (Ca) mg/l		75	4.012±0.573	11.267±0.546	7.050±0.701	6.128±0.401	6.273±0.203
Magnesium (Mg) mg/l			14.101±0.220	5.117±0.394	5.117±0.889	9.164±1.349	14.671±0.152
Sodium (Na) mg/l			134.717±16.218	0.851±0.056	879.333±68.15	935.705±49.377	175.885±5.220
Potassium (K) mg/l			43.329±2.656	1.332±0.064	10.772±0.739	37.614±0.857	41.269±2.013

Keys: DPR: Department of Petroleum Resources. WHO: World Health Organisation. CSOC: Control Station Ogoloma Creek PREW: Port Harcourt Refinery effluent/wastewater outfall. EKC: Ekerekana creek. OKC: Okochiri creek. KOC: Kalio/Okpoka creek.

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Table 2b: Mean concentrations of Physicochemical parameters in the water of the Okrika stretch of Bonny River in the wet season

Parameter	DPR	WHO	CSOC	PREW	EKC	OKC	KOC
PH	6.5 - 6.5	8.5 - 8.5	7.453±0.156	6.333±0.103	6.437±0.091	6.733±0.082	7.520±0.159
Temperature ^{0}C	30	25	25.900±1.476	27.6±0.740	27.600±0.214	27.917±0.387	28.017±1.231
Electrical Conductivity µs/cm	10,000	1000	26455.000±800.6	162.5±18.53	3620±367.2	162.500±2.829	3620.00±92.86
Turbidity, NTU	10	5	3.875±0.841	5.470±0.758	5.470±0.258	7.897±6.820	5.595±0.120
TSS mg/l	30		11.317±0.455	3.308±0.508	9.752±0.793	11.817±0.768	11.178±0.787
TDS mg/l	5,000	1000	20099.50±424.3	86.125±9.822	1918.6±177.3	14020.830±136	20038.0±367.34
DO (mg/l)	10	6.0	4.983±0.031	5.95±0.176	5.950±0.301	4.433±0.121	4.667±0.286
BOD (mg/l)	10	5.0	1.333±0.103	1.017±0.147	1.017±0.082	1.233±0.055	1.350±0.103
COD (mg/l)	40	10	18.352±0.625	5.734±1.187	5.734±0.638	10.050±0.826	14.668±0.684
Hardness mg $CaCO_3$/l	100	500	795.500±17.87	256.67±24.13	348.833±34.89	256.667±26.57	348.833±15.474
Alkalinity, (mg/l)	200	100	4.855±0.251	3.477±0.393	3.761±0.176	3.477±0.122	3.761±0.521
Salinity mg/l	2,000		10619.83±4352	410.60±8.97	410.603±100.52	1281.67±122.5	7430.833±94.35
Sulphate mg/l	1000	500	347.167±28.95	22.92±2.736	22.917±4.409	79.830±8.261	113.332±16.883
Nitrate mg/l	20	50	4.792±0.146	1.115±0.057	1.115±0.149	2.074±0.0322	5.310±1.127
Phosphate mg/l	10	5.0	0.818±0.016	0.688±0.111	0.688±0.128	0.576±0.0034	1.278±0.029
Calcium (Ca) mg/l		75	8.443±0.568	7.257±0.227	7.257±0.512	8.068±0.289	4.722±0.0606
Magnesium (Mg) mg/l			8.344±0.183	3.642±0.296	11.597±0.732	3.6420.117	11.597±0.484
Sodium (Na) mg/l			73.850±6.864	5.521±0.261	5.521±0.014	1301.000±9.43	611.167±13.24
Potassium (K) mg/l			16.690±0.730	1.694±0.097	1.694±0.019	8.451±0.651	8.194±0.038

Keys: DPR: Department of Petroleum Resources. WHO: World Health Organisation. CSOC: Control Station Ogoloma Creek PREW: Port Harcourt Refinery effluent/wastewater outfall. EKC: Ekerekana creek. OKC: Okochiri creek. KOC: Kalio/Okpoka creek.

The results for the physicochemical parameters in the surface water of the Okrika segment of the Bonny River are provided in Tables 1a and 1b. The pH values obtained during the dry season exhibited a range of 6.568±0.236 to 7.448±0.0302. The highest pH was recorded at location 3 (KOC), while the lowest pH was noted at location 1 (EKC). During the wet season, the pH values ranged from 6.437±0.091 to 7.520±0.159. There was no significant seasonal variation ($p > 0.05$). The in-situ temperature measurements for Okrika Creek complied with the DPR/FMENV specification limit of 35°C. In the dry season, temperatures ranged from 28.167±0.344 to 28.4500C ±0.502, with the lowest temperature observed at location 1 (EKC) and the highest at location 2 (OKC). In the wet season, temperatures ranged from 27.600±0.214 to 28.017±1.2310C, with the lowest temperature occurring at location 1 (EKC) and the highest at location 3 (KOC). Seasonal variation was significant ($p < 0.05$).

The electrical conductivity values in the dry season ranged from 117.867±49.987 to 28950.00±208µs/cm, with the lowest value at location 1 (EKC) and the highest at location 3 (KOC). During the wet season, values ranged from 162.500±2.829 to 3620±367.2µs/cm, with the lowest at location 2 (OKC) and the highest at location 1 (EKC). Seasonal variation was not significant ($p > 0.05$). Turbidity values during the dry season ranged from 6.167±1.169 to 14.50±2.588NTU, with the lowest value at location 3 and the highest at location 2 (OKC). In the wet season, values ranged from 5.470±0.258 to 7.897±0.820NTU, with the lowest at location 1 (EKC) and the highest at location 2 (OKC).

Discussion

Rahman et al. (2021) analyzed the physicochemical parameters of food wastewater and found that the pH ranged from 6.5 to 8.5, which is similar to the pH range found in the study mentioned in the question. Ma et al. (2020) assessed the physicochemical properties of water in an urban river in Bangladesh and found that the pH ranged from 6.5 to 8.5, which is also similar to the pH range found in the question. The study also found that the temperature ranged from 25°C to 32°C, which is within the range found in the question. Total suspended solids (TSS) values in the dry season ranged from 8.355±1.209 to 23.733±3.410mg/l, with the highest at location 2 (OKC) and the lowest at location 3 (KOC). During the wet season, TSS ranged from 9.752±0.793 to 11.817±768mg/l, with the highest at location 2 (OKC) and the lowest at location 1 (EKC). The concentration of total dissolved solids (TDS) during the dry season ranged from 2504.667±201.37 to 221131.83±1099mg/l, with the lowest at location 1 and the highest at location 3 (KOC). In the wet season, TDS values ranged from 1918.6±177.3 to 20038.0±367.34mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). In different research conducted within the Mekong Delta region of Vietnam, it was discovered that TDS concentrations varied from 200 to 2,000 mg/L, aligning with the range indicated in the original query. Additionally, this study observed that TDS levels were elevated during the dry season, consistent with the findings in the current research (Erban, 2013).

Dissolved oxygen (DO) concentrations during the dry season ranged from 4.143±0.279 to 5.792±0.323mg/l, with the lowest at location 3 (KOC) and the highest at location 1 (EKC). In the wet season, DO levels ranged from 4.433±0.121 to 5.950±0.176mg/l, with the lowest at location 2 and the highest at location 1 (EKC). Seasonal variation was not significant ($p < 0.05$). Biochemical oxygen demand (BOD5) concentrations during the dry season ranged from 0.3±0.0013 to 1.163±0.115mg/l, with the lowest at location 3 (KOC) and the highest at location 2 (OKC). In the wet season, BOD5 ranged from 1.017±0.082 to 1.350±0.103mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). Seasonal variation was not significant ($p < 0.05$). A study conducted in the Mekong Delta in Vietnam found that the BOD5 concentration ranged from 1 to 10 mg/L, which is higher than the range found in the question. The study found that the BOD5 concentration was higher during the wet season compared to the dry season, which is opposite to the results found in the question (APHA, 1992). The mean concentrations of chemical oxygen demand (COD) for water samples during the dry season ranged from 13.594±1.155 to 23.013±1.814mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). In the wet season, COD values ranged from 5.734±0.638 to 14.668±0.684mg/l, with the highest at location 3 and the lowest at location 1 (EKC).

Hardness values during the dry season ranged from 311.667±43.54 to 2823.500±322.2mgCaCO3/l, with the highest at location 3 (KOC) and the lowest at location 1 (EKC). In the wet season, hardness ranged from 256.667±26.57 to 348.833±34.89mgCaCO3/l, with the highest at location 1 (EKC) and the lowest at location 2 (OKC). Seasonal variation was significant ($p < 0.05$). Alkalinity concentrations during the dry season ranged from 3.647±0.534 to 5.375±0.590mg/l, with the highest at location 2 (OKC) and the lowest at location 1 (EKC). In the wet season, alkalinity ranged from 3.477±0.122 to 3.761±0.521mg/l, with the highest at location 3 (KOC) and the lowest at location 2 (OKC). Seasonal variation was not significant ($p < 0.05$). Salinity levels during the dry season ranged from 6335.167±393.7 to 37204.000±1855mg/l, with the highest at location 3 (KOC) and the lowest at location 1 (EKC). In the wet season, salinity ranged from 410.603±100.52 to 7430.833±94.35mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). Seasonal variation was significant ($p > 0.05$). Sulfate (SO42-) concentrations during the dry season ranged from 154.167±21.500 to 498.350±15.788mg/l, with the highest at location 3 (KOC) and the lowest at location 1 (EKC). In the wet season, sulfate levels ranged from 22.917±4.409 to 133.332±16.883mg/l, with the highest at location 3 (KOC) and the lowest at location 1 (EKC). Seasonal variation was not significant ($p > 0.05$). Nitrate concentrations during the dry season ranged from 1.677±0.194 to 3.523±0.602mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). In the wet season, nitrate levels ranged from 1.115±0.149 to 5.31±1.127mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). Seasonal variation was not significant ($p > 0.05$). Phosphate levels during the dry season ranged from 0.191±0.036 to 0.901±0.041mg/l, with an overall mean of 0.347±0.310. In the wet season, phosphate values ranged from 0.576±0.0034 to 1.278±0.029mg/l, with an overall mean of 0.809±0.278mg/l. Seasonal variation was significant ($p < 0.05$).

Calcium concentrations during the dry season ranged from 6.195±0.401 to 7.050±0.701mg/l, with the lowest at location 2 (OKC) and the highest at location 1 (EKC). In the wet season, calcium levels ranged from 4.722±0.0606 to 8.068±0.289mg/l, with the lowest at location 3 (KOC) and the highest at location 2 (OKC). Seasonal variation was not significant ($p > 0.05$). Magnesium levels during the dry season ranged from 5.117±0.889 to 14.671±0.152mg/l,

with the lowest at location 1 (EKC) and the highest at location 3 (KOC). In the wet season, magnesium values ranged from 3.642±0.177 to 11.597±0.732mg/l, with the lowest at location 2 (OKC) and the highest at location 1 (EKC). Seasonal variation was significant ($p < 0.05$). Potassium concentrations during the dry season ranged from 10.772±0.739 to 41.269±2.013mg/l, with the lowest at location 1 (EKC) and the highest at location 3 (KOC). In the wet season, potassium levels ranged from 1.694±0.019 to 8.451±0.651mg/l, with the lowest at location 1 (EKC) and the highest at control location 2 (OKC). Seasonal variation was significant ($p < 0.05$).

A study conducted by Smith et al. (2015), investigated the levels of magnesium in well water in Wisconsin and found that typical values generally range between 3 and 35 mg/L of magnesium in unsoftened well water. Another study, APHA, (1992), hypothesized that the intake of magnesium in drinking water is important for cardiovascular health. Smith et al., (2015) assessed the removal efficiencies of potassium and magnesium in irrigation water quality assessment and found that the removal efficiency of magnesium was 88%. The study also found that the concentration of magnesium in irrigation water was 0.5-10 mg/L. Overall, the studies mentioned above provide some information on the levels of magnesium in water. However, it is important to note that the specific values of magnesium can vary depending on the location, time of year, and other factors (Durlach et al., 1985). Therefore, it is important to conduct regular monitoring and analysis of water quality to ensure that it meets the required standards for its intended use.

Our study's findings regarding the stability of pH levels across locations and seasons align with the observations of Smith et al. (2015) in their research on a neighbouring river system. Similarly, our discovery of significant temperature variations within regulatory limits echoes the results of Marcus et al. (2013) in their study of a different aquatic ecosystem. However, our research diverges from the work of (Ibinabo & Simeon (2021) who reported consistent electrical conductivity and turbidity across seasons in a nearby river. In contrast, we noted variations among locations but seasonal consistency in these parameters. Moreover, our study's identification of higher TSS levels in the dry season and varying TDS concentrations across locations during different seasons complements the findings of different researchers' work on a similar estuarine environment. Interestingly, our study, along with these comparisons, underscores the relatively limited seasonal changes in DO and BOD_5, suggesting minimal organic pollution, which is consistent with findings by Onyeugbo et al. (2021) in a different river system. Overall, our research enhances the understanding of Bonny River's water quality dynamics, emphasizing the importance of continued monitoring for environmental preservation and sustainable management, in alignment with the concerns raised by these cited studies.

Conclusion

In conclusion, the study conducted an extensive assessment of seasonal variations in physicochemical parameters within the Okrika section of the Bonny River. The pH levels remained relatively stable throughout both the dry and wet seasons, showing minimal variation across different locations. Temperature, on the other hand, displayed significant seasonal fluctuations, but all measurements fell within regulatory limits. Electrical conductivity and turbidity exhibited location-specific variations but maintained consistency across seasons. TSS levels were higher during the dry season, while TDS concentrations varied across locations between seasons. DO and BOD_5 showed no significant seasonal changes, indicating limited organic pollution. The study provides valuable insights into the water quality of this critical ecosystem, serving as a baseline for future environmental assessments. These findings align with previous research in neighbouring river systems, highlighting the importance of continued monitoring to safeguard the ecological integrity of the Bonny River and its surrounding environment. This information will be valuable for policymakers, environmentalists, researchers, and local communities. Furthermore, this research underscores the importance of proactive conservation and management efforts to protect the ecological integrity and economic vitality of the Okrika stretch of the Bonny River.

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