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Water Quality of Buguma Creek, Niger Delta and its Ecological Implications

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Abstract: *Buguma Creek, a brackish waterbody in the Niger Delta region, is known for supporting fisheries and aquaculture operations while being subject to increasing anthropogenic pollution. This study assessed spatial and temporal variation in physicochemical parameters and nutrients, and evaluated ecological implications using correlation analysis, the Single Factor Index, the Nemerow Pollution Index, and the Water Pollution Index. Surface water was sampled monthly at three stations from April to September 2023 and analysed using APHA methods. Spatially, EC, DO, BOD, COD, phosphate and nitrate ranged from 1140.83–1695.83 µS/cm, 3.93–4.80, 2.73–5.84, 4.16–10.82, 3.86–7.62 and 2.63–4.76 mg/L, respectively. Most parameters were within guideline limits; however, BOD, phosphate and sulphate exceeded limits, particularly at Station 2. NPI classified Stations 1 and 2 as slightly polluted, while Station 3 was clean. Although WPI classified all stations as Class II, Buguma Creek shows localised organic and nutrient stress, rather than being entirely unaffected ecologically, and therefore requires targeted monitoring and waste-control measures to protect fisheries and ecosystem function.*

Keywords: Water quality, ecological stress, nutrient enrichment, organic pollution, Buguma Creek; Niger Delta.

INTRODUCTION

Coastal and estuarine water bodies are among the most biologically productive aquatic ecosystems in the world, but they are also highly vulnerable to anthropogenic pollution due to their proximity to human settlements, industrial activities, agricultural catchments, and transport corridors (Mitra and Zaman, 2016; Kennish, 2023). Rapid urbanisation, industrialisation, agricultural runoff, and ineffective waste management practices have transformed the physical and chemical parameters of many water bodies, leading to poor water quality, habitat degradation, and loss of ecosystem services (Ogidi and Akpan, 2022; Okafor *et al.*, 2023; Albou *et al.*, 2024). In particular, the degradation of water quality in coastal and estuarine waters manifests as nutrient and organic enrichment, oxygen depletion, enrichment of suspended particulate material, and changes in salinity and ionic content.

Physical and chemical parameters such as temperature, pH, dissolved oxygen (DO), salinity, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity and concentration of various nutrients serve as common indices of the state of aquatic ecosystems (Punde and Kulkarni, 2025; Verma *et al*., 2025). These indicators directly affect biological productivity and distribution, metabolism, and trophic relationships; hence, any changes in these parameters can be interpreted as environmental stress caused by anthropogenic pollution (Goswami *et al*., 2018; Chakraborty, 2021; Mishra *et al*., 2023). For instance, elevated BOD and nutrient concentrations would indicate organic and nutrient pollution and eutrophication; decreased DO levels would indicate physiological stress in fish and other aquatic organisms and alterations in community structure (Miltner, 2018; Mariu *et al*., 2023).

Brackish water ecosystems are highly susceptible to pollution due to their transitional status between freshwater and seawater (Pérez-Ruzafa *et al*., 2011). They are often used as sinks for pollutants from nearby terrestrial catchments; hence, studying brackish water ecosystems can help understand terrestrial impacts on coastal environments (Thrush *et al*., 2013). Domestic sewage, petroleum industry activities, aquaculture discharges, and agricultural runoff are just a few anthropogenic sources that may affect water quality dynamics in tropical estuaries (Verma *et al*., 2012; Akhtar *et al*., 2021). Thus, it is critical to evaluate water quality spatiotemporally to establish pollution trends and recognise localised stressors and potential ecological risks (Bierman *et al*., 2011; Oyeboade and Olagoke-Komolafe, 2023).

In general, the Niger Delta region of Nigeria is one of the most heavily stressed coastal areas globally due to intensive oil extraction, urbanisation, and coastal development (Zabbey *et* al., 2019; Sunday *et al*., 2024). Aquatic ecosystems suffer from various anthropogenic factors, including hydrocarbon pollution, domestic waste discharge, nutrient pollution, siltation, and land-use changes. All these factors can harm water quality, aquatic habitats, biological diversity, and fisheries that support people in the region (Nduka and Orisakwe, 2011; Okoyen *et al*., 2020; Igbani *et al*., 2024). Prior research in Niger Delta creeks and estuaries revealed water physicochemical changes associated with anthropogenic activities (Abowei and George, 2009; Makinde *et al*., 2015). Nevertheless, modern integrated approaches to evaluating water quality in Buguma Creek, especially those that link physicochemical conditions to pollution indices and ecological implications, are quite scarce.

Buguma Creek is a brackish-water ecosystem in the Niger Delta that supports artisanal fisheries, transportation, and aquaculture activities (Ogbeibu and Oribhabor, 2011). Buguma Creek is bordered by human settlements and is exposed to various anthropogenic pressures, including the dumping of domestic waste, fuel handling, bridge runoff, and aquaculture waste. These activities can result in changes in nutrient concentrations, organic matter loads, DO levels, and overall water quality. Since this ecosystem plays a significant role in both people's welfare and the environment, water quality assessment in Buguma Creek is vital for detecting environmental stress early.

A mere comparison of water quality with the recommended guideline values is insufficient when assessing brackish water systems. Estuarine and brackish water ecosystems are complex environments in which many interacting parameters affect ecosystem processes. Hence, an increase in BOD levels can cause oxygen depletion, and nutrient enrichment can increase eutrophication risk and affect aquatic productivity (Painting *et al*., 2007; Maddah, 2022; Devlin and Brodie, 2023). Therefore, integrating physicochemical parameters, correlation analysis, and water quality indices can provide a better understanding of pollution intensity, contamination sources, and potential ecological risks (Sunday and Everard, 2021; Zhang *et al*., 2022).

In sum, the main goal of this study is to evaluate the spatial and temporal variation of physicochemical parameters and nutrients in Buguma Creek and to identify their ecological implications under anthropogenic pressures. Specific objectives of the study are: (i) determination of physicochemical and nutrient parameters' levels in Buguma Creek; (ii) identification of spatial and temporal variability in water quality; (iii) determination of correlations among physicochemical parameters; (iv) classification of pollution status based on pollution indices; and (v) interpretation of the observed water quality conditions' possible ecological implications.

MATERIALS AND METHODS

Study area

The study area is located in Buguma Creek, Asari Toru Local Government Area of Rivers State (Fig 1). Consisting of the main creek channel and related inter-connecting creeks, which surround Buguma and Ido communities. The study was carried out in the Buguma main creek. The study area location is within the coordinates: longitude 6°51” to 6°52” E and latitude 4°43” to 4°44” N, with an altitude of 10.9m to 2.5m.

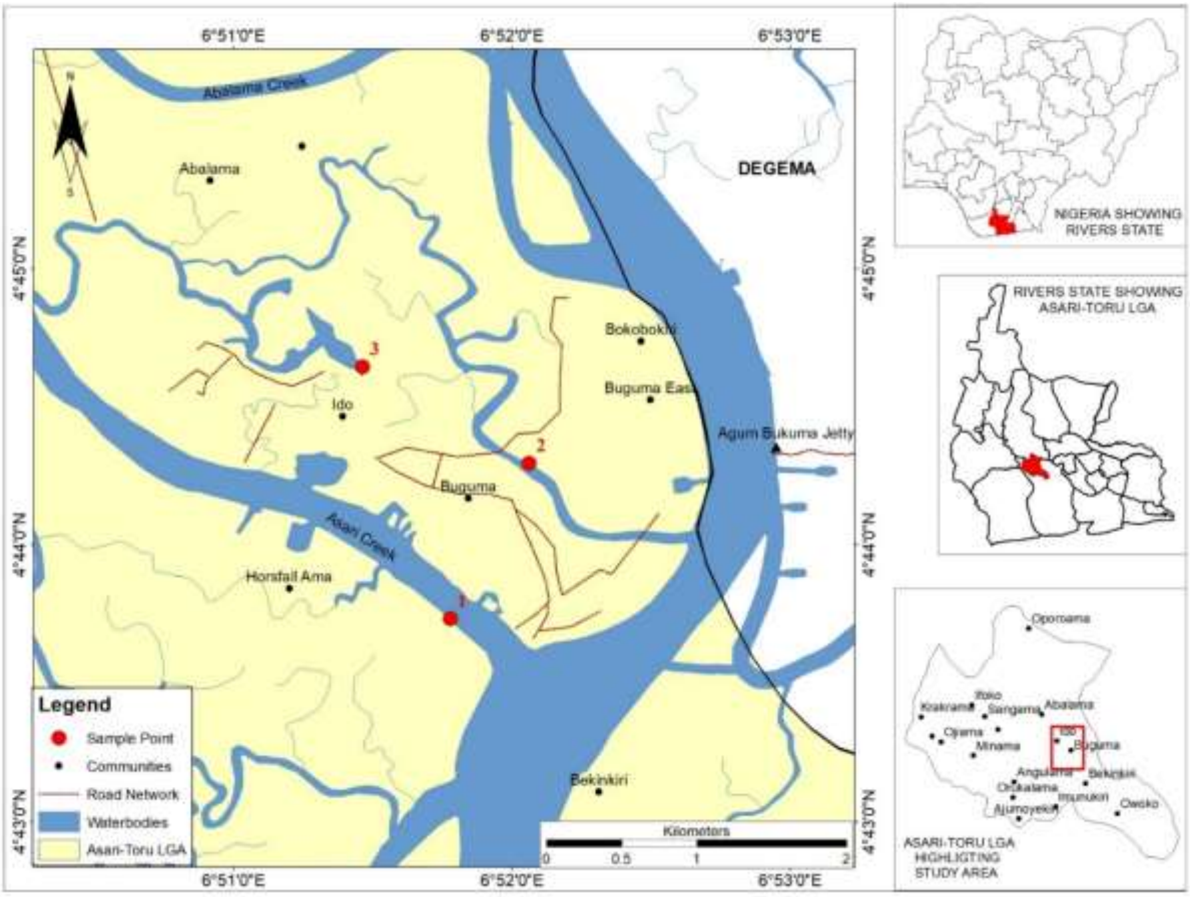

Figure 1: Map of Buguma Creek in the Niger Delta showing the different sampling stations

Sampling Stations

Three sampling stations were selected from the study area at 500m apart. The sampling stations are: NNPC float filling station along Asari creek (Station 1; 4°74" N and 6°88" E), Marywood Bridge along Amayanabo Okolo (Station 2; 4°74" N and 6°87" E) and NIOMR/Buguma brackish water fish farm along Ido canal (Station 3; 4°75" N and 6°86" E).

Sampling Collection and Analysis

Water samples for physico-chemical analysis were collected monthly for six months (April – September 2023) from the three sampling stations. Physico-chemical parameters such as temperature (°C), Salinity (ppt), and pH were measured *in situ*. For temperature and pH, the thermometer or pH meter was dipped into the water and allowed to stay for 3 minutes before the readings were recorded. Temperature was measured with a mercury-in-glass thermometer, while pH was determined with a pH meter (Model HI 9812, Hannah Products, Portugal). Salinity was measured using a hand-held Refractometer (Model RE 6783, Atago Products, Portugal). Water samples were collected in amber bottles for dissolved oxygen (DO, mg/L) and biochemical oxygen demand (BOD, mg/L). At the same time, plastic containers were used to collect water samples for nutrient analysis (mg/L: nitrate, sulphate, and phosphate), which were determined using the standard methods recommended by APHA (2012).

Water quality indices

WQI transforms the measured data into a single value which represents the overall water quality of the particular water body. In the present study, thirteen (13) parameters (EC, temperature, Ph, DO, salinity, TDS, TSS, turbidity, BOD, COD, and sulphate, phosphate, and nitrate) and appropriate standards chosen for the analysis using three water quality indices viz: Single Factor Index (SFI), NEMEROW Pollution Index (NPI), and Water Pollution Index (WPI).

Single Factor Index

The single-factor index method was applied to assess the pollution degree of individual environmental parameters and evaluate whether each parameter exceeded the standard or permissible limits in surface water (Yan *et al*., 2016). This method highlighted the parameters contributing the most to the pollution at each station. The Single Factor index was calculated with the equation:

$$Pi = \frac{Ci}{Si}$$

Where:

Pi is the pollution index for a single parameter; Ci represents the measured average concentration of the parameter; Si is the standard or permissible limit of the value of the parameter. The results from the Single Factor Index are interpreted as $Pi \leq 1$ when the parameter is within permissible limits and $Pi > 1$ when it exceeds the permissible limit, indicating its contribution to pollution.

NEMEROW Pollution Index

The Nemerow Pollution Index was used to assess the combined effects of all the parameters on the surface water quality, considering both the worst-case scenario (maximum individual pollution index, Pmax) and the average pollution condition (Pmean). NPI was calculated with the equation:

$$P_N = \sqrt{\frac{Pi^2 \max + Pi^2 mean}{2}}$$

Where;

PN is the Nemerow pollution index; Pi mean is the arithmetic mean of the pollution index of all the pollutants (average pollution level), and Pi (max) is the maximum pollution index among the pollutants, based on the single pollution index at each station. The results of the NPI are interpreted in terms of pollution degree as PN <1 insignificant pollution (clean); 1≤ PN < 2.5 slightly polluted (low); 2.5 ≤ PN < 7 moderate and PN > 7 heavy (Zhu *et al*., 2017; Li *et al*., 2020).

Water Pollution Index, WPI

The water pollution index was used to assess water pollution by averaging the ratios of measured values to their permissible limits and normalising them by the number of analyses. This method was developed to protect aquatic life and assess water quality by applying guidelines. It was calculated using the mathematical formula described by Lyulko *et al*. (2001) and Ujjania and Dubey (2015).

$$WPI = \sum \left(\frac{Ci}{SFQS}\right) \times \left(\frac{1}{n}\right)$$

Where;

Ci is the measured value of the parameter; SFQS is the Standard for the parameter; and n is the number of analyses. The water quality will be classified into six classes based on the WPI value obtained.: I (very impure: <0.3); II (Pure: 0.3-1.0); III (Moderately polluted: 1.0-2.0); IV (Polluted: 2.0-4.0); V (Impure: 4.0-6.0) and V (Heavily polluted: > 6.0).

Statistical Analysis

Data from water physicochemical analysis were subjected to the Tukey post hoc test at the 95% confidence level to identify which means differed significantly from one another. The product-moment correlation coefficient was calculated to obtain the relationship between the physicochemical variables. Statistics for water parameters were done using Minitab 16 statistical software.

Results

Temporal variation in physicochemical parameters

The monthly variations in physicochemical parameters and nutrients in Buguma Creek are presented in Table 3.1. Most parameters showed limited temporal variability over the six-month sampling period, although some parameters exhibited significant seasonal fluctuations ($p < 0.05$). Temperature varied significantly across months, with the highest mean value recorded in May (30.76 ± 0.29 °C) and the lowest in September (26.00 ± 1.00 °C). Similarly, dissolved oxygen (DO) showed significant variation, ranging from 3.20 ± 0.53 mg/L in August to 6.45 ± 1.15 mg/L in May.

Salinity decreased from April (16.67 ± 2.08 ppt) and May (19.26 ± 0.65 ppt) to September (6.53 ± 1.00 ppt), indicating a seasonal freshwater influence. In contrast, parameters such as electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulphate, phosphate and nitrate did not show statistically significant temporal differences ($p > 0.05$), although moderate fluctuations were observed. Overall, temporal variability was more pronounced for physical parameters (temperature, salinity, and dissolved oxygen) than for nutrient concentrations.

Table 0.1: Monthly variation of the physicochemical parameters and nutrients in surface water at the three sampling stations along Buguma creek during a six-month (April-Sept.2023) sampling period.

PARAMETERS/ NUTRIENTS	**MONTHS**					
	April	**May**	**June**	**July**	**Aug**	**Sept**
EC (µS/cm)	1559.33 ± 341.61**a**	1553.00 ± 342.43**a**	1532.67 ± 333.20**a**	1446.67 ± 253.62**a**	1538.33 ± 323.32**a**	1391.67 ± 292.63**a**
Temp (ºC)	28.00 ± 1.00**bc**	30.76 ± 0.29**a**	27.00 ± 1.00**bc**	26.67 ± 0.58**bc**	28.50 ± 0.50**b**	26.00 ± 1.00**c**
pH	6.83 ± 0.29**a**	6.60 ± 0.30**a**	7.00 ± 0.00**a**	7.00 ± 0.00**a**	6.83 ± 0.29**a**	7.00 ± 0.00**a**
DO (mg/L)	3.88 ± 0.67**bc**	6.45 ± 1.15**a**	3.80 ± 0.20**bc**	3.40 ± 0.35**bc**	3.20 ± 0.53**c**	5.03 ± 0.67**ab**
Salinity (ppt)	16.67 ± 2.08**a**	19.26 ± 0.65**a**	13.33 ± 0.58**b**	7.67 ± 0.58**c**	8.37 ± 0.49**c**	6.53 ± 1.00**c**
TDS (mg/L)	867.33 ± 18.90**a**	834.33 ± 62.17**a**	783.00 ± 137.74**a**	711.00 ± 162.35**a**	822.67 ± 118.87**a**	692.27 ± 140.29**a**
TSS (mg/L)	34.67 ± 9.45**a**	33.33 ± 10.79**a**	30.00 ± 9.64**a**	31.33 ± 9.07**a**	34.00 ± 7.94**a**	27.35 ± 5.69**a**
Turb (NTU)	3.00 ± 1.00**a**	4.10 ± 2.29**a**	3.37 ± 1.36**a**	3.77 ± 1.32**a**	3.50 ± 1.28**a**	5.70 ± 1.40**a**
BOD (mg/L)	3.43 ± 1.07**a**	4.73 ± 0.33**a**	3.30 ± 1.11**a**	4.43 ± 2.95**a**	5.03 ± 2.28**a**	3.97 ± 1.75**a**
COD (mg/L)	7.50 ± 3.70**a**	7.27 ± 3.48**a**	7.33 ± 3.66**a**	7.13 ± 3.56**a**	7.65 ± 3.29**a**	5.95 ± 2.62**a**
SO_4^{2-} (mg/L)	113.33 ± 35.12**a**	145.60 ± 8.75**a**	115.67 ± 31.50**a**	106.17 ± 26.99**a**	117.10 ± 30.36**a**	103.53 ± 28.02**a**
PO_4 (mg/L)	6.00 ± 2.00**a**	5.73 ± 2.19**a**	5.93 ± 2.05**a**	5.53 ± 2.13**a**	5.75 ± 1.85**a**	4.94 ± 1.15**a**
NO_3 (mg/L)	3.83 ± 1.26**a**	3.77 ± 1.11**a**	3.60 ± 1.05**a**	3.72 ± 096**a**	3.71 ± 1.03**a**	3.63 ± 1.02**a**

Data represent mean ±SD for n =3 per parameter. Different letters within rows indicate statistically significant differences ($p < 0.05$).

Spatial variation in physicochemical parameters

Spatial variation in water quality parameters across the three sampling stations is presented in Table 3.2. Significant differences ($p < 0.05$) were observed for several parameters, indicating spatial heterogeneity in water quality.

Electrical conductivity (EC) was significantly higher at Station 1 (1674.17 ± 90.72 µS/cm) and Station 2 (1695.83 ± 81.18 µS/cm) compared to Station 3 (1140.83 ± 42.56 µS/cm). A similar pattern was observed for TDS and TSS, with Station 2 recording the highest mean values (855.75 ± 48.51 mg/L and 38.83 ± 3.60 mg/L, respectively), while Station 3 consistently recorded the lowest values.

BOD and COD also showed significant spatial variation, with the highest values recorded at Station 2 (5.84 ± 1.35 mg/L and 10.82 ± 0.98 mg/L, respectively), followed by Station 1, and the lowest values at Station 3. Nutrient concentrations (sulphate, phosphate and nitrate) were similarly highest at Station 2 and lowest at Station 3.

In contrast, temperature, pH, DO and salinity did not show significant spatial variation ($p > 0.05$), indicating relatively uniform distribution of these parameters across the sampling stations.

Table 0.2: Spatial variation of the physicochemical parameter and nutrient in the surface water at the three sampling stations along Buguma creek during a six-month (April-Sept.2023) sampling period.

Parameters/Nutrients	**Stations**		
	1	**2**	**3**
EC (µS/cm)	1674.17±90.72**a**	1695.83±81.18**a**	1140.83±42.56**b**
Temp (°C)	27.85±1.76**a**	27.67±1.85**a**	27.94±1.89**a**
pH	6.90±0.20**a**	6.80±0.32**a**	6.93±0.16**a**
DO (mg/L)	3.93±1.00**a**	4.14±1.51**a**	4.80±1.37**a**
Salinity (ppt)	12.17±6.33**a**	11.98±5.00**a**	11.76±4.51**a**
TDS (mg/L)	836.97±45.68**a**	855.75±48.51**a**	662.58±128.46**b**
TSS (mg/L)	35.67±3.44**a**	38.83±3.60**a**	22.33±1.75**b**
Turb (NTU)	5.20±1.11**a**	3.97±1.18**ab**	2.55±1.12**b**
BOD (mg/L)	3.89±0.69**b**	5.84±1.35**a**	2.73±1.02**b**
COD (mg/L)	6.44±0.61**b**	10.82±0.98**a**	4.16±0.35**c**
SO_4^{2-} (mg/L)	114.93±16.74**b**	144.55±8.34**a**	91.22±22.60**b**
PO_4 (mg/L)	5.44±0.45**b**	7.62±0.75**a**	3.86±0.23**c**
NO_3 (mg/L)	3.75±0.17**b**	4.76±0.14**a**	2.63±0.12**c**

Data represent mean ±SD for n =3 per parameter. Different letters within rows indicate statistically significant differences (p < 0.05).

Correlation among physicochemical parameters

The Pearson correlation matrix for physicochemical parameters is presented in Table 3.3. Several significant relationships ($p < 0.05$) were observed among the measured variables.

Electrical conductivity (EC) showed strong positive correlations with TDS ($r = 0.824$), TSS ($r = 0.970$), BOD ($r = 0.589$) and COD ($r = 0.782$). TSS was also strongly correlated with COD ($r = 0.863$) and BOD ($r = 0.637$), indicating associations between suspended particles and organic load. Additionally, TDS was positively correlated with COD ($r = 0.668$).

Salinity showed a strong positive correlation with temperature ($r = 0.669$), while turbidity was moderately correlated with EC ($r = 0.506$). Negative correlations were observed between pH and several parameters, including temperature and DO, although these relationships were not statistically significant in most cases.

Overall, the correlation analysis indicates that organic load, suspended solids and dissolved ions are closely interrelated in the study area.

Table 0.3: Correlation (r) of physicochemical parameters in water.

	EC	**Temp**	**pH**	**DO**	**Sal**	**TDS**	**TSS**	**Tur**	**BOD**	**COD**
Temp	0.100 0.692									
pH	-0.291 0.241	-0.527 0.025								
DO	-0.285 0.253	0.493 0.038	-0.425 0.079							
Sal	0.217 0.388	0.669 0.002	-0.437 0.070	0.437 0.070						
TDS	0.824 0.000	0.397 0.103	-0.330 0.182	-0.141 0.576	0.411 0.090					
TSS	0.970 0.000	0.165 0.513	-0.306 0.218	-0.318 0.198	0.236 0.346	0.828 0.000				
Tur	0.506 0.032	-0.158 0.532	-0.086 0.734	0.116 0.647	-0.238 0.342	0.198 0.43	0.389 0.111			
BOD	0.589 0.010	0.151 0.550	-0.206 0.413	-0.103 0.683	-0.077 0.762	0.602 0.008	0.637 0.004	0.16 0.527		
COD	0.782 0.000	0.054 0.831	-0.309 0.213	-0.231 0.357	0.107 0.673	0.668 0.002	0.863 0.000	0.167 0.509	0.781 0.000	

The level of significance is at 0.05

Comparison with permissible limits

The mean values of physicochemical parameters across the sampling stations and their corresponding permissible limits are presented in Table 3.4. Most parameters were within the selected guideline limits; however, some parameters exceeded permissible thresholds at specific stations.

BOD exceeded the NESREA limit of 3 mg/L at Stations 1 and 2, while sulphate exceeded the guideline value of 100 mg/L at Stations 1 and 2. Phosphate concentrations exceeded the permissible limit of 3.5 mg/L at all stations. In contrast, nitrate, COD, TDS, TSS and turbidity were within acceptable limits across all stations.

Table 0.4: Mean values of the water parameters/nutrients in the sampling stations in Buguma Creek, with their respective permissible limits

Parameters/ Nutrients	STATIONS				
	Station 1	Station 2	Station 3	Permissible Limit (P.L)	Reference for P. L
EC	1674.17	1695.83	1140.83	54000	EPA
Temp.	27.85	27.67	27.94	30	Moore, 1991
pH	6.9	6.8	6.93	8.5	NESREA
DO	3.93	4.14	4.8	9.91	EU
Salinity	12.17	11.98	11.76	38	EPA
TDS	836.97	855.75	662.58	2000	Scannell and Jacobs, 2001
TSS	35.67	38.83	22.33	40	WHO, 2006
Turbidity	5.2	3.97	2.55	18	EPA
BOD	3.89	5.84	2.73	3	NESREA
COD	6.44	10.82	4.16	30	NESREA
Sulphate	114.93	144.55	91.22	100	NESREA
Phosphate	5.44	7.62	3.86	3.5	NESREA
Nitrate	3.75	4.76	2.63	9.1	NESREA

EPA: *Environmental water guidelines for Victorian Riverine Estuaries (EPA Victoria, 2011)*

EU: *European Union Estuary and Harbour Basin Water Standard Guidelines (Sciortino and Ravikumar, 1999).*

NESREA: *National Environmental Standards and Regulations Enforcement Agency, Fisheries and Recreation Criteria Standard for Surface Water (NESREA, 2011).*

Water quality indices

The results of the Single Factor Index (SFI) are presented in Table 3.5. Phosphate exceeded the threshold value (Pi > 1) at all stations, indicating its contribution to water quality degradation. BOD and sulphate also exceeded permissible limits at Stations 1 and 2, while other parameters remained within acceptable limits.

The Nemerow Pollution Index (NPI) and Water Pollution Index (WPI) are presented in Table 3.6. The NPI classified Station 1 (1.19) and Station 2 (1.65) as slightly polluted, while Station 3 (0.86) was classified as insignificantly polluted. In contrast, the WPI classified all stations as Class II (pure), with values ranging from 0.53 to 0.81.

Table 0.5: Single factor index, SFI values of the sampling stations in Buguma Creek

Parameters/Nutrients	STATIONS		
	Station 1	Station 2	Station 3
EC	0.03	0.03	0.02
Temp.	0.93	0.92	0.93
pH	0.81	0.80	0.82
DO	0.40	0.42	0.48
Salinity	0.32	0.32	0.31
TDS	0.42	0.43	0.33
TSS	0.89	0.97	0.56
Turbidity	0.29	0.22	0.14
BOD	1.30	1.95	0.91
COD	0.21	0.36	0.14
Sulphate	1.15	1.45	0.91
Phosphate	1.55	2.18	1.10
Nitrate	0.41	0.52	0.29

Pi ≤ 1 when the parameter is within permissible limits, and Pi > 1 when the parameter exceeds the permissible limit, indicating its contribution to the pollution.

Table 0.6: Water pollution index (WPI) of the three sampling stations in Buguma Creek

Classification	**Station 1**	**Station 2**	**Station 3**
NPI Classification	1.19 Slightly polluted (low)	1.65 Slightly polluted (low)	0.86 Insignificantly polluted (clean)
WPI Classification	0.67 II (pure)	0.81 II (pure)	0.53 II (pure)

NPI classification: *PN <1 insignificant pollution (clean); 1≤ PN < 2.5 slightly polluted (low); 2.5 ≤ PN < 7 moderate and PN > 7 heavy.*

WPI Classification*: I (very impure: <0.3); II (Pure: 0.3-1.0); III (Moderately polluted: 1.0-2.0); IV (Polluted: 2.0-4.0); V (Impure: 4.0-6.0) and V (Heavily polluted: > 6.0).*

DISCUSSION

Spatial and temporal variation in water quality

The findings indicate that Buguma Creek forms a brackish estuarine system influenced by seasonality, tidal exchange, and anthropogenic pollution. There was temporal variation in parameters such as temperature, dissolved oxygen (DO), and salinity, while many others showed limited monthly variation (Table 3.1). Salinity dropped from 16.67 ppt in April and 19.26 ppt in May to 6.53 ppt in September due to gradual freshwater dilution during the wet season (Table 3.1). This is consistent with tropical estuarine systems, where precipitation, surface runoff, and freshwater inflow reduce salinity (Pérez-Ruzafa *et al*., 2011; Ezekiel *et al*., 2011; Keremah *et al*., 2014).

The highest mean temperature (30.76 °C) was recorded in May, while the lowest mean temperature (26.00 °C) was observed in September (Table 3.1). Seasonal temperature variation is ecologically significant because it controls metabolic activity, microbial decomposition, and oxygen solubility in aquatic environments. An increase in temperature can lower oxygen solubility and raise the biological oxygen demand (BOD), ultimately leading to oxygen stress in the presence of enriched organic matter (Rabalais *et al*., 2009; Kaizer and Osakwe, 2010). Moreover, Rabalais *et al*. (2009) noted that elevated temperature, enhanced stratification, and increased nutrient inputs can contribute to eutrophication and hypoxic conditions in coastal systems.

More pronounced spatial variation occurred for several pollution-sensitive parameters than for temporal ones. Station 2 had the highest mean values for EC, TDS, TSS, BOD, COD, sulfate, phosphate, and nitrate (Table 3.2). For example, BOD was highest at Station 2 (5.84 mg/L), followed by Station 1 (3.89 mg/L), and Station 3 had the lowest value (2.73 mg/L) (Table 3.2). Similarly, phosphate was highest at Station 2 (7.62 mg/L), followed by Station 1 (5.44 mg/L) and Station 3 (3.86 mg/L) (Table 3.2). This suggests that water quality in Buguma Creek is degrading, but not uniformly so. Rather, it is localised and is associated with anthropogenically affected zones.

The pH values ranged from 6.60 to 7.00 monthly (Table 3.1) and from 6.80 to 6.93 spatially (Table 3.2), showing conditions from slight acidity to near neutrality. These values are below the selected guideline value of 8.5 (Table 3.4) and similar to those found in the Bonny Estuary according to Otene (2014). This indicates that Buguma Creek is currently in relative stability with respect to acid–base balance. However, pH value alone cannot represent the ecologically safe state of water, since other water quality parameters, such as BOD, phosphate, and DO, demonstrate otherwise.

EC varied from 1391.67 to 1559.33 µS/cm monthly (Table 3.1) and from 1140.83 to 1695.83 µS/cm spatially (Table 3.2). Such values confirm the brackish water of Buguma Creek in accordance with Egborge (1994) classifications, since waters with EC between 1000 and 40,000 µS/cm are considered brackish. EC values correlate positively with TDS ($r = 0.824$, $p < 0.05$) and TSS ($r = 0.970$, $p < 0.05$) (Table 3.3), indicating that both parameters originate from similar sources, such as tidal exchange, surface runoff, sediment disturbance, and anthropogenic waste.

Organic enrichment and oxygen dynamics

DO plays an essential role in aquatic ecosystems by affecting fish respiration, aerobic decomposition, and benthic community composition (Bulbul Ali and Mishra, 2022; Singh *et al*., 2025). The DO content varies considerably over time, from 6.45 mg/L in May to 3.20 mg/L in August (Table 3.1). DO also differs spatially, being lowest at Station 1 (3.93 mg/L) and Station 2 (4.14 mg/L) and highest at Station 3 (4.80 mg/L) (Table 3.2). Despite having the highest spatial mean DO values, the water at all three stations still fails to reach the EU guideline value of 9.91 mg/L (Table 3.4).

Relatively low DO levels have ecological importance because they affect fish respiratory rates, growth rates, feeding behaviours, and mortality. Diaz and Rosenberg (2008) found that oxygen depletion in coastal areas is ecologically significant for the overall functioning of ecosystems, benthic organisms, and fisheries productivity. Thus, oxygen depletion in Buguma Creek is not high enough to cause anoxia but does indicate oxygen stress, especially when combined with elevated BOD and phosphate levels. BOD values vary monthly (3.30–5.03 mg/L) and are highest at Station 2 (5.84 mg/L) (Table 3.2). At both Stations 1 and 2, BOD exceeds the NESREA permissible value of 3 mg/L (Table 3.4). The Single Factor Index shows BOD as a factor contributing to pollution at Station 1 (1.30) and Station 2 (1.95), with Station 3 below this threshold (0.91) (Table 3.5). This provides proof of organic enrichment, especially at Station 2.

This finding is supported by correlation results showing positive relationships between BOD and EC ($r = 0.589$), TDS ($r = 0.602$), and TSS ($r = 0.637$), all statistically significant ($p < 0.05$) (Table 3.3). Although the correlation between BOD and DO is weak and negative ($r = -0.103$) (Table 3.3), this relationship is ecologically important because it suggests that microbial decomposition of organic matter consumes oxygen. Organic enrichment is a well-known cause of oxygen depletion, especially in coastal areas receiving domestic waste and other biodegradable pollutants (Gray *et al*., 2002; Rabalais *et al*., 2009).

COD values support this hypothesis, as Station 2 is again the highest with 10.82 mg/L. Station 1 has 6.44 mg/L COD and Station 3 has 4.16 mg/L (Table 3.2). COD values are below the NESREA maximum of 30 mg/L (Table 3.4), yet their spatial pattern coincides with that of BOD. This means that Station 2 has higher concentrations of oxidizable substances, supporting the conclusion above.

Nutrient enrichment and eutrophication potential

Phosphate appears to be a major concern for the aquatic ecology of Buguma Creek. Phosphate concentration remains high throughout the year, ranging from 4.94 mg/L in September to 6.00 mg/L in April (Table 3.1). Similarly, phosphate is highest at Station 2 (7.62 mg/L), then comes Station 1 (5.44 mg/L), and Station 3 (3.86 mg/L) (Table 3.2). None of the three stations meets the NESREA permissible value of 3.5 mg/L (Table 3.4). The Single Factor Index indicates that phosphate is the dominant pollution parameter at Stations 1 (1.55), 2 (2.18), and 3 (1.10) (Table 3.5). Such high phosphate concentrations pose a problem because phosphates stimulate algae growth and increase organic matter, thus potentially contributing to eutrophication (Smith *et al*., 1999; Smith *et al.,* 2017; Tiwari *et al*., 2022; Devlin and Brodie, 2023).

Combined presence of high phosphate, high BOD, and low DO implies the risk of early-stage eutrophication, especially at Station 2. As Rabalais *et al*. (2009) note, nutrient enrichment can contribute to primary production, organic matter accumulation, and hypoxic conditions. Therefore, phosphate enrichment in Buguma Creek should be taken seriously, as it poses a real ecological threat. Nitrate concentration varies within acceptable limits, up to the permissible 9.1 mg/L guideline (Table 3.4). Nitrate levels range from 3.60 mg/L to 3.83 mg/L monthly (Table 3.1) and are highest at Station 2 (4.76 mg/L), while at Station 3 they remain lowest (2.63 mg/L) (Table 3.2). Although nitrate concentration does not exceed any guideline values, its highest level at Station 2 again supports the hypothesis that Station 2 has higher land-based pollution input. Potential sources of nitrogenous substances include freshwater inflows, decomposition of organic matter, sewage disposal, and season-related catchment processes (Govindasamy *et al*., 2000; Sutti *et al*., 2022).

Sulfate level ranges from 103.53 mg/L to 145.60 mg/L monthly (Table 3.1) and is highest at Station 2 (144.55 mg/L) (Table 3.2). Sulfate concentrations are higher than the permissible NESREA level (100 mg/L) in both Stations 1 (114.93 mg/L) and 2 (144.55 mg/L), according to the Single Factor Index (1.15 at Station 1 and 1.45 at Station 2) (Table 3.5). Even though sulfate at this level is unlikely to cause acute toxic effects, its presence, along with high BOD, COD, phosphate, and nitrate levels, provides strong evidence of chemical pollution at Station 2.

Suspended solids, turbidity, and ecosystem functioning

Levels of total suspended solids (TSS) and turbidity can provide information on particulate loading and sediment disturbance (Nguyen and Giao, 2025). The monthly TSS averages ranged from 27.35 to 34.67 mg/L, with no significant differences across months (Table 3.1). The spatial averages of TSS showed the highest values at Station 2 (38.83 mg/L) and Station 1 (35.67 mg/L), and the lowest at Station 3 (22.33 mg/L) (Table 3.2). These values were below the WHO guideline value of 40 mg/L (Table 3.4), although Station 2 was close to the limit. The turbidity varied between 3.00 and 5.70 NTU across months (Table 3.1) and between 2.55 and 5.20 NTU across stations (Table 3.2). Station 1 had the highest turbidity, indicating some localised input of suspended material (runoff, re-suspended sediment, vessel activity, debris, or bank disturbances). These values did not exceed the EPA guideline level of 18 NTU (Table 3.4), and the turbidity SFI was below 1 at all stations (Table 3.5).

Although turbidity and TSS fell within selected permissible limits, their ecological importance should be mentioned. Excessive suspended solids can reduce light penetration, limit photosynthesis, interfere with fish predation, and damage the bottom environment. Bilotta and Brazier (2008) highlighted the critical role of suspended materials in contributing to the overall pollution load and negatively affecting fisheries. As can be seen from Table 3.3, there were significant positive correlations between TSS and EC (r = 0.970), TDS (r = 0.828), BOD (r = 0.637), and COD (r = 0.863) in Buguma Creek. It suggests that TSS can carry pollutants or indicate convergent pollution sources such as runoff and discharge.

Pollution sources and spatial influence

The spatial variations in the results clearly show that Station 2 is the most polluted site in Buguma Creek. Station 2 had the highest values of EC, TDS, TSS, BOD, COD, sulfate, phosphate, and nitrate (Table 3.2). There was probably one main source of pollution or several convergent pollution sources in Station 2. Sources of pollution in this area may include domestic sewage, household sewage, refuse, runoff from the bridge, discharges from settlements, and runoff from the catchment area. High BOD and COD levels indicated the presence of oxidizable material, whereas elevated phosphate and nitrate levels suggested nutrient enrichment. The elevated TDS and EC values indicated increased ionic loading, and elevated TSS indicated particulate pollution (Table 3.2). Thus, the above parameters formed the pollution profile of Station 2.

Station 1 had relatively high turbidity, BOD, sulfate, and phosphate concentrations (Tables 3.2 and 3.4). Sources of pollution in this area might include surface runoff, fuel handling operations, local sewage disposal, or sediment disturbance. Station 3 recorded the lowest values of EC, TDS, TSS, turbidity, BOD, COD, sulfate, phosphate, and nitrate (Table 3.2). It means that this area had either a low anthropogenic impact or sufficient dilution. The correlation matrix supported the conclusions drawn from spatial differences in pollution characteristics (Table 3.3). Specifically, EC was significantly correlated with TSS, TDS, BOD, and COD, and COD correlated with TSS and BOD (Table 3.3). These findings indicated that ions, suspended particles, and organic matter had a common pollution source. In an estuarine setting, these associations often reflect local pollution sources, runoff, and particulate pollution (Kennish, 2003).

Integrated interpretation of water quality indices

Water quality indices provide an integrated approach to assessing the creek's pollution status. According to the SFI, phosphate exceeded permissible limits at all stations, whereas BOD exceeded the limits only at Stations 1 and 2, and sulfate exceeded them at Stations 1 and 2 (Table 3.5). Thus, the most critical water-quality problem was organic and nutrient enrichment, rather than overall physicochemical instability. Based on the SFI, the Nemerow Pollution Index classified Station 1 as slightly polluted (value of 1.19) and Station 2 as slightly polluted (value of 1.65), whereas Station 3 was insignificantly polluted or clean (value of 0.86) (Table 3.6). As can be seen, this classification coincided with that derived from Table 3.2.

According to the WPI, all stations belonged to the Class II described as "pure" (values of 0.67, 0.81, and 0.53 at Stations 1, 2, and 3, respectively) (Table 3.6). Nevertheless, this study would like to draw attention to potential limitations in using this index to evaluate water quality in Buguma Creek. Specifically, the WPI considers multiple factors (as most measured parameters fell within permissible limits); hence, it underestimates the ecological importance of phosphate, BOD, and sulfate, which exceeded permitted levels. Therefore, the condition of the water in the studied creek may not be described as "unpolluted." Overall, water quality was acceptable in Buguma Creek; however, localised organic enrichment and nutrient enrichment existed.

Ecological implications

The major ecological concern regarding Buguma Creek is the interaction among elevated BOD, phosphate enrichment, and relatively low oxygen concentrations. These parameters are directly related to one another: increased BOD can enhance microbial oxygen demand, phosphate enrichment can stimulate algal production, and decomposition of organic and algal biomass consumes additional oxygen. This chain of events is well-known as a cause of oxygen reduction driven by eutrophication (Smith *et al*., 1999; Rabalais *et al*., 2009).

The results of the research showed that the lowest DO occurred in August (3.20 mg/L; Table 3.1), and BOD values were elevated throughout the study (e.g., 5.03 mg/L in August; Table 3.1). Spatially, the highest BOD, COD, phosphate, sulfate, and nitrate concentrations were observed at Station 2, indicating its ecological importance (Table 3.2). The findings of the SFI and NPI confirmed the interpretation, as phosphate, BOD, and sulfate were identified as key stressors, and Station 2 was classified as slightly polluted (Tables 3.5 and 3.6).

From a fisheries standpoint, oxygen stress can have detrimental impacts on their survival. Sensitive species tend to avoid the stressed area, while tolerant species prevail; however, oxygen depletion reduces habitat quality. Breitburg *et al*. (2018) found that oxygen depletion has adverse consequences for coastal ecosystems, reducing their functioning and integrity. Hence, although Buguma Creek is not polluted now, it gives signs of ecological stress.

Overall, Buguma Creek still remains ecologically functional but vulnerable to anthropogenic pressures. According to the WPI, water quality was quite acceptable; however, BOD, phosphate, and sulfate exceeded the limits (Table 3.6). Furthermore, the SFI findings indicated ongoing organic and nutrient enrichment (Tables 3.4 and 3.5). Without management efforts to address domestic waste, nutrients, and runoff, especially in Station 2, Buguma Creek might face serious problems in the future.

CONCLUSION AND RECOMMENDATION

Conclusion

This study examined the spatial and temporal dynamics of the physicochemical parameters and nutrients in Buguma Creek and assessed their ecological implications. According to the research findings, Buguma Creek is a brackish estuarine creek affected by seasonal hydrology, tidal mixing, and anthropogenic activities.

In terms of temporal dynamics, the largest variations occurred in salinity, temperature, and dissolved oxygen, which fluctuated with the seasons. Salinity was gradually decreasing from April to September, indicating increased freshwater dilution during the wet season. Similarly, DO decreased during the same period, having the lowest mean value in August. The highest levels of most investigated variables were observed at Station 2 (Table 3.2).

All measured physicochemical parameters fell within selected permissible limits except BOD, phosphate, and sulfate (Tables 3.1 and 3.4). According to the SFI, phosphate was the most influential pollution-contributing variable across the three stations, whereas BOD and sulfate played this role only at Stations 1 and 2. The Nemerow Pollution Index classified Stations 1 and 2 as slightly polluted, whereas Station 3 was described as clean (Table 3.6). On the other hand, the Water Pollution Index classified all stations as belonging to Class II ("pure"; values of 0.67, 0.81, and 0.53 at Stations 1, 2, and 3, respectively; Table 3.6).

In terms of ecology, the main concern of this study involves the relationships among increased BOD, phosphate enrichment, and low oxygen. Such factors may increase oxygen consumption, stimulate eutrophication, and reduce habitat quality. Overall, Buguma Creek can support fisheries and aquatic life; however, the current situation is not entirely harmless to these organisms.

Recommendations

Continuous monitoring of water quality in Buguma Creek is highly recommended, especially in areas near the most polluted locations, including Station 2, settlements, bridge runoff, fuel-handling sites, and discharge points. During future monitoring, the following parameters should receive the closest attention: dissolved oxygen, BOD, COD, phosphate, nitrate, sulfate, TSS, and turbidity.

The control over the domestic waste and fecal discharges into the creek should be implemented. Specifically, as phosphate and BOD were identified as major pollution indicators, detergent-rich wastewater and organic waste should be eliminated.

Biological indicators (fish, plankton, and benthic macroinvertebrates) should be included in the future monitoring program, as physicochemical indicators are unable to reveal actual effects on aquatic communities and fisheries.

Future research should consider issues related to sediment quality and contamination by heavy metals and hydrocarbons. This is needed because particles could be contaminated, and because the Niger Delta faces various environmental problems not accounted for when using the selected set of physicochemical parameters.

Management interventions are to be conducted in Station 2, where the highest concentrations of BOD, COD, sulfate, phosphate, and nitrate are observed.
Preventive measures should be implemented to mitigate eutrophication and oxygen stress caused by ongoing pollution.

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