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Full Length Research

Impact of urbanization on mangrove wetland at Eagle Island, Rivers State, Nigeria

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ABSTRACT: Urbanization has destroyed wetlands globally, and in the Niger Delta area surge in human population has led to increased encroachment into wetlands area resulting in habitat destruction. This research aims to determine the impact of urbanization on selected wetland areas at Eagle Island, Rivers State. The study was carried out between April 2023 and January 2024. Physico-chemical parameters were assessed using standard procedures. The results of the water quality assessment show the range of temperature, dissolved oxygen, and pH to be within acceptable limits for tropical waters as recommended by WHO, while others, including total dissolved solids and electrical conductivity (µS/cm), were not within acceptable limit as stipulated by WHO. The mean concentration of heavy metals, nitrates, and phosphate in surface water was within the NUPRC permissible limits. The mean concentrations of cadmium, chromium, and lead in sediment were higher than the NUPRC permissible limits, while nickel, iron, nitrate, and phosphate were within the NUPRC permissible limits. The concentration of metals in surface water were: Cd= 0.014 µg/l, Cr = 0.219 µg/l, Ni = 0.651 µg/l, Pb = 0.160 µg/l, Fe = 1.881 µg/l, in the order of Fe>Ni>Cr>Pb>Cd. The result implies that there is a gradual deterioration of environmental quality as a result of human-mediated activities. The soil and water quality in wetland areas are facing degradation because of the unprotected intrusion of private individuals and organizations who enter to carry out the sand filling, swamp reclamation, and construction activities, leading to the loss of wetlands and river systems.

Keywords: Benthos, heavy metals, macro-invertebrates, pollution, urbanization.

INTRODUCTION

Wetlands constitute one of the most vital ecosystems in the world and are mostly considered to be knit zones between terrestrial and aquatic ecosystems (Rupp *et al*., 2010). They are often referred to as “the earth’s kidney”, due to their beneficial roles. Wetlands offer multiple ecosystem functions. Chief among them is their capability to serve as water regulators by cushioning the excesses associated with the discharge of rivers (Rupp *et al*., 2010). They also serve as water storage, flood control, purification of pollutants, and maintenance of biodiversity. They also accomplish essential retention functions in nutrient cycling and the treatment of impurities conveyed in the river system (Rupp *et al*., 2010).

The 1971 Ramsar Convention on Wetlands defined as “areas of marsh, fen peat land or water whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.”

As a result of industrial and socioeconomic enlargement and other pressures, such as land use change in wetland areas, the total area of wetlands in the world is decreasing year on year (Kundu *et al.*, 2024). Previous reports have posited that the expansion of farmland and agronomic factors contributes to 58% of wetland habitat loss (van Ael *et al*., 2012). As a result of the rapid growth in human populations, wetlands worldwide are suffering from severe degradation. (Bai *et al*., 2013). Given that the wetland ecological environment is fragile, land use changes of this nature can result in the non-reversible destruction of the various ecological functions performed by the wetland habitat (Crabbe *et al.,* 2024). Many factors can affect the surface water quality of a wetland, including both point source such as domestic and industrial wastewater discharge and non-point source pollution such as farmland runoff and atmospheric pollutant deposition (Qiu *et al*., 2018). Wetlands can improve water quality through natural processes of pollutant attenuation (USEPA, 2004), such as the removal of phosphorus and nitrogen by biological communities, degradation of hydrocarbons by wetland aquatic plants, dilution of pollutants, or accumulation of sediments in the wetland water body (Ijoma *et al*., 2024). In Nigeria, surface water pollution is majorly caused by anthropogenic activities. These may be in the form of commercial activities, laundering, sawmills and industrial activities. Other anthropogenic activities that cause water pollution and affect aquatic biota on reaching water bodies are various industries such as textile, metal, drying chemicals, fertilizers, pesticides, cement, petrochemical, energy and power, leather, sugar processing, construction, steel, engineering, food processing, mining, and others. They worsen and broaden water pollution (Numbere, 2023). Effluents are dumped into various water bodies, causing surface/groundwater pollution, endangering biodiversity, and lowering agriculture production. A study of rivers around industrial areas indicated that surface water resources are highly vulnerable to pollution as the entire stretch is heavily polluted with sewage and uncontrolled application of chemicals, so their effect on surface and groundwater is an emerging concern (Azimi *et al*., 2019; Rai *et al.,* 2019). Since many effluents are not treated properly, these products are discharged on the ground or into the water bodies (Odiete, 1999), and most of these discharges to water bodies accumulate in the system through the food chain (Odiete, 1999).

Sediment refers to a mixture of several components of minerals, species, and organic debris. Contaminated sediment can cause lethal and sub-lethal effects in benthic and sediment-associated organisms (EPA, 2005). Sediments are an integral part of the aquatic environments, providing habitat, feeding, and rearing areas for shellfish, fish, and other fauna (Odiete, 1999). It serves as a reservoir and source of contaminants in the water column. Usually, the quantity of contaminants found accumulates in sediment to elevated levels (Machado da Silva *et al*., 2024).

Anthropogenic activities negatively influence the water quality and aquatic ecosystem functions and put tremendous pressure on these ecosystems, leading to a decrease in water quality and biodiversity, loss of critical habitats, and ultimately, the quality of life of local inhabitants (Herrera-Silveira and Morales-Ojeda, 2009). Continuous water quality measurements and analyses are necessary to manage coastal water quality effectively. Typical results of human activities proved to be elevated levels of heavy metals present in freshwater, and among these microelements are lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) most specifically (Farkas *et al*., 2002). There is a conspicuous impact from anthropogenic activities in most regions globally. However, it is predominantly evident in estuaries and coastal wetlands subject to several environmental stresses, such as mining, water abstraction, altered hydrology, effluents (industrial and domestic), habitat dilapidation, and excessive harvest of resources (Butler, 2006).

Heavy metal pollution is one of the environmental challenges that has emerged due to the economic growth of many countries (Gao and Chen, 2012). They can accumulate in microorganisms, flora, and fauna of aquatic habitats and find their way into the human food chain, leading to health problems (Alhashemi*et al*., 2012).

Therefore, this research aimed to assess the impact of urbanization on selected wetland areas at Eagle Island in Rivers State, Nigeria. The specific objectives of the study were to:

1. determine the physicochemical parameters in surface water in Eagle Island, Nigeria.
2. evaluate the nutrients and heavy metal concentrations (Lead, Cadmium, Chromium, Iron, and Nickel) in surface water.
3. determine the nutrients (Phosphate and Nitrate) and heavy metals in sediments.

MATERIALS AND METHODS

Description of the study area

The study was carried out in the wetland surrounding Eagle Island, Port Harcourt, Rivers State. Eagle Island is located along latitude 04º47.210˝N and longitude 006’58.990’E within Port Harcourt (Numbere *et al*., 2024; Figure 1a). The study area is Eagle Island Creek, which is bounded by Rivers State University, Agip Oil Company by the West, and the Bonny River by the West and South. The creek is a brackish water with tidal fluxes. The vegetation cover is dominated by mangrove forest (*Rhizophora sp*, *Avicenia germinans*) and Nypa palm (*Nypa fruticans*). Three stations were selected and geo-referenced based on the activities taking place (Figure 1b). Station 1 lies between the latitude of 04º47.210˝N and the longitude of 006’58.943˝E. The station is located near an abattoir and

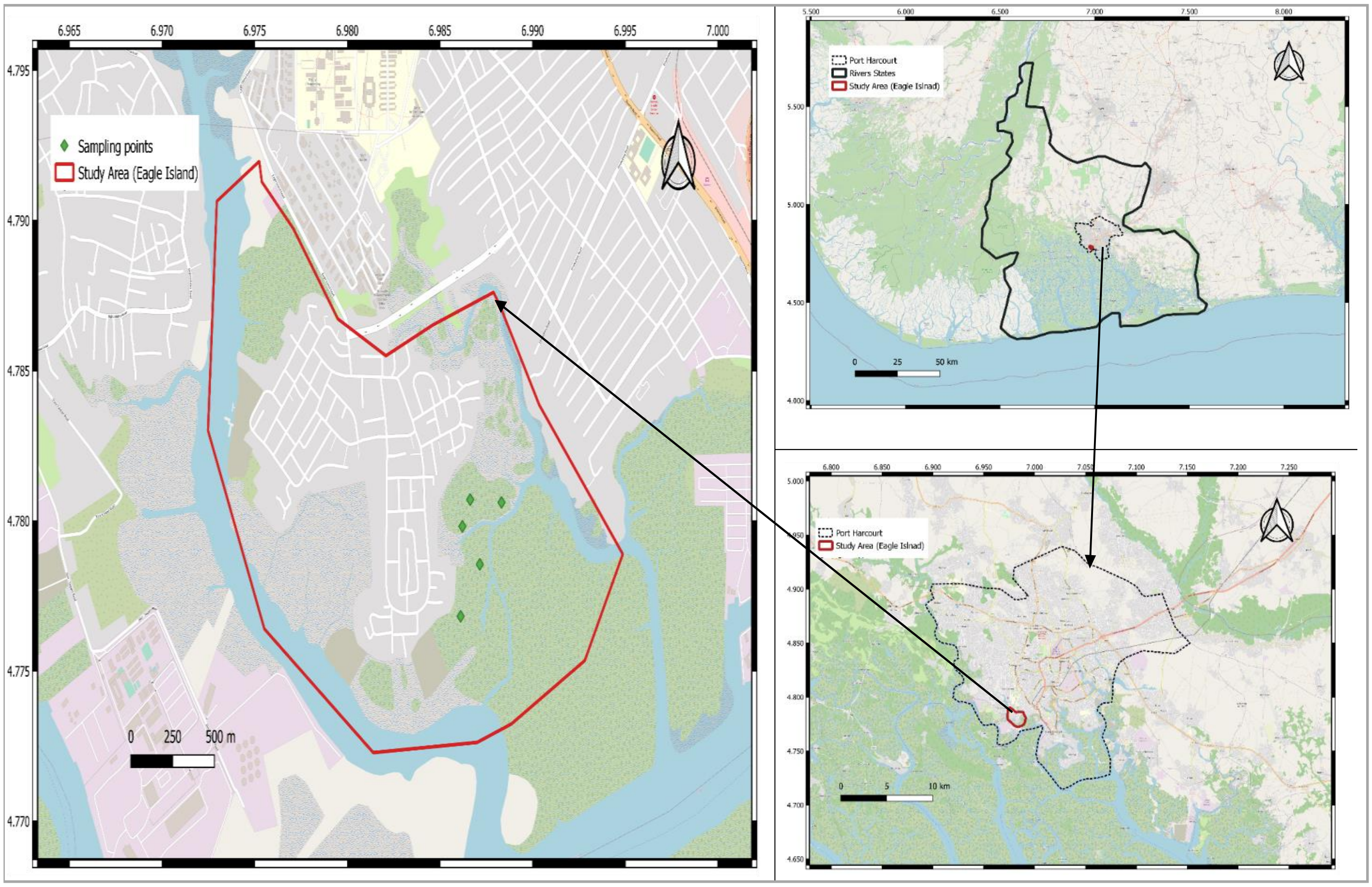

Figure 1a. Map of Study Area Displaying Sample Location (Source: Geography Department University of Port Harcourt, Rivers State Nigeria).

is characterized by the disposal of organic and inorganic wastes. The abattoir discharges organic substances and effluents, which comprise the stomach and intestinal contents of slaughtered animals, into the nearby river. The aquatic vegetation consists mainly of mangroves (Rhizophora species, *Avicenna germinanes*, and *Nypa fruticans*). Station 2 lies between latitude 04º47.236˝N and longitude 006’58.990’E, and about 500 m from station 1. The water here disconnects from station 1 during ebb tide and reconnects during high tide. Human activities include sawmilling and land reclamation (sand filling) for the construction of houses and filling stations. The vegetation has deteriorated due to the land reclamation activity. Station 3 (Control), is where no developmental activities (building, construction, etc.) exist.

Sample collection

Water, sediment, and benthos samples were collected monthly from April 2023 to March 2024. Approximately 0.5 kg of sediment was collected from the bottom of the water body at each sampling point using a stainless steel sampler. Samples collected from each point were thoroughly mixed in a clean plastic container to obtain a representative sample that was dried, crushed, and sieved with 2 mm mesh before being stored in labelled polythene bags prior to the analysis. The sediment samples were labelled in line with the regions from which they were obtained.

Determination of physicochemical properties of water samples

The physical and chemical parameters collected in the study included temperature, pH, electrical conductivity, salinity, total dissolved solids, turbidity, biochemical oxygen demand, and dissolved oxygen. After calibrating the instrument with the standard solutions, the temperature, turbidity, pH, electrical conductivity, and total dissolved solids were measured *in situ* using Extech, a

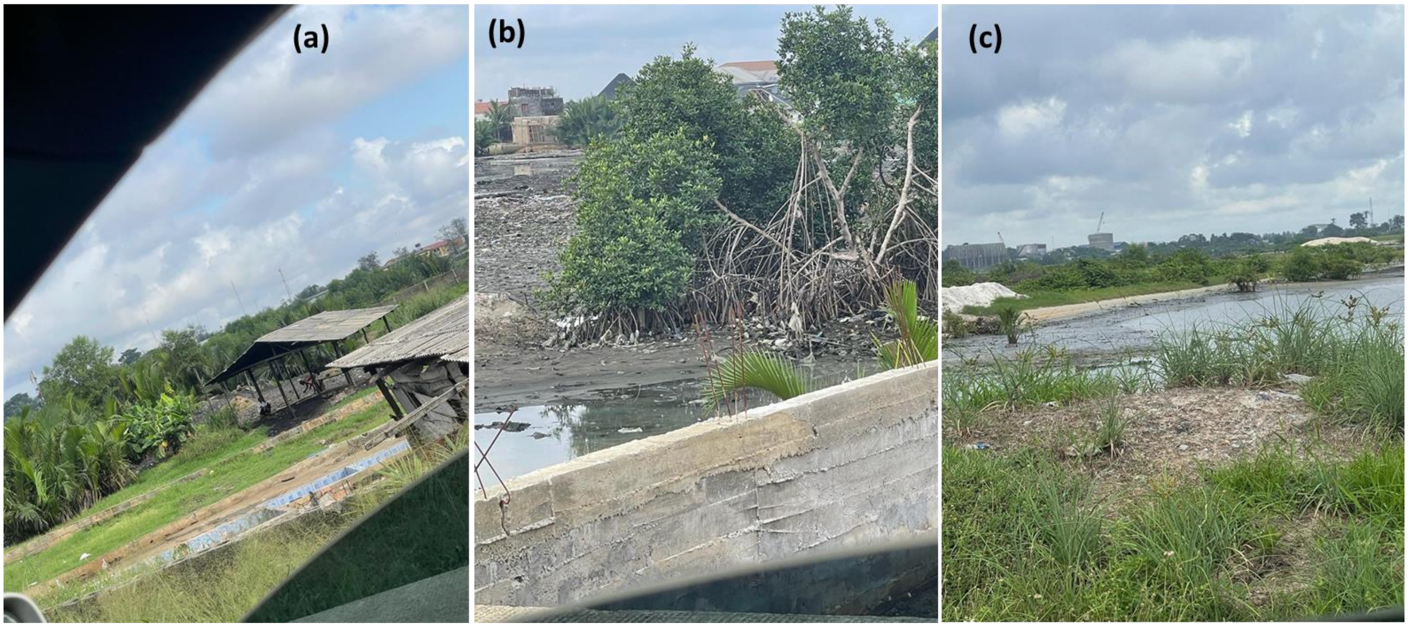

Figure 1b. The study sites: (a) abattoir, (b) bridge separating site a and b and (c) control site at Eagle Island, Niger Delta. Nigeria.

multiple-parameter digital test kit (DO: 700 models). The units of measurement were temperature (C°), turbidity (NTU), conductivity (S/cm), Total dissolved solids (TDS mg/L), Dissolved Oxygen (mg/L), Biochemical Oxygen Demand (mg/l), Total dissolved solids (mg/L), Available Phosphorus (P), and Total Nitrogen (TN). Collected samples were stored in a labeled cellophane bag indicating the sample code, date and time of collection as well as the name of the collector and kept in an ice-chest box before transferring to the laboratory while other parameters such as dissolved oxygen, biochemical oxygen demand were measured in the laboratory.

Temperature

The water temperature was measured using Extech a multiple parameter digital test kit (DO: 700 model). The sensitive part of the thermometer was immersed directly into the water and allowed to stabilize before readings were taken. Three readings were taken and the mean values of the three were calculated and recorded.

Turbidity

The water turbidity was measured *in situ* at a depth of 15 cm below the water surface using Extech a multiple parameter digital test kit (DO: 700 model). The sensitive part of the thermometer was immersed directly into the water and readings were taken. The mean values of the three readings were calculated and recorded as the groundwater turbidity for the stations (measured in the Nephelometric Unit (NTU)) (APHA, 1998).

pH

The water for hydrogen ion concentration pH was also measured in-situ at a depth of 15cm below water surface using a multiple-parameter Extech water checker (Model DO: 7000). The instrument was first calibrated with the standard Horiba solution. The measurement for pH was done as soon as possible by dipping the probe into the water sample. The switch button was put on while the arrow key was moved to the pH command displaying the values. After the value stabilized, the reading was taken. This was repeated three times and the average value was recorded (APHA, 1998). The same was also done for all sampling stations.

Dissolved Oxygen (DO)

Water samples are used to measure dissolved oxygen (DO) according to Modified Azide or Winkler's method (APHA, 1998). A well-labeled clean 70-ml DO bottle initially rinsed with water sample from the station was dipped below the water surface and allowed to fill to overflow to remove every trapped air bubble in the bottle filled with the sample, 0.5 ml Manganous sulfate (Winkler-I) solution was fixed, followed by 0.5 ml alkali-iodide reagent (Winkler-II) was added, stopper placed to remove air bubbles from the sample and mixed properly with several inversions. Water samples previously treated with Winkler I and II were reacted with 0.5 ml concentrated sulphuric acid (H_2SO_4), stopper placed, and mixed properly for the complete dissolution of the precipitate. A volume of 25 ml portion of the sample was placed in an Erlenmeyer flask. A few drops of the freshly prepared starch solution were added and titrated with 0.025 N $Na_2S_2O_3$ (sodium thiosulfate) solution. The titration continued until the first disappearance of the blue color from blue-black to colorless, and the endpoint was recorded (APHA, 1988; ATSDR, 1999).

Biochemical Oxygen Demand (BOD)

Water samples were collected in the same way as the DO was incubated at 20°C for five days. At the end of the incubation period, the samples are treated in the same manner as the DO samples stated above to determine the dissolved oxygen. To ensure the presence of oxygen, the BOD samples were diluted before incubation and the DO of the dilution water was determined. DO at day 5 was determined as in dissolved oxygen above and the BOD5 was calculated using the following:

$(A - B) \times DF$

Where: A is the Initial DO of dilution water, B is DO after 5 days of incubation and DF is the dilution factor of the sample to water.

Total dissolved solids (TDS)

Total dissolved solids were measured *in situ* at a depth of 15 cm below the water surface with Extech Multi-parameter digital meter. The instrument was standardized with Extech standard solution before the measurement was taken. The procedure was similar to those of the above parameters but the difference was that the cursor was moved to dissolve solid parameter. At the stability of the instrument, values were taken repeatedly three times in mg/L.

Electrical conductivity (μSCm^{-2})

The electrical conductivity of the sample at the stations was measured *in situ* using the Extech multi-parameter equipment. The same procedure was adopted in measuring for pH electrical conductivity parameter measured in $uSCm^{-2}$.

Sediments: The dishes were cleaned, dried, touched off, and covered at 50˚C for 30 minutes in the heater to inactivate or kill every enduring microorganism. The dishes were cooled and canvassed in desiccators. They were weighed until a steady weight was obtained. A 5.0 g of the sieved air-dried sediment tests were precisely placed into the dish and lit in a mute heater for 6 hours, opening the cover for the getaway of gases at 50˚C. This was checked occasionally until complete ashing (dark white debris) was obtained. The debris tests were permitted to cool, and 5 ml of 10% HCl was added to each example to upgrade dissolution. 5 ml of 10% HNO3 was added from there and set on a water shower to break down totally. The arrangement was dissipated to approach dryness on the water shower. The sediments were sifted through Whatman No. 42 channel paper into a perfect, dry 50 ml standard volumetric carafe on cooling to room temperature. The dish and the channel paper were washed into the flagons, imprinting them with deionized water (Nwaichi *et al.,* 2016). The resultant arrangements from the separate absorptions were prepared for metal investigation. The clear was additionally pre-arranged after a similar technique. The resultant arrangements from the separate assimilations and clear, arranged after a similar system, were utilized to investigate Cd, Zn, Ni, Cu, and Cr utilizing GBC-Avanta PM SN A6600 Atomic Absorption Spectrophotometer. Lattice coordinating, standard expansion, and foundation amendment were utilized to beat impedance. After each assurance, the spaces and confirmed reference materials were additionally run to determine the accuracy and instrumental vulnerability. The percentage of metals recuperated from the confirmed reference material was 93.2%, 95%, 89%, 85%, and 96% for Cd, Zn, Ni, Cu, and Cr separately. Atomic absorption spectrophotometric methodology was used to determine the concentration of toxic metals in the surface water and sediment samples. Appropriate scaling of the required quantities of water for the test was transferred into laboratory test bottles and taken for analysis.

Surface water: Water samples were acidified using HNO3 to pH < 2 and were well shaken to homogenize, after which duplicate samples were prepared using the following procedure (APHA, 1998). A 50 ± 1 mL sub-sample was then dispensed into a 250 ml beaker (digestion vessel) well fitted with a watch glass, 1.0 ± 0.1Ml of concentrated. HNO3 and 0.50 ± 0.05 mL concentrated HCl were added to each sample. The solution was covered using the watch glass and digested for 2.0 – 2.5 hours at 95 ± 5°C in the fume hood. Samples were removed from the heat source and left to cool for at least 30 minutes to reduce any potentially harmful fumes from the sample. The watch glass was then removed while samples were reconstituted back to 50 ± 1 mL with distilled water and well shaken to mix. The solution was transferred into a 100 ml plastic can for an Atomic absorption spectrophotometer (AAS) for metal concentration measurement.

Statistical analysis

All data from this study are presented as means, standard deviations, and standard error of the mean. Quantitative techniques in data presentation and analysis were employed in the study. SPSS version 22 was used for the statistical analysis. A one-way ANOVA was used to determine the significant difference in gaseous emissions. Microsoft EXCEL was used to illustrate graphs for the air quality parameters. Statistical significance of the values was considered at $p<0.05$ (Logan, 2010).

RESULTS

Physicochemical parameters of surface water

The results of the physicochemical parameters of surface water samples from the sampling stations at Eagle Island during the sampling period are presented in Table 1 and Figure 2.

pH

During the study period, a range of 6.36 to 11.86 was observed for pH (Table 1, Figure 2a). The mean pH across the stations ranged from 8.69 ± 0.37 in station 2 to 8.72 ± 0.26 in station 3. ANOVA results showed no significant difference in mean pH between stations and months at ($p>0.05$).

Dissolved Oxygen

The concentration of Dissolved Oxygen across the stations and months ranged between 4.2 to 6.7 mg/l. The mean dissolved oxygen across the stations was lowest in the station 2 with 4.49 ± 0.06 mg/l and highest in station 3 with 4.88 ± 0.19 mg/l (Table 1, Figure 2b). Statistical Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean DO at ($P>0.05$) across the stations.

Electrical Conductivity

Electrical conductivity observed across the stations and months revealed that there was no much variation throughout the period sampled (Table 1, Figure 2c). The result shows that the mean variation in conductivity values ranges from 1254 to 17440 µs/cm. The maximum mean value of 12006.11 ± 1445.63 µs/cm was recorded in Station 1 while the minimum mean value of 10977.60 ± 665.15 µs/cm was recorded in Station 3. One way analysis of variance revealed that conductivity is not significantly different ($p>0.05$) in the various stations across the months.

Total Dissolved Solids (TDS)

Total dissolved solids TDS concentration collected across the stations and the months revealed that there were no variations throughout the period samples as presented in Table 1 and Figure 2d. The table shows that variations in TDS values range from 627 to 10375 mg/L. Station 1 recorded the highest mean value (7688.26 ± 964.86 mg/L) while station 3 had the least mean value of 6766.32 ± 417.99 mg/L. One way Analysis of Variance revealed that TDS was not significantly different ($p>0.05$).

Salinity

Salinity recorded across the stations showed slight or no variations throughout the period samples as presented Table 1 and Figure 2e. The figure shows that variations in salinity values ranged from 0.65 $^{0}/_{00}$– 1.12 $^{0}/_{00}$. The highest mean value of 0.82 ± 0.27$^{0}/_{00}$ was recorded in station 2 while the minimum mean value 0.78 ± 0.02$^{0}/_{00}$ was recorded in station 3. A One way Analysis of Variance (ANOVA) revealed that salinity in the various stations of the month sampled was not significantly different ($p>0.05$).

Temperature (^{0}C)

The temperature ranged from 28.4 to 32.3ºC throughout the study period (Table 1, Figure 2f). The highest mean temperature 30.40 ± 0.22ºC was observed in station 3 while the lowest mean temperature occurred in station 1 at 29.81 ± 0.35ºC. One way analysis of variance revealed that temperature had no significant difference across the stations at $p>0.05$.

Nutrients and heavy metals in surface water

The results of nutrients and heavy metals in surface water across the various stations are presented in Table 2 and Figure 3.

Nitrate

The concentration of Nitrate ions in surface water across the stations ranged from 0.05 to 2.66 mg/l. The mean Nitrate ion across the stations was lowest in Station 3 with 1.16 ± 0.11 mg/l and highest in Station 2 with 1.86 ± 0.23 mg/l (Table 2, Figure 3a). Statistical Analysis of Variance (ANOVA) result revealed that there was a significant

Table 1. Range, mean and standard error of physicochemical across the stations at Eagle Island, Nigeria (±SE).

Parameters	Station 1	Station 2	Station 3	WHO/NUPRC limit
pH	6.36 - 11.86	6.41 - 11.72	6.44 -11.59	6.5 – 8.5
	8.702 ± 0.50	8.69 ± 0.37	8.72 ± 0.26	
D.O (mg/L)	4.30 - 6.30	4.20 -5.10	4.30 - 6.70	3.0-5.0
	4.88 ± 0.19	4.49 ± 0.27	4.84 ± 0.12	
EC (µs/cm)	1254.0 - 16992.0	3724.0 - 15326.0	4895.0 - 17440.0	2000
	12006.11 ± 1445.63	11438.37 ± 830.19	10977.60 ± 665.15	
TDS (mg/L)	627.0 - 10375.0	2072.0 - 10248.0	2447.0 -10115.0	500
	7688.26 ± 964.86	6844.48 ± 533.86	6766.32 ± 417.99	
Salinity (ppt)	0.7 - 1.02	0.69 - 1.01	0.65 - 1.12	Na
	0.814 ± 0.037	0.82 ± 0.27	0.78 ± 0.02	
Temperature (^{0}C)	28.4 - 31.5	28.2 - 31.5	28.2 - 32.3	25-30
	29.81 ± 0.35	30.19 ± 0.25	30.40 ± 0.22	

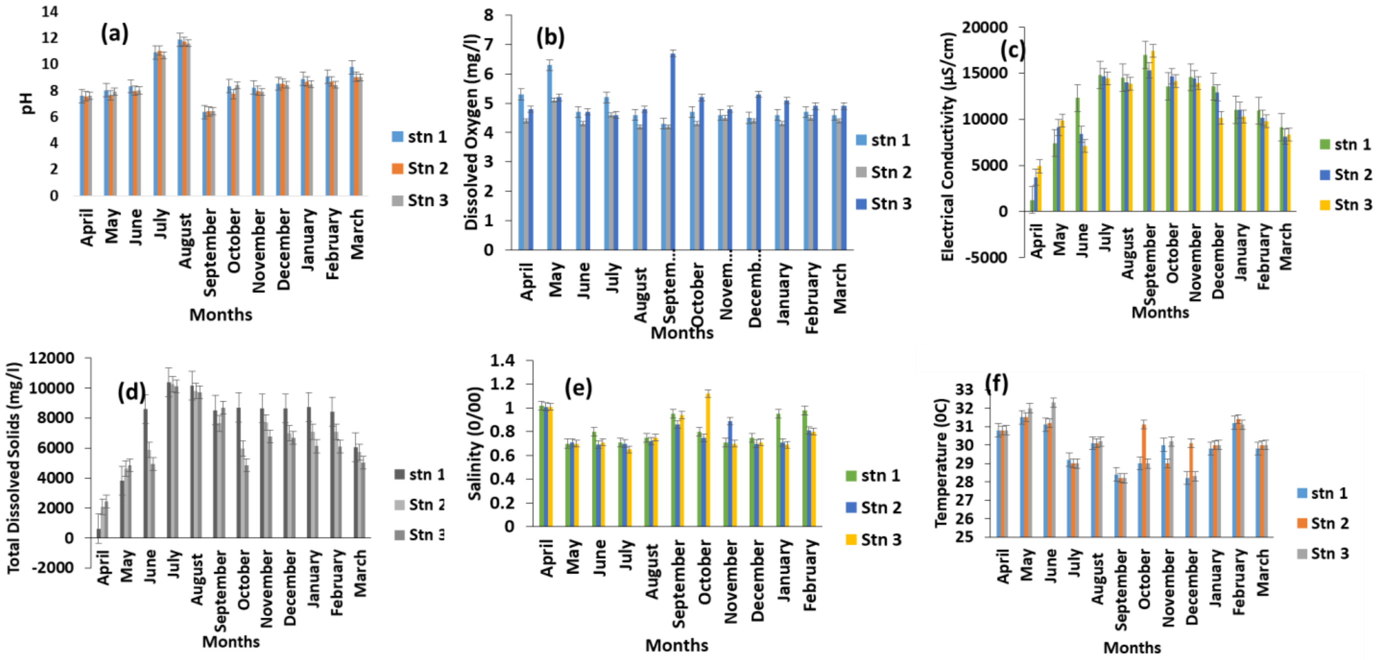

Figure 2. Monthly fluctuation of physicochemical parameters in surface water at Eagle Island, Niger Delta, Nigeria (±SE) (p > 0.05).

difference in the mean NO_2 at ($p<0.05$) across the stations.

Phosphate (PO_4)

The phosphate concentration in surface water across the stations and months ranged between 0.11 to 2.97 mg/l (Table 2, Figure 3b). The highest mean concentration was recorded at station 2 (1.51 ± 0.21 mg/l), while the lowest mean concentration was recorded at station 3 with 1.08 ± 0.10 mg/l. A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean PO_4 at ($p>0.05$) across the stations.

Cadmium (Cd)

The concentration of Cadmium in surface water across the stations ranged between 0.00 to 0.04 mg/L, the mean concentrations across the stations were 0.01 ± 0.00 mg/L). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Cd at

Table 2. Range, mean and standard error of nutrients and heavy in surface water at Eagle Island, Nigeria (±SE).

Parameters	Station 1	Station 2	Station 3	WHO/NUPRC limit
Nitrate (mg/l)	0.15 - 2.66 1.83 ± 0.21	0.10 – 2.66 1.86±0.23	0.05 – 1.85 1.16 ± 0.11	50
Phosphate (mg/l)	0.16 – 2.78 1.49 ± 0.29	0.13 – 2.97 1.51±0.21	0.11 – 1.76 1.08 ± 0.10	5
Cadmium (mg/l)	0.0 - 0.03 0.01 ± 0.00	0.00 – 0.04 0.01±0.00	0.01 – 0.02 0.01±0.00	0.03
Chromium (mg/l)	0.0 – 0.81 0.54 ± 0.11	0.00 – 0.90 0.58±0.08	0.01 – 0.71 0.43 ± 0.05	0.05
Nickel (mg/l)	0.02 – 2.22 1.49 ± 0.30	0.03 – 2.44 1.57 ± 0.23	0.01 – 2.05 1.36 ± 0.16	10
Lead (Pb) (mg/l)	0.07 – 0.23 0.11±0.02	0.02 -0.95 0.25±0.06	0.02 – 0.85 0.23 ± 0.04	0.01
Iron Fe (mg/l)	1.37 – 3.48 2.14 ± 0.16	1.22 – 2.95 2.04 ± 0.08	0.91 – 5.35 2.12 ± 0.19	10

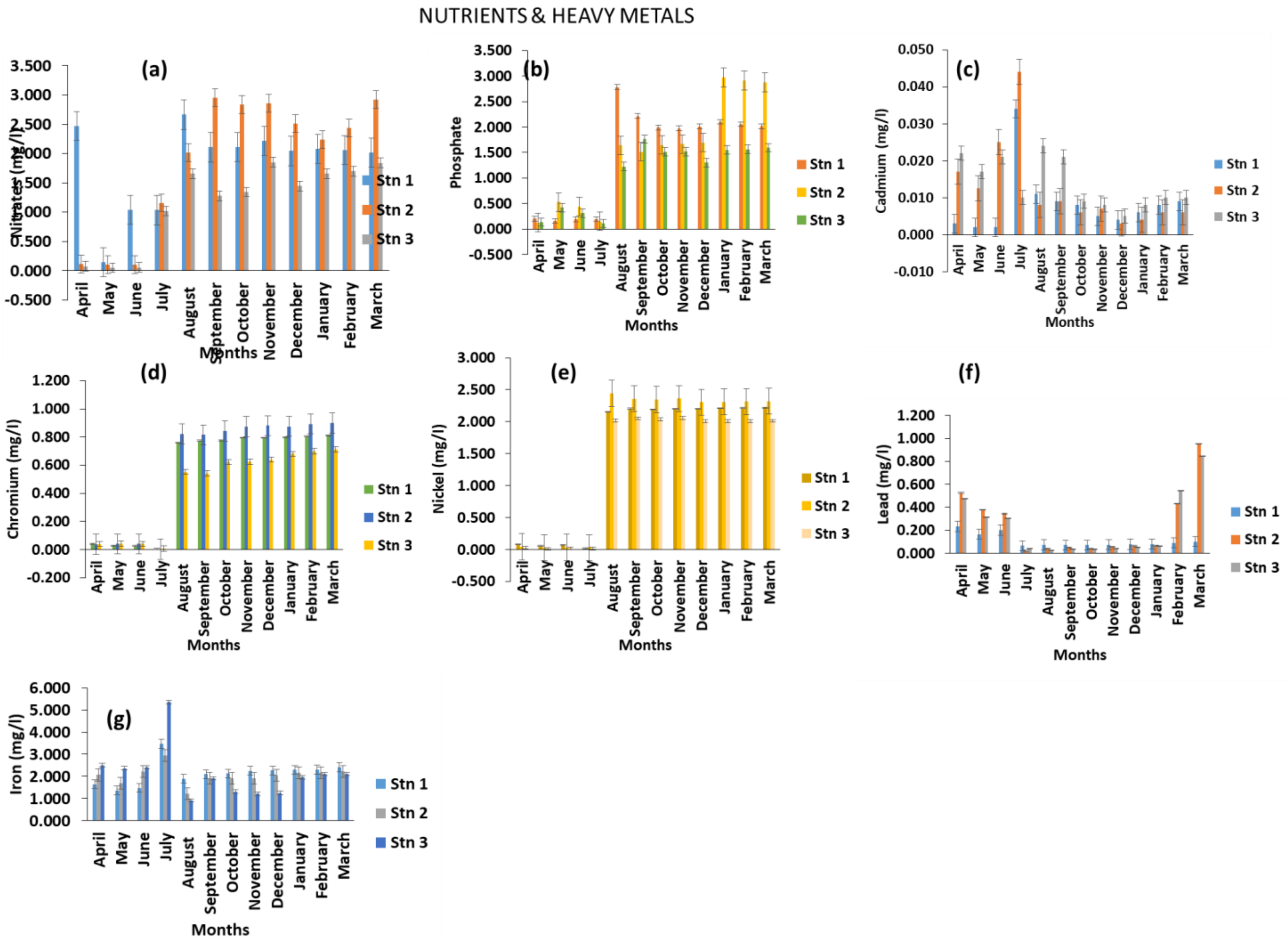

Figure 3. Monthly fluctuation of nutrients and heavy metal concentration in surface water at Eagle Island, Niger Delta, Nigeria (±SE).

($p>0.05$) across the stations as presented in Table 2 and Figure 3c.

Chromium (Cr)

The concentration of Chromium in surface water across the stations ranged between 0.00 to 0.90 mg/L (as presented in Table 2 and Figure 3d), with the highest mean concentration (0.58 ± 0.08 mg/L) recorded in Station 2, while the minimum was recorded in Station 3 (0.43 ± 0.05 mg/L). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Cr at ($p>0.05$) across the stations.

Nickel (Ni)

The concentration of Nickel in surface water across the stations ranged between 0.01 to 2.44 mg/L as presented in Table 2 and Figure 3e. The highest mean concentration (1.57 ± 0.23 mg/L) was recorded in Station 2, while the minimum was recorded in Station 3 (1.36 ± 0.16 mg/L). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Nickel at ($p>0.05$) across the stations.

Lead (Pb)

The concentration of Lead (Pb) in surface water across the stations ranged between 0.02 to 0.95mg/L, the highest mean concentration (0.25 ± 0.06 mg/L) was recorded in Station 2, while the minimum was recorded in station 1 (0.11±0.02mg/L) as presented in Table 2 and Figure 3f. A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Pb at ($p>0.05$) across the stations.

Iron (Fe)

The ironic concentration in surface water across the stations ranged between 0.91 to 5.35 mg/L, with the highest mean concentration (2.14 ± 0.16 mg/L) recorded in Station 1, while the minimum was recorded in Station 2 (2.04 ± 0.08 mg/L) as presented in Table 2 and Figure 3g. A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Fe at ($p>0.05$) across the stations.

Nutrients and heavy metals in sediment

The results of nutrients and heavy metals in sediment across the various stations are presented in Table 3 and Figure 4.

Nitrate

The concentration of Nitrate ions in sediment across the stations ranged from 0.02 to 6.98 mg/kg. The mean Nitrate ion across the stations was lowest in Station 1 with 3.61±0.76 mg/kg and highest in Station 3 with 4.37 ± 0.51 mg/kg. The results of the statistical analysis of variance (ANOVA) revealed that there was no significant difference in the mean NO_2 at ($p>0.05$) across the stations as presented in Table 3 and Figure 4a.

Phosphate (PO_4)

The phosphate concentration in sediment across the stations and months ranged between 0.02 and 3.60 mg/kg (Table 3, Figure 4b). The lowest mean concentration was recorded at Station 1 (2.28 ± 0.48 mg/kg), while the highest mean concentration was recorded at Station 2 (2.54 ± 0.36 mg/kg). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean PO_4 at ($p>0.05$) across the stations.

Cadmium (Cd)

The concentration of Cadmium in sediment across the stations ranged between 0.01 and 1.02 mg/L, with the highest mean concentration (0.65 ± 0.07 mg/kg) recorded in Station 3, while the minimum was recorded in Station 1 (0.50 ± 0.11 mg/kg) (Table 3 and Figure 4c). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Cd at ($p>0.05$) across the stations.

Chromium (Cr)

The concentration of Chromium in sediment across the stations ranged between 0.01 and 3.15 mg/kg, with the highest mean concentration (2.05 ± 0.30 mg/kg) recorded in station 2, while the minimum was recorded in station 1 (1.45 ± 0.31 mg/kg) (Table 3 and Figure 4d). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Cr at ($p>0.05$) across the stations.

Nickel (Ni)

The concentration of Nickel in sediment across the stations ranged between 0.08 and 9.85 mg/kg, with the highest mean concentration (6.18 ± 0.88 mg/kg) recorded in Station 2, while the minimum was recorded in Station 1 (4.91 ± 0.98 mg/kg) (Table 3 and Figure 4e). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Nickel at ($p>0.05$) across the stations.

Table 3. Range, mean and standard error of nutrients and heavy in sediment at Eagle Island, Nigeria (±SE).

Parameters	Station 1	Station 2	Station 3	WHO/NUPRC limit
Nitrate (mg/kg)	0.04 - 0.30 3.61 ± 0.76	0.05 - 6.22 4.02 ± 0.58	5.14 - 6.98 4.37 ± 0.51	50
Phosphate (mg/kg)	0.02 – 3.60 2.28 ± 0.48	0.07 - 3.82 2.54 ± 0.36	0.07 -3.87 2.50 ± 0.29	5
Cadmium (mg/kg)	0.02 – 0.82 0.50 ± 0.11	0.01 – 0.93 0.56 ± 0.09	0.01 – 1.02 0.65 ± 0.07	0.8
Chromium (mg/kg)	0.02 – 2.51 1.45 ± 0.31	0.02 – 3.15 2.05 ± 0.30	0.01 – 3.06 1.81 ± 0.21	100
Nickel (mg/kg)	0.08 - 7.26 4.91 ± 0.98	0.18 - 9.85 6.18 ± 0.88	0.29 – 9.55 5.98 ± 0.68	35
Lead (Pb) (mg/kg)	0.14- 2.72 1.66 ± 0.21	0.18 – 2.81 1.90 ± 0.17	0.18 – 2.42 1.68 ± 0.12	85
Iron Fe (mg/kg)	25.35 - 2411.05 1471.13 ± 266.87	25.51 – 2714.32 1644.10 ± 221.87	30.74 – 2432 1509.87 ± 147.77	200

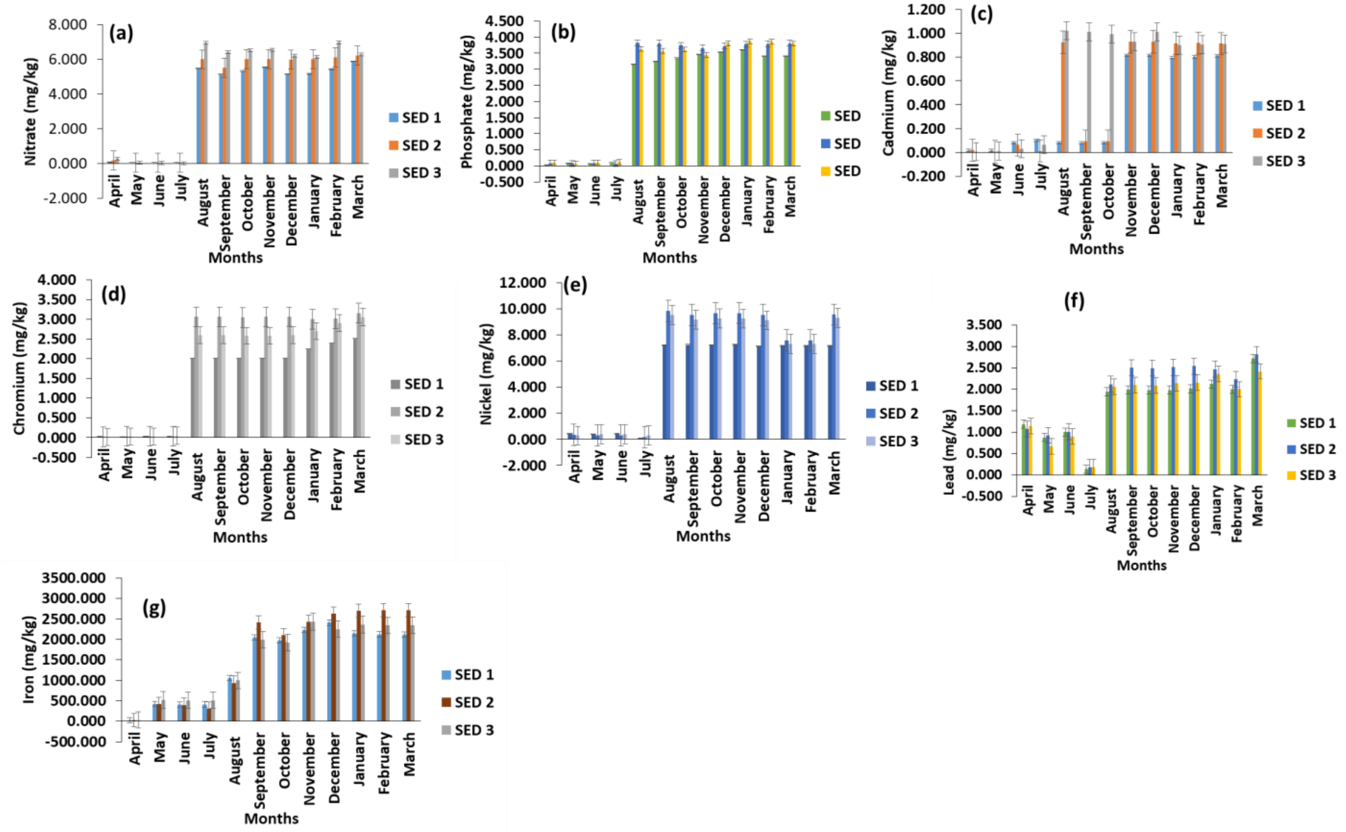

Figure 4. Nutrient and heavy metal concentration in sediments across the stations and months in Eagle Island, Nigeria (±SE).

Lead (Pb)

The concentration of Lead (Pb) in sediment across the stations ranged between 0.14 and 2.81 mg/kg, with the highest mean concentration (1.90 ± 0.17 mg/kg) recorded in Station 2, while the minimum was recorded in Station 1 (1.66 ± 0.21 mg/kg) (Table 3 and Figure 4f). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Pb at (p>0.05) across the stations.

Iron (Fe)

The ironic concentration in sediment across the stations ranged between 25.35 and 2714.32 mg/kg, with the highest mean concentration (1644.10 ± 221.87 mg/kg) recorded in Station 2, while the minimum was recorded in Station 1 (1471.13 ± 266.87 mg/kg) (Table 3 and Figure 4g). A One-way Analysis of Variance (ANOVA) result revealed that there was no significant difference in the mean Fe at (p>0.05) across the stations.

DISCUSSION

The pH range of 6.36 to 11.86 with a mean range of 8.69 ± 0.37 to 8.702 ± 0.50 recorded in this study are within the NUPRC and WHO permissible limits of 6.5 to 8.5 for surface water pH. These were, however, higher than the pH range of 6.58 ± 0.10 to 6.86 ± 0.31 reported by Tamunotonye *et al.* (2021) along the Okpoka Creek, and 4.83 to 7.58 reported by Akankali *et al.* (2022) at Eagle Island, Port Harcourt. The pH concentration was lowest in the month of April and highest in the month of August (Figure 2a), signifying an increase in seasonal changes. The pH range in July and August was higher than the WHO/NUPRC permissible limits for surface water pH. The range of pH values recorded for each month fell below the allowable limit set by WHO (2011). The alkalinity of pH during the study period may be due to the influx of domestic wastes, abattoir waste, industrial activities, and debris decay in the area. Change in pH may have dire consequences for aquatic organisms' health since most of their metabolic activities are pH-dependent (Okorafor *et al*., 2013).

The temperature range of 28.4 to 32.3ºC, recorded in this river, is typical of tropical brackish waters. However, previous researchers had reported similar values of 27 to 32ºC (Sibe *et al.,* 2019) in interstitial waters of K-Dere, 26.2 to 32.4ºC (Emoyoma *et al*., 2019) and 27.2 to 30.7ºC at Eagle Island (Akankali *et al*., 2022). The results obtained are in line with the WHO/NUPRC standards, but Nduka and Orish (2008) attributed this high temperature to be a result of industrial discharges, gas flaring, and fire break and gas exploration in the Niger Delta. Temperature influences migration, spawning, egg incubation, growth, and metabolism of aquatic organisms. An increase in temperature will lead to an increased rate of chemical reactions and the formation of toxic complexes, which may profoundly affect aquatic organisms. Temperatures outside the acceptable limits could directly affect the dissolved oxygen level and pH available to the aquatic environment.

The concentration of Dissolved Oxygen (DO) in natural waters is influenced by the water body's physical, chemical, and biochemical activities. This study's DO values (4.30-6.70 mg/l) varied slightly from the FMENV permissible limit of 5.0 mg/l. This can be as a result of rainfall and run-offs. Dissolved Oxygen is necessary for the survival of aquatic life, and it is also used to ascertain the extent of fresh water in rivers. A DO level as low as 1 1mg/L will slow down the growth of aquatic life when continuously exposed, while a level below 1 mg/L is reported to be lethal when exposed for more than a few hours (Okorafor *et al.,* 2013). Woke and Wokoma (2006) ascribed similar situations to the higher inorganic waste load experienced in rainy months. The variation in dissolved Oxygen concentration across the months was not significantly different at p>0.05 (Figure 2b). Dissolved Oxygen is vital for the survival of living organisms, and its availability in a water body can lead to a direct diffusion from air or production by autotrophs through photosynthesis (Tenagne, 2009). Oxygen depletion often results during times of high community respiration. Hence, DO has been extensively used to delineate water quality and evaluate the degree of freshness of a river (Singh *et al*., 2010). The salinity results of 0.65 0/00 -1.02 0/00 can be ascribed to the influx of fresh water. The mean salinity recorded in this study is below that of Komi and Sikoki (2013), who reported higher values at the Andoni River. The salinity results indicate that Eagle Island River could be fresh or brackish.

The conductivity values of 1254 -17440.00 µs/cm indicate solutes of dissolved solids. The electrical conductivity of a water body indicates the level of ionic concentration, which, therefore, indicates the freshness of the water (Peretiemo-Clarke *et al*., 2009). The average concentration of Electrical conductivity in this study far exceeded the 53.3 to 64.9 µs/cm reported by Davies *et al*. (2018) at the Orashi River. This signified that the river is brackish. Egborge (1994) stated that the general trend of conductivity value below 1000 µs/cm indicates freshwater; above 1000 µs/cm is brackish water, while above 40,000 µs/cm is marine water. Variations in values between stations and months could be attributed to environmental factors such as rainfall and runoff. Previous studies by Akankali *et al.* (2022) have reported 45.53±14.3 µS/cm in Eagle Island, which is lower than the current study.

The results of Total Dissolved solids, which ranged from 627 to 10375 mg/l with a mean range of 6766.32 ± 417.99 mg/l to 7688.26 ± 964.862 mg/l, were above the WHO permissible limit for drinking water. This, however, differs from the report of Akankali *et al*. (2022), who reported 32.5±4.2mg/L along Eagle Island. The concentrations of TDS were almost similar in the stations and across the months. However, there was no significant difference in their concentrations (p>0.05). This could be a result of tidal flows, which spread all activities to all the sampling areas.

The average concentration of Nitrate in this study, which ranges between 1.16 ± 0.11 mg/l to 1.86 ± 0.23 mg/l in surface water and 3.61 ± 0.76 mg/kg to 4.37 ± 0.51 mg/kg in sediment below the limits of set by WHO which is 50 mg/L. This, however, is lower than the range of (6.6 - 9.68 mg/L) reported by Wizor and Nwankwo (2019) from Woji Creek in Rivers State. However, similar values of 0.3-5.23 mg/L and 1.1–7.32 mg/L from surface water samples were reported by Akankali *et al*. (2022) along Eagle Island. The low variation recorded for nitrate concentration in this study may be due to differences in hydrogeological regimes (Akankali *et al.*, 2022). Generally, lifetime exposure to nitrite and Nitrate at levels above the maximum acceptable concentration could cause such problems as diuresis, increased starch deposits, and hemorrhaging of the spleen in aquatic organisms (Reimann *et al.,* 2003).

Phosphate values ranged from 0.08 ± 0.10 mg/L to 1.51 ± 0.21 mg/L in surface water and 2.28 ± 0.48 mg/kg to 2.54 ± 0.36 mg/kg in sediment. The values of phosphate observed in this study are within the WHO permissible limit of 0.1 mg/l. This study's phosphate concentration can be attributed to seepage from run-offs or discharges from the nearby abattoir waste. The principal adverse impact of the high levels of this phosphate on water quality is that it leads to eutrophication, which is more common in lakes and sometimes rivers (Abolude *et al.,* 2009).

The heavy metal concentration in both surface water and sediment fluctuates and is higher in the sediments than in surface waters, especially of Fe. The average metal concentration in the surface water and sediment decreased in the order of Fe>Ni>Pb>Cr>Ni>Cd. The mean concentration of Cadmium in surface water was 0.010 ± 0.00 mg/l. This was low compared to the sediment (0.50 ± 0.11 to 0.65 ± 0.07 mg/kg). The concentrations of Cadmium (Cd) were slightly higher than the 0.5 mg/kg permissible limit of the WHO (2011), as shown in Table 3. Heavy metal concentration in surface water compared to sediment showed higher concentration in the sediments than in surface water (Tables 2 and 3). Analysis of the variance of seasonal fluctuation of heavy metals in surface water showed no significant difference ($p > 0.05$) for all metals except Cadmium.

Lead concentrations across the stations exceeded the WHO permissible limit of 0.01 mg/l in surface water and 0.1 mg/kg in sediment. The concentration of lead in this study is an indication of pollution from anthropogenic sources in the environment. The results recorded were lower than 13.53 to 14.13 mg/kg, as previously recorded by Babatunde *et al.* (2014) in the New Calabar River. The mean concentration of Chromium in surface water was higher than the WHO permissible limit. However, the concentrations in sediments were lower than the WHO permissible limit of 100 mg/kg. Chromium is carcinogenic, resulting in cancer of respiratory organs in workers exposed to Chromium (Iwegbue *et al.*, 2007). Iron exists naturally in rocks in the form of haematite, magnetite, or taconite and in soil as minerals (Popoola *et al.,* 2019). Ironic concentration in surface water was lower than the WHO recommended limit of 10 mg/l. In the sediment, the concentration of iron exceeded the WHO recommended limit. This observation could indicate the major impacts of anthropogenic activities around the study sites. Small levels of Fe have been connected with anaemia in humans. Nickel results were lower than the WHO permissible limit for heavy metals in surface water and sediments. The results obtained in this study are slightly higher than 0.001 – 0.129 ± 0.006 mg/l of Moslen and Aigberua (2018) in Azuabie Creek, Bonny Island. Nickel is commonly considered immunotoxic, genotoxic, and carcinogenic to living organisms (Kasprazak *et al.,* 2003). The accumulation of Nickel (Ni) in different organs may result in disturbed tissue metal content ratio, modifications of the organism’s metabolism (Funakoshi *et al*., 1996), and lipid peroxidation.

Conclusion

Anthropogenic activities such as sand mining, waste disposal, abattoir activities, and building along the wetland have continuously led to the gradual denigration of environmental quality. The physicochemical parameters are within the limit while the nitrate level is below the WHO limit, In contrast, the lead concentration is higher than the WHO limit, which is an indication of pollution. Similarly, the heavy metal concentration in sediment was higher than in surface water. An increase in chemical concentration in minute form can have far-reaching consequences on the health of the public through the consumption of seafood. Although the heavy metal concentrations were below WHO standards, constant monitoring is necessary to detect an increase in deleterious levels

Recommendation

This study recommends that.

1. Human activities that degrade the wetland environment should be reduced, and activities that encourage wetland conservation and preservation should be encouraged.
2. The future benefit of wetland management should be the goal and sole reason for its conservation.
3. Mangrove seedlings should be introduced to turn it back to a forest reserve
4. A fence should be constructed to limit encroachment by humans.
5. People should be prevented from using water for domestic and swimming purposes due to the imminent health implications.

CONFLICT OF INTEREST

The authors declare they have no conflict of interest.

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