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RESEARCH ARTICLE

Ecological and Human Health Risk Assessment of Sediment, Periwinkle and Water in Bodo Creek, Niger Delta Nigeria

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Abstract

The ecological and human health risk assessment of sediment, periwinkle and water in Bodo Creek, Nigeria was carried out between June, 2023-March, 2024. Three sampling sites were chosen in remediated area. Physico-chemical parameters (total dissolved solid (TDS), dissolved oxygen (DO), electrical conductivity (EC), etc) were analyzed in-situ while heavy metals (cadmium. Lead and copper) were analyzed using AAS. Similarly, some health risk analyses were estimated (contamination factor (CF), pollution load index (PLI), geo-accumulation index (Igeo, estimated daily intake (EDI), potential ecological risk index (PERI), hazard index (HI), total target hazard quotient (TTHQ), etc). The mean value of physico-chemicals were pH, 7.522±0.084-7.566 ± 0.088; TDS, 7573.700±235.833mg/l -7931.200 ± 222.808mg/L; EC, 14179.000±684.294µs/cm-15268.200 ± 549.977µs/cm, DO (6.936±0.311mg/L-7.200 ± 0.320mg/L) and temperature (29.180±0.280^{0}C-29.470 ± 0.304^{0}C). Heavy metals results include; surface water; Cd (0.00-0.02mg/L), Pb (0.02-0.07mg/L) and Cu (0.02-3.95mg/L). Sediment; Cd (0.01 to 0.32mg/kg), Pb (0.11- 4.16mg/kg), and Cu (0.08 -14.58mg/kg). Periwinkle; Cd (0.00 to 0.22mg/kg), Pb (0.00- 0.21mg/kg), and Cu (0.00 -12.60mg/kg). WQI was 84.286 - 95.201 (dry season) and 87.559 -89.776 (wet season). CF were Cd, 0.183-0.278 (wet); 0.010 -0.248 (dry); Pb, 0.022-0.026 (wet), 0.027-0.035 (dry); Cu, 0.002 (wet) and 0.106-0.113 (dry). PLI was 0.297-1.404 (wet) and 0.393-2.216 (dry season). Igeo were; Pb 0.004-0.007; Cd, 0.032-0.056 and Cu 0.004-0.023. PERI was 5.467-8.484. EDI sequence were Cu>Pb>Cd, Cu>Pb>Cd and Cu>Cd>Pb for surface water, sediment and periwinkle respectively. HI were 1.146-2.802; 44712.21- 81245.36 and 0.024-0.715 for surface water, sediment and periwinkle respectively. TTHQ ranged between 0.16-1.11; 15.982-29.040 and 0.149-11.000 for surface water, sediment and periwinkle respectively. Cancer Risk ranged between 0.006-0.325 across the samples. The high water quality index observed indicates a highly polluted environment, also, there is very high possibility of cancer risk from the study area via ingestion of surface water, periwinkle and exposure to the sediment in the study area.

1. Introduction

Tympatonusfuscatus has been consumed for centuries in many African cultures because it is very nutritious. Vitamins, minerals, and protein are all abundant in it, making it an important dietary component for many communities. However, the safety of consuming *Tympatonusfuscatus* is a concern, particularly when harvested from polluted environments. Seafood, including shellfish can accumulate contaminants from their surrounding environments, including heavy metals, pesticides, and microbial pathogens (FEPA, 2003). The conventional practice of eating periwinkle using the 'blower's technique', which involves using the mouth to extract the unshelled periwinkle, may need modification due to the potential higher levels of danger associated with ingesting sediments from the digestive system of these organisms compared to the shelled periwinkle (Otitoju andOtitoju, 2013).

According to Ndubuisi et al. (2023), the unintentional release of petroleum hydrocarbons into the environment is called an oil spill. The spread of the spill and the potential danger it may cause are both affected by the oil's specific properties. Therefore, the spreading of an oil spill over water occurs instantly. Evaporation, dissolution in water, oxidation, bacterial transformations, and gravitational force cause part of the gaseous and liquid components to fall to the bottom (Duru et al., 2009). The discharge of crude oil

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from several sources may lead to an oil spill. These include ships, offshore platforms, drilling rings, refinery operations, blowouts, and mud waste. Minor, medium, large, and catastrophe oil spills are the four main types. While the lighter crude fractions are more poisonous and less physically destructive, the larger fractions are more prone to inflict mechanical damage (Akinwumiju et al. 2020).

Crude oil exploration and its refining process, which is broken into different fractions is a major cause of contamination in the environmental. For example, processes such as dredging and canalization preceding offshore exploration results in several impacts on the environment as well as pollution by noxious metal, water physico-chemical alterations, impact on plankton (Ohimain et al., 2012). One of the most significant contributors to environmental pollution is oil spill. In the Niger-Delta region of Nigeria, oil spills are the most significant and frequent environmental threat, (Anyanwu, 2019). According to Ordinioha and Brisibe (2013), oil exploration and exploitation pose hidden and slow-moving health risks. Despite the fact that they have the potential to significantly increase the prevalence of disease in oil

Additionally, during unrefined petroleum and flammable gas investigation, additional gas is erupted into the biological system, influencing crop ripeness, crop yield, soil physicochemical characteristics like pH, temperature, soil dampness, soil microbial population, phytochemicals in plants, water quality, and crop yield.

Particularly, the physicochemical, heavy metal, hydrocarbon, and nutritional composition of the soil as a whole may be affected by spilled crude oil (Shahzad et al. 2024).

The microflora in soil may change depending on the soil's characteristics. Depending on the kind of microbes, soil micro flora affects biogeochemical cycles, the rhizosphere, and the breakdown of chemicals and materials.

Crude oil, a dark liquid that is naturally occurring and converted into various fuels, comes from underground geological formations (Li et al. (2024). The properties, molecular weights, and other constituents of many hydrocarbons are primarily what determine their characteristics. Studies on crude oil spills indicate that vessels or pipelines can accidentally release petroleum into the environment. This can occur extensively and most frequently in water bodies, primarily as a result of human carelessness (Angelova et al. 2011). Oil spills come from a variety of sources, including crude oil released by tankers onto land and water, oil spills during rig drilling, and oil spills on offshore platforms, all of which have a significant environmental impact (Bhatnager and Sallanpaa, 2010). When the remediation reaction is low, cleanup is time-consuming and most of the damage to the environment is long-lasting. According to de Lima et al. (2013), the oil film that floats on the surface prevents sunlight from reaching plants, animals, and the surrounding environment.

The 2008 spills had an environmental impact on mangrove communities all along the creek. Depending on variables like proximity to the spill, topography between the tides, tidal hydrology, root architecture of the mangroves, and the amount of time they lived in the area, the effects were either acute or chronic, as can be seen visually (Pegg and Zabbey, 2013). There is a high probability of the oil's long-term reappearance since tidal pumping facilitates its percolation and burial into sediments. Mangroves on higher platforms are always under stress, but mangroves in stream channels and in relatively low-lying regions further inland have experienced total loss. Only the roots of mangrove trees are left in several places (UNEP, 2011). The best indicator fauna for gauging the health of aquatic ecosystems are zoobenthos, which are creatures that live in sediment. According to Jordan and Smith (2004), it is formed from zoobenthos's intrinsic ecological traits, which include huge size, relative immobility, abundance, variety, and longevity.

Seafood consumption, particularly shellfish, is healthy and one of the primary sources of nutrients supplying a significant percentage of dietary protein and fat intake in many nations (Moruf *et al.,* 2020). The ecology is threatened by trace metals from the environment, which are typically found in extremely high concentrations and pose a harm to aquatic life. Due to a number of anthropogenic activities over the past two decades, significant amounts of metals and their compound both inorganic and organic have been released into the environment (Budi*et al.,* 2024). The accumulation of heavy metals in aquatic organisms that humans consume poses a threat to the health of humans (Budi et al., 2024). Fish and other aquatic organisms may readily absorb these metals due to their high solubility. Trace elements can later return to the aquatic medium after being absorbed to sediment particles in the aquatic environment. These trace metals accumulate in food sources and pose a health risk to humans when exposed to them over time (Ahmed et al. 2022). Crabs, lobsters, and shrimp are examples of benthos organisms that can gather food, water, and sediment (Baki *et al*., 2018). Since crabs are a kind of benthic organism—a distinct aquatic species—and because of their role in the food web, they may provide useful information on the extent to which surface material is contaminated (Ololade et al., 2008). Thus, microbes, shellfish, and other marine animals may consume traces of metal from polluted environments, putting humans at danger through the food chain.

2. Aim and Objectives

This research aims to examine the hazards to human and environmental health posed by *Tympanotonusfuscatus*, water, and sediments collected from Bodo Creek in Rivers State, Nigeria.

The specific Objectives of the study are to determine the;

i. Physicochemical properties of the Bodo Creek,

ii. Heavy metals concentration of periwinkles, sediment and water from Bodo Creek, Rivers State,

iii. Seasonal Ecological risk of water and sediment from Bodo Creek, Rivers State,

iv. Seasonal human health risk of consuming water and periwinkle (via ingestion of the periwinkles) in Bodo Creek, Rivers State.

3. Materials and Methods

Approximately 9230 hectares make up Bodo Creek, and according to Pegg and Zabbey (2013), the riverine water mangrove ratio is 45:55, meaning that there are around 4154 hectares of river channels and 5076 hectares of mangroves. On Ogoni-land, it is among the four main oil fields. In the upper parts of the Andoni-Bonny river system, close to Bodo Community, there is a confluence of streams and creeklets that form Bodo creek. A “mixing sponge” for the waters of the Andoni and Bonny river estuaries, Bodo stream is intricate and follows a complicated hydrological cycle. The two main creeks that connect Bodo Creek to the rivers Bonny and Andoni are DorNwezor and Kpador, respectively. Inlet, the two main channels branch out into a plethora of smaller creeks; some of these creeks empty out into mangrove swamps, while others join together, mixing the flood and ebb tides from both sources (Onwugbuta-Enyi et al., 2008). Figure 1 shows the sampling area map.

4. Description of Study Area

Station 1 (Goi): Geographically, it is located at latitude 4° 62’ 49.1” E and longitude 7° 25’ 02.2” N (Figure 1). The mangrove vegetation, which was a major part of the ecology in this area before to the crude oil leak, was eradicated by the disaster.

Station 2 (St Patrick): This station is located immediately after the Bodo-Bonny bridge at latitude 4° 63’ 00.5” N and longitude 7° 24’ 38.1” E (Figure 1). This location was polluted but declared remediated by SPDC. This site is 1km away from station 1. It is one of the earliest remediated sites and it is characterized with the presence of re-vegetated mangrove shrubs.

Station 3 (Kozo 3): This station is about 420 m away from the station 2 at latitude 4° 63’ 00.5” N and longitude 7° 24’ 38.1” E (Figure 1). This location is a newly remediated site.

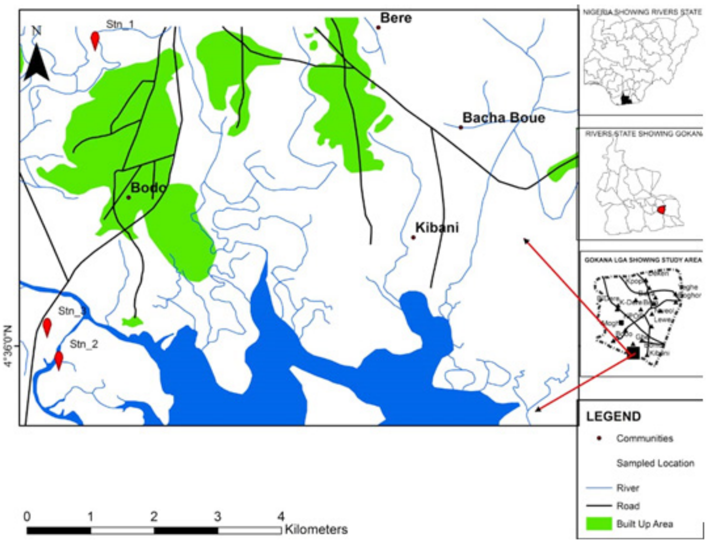

Figure 1. *Map of Bodo Creek in the Niger Delta, Nigeria*

4.1 Sample Collection

A comprehensive ten-month study was conducted to assess the physicochemical properties of water, heavy metals in sediment, surface water, and periwinkle across both the wet and dry seasons. The duration of the wet season was from June to September 2023, while the dry season was from October 2023 to March 2024.

4.2 Physico-Chemical Analysis of Water

Temperature, pH, electrical conductivity, salinity, total dissolved solids, and dissolved oxygen were among the physico-chemical characteristics measured in the research. After calibrating the instrument with the relevant reference solutions, the following parameters were measured in-situ: temperature, pH, dissolved oxygen, electrical conductivity, and total dissolved solids. The equipment was an Extech multiple parameter digital: DO: 700 model. All of the following were measured in milligrams per litre: temperature (°C), conductivity (S/cm), total dissolved solids (mg/L), and distillation efficiency (mg/L). After being properly identified with the sample number, date and time of collection, and collector's identity, specimens gathered in the field were carefully labelled and stored in an ice chest until they were sent to the lab for more in-depth study.

4.3 Temperature

The water temperature was determined using an Extech multiple parameter digital instrument (DO: 700 model number). Submerging the sensitive section of the thermometer straight into the water enabled the device to get a stable reading. Triplicate measurements were obtained and the average values of the triplicate measurements were computed and documented.

4.4 pH

A multiple-parameter Extech water checker (Model DO: 700) was also used for in-situ pH measurements, which were taken 15 cm below the water's surface. Using the usual Horiba solution, the device was first calibrated. Quickly submerging the probe into the water sample allowed for the pH measurement to be taken. By pressing the switch button and navigating to the pH command that displayed the values, the data could be obtained. When the value had settled down, the measurement was made. After doing this a total of three times, the average value was noted (APHA, 2005). Each sample station underwent the same procedure.

4.5 Dissolved Oxygen (DO)

Dissolved Oxygen was measured in-situ using Extech a multiple parameter digital (DO: 700 model) after calibrating the instrument with the necessary standard solutions. After submerging the probe in the surface water for one minute, measurements were collected.

4.6 Total Dissolved Solids (TDS)

Extech Multi-parameter digital meters were also used for in-situ measurements of total dissolved solids, which were taken 15 cm below the water's surface. Prior to taking the measurement, the instrument was standardised using Extech standard solution. 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 for three times in mg/L.

4.7 Electrical Conductivity (µS/cm)

Extech multi-parameter equipment was used to test the electrical conductivity of the sample at each station in real-time. The pH electrical conductivity parameter, expressed in uS/cm, was also determined using the same methodology.

4.8 Sediment Sampling

An eckman-grab was used to gather about 0.5 kg of sediment at each sample station. Before analysis, samples were mixed well in a clean plastic container to generate a representative sample. The samples were then dried, crushed, and sieved with a 2 mm screen. They were then kept in marked polythene bags and clearly labelled. The heavy metal in sediment was determined using PG Instruments AA500 model with AAWin 3.0 Instrument set-up.

Periwinkle (*T. fuscatus*) collection: Periwinkles were collected from the bottom of the river at each station using Eckman Grab, while those collected during ebbs were handpicked. Heavy metal analysis was done in accordance with APHA (2005) using the Atomic Absorption Spectrometer (AAS).

4.9 Laboratory Analysis of Heavy Metals in Water

The materials used for the analyses include the reagents, which include heavy metals primary standard (AccuStandard), analytical grade concentrated nitric acid, hydrochloric acid and distilled water. The equipment used are Atomic Absorption Spectrophotometry (AAS) AA500 PG Instruments, Hot plate or thermal heater, Funnel, Filter paper, Beakers, 100ml volumetric flask, 100ml plastic can, Fume cupboard, Masking tape for labeling and Marker.Sample Treatment and Digestion procedure for heavy metals include the use of water samples treated with HNO3 until their pH was less than 2, then thoroughly mixed by shaking. A second set of samples was then made from the original using the same method (APHA, 2005).

4.10 Ecological Risk Assessment

According to Fiori*et al.,* (2013), environmental risk assessment frequently takes into account various environmental factors, including chemical, physicochemical, biological, and eco-toxicological parameters. There is a connection to contaminants in the biophysical aspects of the environment, including air, water, and soil. The ecological importance of heavy metals has been brought to light due to the substantial correlation between soil heavy metals and human health, especially in rural areas such as Bodo Creek. To determine the level of pollution in the research region, the following ecological risk indicators were calculated:

4.11 Contamination Factor (CF)

The primary function of the Contamination Factor (CF) is to determine the level of heavy metal contamination in a sample (1). The heavy concentration relative to the background value is the unit of expression (Chen et al., 2019). The background value used in this work is the standard value stipulated by Department of petroleum resources (Olawuyi & Tubodenyefa, 2018).

$$\mathrm{CF} = \frac{\mathrm{Cmetal}}{\mathrm{C{-}background}} \tag{1}$$

Where**:** Cmetal is the metal concentration in polluted media and, C-background is the background value of that metal (Aali et al. 2024).

Contamination factor will be expressed as; CF<1 (low risk), 1≤CF<3 (moderate risk), 3≤CF<6 (considerable risk) and CF≥6 (very high risk) (Ustaoğlu et al. 2020).

4.12 Degree of Contamination

In addition, the degree of contamination will be assessed as shown in equation 2;

Degree of contamination = $\sum Pb + \sum Cd + \sum Cu + \sum Hg + \sum Cr \ldots\ldots \sum n$ (2)

4.13 Pollution Load Index (PLI)

Pollution Load Index (PLI) quantifies the frequency at which the metal content in the soil surpasses the mean background concentration (3). It provides a comprehensive measure of the total toxicity of TCEs in a specific sample (USEPA, 2005). The Pollution Load Index (PLI) assesses the extent to which the soil is linked to certain heavy metals that might affect the ecology of soil microorganisms (Hassan et al. 2024).

$$\mathrm{PLI} = \sqrt[n]{(\mathrm{CF1} \times \mathrm{CF2} \times \mathrm{CF3} \times \mathrm{CF4} \ldots\ldots \mathrm{CFn})} \tag{3}$$

(Hakanson, 1980)

Where CF represents the contamination factor,

n is the number of metals investigated,

The *PLI* is scored using a scale from 0-6

The pollution load index will be depicted as; PLI < 1 (no pollution); 1< PLI< 2 (moderate pollution); 2< PLI< 3 (heavy pollution); 3<PLI (extremely heavy pollution) (Aigberua and Tarawou, 2018)

4.14 The Geo-Accumulation Index (Igeo)

The geo-accumulation factor is a metric used to evaluate the existence and severity of human-induced pollution (4). The method used to assess metal pollution in soils involves the comparison of present concentrations with levels observed before industrialization (Hakanson, 1980). It is expressed as:

$$\mathrm{Igeo} = \log2(\mathrm{Cn}/1.5\mathrm{Bn}) \tag{4}$$

Cn = concentration of metal in the soil,

Bn is the value of geochemical background for the element.

Where Cn is the measured concentration of heavy metals in the sample and

A factor of 1.5 is used to account for any discrepancies in the background data caused by lithological changes.

4.15 Potential Ecological Risk INDEX (PERI)

The Potential Ecological Risk Index is a mechanism used to evaluate the ecological risk associated with toxins and heavy metals present in the environment (Bhutiani et al. 2017). Their potential toxicity to the environment and its related biota has been documented (Hakanson, 1980).

Potential Ecological risk Index (PERI) (5) will be calculated as the sum of ecological risk factors indexes (Eri) (6) for specific metals in a sample according to (Hakanson, 1980).

$$\mathrm{PERI} = \sum \mathrm{Eri1} + \mathrm{Eri2} + \mathrm{Eri3} + \mathrm{Eri4} + \mathrm{Eri5} \ldots\ldots\ldots \mathrm{Erin} \tag{5}$$

$$\mathrm{ERi} = (\mathrm{Tr}) \times (\mathrm{CF}) \tag{6}$$

Where CF is the contamination factor and Tr is the toxic response factor viz: Cr =2, Pb=Cu=5, V=2, Cd=30 and Zn=1(Hakanson, 1980), Ni=5 (Bhutiani*et al.,* 2017).

The resultant values will be rated as; R'<150 (low), 150≤R'<300 (moderate), 300≤R'<600 (considerable) and R'≥ 600 (very high).

4.16 Non-Cancer Risk Indices

4.16.1 Estimated Daily Intake (EDI)

The acceptable daily intake (ADI) is used to make risk assessments about systemic toxicity. An empirically established "no-observed-adverse-effect level (NOAEL)" is the basis for its derivation. The Adverse Diffusion Index (ADI) is the maximum quantity of a chemical that an individual may be exposed to everyday for a prolonged duration (sometimes a lifetime) without experiencing harmful effects. Furthermore, it functions as a risk management instrument, namely in determining permissible levels of pollutants in food and water (USEPA, 2005). Excessive exposure beyond the EDI is considered "unacceptable", whereas exposure below the EDI is considered "acceptable" or "safe". The designated amount of exposure is considered "acceptable," while any degree of exposure beyond the EDI is considered "unacceptable." Error Dose Index (EDI) is a conservative estimate that may vary by an order of magnitude within safe boundaries. Exposures above the EDI are linked to a greater likelihood, but not with certainty, of negative consequences. Furthermore, the EDI is seen as a threshold where the likelihood of severe consequences is minimal.

Estimated daily intake (EDI) was calculated by the following equation (Ahmed, et al, (2019):

$$\mathrm{EDI} = \frac{(\mathrm{Cn\ X\ IGr\ X\ EF\ X\ ED})}{Bwt\ \mathrm{X\ AT}} \tag{3}$$

where C*n* is the concentration level of metal (mg/kg dry-wt); *IGr*is the acceptable ingestion rate, which is 55.5 g/day for adults and 52.5 g/day for children; *Bwt*is the body weight: 70 kg for adults and 15 kg for children, EF is exposure frequency and ED exposure duration.

4.16.2 Hazard Quotients (HQ)

The health hazards associated with human exposure to heavy metals in samples from Ibaa community will be assessed using hazard quotients (HQ) based on the non-carcinogenic risks criteria set by USEPA (2004). The hazard index (HI) will be computed to evaluate the cumulative non-carcinogenic hazards of exposures. This index accounts for the overall hazard quotients across different exposure pathways (Şimşek et al., 2022).

$$\mathrm{HQ} = \frac{\mathrm{CDE}}{\mathrm{RfD}} \tag{18}$$

4.16.3 The Hazard Index (HI)

The hazard index (HI) is the cumulative total of dangers presented by the potentially absorbed types of pollutants. It is sum of non-carcinogenic effects:

Hazard Index

$$\mathrm{HI} = \sum \mathrm{HQIng} + \mathrm{HQInh} + \mathrm{HQDerm} \tag{19}$$

HI <1 for non-carcinogenic effects (acceptable risk, no action required from a human health perspective (policy decision) (USEPA, while

HI > 1 reflect the occurrence of negative effects (further chemical-specific evaluation required (USEPA, 2005), HI > 4 is regarded as high negative effect according to US EPA.

5. Statistical Analysis

Data collected generated from laboratory analysis was subjected to statistical analysis using mean, standard error mean and Analysis of variance (ANOVA) to determine the differences between stations and months. The health risk and ecological risk will be calculated using the result. The analysis was done using Statistical Package for Social Sciences (SPSS), Version 25.

6. Results

6.1 Physicochemical Parameters of Surface Water

This report presents the physicochemical properties of water samples obtained from three monitoring sites across the sampling period.

6.2 pH

The pH values obtained throughout the research period ranged from 6.950 to 8.000 (Table 1; Figure 2a). The lowest pH value was recorded at Station in March, while the highest pH value was reported at Station 2 in October. According to Table 1, the lowest mean pH was observed at Station 1 with a value of 7.522±0.084, while the highest mean pH of 7.566±0.088 was determined at Station 3. A one-way analysis of variance (ANOVA) conducted across the months and stations revealed that there was no statistically significant variation in the average pH levels across the stations and months (p>0.05).

6.3 Total Dissolved Solids (TDS)

Total dissolved solids TDS concentration collected across the stations and the months revealed that there were slight variations throughout the period samples as presented in Table 1 and Figure 2b. The table shows that variations in TDS values ranges from 6213.000mg/L – 8923.000mg/L with the lowest TDS recorded in station 3 in the month of November, while the highest was recorded in Station 2 in the month of March. Station 2 recorded the highest mean value (7931.200 ± 222.808mg/L) while Station 1 had the least mean value of 7573.700±235.833mg/l (Table 1). There was no statistically significant difference in TDS across the months and stations, according to a one-way analysis of variance (p>0.05).

6.4 Electrical Conductivity (µs/cm)

Electrical conductivity observed across the stations and months revealed that there was no much variation throughout the period sampled as presented in Table 1 and Figure 2c. From November to March, the mean variance in electrical conductivity values at Station 3 varies from 10430,000µS/cm to 1,783,000µS/cm. Station 1 reported a minimum of 14179.000±684.294µs/cm, whilst Station 2 recorded a high of 15268.200 ± 549.977µs/cm. Conductivity does not vary substantially (p>0.05) among stations or months, according to a one-way analysis of variance.

6.5 Dissolved Oxygen

The values for DO varied from 5.400 mg/L in September at station 3 to 9.400 mg/L in June at station 2 (Figure 2d). According to Table 1, the mean value was 6.936±0.311mg/L at Sampling Station 1, while the maximum value was 7.200 ± 0.320mg/L at Station 3. No statistically significant differences (p>0.05) were found in the concentrations of dissolved oxygen among the sample sites according to a one-way analysis of variance (ANOVA).

6.6 Temperature

Throughout the course of the research, the surface water temperature varied between 27.500ºC in January at station 2 to 31.000ºC in June at station 3. Table 1 and Figure 2e demonstrate that the maximum mean temperature (29.470 ± 0.3040C) was recorded at site 3, while the lowest (29.180±0.2800C) was reported at Station 1 sampling site. No statistically significant difference was found across months and stations according to a One-way Analysis of Variance (ANOVA) (p>0.05).

Table 1. *Range, Mean ± Standard Error (SE) of Physico-chemical parameters of water in Bodo Creek, Rivers State, Nigeria.*

	Range, Mean±SE	Range, Mean±SE	Range, Mean±SE	p-value	NUPRC limit	WHO limit
	Stn 1 (Goi)	Stn 2 (St Pat water side)	Station 3 (Kozo)			
pH	6.950-7.800 7.522±0.084	7.150 - 8.000 7.566 ± 0.088	7.210 - 7.800 7.551 ± 0.059	0.082	6.5-9.2	6.5-8.5
TDS (mg/l)	6213.000-8581.000 7573.700±235.833	7079.000 - 8923.000 7931.200 ± 222.808	6219.000 - 8871.000 7747.300 ± 271.275	0.536	500	250
EC (µS/cm)	10520.000-17247.000 14179.000±684.294	12290.000 -17766.00 15268.200 ± 549.977	10430.000 - 17830.00 14750.900 ± 757.776	0.662	2000	2000
D.O (mg/l)	5.500-8.920 6.936±0.311	5.700 - 9.400 6.904 ± 0.344	5.400 - 8.600 7.200 ± 0.320	0.249	3.0-5.0	>4
Temperature (°C)	27.600- 30.400 29.180±0.280	27.500 - 30.100 29.280 ± 0.255	27.600 - 31.000 29.470 ± 0.304	0.276	25-30	25-32

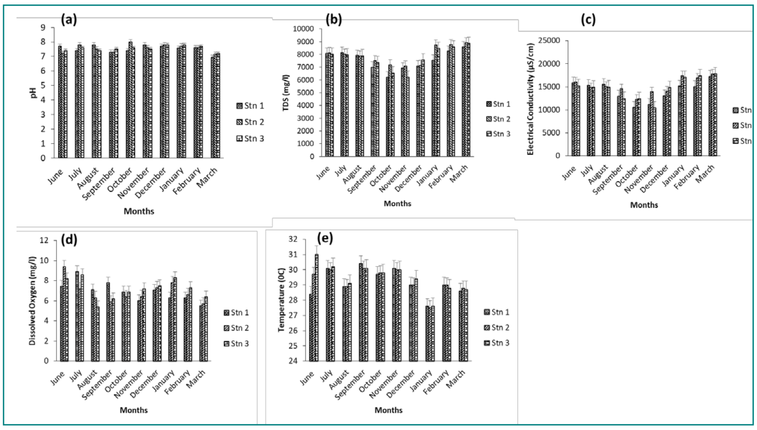

Figure 2. *Monthly physico-chemical parameters in surface water across station in Bodo Rivets State, Nigeria (±SE)*

6.7 Heavy Metals in Surface Water

Table 2 and Figure 3 show the results of the heavy metals in surface water across all sample locations.

6.7.1 Cadmium (Cd)

In the months of February and March, the surface water Cd content varied among the sites, ranging from 0.00mg/L at stations 2 and 3 to 0.02mg/L at stations 1 and 3 (Figure 3a). The mean concentration was 0.01±0.00mg/L, as shown in Table 4.2. The results of the analysis of variance (ANOVA) showed that there were substantial variations in cadmium levels across the stations (P<0.05).

6.7.2 Lead (Pb)

As shown in Figure 3b, the concentration of lead in the surface water varied throughout the stations. At station 3, it was 0.02 mg/L in June, August, November, and December, whereas at station 2, it was 0.07 mg/L in November and December. In Station 2, the mean concentration was 0.05±0.00 mg/L, whereas in Station 3, the mean concentration was 0.03±0.00 mg/L (Table 2). Distinct variations in Pb concentrations between the stations were shown using a one-way analysis of variance (ANOVA) with a significance level of P<0.05.

6.7.3 Copper (Cu)

In November, the concentration of copper (Cu) in surface water at station 1 was 0.03 mg/L, but in March, the value at station 3 was 3.95 mg/L (Figure 3c). According to Table 4.2, Station 2 had the greatest mean concentration of 0.89±0.22mg/L, while Station 3 had the lowest mean concentration of 0.83±0.39mg/L. There was no statistically significant variation in Cu concentrations among stations at P>0.05 (P=0.986) according to the one-way analysis of variance (ANOVA).

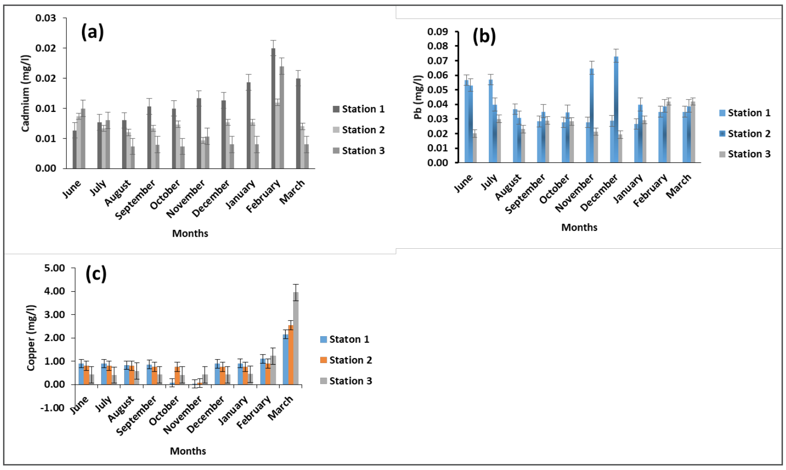

Figure 3. *Monthly heavy metal concentration in surface water across sampling station in Bodo, Rivers State, Nigeria (±SE)*

Table 2. *Mean ±S.E concentration of Heavy metals in Surface water (mg/l) (± SE)*

Metals	Station 1	Station 2	Station 3	p-value	NUPRC/ WHO limit
Cd (mg/l)	0.01±0.00	0.01±0.00	0.01±0.00	0.017	0.03
Pb (mg/l)	0.04± 0.00	0.05±0.00	0.03±0.00	0.005	0.01
Cu (mg/l)	0.84±0.20	0.89±0.22	0.83±0.39	0.986	1.0

6.8 Heavy Metals in Sediment

Table 3 and Figures 4a-c show the findings of the heavy metals in sediment across all test locations.

6.8.1 Cadmium (Cd)

As shown in Figure 4a, the concentration of Cadmium (Cd) in the sediment varied from 0.01 mg/kg in March to 0.32 mg/kg in February at station 3. The mean was 0.20±0.01mg/kg at sampling station 1, with 0.16±0.03mg/kg being the lowest at station 3. No significant difference was found among the stations in the analysis of variance (ANOVA) (P>0.05), as shown in Table 3.

6.8.2 Lead (Pb)

The concentration of Pb in sediment across the stations ranged from 0.11mg/kg in station 3 in the month of September - 4.16mg/kg in station 3 in the months of February and March (Figure 4b) with the highest mean of 2.45±0.36mg/kg in recorded in Station 2 and lowest mean 2.45±0.36mg/kg in Station 3 (Table 3). With a p-value greater than 0.05, the analysis of variance (ANOVA) revealed no statistically significant variation across the stations.

6.8.3 Copper (Cu)

The sediment concentration of Copper (Cu) across the stations ranged from 0.08mg/kg in station 2 in the months June, July, August and September -14.58mg/kg in station 2 in the months of February and March (Table 3). The highest mean was at Station 2 (3.08±1.92mg/kg) and lowest at Station 1 (2.90±1.57mg/kg). Table 3 displays the results of the analysis of variance (ANOVA), which demonstrated that there were no statistically significant differences between the stations (P>0.05).

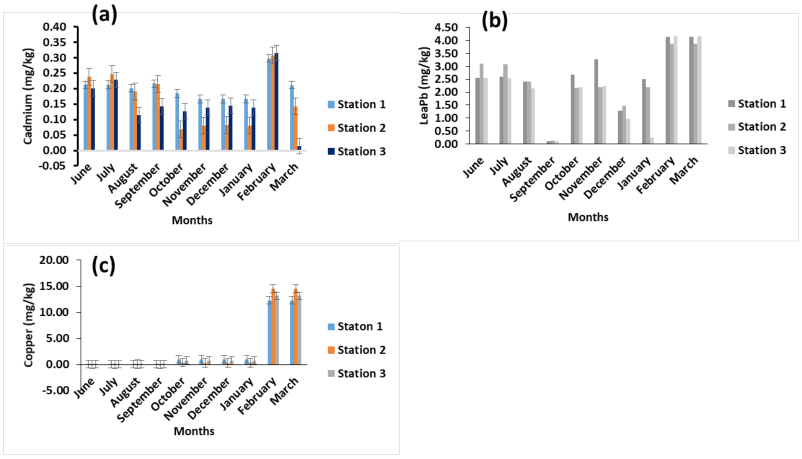

Figure 4. *Mean concentration of heavy metal in sediments at Bodo sites in Rivers State, Nigeria (±SE)*

Table 3. *Mean ± SE of heavy metals in sediment (mg/kg)*

Stations	Stn 1 (Goi)	Stn 2 (St Pat water side)	Station 3 (Kozo)	p-value	NUPRC/WHO limit
Cd (mg/kg)	0.20±0.01	0.17±0.03	0.16±0.03	0.303	0.8
Pb (mg/kg)	2.57±0.38	2.45±0.36	2.13±0.44	0.722	85
Cu (mg/kg)	2.90±1.57	3.08±1.92	2.97±1.70	0.997	36

6.9 Heavy Metals in Periwinkle

Table 4 summarizes the heavy metal data obtained from the sample sites in periwinkle.

6.9.1 Cadmium (Cd)

Periwinkle exhibited Cadmium (Cd) concentrations ranging from 0.00mg/kg to 0.22mg/kg. The maximum average cadmium content was documented at Sampling Station 3 at 0.07±0.05mg/kg, whereas the lowest found at Station 2 was 0.05±0.05mg/kg. An analysis of variance (ANOVA) revealed no statistically significant difference among the stations (P>0.05).

6.9.2 Lead (Pb)

The concentration of Pb in periwinkle across the stations ranged from 0.00 mg/kg - 0.21 mg/kg (Table 4) with the highest mean of 0.05±0.05mg/kg in Station 1 and lowest mean 0.00±0.00mg/kg in Station 3. An analysis of variance (ANOVA) revealed no statistically significant difference among the stations (P>0.05).

6.9.3 Copper (Cu)

The concentration of Copper (Cu) in periwinkle across the stations ranged from 0.00 -12.60mg/kg (Table 4). Station 3 had the lowest mean concentration (2.99±2.32mg/kg), whereas Station 1 had the highest (4.22±2.84mg/kg). There were no statistically significant differences between the stations, according to the analysis of variance (ANOVA) (P>0.05).

Table 4. *Concentration of heavy metals (mg/kg) in periwinkle (Range, Mean ± SE)*

Parameters	Goi	St Pat w/s	Kozo	p-Value	WHO limit
Cd	0.06±0.05	0.00-0.19 0.05±0.05	0.00-0.22 0.07±0.05	0.981	0.003
Pb	0.00-0.21 0.05±0.05	0.00-0.08 0.03±0.02	0.00-0.01 0.00±0.00	0.541	0.001
Cu	0.03-12.60 4.22±2.84	0.04-10.40 3.64±2.30	0.00-9.82 2.99±2.32	0.942	0.05

6.9.4 Contamination Factor (CF)

Analysis of sediment samples at the three sampling locations yielded the following Contamination Factor: During the rainy season, the reported values for Pb are 0.023 at station 1, 0.026 at station 2, and 0.022 at station 3. In the dry season, the corresponding values for stations 1, 2, and 3 are 0.035, 0.031, and 0.027. The Cadmium (Cd) values for stations 1, 2, and 3 were 0.263, 0.278, and 0.183 respectively during the rainy season, and 0.248, 0.158, and 0.010 correspondingly during the dry season. CF for copper (Cu) during the wet season was 0.002 at all locations. Figure 5a shows that the CF for copper during the dry season was lowest at station 1 (0.106) and highest at Station 2 (0.113).

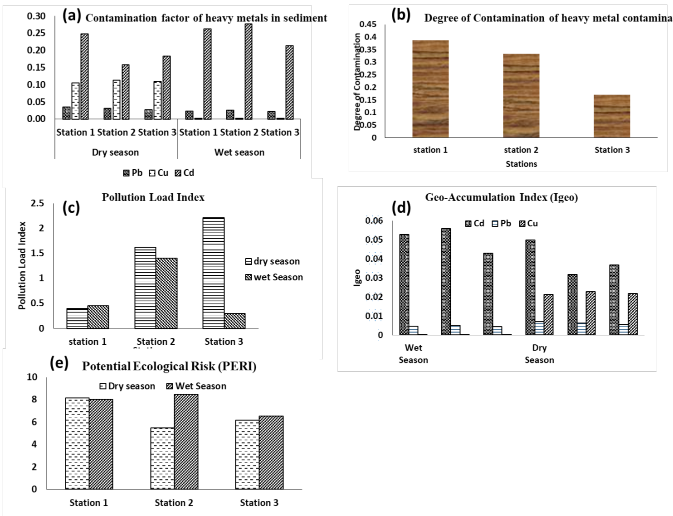

Figure 5. *(a) Contamination factor of heavy metals in sediment (b) degree of Contamination of heavy metal contamination in sediment, (c) pollution Load Index, (d) geo-Accumulation Index (Igeo), (e) potential Ecological Risk of heavy metals.*

6.9.5 Degree of Contamination

According to Figure 5b, the heavy metal contamination levels at the three sample sites were as follows: 0.386 at station 1, 0.334 at station 2, and 0.170 at station 3.

6.9.6 Pollution Load Index of Metals in Sediment

The Pollution load index (PLI) in sediment across the stations were: 0.393 in station 1, 1.625 in Station 2 and 2.216 in station 3 during the dry season, and 0.447 in station 1, 1.404 in Station 2 and 0.297 in station 3 during the wet season (Figure 5c).

6.9.7 The Geo-accumulation Index (Igeo)

The Geo-accumulation index of analyzed sediment samples in the 3 sampling points was as follows: Pb= 0.005 (station 1), 0.005 in station 2 and 0.004 in station 3 during the wet season and 0.007, 0.006 and 0.006 for stations 1, 2, and 3 respectively in the dry season. The concentrations of Cd were 0.053, 0.056, and 0.043 for stations 1, 2, and 3 throughout the rainy season, and 0.050, 0.032, and 0.037 for stations 1, 2, and 3 during the dry season, respectively. A copper (Cu) Igeo value of 0.0004 was recorded at all sites during the rainy season. During the dry season, the Igeo of copper was found to be lowest at station 1 (0.021) and greatest at Station 2 (0.023), as shown in Figure 5d.

6.9.8 Potential Ecological Risk Index (PERI) in Surface Water

The Potential Ecological Risk Index (PERI) across the stations were: 8.159 in Station 1, 5.467 in Station 2 and 6.166 in station 3 during the dry season, while in the wet season, the Potential Ecological Risk was 8.010 in station 1, 8.484 in Station 2 and 6.544 in station 3 (Figure 5e).

6.10 Human Health Risk

6.10.1 Estimated Daily Intake (EDI)of Toxic Metals Study Area

In Table 5, the Estimated Daily Intake (EDI) of the examined samples in the surface water is shown. During the rainy season, the EDI values of Pb varied from 0.0009mg/l to 0.0011mg/l, whereas in the dry season, they ranged from 0.0009 to 0.0014mg/l. The elemental distribution index (EDI) of Cadmium (Cd) varied from 0.0003mg/l to 0.0003mg/l during the rainy season and from 0.0003mg/l to 0.0003mg/l during the dry season. The Cu levels ranged from 0.0131mg/l to 0.0249mg/l during the rainy season and from 0.023 to 0.032mg/l during the dry season. The computed expected daily intake of hazardous metals followed the pattern Cu>Pb>Cd.

6.10.2 Periwinkle (Tympanotonusfuscatus)

Biota: Table 5 displays the Estimated Daily Intake (EDI) of the examined substances in the surface water. The EDI values of Pb during the wet season varied from 0.00mg/l to 0.00mg/l, including a range of 0.00 to 0.0006 during the dry season. Cadmium (Cd) EDI varied from 0.0054mg/l to 0.0063mg/l during the rainy season and from 0.0004mg/l to 0.0007mg/l during the dry season. The copper levels were among 0.2784mg/kg - 0.3234mg/kg during the rainy season and 0.000 to 0.0311mg/kg during the dry season. The computed estimated daily intake of hazardous metals flowed in the order Cu>Cd>Pb.

Table 5. *Estimated daily intake of human exposure to metals*

	Surface water (mg/l/Bw)			Periwinkle (mg/kg/Bw)		
	Stn 1	**Stn 2**	**Stn 3**	**Stn 1**	**Stn 2**	**Stn 3**
Wet season						
Pb	0.0011	0.0011	0.0009	0.0060	0.0023	0.00
Cd	0.0003	0.0003	0.0003	0.0060	0.0054	0.0063
Cu	0.0249	0.0226	0.0131	0.3234	0.2874	0.2780
Dry season						
Pb	0.0009	0.0014	0.0009	0.000	0.0006	0
Cd	0.0003	0.0003	0.0003	0.0004	0.0004	0.0007
Cu	0.0231	0.0277	0.0323	0.0311	0.0303	0.0000

6.10.3 Hazard Quotient (HQ) and Hazard Index (HI) of Toxic Metals

The Hazard Quotient of analyzed surface water samples and periwinkle in the 3 sampling points in both seasons was as follows:

Surface Water: The hazard quotient via ingestion route (HQi) of Pb in the wet season was highest in station 1 (0.028) and lowest in station 3 (0.022), while in the dry season, the HQi ranged between 0.022in Station 3 to 0.048 in station 1. HQi of Cd in the wet season was highest in Station 1 (2.137) and lowest in station 3 (1.115), while in the dry season, the HQi ranged between 1.982in station 1 to 2.771 in station 3. HQi of Cu in the wet season was highest in station 1 (0.014) and lowest in station 3 (0.008), while in the dry season, the HQi of Cu ranged between 0.009 in stations 1 and 3 to 0.015 in station 2 as presented in Table 6. The Hazard Index via ingestion route (HIi) values in the wet season ranged between 1.146 in station 3 to2.178 in station 1, in the dry season,HIi values ranged between 2.039 in station 1 to 2.802 in station 3.

Periwinkle: HQi of Pb in the wet season was highest in station 3 (0.024) and lowest in station 2 (0.014), while in the dry season, the HQi ranged between 0.014in Station 2 to 0.024 in station3. HQi of Cd in the wet season was 0.000 across the stations, while in the dry season, the HQi ranged between 0.042in station 1 to 0.049 in station 2. HQi of Cu in the wet season was highest in station 1 (0.639) and lowest in station 3 (0.000), while in the dry season, the HQi of Cu ranged between 0.627 in station 3 to 0.655 in station 1 as presented in Table 6.

The Hazard Index via ingestion route (HIi) values in the wet season ranged between 0.024 in station 3 to 0.656 in station 1, in the dry season, HIi values ranged between 0.698 in station 3 to 0.715 in station 1.

Table 6. *Hazard quotient and Hazard Index of human exposure to heavy metals*

Wet	**Wet season**			**Dry season**		
	Stn 1	**Stn 2**	**Stn 3**	**Stn 1**	**Stn 2**	**Stn 3**
Surface water						
Metals	HQi	HQi	HQi	HQi	HQi	HQi
Pb	0.028	0.024	0.022	0.048	0.026	0.022
Cd	2.137	1.935	1.115	1.982	2.383	2.771
Cu	0.014	0.012	0.008	0.009	0.015	0.009
HI	**2.178**	**1.972**	**1.146**	**2.039**	**2.424**	**2.802**
Periwinkle	HQi	HQi	HQi	HQi	HQi	HQi
Pb	0.017	0.014	0.024	0.017	0.014	0.024
Cd	0.000	0.000	0.000	0.042	0.049	0.047
Cu	0.639	0.627	0.000	0.655	0.639	0.627
HI	**0.656**	**0.641**	**0.024**	**0.715**	**0.702**	**0.698**

Table 7. *Target Hazard quotient (THQ) and Total Target Hazard Quotient (TTHQ)*

Wet	**Wet season**			**Dry season**		
	Stn 1	**Stn 2**	**Stn 3**	**Stn 1**	**Stn 2**	**Stn 3**
Surface water						
Metals	THQ	THQ	THQ	THQ	THQ	THQ
Pb	0.327	0.327	0.245	0.245	0.408	0.245
Cd	0.057	0.057	0.057	0.057	0.057	0.057
Cu	0.621	0.564	0.329	0.579	0.693	0.807
TTHQ	**1.01**	**0.95**	**0.63**	**0.88**	**0.16**	**1.11**
Periwinkle						
Pb	1.714	0.653	0.000	0	0.163	0
Cd	1.200	1.086	1.257	0.086	0.08	0.149
Cu	8.086	7.186	6.950	0.779	0.757	0
TTHQ	**11.000**	**8.924**	**8.207**	**0.864**	**1.000**	**0.149**

7. Discussion

7.1 Physicochemical Parameters

The mean temperature range (Table 1, Figure 2) falls within the DPR and WHO limit of 25 to 32^0C for surface water. The results obtained are typical of tropical waters and it is similar to earlier reports in interstitial waters (e.g., Emoyoma, *et al*., (2020).

The pH range of 6.95 to 7.21 obtained in this study is slightly neutral. The pH result obtained in this study is higher than 5.34± 0.11 to 6.92±0.04 reported by Komi and Sikoki, (2013) which they described to be optimal for a freshwater but not optimal for a brackish or sea water.

The results of pH from this study falls within the WHO/NUPRC regulatory limit for surface water as suitable for the sustenance of aquatic lives.

Total Dissolved Solids mean range value were far higher than the permissible limit of 250mg/l by the WHO and 500mg/l by NUPRC (Table 1). In natural waters, biochemical, physical and chemical activities affects dissolved oxygen's concentration. In contrast, the dissolved oxygen concentration was within the WHO and NUPRC acceptable limit of >4mg/l. This can be as a result of the influence of runoffs.

Electrical conductivity indicates a very high amount of solutes, it is a medium that indicates the ability to conduct an electric current and tells the level of freshness of a water body (Emoyan et al, 2021). The result of this study far exceeds the 1190, 550, 890 and 450 µS/cm by Popoola, *et al*., (2019). Results for electrical conductivity across all stations are more than what is considered safe by the World Health Organization.

7.2 Heavy Metals

Many harmful heavy metals become less soluble at higher pH levels, and temperature and DO concentrations also have a role in heavy metal toxicity (Avila-Perez et al., 1999). In the surface water, the concentration of heavy metals was in the order Cd>Pb>Cu. Although it was greater than the 0.20±0.14mg/l found in Lagos Lagoon by Aderinola et al. (2009), the concentration of copper in the surface water (Table 2, Figure 3) was lower than the water copper limit set by the World Health Organization. All of the stations' lead concentrations were below the 0.03 mg/l threshold set by the World Health Organization. There is no evidence of pollution from human activities in the environment based on the lead levels in the surface water. The concentration cadmium as obtained in this study is below the WHO permissible limit. In sediment, Cadmium results were lower than the WHO permissible limit of 0.8mg/kg, a lower range has also been reported by Chindah, *et al.,* (2009) in the Bonny river system. Cadmium is considered a very noxious metal to human health. Cadmium concentration in this study showed no significant difference across the various sampling stations. High cadmium across the stations is as a result of high input of cadmium materials. The concentration of Copper in the sediment (2.90±1.57mg/kg to 3.08±1.92mg/kg) was lower than the WHO permissible limit for copper in sediment. Lead concentration across the stations were lower than the WHO permissible limit of 50mg/kg. 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 14.13mg/kg recorded previously by Babatunde, *et al*. (2014).

In the Periwinkle samples, lead concentrations were above the regulatory limit of 0.003mg/kg by the WHO (WHO, 2006) (Table 4), thus indicating possible health concern from the consumption of periwinkle in the study area. Onwuli et al. (2014) reported a similar range of 0.91±0.54mg/kg in periwinkles at the Eagle Island, Nigeria. In addition, lead poisoning may be transmitted via water, food, and even the air we breathe (Olufemi et al. 2022). Cadmium concentration in periwinkle (Table 2) were slightly higher than the WHO recommended standards. Copper in Periwinkle (Table 2) far exceed the regulatory limits of the WHO (WHO, 2006). Similarly, Aderinola*et al*. (2009) reported a lower concentration 0.36±0.39mg/kg in Lagos Lagoon. Copper is essential to human life, but excessive exposure may cause gastrointestinal distress, kidney and liver problems, and blood disorders (Silver et al. 2019).

7.3 The Pollution Index (PI) of Toxic Metals in Sediment Samples

The results of all the heavy metal pollution index across the stations were all above the critical pollution index of 100 thus indicating possible pollution from heavy metals (Kumar *et al*, 2018).Müller (1979) introduced a method for quantitatively estimating metal contamination in aquatic sediment using the Igeo (Index of Geo-accumulation), which measures the loading of metals on a geological matrix. The geo-accumulation index (Igeo) is a metric used to determine metal concentrations in sediment by comparing observed concentrations with undisturbed or crustal sediment (control) levels. It is calculated using the formula: Igeo = ln (Cn/1.5×Bn), where Cn represents the measured content of element "n", Bn represents the geochemical background value of the same element (metal) 'n', and factor 1.5 represents the potential variations in background data caused by lithogenic disturbances. Interpretation of the data was based on Muller's (1979) geo-accumulation index categorization table.

The results of Geo-accumulation index (Igeo) across the stations and seasons showed that the sediments were practically unpolluted from Pb, Cd and Cu (Table 5). The index values observed were substantially lesser than those of Chris *et al*, (2023) in some polluted sites in the Niger Delta. The analysis of the contamination factor (CF) and pollution load index (PLI) of the metals from the different sample stations indicates that the sediment of these stations is free from contamination with Cd, Pb, and Cu. A comparative analysis of the metals at the sites, using the Pollution Index (PI) as a classification, revealed that the sediment was free from metal contamination (Aigberua andTarawou, 2018).

The Estimated Daily Intake (EDI) values of surface water Pb, Cd and Cu in the wet and dry seasons across the stations were less than the RfDas stipulated by the USEPA/WHO (Table 5).The EDI of metals in periwinkle (*Tympanotonusfuscatus*) were less than the standard RfD's for Pb, and Cd, but higher than the recommended RfDs in Cu in both seasons. The EDI values obtained differs from the values reported by Anyanwu and Chris, (2023) from some polluted creeks.

The target hazard quotients were computed to assess the non-carcinogenic health hazards resulting from the population's exposure to the pollutants (Yi et al., 2017). HQ values less than 1 is an indication that there is no apparent risk to the population, however, when HQ results are greater one, it signifies potential non-carcinogenic risk (Okati et al. 2021). However, in this investigation, the concentration of HQ in Periwinkle was found to be less than 1 in all heavy metal species. Regarding surface water, the HQ values for Pb and Cu were all below 1, while for Cadmium they were over 1 (Table 6). The hydroluminescence (HQ) of heavy metals from the surface decreased in the order of Cd>Pb>Cu and in the decreasing order of Cu>Pb>Cd in Periwinkle rocks.All metal hazard quotients in the sediment samples of the research region were more than 1 and ranked in decreasing order as Pb>Cd>Cu, based on cutaneous exposure. Results showed that cadmium (HQ > 1) is the primary factor contributing to the health risk to residents when consuming water from the study region. In comparison, Pb and Cu are the least significant contributors. Conversely, none of the metals presented any non-cancerous hazard when consumed from periwinkles in the research region. However, they did increase the chance of severe health problems when exposed to the sediment in the study area.Therefore, it is important to closely monitor and maintain the levels of cadmium and lead in sediment and surface water from the study area to prevent non-carcinogenic risks like cadmium and lead poisoning. The present study agrees with Kamunda et al. (2018) that cadmium is a major contributor to these non-carcinogenic risks in surface water and sediment.

It is important to know the non-carcinogenic health hazards associated with pollutant exposure in order to calculate the target hazard quotients (Yi et al., 2017). There is a consistent order of Cu>Pb>Cd in the findings of THQ in surface water across sites and seasons (Table 7).

When measuring surface water, the Total Target Hazard Quotient (TTHQ) was 0.63 to 1.01 during the rainy season and 0.16 to 1.11 during the dry season, indicating a healthy state. Stations 2 and 3 had a Lead Target Hazard Quotient of less than 1, while all stations had a value of less than 1 during the dry season. With the exception of one station during the dry season, the total HM of Cd was more than 1 during the rainy season. Comparatively, Cu's THQ was above 1 during the rainy season but below 1 during the dry. Wet season total target hazard quotient (TTHQ) readings for sediment and periwinkle indicated a high danger to human health; dry season readings for periwinkle did not indicate any harm to human health, although they were beyond the threshold at Station 2.

8. Conclusion

There is a lot of pollution in the area because of the high water quality index. Sediment heavy metal concentrations below legal limits suggest little contamination from these contaminants. Exposure to sediment and ingestion of periwinkles from the research region likely represent non-cancer health risks, however dietary intakes and hazard quotients demonstrated that Pb and Cu did not constitute a considerable health risk. Furthermore, there is very high possibility of cancer risk from the study area via ingestion of surface water, periwinkle and exposure to the sediment in the study area. Furthermore, artisanal activities that lead to deposition of oil in the environment should be discouraged and awareness should be given to the locals in the study area of the possible side effects of direct exposure to pollution in surface water, sediment and periwinkles.

Recommendations

This study recommends that:

i. The detrimental effects of heavy metal concentrations in sediment surface water and periwinkle should be brought to the attention of the residents.

ii. The remediation activities should be quickly done so as to reduce the exposure duration of the locals to the heavy metals in the environment.

iii. Further studies should be carried out on the potential cancer health risk in the study area.

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