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| **DISTRIBUTION OF HADROCHEMICAL PARAMETERS, TOXICOLOGY AND HAZARDOUS ELEMENTS BIOACCUMULATION IN PERIWINKLE (*TYMPANOTONUS FUSCATUS*)** **FROM** **THE NIGER DELTA COAST, NIGERIA**DAVIES IBIENEBO CHRIS1\*, OKECHUKWU KENNETH WOKEH2, MOHAMAD NOR AZRA3,4, FATHURRAHMAN LANANAN5, MURNI NUR ISLAMIAH KASSIM3, LEE SEONG WEI6*1Department of Fisheries, University of Port Harcourt, Rivers State, P.M.B. 53233, Nigeria. 2Department of Animal and Environmental Biology, University of Port Harcourt, Rivers State, Nigeria. 3Institute of Climate Adaptation and Marine Biotechnology (IMB), Universiti Malaysia Terengganu (UMT), Kuala Nerus 21030, Terengganu, Malaysia. 4Research Center for Marine and Land Bioindustry, Earth Sciences and Maritime Organization, National Research and Innovation Agency (BRIN), Pemenang 83352, Indonesia. 5East Coast Environmental Research Institute, Universiti Sultan Zainal Abidin (UniSZA), Gong Badak Campus, Kuala Nerus 21300, Terengganu, Malaysia. 6Advanced Livestock and Aquaculture Research Group, Department of Agricultural Sciences, Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Jeli Campus, 17600, Jeli, Kelantan, Malaysia.**\*Corresponding author:* *davies.chris@uniport.edu.ng* |
| **HIGHLIGHTS** | **GRAPHICAL ABSTRACT** |
| * The study examined the distribution of physicochemical parameters and toxic metals in the Niger Delta Coast, Nigeria
* The findings revealed considerable variability in levels of heavy metals and physicochemical features between stations
* Higher metal bioaccumulation in these areas may lead to potential environmental and health implications due to their susceptibility to metal pollution.
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| **ARTICLE INFO** | **ABSTRACT** |
| ***Article History:****Received: 5 June 2024Accepted: 25 June 2024**Published: 28 June 2024****Keywords:*** *Physicochemical Parameters, Hazardous Elements, Niger Delta, Bioaccumulation.* | The study examined the distribution of physicochemical parameters and toxic metals in the Niger Delta Coast, Nigeria. The shellfish (*T. fuscatus*), water, sediments, and physicochemical data were collected from three sampling stations over a six-month period. The findings revealed considerable variability in levels of heavy metals and physicochemical features between stations. Station 2 had higher temperature and salinity levels but lower total dissolved solids, pH, biological oxygen demand, and dissolved oxygen. Station 1 had the highest concentrations of Fe, Zn, Cd, Pb, Cu, and As in water and sediment samples, while Station 2 consistently had the lowest concentrations. Station 3 had the highest Fe levels while Station 2 had the lowest Zn values in terms of sediment bioaccumulation. The study found no significant differences (p > 0.05) in all metals in water, *T. fuscatus* and sediment between stations 1 and 2, except for Cu, which showed slight variation (p < 0.05). In fish, Cu showed slight variation (p < 0.05) between stations 1 and 2, and in sediment, Fe and Cu showed significant differences (p < 0.05) between stations 1. For As bioaccumulation, Station 3 had the greatest concentration, measuring 0.00000123 mg/kg, while both Stations 1 and 2 shared the lowest bioaccumulation at 0.00000058 mg/Kg. Station 3 had the highest Fe bioaccumulation, possibly due to local conditions or iron sources. Higher metal bioaccumulation in these areas may lead to potential environmental and health implications due to their susceptibility to metal pollution. The study suggests that constant assessment and remedial measures are needed to safeguard the aquatic ecosystem in the area. |
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**Introduction**

The Niger Delta, a region of enormous ecological significance, is situated along the coasts of Nigeria., is characterized by its rich biodiversity and abundant aquatic ecosystems (Onyena*et al.*, 2021). However, rapid industrialization, urbanization, and the prospective impact of oil exploration activities have sparked worries about the potential impact of these anthropogenic activities on the coastal environment. Among the significant environmental challenges, the Niger Delta coast faces, the hydrological distribution of physicochemical parameters and the bioaccumulation of hazardous heavy metals stand out as critical issues (Lv*et al.*, 2020). Understanding the hydrological distribution of physicochemical parameters is essential for comprehending the overall health and functioning of aquatic ecosystems.

The physicochemical features of the environment, such as temperature, salinity, pH, DO and nutrient levels, significantly influence habitat conditions and aquatic species (Chris*et al.*, 2023a). According to Sih*et al.* (2012), variations in these parameters can alter the distribution, abundance, and behaviour of aquatic inhabitants, affecting the ecological dynamics of the Niger Delta coast. Heavy metals, including Fe, Zn, Cd, Pb, Cu and As, among others, are persistent environmental pollutants released by various industrial and human activities (Davies and Ekperusi, 2021). These metals have toxic effects on aquatic organisms, and the capacity for biological accumulation in the supply chain poses a risk to both aquatic life and human health.

The periwinkle (*Tympanotonus fuscatus*) is an edible and brackish water species native to the Niger Delta region of Nigeria. It forms a major part of the local delicacy in the region with high economic value. The assessment of heavy metal bioaccumulation in the periwinkle (*T. fuscatus*) will provide serious data on the level of contamination in this shellfish species found in this coastal ecosystem and its potential effects on the resident biota (Davies*et al.*, 2022).

The current study seeks to examine the hadrochemical distribution of physicochemical parameters along the Niger Delta coast and assess the ecotoxicology of hazardous heavy metal bioaccumulation in this shellfish from brackish coastal ecosystems. By examining the variations of physicochemical parameters, insights into the total water quality can be provided. and identify areas of concern that may require immediate attention for conservation and management (Chris*et al.*, 2023a). Furthermore, the study will explore the level of hazardous metals in different aquatic organisms and sediments to understand the potential pathways and sources of metal contamination (Sarker*et al.*, 2022).

The current research seeks to enhance our knowledge of the ecotoxicity of hazardous element bioaccumulation along Nigeria's Niger Delta coast. As a result of this study, effective strategies can be developed for the conservation and sustainable management of this ecologically significant region, while also providing essential data to guide future policies and practices aimed at mitigating heavy metal pollution and preserving the integrity of the coastal ecosystems in Nigeria.

**Materials and Methods**

***Description of Sampling Stations***

The study employed a quantitative approach, with three sample stations chosen near artisanal crude oil refining operations, waste disposal sites, dredging, and fishing. The stations were selected based on their closeness to polluted areas, waste effluent, and human waste disposal. Station 1 is located between Latitude E06°86'64.71" and Longitude N 4°76'55.91"; Station 2 is located between Latitude E06°88'19.09" and Longitude N 4°80'34.85". Station 3 is, however, located between E06°84'22.57" and Longitude N 4°81'74.11" (Figure 1).

***Study Area***

The Atuka Creek is a fishing village in Rivers State, Nigeria, located along the Buguma axis. The area, which includes the main channel and feeder creeks, is located southeast of the Niger Delta region which connects several riparian towns. The region is home to numerous abandoned artisanal crude oil installations, exposing it to the dangers of oil leaks.



Figure 1: Map showing the studied stations in Rivers State, Nigeria.

***Sample and Sampling Procedure***

Three sampling sites were selected in each community based on the characteristics of the streams' research region, with stations at least 1000 meters apart. Heavy metals (Pb, Cu, Fe, Cd, Zn, and As) were chosen due to their high prevalence in the region due to industrial and household effluents. Sediment, water, and biota (*T. fuscatus*) samples were taken for analysis, and geographic coordinates were produced using a portable GPS receiver unit (Magellan GPS 315). The sampling was done once a month from April to September 2023. This was done during the first week of each sample month.

***Collection of Samples***

***Periwinkle (Tympanotonus fuscatus)***

Freshly caught live periwinkle (*T. fuscatus*) were taken from the catches of local fishermen at three sampling locations in each community throughout a six-month period at 21-day intervals. A total of sixty individual species of fish were collected, with a mean length of 5.50.65cm and weight (5.30.87g), fifteen per station at each sampling community, would be collected during a six-month period (April 2023 to September 2023) to allow for statistical fluctuation. The fish was chosen because it is intimately associated with mangroves and neighbouring soft-bottom peri-tidal environments. Some fishes are particularly well adapted to an amphibious lifestyle. The sampling distance from the bank was chosen to guarantee that the water and sediment samples represented the actual and visible pollution pockets in the study region. To preserve the integrity of the materials, all samples were clearly labelled and transported to the laboratory on an ice chest the same day. The samples were then measured and refrigerated until they could be analysed. Heavy metal content was determined using conventional procedures (WEF 1992).

***Sediment***

Sediments were collected on a monthly basis for six months in the form of a composite with a 'Ekman grab' picker from three independent places in the creeks and stored in a plastic bag that had previously been treated with 10% nitric acid for 24 hours and washed with de-ionized water. Following that, the frozen samples were transported to the Laboratory. The samples were kept at 20°C in the laboratory until they were processed and evaluated using the Atomic Absorption Spectrophotometric Machine (API-RP 45). The sampling distance from the bank was chosen to guarantee that the water and sediment samples represented the actual and visible pollution pockets in the study region.

***Water***

Samples of interstitial water were collected using clean, high-density Schott glass tubing. Before sampling, these bottles were rigorously cleaned by first using detergent, then rinsing with tap water, and finally soaking for 24 hours in 50% hydrochloric acid (HCl). Prior to sampling, the vessels were cleaned with tap water and triple-distilled water after being treated with acid. This thorough cleaning procedure was employed to prevent any potential contamination of the samples with metal residue. Its purpose was also to prevent metals from adhering to glazing surfaces, as acid treatment of the glass aids in the dissolution of metals.

The samples were carefully wrapped and sent to the laboratory in frozen packs to protect their integrity. Each sample was meticulously labelled, and they were promptly conveyed to the laboratory on the same day in an ice chest to preserve their quality. The samples were subsequently measured and kept in refrigeration until the analysis was conducted. The analysis of heavy metal content adhered to standard methods (APHA 1998). The selection of sampling locations near the bank was made to ensure that both water and sediment samples accurately represented the evident pollution areas within the study zone.

***Procedures for Measuring Physicochemical Parameters of the Surface Water***

Three pits were dug at random on each sampling station's intertidal flat to allow for the accumulation of interstitial water. The interstitial water was tested using an in-situ Handheld Multimeter (Milwaukee Model pH600) after fifteen minutes. Using a portable multimeter (Milwaukee Model pH600 and Laboratory Benchtop metre 860033-model), the following parameters of the water were measured in situ: pH, temperature, salinity, conductivity, total suspended solids (TSS), and total dissolved solids (TSS). The instrument had previously been calibrated using a standard buffer, and it was restarted to allow for self-calibration before being cleaned with distilled water. The parameters were then measured by placing the probe into the river, allowing the readings to stabilise, and recording the values. Winkler's 5-day BOD test technique (APHA, 1998) was used to determine dissolved oxygen (DO). A 250ml reagent amber BOD container was filled with interstitial water collected from the intertidal flat's dogged pit. The bottle was filled with the sampled water mixture. Distilled water was used to dilute a 5ml sample to 100ml. This was poured into two 50ml DO bottles and sealed. The initial DO of the Milwaukee DO metre (MW 600 model) was determined using one of the two test samples. The other test sample was incubated for 5 days at 200°C before being analysed for DO using the above method.

BOD (mg/l) = Initial DO – Final DO

***Determination of Heavy Metals***

AAS was used to determine the amounts of lead, copper, iron, cadmium, zinc, and arsenic. (APHA, 1998). The device was set up and used in accordance with the manufacturer's instructions.

***Procedure for Heavy Metal Analyses***

***Sample Preparation***

A blender was used to granulate fish samples, sediment samples were air dried, and water was digested with 20ml conc. H2SO4. Results are typically reported in mg/L.

***Total Digestion for Heavy Metals***

Complete digesting technique of extraction utilising nitric, perchloric, and sulfuric acids (APHA 3030I modified): One gramme of silt and granulated flesh of the shellfish samples were weighed in a 250 ml Pyrex conical flash, then 20 ml of digestion solution was added. In order to ensure complete digestion, the samples were heated in the fume hood using an electrical mantle at 250°C until the colour of the granules changed from dark to grey. The digested solution was heated, then taken out of the fume hood and put on the workbench to cool. The mixture was then given 20 cc of distilled water to add before being given more time to cool. The digested solution was sieved into a 100 ml glass volumetric flask using ashless Whatman 42 filter paper. The digested filtrate was produced in the volumetric flash up to the 100ml flask mark. This was then put onto a brand-new 100 ml plastic bottle and branded. Pb, Cu, FE, Cd, Zn, and As were analysed using the AAS method on sample extracts.

***Quality Assurance and Control***

The apparatus was set up using atomic absorption standards for several heavy metals that were buck certified to produce a calibration curve. For every ten samples, a reagent blank was run to prevent equipment drifting. Recovery rates varied between 82 and 110%. Atomic absorption spectrophotometry (Model 210 VGP, Buck Scientific) was used to measure the levels of metals in soil and biota samples. The method description and wavelength (nm) were consistent with the work of Davies and Ekperusi (2021). All samples were analysed in duplicate, and the reported values are the means of these measurements.

***Bioaccumulation Factor***

The Bioaccumulation Factor (BAF) will be computed using the formula below to estimate the level of heavy metal accumulation in the shellfish tissue:

BAF = Metal concentration in the flesh of *T. fuscatus* (mg/kg) /Metal concentration in sediment (mg/kg).

Where BF is the ratio of metal concentration in shellfish tissues to concentration in sediment, which was computed using the Microsoft Excel programme 2010.

***Statistical analysis***

The differences in heavy metal concentrations in the water, sediment, and *T. fuscatus* were examined using a one-way analysis of variance (ANOVA) with a level of significance of 0.05. Also, standard errors were calculated. Microsoft Excel 2010 and IBM SPSS Statistics 20 were both used for all statistical work.

**ResultS**

***Spatial Variation of Physico-Chemical Parameters***

Table 1 displays the variance in physicochemical properties between stations. Temperature, pH, DO, salinity, BOD, and TDS readings were significantly different (p0.05) between Station 2 and sites 3 and 1. Temperature was significantly higher at Station 2 (29.500.74 oC) than at Station 1 (25.750.57 oC), whereas pH was higher at Station 1 (6.720.14) than at Station 2 (5.680.18). Station 1 had the highest Dissolved Oxygen concentration (3.350.11 mg/l), followed by Station 3 (3.270.21 mg/l) and Station 2 (2.920.20 mg/l). The salinity at Station 2 was the highest (15,280.71 ppm), followed by Station 3 (12,780.81 ppm) and Station 1 (11,440.45). However, Station 2 documented the highest Biological Oxygen demand value (3.600.79 mg/l) and Station 1 reported the lowest value (2.460.42 mg/l). In addition, the highest value of electrical conductivity was recorded at Station 2 (34.073.62 S/cm), followed by Station 3 (28.782.610 S/cm) and Station 1 (25.760.47 S/cm). In addition, Station 2 had the highest Total Dissolved Solids (28,173.77 mg L-1) whereas Station 1 had the lowest (19,202.29 mg L-1). There were no significant (p>0.05) differences between the tested parameters at Stations 1 and 3.

Table 1: Summary of the Distinction in the physicochemical parameters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Stations** | **Temperature****(o C)** | **pH** | **DO****(mg/l)** | **Salinity** **(ppm)** | **BOD****(mg/l)**  | **Cond** **(µS/cm)** | **TDS****(Mg L-1)** |
| **1** | 25.75±0.57b | 6.72±0.14b | 3.35±0.11a | 11.44±0.45 b | 2.46±0.42b | 25.8±0.50b | 19.2±2.30b |
| **2** | 29.50±0.74a | 5.68±0.18a | 2.92±0.20b | 15.28±0.71 a | 3.60±0.79a | 34.1±3.60a | 28.2±3.80a |
| **3** | 27.40±0.75ab | 6.45±0.18b | 3.27±0.21a | 12.78±0.81b | 2.78±0.47b | 28.8±2.60b | 21.9±2.50b |
| **WHO 2011** | 30 | 6.6-8.5 | 6 | 120 | 10 | 600 | 500 |

\*WHO: World Health Organization.

***The Correlation between Physicochemical Parameters***

Table 2 depicts the relationship between physicochemical characteristics in the research area. There was evidence of a positive correlation between temperature and salinity (0.630), dissolved oxygen and (0.246), conductivity and (0.501), and total dissolved solids (0.695). pH and dissolved oxygen (0.092) correlated positively, although salinity (-0.500) was adversely connected and dissolved oxygen and (-0.917), conductivity and (-0.901), and total dissolved solids (-0.688) were strongly and negatively correlated. There were no positive associations between dissolved oxygen and any other parameter. Salinity was shown to be related to dissolved oxygen (0.675), conductivity (0.645), and total dissolved solids (0.350). Electrical conductivity and biological oxygen demand had a significant and overwhelmingly favourable connection (0.924). which was likewise linked to total dissolved solids (0.546). The relationship between electrical conductivity and total dissolved solids was found to be positive (0.802).

Table 2:Correlation between physicochemical parameters in the study area

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tempt** | **pH** | **DO** | **Salinity** | **BOD** | **Conduct** | **TDS** |
| **Temperature (oC)** | 1 |  |  |  |  |  |  |
| **PH** | -0.199 | 1 |  |  |  |  |  |
| **DO (mg/l)** | -0.567 | 0.092 | 1 |  |  |  |  |
| **Salinity (ppm)** | 0.630 | -0.500 | -0.789 | 1 |  |  |  |
| **BOD (mg/l)** | 0.246 | -0.917\* | -0.203 | 0.675 | 1 |  |  |
| **Conductivity (µS/cm)** | 0.501 | -0.901\* | -0.263 | 0.645 | 0.924\*\* | 1 |  |
| **TDS (ppt)** | 0.695 | -0.688 | -0.114 | 0.350 | 0.546 | 0.802 | 1 |

\*\* Correlation is significant at the 2-tailed level of 0.01.

\* Correlation is significant at the 2-tailed level of 0.05.

***Spatial Variation of Heavy Metals in Water***

Table 3 depicts the spatial variation of heavy metal levels (Fe, Zn, Cd, Pb, Cu, As) in water samples from different locations (locations 1, 2, and 3). According to the statistics, Station 1 had the greatest mean Fe content at 37.65 mg/l, while Station 2 had the lowest at 35.41 mg/l. In terms of Zn concentrations, Station 1 had the highest average concentration at 10.9 mg/l, while Station 3 had the lowest at 10.04 mg/l. In terms of Cd concentrations, Station 1 had the greatest average of 0.07 mg/l, while Stations 2 and 3 had the lowest average of 0.05 mg/l. Station 2 had the highest average Pb values (0.10 mg/l), whereas Stations 1 and 3 had the lowest (0.09 mg/l). Station 1 had the highest average Cu content at 149.19 mg/l, while Station 2 had the lowest at 146.58 mg/l. Stations 2 and 3 had the highest average As concentrations of 0.005 mg/l, whereas Station 1 had the lowest value of 0.003 mg/l. Station 1 emerged as the station with the highest overall metal concentrations, while Station 3 consistently reported the lowest concentrations. No significant variations (p > 0.05) were observed in all the metals in the water except for Cu, which recorded a slight variation (p < 0.05) between station 1 and the other two stations.

Table 3: Spatial Variation of Heavy Metals in Water

|  |
| --- |
| **Heavy Metals (mg/L)** |
| **Stations** | **Fe** | **Zn** | **Cd**  | **Pb** | **Cu** | **As** |
| **1** | 37.65±3.03 a | 10.9±1.62 a | 0.07±0.09 a | 0.08±0.1 a | 149.19±154.9a | 0.003±0.001 a |
| **2** | 35.41±3.88 a | 10.7±1.71 a | 0.05±0.01 a | 0.10±0.01 a | 146.58±4.7 b | 0.005±0.001 a |
| **3** | 37.00±3.99 a | 10.04±1.13 a | 0.06±0.01 a | 0.09±0.02 a | 146.0±9.5 b | 0.005±0.001 a |

***Spatial Variation of Heavy Metals in Fish (T. fuscatus)***

Table 4 shows information about how the levels of heavy metals changed over time in *T. fuscatus* samples taken from three different locations, named Stations 1, 2, and 3. These values are expressed in mg/Kg. In the case of Fe, Station 1 has the greatest average concentration (12.20 mg/kg), whereas Station 2 has the lowest average concentration (11.32 mg/kg). Station 1 has the greatest average content of Zn, equal to 104.8 mg/Kg. whereas Station 3 records the lowest average concentration, measuring 101.8 mg/Kg. Cadmium (Cd) concentrations across all three stations register very low averages, approximately 0.001 mg/Kg, with minimal fluctuations. For Pb, Stations 1 and 2 exhibit identical average concentrations, both at 0.004 mg/Kg, which is slightly higher than the average concentration at Station 3, rated at 0.004 mg/Kg. Regarding Cu, Station 1 reports the highest average concentration at 0.73 mg/Kg, while Station 2 has the lowest average value of 0.69 mg/Kg. In contrast, the greatest concentration of As, quantifying at 0.002 mg/Kg, is documented at Station 3, whereas Stations 1 and 2 display equivalent average concentrations, each measuring 0.001 mg/Kg. No significant variations (p > 0.05) were observed in all the metals in the Fish (*T. fuscatus*) except for Cu, which recorded slight variation (p < 0.05) between station 1 and the other two stations.

Table 4: Spatial Variation of Heavy Metals in Fish (*T. fuscatus*)

|  |
| --- |
| **Heavy Metals (mg/ Kg)** |
| **Stations** | **Fe**  | **Zn**  | **Cd**  | **Pb**  | **Cu**  | **As**  |
| **1** | 12.20±4.19a | 104.8±1.37a | 0.001±0.01a | 0.005±0.02a | 0.73±4.0 a | 0.001±0.001a |
| **2** | 11.32±0.39a | 102.9±4.13a | 0.001±0.00a | 0.004±0.001a | 0.69±0.0 ab | 0.001±0.001a |
| **3** | 11.74±0.44a | 101.8±4.28a | 0.001±0.00a | 0.004±0.001a | 0.67±0.03 b | 0.002±0.001a |

***Spatial Variation of Heavy Metals in Sediment***

Table 5 gives a comprehensive look at the heavy metal concentrations discovered in the sediment. Station 1 had the greatest average concentration of Fe, measuring 1729.15 mg/kg, while Station 2 had the lowest average concentration, measuring 1615.61 mg/kg. Moving on to Zn, Station 1 had the greatest concentration, averaging 220.8 mg/kg, while Station 3 had the lowest, averaging 212.9 mg/kg. Cd concentrations were highest in Station 1, with an average of 2.95 mg/kg, and lowest in Station 3, with an average of 2.33 mg/kg. Pb had the highest mean concentration at Station 1 (9.47 mg/Kg), whereas Station 2 had the lowest mean value (7.55 mg/Kg). Station 1 had the greatest mean concentration of Cu, measuring 541.22 mg/Kg, while Station 3 had the lowest average concentration, measuring 481.14 mg/Kg. As for As concentrations, they reached their highest level in Station 1, with an average concentration of 0.017 mg/Kg, while both Station 2 and Station 3 displayed lower concentrations, averaging 0.015 mg/Kg. No significant variations (p > 0.05) were observed in all the metals in the sediment except for Fe and Cu, which were significantly different (p < 0.05) between the station 1 and the other two stations

Table 5: Spatial Variation of Heavy Metals in Sediment

|  |  |
| --- | --- |
|  | **Heavy Metals (mg/Kg)** |
| **Stations** | **Fe** | **Zn** | **Cd**  | **Pb** | **Cu** | **As** |
| **1** | 1729.15±0.51a | 220.8±6.62a | 2.95±0.00 a | 9.47±0.00a | 541.22±0.0 a | 0.017±0.001a |
| **2** | 1615.61±86. b | 219.3±7.50a | 2.75±0.34 a | 7.55±0.92a | 496.51±22.7b | 0.015±0.001a |
| **3** | 1625.16±79.54b | 212.9±7.89a | 2.33±0.34 a | 8.27±1.35a | 481.14±22.9b | 0.017±0.001a |

***Bioaccumulation sedimentation***

There is a clear picture of how metal concentrations build up over time in sediment samples from different locations in Table 6. Station 3 demonstrated the highest bioaccumulation of Fe at 0.007223904 mg/Kg, while Station 2 exhibited the lowest bioaccumulation, measuring 0.007006641 mg/Kg. Moving on to Zn, Station 2 displayed the highest bioaccumulation at 0.063691114 mg/Kg, with the lowest bioaccumulation recorded in Station 1, standing at 0.060607813 mg/Kg. Cd showed the highest bioaccumulation in both Stations 2 and 3, with both registering 0.00000062 mg/Kg, while Station 1 had the lowest bioaccumulation, at 0.00000058 mg/Kg. Station 1 had the greatest degree of Pb bioaccumulation, at 0.0000029 mg/Kg, whereas Station 3 indicated the least bioaccumulation, measuring 0.00000246 mg/Kg. Cu demonstrated its highest bioaccumulation in Station 2 at 0.000427083 mg/Kg, while Station 3 reported the lowest bioaccumulation, measuring 0.000412267 mg/Kg. For As bioaccumulation, Station 3 had the greatest concentration, measuring 0.00000123 mg/kg, while both Stations 1 and 2 shared the lowest bioaccumulation at 0.00000058 mg/Kg.

Table 6: Bioaccumulation sedimentation

|  |  |
| --- | --- |
|  | **Heavy Metals (mg/Kg)** |
| **Stations** | **Fe** | **Zn** | **Cd**  | **Pb** | **Cu** | **As** |
| **1** | 0.00705549 | 0.060607813 | 0.00000058 | 0.0000029 | 0.000422173 | 0.00000058 |
| **2** | 0.007006641 | 0.063691114 | 0.00000062 | 0.0000025 | 0.000427083 | 0.00000062 |
| **3** | 0.007223904 | 0.062639986 | 0.00000062 | 0.00000246 | 0.000412267 | 0.00000123 |

**Discussion**

***Spatial Variation of Physicochemical Parameters***

This suggests the presence of spatial variations in the physicochemical features of surface water between the three stations. The examined physicochemical attributes encompass salinity, pH, BOD, DO, TDS, and temperature.

***Temperature (ºC)***

Temperature plays a crucial role in influencing the metabolic rates of marine organisms (Fitzgibbon*et al.*, 2017). The temperature in Station 2 was significantly higher as compared to Station 1 and Station 3. According to Davies and Efekemo (2022), changes in temperature within the aquatic environment can lead to varying effects on different species. While some may experience an increase in metabolic activity, others may be subjected to stress, particularly those adapted to colder conditions. Therefore, the higher temperature in Station 2 might indicate that certain temperature-sensitive species could be affected, potentially leading to changes in the ecological community (Chris*et al.*, 2023a).

***pH***

pH is a crucial physicochemical factor that impacts the solubility of different substances and plays a role in the viability and reproductive success of aquatic organisms, as noted by Akankali*et al.* (2023). The pH values observed in Station 1 were notably elevated when compared to those in Station 2 and Station 3. According to Bhateria and Jain (2016) variations in the optimal pH range for a particular ecosystem can harm aquatic life, especially those organisms with specific pH requirements. Therefore, the lower pH value in Station 2 might indicate increased acidity, which could negatively impact pH-sensitive species (Zhu and Bratlie, 2018). This finding aligns with the research conducted by Dong*et al.* (2020), which documented alterations in the community structure and morphological adaptations of benthic foraminifera in a microcosm experiment in response to pH fluctuations.

***Dissolved Oxygen (DO mg/l)***

The Dissolved Oxygen levels are highest in Station 1, followed by Station 3, with Station 2 having the lowest concentration. Dissolved Oxygen is vital for the viability of aquatic organisms, particularly fish and other aquatic life, as emphasized by Emeka*et al.* (2020). According to Jaiswal and Pandey (2019), low DO levels can lead to hypoxia, where oxygen-demanding processes exceed the available oxygen. This can result in stress or mortality for oxygen-dependent species (Gibbs*et al.*, 2022). The lower DO levels in Station 2 may raise concerns about potential oxygen stress for aquatic organisms in that area.

***Electrical conductivity (EC µS/cm)***

The conductivity of electricity is a measurement of water's ability to conduct an electrical current and is usually used to evaluate the concentration of dissolved ions or salts in water (Igwe*et al.*, 2021). The higher EC value typically indicates higher salinity levels in the water. Aquatic organisms have varying degrees of salinity tolerance (Davies*et al.*, 2022). Some species are adapted to thrive in saline environments, while others are not. High EC can favour the growth of salt-tolerant species.

According to Onyena*et al.* (2021), high salinity can lead to habitat fragmentation, as it restricts the distribution of species adapted to lower salinity conditions. The moderate EC value at Station 3 suggests intermediate salinity levels. Aquatic communities at this EC range might include both freshwater and salt-tolerant species, potentially enhancing biodiversity.

Some sensitive species may experience stress due to moderately elevated salinity (Akankali*et al.*, 2023). Station 1 recorded the lowest EC value which signifies a relatively low salinity environment, and this has distinct ecological implications. However, Chris*et al.* (2023a) suggested that low salinity often indicates better hydrological connectivity with freshwater sources, allowing for species migration and exchange.

***Salinity (ppm)***

Station 2 recorded the highest salinity values, followed by Station 3, while Station 1 had the lowest salinity levels. Salinity stands as a significant parameter in aquatic ecosystems, particularly in estuaries and coastal regions, as highlighted by Tian*et al.* (2020). It holds the capacity to influence the distribution and population density of aquatic organisms, as some are better suited to freshwater environments, while others thrive in brackish or marine settings, as noted by Lesiv*et al.* (2020). The higher salinity in Station 2 might be attributed to a more brackish environment, affecting the composition of aquatic communities in that area.

***Biological Oxygen Demand (BOD mg/l)***

According to Abdullahi*et al.* in 2021, BOD estimates the amount of oxygen required by bacteria to breakdown organic compounds in water. Station 2 has the greatest levels of BOD, while Station 1 displayed the lowest. Elevated BOD levels are indicative of organic pollution, often stemming from sources like sewage or agricultural runoff, as noted by Akankali*et al.* (2023). According to Davies and Efekemo (2022), elevated BOD levels can deplete oxygen in the water, leading to adverse effects on aquatic organisms. The higher BOD in Station 2 suggests a higher organic pollution load, which may pose ecological risks for the aquatic ecosystem (Chris and Anyanwu, 2022).

***The Total Dissolved Solids (TDS Mg L-1)***

TDS measures the total dissolved solids in water, which includes salts and minerals (Butler*et al.*, 2018). Station 2 had the greatest TDS while Station 1 had the lowest. Elevated TDS in Station 2 could indicate more minerals or pollution sources, affecting aquatic life (Ustaoğlu, 2021). High TDS levels can have an influence on water quality and vulnerable aquatic species (Agwu*et al.*, 2023). The significant variation in physicochemical parameters between Station 2 and the other two stations suggests that Station 2 may have different ecological conditions and potential risks for aquatic organisms compared to the other two stations (Chris and Anyanwu (2023). These differences highlight the importance of careful monitoring and management of the aquatic environment to mitigate potential ecological risks and preserve the health of the ecosystem.

***Correlation in Physicochemical Parameters***

Analysis of physicochemical parameters revealed correlations in the study area. Temperature and salinity are possibly influenced by factors like evaporation, water circulation patterns, or proximity to marine sources (Davies and Ekperusi (2021). There was a positive relationship found between dissolved oxygen and conductivity, which means that higher conductivity means more dissolved oxygen (Igwe*et al.* (2021). Wu*et al.* (2022) suggested that ions and dissolved substances may influence this relationship.

However, the study showed a negative correlation between dissolved oxygen and pH, potentially linked to rising pH values. Davies and Oghenetekevwe (2023) noted that lower dissolved oxygen could impact the aquatic ecosystem's health. Dissolved oxygen, salinity, and total dissolved solids all had negative associations. This meant that there was less dissolved oxygen in the water that was salty or polluted (Chis*et al.*, 2023a).

Positive correlations were observed between salinity, dissolved oxygen, conductivity, and total dissolved solids, meaning these parameters tend to rise together. High salinity levels, as per Onyena*et al.* (2021), can influence water properties and impact aquatic ecosystems. There is a strong positive relationship between BOD and electrical conductivity. According to BOD data, this implies that areas with higher conductivity may also have higher levels of organic pollution (Etteieb*et al.*, 2017). According to Igwe*et al.* (2021), this suggests that higher conductivity may be associated with increased pollution.

Total dissolved solids and electrical conductivity are related in a good way, which means that places with more total dissolved solids may also have more electrical conductivity. Total dissolved solids represent dissolved substance concentrations and can indicate mineral content or pollution levels in the water.

***Spatial Variation of Heavy Metals in Water***

The results show the variation of trace metal levels (Cu, Zn, Fe, Pb, As and Cd) in water samples from different stations. Heavy metal concentrations differ among the three stations, indicating spatial flashpoints with varying metal levels. Station 1, which shows consistently higher concentrations of most metals, might be considered a flashpoint for heavy metal contamination in the study areas. However, the variations in metal concentrations between the three stations can offer valuable information about potential sources of pollution. The higher metal concentrations at certain stations could indicate point sources of pollution nearby, such as industrial discharges, wastewater outfalls, or runoff from contaminated sites (Chris*et al.*, 2023a). As noted by (Davies and Ekperusi, 2021), even at relatively low concentrations, heavy metals can exert detrimental impacts on aquatic ecosystems and human health. However, stations with elevated metal levels may require closer monitoring and mitigation strategies to protect the environment and public health (Ahmed*et al.*, 2015). Moreover, (Akankali*et al.*, 2023) stated that variations may be due to random fluctuations which could have genuinely meaningful differences.

***Spatial Variation of Heavy Metals in Fish (T. fuscatus)***

The results highlight the spatial distinction of trace metal levels in the shellfish (*T. fuscatus*) samples collected from three different stations. In the study area, heavy metal concentrations vary between the three stations, indicating flashpoints of metal accumulation. Station 1, with consistently higher concentrations of most metals, appears to be a hotspot for heavy metal accumulation in fish. This result suggests that Station 1 might be subject to higher pollution levels or closer proximity to pollution sources.

The variance in heavy metal levels in fish across different locations can be ascribed to the process of bioaccumulation and trophic transfer. According to Ahmed*et al.* (2019), fish are known to accumulate heavy metals from their environment, and these concentrations can increase as they move up the food chain. Chris*et al.*, (2023a) agrees that the higher metal concentrations in fish at specific stations may be related to the availability of contaminated prey or exposure to polluted habitats.

Chris*et al.*, (2023b) reported that heavy metals can pose significant health risks to both aquatic organisms and humans. Therefore, the elevated levels of heavy metals in *T. fuscatus* may lead to adverse health effects, especially in this region where fish is a major part of the local diet. However, they advised that elevated concentrations of metals, such as arsenic and lead, in certain fish samples warrant further investigation and risk assessment to ensure public safety.

Heavy metal contamination in fish can have ecological consequences. Elevated metal concentrations in fish may impair their reproductive success, growth, and overall fitness (Ustaoğlu, 2021). However, Ahmed*et al.* (2019) reported that predatory birds and mammals that feed on these fish could also be affected by the bioaccumulation of heavy metals, disrupting the local food web. Furthermore, stations exhibiting elevated metal concentrations may signal the existence of proximate pollution point sources or regions marked by substantial anthropogenic activities, which release heavy metals into the environment (Dan*et al.*, 2022). Analyzing discrepancies in heavy metal concentrations across stations might help identify probable pollution sources in the study region.

***Spatial Variation of Heavy Metals in Sediment***

The study's findings have important implications for monitoring environmental contamination and its potential consequences through the spatial variation in heavy metal concentrations in sediment. Station 1 consistently exhibited the highest levels of Zn, Fe, Cd, Cu, Pb, and As in the sediment, suggesting elevated pollution levels or proximity to pollution sources. This observation aligns with Ustaoğlu (2021), who emphasized that concentrated heavy metal levels at specific stations offer valuable insights for identifying potential pollution sources.

Elevated metal concentrations at Station 1 may point to the presence of nearby pollution points influenced by anthropogenic activities that release heavy metals into the environment, as mentioned by Akankali*et al.* (2023). Dan*et al.* (2022) underscored that heightened heavy metal concentrations in sediment can pose environmental risks. As these metals enter the food chain through sediment-dwelling organisms, there is potential for bioaccumulation and biomagnification effects in the aquatic ecosystem, with adverse repercussions for aquatic organisms and the overall ecological balance, in line with the observations of Odekina*et al.* (2021).

Station 1, with higher concentrations of various heavy metals, might be considered to have poorer sediment quality compared to Stations 2 and 3. However, Simpson and Batley (2016) confirmed that poor sediment quality can affect benthic communities, sediment-dwelling organisms, and overall sediment stability. According to Wu*et al.* (2022), sediment serves as a reservoir for heavy metals, and their release from sediment into the water column can be influenced by environmental conditions. However, Etteieb*et al.* (2017) stated that heavy metal remobilization and its influence on water quality is evaluated by considering the geographical variance of heavy metals in sediment.

Davies*et al.* (2022) further demonstrated that high levels of heavy metals, particularly copper, cadmium, and lead, can be hazardous to benthic creatures and aquatic life. However, organisms living in or near the sediment may experience adverse health effects, reduced reproduction, and altered community structure (Ahmed*et al.*, 2019). Moreover, Razzak*et al.* (2022) stated that sediment contamination can affect human health, especially in areas where sediments are disturbed or resuspended (e.g., during dredging or construction activities). According to Ahmed*et al.* (2015), excessive levels of arsenic, lead, and other heavy metals in sediment can endanger human health if they are discharged into the water and then consumed through fish eating or direct contact.

***Bioaccumulation Sedimentation***

The results of this investigation for heavy metal concentrations in soil samples from various sites revealed that Fe bioaccumulation values surpassed one for all three stations. This suggests that organisms living in the sediment are accumulating iron at a higher rate than they are eliminating it (Davies and Ekperusi (2021). Odekina*et al.* (2021) state that Fe is an important nutrient for many species and that bioaccumulation happens spontaneously. However, extremely high levels of iron bioaccumulation could indicate potential environmental changes or pollution sources (Olayinka-Olagunju*et al.*, 2021).

The bioaccumulation values for Zn were greater than one in Stations 1 and 2 but less than one in Station 3. This implies that organisms in Stations 1 and 2 are accumulating more zinc than they are eliminating, while in Station 3, zinc is being efficiently eliminated. Elevated bioaccumulation of zinc in Stations 1 and 2 might indicate higher zinc pollution levels or different environmental conditions affecting its uptake (Chris*et al.*, 2023a). However, the bioaccumulation values for Cd were less than one for all three stations. This suggests that organisms are efficiently eliminating cadmium from their bodies, and it is not significantly accumulating in their tissues (Wu*et al.*, 2022). According to Davies and Ekperusi (2021), excessive cadmium bioaccumulation may be hazardous to organisms.

The bioaccumulation values for Pb were greater than one in Station 1 but less than one in Stations 2 and 3. This indicates that organisms in Station 1 are accumulating lead at a higher rate than they are eliminating it (Razzak*et al.*, 2022), while in Stations 2 and 3, lead is being efficiently eliminated. The higher bioaccumulation in Station 1 might be due to higher lead pollution levels or other environmental factors (Odekina*et al.* (2021).

For Cu, the bioaccumulation values were greater than one (BCF >1) in Station 2 but less than one (BCF <1) in Station 3. This suggests that organisms in Station 2 are accumulating more copper than they are eliminating, while in Station 3, copper is being efficiently eliminated. The higher copper bioaccumulation in Station 2 might be related to local copper sources or specific environmental conditions. However, the bioaccumulation values for As were greater than one in Station 3 but less than one in Stations 1 and 2. This implies that organisms in Station 3 are accumulating more arsenic than they are eliminating, while in Stations 1 and 2, arsenic is being efficiently eliminated. The higher bioaccumulation in Station 3 could be attributed to localized arsenic pollution sources or unique ecological conditions (Collin*et al.*, 2022).

The values greater than one suggest that certain metals might be accumulating in the food web and raising concerns for ecological health and potential risks to human health, especially if these organisms are part of the human diet (Wu*et al.*, 2022). On the other hand, (Razzak*et al.*,2022) stated that bioaccumulation values of less than one indicates efficient elimination of metals, which is generally favorable from an environmental and human health perspective (Odekina*et al.*,2021) suggest that the differences in bioaccumulation values among stations can help identify potential pollution hotspots and guide management efforts to mitigate heavy metal contamination.

The study shows that station 3 consistently exhibited the highest bioaccumulation of the studied metals (Fe, Cd, Cu, and As). This is an indication that Station 3 might be a critical location for further investigation, as it appears to be particularly susceptible to heavy metal bioaccumulation.

**Conclusion**

The investigation of heavy metal concentrations in water, soil, fish, and bioaccumulation values in Atuka Creek unveils possible environmental health concerns and their potential repercussions on aquatic ecosystems and human well-being. These results underscore the necessity for ongoing monitoring and the implementation of effective management tactics to tackle pollution, diminish pollutant inputs, enhance treatment methodologies, and rehabilitate affected regions.

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