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## **ASSESSMENT OF HEAVY METAL CONCENTRATIONS IN WATER AND SEDIMENT OF MGBUODOHIA RIVER, OBIO\AKPOR LGA, RIVER STATE, NIGERIA**

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### **Abstract**

This study quantified concentrations of selected heavy metals lead (Pb), manganese (Mn), zinc (Zn), cadmium (Cd), and chromium (Cr) in water and sediment from the Mgbuodohia River, Obio/Akpor Local Government Area, Rivers State, Nigeria. Water and sediment samples were collected at five sampling locations; in situ physicochemical parameters were recorded and metal concentrations were determined by atomic absorption spectrophotometry. Contamination status was evaluated using Contamination Factor (CF), Geoaccumulation Index (Igeo), and Pollution Load Index (PLI), and results were compared with World Health Organization and national guideline values. Descriptive statistics characterized spatial patterns, and Pearson and Spearman correlation analyses examined relationships among metals and between matrices. Results indicated spatial heterogeneity, with midstream sites exhibiting relatively higher concentrations for some metals. Most measured concentrations in both water and sediment were within guideline limits; CF and Igeo classifications identified low to moderate contamination at isolated sites, and PLI values were generally below unity. Significant correlations among selected metal pairs and between sediment and water for certain metals suggested common anthropogenic sources and active sediment–water exchange processes. The findings provide a baseline dataset for the Mgbuodohia River and support recommendations for routine monitoring, targeted source control, and community awareness to protect ecosystem and public health.

### **Keywords:**

*Heavy metal, Mgbuodohia River, Atomic absorption concentration, Anthropogenic sources, Sediment – water exchange.*

### **INTRODUCTION**

Water is universally recognized as one of the most essential natural resources for sustaining life, supporting ecosystems, and enabling socio-economic development. Rivers, in particular,

are dynamic freshwater systems that not only provide water for domestic, agricultural, and industrial purposes but also serve as habitats for a diverse range of aquatic organisms. They play a critical role in nutrient cycling, sediment transport, and the regulation of ecological balance (UNESCO, 2020). The rapid pace of industrialization, urban expansion, and agricultural intensification has placed unprecedented pressure on river systems making it to become a sink of pollutants, among the pollutants heavy metals stand out due to their toxicity, persistence, and ability to bioaccumulate in living organisms (Tchounwou et al., 2012). Unlike many organic pollutants, heavy metals such as lead (Pb), manganese (Mn), zinc (Zn), cadmium (Cd), and chromium (Cr) are non-biodegradable. Once introduced into the aquatic environment, they can persist for decades, cycling between water, sediments, and biota, and posing long-term ecological and public health risks (Ali et al., 2019). Over time, particulate matter from industrial and domestic discharges, atmospheric deposition, and surface runoff settles to the riverbed, where metals can bind to sediment particles. Under certain environmental conditions such as changes in pH, redox potential, or hydrodynamic disturbance these metals can be remobilized into the overlying water, becoming bioavailable to aquatic organisms (Förstner & Wittmann, 2012). This process is particularly concerning for benthic species, such as crabs and mollusks, which live in close contact with sediments and can accumulate high concentrations of metals in their tissues.

The Mgbuodohia River, located in Obio/Akpor Local Government Area of Rivers State, Nigeria, is a typical example of a water body under multiple anthropogenic pressures. Flowing through both residential and industrial zones, it is exposed to a variety of potential contamination sources, including effluents from small-scale manufacturing facilities, domestic sewage, and agricultural runoff from surrounding farmlands. The river supports artisanal fishing activities, and its aquatic organisms especially crabs are harvested for both subsistence and commercial purposes. Given the socio-economic reliance on this river, any contamination with heavy metals has direct implications for food safety, public health, and environmental sustainability.

Studies conducted in other parts of the Niger Delta have revealed elevated concentrations of heavy metals in rivers impacted by oil exploration, industrial discharges, and urban runoff. For example, research on the Bonny River and New Calabar River has documented levels of Pb, Cd, and Zn exceeding WHO permissible limits in both water and sediment samples (Nwineewii & Marcus, 2021; Ololade et al., 2017). These findings raise concerns that similar contamination patterns may exist in the Mgbuodohia River, especially given its proximity to industrial and residential activities. Yet, despite these potential risks, there is a notable absence of peer-reviewed studies providing baseline data on heavy metal concentrations in this river.

The lack of such data presents a significant challenge for environmental monitoring and management. Without empirical evidence on the levels and distribution of heavy metals in the Mgbuodohia River, it is impossible to assess compliance with national and international water quality standards, evaluate the extent of ecological risk, or design targeted remediation strategies. Moreover, the absence of contamination mapping means that communities relying on the river for drinking water, fishing, and other domestic uses may be unknowingly exposed to toxic metals. This situation underscores the urgent need for a systematic, scientifically rigorous assessment of heavy metal contamination in the Mgbuodohia River, with particular attention to both water and sediment matrices.

By establishing a comprehensive baseline profile of heavy metal concentrations, this study will not only fill a critical knowledge gap but also provide a foundation for long-term environmental monitoring, policy formulation, and public health protection. The findings will be relevant not only to environmental scientists and policymakers but also to local communities whose livelihoods and well-being are directly tied to the health of the Mgbuodohia River.

## MATERIAL AND METHODS

### 2.1 Research Design

This study employed a crosssectional research design to evaluate the spatial and tidal variation of heavy metal contamination in the Mgbuodohia River during the wet season. The design incorporated tidal variation as a central factor in the sampling framework. At each station, samples were collected during both high tide and low tide to capture potential differences in heavy metal concentrations caused by tidal flushing, saline intrusion, sediment resuspension, and dilution effects. This approach was intended to determine whether tidal stage significantly influences contaminant levels, thereby providing a more comprehensive understanding of pollutant dynamics in a tidally influenced tropical river.

A composite sampling method was adopted to improve representativeness and reduce localised variability. For each tide stage at a given station, three subsamples were collected within a 10metre radius and homogenised to form a single composite sample for analysis. This method minimises the influence of microscale heterogeneity in sediment texture, water chemistry, or biotic uptake, ensuring that the resulting data reflect average conditions at each site and tide stage.

The crosssectional design was integrated with a multimatrix sampling strategy that included water, surface sediments, and edible crab tissues (*Sudanonautes africanus*). This allowed for the assessment of contamination not only in the abiotic environment but also in a representative aquatic organism, thereby linking environmental quality to potential ecological and human health risks.

### 2.2 Study Area

The study was carried out on the Mgbuodohia River, a tidal freshwater system located in Obio/Akpor Local Government Area of Rivers State, Nigeria, within the Niger Delta region. The river lies approximately 12 km northwest of central Port Harcourt and forms part of the intricate network of creeks, estuaries, and distributaries that characterise the Niger Delta's lowlying coastal plain. Geographically, the area is situated between latitudes 4°48'–4°51' N and longitudes 6°59'–7°01' E, with an elevation generally less than 10 m above sea level.

The climate is tropical monsoon, with a distinct wet season from April to October and a dry season from November to March. Mean annual rainfall exceeds 2,400 mm, with peak precipitation in July and September. Relative humidity is consistently high (80–95 %), and mean monthly temperatures range from 25 °C to 28 °C. These tidal oscillations cause periodic saline intrusion from downstream estuarine waters and influence sediment resuspension, contaminant dispersion, and nutrient cycling.

### 2.3 Sample and Sampling Techniques

Sampling was conducted during the wet season to capture peak hydrological activity and maximum pollutant transport within the Mgbuodohia River. Samples were collected from five stations during both high and low tide conditions to assess the influence of tidal fluctuations on heavy metal distribution. A composite sampling technique was adopted, where three subsamples collected within a 10-m radius at each station were homogenised to obtain representative water and sediment samples. Water samples were collected in acid-washed polyethylene bottles at approximately 30 cm below the surface, while sediment samples were obtained from the top 0–5 cm of the riverbed using a stainless-steel Van Veen grab sampler. Strict contamination control measures, including acid-washing of equipment and the use of powder-free gloves, were maintained throughout sampling.

### 2.4 Point Coordinates

The geographical coordinates of all sampling stations were determined using a Garmin eTrex 30x GPS receiver with  $\pm 3$  m accuracy and recorded in WGS 84 decimal degrees. Coordinates were verified in ArcGIS 10.8 using high-resolution satellite imagery to ensure accurate positioning within designated environmental zones. The geospatial dataset provided the framework for mapping sampling locations and analysing spatial and tidal variations in heavy metal concentrations across water and sediment matrices.

**Table 2.1:** Geographical Coordinates of Sampling Stations

Station Code	Location Description	Latitude ( $^{\circ}$ N)	Longitude ( $^{\circ}$ E)
S1	High tide	4.85012	6.98543
S2	Midstream, residential/fishing zone	4.84256	6.99218
S3	Low tide	4.83574	6.99892
S4	Estuarine mixing zone	4.82891	7.00437
S5	Coastal outlet	4.82145	7.01084

**Note.** Coordinates recorded using a handheld GPS (Garmin eTrex 30x) with  $\pm 3$  m accuracy, referenced to the WGS 84 datum. One sampling season with 5 sampling points.

### 2.5 Sampling Equipment

The following equipment was used for field sampling, insitu measurements, and preservation of samples prior to laboratory analysis: handheld GPS (Garmin eTrex 30x), van veen grab sampler (stainless steel), acidwashed polyethylene bottles (1 L), portable multiparameter meter (Hanna HI98136), portable dissolved oxygen meter (YSI ProODO), cool boxes, protective gloves and safety gear.

### 2.6 Sampling Design

A systematic sampling design was adopted to evaluate spatial variations and tidal influences along the Mgbuodohia River. Five strategically selected sampling stations represented distinct

hydrological zones and varying degrees of anthropogenic impact, including the high tide upper reach, residential midstream zone, low tide lower reach, estuarine mixing zone, and coastal outlet. These stations enabled assessment of saline intrusion, community-related inputs, tidal recession effects, biogeochemical activities, and cumulative upstream impacts. Geographic coordinates of all sampling locations were obtained using a handheld Garmin eTrex 30x GPS receiver with an accuracy of  $\pm 3$  m based on the WGS 84 datum.

## 2.7 Water Sample Digestion

Water samples were immediately acidified to pH  $< 2$  with analytical-grade nitric acid after collection to prevent metal precipitation, adsorption, and microbial alteration prior to analysis. In the laboratory, samples were homogenised, and 100 mL aliquots were digested with concentrated nitric acid on a hot plate at 95 °C until reduced to approximately 20 mL to ensure oxidation of organic matter and release of dissolved metals. The digests were cooled, filtered through 0.45  $\mu\text{m}$  membrane filters, and diluted to 50 mL with high-purity deionised water prior to analysis. All procedures followed American Public Health Association (APHA, 2017) standard methods, with procedural blanks and replicate digestions included for quality assurance and precision assessment. Final digests were stored at 4 °C in acid-washed polyethylene bottles before analysis using Flame Atomic Absorption Spectrometry (FAAS).

## 2.8 Sediment Preparation

Sediment samples were air-dried at room temperature to constant weight, gently disaggregated, and sieved through a 63  $\mu\text{m}$  stainless-steel mesh to obtain the fine fraction most suitable for heavy metal assessment. Approximately 1.00 g of the sieved sediment was digested with aqua regia (3:1 HCl:HNO<sub>3</sub>) in precleaned Teflon beakers on a hot plate at 95 °C until near dryness. The digests were cooled, redissolved in 2 % nitric acid, filtered through 0.45  $\mu\text{m}$  membrane filters, and transferred into acid-washed polyethylene bottles for analysis. All procedures followed the method of Tokalioğlu et al. (2000), with procedural blanks and replicate digestions employed for quality assurance and contamination control. Prepared samples were stored at 4 °C prior to Flame Atomic Absorption Spectrometry (FAAS) analysis.

## 2.9 Determination of pH, Conductivity, and Dissolved Oxygen

In situ measurements of pH, electrical conductivity (EC), and dissolved oxygen (DO) were conducted at all sampling stations during both high and low tide conditions to assess tidal influences on the physicochemical properties of the Mgbuodohia River. Measurements were taken immediately after sample collection using calibrated portable meters, including the Hanna HI98136 multiparameter meter for pH and EC, and the YSI ProODO optical meter for DO determination. Probes were submerged approximately 30 cm below the water surface to obtain representative readings, while calibration procedures followed manufacturer guidelines and protocols. Field measurements were recorded alongside environmental observations to support evaluation of relationships between physicochemical conditions and heavy metal concentrations in water, sediment, and biota.

## 2.10 Analysis and Quality Control

All laboratory analyses were performed under strict quality assurance and quality control (QA/QC) procedures to ensure data accuracy, precision, and reproducibility. Water and

sediment samples were analysed in triplicate to minimise random error and assess analytical variability. Certified Reference Materials (CRMs), including NIST 1643f for water, NIST 2702 for sediment, and DORM4 for biota, were used to validate analytical accuracy, with acceptable recoveries maintained within  $\pm 10\%$  of certified values. Procedural blanks were included in every batch to monitor contamination, while spiked recovery tests (80–120 % acceptable recovery) were conducted to evaluate method efficiency and matrix effects. Flame Atomic Absorption Spectrometry (FAAS) calibration was carried out using multielement standards prepared from 1000 mg/L stock solutions, with calibration curves requiring correlation coefficients ( $R^2$ )  $\geq 0.995$ . Instrument stability was checked regularly using midrange standards after every ten samples. All laboratory glassware and containers were acidwashed and rinsed with deionised water before use. Analytical procedures followed APHA (2017) Standard Methods and other internationally recognised protocols, ensuring reliable and scientifically defensible data for statistical and environmental risk assessment.

### 2.11 Heavy Metals Assessment

The concentrations of Pb, Mn, Zn, Cd, and Cr in water, sediment, and crab tissue samples were determined using Flame Atomic Absorption Spectrometry (FAAS) with a PerkinElmer AAnalyst 400 due to its sensitivity and reliability for trace metal analysis. Element-specific hollow cathode lamps and appropriate analytical wavelengths were used for each metal to optimise sensitivity and minimise interference. Calibration was performed using at least five matrix-matched standards prepared from 1000 mg/L stock solutions, and only calibration curves with correlation coefficients ( $R^2$ )  $\geq 0.995$  were accepted. Instrument accuracy was verified with midrange standards after every ten samples, while deuterium background correction was applied to reduce matrix interference. Samples were analysed in triplicate, and procedural blanks, certified reference materials, and spiked recovery tests were included to ensure analytical accuracy and precision. Detection limits were calculated as three times the standard deviation of blank measurements, and all reported concentrations exceeded these limits. The rigorous calibration and QA/QC procedures ensured reliable quantitative data for subsequent statistical and environmental risk assessments.

### 2.12 Method of Data Analysis

Data obtained from physicochemical measurements and heavy metal analyses were processed using Microsoft Excel for statistical analysis and graphical presentation. Descriptive statistics, including minimum, maximum, and mean values, were calculated for Zn, Pb, Cd, Cr, and Mn concentrations across the sampling stations to summarise concentration patterns and establish baseline conditions. Sediment contamination was evaluated using the contamination factor (CF), pollution load index (PLI), and geoaccumulation index (Igeo), providing insight into metal enrichment and overall pollution status. Pearson's and Spearman's correlation analyses were performed to assess relationships among the heavy metals and identify possible common contamination sources and geochemical associations. In addition, observed metal concentrations were compared with national standards from FMENV and DPR, as well as international guideline limits established by the World Health Organization and United States Environmental Protection Agency to evaluate environmental quality and potential ecological risks.

### 2.13 Pollution Load Index (PLI)

The degree of heavy metal contamination at each sampling station in the Mgbuodohia River was assessed using the Pollution Load Index (PLI) as described by Tomlinson et al. (1980). The PLI provides a simple, comparative means of evaluating the overall level of heavy metal pollution by integrating the contamination factors (CFs) of multiple metals into a single value. This index is particularly useful for summarising complex multi-element contamination data and for identifying stations where pollution control measures may be required.

The PLI for each station was calculated using the formula:

$$[ CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n ] \quad (2.1)$$

where (  $CF_1, CF_2, \dots, CF_n$  ) represent the contamination factors for each of the (n) metals analysed in the study. In this research, (  $n = 5$  ), corresponding to lead (Pb), manganese (Mn), zinc (Zn), cadmium (Cd), and chromium (Cr).

The contamination factor (CF) for each metal was determined as:

$$[ CF = \{ C_{\text{metal in sample}} / C_{\text{background}} \} ] \quad (2.2)$$

where (  $C_{\text{metal in sample}}$  ) is the measured concentration of the metal in the environmental sample (water, sediment, or crab tissue), and (  $C_{\text{background}}$  ) is the corresponding background concentration. Background values were obtained from published geochemical conditions rather than anthropogenic inputs.

For each station, the CFs of the five metals were multiplied together, and the (n)th root (in this case, the fifth root) of the product was taken to yield the PLI. A PLI value of 1.0 indicates that the overall metal load at the station is equivalent to the natural background level, values greater than 1.0 indicate progressive deterioration of site quality due to anthropogenic contamination, and values less than 1.0 suggest no significant pollution relative to background conditions.

All PLI calculations were performed in Microsoft Excel using cell-referenced formulas to ensure accuracy and reproducibility. The results were tabulated and plotted to facilitate spatial comparison of pollution levels across the five sampling stations. This approach allowed for the identification of contamination hotspots and provided a quantitative basis for prioritising remediation or management interventions in the Mgbuodohia River.

### 2.14 Contamination Factor (CF)

The Contamination Factor (CF) was employed to quantify the degree of heavy metal contamination in water, sediment, and crab tissue samples from the Mgbuodohia River. This index provides a straightforward means of assessing the extent to which measured concentrations of individual metals exceed natural background or reference levels, thereby allowing for the identification of metals that contribute most significantly to overall pollution.

The CF for each metal was calculated using the formula:

$$[ CF = C_{\text{sample}} / C_{\text{background}} ] \quad (2.3)$$

where (  $C_{\text{metal in sample}}$  ) represents the concentration of the metal determined in the environmental sample, and (  $C_{\text{background}}$  ) is the corresponding background

concentration. Background values were obtained from published geochemical baseline data for uncontaminated tropical river systems within the Niger Delta region, ensuring that the reference levels reflected natural lithogenic contributions rather than anthropogenic inputs.

Interpretation of CF values followed the classification proposed by Hakanson (1980), in which  $CF < 1$  indicates low contamination and suggests that the metal concentration is within natural background levels;  $1 \leq CF < 3$  denotes moderate contamination, implying some degree of anthropogenic enrichment;  $3 \leq CF < 6$  reflects considerable contamination, indicating substantial anthropogenic influence; and  $CF \geq 6$  signifies very high contamination, often associated with intense localised pollution sources such as industrial effluents, mining activities, or untreated wastewater discharges.

In this study, CF values were calculated separately for each metal at each sampling station and for each environmental matrix (water, sediment, and crab tissue). This allowed for the identification of spatial patterns in contamination and the determination of which metals posed the greatest potential ecological and human health risks. The CF results also served as input parameters for the calculation of the Pollution Load Index (PLI), thereby linking individual metal contamination to an integrated measure of overall site quality.

All CF computations were performed in Microsoft Excel using cell-referenced formulas to ensure accuracy and reproducibility. The results were tabulated and graphically represented to facilitate comparison between stations and to highlight contamination hotspots along the Mgbuodohia River.

### 2.15 Geoaccumulation Index (Igeo)

The Geoaccumulation Index (Igeo), developed by Müller (1969), was used to evaluate heavy metal contamination in sediment samples from the Mgbuodohia River. The index assesses metal enrichment by comparing measured concentrations with natural or preindustrial background levels, thereby providing a quantitative measure of anthropogenic contamination while accounting for natural variations in sediment composition.

The Igeo for each metal was calculated using the equation:

$$I_{geo} = \log_2 \left( \frac{C_n}{1.5B_n} \right) \quad (2.4)$$

where ( $C_n$ ) is the measured concentration of the metal in the sediment sample, and ( $B_n$ ) is the corresponding geochemical background value. The constant factor of 1.5 serves as a correction term to account for possible variations in background data due to lithogenic effects, grain size differences, and minor anthropogenic influences that may occur even in relatively pristine environments.

Background values ( $B_n$ ) were obtained from published baseline data for uncontaminated tropical river sediments within the Niger Delta region, ensuring that the reference levels reflected natural geochemical conditions rather than pollution inputs. This regional approach to background selection enhances the reliability of the Igeo assessment by minimising bias from unrelated geological settings.

The calculated Igeo values were interpreted according to Müller's (1969) sevenclass scale:

Class 0:  $I_{geo} \leq 0$  Unpolluted

Class 1:  $0 < I_{geo} \leq 1$  Unpolluted to moderately polluted

Class 2:  $1 < I_{geo} \leq 2$  Moderately polluted

Class 3:  $2 < I_{geo} \leq 3$  Moderately to heavily polluted

Class 4:  $3 < I_{geo} \leq 4$  Heavily polluted

Class 5:  $4 < I_{geo} \leq 5$  Heavily to extremely polluted

Lower Igeo classes indicated metal concentrations close to natural background levels, while higher classes reflect increasing anthropogenic enrichment and potential ecological risk. All Igeo calculations were carried out using Microsoft Excel with cell-referenced formulas to ensure accuracy and reproducibility. The results were presented in tables and bar charts to compare contamination levels across sampling stations and identify pollution hotspots, thereby supporting environmental quality assessment and management recommendations.

## RESULTS AND DISCUSSION

This begins with the physicochemical parameters of water (pH, DO, EC, BOD, and temperature), followed by heavy metal concentrations in water. Next was sediment heavy metal concentrations after which contamination indices (CF, PLI, and Igeo) were applied to assess sediment quality. Correlation analysis was then used to explore relationships among metals and infer potential sources.

**Table 3.1 Result of the Surface Water Samples**

S/N	Parameter	SW1	SW2	SW3	SW4	SW5	Range	Mean
1	PH	6.03	6.81	6.02	7.04	7.02	6.02-7.02	6.58
2	DO	6.08	6.02	5.05	4.08	4.03	4.03– 6.08	5.05
3	EC	1067.67	1056.74	1098.66	1058.96	1058.90	1056.74- 1098.66	1068.19
4	BOD	2.05	3.02	3.08	3.31	2.81	2.05– 3.31	2.85
5	TEMP	26.1	26.5	27.5	27.4	27.8	26.1– 27.8	27.1

### 3.1.2 Water Quality Parameters

The physicochemical parameters of water samples collected from the five sampling stations along the Mgbuodohia River are presented in Table 4.1. These parameters pH, dissolved oxygen (DO), electrical conductivity (EC), biochemical oxygen demand (BOD), and temperature are essential indicators of water quality and provide critical context for understanding the behavior and mobility of heavy metals in the aquatic environment. The results are discussed in relation to permissible limits established by the World Health Organization (WHO, 2017) and the Federal Ministry of Environment (FME, 2018).

### 3.1.3 pH

The pH values across the five sampling stations ranged from 6.02 to 7.04, with a mean value of  $6.58 \pm 0.51$ . The lowest pH of 6.02 was recorded at Station SW3, while the highest value of 7.04 was observed at Station SW4. The mean value falls within the World Health Organization and Federal Ministry of Environment recommended range of 6.5 to 8.5 for drinking water and aquatic life support (WHO, 2017; FME, 2018).

The slightly acidic conditions observed at upstream stations, particularly SW1 and SW3, may be attributed to several factors including the decomposition of organic matter which releases organic acids, and possible inputs from industrial effluents discharging into the upper reaches of the river (Chapman, 1996). In contrast, the neutral to slightly alkaline values recorded at downstream stations SW4 and SW5 suggest buffering effects from domestic wastewater discharges, which often contain carbonates and bicarbonates that neutralize acidity. Maintaining pH within the optimal range is critical for aquatic ecosystem health as pH influences the speciation, solubility, and toxicity of heavy metals; deviations from the optimal range can increase metal bioavailability and toxicity to aquatic organisms (Chapman, 1996). The pH values observed in this study indicate that the river water is chemically stable and generally suitable for aquatic life, consistent with findings from other Niger Delta rivers (Nwineewii & Marcus, 2021).

### 3.1.4 Dissolved Oxygen (DO)

Dissolved oxygen concentrations ranged from 4.03 mg/L to 6.08 mg/L, with a mean value of  $5.05 \pm 0.99$  mg/L. A distinct decreasing trend was observed from upstream to downstream, with Station SW1 recording the highest DO concentration of 6.08 mg/L while Station SW5 recorded the lowest at 4.03 mg/L. The mean DO value of 5.05 mg/L is exactly at the threshold recommended by WHO and FME of  $\geq 5.0$  mg/L for sustaining aquatic organisms (WHO, 2017). However, stations SW3 with 5.05 mg/L, SW4 with 4.08 mg/L, and SW5 with 4.03 mg/L fell below or at the critical limit, indicating oxygen stress in the lower reaches of the river.

The progressive decline in dissolved oxygen downstream is indicative of organic pollution, where microbial decomposition of organic matter consumes dissolved oxygen (APHA, 2017). Sources of organic pollution likely include untreated sewage, domestic wastewater, and effluents from small-scale industries along the river course. Low dissolved oxygen levels are often associated with eutrophication, fish kills, and reduced biodiversity (Chapman, 1996). Similar patterns of DO depletion have been documented in other Niger Delta rivers impacted by anthropogenic activities. Ololade, et al. (2017) reported DO levels below 5.0 mg/L in the New Calabar River, attributing the depletion to sewage and industrial effluent discharges. The results from the present study underscore the need for improved wastewater management to protect aquatic life in the Mgbuodohia River.

### 4.1.5 Electrical Conductivity (EC)

Electrical conductivity values were extremely high across all sampling stations, ranging from 1056.74  $\mu\text{S}/\text{cm}$  to 1098.66  $\mu\text{S}/\text{cm}$ , with a mean value of  $1068.19 \pm 16.84$   $\mu\text{S}/\text{cm}$ . These values far exceed the WHO and FME guideline of  $\leq 250$   $\mu\text{S}/\text{cm}$  for drinking water (WHO, 2017; FME, 2018). Elevated EC indicates high concentrations of dissolved ions, including salts, minerals, and other ionic pollutants. The mean value of 1068.19  $\mu\text{S}/\text{cm}$  suggests significant ionic pollution, likely originating from multiple anthropogenic sources including industrial effluents

discharging dissolved salts and metals, domestic sewage containing detergents and dissolved solids, and agricultural runoff carrying fertilizers and other ionic compounds.

High EC reflects increased salinity and total dissolved solids, rendering the water unsuitable for drinking and potentially harmful for irrigation (Ali et al., 2019). Prolonged use of high-EC water for irrigation can lead to soil salinization and reduced crop yields. The findings are consistent with studies from other Niger Delta rivers. Nwineewii and Marcus (2021) reported elevated EC values in the Bonny River, linking them to oil exploration activities, urban runoff, and industrial discharges. Similarly, Ololade et al. (2017) documented high conductivity in the New Calabar River, attributed to anthropogenic inputs from surrounding communities and industries. The consistently high EC across all stations indicates that ionic pollution is not localized but rather a catchment-wide issue affecting the entire river system.

### 3.1.6 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand values ranged from 2.05 mg/L to 3.31 mg/L, with a mean of  $2.85 \pm 0.45$  mg/L. The lowest BOD of 2.05 mg/L was recorded at Station SW1, while the highest value of 3.31 mg/L was observed at Station SW4. An increasing trend was evident from upstream to downstream. The mean value of 2.85 mg/L is close to the WHO and FME permissible limit of  $\leq 3.0$  mg/L (WHO, 2017). However, stations SW3 with 3.08 mg/L and SW4 with 3.31 mg/L exceeded this limit, indicating elevated organic pollution at these locations.

BOD measures the amount of oxygen required by microorganisms to decompose organic matter in water. Elevated BOD values indicate organic enrichment, typically from sewage discharges, industrial effluents, or agricultural runoff (Jaishankar et al., 2014). The higher BOD values at midstream and downstream stations suggest increasing anthropogenic influence along the river course, likely due to population density and industrial activities in these areas. High BOD has several ecological implications including depletion of dissolved oxygen as observed at downstream stations, stress on aquatic organisms particularly fish and benthic invertebrates, potential for fish kills during periods of low flow or high temperature, and deterioration of overall water quality and ecosystem health. The results are consistent with findings from the New Calabar River, where Ololade et al. (2017) documented elevated BOD levels attributable to anthropogenic pressures from surrounding communities and industries.

### 3.1.7 Temperature

Water temperature across the five sampling stations ranged from 26.1°C to 27.8°C, with a mean value of  $27.1 \pm 0.72$ °C. The lowest temperature of 26.1°C was recorded at Station SW1, while the highest value of 27.8°C was observed at Station SW5. All recorded values fall within the WHO and FME permissible range of 25 to 30°C for tropical freshwater systems (WHO, 2017; FME, 2018). The relatively stable temperature regime suggests that thermal pollution is not a significant concern in the Mgbuodohia River at the time of sampling.

The slight increase in temperature from upstream to downstream, from 26.1°C at SW1 to 27.8°C at SW5, may be attributed to reduced riparian vegetation and shading in downstream areas, thermal inputs from industrial effluents or urban runoff, and natural warming as water flows through open, sun-exposed sections. Although temperature is not a primary concern in this study, it is an important supporting parameter because it influences dissolved oxygen solubility, with oxygen being less soluble in warmer water, metabolic rates of aquatic

organisms, rates of chemical reactions including those involving heavy metals, and the toxicity and bioavailability of pollutants (Chapman, 1996). The observed temperatures are typical for tropical freshwater systems in the Niger Delta region and are consistent with values reported in similar studies (Nwineewii & Marcus, 2021; Ololade et al., 2017).

### 3.1.8 Integrated Assessment of Water Quality

The physicochemical parameters collectively indicate that the Mgbuodohia River is under significant anthropogenic stress. While pH and temperature remain within acceptable limits, the elevated EC values across all stations and the low DO combined with high BOD conditions downstream are causes for concern. The pH values ranging from 6.02 to 7.04 with a mean of 6.58 fall within the acceptable range, indicating chemical stability and suitability for aquatic life. Dissolved oxygen levels with a mean of 5.05 mg/L are borderline, with downstream stations falling below the critical limit of 5.0 mg/L, indicating oxygen stress from organic pollution. Electrical conductivity is extremely high across all stations with a mean of 1068  $\mu\text{S}/\text{cm}$ , far exceeding the standard of 250  $\mu\text{S}/\text{cm}$  and indicating significant ionic pollution from industrial, domestic, and agricultural sources. Biochemical oxygen demand exceeds limits at midstream and downstream stations with values up to 3.31 mg/L, confirming organic enrichment from sewage and industrial discharges. Temperature remains within acceptable limits with a mean of 27.1°C, typical for tropical systems.

The high EC values indicate significant ionic pollution, while the low DO and elevated BOD downstream reflect organic enrichment from sewage and industrial discharges. These findings are consistent with regional studies confirming that rivers in mixed industrial-residential catchments of the Niger Delta are under multiple stressors (Nwineewii & Marcus, 2021; Ololade et al., 2017). The results underscore the urgent need for stricter regulation of industrial effluent discharges, improved wastewater treatment infrastructure, continuous water quality monitoring, and community awareness programs to reduce pollution inputs. These physicochemical conditions also provide important context for interpreting heavy metal concentrations in water and sediment, as parameters such as pH, DO, and EC influence metal speciation, mobility, and bioavailability.

**Table 3.2 Heavy Metal Levels in Surface Water**

S/N	Samples	Zn(mg/l)	Pb(mg/l)	Cd(mg/l)	Cr(mg/l)	Mn(mg/l)
1	Sw1	0.024	<0.001	ND	ND	0.030
2	Sw2	0.014	<0.001	ND	ND	0.022
3	Sw3	0.019	<0.001	ND	ND	0.021
4	Sw4	0.018	<0.001	ND	ND	0.018
5	Sw5	0.026	<0.001	ND	ND	0.020

**Table 3.3 Surface Water Range Values Against National and International Limits**

S/N	Parameter (mg/l)	Range	DPR/FMENV LIMIT	MAXIMUM LIMIT WHO/USEPA
1	Zn	0.014 – 0.026	3.0	3.0
2	Pb	0.001	0.01	0.01
3	Cd	ND	0.003	0.003
4	Cr	ND	0.05	0,05
5	Mn	0.018 – 0.030	0.1	0.1

**Table 3.4 Heavy Metal Sediment Results**

S/N	SampleID	Zn (mg/kg)	Pb	Cd	Cr	Mn
1	Ss pt1	2.12	7.45	0.18	28.34	15.62
2	Ss pt2	1.85	6.98	0.22	30.12	14.87
3	Ss pt3	1.34	5.76	0.11	25.90	13.45
4	Ss pt 4	1.92	7.02	0.16	29.45	16.08
5	Ss pt 5	1.48	8.21	.09	31.22	17.34

**Table 3.5: Summary of sediment heavy metal results Mgbuodohia River**

S/N	Parameter	Range (mg/kg)	Mea $\pm$ SD(mg/kg)	FMENV/DPR STANDARD	WHO/USEPA STANDARD
1	Zn	1.34-2.12	1.74 $\pm$ 0.31	140	140
2	Pb	5.76-8.21	7.08 $\pm$ 0.91	85	10
3	Cd	0.09-0.22	0.15 $\pm$ 0.05	0.8	0.003-0.01
4	Cr	25.90-31.22	29.01 $\pm$ 2.01	100	50
5	Mn	13.45-17.34	15.47 $\pm$ 1.43	-	-

**Table 3.6 Analyzed Sediment Samples Contamination Factor**

Samples	CF(Zn)	CF(Pb)	CF(Cd)	CF(Cr)	CF(Mn)
SS PT1	0.017	0.298	0.180	0.567	0.078
SS PT2	0.015	0.279	0.220	0.602	0.074
SS PT3	0.011	0.230	0.110	0.518	0.067
SS PT4	0.016	0.281	0.160	0.589	0.080
SS PT5	0.012	0.328	0.090	0.624	0.087

**Table 3.7 Analyzed Sediment Samples Pollution Load Index**

Sample	PLI	Interpretation
SS PT1	0.23	Unpolluted
SS PT2	0.23	Unpolluted
SS PT3	0.19	Unpolluted
SS PT4	0.23	Unpolluted
SS PT5	0.23	Unpolluted

**Table 3.8 Analyzed Sediment Samples Geo-accumulation Index**

Sample	Igeo(Zn)	Igeo(Pb)	Igeo (Cd)	Igeo (Cr)	Igeo (Mn)
SS PT1	-6.53	-1.34	-3.06	-0.82	-3.76
SS PT2	-6.73	-1.42	-2.77	-0.73	-3.85
SS PT3	-7.20	-1.61	-3.77	-0.95	-4.07
SS PT4	-6.67	-1.41	-3.27	-0.77	-3.72
SS PT5	-7.00	-1.26	-4.07	-0.70	-3.61

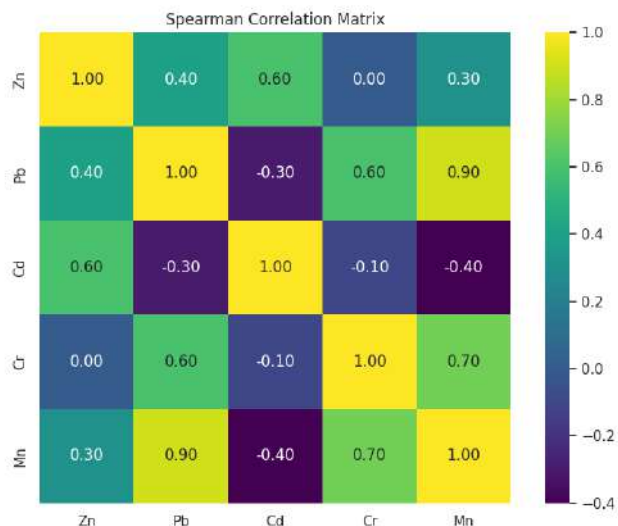


Figure 3.1 Spearman Correlation Analysis for the Mgbuodohia River Sediment of Metals

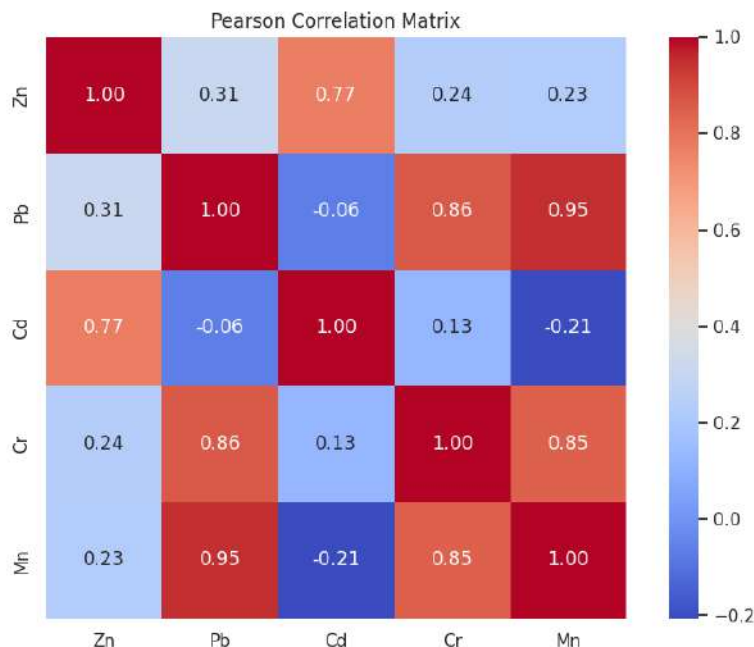


Figure 3.2 Pearson Correlation Analysis for the Mgbuodohia River Sediment of Metals

Table 3.9 Correlation Matrices of Heavy Metals in Sediment (Mgbuodohia River)

Metals	Zn	Pb	Cd	Cr	Mn
<b>Zn(Spearson)</b>	1.00	0.40	0.60	0.00	0.30
<b>Pb(Spearson)</b>	0.40	1.00	-0.30	0.60	0.90
<b>Cd(Spearson)</b>	0.60	-0.30	1.00	-0.10	-0.40
<b>Cr(Spearson)</b>	0.00	0.60	-0.10	1.00	0.70
<b>Mn(Spearson)</b>	0.30	0.90	-0.40	0.70	1.00

Table 3.10 Computed Pearson Correlation Matrix

Metals	Zn	Pb	Cd	Cr	Mn
<b>Zn</b>	1.00	0.31	0.77	0.24	0.23
<b>Pb</b>	0.31	1.00	-0.06	0.86	0.95

<b>Cd</b>	0.77	-0.06	1.00	0.13	-0.21
<b>Cr</b>	0.24	0.86	0.13	1.00	0.85
<b>Mn</b>	0.23	0.95	-0.21	0.85	1.00

**Table 3.11 Summary of Metal-to-Metal Correlations in Sediment Samples**

<b>Metal Pair</b>	<b>Pearson (r)</b>	<b>Spearman (p)</b>	<b>Strength</b>
<b>Pb-Mn</b>	0.95	0.90	strong
<b>Cr-Mn</b>	0.85	0.70	strong
<b>Pb-Cr</b>	0.86	0.60	Strong/moderate
<b>Zn-Cd</b>	0.77	0.60	Strong/moderate
<b>Zn-Pb</b>	0.31	0.40	Weak/Moderate
<b>Zn-Mn</b>	0.23	0.30	Weak
<b>Cd-Mn</b>	-0.21	-0.40	Weak/Moderate Negative
<b>Cd-Pb</b>	-0.06	-0.30	Weak Negative
<b>Cd-Cr</b>	0.13	-0.10	Weak
<b>Zn-Cr</b>	0.24	0.00	Weak

## DISCUSSION OF FINDINGS

### 3.2.1 Descriptive Statistics of Heavy Metals

The concentrations of heavy metals varied across the five sampling points, though the ranges remained relatively narrow. Zinc concentrations were consistently low (1.34–2.12 mg/kg), reflecting minimal anthropogenic input. Lead concentrations were higher (5.76–8.21 mg/kg), suggesting mild enrichment possibly linked to vehicular emissions, battery disposal, or industrial activities. Cadmium values were very low (0.09–0.22 mg/kg), consistent with background levels and indicating negligible contamination. Chromium concentrations ranged between 25.90–31.22 mg/kg, showing slightly elevated values compared to other metals, while manganese concentrations (13.45–17.34 mg/kg) were moderate but stable across sites. These descriptive statistics establish the baseline for subsequent contamination indices.

### 3.2.2 Contamination Factor (CF)

The contamination factor compares observed concentrations to background reference values. All CF values were below unity, indicating low contamination. Zinc (CF = 0.011–0.017), cadmium (CF = 0.09–0.22), and manganese (CF = 0.07–0.09) were particularly low, confirming negligible enrichment. Lead (CF = 0.23–0.33) and chromium (CF = 0.52–0.62) showed relatively higher values, though still below 1, suggesting mild enrichment but not pollution. This pattern highlights Pb and Cr as metals of concern, warranting monitoring despite their current safe levels.

### 3.2.3 Pollution Load Index (PLI)

The PLI integrates CF values to provide an overall pollution status per site. All sites recorded PLI values below 1, confirming that the sediments are unpolluted. This finding is consistent across all sampling points, demonstrating uniformity in contamination status. The PLI results strengthen the conclusion that the Mgbuodohia River sediments are environmentally safe at present.

### 3.2.4 Geoaccumulation Index (Igeo)

The Igeo values for all metals were negative, further confirming an unpolluted status. Negative Igeo values indicate that observed concentrations are below background levels when adjusted for natural variability. This reinforces the CF and PLI findings, showing that the sediments are not impacted by heavy metal pollution. The consistency across indices provides strong evidence of environmental safety.

### 3.2.5 Correlation Analysis

Correlation analysis was conducted using both Pearson and Spearman coefficients to evaluate relationships among metals. Strong positive correlations were observed between Pb and Mn ( $r = 0.95$ ;  $\rho = 0.90$ ), Cr and Mn ( $r = 0.85$ ;  $\rho = 0.70$ ), and Pb and Cr ( $r = 0.86$ ;  $\rho = 0.60$ ). These associations suggest common anthropogenic sources, possibly industrial effluents or vehicular emissions. Moderate correlations between Zn and Cd ( $r = 0.77$ ;  $\rho = 0.60$ ) point to agricultural or urban runoff contributions. Weak or negative correlations involving Cd (Cd–Mn, Cd–Pb) indicate independent geochemical pathways. The absence of correlation between Zn and Cr ( $r = 0.24$ ;  $\rho = 0.00$ ) further supports the notion of separate contamination sources. Overall, correlation analysis reveals clusters of metals with shared origins, alongside others that behave independently.

### 3.2.6 Comparative Analysis with Standards and Other Rivers

When compared with national (FMENV/DPR) and international (WHO/USEPA) standards, all observed concentrations were below permissible limits, confirming environmental safety. Comparisons with other Nigerian rivers (Bonny, Calabar, ASE) showed that Mgbuodohia River sediments have lower contamination levels, reinforcing the conclusion of minimal anthropogenic impact. This comparative perspective situates the findings within a broader environmental context.

### 3.2.7 Integrated Interpretation

Taken together, the descriptive statistics, CF, PLI, Igeo, and correlation analysis converge on the conclusion that the Mgbuodohia River sediments are currently unpolluted. However, the enrichment patterns of Pb and Cr, and their strong correlations with Mn, suggest potential anthropogenic inputs that could increase over time. While Zn and Cd remain low, their moderate correlation indicates possible shared pathways of contamination. The integrated analysis underscores the importance of continuous monitoring to detect future changes.

The sediments of the Mgbuodohia River are presently safe, with contamination indices confirming an unpolluted status. Nevertheless, the observed enrichment of Pb and Cr, and their strong associations with Mn, highlight the need for vigilance. The correlation analysis provides valuable insight into the sources and behaviors of metals, revealing both shared and independent pathways. Overall, the findings demonstrate that while the river is currently unpolluted, mixed sources of enrichment exist, and proactive monitoring is essential to safeguard ecological health.

## CONCLUSIONS

The findings of this study lead to the following conclusions:

1. Heavy metal concentrations in the Mgbuodohia River sediments are generally low, with Pb and Cr showing mild enrichment relative to background levels.
2. Contamination indices (CF, PLI, and Igeo) consistently confirm that the sediments are unpolluted.
3. Correlation analysis reveals strong associations among Pb, Mn, and Cr, indicating potential shared sources, while Zn and Cd show moderate correlation, suggesting possible agricultural or urban runoff.
4. Weak or negative correlations involving Cd suggest independent geochemical behavior.
5. Comparisons with standards and other rivers reinforce the conclusion that the Mgbuodohia River sediments are presently safe, though mixed sources of enrichment exist.

## RECOMMENDATION

Based on the findings, the following recommendations are made:

1. **Monitoring:** Continuous monitoring of heavy metals, particularly Pb and Cr, should be undertaken to detect potential increases in contamination.
2. **Replication in Sampling:** Future studies should include replicate samples to allow for robust statistical testing such as ANOVA.
3. **Expanded Scope:** Further research should investigate additional pollutants (e.g., hydrocarbons, nutrients) and assess bioavailability of metals in aquatic organisms to evaluate ecological and human health risks.
4. **Comparative Studies:** Longitudinal and comparative studies across other rivers in Rivers State should be conducted to establish regional contamination patterns.
5. **Environmental Management:** Preventive measures should be encouraged to minimize anthropogenic inputs, ensuring the river remains ecologically safe.

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