



Ecological Risk Assessment of Heavy Metals in Nembe Mangrove Forest Sediments, Bayelsa State

Ihinmikaiye, Samuel Olatokunbo¹ and Ojo, Victor Idowu*²

¹ Department of Plant Science and Biotechnology, Federal University Otuoke, Nigeria.

² Department of Biological Sciences, University of Canterbury, Christchurch, New Zealand

ARTICLE'S INFO

Article No.: 021025022

Type: Research

Full Text: [PDF](#), [PHP](#), [EPUB](#), [MP3](#)

DOI: [10.15580/gjbs.2025.1.021025022](https://doi.org/10.15580/gjbs.2025.1.021025022)

Accepted: 10/02/2025

Published: 24/03/2025

Keywords: Heavy metals, Mangrove sediments, Ecological risk, Contamination indices, Nembe

*Corresponding Author

Ojo Victor Idowu

E-mail: ojovictoridowu@gmail.com

Article's QR code



ABSTRACT

This study assessed the concentrations and ecological risks of heavy metal contamination in mangrove swamp sediments across four communities in Nembe LGA, Bayelsa State: Sounikiri, Ikrikokiri, Odekiri and Obiama. Obiama sampling point served as the geochemical background due to its relatively undisturbed ecosystem. Sediment samples were collected using standard methods at two depths (0–10 cm and 10–20 cm), except at the geochemical background location (Obiama), where samples were taken at a depth of 0–20 cm. The concentrations of cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), lead (Pb), and zinc (Zn) were determined using standard procedures. Statistical analyses were conducted to assess significance at $p < 0.05$. Environmental impacts were evaluated using key ecological indices including Geoaccumulation Index (Igeo), Contamination Factor (CF), Degree of Contamination (Cd), Ecological Risk Factor (Er), and Potential Ecological Risk Index (PERI). Results revealed that Cd concentrations (3.89 - 7.48 mg/kg) exceeded the DPR permissible limit (0.8 mg/kg), categorizing it as a high-risk contaminant. Cr level (8.54–10.84 mg/kg) remained within the DPR limit (100 mg/kg). Mn concentrations (34.61 - 78.51 mg/kg) were below the threshold (500 mg/kg) but varied significantly across sites. Pb concentrations (10.90–13.76 mg/kg) were within the DPR limit (85 mg/kg), whereas Zn levels in Odekiri (156.20 mg/kg) exceeded the permissible threshold of 140 mg/kg. Cu concentrations (40.50–55.68 mg/kg) also surpassed the DPR limit (36 mg/kg), indicating significant contamination. Er indicated that Cd posed the highest risk ($Er = 186$), followed by Cu, which also presented a considerable risk. PERI values classified Sounikiri and Ikrikokiri as moderate risk areas, while Odekiri exhibited considerable ecological risk ($PERI = 309.82$). The findings reveal significant heavy metal contamination in the region, highlighting the need for mitigation measures to protect the mangrove ecosystem.

INTRODUCTION

Mangrove forests are among the most productive ecosystems found in tropical regions of the world (Marchand *et al.*, 2011; Rasika *et al.*, 2018). They are unique estuarine ecosystems considered as zone of transition between freshwater and marine habitats (Feller *et al.*, 2010; Udechukwu *et al.*, 2015). As a major provider of food for several faunae, they host complex food webs. While providing plethora ecological functions, mangrove habitats are exploited by coastal development, unsustainable fishing and agriculture practices (Macfarlane *et al.*, 2007). And because they trap suspended particles and organic materials, they are exposed to a variety of contaminants and anthropogenic agents which impact sedimentation process. Heavy metals are significant contaminants in mangrove swamp forest, whereas anthropogenic waste and industrial discharges are major contributors (Rasika *et al.*, 2018; Marchand *et al.*, 2011).

In soils, heavy metals have been considered as powerful tracers for monitoring impact of anthropogenic activity (Siti *et al.*, 2014). According to Bi *et al.* (2017); Chakraborty *et al.* (2015) and Jafarabadi *et al.* (2017) heavy metals incorporated into organic matter in swamps have been identified as secondary causes of aquatic biological systems pollution. Due to their non-biodegradable nature; they gradually bio-accumulate in systems (Okocha and Adedeji, 2012), and may be reabsorb into the water body. Mangroves are particularly

vulnerable to heavy metal (Puthusseri *et al.* 2021), according to Zhu *et al.* (2006); Chakraborty *et al.* (2014); Liu *et al.* (2017) the level of bioavailability, and distribution of metals in mangrove swamps are influenced by chemical parameters including weathering and sediment composition. Also, physical parameters may influence heavy metals accumulation in mangrove swamp (Maslennikova *et al.*, 2012). but, excessive heavy metals in plants alter normal metabolic pathways, and may fast reach lethal levels quickly (Turer *et al.*, 2003). As such, heavy metal accumulation in aquatic environments is a growing cause for concern due to its toxicity to living organisms (MacFarlane and Burchett, 2000).

Nembe mangrove forest provides numerous ecological services, and covers a significant portion of Bayelsa state land mass. The region is known for its contribution to the Nigeria economy, yet the risk of anthropogenic activities is of major concern in communities in the region. Despite the region's ecological significance, there is a lack of comprehensive studies assessing the concentration of heavy metals in the region's mangrove swamp forest. Thus, concentrations of heavy metals in the mangrove swamp sediment were investigated in this study, and various ecological indices were employed to gauge and quantified the impact of heavy metals contamination in the enclave.

MATERIALS AND METHODS

The Study Area

This research was conducted between January 15 and March 28, 2023, at four distinct locations within the mangrove forest swamp of Nembe Local Government Area (LGA): Sounikiri (Lat. 4.61°N, Long. 6.25°E), Ikrikokiri (Lat. 4.43°N, Long. 6.53°E), Odekiri (Lat. 4.67°N, Long. 6.53°E), and Obiama (Lat. 4.59°N, Long. 6.35°E). Obiama sampling point served as the 'geochemical background' site due to its relatively undisturbed ecosystem. Nembe LGA is characterized by a tropical climate with high humidity and temperatures throughout the year, and the annual rainfall ranges from 3,500 to 4,500 mm along the coastal front. Geographically, the LGA functions as an ecotone, featuring a complex network of estuaries, creeks, tides, and mangrove trees that contribute to its unique biodiversity.

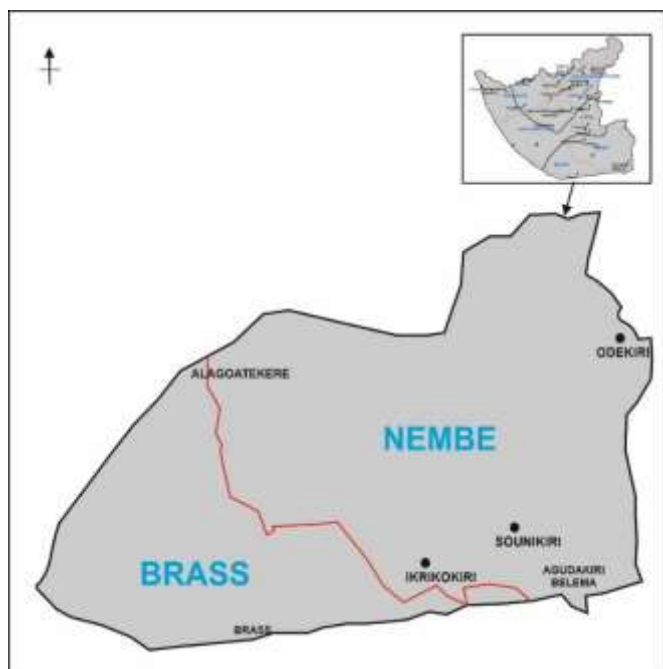


Fig. 1: Map of Nembe in Bayelsa State showing the study area

Sample Collection and Laboratory Analysis

Sediment samples were collected from three designated points within a 100 m × 100 m plot at two depths: 0–10 cm and 10–20 cm. However, at the geochemical background location (Obiama community), samples were collected at a single depth of 0–20 cm. A cylindrical corer sampler with a 5 cm inner diameter was used to extract sediment cores from the swamp. The sampling process involved inserting a cylindrical corer into the sediment to a depth of 20 cm at each sampling point. Upon extraction, the core samples were sliced into two segments (0–10 cm and 10–20 cm), except for the

geochemical background location. Each segment was then transferred into labelled black polythene bags to prevent degradation and ensure proper identification. The samples were subsequently transported to the laboratory for further analysis. This structured approach ensures that the collected data is both reliable and representative of sediment characteristics in the study area.

Sample Analysis

The sediment samples were dried in a Supertek forced air oven at 400°C until a constant weight was achieved. Subsequently, the samples were pulverized using a mechanical grinder. A total of 0.5 g of each pulverized sediment sample was weighed into glass beakers, followed by the addition of 10 mL of nitric acid (HNO₃) and 5 mL of hydrochloric acid (HCl). All chemicals and reagents used were of analytical grade. The combination of concentrated HNO₃ and HCl was employed due to their effectiveness in breaking down various matrices, maximizing metal recovery and ensuring thorough digestion of sediment samples. The samples were then placed in a microwave digestion system at a constant temperature of 200°C for 30 minutes. After digestion and cooling, the resulting solution was filtered through Whatman filter paper using gravity filtration methods; distilled water was added to dilute the filtrate to a final volume of 50 mL using volumetric flasks. The concentrations of the metals, cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), lead (Pb), and zinc (Zn) in the samples were determined using a Thermo Scientific ICE 3500 atomic absorption spectrometer (AAS) utilizing air and acetylene gas for flame atomization mode.

The data obtained were subjected to descriptive statistics, such as ANOVA, mean±SD, and LSD was used to determine significance at p≤0.05.

Risk Assessment of Sediment Contamination

The concentration of the heavy metals in the sediments were determined using the following ecological assessment indices: The Geoaccumulation Index (Igeo) was used to evaluate the degree of heavy metal pollution in sediments (Barbieri, 2016). It aids in identifying areas with significant heavy metal pollution by comparing concentration values of contaminated site with uncontaminated site (pre-industrial concentration), and provide insights into the potential environmental impact of heavy metals on ecosystems (Looi et al., 2019; Walla and Anmar-Dherar, 2015). Originally defined by Muller (1979), the Igeo focuses on metal concentrations in the 2-micron fraction and employs global standard shale values. The formula used is: $I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n}$ (Muller (1979), where C_n represents the concentration of the metal in sediment (mg/kg) and B_n denotes the background concentration (pre-industrial level). In this study, Obiama community was selected as the reference

site for determining background concentrations based on a local geological survey (Table 1). The results are classified into seven categories (Table 2) based on calculated Igeo values, facilitating monitoring of metal contamination over time (Abdullah et al., 2020).

The **Contamination factor (CF)** is a metric used in these studies to evaluate heavy metal levels in sediment. It is defined as the ratio of the contaminant concentration in sample to its background concentration, calculated as $Cf = \frac{C_{sample}}{C_{background}}$ (Hakanson, 1980). Where, C_{sample} = is the concentration of metal in sediment, and $C_{background}$ is the background concentration from a reference site (Hakanson, 1980) (Table 1). CF values are categorized into four levels (Table 2) for monitoring contamination at specific points in time (Al-Dahar et al., 2023).

Table 1: Concentrations of Heavy Metals in Mangrove Sediments from Obiama Community (Geochemical Background Values, Mg/Kg)

Heavy metal	Value
Cd	1.20
Cr	5.01
Cu	2.84
Mn	4.08
Pb	2.70
Zn	55.00

To measure overall heavy metal contamination in sediments, the **Degree of Contamination (Cd)** is utilized. It is calculated using: $Cd = \frac{1}{n} \sum (Cf)_i$, (Kowalska et al., 2018). Where Cf_i is the contamination factor for each heavy metal, and n is the number of metals analysed. Cd values are classified into four levels (Table 2) for monitoring contamination over time (Khemmoudj et al., 2017).

Table 2: Ecological Indices for Heavy Metal Assessment in the Mangrove Swamp Sediment

Index	Class Value	Degree quality	Reference
*Igeo	Igeo ≤ 0	Uncontaminated	Barbieri, 2016 Looi et al. (2019); Walla and Anmar (2015) Abdullah et al. (2020)
	0 < Igeo < 1	Uncontaminated to moderately contaminated	
	1 < Igeo < 2	Moderately contaminated	
	2 < Igeo < 3	Moderately to heavily contaminated	
	3 < Igeo < 4	Heavily contaminated	
	4 < Igeo < 5	Heavily to extremely contaminated	
	Igeo ≥ 5	Extremely contaminated	
**Cf	Cf < 1	Low contamination	Hakanson (1980); Al-Dahar et al. (2023)
	1 ≤ Cf < 3	Moderate contamination	
	3 ≤ Cf < 6	Considerable	
	Cf > 6	Very high contamination	
†Er	Er < 40	Low risk	Agyeman et al. (2021)
	40 ≤ Er < 80	Moderate risk	
	80 ≤ Er < 160	Considerable risk	
	160 ≤ Er < 320	High risk	
	Er ≥ 320	Very high risk	
††Cd	Cd < 8	Low degree of contamination	Hakanson (1980); Khemmoudj et al. (2017)
	8 ≤ Cd < 16	Moderate degree of contamination	
	16 ≤ Cd < 32	Considerable degree of contamination	
	Cd ≥ 32	A very high degree of contamination	
□ PERI	PERI < 150	Low risk	Hakanson (1980); Al-Shami et al. (2019).
	150 ≤ PERI < 300	Moderate risk	
	300 ≤ PERI < 600	Considerable risk	
	PERI ≥ 600	Very high risk	
□□ Tr	Heavy Metal	Toxic Response Factor (Tr)	Xu et al. (2008); Liu et al. (2021)
	Lead (Pb)	5	
	Copper (Cu)	5	
	Cadmium (Cd)	30	
	Zinc (Zn)	1	
	Chromium (Cr)	1	
	Manganese (Mn)	1	

*Geo-accumulation index, **Contamination factor,

□ Potential Ecological Risk Index, □□ Toxic response factor

†Ecological risk index factor ††Degree of contamination

The **Ecological Risk Index Factor (Er)** assesses potential risks posed by heavy metals in the environment. It is calculated as follows: $Er = Tr \times Cf$, where, Er is the ecological risk factor for a specific heavy metal, Tr is the toxic response factor reflecting the toxicity and potential harm of each metal, while Cf is the contamination factor, calculated as $Cf = \frac{C_{sample}}{C_{background}}$, C_{sample} measured concentration of the metal in the sample sediment, and $C_{background}$ is the background concentration of the metal from the reference site. The classification of Er values follow guidelines provided by Xu et al. (2008), Agyeman et al. (2021), and Liu et al. (2021), with categories detailed in Table 2. The **Potential Ecological Risk Index (PERI)** evaluates overall ecological risk from multiple contaminants (heavy metals) in sediments. It is derived from summing individual ecological risk factors: $PERI = \sum(Er) = \sum(Tr * Cf)$. The categorization of potential ecological risk follows Hakanson (1980) and Al-Shami et al. (2019), providing a comprehensive assessment of ecological risks associated with heavy metal contamination.

RESULTS AND DISCUSSION

RESULTS

Table 3 shows heavy metals (Cadmium (Cd), Chromium (Cr), Manganese (Mn), Lead (Pb), Zinc (Zn), and Copper (Cu)) concentrations at varying depths (0-10 cm and 10-20 cm) across three mangrove swamp communities: Odekiri, Sounikiri, and Ikrikokiri. The concentrations are expressed as mean values ($X \pm SD$) in mg/kg, with statistical comparisons made to assess the significance of differences observed among the communities. Cadmium (Cd) concentrations ranged from 3.89 ± 0.56 mg/kg to 7.48 ± 0.31 mg/kg. The highest level was observed in Odekiri at (0-10cm) depth, with values of 7.48 ± 0.31 mg/kg. This concentration was significantly higher ($p < 0.05$) compared to those in Sounikiri and Ikrikokiri. Notably, all recorded Cd concentrations exceeded the DPR's permissible limit of 0.8 mg/kg (Table 4).

Table 3: Values of heavy metal concentration Accessed in three Sampling Sites

Metal/Depth	Sounikiri ($X \pm SD$)	Odekiri ($X \pm SD$)	Ikrikokiri ($X \pm SD$)	LSD	p-value
Cd (0–10 cm)	6.01 ± 0.80 (c)	7.48 ± 0.31 (a)	4.08 ± 0.42 (b)	1.12	< 0.05
(10–20cm)	5.62 ± 0.42 (b)	5.93 ± 1.38 (a)	3.89 ± 0.56 (c)	1.25	< 0.05
Cr (0–10cm)	10.84 ± 0.90 (a)	9.84 ± 0.49 (b)	8.54 ± 1.27 (c)	1.19	< 0.05
(10–20cm)	10.62 ± 0.40 (a)	9.59 ± 0.56 (b)	8.66 ± 0.73 (c)	0.98	< 0.05
Mn (0–10cm)	34.61 ± 5.82 (c)	78.51 ± 5.29 (a)	63.59 ± 1.95 (b)	7.88	< 0.05
(10–20cm)	34.84 ± 4.51 (c)	78.44 ± 6.06 (a)	63.33 ± 2.47 (b)	8.12	< 0.05
Pb (0–10cm)	13.23 ± 0.84 (a)	13.54 ± 0.81 (a)	10.90 ± 1.22 (b)	1.52	< 0.05
(10–20cm)	13.07 ± 1.62 (a)	13.76 ± 0.50	10.96 ± 0.44 (b)	1.68	< 0.05
Zn (0–10cm)	134.74 ± 17.63 (b)	149.97 ± 23.38 (a)	129.03 ± 23.89 (b)	22.81	< 0.05
(10–20 cm)	131.50 ± 15.98 (b)	156.20 ± 17.17 (a)	130.87 ± 20.63 (b)	20.45	< 0.05
Cu (0–10cm)	50.48 ± 8.03 (b)	42.51 ± 2.22 (c)	55.68 ± 3.93 (a)	9.12	< 0.05
(10–20cm)	47.62 ± 8.82 (b)	40.50 ± 1.50 (c)	54.37 ± 4.80 (a)	9.75	< 0.05

Note: Means with same superscript in the same row are not different

Chromium (Cr) levels show variability across the three communities, with concentrations ranging from 8.54 ± 1.27 mg/kg in Ikrikokiri (10–20 cm) to 10.84 ± 0.90 mg/kg in Sounikiri (0–10 cm). The results reveal that Sounikiri consistently exhibited the highest Cr concentrations, and were significantly different ($p < 0.05$) from those in the other communities. However, all Cr values remained within the DPR's permissible limit of 100 mg/kg. The concentration of manganese (Mn) ranged from 34.61 ± 5.82 mg/kg in Sounikiri (0–10 cm) to 78.51 ± 5.29 mg/kg in Odekiri (0–10 cm). Odekiri recorded significantly higher Mn levels ($p < 0.05$) compared to Sounikiri and Ikrikokiri. yet all Mn levels were well within the permissible limit of 500 mg/kg as reported in the literature. Also, the value of Lead (Pb) varied between 10.90 ± 1.22 mg/kg in Ikrikokiri (10–20 cm) and 13.76 ± 0.50 mg/kg in Odekiri at a depth of 10–20 cm. The Pb

levels in Odekiri were significantly higher ($p < 0.05$) than those in Ikrikokiri and Sounikiri, but all recorded values remained within the DPR recommended limit of 85 mg/kg.

Table 4: Department of Petroleum Resources permissible limit for heavy metals (mg/kg) in Soil /sediment

Cd	0.8
Cr	100
Cu	36
Mn	*500 (Not specified)
Pb	85
Zn	100

Source: DPR (2002)

The value of Zn present in Table 3 showed a range from 129.03 ± 23.89 mg/kg in Ikrikokiri to 156.20 ± 17.17 mg/kg in Odekiri at a depth of 10-20 cm. The values for Zn in Odekiri were significantly higher ($p < 0.05$) compared to those in Sounikiri and Ikrikokiri, which had comparable levels. While Zn concentrations in Ikrikokiri and Sounikiri were within the DPR's limit of 140 mg/kg, those recorded in Odekiri's exceeded the permissible

threshold of DPR (table 4). Also, Copper concentrations ranged from 40.50 ± 1.50 mg/kg in Odekiri to 55.68 ± 3.93 mg/kg in Ikrikokiri, with Ikrikokiri consistently showing higher levels than the other communities ($p < 0.01$). importantly, all Cu values surpassed the DPR acceptable limit of 36 mg/kg.

Table 5: Contamination Factor (Cf) and Ecological Risk (Er) of Heavy Metals in the Mangrove Swamp sediments

Metal (Mg/Kg)	Sounikiri		Odekiri		Ikrikokiri	
	Cf	Er	Cf	Er	Cf	Er
Cd	5.01	150.3	6.20	186.0	3.4	102.0
Cr	2.16	4.32	1.94	1.94	1.71	3.42
Mn	8.48	8.48	19.2	19.2	15.6	15.6
Pb	4.9	24.5	5.02	25.1	4.04	20.2
Zn	2.44	2.44	2.73	2.73	2.35	2.35
Cu	17.78	88.7	14.97	74.85	23.13	115.65
*PERI values		278.74		309.82		259.22
**Cd	40.77		50.06		50.23	

*Potential ecological risk index, **Degree of contamination

Table 5 summarizes the results for the Contamination Factor (Cf), Ecological Risk (Er), Degree of Contamination (Cd), and the Potential Ecological Risk Index (PERI) for heavy metals in the samples collected from the three locations in Nenbe LGA. The Cf analysis reveals contamination across all study sites, albeit at varying levels. Chromium (Cr) and Zinc (Zn) exhibited moderate contamination levels ($1 \leq Cf < 3$) as presented in Table 2. In contrast, the highest Cf values were recorded for Copper (Cu) and Manganese (Mn). Specifically, Cu levels ranged from 23.13mg/kg in Ikrikokiri to 17.78mg/kg in Sounikiri and 14.97mg/kg in Odekiri, while Mn levels varied from 8.48mg/kg in Sounikiri to 15.6mg/kg in Ikrikokiri and 19.2mg/kg in Odekiri.

Ecological risk (Er) values for the heavy metals are detailed in Table 5. Cr, Mn, Lead (Pb), and Zn exhibited Er values below 40, classifying them as low-

risk. However, Cu levels at Odekiri ($40 \leq Er < 80$) were categorized as moderate risk. More concerning was the Er values for Cu and Cadmium (Cd) at Sounikiri and Ikrikokiri communities, which fell within the range $80 \leq Er < 160$, indicating considerable risk. Cd recorded the highest Er value of 186 mg/kg, classifying it as high risk ($160 \leq Er < 320$). The Degree of Contamination (Cd) values (40.77mg/kg, 50.06mg/kg, and 50.23mg/kg for Sounikiri, Odekiri, and Ikrikokiri respectively) are provided in Table 5. These values, exceeding $Cd \geq 32$ threshold, indicate a very high degree of contamination. The PERI values also varied across locations: 278.74mg/kg for Sounikiri and 239.22mg/kg for Ikrikokiri fall within the range of moderate risk ($150 \leq PERI < 300$), while the PERI value for Odekiri (309.82mg/kg) indicates considerable risk as it falls within the range of ($300 \leq PERI < 600$).

Table 6: Geo-accumulation Index (Igeo) for the Heavy Metals in Mangrove Swamp Sediments

Metal (Mg/Kg)	Sounikiri	Odekiri	Ikrikokiri
Cd	2.61	2.99	2.64
Cr	0.53	0.39	0.19
Mn	2.5	3.68	3.38
Pb	1.71	1.74	1.43
Zn	0.7	0.68	0.65
Cu	3.57	3.32	3.95

The Geo-accumulation Index (Igeo) values for heavy metals across the three sampling communities are presented in Table 6. Cr and Zn had Igeo values below 1.0, categorizing them as uncontaminated to moderately contaminated ($0 < Igeo < 1$). Pb had Igeo values between 1 and 2, indicating moderate contamination. In contrast,

Cd at all sampling points and Mn at Sounikiri (2.5 mg/kg) fell within the range of $2 < Igeo < 3$, indicating moderate to heavy contamination. Whereas, Cu displayed the highest Igeo values, ranging from 3.32mg/kg in Odekiri to 3.57mg/kg in Sounikiri and 3.95mg/kg in Ikrikokiri, classifying it as heavily contaminated ($3 < Igeo < 4$).

DISCUSSION

This study reveals significant variations in the concentrations of heavy metals across the mangrove swamp communities (Odekiri, Sounikiri, and Ikirikokiri) at both sampling depths (0–10 cm and 10–20 cm). The findings reveal that Cadmium (Cd), Copper (Cu), and Zinc (Zn) exceeded the permissible limits set by the Department of Petroleum Resources (DPR, 2002), indicating substantial environmental contamination. These results align with previous studies (Akagbue et al., 2011; Omoogun et al., 2021; Ikezam et al., 2021), which attributed ecological risks in the region primarily to anthropogenic activities such as artisanal oil refining, industrial discharges, and oil exploration.

Cadmium (Cd) concentrations across all locations significantly exceeded the DPR threshold of 0.8 mg/kg, with Odekiri recording the highest concentration (7.48 ± 0.31 mg/kg). Additionally, Zinc (Zn) levels in the communities (156.20 ± 17.17 mg/kg) surpassed the DPR standard of 140 mg/kg, indicating severe contamination. Among the three locations, Odekiri exhibited the highest degradation, a trend consistent with its Potential Ecological Risk Index (PERI) score of 309.82 mg/kg, categorizing it as a site of considerable ecological risk ($300 \leq \text{PERI} < 600$). In contrast, Sounikiri and Ikirikokiri fell within the moderate-risk category. The high Ecological Risk (Er) value for Cd (186 mg/kg) and Cu, which falls within the high-risk ($160 \leq \text{Er} < 320$) and considerable-risk ($80 \leq \text{Er} < 160$) categories, suggests significant industrial and anthropogenic inputs. These findings are corroborated by recent studies in the Niger Delta, which have also reported elevated Cd levels linked to industrial activities and urban runoff (Kieri et al., 2021; Ehiemere et al., 2022; Chris and Anyanwu, 2022, 2023). Similarly, Okwakpam et al. (2024) reported comparable contamination patterns in Degema, Rivers State, where artisanal refining activities resulted in high ecological risks for Cu and Cd, further affecting mangrove ecosystems. Chromium (Cr) concentrations varied across the locations but remained below the DPR threshold of 100 mg/kg, with Sounikiri exhibiting the highest levels (10.84 ± 0.90 mg/kg). This spatial variation likely reflects localized industrial inputs, long-distance transport, or natural geochemical processes. Huang et al. (2019) noted that Chromium, particularly in its hexavalent form (Cr VI), has high mobility in aquatic environments, allowing for long-distance transport and potential ecological impacts (Choppala et al., 2013).

Manganese (Mn) exhibited low ecological risk ($\text{Er} < 40$), while Lead (Pb) remained within regulatory limits (85 mg/kg). However, the high Mn concentrations may impact sediment microbial communities, and Pb's moderate contamination levels (Igeo values: 1–2) warrant continuous monitoring due to bioaccumulation concerns. Copper (Cu) consistently exceeded the DPR limit of 36 mg/kg across all locations, with Ikirikokiri recording the highest concentration (55.68 ± 3.93 mg/kg). The elevated Cu levels, alongside its heavy

contamination classification ($\text{Cf} > 6$) and Igeo values ($3 < \text{Igeo} < 4$), indicate significant anthropogenic inputs, particularly from artisanal refining, industrial effluents, and agrochemical applications. These results are consistent with findings from Nnawugwu and Hiroaki (2018) on heavy metal contamination in Niger Delta mangrove sediments. Mahamoud-Ahmed et al. (2018) further noted that excessive Cu concentrations can disrupt sediment microbial communities, which are crucial for organic matter decomposition and nutrient cycling.

The Contamination Factor (Cf) and Degree of Contamination (Cd) analyses indicate a concerning contamination profile, particularly for Cu and Cd. The Cf analysis reveals varying contamination levels, with Cu and Mn exhibiting the highest values across all sites, reinforcing the significant anthropogenic influence on metal distribution. These findings align with research from other regions, where Cu contamination has been attributed to artisanal refining and mining activities (Ikezam et al., 2021; Saha et al., 2022). The ecological risk assessment suggests that while Cr, Mn, Pb, and Zn pose low risks, Cu at Odekiri falls within the moderate-risk category, emphasizing the need for remediation measures. However, the Degree of Contamination (Cd) values of all the metals analyzed exceed the contamination threshold, indicating a high level of pollution at all sites. This is particularly concerning given the well-documented adverse effects of all the metals on biodiversity and ecosystem health (Chris and Anyanwu, 2022).

Geo-accumulation Index (Igeo) results further confirm the severity of contamination, with Cu and Cd exceeding their respective background values, classifying all locations as moderately to heavily contaminated. The high heavy metal concentrations raise serious concerns regarding potential ecological damage to mangrove biodiversity and ecosystem functions. High metal concentrations disrupt sediment chemistry, impair microbial activity, and bioaccumulate in aquatic organisms, posing risks to biodiversity and ecological balance (Maiti and Chowdhury, 2013; Anouti, 2014; MacFarlane and Burchett, 2002). The broader contamination trends observed in this study align with global patterns, where rapid urbanization and industrialization contribute significantly to heavy metal accumulation in coastal ecosystems (Nwankwoala et al., 2020). The contamination profile of these mangrove swamps stresses the need for urgent intervention and targeted environmental management strategies to mitigate ongoing degradation. Protecting these ecosystems from further contamination is crucial for maintaining their ecological integrity and ensuring long-term sustainability.

REFERENCES

- Abdullah, M.I.C, Sah, A.S.R.M., and Haris, H. (2020). Geoaccumulation Index and Enrichment Factor of

- Arsenic in Surface Sediment of Bukit Merah Reservoir, Malaysia. *Trop Life Sci Res.* (3):109-125. doi: 10.21315/tlsr2020.31.3.8.
- Agyeman, P.C., John, K., Kebonye, N.M. *et al.* (2021). Human health risk exposure and ecological risk assessment of potentially toxic element pollution in agricultural soils in the district of Frydek Mistek, Czech Republic: a sample location approach. *Environ Sci Eur* **33**, 137.
- Akagbue, B. O., Popoola, T. O., Aminu, M. B., Nenger, J. A., and Babatunde, S. (2024). Negative Health and Environmental Effects of Oil Exploitation in Southern Ijaw, Bayelsa State, Nigeria. *European J. of Environment and Earth Sciences.* 5(3):34–41.
- Al-Dahar, R. K., Rabee, A. M., Mohammed, R. J. (2023) Calculation of Soil Pollution Indices with Elements in Residential Areas of Baghdad City. *Revis Bionatura.* 8 (1)43.
- Al-Shami, S. A., Yap, C. K., Wong, K. W., Al-Qahtani, S. M., Alsabih, L. And Al-Zaqri, N. (2019). Ecological Risk Assessments of Heavy Metals in Surface Sediments Collected from Haqal Coastal Waters (Tabuk Region), Saudi Arabia. *Applied Ecology and Environmental Research* 17(2): 3065-3075.
- Anouti, F.A. (2014) Bioaccumulation of Heavy Metals within Mangrove Ecosystems. *J Biodivers Endanger Species* 2:2.: e113. doi:10.4172/2332-2543.1000e113
- Barbieri M (2016) The Importance of Enrichment Factor (EF) and Geoaccumulation Index (Igeo) to Evaluate the Soil Contamination. *J Geol Geophys* 5: 237. doi:10.4172/2381-8719.1000237
- Bi S., Yang Y., Xu C., Zhang Y., Zhang X. and Zhang X. (2017). Distribution of heavy metals and environmental assessment of surface sediment of typical estuaries in eastern China. *Marine Pollution Bulletin*, 121(1–2), 357–366.
- Chakraborty, P., Babu, P. R., Vudamala, K., Ramteke, D., and Chennuri, K. (2014). Mercury speciation in coastal sediments from the central east coast of India by modified BCR method. *Marine Pollution Bulletin*, 81(1), 282–288.
- Chris, D. I., and Anyanwu, E. D. (2023). Assessment of some heavy metal content in sediments of a mangrove swamp, Niger Delta, Nigeria using applicable ecological risk indices. *Acta Aquatica: Aquatic Sciences Journal*, 10(3): 260-268
- Chris, D. I., and Anyanwu, B. O. (2022). Pollution and Potential Ecological Risk Evaluation Associated with Toxic Metals in an Impacted Mangrove Swamp in Niger Delta, Nigeria. *Toxics*, 11(1), 6.
- Choppala, G., Bolan, N., Lamb, D. *et al.* (2013). Comparative Sorption and Mobility of Cr(III) and Cr(VI) Species in a Range of Soils: Implications to Bioavailability. *Water Air Soil Pollut* **224**, 1699.
- Department of Petroleum Resources (2002). Environmental guidelines and standards for the petroleum industry in Nigeria (revised edition, 2002). Department of Petroleum Resources, Abuja, Nigeria
- Ehiemere, V. C., Ihedioha, J. N., Ekere, C. R., Ibeto, C. N. and Abugu, H.O. (2022). Pollution and risk assessment of heavy metals in water, sediment and fish (*Clarias gariepinus*) in a fish farm cluster in Niger Delta region, Nigeria. *J Water Health.* 20 (6): 927–945.
- Feller, I. C., Lovelock C. E., Berger U., McKee K.L., Joye S. B., and Ball, M. C. (2010). Biocomplexity in Mangrove Ecosystems. *Annual review of marine science.* Vol. 2: 395-417.
- Jafarabadi A. R., Bakhtiyari A. R., Toosi A. S. & Jadot C. (2017). Spatial distribution, ecological and health risk assessment of heavy metals in marine surface sediments and coastal seawaters of fringing coral reefs of the Persian Gulf, Iran. *Chemosphere*, 185, 1090–1111.
- Hakanson, L. (1980). An ecological risk index for aquatic pollution control: A sedimentological approach, *Water Research*, Volume 14, Issue 8, Pages 975-1001.
- Huang, J., Hao, J., Huang, F., Sverjensky, D.A. (2019) Mobility of chromium in high temperature crustal and upper mantle fluids. *Geochem. Persp. Let.* 12, 1–6.
- Ikezam, P., Elenwo., E.I., and Oyegun., C. U. (2021). Assessment of physicochemical parameters and heavy metals concentration across artisanal refining sites in the core Niger Delta Region. *Journal of Research in Humanities and Social Science.* 9 (8): 85-91
- Kieri, I.B.S., Ekpote, O. A., and Edori, O. S. (2021). Assessment of heavy metal pollution in sediments of silver river, Southern Ijaw, Bayelsa State, Nigeria. *Environmental Analysis and Ecology Studies*, 7(5): 837-842.
- Khemmoudj, K., Merabet, S., Bendadouche, H., Abdelkrim, B., and Balla, E. (2017). Assessment of Heavy Metal pollution due to the Lead –Zinc Mine at the Ain Azel area (northeast of Algeria). *E3 Journal of Environmental Research and Management* Vol. 8(1). pp. 001-011.
- Kowalska, J.B., Mazurek, R., Gąsiorek, M. *et al.* (2018). Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination—A review. *Environ Geochem Health* **40**, 2395–2420.
- Liu, D., Wang, J., Yu, H. *et al.* (2021). Evaluating ecological risks and tracking potential factors influencing heavy metals in sediments in an urban river. *Environ Sci Eur* **33**, 42 (2021).
- Looi, L.J., Aris, A.Z., Yusoff, F.M. *et al.* (2019). Application of enrichment factor, geoaccumulation index, and ecological risk index in assessing the elemental pollution status of surface sediments. *Environ Geochem Health* **41**, 27–42.
- MacFarlane, G. R., and Burchett, M. D. (2002). Toxicity, growth and accumulation relationships of copper, lead and zinc in the grey mangrove *Avicennia*

- marina (Forsk.) Vierh. *Marine environmental research*, 54(1): 65–84.
- Maiti, S. and Chowdhury, A. (2013). Effects of Anthropogenic Pollution on Mangrove Biodiversity: A Review. *Journal of Environmental Protection*, 4, 1428-1434.
- MacFarlane G. R., Koller C. E. &Blomberg S. P. (2007). Accumulation and partitioning of heavy metals in mangroves: A synthesis of field-based studies. *Chemosphere*, 69(9), 1454–1464.
- Mahamoud-Ahmed, A., Lyautey, E., Bonnineau, C., Dabrin, A., and Pesce, S. (2018). Environmental Concentrations of Copper, Alone or in Mixture with Arsenic, Can Impact River Sediment Microbial Community Structure and Functions. *Frontiers in microbiology*, 9, 1852.
- Marchand C., Allenbach M. and Lallier-Vergès E. (2011). Relationships between heavy metals distribution and organic matter cycling in mangrove sediments (Conception Bay, New Caledonia). *Geoderma*, 160(3–4), 444–456.
- Maslennikova S., Larina N. and Larin S. (2012).The effect of sediment grain size on heavy metal content. *Lakes Reservoirs and Ponds*, 6(1), 43–54.
- Müller, G. (1979) Schwermetalle in den sedimenten des RheinseVeränderungen seitt 1971. *Umschau* 79: 778-783.
- Nnawugwu, N. and Hiroaki, I. (2018). Geochemical Evaluation of Surface Sediments in Niger Delta Mangrove, Nigeria. *Journal of Environment and Earth Science*. 8(2): 48-60.
- Nwankwoala, H. O., Amadi, A. N., Ige, O. O., Osayande. A. D., Ugbor, C. C., Koate, B. D., Bolaji, T. A., Orji, E. A. and Okujagu, D. C. (2022). Health implications of selected heavy metals around hydrocarbon impacted sites in the Niger Delta: A preliminary investigation. *GSC Adv. Res. Rev.*11(1):113–128.
- Okocha R. O. &Adedeji O. B. (2012). Over view of copper toxicity to aquatic life. *Report and Opinion*, 4(8), 57–68.
- Okwakpam, I. O., Barango, S. L., and Onugha, A. C. (2024). Assessment of Heavy Metal Contamination in Mangrove Habitats of Crude Oil Exploration and Artisanal Refining Sites in Degema Oilfield. *Faculty of Natural and Applied Sciences Journal of Basic and Environmental Research Print* 2(1):95-105
- Omoogun, A., Olayemi, T. E. and Ogungbade, T. (2021). Environmental Pollution and Its Ecological Consequences on the Niger Delta: A review of the Literature. *African Journal of Environment and Natural Science Research*. 4(4): 27-42
- Puthusseri, R.M., Nair, H.P., Johny, T.K., and Bhat, S.G. (2021). Insights into the response of mangrove sediment microbiomes to heavy metal pollution: Ecological risk assessment and metagenomics perspectives. *Journal of Environmental Management*, Volume 298, 2021, 113492,
- Rasika, K., Deepti, D., and Smita, Z. (2018). Metals in mangrove ecosystems and associated biota: A global perspective, *Ecotoxicology and Environmental Safety*, Vol. 153, Pages 215-228.
- Saha, A., Gupta, B.S., Patidar, S., and Martínez-Villegas, N. (2022). Evaluation of Potential Ecological Risk Index of Toxic Metals Contamination in the Soils. *Chem. Proc.* 2022, 10, 59.
- Siti, N. M. R., Sharizal, H., Mohd, L. K. and NorShahrizan, M. H. (2014). Analysis and Pollution assessment of heavy metal in soil, perlis The Malaysian J. of Analytical Sciences, 18 (2014): 155-161.
- Turer, D. G. and Maynard, J. B. (2003). Heavy metal contamination in high way soil. Comparison Corpus Christi, Texas and Cincinnati Ohio shows organic matter is key to mobility clean technology and environ mental policy, 4: 235-245.
- Udechukwu B. E., Ismail A., Zulkifli S. Z. and Omar H. (2015). Distribution, mobility, and pollution assessment of Cd, Cu, Ni, Pb, Zn, and Fe in intertidal surface sediments of Sg. Pulohvmangrove estuary, Malaysia. *Environmental Science and Pollution Research*, 22(6), 4242–4255.
- Walla, A. and Anmar-Dherar, K. (2015). Enrichment Factor and Geo-accumulation Index for Heavy Metals at Industrial Zone in Iraq. *IOSR-JAGG*. Volume 3, Issue 3 Ver. I. PP 26-32
- Xu, Z.Q., Ni, S.J., Tuo, X., Zhang, C.J. (2008). Calculation of heavy metals' toxicity coefficient in the evaluation of potential ecological risk index. *Environ. Sci. Technol.* 2008, 31, 112–115.
- Zhu Y., Zou X., Feng S. & Tang H. (2006). The effect of grain size on the Cu, Pb, Ni, Cd Speciation and distribution in sediments: A case study of Dongping Lake, China. *Environmental Geology*, 50(5), 753–759.