The University of Tehran Press

Pollution

https://jpoll.ut.ac.ir/

Print ISSN: 2383-451X
Online ISSN: 2383-4501

Geo-Ecological Risk Assessment of Heavy Metals in Sediment and Water from Coastal Marine Wetland in Rivers State, Nigeria

Davies, Ibienebo Chris [1]✉ | Davies Imachrist Ibienebo [2]

1. Department of Fisheries, Faculty of Agriculture, University of Port Harcourt, P.M.B. 5323, Port Harcourt, Rivers State, Nigeria
2. Department of Animal and Environmental Biology, University of Port Harcourt, P.M.B. 5323, Port Harcourt, Rivers State, Nigeria

Article Info

Article type:
Research Article

Article history:
Received: 20 March 2024
Revised: 24 July 2024
Accepted: 12 August 2024

Keywords:
Coastal, Ecological, Metals, Pollution, Wetlands

ABSTRACT

This study investigates the heavy metal concentrations in water and sediment samples from three stations in coastal marine wetlands in Rivers State, Nigeria: Sangama, Degema, and Tema. Samples were collected monthly from October 2021 to April 2022. Igeo, metal pollution load index (MPLI), ecological risk assessment, ecological risk factor (Er), and potential ecological risk index (PERI) were used to evaluate the impact of pollution levels. The average concentrations of heavy metals like Fe, Zn, Pb, Cd, and Cu were analyzed to assess contamination levels and ecological risks. Results show spatial variations in metal concentrations, with Sangama having the highest levels in both water and sediment. The geoaccumulation index (Igeo) and ecological risk factor (Er) were used to evaluate contamination levels and risks. Tema and Degema have generally favourable conditions with low to moderate contamination, while Sangama shows higher levels, especially for Cd, Pb, and Cu. The potential ecological risk index (PERI) and metal pollution load index (MPLI) emphasize the significant ecological risks from heavy metal pollution at all three stations. Urgent action is needed to implement effective environmental management strategies and reduce the impacts of metal pollution on aquatic ecosystems in these areas.

Cite this article: Ibienebo Chris D. & Imachrist Ibienebo D. (2024). Geo-Ecological Risk Assessment of Heavy Metals in Sediment and Water from Coastal Marine Wetland in Rivers State, Nigeria. *Pollution*, 10 (4), 1103-1116.
https://doi.org/10.22059/poll.2024.373993.2287

DOI: https://doi.org/10.22059/poll.2024.373993.2287

INTRODUCTION

The coastal marine wetlands of Rivers State, Nigeria, represent ecologically crucial areas providing essential services and contributing to the preservation of coastal integrity. These dynamic ecosystems, particularly mangroves thriving along estuaries and intertidal zones of sub-tropical and tropical coastlines, offer vital functions such as shoreline stabilization, habitat provision, and carbon sequestration (Adekola & Mitchell, 2011; Agboola *et al.*, 2016). However, the rapid pace of urban development and extensive industrial activities have introduced an array of environmental challenges, with heavy metal pollution emerging as a significant concern in these sensitive habitats.

Nigeria, experiencing rapid urbanization and industrial development, is grappling with increasing concerns regarding heavy metal pollution in its water sources (Müller *et al.*, 2020; Fashae & Obateru, 2021). As urban and industrial areas expand, the risk of pollutants infiltrating aquatic environments is notably on the rise. Hence, it is essential to monitor and assess the extent of heavy metal contamination in coastal marine wetlands to understand the potential

*Corresponding Author Email: *davies.chris@uniport.edu.ng*

hazards and implications for the environment and human well-being.

Heavy metals like copper (Cu), zinc (Zn), manganese (Mn), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) present distinct dangers due to their toxic properties and resistance to natural degradation (Nivetha *et al*., 2023). These pollutants originate from sources such as domestic sewage, industrial effluents, and maritime operations, posing harmful consequences for both environmental and human health (Bashir *et al*., 2020). Heavy metals, arising from natural geological processes and human activities, have attracted considerable attention due to their enduring nature, potential for bioaccumulation, and toxicity. These substances not only jeopardize water, soil, and food quality but also accumulate in aquatic organisms, enter the food chain, and impact human health through the consumption of marine products (Chris & Anyanwu, 2023; Chris *et al*., 2023).

The physical and chemical characteristics of water significantly influence the condition, productivity, and long-term viability of aquatic ecosystems. Factors like temperature, pH, salinity, dissolved oxygen, and nutrient levels play a crucial role in determining the well-being of water sources, with alterations in these factors indicating changes in ecological equilibrium and the overall health of ecosystems (Akankali & Davies 2021; Carpenter *et al*., 2021). By evaluating heavy metal pollution in these ecosystems, the study aims to contribute valuable insights into the extent of contamination, potential risks, and overall ecological health of these vital coastal habitats. Understanding the intricate interplay between, urbanization, industrialization and heavy metal pollution is essential, and the findings of this study can inform targeted environmental management strategies to ensure the sustainability and well-being of these sensitive ecosystems. The study aims to assess heavy metal concentrations in Rivers State's coastal marine wetlands using probabilistic geo-ecological risk assessment techniques. The findings will aid in informed decision-making and conservation efforts, ensuring the ecological integrity and sustainability of these wetlands in Nigeria.

MATERIALS AND METHODS

Research Design

Three communities (Sangama, Degema and Tema) were selected based on proximity to obvious pollution from illegal refining activities and are designated imitations: Upstream, Midstream and Downstream. These three sampling stations at best represent near contact points with visible sites polluted by illegal refining waste effluent and sampled at least 1000 meters to capture wider areas with various contaminants. A composite sample was taken from three points in three stations to represent the true environmental conditions at each station, allowing for statistical variation during computation.

Study Area

Study areas included three riparian communities in Rivers State, Nigeria, including Degema, Tema, Sangama, Degema, and Krakrama. In Degema, southeast of the Niger Delta, illegal waste processing, dumping, dredging, and fishing are common. Sangama, in the same area, is characterised by residential waste, illegal refining overflow, refuse dumping, and fishing operations. In the same area, Tema is associated with rubbish and human waste disposal, dredging, and fishing. Addressing ecological challenges requires environmental management and sustainable practices. Adaptations for the ecosystem's evolution were necessary in these areas because of complex conditions. Gobies, periwinkles, crabs, and mudskippers inhabit tidal mudflats, including Claroteidae and Cichlidae. These areas have typical Niger Delta mangrove vegetation.

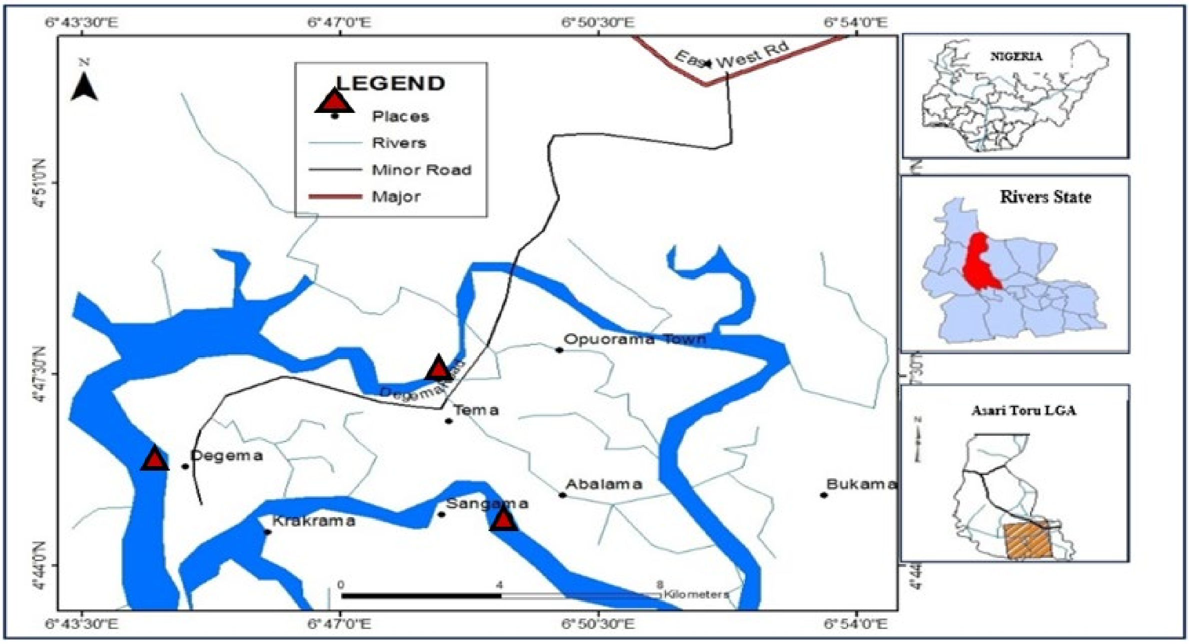

Fig. 1. Map showing the sampled locations along the Creeks.

Sample and Sampling Procedure

Sampling stations were chosen in each community based on their characteristics and importance as pollution sites to represent the catchment activities. To reflect different activities, each creek was sampled at least 1000 metres apart. Lead (Pb), copper (Cu), iron (Fe), cadmium (Cd), zinc (Zn), and arsenic (As) were heavy metals of interest based on industrial and domestic effluents in the study area. At each station, sediment and water samples were collected. All sampling sites (longitudes and latitudes) were georeferenced using GPS receivers (Magellan GPS 315). Between October 2021 and April 2022, samples were taken once a month. Sampling was conducted every month during the first week.

Water

Surface water samples were collected using pre-cleaned Schott glass bottles, which were washed with detergent, rinsed with tap water, and soaked in 50% hydrochloric acid for 24 hours. The bottles were then rinsed with tap water and triple-distilled water to prevent metal adhesion. Post-collection, the samples were sealed and transported to the lab in ice packs, labeled, and stored in ice chests to maintain integrity. Heavy metal content was analyzed following standard methods (APHA 2000), with sampling distances set to accurately represent pollution pockets in the study area.

Sediment

A composite sediment sample, collected monthly for six months from three different sites in both creeks, was obtained using an ‘Ekman grab’ sampler. The sampler was stored in a plastic container and pre-soaked for 24 hours in 10% nitric acid. After transportation to the laboratory, the frozen samples were stored at 20°C for subsequent analysis using the API-RP 45 Atomic Absorption Spectrophotometric Machine. The sampling distance from the bank aimed to capture pollution pockets in the study area, ensuring the representation of actual contamination.

Quality Assurance and Control

The research employed NIST-certified atomic absorption standards to create a calibration curve for heavy metals in water, sediment, and biota samples. A reagent blank was run after every ten samples for assurance. Recovery rates varied from 82% to 110%. The method and wavelength were consistent with Davies *et al*. (2024) protocols. Each sample was analyzed twice, and the reported values indicate the average. This meticulous quality assurance and control methodology boosts the precision and trustworthiness of the findings.

Sample Digestion for Heavy Metal Analyses

The sediment samples were air-dried and digested with 20 ml of concentrated H2SO4 in a Pyrex conical. The solution was then mixed with nitric acid, perchloric acid, and sulfuric acid (APHA 3030I modified) and heated until the granules turned grey. Distilled water was added, and the resulting solution was filtered through a Whatman 42 ashless filter paper into a 100 ml glass flask. The filtrate was subsequently transferred to a clean plastic bottle. An atomic absorption spectrophotometer (AAS) was utilized to determine the concentrations of lead, copper, iron, cadmium, zinc, and arsenic in the sediment samples (Davies *et al*., 2024b). The instrument was set up and operated by the manufacturer's instructions.

The Geo-accumulation Index (Igeo)

The geoaccumulation Index (Igeo), which was first proposed by the German scientist (Muller, 1969), is used to evaluate the contamination level of heavy metals in the sediment and water near the metal industry in comparison to background (control) values The geochemical background levels for various metals are: Cadmium (0.10 mg/kg), Copper (22.50 mg/kg), Iron (3850 mg/kg), Lead (21.00 mg/kg), and Zinc (65.40 mg/kg) (Guan *et al*., 2014; Chris and Anyanwu, 2023). These values are based on research findings and serve as a reference point for assessing sediment contamination ((Islam *et al*., 2014; Ahirvar *et al*., 2023). The geo-accumulation Index was calculated using equation (1).

$$\mathrm{Igeo} = \log2\left(\mathrm{Cn} / 1.5\mathrm{Bn}\right) \tag{1}$$

The Cn value represents the level of heavy metals and metalloids in the sediment and water around the metal works, and the Bn value represents the geochemical or background (control) value used by the constant value, 1.5, is the background matrix correction factor due to lithological variations. The contamination levels were based on geo-accumulation values: (Igeo≤0) uncontaminated; (0<Igeo≤1) uncontaminated to moderately contaminated; (1<Igeo≤2) moderately contaminated; (2<Igeo≤3) moderately to strongly contaminated; (3<Igeo≤4) strongly contaminated; (4<Igeo≤5) highly to extremely highly contaminated; (Igeo≥5) extremely contaminated (Yerima *et al*., 2020; Luo and Jia, 2021).

The Metals Pollution Load Index (MPLI)

MPLI is a measure of how often sediment and water metal concentrations exceed average background levels. As a result, it indicates the overall level of TCE toxicity in a particular sample (USEPA, 2001). According to Chris and Anyanwu (2023), the Pollution Load Index (PLI) measures how heavy metals may affect the microflora and fauna of sediment and water. Below is Equation 2 showing the formula.

$$\mathrm{MPLI} = \sqrt[n]{\left(\mathrm{CF1} \times \ \mathrm{CF2} \times \mathrm{CF3} \times \mathrm{CF4} \ldots ..\mathrm{CFn}\right)} \tag{2}$$

PLI is ranked from 0 to 6, CF stands for contamination factor, and n for the number of metals examined. According to Barakat *et al*. (2020), the pollution load index will be shown as follows: PLI < 1 (no pollution); 1< PLI< 2 (moderate pollution); 2< PLI< 3 (heavy pollution); and 3<PLI (very heavy pollution).

Ecological Risk Assessment

As part of the risk factors evaluation (Er and PERI), a single contaminant or a group of metal pollutants in sediment and water is evaluated for its ecological risk potential.

Ecological risk factor (Er)

Equation 3 below calculates the ecological risk factor (Er) quantitatively Hakanson (1980):

$$Er = Tr \times C_f \quad (3)$$

Tr, denoting the toxic-response factor for a specific metal, and Cf, representing the contamination factor for the metal, are associated with respective values for Cd (30), Pb (5), Zn (1), and Cu (5). The ecological risk factor (Er) classification, as outlined by Mugoša *et al.* (2016), is determined based on Er values: Er < 40 is categorized as low, 40 ≤ Er < 80 indicates a moderate risk, 80 ≤ Er < 160 signifies a considerable risk, 160 ≤ Er < 320 represents a high risk, and Er ≥ 320 is classified as very high.

Potential Ecological Risk Index (PERI)

According to Hakanson (1980), the potential ecological risk index (PERI) can be calculated using the equation 4 below:

$$PERI = \sum_{i=1}^{n} E_r^i \quad (4)$$

The number of heavy metals is n, and the single ecological risk factor is Er. The risks are categorized as PERI < 150 low ecological risks, 150 < PERI < 300 moderate ecological risks, 300 < PERI < 600 high ecological risks, and PERI ≥ 600 significantly high ecological risks (Mwakisunga *et al.*, 2021).

Statistical Analysis

Analyses of variance (ANOVA) and descriptive statistics were conducted using SPSS version 16. The Duncan Multiple Range Test was used to separate significant means at 0.05. Using the mean values generated, water and sediment concentrations were calculated. The data presented was interpreted using Microsoft Excel software, and the means, standard deviations, and standard errors of the means were used to manage the data.

RESULTS AND DISCUSSION

Water

Table 1 depicts the average concentration of heavy metals at different stations and in various mediums. The highest Fe value was found in water at Sangama (37.92±3.95 mg L^{-1}), followed by Degema (36.25±4.01 mg L^{-1}), and the lowest was in Tema (35.90±4.12 mg L^{-1}). Sangama presents a higher risk due to elevated Fe levels compared to Degema and Tema. elevated Fe concentrations may impact water quality and aquatic ecosystems, potentially leading to adverse effects on aquatic life (Akhtar *et al.*, 2021). According to them, Various natural and anthropogenic factors may be responsible for water quality degradation. Häder *et al.* (2020) suggested that anthropogenic pollution may elevate Fe concentrations thereby impacting aquatic ecosystems and leading to problems with global implications.

Additionally, the greatest Zn concentration was observed in Sangama (10.99±1.71 mg L^{-1}), followed by Tema (10.76±1.253 mg L^{-1}), and the lowest was recorded in Degema (9.94±1.25 mg L^{-1}). The elevated Zn concentration in Sangama raises concerns for water quality. Zn can be toxic to aquatic organisms, affecting their health and the overall balance of the ecosystem (Okereafor *et al*., 2020; Kolarova and Napiórkowski 2021). This agrees with Singh *et al*. (2022) who reported that heavy metals contamination of water have a toxic effect on living organisms. Pb levels were highest in Degema (0.12±0.02 mg L^{-1}) and lowest in Sangama (0.07±0.01 mg L^{-1}). Degema, with the highest Pb concentration, may pose a potential risk to water quality. Pb is a heavy metal known for its harmful effects on human health and aquatic life (Sonone *et al*., 2020). Sangama showed the highest concentration of Cu in water (149.24±4.89 mg L^{-1}), with the lowest in Degema (145.95±3.66 mg L^{-1}). The high Cu concentration in Sangama raises concerns due to Cu's toxic effects on aquatic life. There is a possibility that it will affect water systems' ecological balance (Mebane, 2023). Davies *et al*. (2024) found that Pb, Zn, and Cd contamination levels were moderate to considerable, while Fe contamination was relatively low. However, Cu contamination was moderately high. Both water and sediment showed varying degrees of contamination. In riparian communities in Rivers State, Nigeria, sediment and water exhibited low to moderate levels of Pb, Zn, and Cu contamination. Similar findings were observed by Oghenetekevwe *et al*. (2024) in sediments and water within mangrove swamps in Rivers State, Nigeria. On the other hand, Emeka *et al*. (2023) reported lower contamination levels in sediments and associated ecological risks in the Ikwu River, Umuahia, Nigeria.

The notable differences among the three stations suggest distinct challenges and environmental features. However, these results highlight the spatial variation in heavy metal levels, pointing to potential ecological risks and the need for further evaluation of the environmental impact on water quality in these areas.

Geo-accumulation index (Igeo) in water

The geo-accumulation index (Igeo) in water for the specified metals across the three locations shows a similar pattern to the contamination factor and degree of contamination in sediment, providing insights into the levels of metal accumulation in aquatic environments. For Cd, the Igeo descends as follows: Tema (0.080) > Degema (0.100) > Sangama (0.120). For Pb, the Igeo remains constant at 0.001 across Tema, Degema, and Sangama. For Zn, the Igeo follows a descending order: Tema (0.033) > Degema (0.031) > Sangama (0.034). For Fe, the Igeo is consistent at 0.002 across Tema, Degema, and Sangama. For Cu, the Igeo descends Tema (1.310) > Degema (1.302) > Sangama (1.331).

Based on the given criteria suggest that for most metals (Cd, Pb, Zn, Fe), the water in all three locations (Tema, Degema, Sangama) is categorized as uncontaminated to moderately contaminated (Yerima *et al*., 2020). Copper (Cu) levels, however, are classified as moderately contaminated in all locations. Overall, these results indicate a relatively low to moderate level of contamination in the water samples from the assessed locations, emphasizing a favourable environmental condition in terms of geo-accumulation indices for the considered metals.

Table 1. The mean concentration (mg/L) of heavy metals in the water across the three stations.

	Concentrations in mg/L				
Locations	**Cd**	**Pb**	**Zn**	**Fe**	**Cu**
Tema	0.04±0.01 ^{a}	0.08±0.01^{b}	10.76±1.25 ^{a}	35.90±4.12 ^{a}	146.58±9.50 ^{a}
Degema	0.05±0.01 ^{a}	0.12±0.02 ^{a}	9.94±1.25 ^{b}	36.25±4.01 ^{a}	145.95±3.66 ^{a}
Sangama	0.06±0.01 ^{a}	0.07±0.01^{b}	10.99±1.71 ^{a}	37.92±3.95 ^{a}	149.24±4.89 ^{a}
CCME (2002)	0.12	4.0	7.0	-	3.0
USEPA. 2018	0.005	0.05	0.3	-	1.3

(CCME) CCME Water Quality Guidelines for the Protection of Aquatic Life
(USEPA) United States Environmental Protection Agency.

The assessment of water quality based on the geo-accumulation index (Igeo) criteria shows different contamination levels for various metals in three locations (Tema, Degema, Sangama). The results indicate that the water quality in all three locations generally falls within the uncontaminated to moderately contaminated range for most metals (Luo & Jia, 2021). Copper levels, while still within the moderately contaminated category, show slightly higher contamination compared to other metals (Yerima *et al*., 2020). These findings from Table 2 suggest an overall favourable environmental condition, emphasizing the importance of ongoing monitoring and management practices to ensure the sustained health of water resources in these areas.

The findings suggest relatively favourable environmental conditions in terms of geo-accumulation indices for the metals in water samples from Tema, Degema, and Sangama. The ecological risk implications indicate generally favourable water quality in Tema, Degema, and Sangama, with a need for sustained monitoring and management practices to preserve and protect aquatic ecosystems in these locations.

Ecological risk Factor and potential ecological risk (PERI) for water

In the examination of ecological risk at three distinct locations (Tema, Degema, and Sangama) using the ecological risk factor (Er) values and the potential ecological risk index (PERI), distinct patterns emerge with noteworthy implications for each station. The assessment for Tema from Table 3 reveals low ecological risks for individual metals, as evidenced by Er values below 40 for Cadmium (Cd), Lead (Pb), Zinc (Zn), and Copper (Cu). However, the collective impact, reflected in the overall PERI of 746.86, indicates a significantly high ecological risk. Similarly, Amarachi *et al*. (2023) reported high ecological risks (PERI > 400) were observed for human consumption and aquatic life. Chanomi Creek. According to Chris and Anyanwu's 2022 research, the toxic metals in the sediments and water of the Isaka-Bundu tidal mangrove swamp pose a significant environmental threat, with a potential ecological risk index (PERI) of 600 or higher, indicating a very high ecological risk. Despite low individual metal risks, the combined effect poses a substantial threat to the ecological health of the water in Tema, necessitating urgent and comprehensive environmental management measures.

Table 2. Geoaccumulation index (Igeo) in water.

Metals	Tema	Degema	Sangama
Cd	0.080	0.100	0.120
Pb	0.001	0.001	0.001
Zn	0.033	0.031	0.034
Fe	0.002	0.002	0.002
Cu	1.310	1.302	1.331

Table 3. Ecological risk Factor and potential ecological risk (PERI) for water.

Metals	Tema	Degema	Sangama
Cd	1.20	1.50	1.80
Pb	0.40	0.60	0.35
Zn	10.76	9.94	10.99
Cu	734.50	730.00	746.00
PERI	746.86	742.04	759.14

Similar to Tema, Degema demonstrates low ecological risks for Cd, Pb, Zn, and Cu, with Er values below 40. However, the overall PERI of 742.04 highlights a significantly high ecological risk (Mwakisunga *et al*., 2021). This underscores the importance of implementing comprehensive strategies to address the cumulative impact of multiple contaminants in Degema, despite the low individual metal risks.

Sangama exhibits low ecological risks for individual metals, reflected in Er values below 40 for Cd, Pb, Zn, and Cu. However, the overall PERI of 759.14 indicates a considerable ecological risk (Chris *et al*., 2023b). Like Tema and Degema, Sangama's cumulative ecological risk is significantly high, emphasizing the imperative for robust environmental management strategies to mitigate the combined impact of multiple contaminants. Similar issues of anthropogenic pollution have also been reported in other countries, such as China, where aquatic environments have been heavily polluted due to rapid industrialization and urbanization (Sodango *et al*. 2018).

The PERI values in Tema, Degema, and Sangama reveal a significant combined ecological risk due to various metals. The findings emphasize the need for coordinated environmental management practices to protect and restore water ecosystems, emphasizing the complexity of ecological risks.

Sediment

Sangama in Table 4 recorded the greatest Fe concentration of 1748.44±88.22 mg kg^{-1} in the sediment, followed by Tema (1643.88±83.5 mg kg^{-1}), while the least was seen in Degema (1577.60±107.5 mg kg^{-1}). Sangama's high Fe concentration in sediment may indicate potential contamination, impacting sediment quality and benthic organisms (Arisekar *et al*., 2023). Zn was greatest at Sangama (225.31±7.83 mg kg^{-1}) and lowest at Degema (205.76±1.88 mg kg^{-1}). The high Zn concentration raises concerns about potential ecological risks, as Zn can accumulate in sediments and affect bottom-dwelling organisms (Ezekwe *et al*., 2022). Pb was highest at Sangama (10.57±0.62 mg kg^{-1}) and lowest at Degema (6.93±1.03 mg kg^{-1}). Sangama's sediment concentrations of lead indicate potential contamination, which may pose a threat to sediment-dwelling organisms and the food chain (Luo *et al*., 2016).

However, the Cd concentrations were highest in the sediment of Sangama (3.15±0.33 mg kg^{-1}) and lowest at Degema (2.48±0.32 mg kg^{-1}). Sangama's elevated Cd concentration in sediment signifies potential contamination, with Cd known for its toxicity and potential adverse effects on benthic organisms (Enuneku *et al*., 2018; Zhang *et al*., 2020). Besides, Cu concentrations in the sediment were highest at Degema (563.48±14.82 mg kg^{-1}) and least at Degema (451.58±40.29 mg kg^{-1}). Degema's significantly high Cu concentration in sediment raises concerns for potential ecological impacts, as Cu can accumulate in sediments and affect the health of benthic organisms (Birch *et al*., 2012; Jafarabadi *et al*., 2020).

Furthermore, no difference was observed in the concentration of As (<0.01 mg kg^{-1}) in the sediment samples at all three stations. Sangama showed the highest concentrations of Fe, Zn, Pb, Cd, and Cu, followed by Tema, and the lowest concentrations in Degema for all the heavy metals analysed.

Table 4. The mean concentration of heavy metals (mg/kg) in the Sediment across the three stations.

	Concentrations in mg/kg				
Locations	**Fe**	**Zn**	**Pb**	**Cd**	**Cu**
Tema	1643.8±83.5^{b}	221.94±7.16^{a}	7.79±1.28^{ab}	2.50±.055^{ab}	503.81±21.81^{a}
Degema	1577.6±107.5^{c}	205.76±1.88^{b}	6.93±1.03^{b}	2. 48±0.32^{ab}	451.58±40.29^{b}
Sangama	1748.4±88.2^{a}	225.31±7.83^{a}	10.57±0.62^{a}	3.15±0.33^{a}	563.48±14.82^{a}
CCME (2002)	-	123.0	35.0	6	35.7
USEPA. 2018	-	271	112	3.53	108

(CCME) = Canadian Sediment Quality Guidelines for the Protection of Aquatic Life.
(USEPA) United States Environmental Protection Agency.

Research by Moslen *et al*. (2018) and Oghenetekevwe *et al*. (2024) showed higher metal levels in sediment and water from Azuabie Creek and Ogoloma, respectively, compared to our study's findings. However, Iwegbue *et al*. (2018) reported higher metal concentrations in surface sediments from coastal creeks in the Niger Delta, except for chromium. Their results revealed that cadmium, chromium, nickel, and zinc levels in sediment exceeded regulatory limits set by the Nigerian Regulatory Authority, with cadmium posing the most significant ecological risk.

Geo-accumulation index (Igeo) in sediment

Assessing the sediment quality using the geo-accumulation index (Igeo) criteria provides insights into the contamination levels for different metals in three distinct locations (Tema, Degema, and Sangama). From Tabe 4, the geoaccumulation index (Igeo) in sediment for the specified metals across the three locations can be analyzed as follows: For Cd, the Igeo shows varying levels: Tema (5.017) < Degema (4.977) < Sangama (6.322). For Pb, the Igeo follows a similar trend: Tema (0.074) < Degema (0.066) < Sangama (0.101). For Zn, the Igeo exhibits minor fluctuations: Tema (0.681) < Degema (0.632) < Sangama (0.691). For Fe, the Igeo remains relatively consistent: Tema (0.086) < Degema (0.082) < Sangama (0.091). For Cu, the Igeo shows significant variations: Tema (0.453) < Degema (0.428) < Sangama (0.526).

The results in Table 5 indicate that the sediment in Tema and Degema is generally uncontaminated for most metals, except for moderate contamination of Copper in Degema (Muller, 1969). Sangama, however, shows higher contamination levels, particularly for cadmium, Lead, and Copper. The varying values for each parameter highlight the spatial variability in contamination levels among the three locations, emphasizing the need for targeted environmental management strategies in Sangama to address the observed higher contamination levels (Sharma, 2020). However, Tema and Degema show low contamination for most metals, with moderate copper contamination in Degema (Yerima *et al*., 2020). Sangama, on the other hand, exhibits higher levels of contamination, especially for cadmium, lead, and copper. The varying contamination levels across the locations indicate differing ecological risks (Luo & Jia, 2021).

The elevated contamination levels in Sangama, particularly for critical metals like cadmium, lead, and copper, may pose ecological threats to sediment-dwelling organisms and associated ecosystems (Ali *et al*., 2022). Chris and Anyanwu (2023) revealed that the sediments of a mangrove swamp, Niger Delta had varying degrees of heavy metal pollution, with copper and cadmium playing a major role. However, Kpee *et al*. (2019) reported that the ecological risk analysis revealed that the heavy metal content in sediment did not pose a risk to the ecology of Andoni River, Rivers State, Niger Delta. However, if the situation continues unabated, there may be a risk of Zn and Cd.

The ecological implications highlight the greater contamination risks faced by Sangama's sediment compared to Tema and Degema, underscoring the importance of tailored environmental management strategies to preserve the ecological integrity of the sediment environment in Sangama. Therefore, continuous monitoring of sediment quality in all locations is crucial to track changes over time and assess the effectiveness of environmental management interventions.

Table 5. Geoaccumulation index (Igeo) in sediment.

Metals	Tema	Degema	Sangama
Cd	5.017	4.977	6.322
Pb	0.074	0.066	0.101
Zn	0.681	0.632	0.691
Fe	0.086	0.082	0.091
Cu	0.453	4.028	5.026

Table 6. Ecological risk Factor and potential ecological risk Index (PERI) for sediment.

Metals	Tema	Degema	Sangama
Cd	75.00	74.40	94.50
Pb	38.95	34.65	53.00
Zn	221.90	205.80	225.30
Cu	254.00	2258.00	2817.50
PERI	589.85	2572.85	3190.30

Ecological risk Factor and potential ecological risk Index (PERI) for sediment

The comprehensive evaluation of sediment ecological risk factors and potential ecological risk indices (PERI) across three distinct locations (Tema, Degema, and Sangama) in Table 6 provides a nuanced understanding of the ecological risks associated with various metals and their cumulative impact on sediment quality.

In Tema, a combination of moderate to considerable risk levels for Cadmium (Cd), Lead (Pb), Zinc (Zn), and Copper (Cu) contributes to a high overall PERI value of 589.85, signifying a substantial ecological risk. Despite moderate individual risks, the cumulative effect underscores the imperative for targeted mitigation strategies to address the heightened ecological risks in the water of Tema.

Similarly, Degema exhibits considerable risks for Cd, Pb, and Zn, with the additional challenge of extremely high Copper (Cu) levels. This results in a significantly high overall PERI of 2572.85, emphasizing the urgent need for intervention to mitigate the heightened ecological risks associated with Cu contamination in the sediment of Degema.

Sangama faces considerable to very high risks for Cd, Pb, Zn, and Cu, with particularly severe threats posed by elevated Cu levels. The overall PERI of 3190.30 signals a significantly high ecological risk, necessitating comprehensive and immediate remediation measures to safeguard sediment quality and preserve the health of aquatic ecosystems in Sangama.

The consistent pattern of considerable to significantly high ecological risks across all three locations, with the cumulative impact of multiple metals amplifying overall risk levels (Mwakisunga *et al*., 2021). A study by Ezekwe and Utong (2017) detected high levels of heavy metals in sediment samples, surpassing commonly used quality guidelines and exceeding thresholds for potential environmental harm. Aigberua and Tarawou's 2018 study assessed metal contamination and found moderate levels of contamination. While most heavy metals showed no contamination, copper and nickel exhibited a range of contamination levels from none to moderate. The potential ecological risk index indicated a low likelihood of environmental harm.

Urgent and coordinated efforts are imperative to implement effective environmental management practices, mitigate ecological risks, and ensure the sustained health of aquatic ecosystems and surrounding environments in Tema, Degema, and Sangama. The findings emphasise the critical need for immediate and targeted interventions to address the heightened ecological risks in sediment across all three locations.

Metal Pollution Load Index (MPLI)

The Metal Pollution Load Index (MPLI) is a crucial tool for evaluating pollution levels in water and sediment and shedding light on the environmental health of Tema, Degema, and Sangama. The MPLI values, indicative of the Pollution Load Index (PLI), are essential metrics, with values above 1 suggesting varying degrees of pollution according to Barakat *et al*. (2020). Water samples from all three stations in Table 7 reveal MPLI values well above 1, signifying moderate to heavy pollution. Degema has the highest MPLI, followed by Sangama and Tema. These results indicate a significant level of pollution in the water environments of

Table 7. Metal Pollution Load Index (MPLI).

Stations	Water	Sediment
Tema	53.843	239317.466
Degema	71.053	200769.956
Sangama	64.649	343876.619

these locations, necessitating urgent and targeted remediation measures.

In addition, the sediment MPLI values for Tema, Degema, and Sangama exhibit exceptionally high levels, pointing to the prevalence of very heavy pollution. The excessive cadmium levels in Sangama stem from unauthorized refining discharge, residential waste disposal, and fishing activities and byproducts. These practices combined increase cadmium concentrations, underscoring the necessity for focused remediation efforts and sustainable environmental measures to combat pollution and safeguard the health of the aquatic ecosystem.

Sangama records the highest sediment MPLI, followed by Tema and Degema. According to Chris and Anyanwu (2023) elevated MPLI values underscore an alarming degree of pollution in the sediment, emphasizing the urgent need for comprehensive environmental management strategies to mitigate the substantial impact on sediment quality.

The collective MPLI results across both water and sediment underscore a concerning level of pollution in all three stations, highlighting the critical importance of immediate and coordinated efforts to identify and address the sources of pollution (Diez *et al*., 2019). Effective remediation measures are imperative for Tema, Degema, and Sangama to ensure the preservation of water and sediment quality and, ultimately, the overall health of aquatic ecosystems in these regions.

CONCLUSION

The Geo-Ecological Risk Assessment of heavy metals in sediment and water from coastal marine wetlands in Rivers State, Nigeria, has revealed complex dynamics of ecological risks, and metal pollution and contamination levels. The research underscores the importance of monitoring and controlling heavy metal pollution in coastal marine wetlands in Rivers State, Nigeria. The study reveals the spatial variation in contamination levels and ecological risks linked to heavy metal pollution, with Sangama showing the highest contamination levels and associated ecological risks. The outcomes stress the pressing need for targeted environmental management actions to alleviate the negative impacts of heavy metal pollution on water and sediment quality and safeguard the overall well-being of aquatic ecosystems in Tema, Degema, and Sangama. Moreover, the research highlights the significance of ongoing monitoring initiatives to monitor changes in contamination levels over time and evaluate the efficacy of remediation measures. In summary, the results offer valuable insights into the environmental well-being of coastal marine wetlands in Rivers State and guide decision-making processes focused on safeguarding and conserving these vital ecosystems for future generations.

GRANT SUPPORT DETAILS

The current research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest regarding the publication of this manuscript.

LIFE SCIENCE REPORTING

There were no life science threats involved in this research.

REFERENCES

Abdullah, M.I.C., Sah, A.S.R.M. & Haris, H. (2020). Geoaccumulation Index and Enrichment Factor of Arsenic in Surface Sediment of Bukit Merah Reservoir, Malaysia. *Tropical Life Science Research*, 31(3):109-125.

Adekola, O., & Mitchell, G. (2011). The Niger Delta wetlands: threats to ecosystem services, their importance to dependent communities and possible management measures. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *7*(1), 50-68.

Agboola, J. I., Ndimele, P. E., Odunuga, S., Akanni, A., Kosemani, B., & Ahove, M. A. (2016). Ecological health status of the Lagos wetland ecosystems: Implications for coastal risk reduction. *Estuarine, Coastal and Shelf Science*, *183*, 73-81.

Ahirvar, B. P., Das, P., Srivastava, V., & Kumar, M. (2023). Perspectives of heavy metal pollution indices for soil, sediment, and water pollution evaluation: An insight. *Total Environment Research Themes*, *6*, 100039.

Aigberua, A. O., & Tarawou, T. (2018). Ecological Risk Assessment of Selected Elements in Sediments from Communities of Theriver Nun, Bayelsa State. *Nigeria J Environ Bio Res*, *2*(1).

Akankali, J. A., & Davies, I. C. (2021). Heavy Metals and Physicochemical Parameters Evaluation in the Upper Reaches of Bonny River, Niger Delta, Nigeria. *Journal of Applied Sciences and Environmental Management*, *25*(8), 1341-1348.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. Water, 13(19), 2660.

Ali, M. M., Ali, M. L., Rakib, M. R. J., Islam, M. S., Habib, A., Hossen, S., ... & Phoungthong, K. (2022). Contamination and ecological risk assessment of heavy metals in water and sediment from hubs of fish resource river in a developing country. *Toxin Reviews*, *41*(4), 1253-1268.

Arisekar, U., Shalini, R., Sundhar, S., Sangma, S. R., Rathinam, R. B., Albeshr, M. F., ... & Sahana, M. D. (2023). De-novo exposure assessment of heavy metals in commercially important fresh and dried seafood: Safe for human consumption. *Environmental Research*, *235*, 116672.

Barakat, A., Ennaji, W., Krimissa, S., & Bouzaid, M. (2020). Heavy metal contamination and ecological-health risk evaluation in peri-urban wastewater-irrigated soils of Beni-Mellal city (Morocco). *International Journal of Environmental Health Research*, *30*(4), 372-387.

Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020). Concerns and threats of contamination on aquatic ecosystems. *Bioremediation and biotechnology: sustainable approaches to pollution degradation*, 1-26.

Birch, G. F., Olmos, M. A., & Lu, X. T. (2012). Assessment of future anthropogenic change and associated benthic risk in coastal environments using sedimentary metal indicators. *Journal of Environmental Management*, *107*, 64-75.

Carpenter, S. R., Stanley, E. H., & Vander Zanden, M. J. (2011). State of the world's freshwater ecosystems: physical, chemical, and biological changes. *Annual Review of Environment and Resources*, *36*, 75-99.

CCME (2002). Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment. https://ccme.ca/en/summary-table

Chris, D. I., & 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.

Chris, D. I., & 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., Onyena, A. P., & Sam, K. (2023a). Evaluation of human health and ecological risk of heavy metals in water, sediment and shellfishes in typical artisanal oil mining areas of Nigeria. *Environmental Science and Pollution Research*, 1-15.

Chris, D. I., Wokeh, O. K., Lananan, F., & Azra, M. N. (2023b). Assessment of Temporal Variation of Water Quality Parameters and Ecotoxic heay Metals in Southern Nigeria Coastal Water. *Polish Journal of Environmental Studies*, 32(5).

Davies, I. C., Anyanwu, E. D., & Amaewhule, E. G. (2024a). Evaluation of Heavy Metal Pollution in Commonly Consumed Mollusc (*Crassostrea gasar*) from Elechi Creek, River State, Nigeria and the Health Risk Implications. *Journal of the Turkish Chemical Society Section A: Chemistry*, *11*(2), 525-532.

Davies, I. C., Sulaiman, Y., & Efekemo, O. (2024). Ecotoxicity of trace metal enrichment and the degrees of contaminated sediment and water from Riparian communities in Rivers State, Nigeria. *Scientia Africana*, *23*(2), 370-382.

Diez, S. M., Patil, P. G., Morton, J., Rodriguez, D. J., Vanzella, A., Robin, D. V., ... & Corbin, C. (2019). Marine pollution in the Caribbean: not a minute to waste.

Efekemo O., Davies I. C., and Orororo C. O. (2024), Water Quality Assessment and Heavy Metal Levels in Mudskipper (*Periophthalmus Papilio*), Sediments and Water of Mangrove Swamps, Rivers State, Nigeria. African Journal of Environment and Natural Science Research 7(1), 128- 145.

Emeka Donald Anyanwu, Davies I. C., and Onyinyechi Gladys Adetunji (2023). Assessment Of Heavy Metals in Sediments and Associated Ecological Risks in Ikwu River, Umuahia, Nigeria. *Environmental Problems*. 8, (3): pp.167-177.

Enuneku, A., Omoruyi, O., Tongo, I., Ogbomida, E., Ogbeide, O., & Ezemonye, L. (2018). Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. *Applied water science*, *8*, 1-13.

Ezekwe, C. I., & Utong, I. C. (2017). Hydrocarbon Pollution and Potential Ecological Risk of Heavy Metals in the Sediments of the Oturuba Creek, Niger Delta, Nigeria. *Journal of Environmental Geography*, *10*(1-2), 1-10.

Ezekwe, I. C., Otiasah, C. L., Raimi, M. O., & Austin-Asomeji, I. (2022). Hydrocarbon-based contaminants in drinking water sources and shellfish in the Soku oil and gas fields of South-South Nigeria. *Open Journal of Yangtze Oil and Gas*, *7*(4), 213-230.

Fashae, O. A., & Obateru, R. O. (2021). Geospatial assessment of surface water pollution and industrial activities in Ibadan, Nigeria. *Spatial Modeling and Assessment of Environmental Contaminants: Risk Assessment and Remediation*, 189-211.

Guan, Y., Shao, C., & Ju, M. (2014). Heavy metal contamination assessment and partition for industrial and mining gathering areas. *International journal of environmental research and public health*, *11*(7), 7286-7303.

Habib, J., Sadigheh, J. & Mohammad, A.K. (2018). Assessment of heavy metal pollution and ecological risk in marine sediments (A case study: Persian Gulf). *Human and Ecological Risk Assessment,* 24(8):1–10.

Häder, D. P., Banaszak, A. T., Villafañe, V. E., Narvarte, M. A., González, R. A., & Helbling, E. W. (2020). Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. *Science of the Total Environment,* 713, 136586.

Hakanson, L., 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research*, *14*(8), pp.975-1001.

Islam, M. S., Han, S., Ahmed, M. K., & Masunaga, S. (2014). Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. *Journal of water and environment technology*, *12*(2), 109-121.

Iwegbue, C., Beecroft, O., Ogala, J., Egobueze, F., Tesi, G., Nwajei, G., & Martincigh, B. (2018). Concentrations and ecological risks of metals in surface sediments of some coastal creeks in the Niger Delta, Nigeria. *African Journal of Aquatic Science*, *43*(3), 241–253.

Jafarabadi, A. R., Mitra, S., Raudonytė-Svirbutavičienė, E., & Bakhtiari, A. R. (2020). Large-scale evaluation of deposition, bioavailability and ecological risks of the potentially toxic metals in the sediment cores of the hotspot coral reef ecosystems (Persian Gulf, Iran). *Journal of Hazardous Materials*, *400*, 122988.

Kolarova, N., & Napiórkowski, P. (2021). Trace elements in aquatic environment. Origin, distribution, assessment and toxicity effect for the aquatic biota. *Ecohydrology & Hydrobiology*, *21*(4), 655-668.

Kpee, F., Edori, O. S., & Okotume, S. C. (2019). Geo-accumulation and ecological risks of heavy metals in sediments of Andoni River, Rivers State, Niger Delta, Nigeria. *Int. J. Res. Sci. Innov*, *6*, 197-202.

Luo, J., Ye, Y., Gao, Z., Wang, Y., & Wang, W. (2016). Trace element (Pb, Cd, and As) contamination in the sediments and organisms in Zhalong Wetland, Northeastern China. *Soil and Sediment Contamination: An International Journal*, *25*(4), 395-407.

Luo, Y., & Jia, Q. (2021). Pollution and Risk Assessment of Heavy Metals in the Sediments and Soils around Tiegelongnan Copper Deposit, Northern Tibet, China. *Journal of Chemistry*, *2021*, 1-13.

Mebane, C. A. (2023). Bioavailability and toxicity models of copper to freshwater life: The state of regulatory science. *Environmental Toxicology and Chemistry*, *42*(12), 2529-2563.

Moslen, M., Ekweozor, I. K., & Nwoka, N. D. (2018). Assessment of heavy metals pollution in surface sediments of a tidal creek in the Niger Delta, Nigeria. *Archives of Agriculture and Environmental Science*, *3*(1), 81-85.

Mugoša B, Đurović D, Nedović-Vuković M, Barjaktarović-Labović S, Vrvić M. Assessment of Ecological Risk of Heavy Metal Contamination in Coastal Municipalities of Montenegro. *Int J Environ Res Public Health.* 2016 Mar 31;13(4):393.

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of the Total Environment*, *709*, 136125.

Muller, G. M. M. G. M. G. M. G. P. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geojournal*, *2*, 108-118.

Mwakisunga, B., Pratap, H.B., Machiwa, J.F. & Stephano, F. (2021). Heavy Metal Contamination and Potential Ecological Risks in Surface Sediments along Dar es Salaam Harbour Channel. *Tanzania Journal of Science,* 47(5): 1606-1621.

Nivetha, N., Srivarshine, B., Sowmya, B., Rajendiran, M., Saravanan, P., Rajeshkannan, R., ... & Dragoi, E. N. (2023). A comprehensive review on bio-stimulation and bio-enhancement towards remediation of heavy metals degeneration. *Chemosphere*, *312*, 137099.

Okereafor, U., Makhatha, M., Mekuto, L., Uche-Okereafor, N., Sebola, T., & Mavumengwana, V. (2020). Toxic metal implications on agricultural soils, plants, animals, aquatic life and human health. *International journal of environmental research and public health*, *17*(7), 2204.

Onyena, A., Nkwoji, J., Chukwu, L., Ifediba, E., Afonne, O., & Amachree, D. (2023). Metal Pollution and Ecological Risk in Water from Chanomi Creek, Warri, Niger Delta, Nigeria. *Journal of Chemical Health Risks*, *5*(4), 789.

Sharma, S. D. (2020). Risk assessment via oral and dermal pathways from heavy metal polluted water of Kolleru Lake - A Ramsar wetland in Andhra Pradesh, India. *Environmental Analysis Health and Toxicology*, 35(3): e2020019.

Singh, A., Sharma, A., Verma, R. K., Chopade, R. L., Pandit, P. P., Nagar, V., ... & Sankhla, M. S. (2022). Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms. In *The Toxicity of Environmental Pollutants*. IntechOpen.

Sodango, T. H., Li, X., Sha, J., & Bao, Z. (2018). Review of the spatial distribution, source and extent of heavy metal pollution of soil in China: impacts and mitigation approaches. *Journal of Health and Pollution*, *8*(17), 53-70.

Sonone, S. S., Jadhav, S., Sankhla, M. S., & Kumar, R. (2020). Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain. *Lett. Appl. NanoBioScience*, *10*(2), 2148-2166.

USEPA (2001). Baseline Human Health Risk Assessment Vasquez Boulevard and I-70 Superfund Site Denver CO. U.S. Environmental Protection Agency. Available online: https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/786143.

USEPA. 2018. Aquatic Life Ambient Water Quality Criteria for Aluminum. U.S. Environmental Protection Agency, EPA-822-R-18-001. 278 pp. https://www.epa.gov/wqc/aquatic-life-criteria-aluminum.

Yerima E. A, Itodo A. U., Sha'Ato R., & Wuana R. A. (2020) Ecological risk assessment of mineral and heavy metals level of soil around auto mechanic village Wukari, Nigeria. *Academic Journal of Chemistry* 5: 81-90.

Zhang, P., Pan, X., Wang, Q., Ge, G., & Huang, Y. (2020). Toxic effects of heavy metals on the freshwater benthic organisms in sediments and research on quality guidelines in Poyang Lake, China. *Journal of Soils and Sediments*, *20*, 3779-3792.