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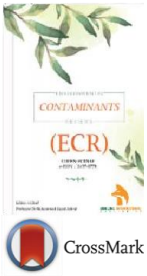

RESEARCH ARTICLE

ASSESSMENT OF THE CONCENTRATION OF HEAVY METALS IN ROAD-DEPOSITED SEDIMENTS ALONG ORHO AGBARHO-PATANI ROAD, NIGER DELTA, NIGERIA

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ABSTRACT

This study investigated the concentration of heavy metal in road-deposited sediments along Orho Agbarho-Patani Road in the Niger Delta region of Nigeria. Seven (7) samples were randomly collected by systematically sweeping an area of 1 m^2 on the road surface with a hard broom and collecting it with a clean plastic dustpan, while a control sample was obtained from an uncontaminated site. The samples were analyzed for some heavy metals (Pb, Cr, Cd, Zn, Mn, Ni, and Fe) using the atomic absorption spectrophotometer (AAS). The results obtained showed that the mean concentrations of Pb (0.04 mg/kg), Cr (0.24 mg/kg), Cd (0.001 mg/kg), Zn (14.86 mg/kg), Mn (2.85 mg/kg), Ni (0.001 mg/kg), and Fe (107.78 mg/kg) were below the WHO maximum permissible limit and the Nigerian Soil Quality Standards, although localized contamination of Mn (15.221 mg/kg) and Fe (255.564 mg/kg) were observed at BC2 and BC3, respectively. Comprehensive environmental indices, including geo-accumulation index, enrichment factor, contamination factor, degree of contamination, pollution load index, and potential ecological risk index, confirmed severe contamination, particularly at specific sites. Notably, Pb and Cr posed significant ecological risks, while Cd and Mn posed moderate to high risks. Although the overall contamination levels were not immediately harmful, the long-term implications for human health and the environment cannot be ignored. Therefore, continuous monitoring and potential remediation strategies are necessary to mitigate the risks associated with heavy metal pollution in the region.

KEYWORDS

Road-deposited sediments, heavy metals, contamination, geo-accummulation index, ecological risk assessment.

1. INTRODUCTION

Road-deposited sediments (RDS) refer to a type of environmental medium that accumulates on road surfaces and aid in the transportation of heavy metals and other pollutants (Gao et al., 2022). Road-deposited sediments originate from the build-up of particles from natural sources such as erosion and weathering, and anthropogenic sources like vehicular traffic, industrial activities or construction. They contain diverse and complex combination of pollutants due to their varied emission sources which can introduce toxins into the environment through processes like wind- and traffic-induced resuspension and surface runoff washing, posing serious risks to the environment and public health (Goya-Heredia et al., 2023).

Heavy metals found in road-deposited sediment come from a variety of sources like traffic-related activities (emissions and wear), dust settling from the air (atmospheric deposition), and industrial activities in urban areas (Gao et al., 2022). Some researcher categorize these sources into extrinsic and intrinsic sources (Sutherland and Tolosa, 2000). Extrinsic sources include erosion from surrounding soil and slopes, atmospheric deposition, and biological materials like fallen leaves. Intrinsic sources originate from the road and traffic itself, including wear and tear of road surfaces, degradation of road paint, wear and tear of vehicles, leakage of vehicle fluids, and exhaust emissions.

Heavy metal contamination in road-deposited sediments is impacted by a number of factors, including traffic density, road type, land use, rainfall, and particle size distribution. Traffic density raises heavy metal concentrations in RDS owing to activities like vehicle emissions, tyre wear, and brake abrasion, all of which emit pollutants into the environment. Road types with impermeable surfaces that inhibit water infiltration, such as urban expressways and intercity roads, can lead to heavy metal pollution in RDS (Gao et al., 2022). Land use near roadways, factories, and homes can lead to elevated heavy metal concentrations in road-deposited sediments (Zhu et al., 2007). Rainfall events mobilize heavy metals from RDS into runoff with the first flush effect, causing pollutants to be washed off roads and transported to nearby water bodies.

The size distribution of RDS particles influences their mobility and contamination potential. Fine-grained RDS particles tend to carry higher concentrations of heavy metals and contribute significantly to overall metal loads in runoff compared to coarse particles (Zhao et al., 2010). These sediments pose potential environmental and human health hazards due to toxins introduced through processes like wind and traffic-induced resuspension and surface runoff washing (Goya-Heredia et al., 2023). Sediments can be washed off by rainfall, contributing to stormwater pollution and affecting water quality and aquatic biodiversity. Contaminated sediments can also be washed off into surrounding soils, leading to a gradual increase in heavy metal content over time, negatively impacting crop health. If consumed by animals, they can bioaccumulate through the food chain, posing health risks to humans and animals. Road-deposited sediments undergo resuspension by wind or vehicle movement, becoming airborne and contributing to particulate matter (PM) pollution, degrading air quality.

Nigeria's rapidly growing industrialization has brought about substantial

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economic growth and development. The surge in manufacturing activities has resulted in increased emissions and effluents containing heavy metals. This, coupled with urbanization and transportation infrastructure growth, has led to the accumulation of heavy metal in road-deposited sediments. These sediments, derived from various sources like vehicular emissions, industrial discharges, and atmospheric deposition, pose significant health risks. They can be re-suspended, contaminating air and water. Moreover, food items sold along roads are exposed to potential contamination. The persistence, bioaccumulation potential, and toxicity of these heavy metals pose a serious threat to both the environment and public health. To mitigate these risks and promote sustainable development, there is an urgent need to collect data on the concentration of heavy metals in the study area.

This study therefore aim to assess the concentration of heavy metals in RDS along the Orho Agbarho-Patani Road in Niger Delta, Nigeria. The objectives are to quantify the concentrations of heavy metals (Pb, Cr, Cd, Zn, Mn, Ni, and Fe) in RDS and assess their levels relative to established guideline values to determine the extent of contamination; to identify potential sources of heavy metal contamination in RDS and investigate the factors influencing the variability of metal concentrations; to evaluate the degree of heavy metal contamination using various pollution indices, such as the geo-accumulation index, enrichment factor, contamination factor, degree of contamination, pollution load index, and potential ecological risk index, to assess the risks to public health and the environment posed by heavy metal contamination in RDS along the Orho Agbarho-Patani Road corridor; and to provide crucial data that can inform the development and implementation of effective remediation strategies and sustainable environmental management practices.

2. Materials and Methods

2.1 Study Area

The study area is an important part of the broader Warri-Patani Road network located in Effurun, the headquarters of the Uvwie Local Government Area, Delta State, Nigeria. It is located between Latitude 5° 31′ 0″ N and Longitude 5° 45′ 0″ E (Figure 1). Its physiography is influenced by its location in the Niger Delta region, which features low-lying topography, river deltas, mangrove forests, and estuaries.

The study area experiences a tropical monsoon climate, characterized by distinct wet and dry seasons. The rainy season typically begins in late February or early March and lasts until July, with peak rainfall occurring in June. This is followed by a brief dry period known as the "August break," lasting two to three weeks. A second, shorter rainy season occurs from early September to mid-October, peaking at the end of September. The harmattan, a dry, dusty wind, affects the region only during November and February. Temperatures in the Niger Delta are relatively constant throughout the year, with daytime highs around 30°C and nighttime lows around 20°C.

As part of the Niger Delta Basin which is one of the world's largest and most prolific sedimentary basins, the study area is primarily composed of sedimentary rocks, including sandstone, shale, and clay.

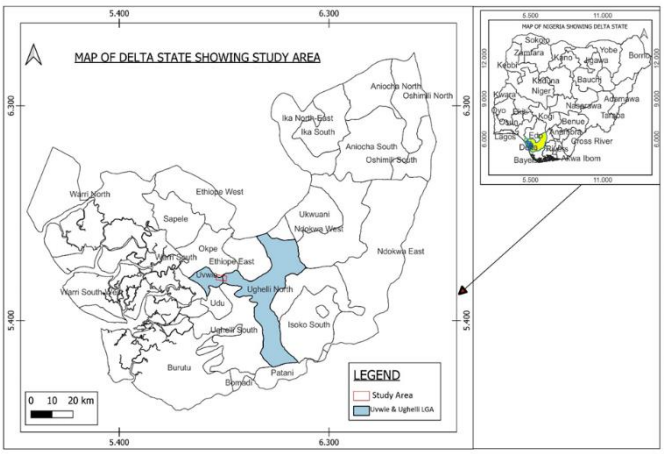

Figure 1: Map of Delta State showing the study area

2.2 Sample Collection

Seven (7) sediment samples and one (1) control sample were carefully collected from the study area as shown in Figure 2 by systematically sweeping an area of 1 m2 on the road surface with a hard broom and collecting it with a clean plastic dustpan, which was thoroughly cleaned prior to use. The collected sediment samples were labeled and taken to the laboratory for further analysis. To achieve accurate spatial referencing, the sampling points were recorded using a Global Positioning System (GPS) device. This comprehensive approach to sample collection laid the groundwork for a thorough investigation of the road-deposited sediment within the study area.

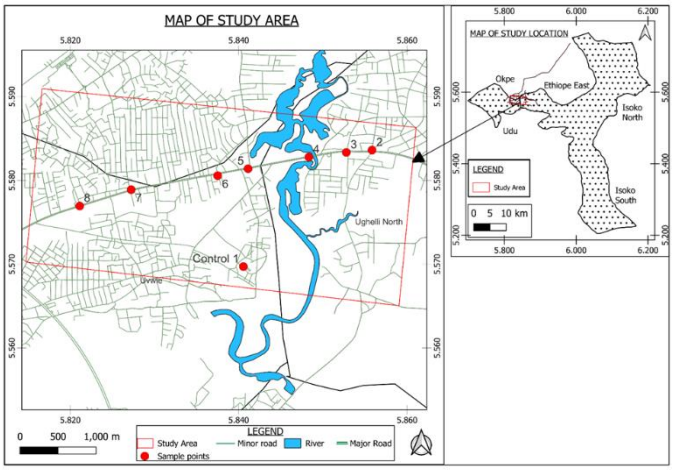

Figure 1: Map of study area showing sampling points

2.3 Sample Preparation and Determination of Metal Content

The sample preparation process involved first air-drying the samples at room temperature to remove excess moisture. Then the dried samples were crushed into a fine powder using a mortar and pestle, after which 5 grams of this powdered sample were subjected to additional grinding until a fine powder that could pass through a 2 mm mesh sieve was obtained. The following heavy metals were recovered from the road dust using the wet oxidation technique by digestion: cadmium, lead, chromium, manganese, zinc, iron, and nickel. To digest the samples, this approach used a combination of perchloric and nitric acids. Approximately 2 grams of the powdered sample were placed in a 250 cm3 conical flask, followed by 1 ml of perchloric acid and 3 ml of nitric acid.

The mixture was then heated on a hot plate in a fume cupboard at 40 °C until it was completely digested. The solution was then allowed to cool before the liquid was transferred to a 50 ml volumetric flask. The sample solution was then stored in a polypropylene bottle. A blank sample was prepared in the same manner as the unknown samples and went through all of the procedures. The sample solution, standard, and blank were then sucked into the air-acetylene flame of an atomic absorption spectrophotometer (AAS) for heavy metal analysis with various heavy metal cathode lamps. The Varian Spectra Model 220 (Fast Sequential) AAS was utilized for the analysis.

2.4 Statistical Analysis

The contamination level of the road-deposited sediments was assessed using several environmental indices, including the geo-accumulation index, enrichment factor, contamination factor, pollution load index, and possible ecological risk index. These methods all provide a robust framework for evaluating the extent and severity of contamination.

2.4.1 Geo-accumulation Index (Igeo)

Geo-accumulation index (Igeo) was originally defined by Muller in 1969 to assess metal pollution in sediments by comparing current concentrations to pre-industrial levels. It evaluates the accumulation of a particular pollutant over time, indicating the contamination level relative to background concentration. The equation for calculating the geo-accumulation index is captured in equation (1).

$$Igeo = log_2(\frac{C_n}{1.5 \times B_n}) \quad (1)$$

Where Cn is the measured concentration of the element in the sediment, Bn is the geochemical background concentration of the heavy metal and the factor 1.5 is used to account for the natural changes of heavy metals in the environment and accommodates a very little effect caused by human origin (Lu et al., 2009). The reference values for calculating the Igeo values in this study were derived from a control sample designated as BC1. This control sample is considered to be from a relatively clean or unpolluted environment, serving as a baseline for comparison to other samples. Igeo employs a pollution scale devised by that ranges from non-contaminated

(0) to severely polluted (6) (Muller, 1969).

2.4.2 Enrichment Factor (EF)

The enrichment factor (EF) is a technique for determining anthropogenic influence. It measures the extent to which a pollutant is enriched in a sample compared to its natural abundance. The mathematical expression is illustrated by equation (2).

$$EF_y = \left(\frac{X_i}{E_{i(ref)}}\right) \div \left(\frac{Y_w}{E_{w(ref)}}\right) \quad (2)$$

Where EFy is the enrichment factor of the element Y, Xi is the concentration of the element in the sample, Ei(ref) is the concentration of the reference element in the sample, Yw is the concentration of the element in the crust and Ew(ref) is the concentration of the reference element used for normalization in the crust (Taylor, 1964). The reference element employed in this study is iron (Fe). Five categories of contamination based on the enrichment factor has been established by and ranges from minimal (<2) to extremely high enrichment (>40), and EF values greater than 10 are indicative of anthropogenic sources (Kartal et al., 2006).

2.4.3 Contamination Factor (CF) and Degree of Contamination (Cdeg)

Contamination factor (CF) is used to quantify the contamination of a given metal in sediment (Shen et al., 2019). It assesses the contamination level of a pollutant in a specific area or sample relative to a reference site. It is expressed mathematically as illustrated by equation (3). Where Ci is the concentration of the metal in the sediment and Bi is the background concentration of the metal.

Equation (4) indicates the degree of contamination, which is calculated using the total contamination factors of all elements present in the sample (Odochi et al., 2024). The degree of contamination can be categorized into four classes: Cdeg < 8 indicates low contamination, 8 ≤ Cdeg < 16 indicates reasonable contamination, 16 ≤ Cdeg < 32 indicates substantial contamination, and Cdeg ≥ 32 indicates an enhanced degree of contamination.

$$CF = {}^{C_i}/_{B_i} \quad (3)$$

$$C_{deg} = \sum CF \quad (4)$$

2.4.4 Pollution Load Index (PLI)

Pollution load index (PLI) is a tool developed by Tomlinson et al. (1980) to measure the cumulative level of heavy metal pollution in a site, considering all metals at different locations and a geometric mean of the CF (Rahman et al., 2022). It is expressed mathematically as illustrated in equation (5).

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n} \quad (5)$$

Where CFn is the contamination factor of the n-th metal and n is the number of metals analyzed. According to a study, PLI value of 1 shows the presence of background pollutants, whereas PLI > 1 indicates that soil quality is degrading (Tomlinson et al., 1980).

2.4.5 Potential Ecological risk Index (PERI)

The potential ecological risk index, established by estimates the potential ecological risk posed by pollutants, considering factors like toxicity, persistence, and bioaccumulation potential, aiding in prioritizing pollution management efforts based on ecological impact (Hakanson, 1980). The potential ecological risk index is calculated using many components, including the individual pollution coefficient, the toxic-response factor associated with each heavy metal, and the potential ecological risk factor assigned to each metal. The correlations between these variables are given using Hakanson's (1980) equations (6), (7), and (8).

$$E_r^i = T_r^i \quad (6)$$

$$RI = \sum_{i=1}^{n} E \quad (7)$$

$$C_f^i = \frac{c_s^i}{c_n^i} \quad (8)$$

The possible ecological risk index associated with heavy metal 'i' is denoted as E_r^i. The potential ecological risk factor associated with numerous metals is denoted as RI, while the "toxic-response" component specific to heavy metal 'i' is denoted as T_r^i (Odochi et al., 2024). According to a study, proposal, the T_r^i values of the elements follow the order Zn = 1 < Cr = 2 < Pb = Ni = 5 < Cd = 30 (Hakanson's, 1980). The level of pollution caused by the heavy metal 'i', referred to as the pollution coefficient, is denoted as C_f^i and the measured concentration of heavy metal 'i' in the soil, which is measured in mg/kg, is denoted as C_s^i. On the other hand, C_n^i represents the background value of the heavy metal i, which indicates the concentration of the heavy metal in unpolluted soil (Taylor, 1964). A researcher has delineated four distinct kinds of RI and five categories of E_r^i, as presented in Table 1 (Hakanson, 1980).

Table 1: Potential Ecological Risk Categories based on E_r^i and RI values (Source: Ichu et al., 2021)

Single-potential ecological risk		Comprehensive-potential ecological risk	
$E_r^i < 40$	Classified as Low Risk	$RI < 150$	Classified as Low Risk
$40 \leq E_r^i < 80$	Classified as Moderate Risk	$150 \leq RI < 300$	Classified as Moderate Risk
$80 \leq E_r^i < 160$	Classified as Considerable Risk	$300 \leq RI < 600$	Classified as Considerable Risk
$160 \leq E_r^i$	Classified as High Risk	$600 \leq RI$	Classified as Very High Risk
$320 \leq E_r^i$	Classified as Very High Risk		

3. Results and Discussion

3.1 Heavy Metal Concentrations in RDS

The concentrations of Pb, Cr, Cd, Zn, Mn, Ni, and Fe in the road-deposited sediments varied from 0.001 - 0.162, 0.001 - 1.621, 0.001 - 0.003, 7.413 - 25.374, 0.254 - 15.221, 0.001 - 0.001, and 16.125 - 255.564 mg/kg, respectively. The mean concentrations were 0.04, 0.24, 0.00, 14.86, 2.85, 0.00, and 107.78 mg/kg for Pb, Cr, Cd, Zn, Mn, Ni, and Fe, respectively. Notably, all observed values were below the WHO maximum permissible limits and Nigerian Soil Quality Standards. However, localized contamination of Mn (15.221 mg/kg) and Fe (255.564 mg/kg) was observed at BC2 and BC3, respectively, indicating site-specific pollution. The results of the concentration of heavy metals measured in the road-deposited sediment samples are presented in Table 2.

Table 2: Laboratory result for RDS samples in comparison with WHO permissible limit and Nigerian Soil Quality Standards

Locations	pH	EC	Pb	Cr	Cd	Zn	Mn	Ni	Fe
BC1(Control)	6.63	7.82	0.001	0.001	0.001	9.184	4.651	0.001	122.234
BC2	6.42	5.51	0.002	0.014	0.001	24.541	15.221	0.001	94.653
BC3	7.65	11.32	0.015	1.621	0.001	25.374	0.254	0.001	255.564
BC4	7.35	6.13	0.021	0.001	0.001	12.933	0.331	0.001	16.125
BC5	7.05	8.64	0.034	0.001	0.001	13.761	1.125	0.001	71.221
BC6	7.45	9.12	0.162	0.001	0.001	12.243	1.356	0.001	99.12
BC7	7.22	6.56	0.001	0.001	0.001	7.754	0.521	0.001	124.564
BC8	7.15	9.41	0.031	0.024	0.003	7.413	1.172	0.001	93.221

Table 2 (cont): Laboratory result for RDS samples in comparison with WHO permissible limit and Nigerian Soil Quality Standards

Range			0.001 - 0.162	0.001 - 1.621	0.001 - 0.003	7.413 - 25.374	0.254 - 15.221	0.001 - 0.001	16.125 - 255.564
Mean			0.04	0.24	0.001	14.86	2.85	0.001	107.78
WHO Maximum Permissible Limit*			85	100	0.8	50	12	35	NA
Nigerian Soil Quality Standards**			164	100	3	421	NA	70	NA

*WHO (1996) **National Environmental Standards and Regulations Enforcement Agency (2013), NA (Not Available)

3.2 Physicochemical Properties

The pH and electrical conductivity (EC) provide important information on the nature of the chemical components of the road-deposited sediments. Figure 3 captures the results of the pH and EC tests on the road-deposited sediment samples.

The pH level in the sampled sites was within a slightly acidic to neutral range. The pH values of Locations 1 to 8 were determined to be 6.63, 6.42, 7.65, 7.35, 7.05, 7.45, 7.22, and 7.15, respectively. The behavior of metallic elements in RDS is significantly influenced by pH levels because they play a major role in mechanisms such as precipitation, which contribute to the retention of these constituents within the soil (Evans et al., 1995). According to a study, the transportation of metallic contaminants decreases when soil pH levels rise, particularly when they approach 8 or above (Appleyard et al., 2004). As a result, the pH values obtained in the samples indicate that the mobility and solubility of metallic contaminants found in the soil samples are relatively high. This could increase the potential for these metals to contaminate groundwater or surface water and to be taken up by plants.

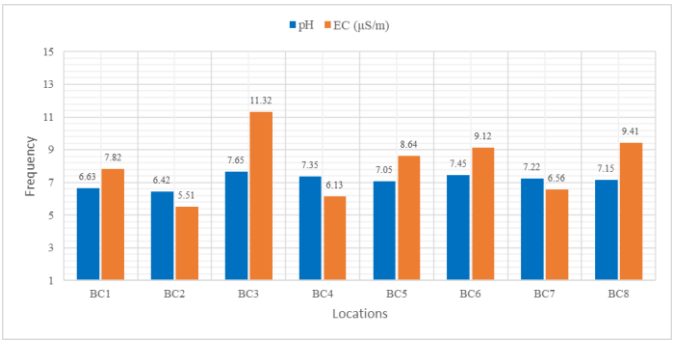

Figure 3: Physicochemical parameters of the RDS samples

The EC is used to detect the presence of dissolved ions in a sample. The EC values recorded for the eight locations were 7.82, 5.51, 11.32, 6.13, 8.64, 9.12, 6.56, and 9.41 µS/m, respectively. Smith and Giller (1992) introduced a widely accepted categorization system for electrical conductivity (EC) values. This approach categorizes soil EC values as non-saline (<2), moderately saline (2 – 8), very saline (8 – 16), and extremely saline (>16). The study's findings indicate that EC values varied somewhat across all sample locations. The EC level varies from moderately saline to highly saline, based on the EC classification.

3.3 Index of Geoaccumulation

Figure 4 captures the results of the estimated geo-accumulation index. Lead varies from (-0.58) - 6.75, chromium ranges from (-0.58) - 10.08, cadmium from (-0.58) - 1.00, zinc from (-0.89) - 0.88, manganese from (-4.78) - 1.13, nickel from (-0.58) – (-0.58), and iron varies from (-3.51) - 0.48, with the mean for each heavy metal being 3.23, 2.14, -0.36, -0.04, -2.77, -0.58, and -1.11, respectively. The results indicate that the sediment is extremely contaminated with lead and chromium, moderately contaminated with cadmium and manganese, and relatively less contaminated with zinc, nickel, and iron. These findings suggest that the contamination in the area is caused by anthropogenic and industrial sources, with considerable human activity and industrial processes contributing to the heavy metal presence. The elevated levels of lead and chromium, in particular, indicate major contamination, most likely from industrial activity or waste disposal. The moderate contamination by cadmium and manganese might be caused by agricultural activities or runoff from industrial areas.

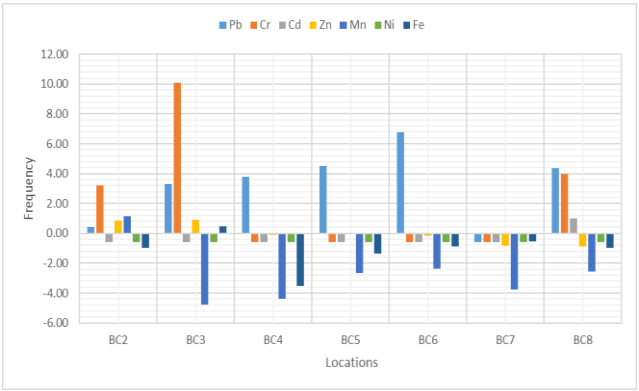

Figure 2: Index of Geo-accumulation of road deposited sediments in the study area

3.4 Enrichment Factor

The enrichment factor was computed using Equation 2, with iron (Fe) selected as the reference element for normalization, and the result is captured in Figure 5. The metals demonstrated varying amount of enrichment. Lead ranges from 0.98 - 199.78, chromium from 0.98 - 775.31, cadmium from 0.48 - 7.58, zinc from 0.83 - 10.67, manganese from 0.03 - 4.23, nickel from 0.48 - 7.58, and iron from 1.00 - 1.00. The mean of the metals was 66.96, 119.48, 2.46, 3.08, 0.86, 2.08, and 1.00, respectively. Lead and chromium exhibit very high enrichment, suggesting significant contamination, while cadmium and nickel show high enrichment. Manganese displays low enrichment, zinc shows moderate enrichment, and iron does not exhibit any enrichment. The highest observed EF value for chromium at BC3 was 775.31. This increase can be suggestive of significant urban and industrial contributions, the same can be said for the very high enrichment lead indicated. Cadmium and nickel, showing high enrichment, may also come from industrial sources and agricultural inputs. Zinc's moderate enrichment could be from industrial discharges and urban runoff and manganese's low enrichment suggests less significant anthropogenic input compared to other metals.

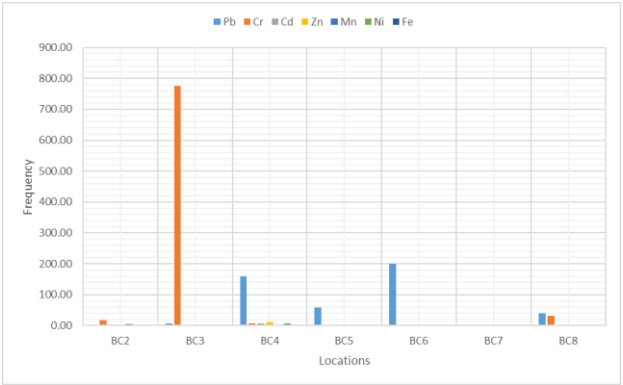

Figure 5: Enrichment Factors of road deposited sediments in the study area

3.5 Contamination Factor

The contamination factor was calculated using Equation 3 and is shown in Table 3. Each heavy metal's contamination factor across different points revealed a diverse level of contamination. Lead and chromium varied from moderate to very high contamination, cadmium ranged from moderate to considerable contamination, zinc and iron varied from low to moderate contamination, manganese varied from low to considerable contamination, and nickel mostly showed moderate contamination. This result is consistent with the results obtained from the geo-accumulation index and indicates a considerable presence of contamination resulting from human activities.

3.6 Degree of Contamination

The degree of contamination (Cdeg), as determined by Equation 4, is displayed in Table 3, and shows a value of 24.72 at BC2, 1642.91 at BC3, 25.61 at BC4, 39.32 at BC5, 167.44 at BC6, 5.98 at BC7, and 60.82 at BC8. The findings of this study indicate a substantial level of contamination 45 in BC2 and BC4, enhanced degree of contamination in BC3, BC5, BC6, and BC8. While BC7 exhibited low level of contamination.

Table 3: Contamination Factors of the metals, Degree of Contamination (Cdeg) and the Pollution Load Index (PLI)

Locations	Pb	Cr	Cd	Zn	Mn	Ni	Fe	Cdeg	PLI
BC2	2.00	14.00	1.00	2.67	3.27	1.00	0.77	24.72	2.12
BC3	15.00	1621.00	1.00	2.76	0.05	1.00	2.09	1642.91	3.59
BC4	21.00	1.00	1.00	1.41	0.07	1.00	0.13	25.61	0.83
BC5	34.00	1.00	1.00	1.50	0.24	1.00	0.58	39.32	1.33
BC6	162.00	1.00	1.00	1.33	0.29	1.00	0.81	167.44	1.75
BC7	1.00	1.00	1.00	0.84	0.11	1.00	1.02	5.98	0.72
BC8	31.00	24.00	3.00	0.81	0.25	1.00	0.76	60.82	2.31
Degree of Contamination	266.00	1663.00	9.00	11.33	4.30	7.00	6.17		

3.7 Pollution Load Index

The pollution load index computed using Equation 5 is captured in Table 3. The values suggest that the soil quality is degrading in most of the locations, as they have values greater than 1. However, at locations BC4 and BC7, the PLI values are below 1, indicating that these locations only have background levels of pollutants and are not experiencing significant soil quality degradation.

3.8 Potential Ecological Risk Index

The heavy metal potential ecological risk and potential ecological risk indices in the study area are captured in Table 4 and 3. The calculated values for the potential ecological risk of the metals across all sampling points revealed a low-risk classification for zinc, manganese, nickel, and iron. Cadmium showed considerable to high risk. Lead presented a range of risks: from low risk in BC2 and BC7 to moderate in BC3, considerable in BC4, high in BC5 and BC8, and very high risk in BC6. Chromium generally exhibited a low-risk classification, except at BC3, where it showed a very high risk, and BC8, with a moderate risk.

The result of the potential ecological risk indices revealed an index of 3326 for chromium, implying a very high-risk classification. Similarly, a very high-risk classification was found for lead with a value of 1330 and a moderate-risk classification for cadmium with a value of 270. These findings highlight significant ecological concerns, necessitating urgent environmental management. These results are consistent with other environmental indices ratings used to assess metal contamination.

Table 4: Comparison of Heavy Metal Pollution and Pollution Ecological Risk Indices (PERI) of the study area

Locations	BC2	BC3	BC4	BC5	BC6	BC7	BC8	RI	PERI
Pb	10.00	75.00	105.00	170.00	810.00	5.00	155.00	1330.00	Very high risk
Cr	28.00	3242.00	2.00	2.00	2.00	2.00	48.00	3326.00	Very high risk
Cd	30.00	30.00	30.00	30.00	30.00	30.00	90.00	270.00	Moderate risk
Zn	2.67	2.76	1.41	1.50	1.33	0.84	0.81	11.33	Low risk
Mn	3.27	0.05	0.07	0.24	0.29	0.11	0.25	4.30	Low risk
Ni	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00	Low risk
Fe	3.87	10.45	0.66	2.91	4.05	5.10	3.81	30.86	Low risk

4. Conclusion

This study investigated the concentration of heavy metals in road-deposited sediments (RDS) along Orho Agbarho-Patani Road in the Niger Delta, Nigeria. Seven (7) sampling locations were selected, and the collected samples were analyzed for the presence of lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), manganese (Mn), nickel (Ni), and iron (Fe) using atomic absorption spectroscopy (AAS). The pH of the soil was slightly acidic to neutral, indicating that the metals in the sediments were relatively mobile and could potentially leach into groundwater or surface water. The electrical conductivity (EC) varied from moderately saline to highly saline. The results revealed that the mean concentrations of Pb (0.04 mg/kg), Cr (0.24 mg/kg), Cd (0.001 mg/kg), Zn (14.86 mg/kg), Mn (2.85 mg/kg), Ni (0.001 mg/kg), and Fe (107.78 mg/kg) were below the WHO maximum permissible limits and Nigerian Soil Quality Standards. However, localized contamination of Mn (15.221 mg/kg) and Fe (255.564 mg/kg) was observed at BC2 and BC3, respectively, indicating site-specific pollution.

Comprehensive environmental indices, including geo-accumulation index, enrichment factor, contamination factor, degree of contamination, pollution load index, and potential ecological risk index, confirmed severe contamination at specific sites. The geo-accumulation index (Igeo) results indicated extreme to moderate contamination by Pb, Cr, Cd, and Mn, suggesting anthropogenic sources. The calculated enrichment factor showed very high enrichment for Pb and Cr; high enrichment for Cd and Ni; moderate enrichment for Zn; and low enrichment for Mn. The contamination factor (CF) analysis revealed a range of contamination levels from low to very high, consistent with the results of the geo-accumulation index. The degree of contamination (Cdeg) suggested that the sampled points were contaminated in the following order: BC3 > BC6 > BC8 > BC5 > BC4 > BC2 > BC7. The pollution load index (PLI) indicated soil quality degradation in most locations due to heavy metal pollution, except at BC4 and BC7, where only background levels of pollutants were present. The potential ecological risk indices (PERI) calculated for the metals showed that Pb and Cr posed significant ecological risks, while Cd and Mn presented moderate to high risks. Although the overall contamination levels were concluded not to be immediately harmful, the long-term implications for human health and the environment cannot be ignored. These findings underscore the need for continuous monitoring and potential remediation strategies to mitigate the risks associated with heavy metal pollution in the region. The study highlights the importance of addressing anthropogenic sources of heavy metal contamination to protect environmental and public health.

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