Assessment of Heavy Metal Contamination and Health Risks in Road Deposited Sediments: A Study in Owerri, Nigeria

Ubechu Bridget Odochi[1], Enimakpokpo Joan[1], Akaolisa Casmir Chukwuemeka Zanders[1], Agbasi Okechukwu Ebuka[2,*], Nwachukwu Helen[1]

[1]Department of Geology, School of Physical Sciences, Federal University of Technology, Owerri, Nigeria
[2]Okan Geoservices Nigeria Limited, Nigeria

[*]Corresponding author e-mail: agbasi.okechukwu@gmail.com

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Abstract. The study aims to conduct an ecological risk assessment and build a pollution model for assessing trace metal concentrations in road dust in Owerri, Nigeria. Key roadways in the urban area were chosen based on traffic volume, population density, and human activity. Data was collected at 500-meter intervals throughout each route, and silt samples were collected by systematic sweeping of a 1 square metre area covering road pavements and curbs. The examination found metallic pollutants such as chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and lead (Pb) inside the RDS. Nickel (Ni), copper (Cu), cadmium (Cd), and lead (Pb) levels were substantially higher than their respective background values. Carbon monoxide levels along Port Harcourt Road, specifically 670 mg/l, are much higher than the background norm, indicating a considerable influence of human activity. Estimated enrichment values for the metallic elements ranged from insignificant (Mn) to extremely high (Co, Ni, Cu, Zn, Pb). Based on geoaccumulation index data, it can be concluded that the RDS has significant levels of contamination in terms of Ni and Pb, implying a considerable buildup of certain heavy metals, most likely due to anthropogenic acts. The study identified two major sources of heavy metal contamination: natural sources originating in the Earth's crust and transportation-related activities such as air deposition, corrosion, and vehicle degradation.

Keywords: heavy metal contamination, road deposited sediments, ecological risk assessment, trace metal concentrations, health risk assessment.

1. Introduction

Deposition of microscopic solid particles on urban surfaces such as paved areas is prevalent (Xie et al., 1999; Ichu et al., 2021). RDS are a heterogeneous collection of tiny solid particles and pollutants originating from a variety of industrial and urban sources (Robertson et al., 2003; Lecoanet et al., 2003; Cui et al., 2022). These contaminants may be traced back to anthropogenic activities such as tyre and automobile deterioration, brake-lining materials, exhaust system emissions, construction materials, plant waste, and atmospheric depositions (Lecoanet et al., 2003; Robertson et al., 2003).

Ensuring the protection of a sustainable environment is critical in enhancing the well-being of urban dwellers on a global scale (Dash et al., 2019). Environmental pollution poses substantial issues to urban areas, notably in terms of air, water, and soil contamination. These problems may be linked back to a variety of human activities, such as the release of pollutants from industrial sources, automobile emissions, and insufficient waste disposal practises (Taşpnar & Bozkurt, 2018). According to Dash et al. (2019) and Egbueri & Unigwe (2020), the identification of pollutants in soils close to highways in urban environments might potentially serve as a credible indicator for determining the degree of sustainable development. The toxicological repercussions of heavy metal presence in soil have significant environmental implications. These metals have toxic effects, long-term persistence, and can accumulate inside the human body over time (Mama et al., 2020).

Despite the cessation of traffic-related emissions, the persistence of excessive levels of heavy metals in soils near roadways continues to exacerbate their environmental consequences. According to Mama et al. (2020), the dense urban population exacerbates the direct effects of polluted soils on human health and ecosystems.

The increased awareness of heavy metal pollutants in road deposited sediments has been spurred by the widespread presence of heavy metal pollution and the resulting health problems in numerous cities across the world. According to Li et al. (2014), there is a significant increase in the occurrence of hazardous metals in urban environments, with roads and vehicles emerging as significant drivers of this phenomena.

Various human activities, notably automotive movement, cause a substantial quantity of toxic metallic elements, such as zinc, copper, and lead, to be released into the surrounding ecosystem. The aforementioned actions have been linked to tyre degradation, brake lining/pad deterioration, and the production of exhaust pollutants (Li et al., 2014). According to Ibe et al. (2018), the metals described in their study account for about 90% of the total metal contaminants discovered in road deposits and runoff. According to Yisa (2010), the deposition of automobile dust on paved urban surfaces has the potential to contribute to significant levels of heavy metal concentrations in neighbouring streams and rivers. In comparison to other types of harmful pollutants, these trace metallic contaminants are distinguished by their resistance to natural biodegradation processes (Sezife et al., 2013; Nkansah et al., 2021). Furthermore, the problem is exacerbated by the possibility of bioaccumulation and biomagnification, in which organisms in the surrounding environment accumulate higher concentrations of these harmful substances than their naturally occurring counterparts (Sezife et al., 2013; Ichu et al., 2021). Consuming contaminated food produced from the neighbouring polluted environment frequently results in the buildup of these hazardous metallic elements inside the biological systems of humans and other species (Ibe et al., 2018; Ichu et al., 2021).

The major goal of this research is to analyse the ecological and health consequences of the quantities of trace metals discovered in road dust in specific districts of Owerri, Nigeria. In addition, a pollution model will be built to investigate the aforementioned concentrations.

2. Study Area

The research area is located at the geographical coordinates of Latitude 5.485°N and Longitude 7.035°E, as seen in Figure 1. The geographic area being examined include the Niger Delta basin. The region's physical features are characterised by its favourable accessibility, which is helped by a well-developed network of motorways that link with Onitsha, Port Harcourt, and Aba Motorway. As a result, this region occupies a central and strategic location within the southeastern region of Nigeria.

The research site has a tropical wet and dry climate, marked by continuously high temperatures and noticeable seasonal fluctuations in precipitation. The dry season is commonly seen to occur between the months of October and March, whereas the rainy season is typically recognised to last from March to October. The territory has a significant variation in daily sunlight hours throughout the year. Specifically, from January to April and November to December, the region receives an average of over six hours of sunlight each day. However, during the months of May to October, the region experiences a notable decrease in sunlight, with an average of roughly three hours per day. The diurnal temperature range spans a spectrum of temperatures, commencing at around 18°C and culminating at a maximum of 34°C. The mean daily minimum and maximum temperatures exhibit a stable pattern, with values of 19°C and 28°C, respectively. The anticipated rates of evapo-transpiration exhibit a range of 1450 to 1460 mm annually.

The relative humidity patterns exhibit distinguishable characteristics, characterised by decreased values observed during the arid periods of January to March and November to December. These values often attain levels of up to 95%. During the period spanning from April to October, there is a notable increase in relative humidity levels, often exceeding 97%. The wet season's advancement is closely linked to the northward movement of maritime air masses originating from the Atlantic Ocean (Akaolisa et al., 2023). The zenith of the wet season transpires during the months of July and August. Intense precipitation is a noteworthy meteorological phenomenon that exerts a substantial influence on several environmental facets. According to the findings of Okoro et al. (2014), the period of increased rainfall, commonly referred to as the rainy season, occurs between the months of April and October. In this particular chronological epoch, the geographical region has an average yearly precipitation ranging from 2500 to 4000 mm. Furthermore, a substantial proportion of the precipitation, around 89%, is mostly recorded throughout the time frame ranging from May to October. The combination of heavy precipitation and the existence of steep topographical characteristics in the area results in significant surface water runoff, hence exacerbating the issue of floods (Akaolisa et al., 2023). Specific temporal periods display notable amounts of precipitation, resulting in the occurrence of floods, the leaching of soil, and the massive erosion phenomena known as sheet wash.

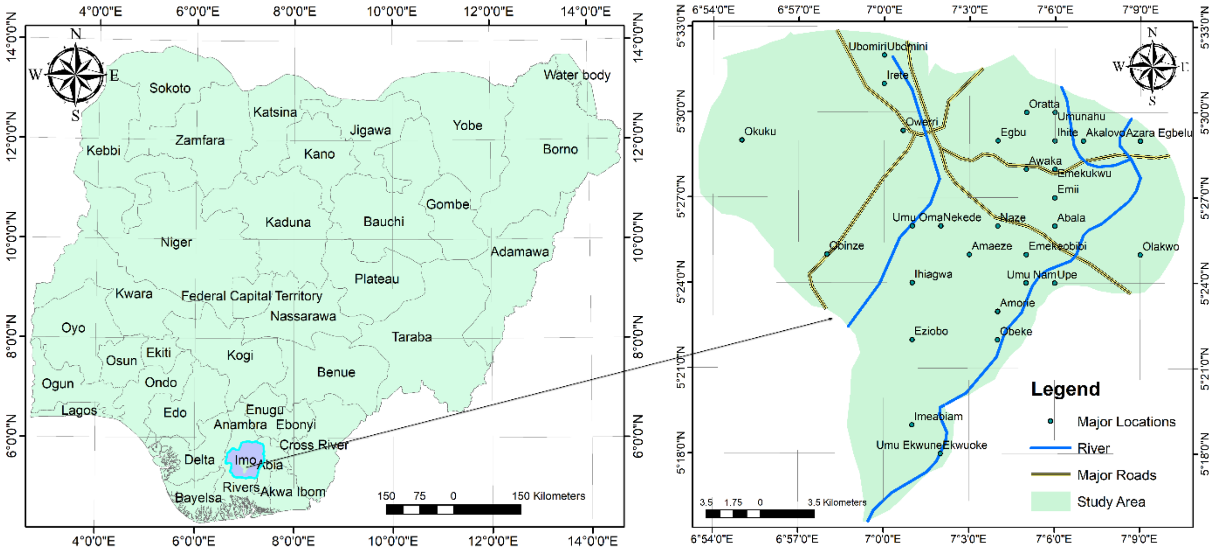

Figure 1. Location Map of Owerri and Environs

3. Materials and Methods

3.1. Materials

The first stage of sample collection will involve the use of topographic map in the identification and demarcation The field research methodology involved two stages for studying the study area. The first stage encompassed a reconnaissance survey, followed by a subsequent phase of detailed geological mapping, employing various geological tools including:

- Utilization of a location map of the study area, facilitating navigation within and around the sampling sites.
- Reference to the Geologic map for pinpointing specific locations within the study area.
- Application of a hand lens for comprehensive megascopic field observations.
- Implementation of labeled sample bags to ensure proper collection and straightforward identification of samples from different locations.
- Employment of the Global Positioning System (GPS) to capture precise coordinates for each sampling point, enhancing accuracy and geospatial referencing.

This comprehensive approach ensured a meticulous exploration of the study area, enabling a robust geological mapping process.

3.2. Methods

3.2.1. Selection of Sampling Points

Many variables, like as traffic flow, population concentration, and human-induced activities, were considered in the selection of key thoroughfares in the Owerri metropolitan region. The sampling was carried out at 500-metre intervals along each route. The methodical sweeping of a predetermined 1 m^2 patch covering road pavements and curbs was used to gather silt samples. The sediments were carefully collected, placed in clean plastic dustpans, tagged, and transported to the laboratory for further examination. Three sub-samples were obtained at each chosen sampling point, each one metre apart from the others. These sub-samples were then combined and homogenised to create a composite sample weighing about 200 grammes for each location. All sampling points were georeferenced using a portable GPS device, namely the Garmin eTrex Venture HC. To ensure consistency, the collecting of sediment samples from highways was restricted to the month of February 2022.

3.2.2. Sample Preparation and Analysis Methods for Metal Content

The collected samples were allowed to dry naturally in the air at the ambient temperature. They were then put through a sieve with a mesh size of 1 mm to eliminate any undesired impurities. Following that, the desiccated specimens were filtered again using a plastic sieve with a 230-mesh size and an opening of 63 m, with the goal of keeping particles of smaller size. Each sample was weighed using a high precision analytical balance (Ohaus EB series, China) with an accuracy of one gramme. The samples were carefully transferred into glass beakers with a volume of 50 cm^3 and then exposed to digestion at 105°C on a hot plate for 2 hours in a fume closet. For the digesting process, a solution containing concentrated nitric acid (HNO3), hydrofluoric acid (HF), and perchloric acid (HClO4) in a volume ratio of 2:2:1 was utilised. This solution was required for each sample in the amount of 20 cm3. Following the digestion procedure, the samples were cooled before being filtered using Whatman No. 1 filter paper. The filtrate was then diluted to a volume of 100 cm^3 with distilled deionized water produced using an Eco-Still Mark, BSIC/ECO-4 apparatus (made by Bhanu Scientific Instruments Company, India). This dilution was performed in a volumetric flask. Metal concentrations in digested samples were determined using a Buck 210 VGP atomic absorption spectrophotometer. The pH and electrical conductivity of a sample-to-water suspension formed in a 1:2 (w/v) ratio were measured with a pH metre made by LIDA Instruments and an EC metre made by Sanxin (model SX 723).

3.2.3. Quality Control Measures

To ensure the validity of analytical data, stringent quality control measures were followed. Double distilled deionized water produced from the Eco-Still Mark, BSIC/ECO-4 equipment was used for sample preparation and analysis. Finlab Owerri in Imo State provided the analytical grade standard reagents, metal standards, and chemicals. The containers and glassware were thoroughly cleaned with detergent, rinsed with distilled deionized water, and then dried in a DHG - 9023A oven (made by B. Brans Scientific and Instrument Company, England). The precision and accuracy were validated by running triple analyses on both the samples and the reference standards. Heavy metals were analysed using X-ray diffraction (XRD) apparatus with a wavelength range of 190 to 900 nm. The equipment was accurate to 0.2 nm, precise to 0.1 nm, and reproducible to less than or equal to 5% relative standard deviation (RSD).

3.2.4. Data Analysis

The road deposited sediments were analysed using several methods to determine the geo-accumulation index, enrichment factor, contamination factor, possible ecological risk index, and health risk evaluation of metals in the surrounding environment.

3.2.5. Geo-accumulation Index (Igeo)

The utilisation of the Geo-accumulation Index (Igeo) has been previously applied to assess the level of heavy metal contamination in road deposited sediments in metropolitan areas (Lu et al., 2009; Lu et al., 2010). The mathematical formulation of Igeo is illustrated by equation (1).

$$I_{geo} = log_2\left(\frac{CRDS}{1.5B_S}\right) \qquad 1$$

The element concentration discovered in the sediment or road deposited sediment is represented by CRGS, whilst the geochemical background value recorded in the soil is represented by Bs. The background geochemical concentrations of the metals, which were computed based on the average values found in the Earth's crust, were used as the reference values for computing the I_{geo} values in this study (Taylor, 1964). The addition of a constant factor of 1.5 accounts for the intrinsic unpredictability of heavy metal concentrations in the natural environment, as well as any little influence caused by human activity (Lu et al., 2009; Yang et al., 2022). The geoaccumulation index (I_{geo}) employs a pollution scale devised by Muller (1969) that ranges from non-contaminated (0) to severely polluted (6).

3.2.6. Enrichment factor (EF)

The Enrichment Factor (EF) is utilised as a means of evaluating the extent of human-induced influence on a metal ion that is found within sediments deposited on road surfaces. In general, a reference element that exhibits minimum variability is selected to assist in this evaluation. This reference component facilitates the differentiation between heavy metals that are derived from anthropogenic activities and those that have natural or geogenic origins. The establishment of this difference is predicated upon the link described in equation 2.

$$EF_y = \left[\frac{X_i}{E_{i_{(ref)}}}\right] \div \left[\frac{Y_w}{E_{w_{(ref)}}}\right] \quad 2$$

The enrichment factor (EF_y) of element y is determined by the concentration of the element (X_i) in the sample relative to the concentration of the reference element ($E_{i_{(ref)}}$) in the sample. In this study, Iron (Fe) was used as the reference element. The concentration of the element in the crust (Y_w) is compared to the concentration of the reference element ($E_{w_{(ref)}}$) used for normalisation, as described by Taylor (1964). Kartal et al. (2006) have previously established five categories of contamination based on the enrichment factor.

3.2.7. Contamination factor and degree of contamination

In order to assess the extent of heavy metal pollution in the RDS, the contamination factor and degree of contamination were utilised, as described by Rastmanesh et al. (2011). The single element indicator, denoted as $C^i{}_f$, is determined through the utilisation of equation 3.

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \quad 3$$

The contamination factor of the element of concern is denoted as C_f^i, whereas C_{0-1}^i represents the value of the element in the sediment deposited on the road. Additionally, C_n^i refers to the value of the background concentration. The background concentration in the present investigation was determined using averages of continental crustal data (Taylor, 1964; Hanfi et al., 2023). The classification of C_f^i is conducted based on four distinct categories, which are delineated as follows: A C_f value less than 1 signifies a low level of contamination, whilst a Cf value between 1 and 3 suggests a moderate level of contamination. A C_f value between 3 and 6 shows a substantial level of contamination, while a C_f value equal to or greater than 6 represents excessive contamination. The degree of contamination can be categorised into four descriptions: a low degree of contamination ($C_{deg} < 8$), a reasonable degree of contamination ($8 \leq C_{deg} < 16$), a substantial degree of contamination ($16 \leq C_{deg} < 32$), and an enhanced degree of contamination ($C_{deg} \geq 32$).

The total contamination factors of all elements present in the sample are used to quantify the level of pollution, as denoted by equation (4).

$$C_{deg} = \sum C_f^i \quad 4$$

3.2.8. The potential ecological risk index

Hakanson (1980) established the projected ecological risk index as a mechanism for estimating the amount of heavy metal contamination while taking into consideration natural variables such as sedimentary rock formation. This concept not only analyses heavy metal concentrations in soil, but also establishes links between ecological and environmental implications and toxicological effects. The pollution evaluation method used in this study employs a uniform and comparable property index grading system. 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 (5), (6), and (7).

$$E_r^i = T_r^i \quad 5$$

$$RI = \sum_{i=1}^{n} E \quad 6$$

$$C_f^i = \frac{C_s^i}{C_n^i} \quad 7$$

The notation E_r^i represents the possible ecological risk index associated with heavy metal i. The variable RI denotes the potential ecological risk factor associated with numerous metals, whereas T_r^i represents the "toxic-response" component specific to heavy metal i. According to Hakanson's (1980) proposal, the T_r^i values of the elements follow the order Zn = 1 < Cr = 2 < Cu = Ni = Pb = 5 < Cd = 30. The pollution coefficient, denoted as $C^i{}_f$, represents the level of pollution caused by the heavy metal I. C_i s refers to the measured concentration of heavy metal i in the soil, measured in mg/kg. On the other hand, C_f^i represents the background value of the heavy metal i, which indicates the concentration of the heavy metal in unpolluted soil (Taylor, 1964). This work aims to evaluate the mean values of E_r^i and RI for Cd, Cr, Cu, Ni, Pb, and Zn, individually, in relation to each metal contaminant. Hakanson (1980) has delineated four distinct kinds of RI and five categories of E_r^i, as presented in Table 1.

Table 1. Potential Ecological Risk Categories based on $E_r^i$and *RI* values (Taylor, 1908).

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

3.2.9. Human Health Risk Assessment

The human health risk assessment technique has been extensively used to illustrate the relationship between heavy metal exposure and unfavourable health effects in humans (Man et al., 2010). Individuals may be exposed to contaminants through a variety of routes within the realm of soil, including inhalation, ingestion, and skin absorption.

The health concerns associated with heavy metal consumption, which may enter the human body via many ways, may be divided into two categories: carcinogenic and non-carcinogenic dangers. This research entails a thorough assessment of both non-carcinogenic and carcinogenic risks, including exposure by inhalation, ingestion, and skin contact with soil. Fakhri et al. (2018) did past research that yielded the equations (8)-(10) reported in this work.

$$ADD_{inh} = \frac{C \times IR \times EF \times ED}{PEF \times BW \times AT_{nc}} \quad 8$$

$$ADD_{ing} = \frac{C \times IR \times EF \times ED}{BW \times AT_{nc}} \quad 9$$

$$ADD_{derm} = \frac{C \times SL \times SA \times ABS \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6} \quad 10$$

Where; ADD_{inh}, ADD_{ing} and ADD_{derm} (mg/kg/d): are average daily dosage via inhalation ingestion and dermal contact, respectively (USEPA, 2011). The input

$$HQ = \frac{ADD}{RfD} \quad 11$$

The parameters are outlined in Table 2, with the hazard quotient (HQ) employed to assess the non-carcinogenic risk. This estimation is calculated utilizing Equation (11) as specified by USEPA in 2001. The collective non-carcinogenic risk is quantified as the overall hazard index (HI), representing the summation of individual hazard quotients. This aggregation is formulated using the equation provided below as Equation (12).

$$HI = \sum HQ_i \quad 12$$

Table 2. The input values and assumptions for the assessment of heavy metal exposure by ingestion, absorption, and cutaneous routes.

Parameters	Meaning	Unit	Adult	Child	Cancer
C	Concentration of metals in the soil	mg/kg			
RfD	Reference dose for different exposure	mg/kg/day			
ATnc	Average time for carcinogens	Days	ED × 365 days	ED × 365 days	70 × 365 days
CSF	Cancer slope factor of a metal	mg/kg/day			
EF	Exposure frequency	days/year	365	365	70
ED	Exposure duration	Years	30	6	70
BW	Body weight	Kg	70	15	2
IR	Ingestion rate	L/day	2	1	

SA	Skin surface area	cm2	18000	6600
PEF	Particulate emission factor	cm/hr		
ABS	Dermal absorption factor		0.1	0.1

4. Results and Discussion

4.1. Heavy Metals Concentration

The three sampling points are located along the Port-Harcourt Obinze road. Concentrations of Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb in the road deposited sediments exhibited ranges of 24 – 33, 152 - 234, 46508 - 59573, 465 - 1061, 575 - 610, 508 - 720, 0.0946 - 0.1937, and 0.0004 - 0.0452 mg/l, respectively. The respective mean concentrations for Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb were measured at 70.6, 194, 54745, 670, 594.3, 581.3, 1407, 228.3, 93932, and 376062 mg/l. Notably, heavy metals including Co, Ni, Cu, and Zn exceeded the acceptable soil quality standards set by Nigeria. This suggests that the pH and electrical conductivity of these areas are notably elevated, posing health risks including those associated with heavy metals like Cr at PHR 2 and Fe at PHR 1 & 2. The heavy metal concentrations (mg/kg dry weight) in the RDS samples are presented in Table 3.

Table 3. Heavy Metal Concentrations (mg/kg) in Nigerian Road Soils and Comparison with Literature and Soil Quality Standards.

Roads	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
PHR 1	33	234	59573	1061	610	516	1937	452
PHR 2	155	152	46508	465	575	508	946	4
PHR 3	24	196	58154	484	598	720	1338	229
Range	24 – 33	152 – 234	46508 – 59573	465 – 1061	575 – 610	508 – 720	0.0946 – 0.1937	0.0004 – 0.0452
Mean	70.6	194	54745	670	594.3	581.3	1407	228.3
Background Values in Literature	100	950	56300	25	76	55	70	12.5
Nigerian Soil Quality standards**	100	NA	NA	50	70	100	421	164

* Taylor (1964) **National Environmental Standards and Regulations Enforcement Agency (2013), NA (Not available)

4.2. Physicochemical properties

Figure 2 depicts the results of the pH and electrical conductivity (EC) tests on road deposited sediment (RDS) samples. The pH and EC measurements give important information on the chemical composition of road-deposited sediments. The pH levels measured at the test sites were found to be in the neutral-alkaline range. PHR 1, PHR 2, and PHR 3 pH values were determined to be 7.76, 8.03, and 8.10, respectively. The behaviour of metallic elements in RDS is heavily impacted by pH levels because they play an important role in mechanisms such as precipitation that contribute to the retention of these constituents within the soil (Evans et al., 1995). It is worth noting that the transportation of metallic pollutants tends to diminish when soil pH levels rise, especially when they approach 8 or above (Appleyard et al., 2004). As a consequence, the pH values obtained in the samples show that the mobility and solubility of metallic pollutants contained in the soil samples has decreased.

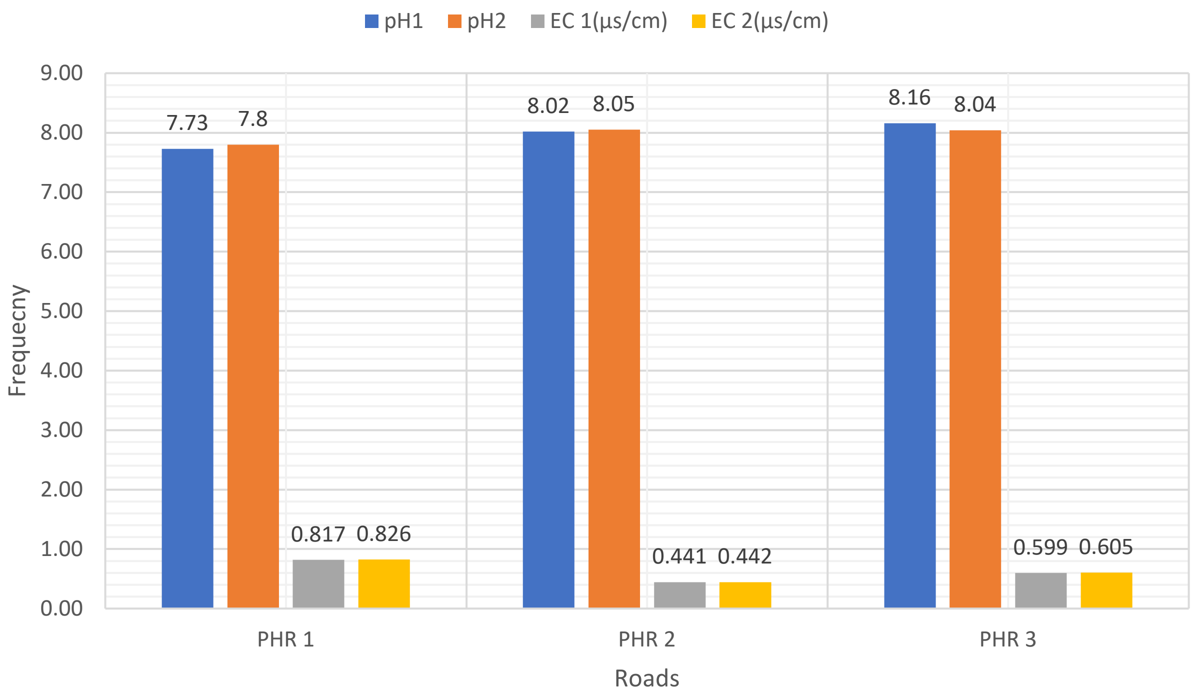

Figure 2. Physicochemical parameters of road deposited sediments in the study area

Electrical conductivity (EC) is used to detect the presence of dissolved ions in a sample. The average EC values recorded for the three highways were 0.8125, 0.4415, and 0.602 mS/cm, respectively. Fuente et al. (2006) show EC values that imply a considerable presence of ionizable components in the samples, including both cations and anions. The EC values at all of the locations studied showed little variation. Smith and Giller (1992) presented a generally recognised categorization system for soil electrical conductivity (EC) values. This approach divides soil EC values into four categories: non-salty, moderately salty, very salty, and highly salty. The non-saline group comprises values less than 2, whereas the moderately saline category covers values between 2 and 8. The very saline category includes values between 8 and 16, whereas the highly saline category includes values more than 16. The EC level is classified as highly saline based on the findings of this inquiry and the designated EC classification.

4.3. Index of geo- accumulation

The results of the estimated geoaccumulation index (Igeo) for the metals are displayed in Figure 3. The ionic geochemical (Igeo) values for the metals exhibit the subsequent intervals: Chromium (Cr) varies from 4.6 to 69, Manganese (Mn) ranges from 6.66 to 7.28, Iron (Fe) ranges from 14.92 to 15.28, Cobalt (Co) ranges from 8.23 to 9.47, Nickel (Ni) ranges from 8.58 to 8.67, Copper (Cu) ranges from 8.40 to 8.90, Zinc (Zn) ranges from 9.30 to 10.33, and Lead (Pb) ranges from 1.41 to 8.24. The mean Igeo values for each individual entity are computed as follows: 5.05, 20.97, 15.15, 8.67, 8.63, 8.57, 9.81, and 5.63. Based on the information gathered, it can be concluded that the average Igeo values observed on the selected roadways inside the Owerri metropolis indicate a significant level of contamination, ranging from severe to very contaminated situations. It is worth noting that these roadways have a considerable volume of both vehicle and pedestrian traffic, as well as a large presence of commercial operations. This finding strongly indicates that the pollution is derived from anthropogenic and industrial sources.

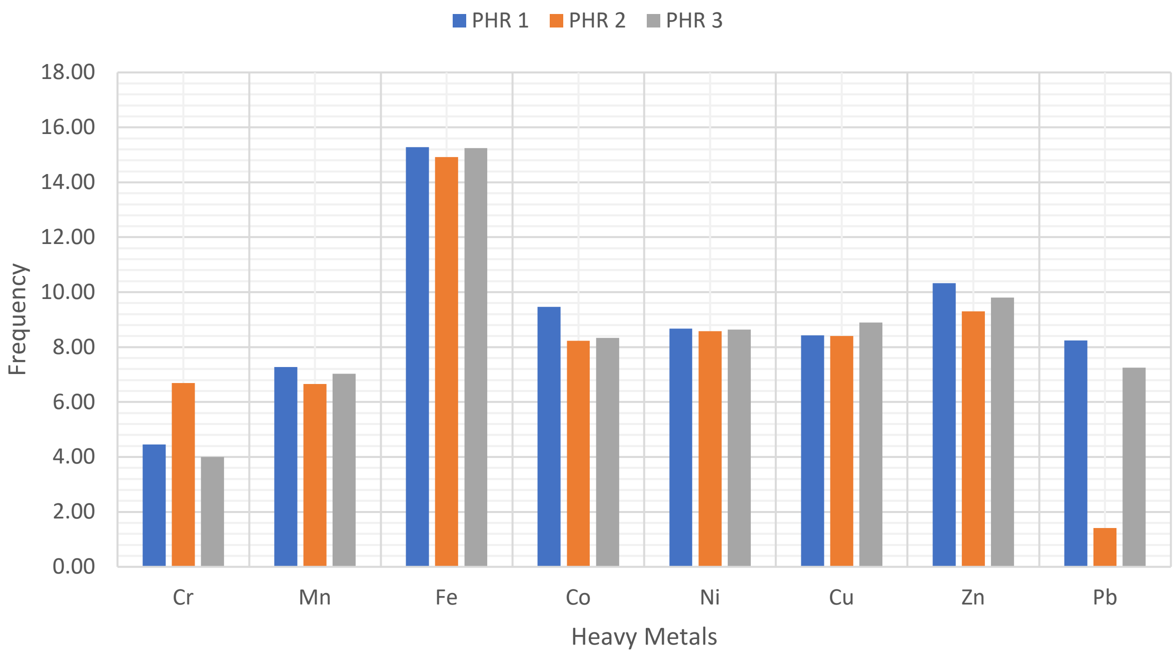

Figure 3. Index of geo-accumulation of road deposited sediments in the study area

4.4. Enrichment Factor (EF) analysis

The enrichment factors (EF) for the metals were computed using Equation 2 and are presented in Table 6 for the road deposited sediment (RDS) samples. Iron (Fe) was selected as the reference metal for normalisation based on the utilisation of average values derived from continental crust data. The EF values, which were calculated using Equation 2 for the RDS samples and are shown in Figure 4, demonstrate varying amounts of enrichment. The elements Chromium (Cr) with a range of 0.03-1.86, Manganese (Mn) with a range of 0.19-0.23, and Iron (Fe) with a range of 0.90-1.21, demonstrated varying degrees of enrichment, ranging from minimal to moderate. In contrast, the elements Co, Ni, Cu, Zn, and Pb exhibited a range of enrichment factor (EF) values, spanning from minimal to exceptionally high levels. The EF values for Co ranged from 18.86 to 40.90, for Ni from 7.60 to 8.06, for Cu from 9.27 to 13.14, for Zn from 13.57 to 27.79, and for Pb from 0.34 to 37.90. The mean values that corresponded to the data points were 27.42, 23.55, 31.82, 60.56, and 57.46, indicating substantial to exceptionally high enrichments. It is worth mentioning that EF values more than 10 are indicative of anthropogenic sources, as stated by Eze et al. (2020).

According to Han et al. (2006), the conceptual understanding of ecosystem functioning (EF) includes both natural and human-induced aspects. The highest observed EF value for Cobalt (Co) at the PHR1 location was 40.90. The increased numerical value can be attributed to a variety of variables, including increased population density, significant vehicle congestion, and significant business activity around major thoroughfares. The discovery of a considerable increase in cobalt (Co) content in soil over the baseline level of 25 mg/kg shows a strong human effect. Within the domain of metallic elements, the average EF values can be structured in descending order, beginning with zinc (Zn), followed by lead (Pb), copper (Cu), cobalt (Co), nickel (Ni), iron (Fe), chromium (Cr), and manganese (Mn). The lower average EF values for Mn suggest the preponderance of natural sources. The main factors that lead to the presence of heavy metal pollution in the environment are associated with a variety of human activities. These activities include the use of fossil fuels and biomass, the production of greenhouse gases from vehicles, and other industrial processes (Meza-Figueroa et al., 2007; Ibe et al., 2016).

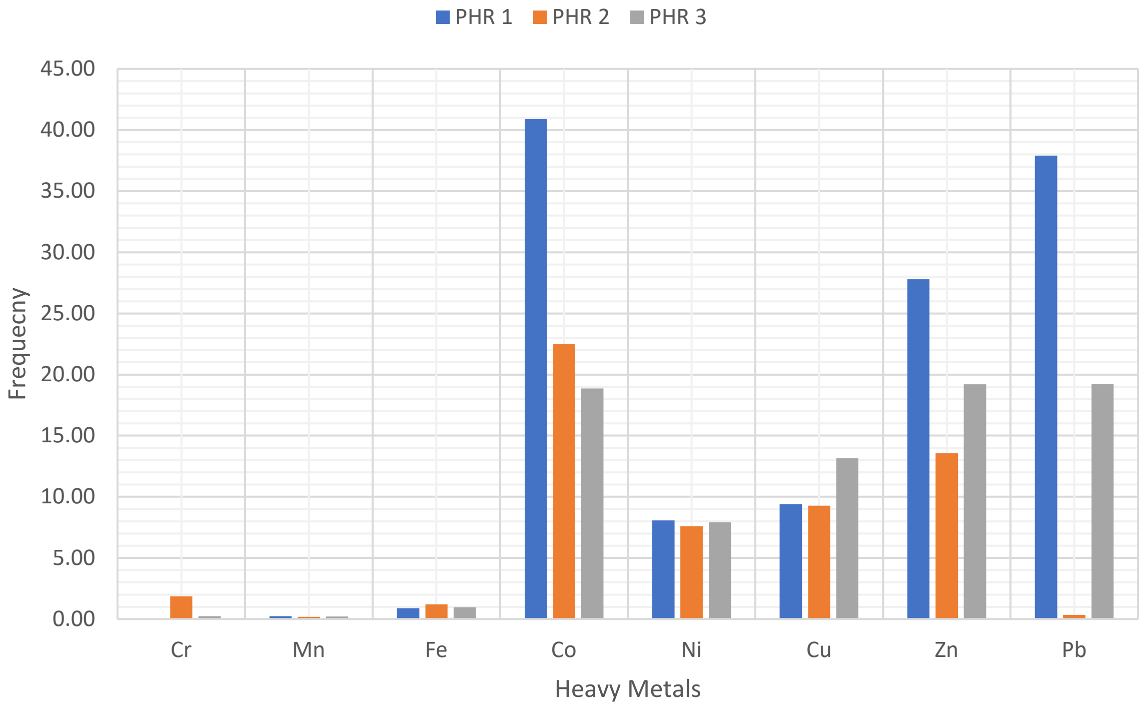

Figure 4. Enrichment Factors of road deposited sediments in the study area

4.5. Contamination factor

The contamination factor for the metallic elements under consideration was calculated using Equation 3 and is shown in Table 4. According to the study's findings, manganese (Mn) was the only element with contamination factor values less than one at the three road sites. This shows that Minnesota had a comparatively low amount of pollution caused by human activity. In the present study, it was shown that chromium and iron exhibited varying degrees of pollution, ranging from moderate to low levels, across all road samples. On the other hand, cobalt, nickel, copper, zinc, and lead exhibited substantial to exceedingly high contamination factors throughout all roadways. The observation of significantly elevated contamination factors is consistent with the results obtained from the Geo-accumulation Index, indicating a considerable presence of contamination resulting from human activities.

The contamination degree (Cdeg), as determined by the equation 4, is displayed in Table 10, showing values of 125.32 for PHR 1, 51.36 for PHR 2, and 79.04 for PHR 3. The findings of this study indicate a substantial level of contamination in PHR 1-3, suggesting a significant degree of metal pollution in the paved roads examined inside Owerri Metropolis.

Table 4. Contamination factors of the metals.

Roads	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb	Degree of Contamination
PHR 1	0.33	0.25	1.06	42.44	8.03	9.38	27.67	36.16	125.32
PHR 2	1.55	0.16	0.83	18.6	7.57	9.24	13.51	0.32	51.36
PHR 3	0.24	0.03	1.03	19.36	7.86	13.09	19.11	18.32	79.04
Degree of Contamination	2.12	0.44	2.92	50.4	23.46	31.71	60.29	54.8	

4.6. Potential Ecological Risk Index (PERI)

Table 5 shows the possible ecological danger and associated indices for heavy metals on Owerri metropolis highways. The computed potential ecological risk values (Ei r) for the metals across all highways indicated that numerous metals were classified as low risk: Cr, Mn, Fe, Zn, and Pb were classified as low risk across PHR 1-3. Ni and Cu, on the other hand, were classed as moderate danger on all three roadways. Furthermore, the prospective ecological risk indices revealed a value of 158.54 for Co, indicating that Co in the road deposited sediments (RDS) inside Owerri's road network is classified as extremely high risk. These findings are consistent with the outcomes of numerous mathematical models used to determine the prevalence of metallic contamination within RDS.

Table 5. Comparison of Heavy Metal Pollution and Ecological Risk Indices of the study area.

Roads	PHR 1	PHR 2	PHR 3	RI	Potential ecological risk index
Cr	0.06	3.10	0.48	3.64	Low risk
Mn	0.25	0.16	0.21	0.61	Low risk
Fe	40.13	37.83	39.34	39.34	Low risk
Co	46.90	46.18	65.45	158.54	Very high risk
Ni	27.67	13.51	19.11	60.29	Moderate risk
Cu	36.16	0.32	18.32	54.80	Moderate risk
Zn	0.06	3.10	0.48	3.64	Low risk
Pb	0.25	0.16	0.21	0.6	Low risk

4.7. Health Risk Assessment

The study of both non-carcinogenic and carcinogenic consequences of exposure to heavy metals is included in the discipline of health risk assessment's thorough investigation of possible health risks. This evaluation considers people of all ages, including both adults and children. Data on the Average Daily Dose (ADD) of heavy metal concentrations from ingestion, especially for adults and children, are shown in Table 6. Tables 7 and 8 are used in the current investigation to show the pathways related with inhalation and cutaneous contact, in particular for adults and children.

Table 6. Average daily dose of contaminants for adult and children via ingestion pathway.

Contaminant	PHR 1 Adult	PHR 1 Child	PHR 2 Adult	PHR 2 Child	PHR 3 Adult	PHR 3 Child
Cr	8.08×10^{-6}	4.7×10^{-6}	3.79×10^{-5}	1.96×10^{-5}	5.87×10^{-6}	3.03×10^{-6}
Mn	5.72×10^{-5}	2.96×10^{-5}	3.72×10^{-5}	1.92×10^{-5}	4.79×10^{-5}	2.48×10^{-5}
Fe	1.45×10^{-2}	7.54×10^{-3}	1.14×10^{-2}	5.88×10^{-3}	1.14×10^{-2}	7.36×10^{-3}
Co	2.59×10^{-5}	1.34×10^{-4}	1.14×10^{-4}	5.88×10^{-5}	1.18×10^{-4}	6.13×10^{-5}
Ni	1.49×10^{-4}	7.72×10^{-5}	1.40×10^{-4}	7.28×10^{-5}	1.46×10^{-4}	7.57×10^{-5}
Cu	1.26×10^{-4}	6.53×10^{-5}	1.24×10^{-4}	6.43×10^{-5}	1.76×10^{-4}	9.11×10^{-5}
Zn	4.74×10^{-4}	2.45×10^{-4}	2.31×10^{-4}	1.19×10^{-4}	3.27×10^{-4}	1.69×10^{-4}
Pb	1.11×10^{-4}	5.72×10^{-5}	9.79×10^{-7}	5.06×10^{-7}	5.61×10^{-5}	2.89×10^{-5}

Table 7. Average daily dose of contamination for adult and children inhalation.

Roads		Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
PHR1	Adult	$8.91x10^{-15}$	$5.80x10^{-14}$	$1.47x10^{-11}$	$2.63x10^{-13}$	$1.15x10^{-13}$	$1.25x10^{-13}$	$4.80x10^{-13}$	$1.12x10^{-13}$
	Children	$3.11x10^{-15}$	$2.20x10^{-14}$	$5.62x10^{-12}$	$9.87x10^{-14}$	$5.35x10^{-14}$	$4.86\ x10^{-14}$	$1.82x10^{-13}$	$4.20x10^{-14}$
PHR 2	Adult	$3.84x10^{-14}$	$3.77x10^{-14}$	$1.54x10^{-11}$	$1.15x10^{-13}$	$1.42x10^{-13}$	$1.26x10^{-13}$	$2.34x10^{-13}$	$9.93x10^{-16}$
	Children	$1.45x10^{-14}$	$1.43x10^{-14}$	$4.38x10^{-12}$	$4.32x10^{-14}$	$5.67x10^{-14}$	$4.79x10^{-14}$	$8.92x10^{-14}$	$3.72x10^{-16}$
PHR 3	Adult	$5.95x10^{-15}$	$4.86x10^{-14}$	$1.44x10^{-11}$	$1.20x10^{-13}$	$1.48x10^{-13}$	$1.78x10^{-13}$	$3.32x10^{-13}$	$5.68x10^{-14}$
	Children	$2.26x10^{-15}$	$1.84x10^{-14}$	$5.48x10^{-12}$	$4.50x10^{-14}$	$5.56x10^{-14}$	$6.79x10^{-14}$	$1.26x10^{-13}$	$2.13x10^{-14}$

Table 8. Average daily dose of contamination for adult and children on dermal.

Contaminant	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb

PHR 1 Adult	0.22	1.50	401.28	7.14	4.10	3.47	13.04	3.04
PHR 1 Child	0.95	6.77	1724.52	30.17	17.65	14.93	56.07	13.08
PHR 2 Adult	1.04	1.02	313.27	3.13	3.87	3.42	6.37	0.02
PHR 2 Child	4.48	4.40	1346.31	13.46	16.64	14.70	27.38	0.12
PHR 3 Adult	0.16	1.32	391.72	3.26	4.02	4.84	9.01	1.54
PHR 3 Child	0.69	5.67	1683.44	14.01	17.31	20.84	38.73	6.63

When evaluating intake, Table 9 shows the values of the Target Hazard Quotient (THQ) and non-carcinogenic risk (HI) associated with pollutants for adults and children. Concentrations of hazardous quotients (HQs) and hazard indices (HIs) for six metals in children's settings surpass recognised safety standards, posing a serious threat to human health. Tables 10 and 11 give equivalent results for the inhalation and dermal contact pathways, respectively. The tables show that the Hazard Quotients (HQs) and Hazard Indices (HIs) for seven metals are generally less than the recognised safe limit of 1 x 10^{-4}, meaning that there are no significant adverse health concerns.

Table 9. Target hazard quotient (THQ) and non-carcinogenic risk (HI) of contaminants for Adult and Children through ingestion pathway.

		Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
HQ	Adult	2.6×10^{-13}	-	32079.64	8.6×10^{-4}	7.45×10^{-3}	3.15×10^{-3}	1.58×10^{-3}	3.17×10^{-1}
	Children	1.3×10^{-3}	-	16681.41	4.4×10^{-3}	3.86×10^{-3}	1.63×10^{-3}	8.16×10^{-4}	1.63×10^{-1}
HQ	Adult	1.2×10^{-2}	-	25221.23	3.8×10^{-3}	7.0×10^{-3}	3.1×10^{-3}	7.7×10^{-4}	2.79×10^{-3}
	Children	6.5×10^{-3}	-	13008.84	1.96×10^{-3}	3.64×10^{-3}	1.60×10^{-3}	3.96×10^{-4}	1.44×10^{-3}
HQ	Adult	1.9×10^{-3}	-	25221123	3.9×10^{-3}	7.3×10^{-3}	4.4×10^{-3}	1.09×10^{-3}	1.60×10^{-3}
	Children	1.10×10^{-3}	-	16283.18	2.0×10^{-3}	3.78×10^{-3}	2.27×10^{-3}	5.63×10^{-4}	8.25×10^{-2}
HI	Adult	5.92×10^{-18}	NIL	25278423.90	$8.56\mathrm{X}10^{-3}$	0.02175	0.01065	$3.44\mathrm{X}10^{-3}$	0.33579

Table 10. Target hazard quotient (THQ) and non-carcinogenic risk (HI) of contaminants forAdult and Children through Inhalation pathway.

		Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
HQ	Adult	2.73×10^{-12}	-	2.5×10^{-5}	1.31×10^{-11}	7.55×10^{-12}	3.12×10^{-12}	1.6×10^{-12}	3.2×10^{-10}

	Children	$1.03x10^{-12}$	-	$1.2x10^{-5}$	$4.9x10^{-12}$	$2.67x10^{-12}$	$1.21x10^{-12}$	$6.06x10^{-13}$	$1.2x10^{-10}$
HQ	Adult	$1.28x10^{-11}$	-	$3.3x10^{-5}$	$5.75x10^{-12}$	$7.1x10^{-12}$	$3.15x10^{-12}$	$7.8x10^{-13}$	$2.83x10^{-12}$
	Children	$4.82x10^{-12}$	-	$9.6x10^{-6}$	$2.16x10^{-12}$	$2.83x10^{-12}$	$1.19x10^{-12}$	$2.97x10^{-13}$	$1.06x10^{-12}$
HQ	Adult	$1.98x10^{-12}$	-	$3.18x10^{-5}$	$6.00x10^{-12}$	$7.4x10^{-12}$	$4.45x10^{-12}$	$1.10x10^{-12}$	$1.62x10^{-16}$
	Children	$7.53x10^{-13}$	-	$1.21x10^{-5}$	$2.25x10^{-12}$	$2.78x10^{-12}$	$1.69x10^{-12}$	$4.2x10^{-13}$	$6.08x10^{-11}$
HI	Adult	$1.75x10^{-11}$	NIL	$8.98x10^{-5}$	$2.48x10^{-11}$	$2.20x10^{-11}$	$1.07X10^{-12}$	$3.48x10^{-12}$	$3.24x10^{-11}$
HI	Children	$1.783x10^{-12}$	NIL	$3.37x10^{-5}$	$2.16x10^{-12}$	$8.28x10^{-12}$	$4.09x10^{-12}$	$1.32x10^{-12}$	$1.81x10^{-11}$

Table 11. Target hazard quotient (THQ) and non-carcinogenic risk (HI) of contaminants for Adult and Children through dermal pathway.

		Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
HQ	Adult	73.33	-	88778.10	-	205	867.50	43.46	8685.71
	Children	316.66	-	38153.10	-	882.5	373.25	186.90	37371.42
HQ	Adult	346.66	-	69307.10	-	193.5	85.50	21.23	57.14
	Children	1493.33	-	29787.10	-	832	367.50	91.26	342.85
HQ	Adult	53.33	-	86663.10	-	201	112.00	30.03	4400.00
	Children	230.00	-	37244.10	-	865.5	521.00	129.10	18942.85
HI	Adult	473.32	NIL	244748.30	NIL	599	1065.00	94.72	13142.85
HI	Children	2039.99	NIL	105184.30	NIL	2580	1261.75	407.26	56657.12

Tables 12 – 14 show the carcinogenic risk (CR) associated with pollutants for people of various ages, including adults and children, taking into account the pathways of ingestion, inhalation, and skin exposure.

Table 12. Carcinogenic risk (CR) of contaminants for Adult and Children through ingestion pathway.

Sample Code	AD/CH	Cr	Ni	Pb
PHR1	Adult	4.04×10^{-16}	1.91×10^{-4}	9.43×10^{-7}
	Children	2.08×10^{-6}	6.1×10^{-5}	4.86×10^{-7}
PHR2	Adult	1.8×10^{-15}	1.12×10^{-4}	8.32×10^{-9}
	Children	9.8×10^{-6}	5.82×10^{-5}	14.3×10^{-9}
PHR3	Adult	2.93×10^{-6}	4.76×10^{-7}	4.76×10^{-7}
	Children	1.51×10^{-6}	12.45×10^{-7}	12.45×10^{-7}

CR	TCR (AD)	2.93×10^{-9}	3.03×10^{-8}	1.41×10^{-6}
	TCR (CH	1.33×10^{-3}	1.20×10^{-4}	1.73×10^{-3}

The study used road dust sediment to calculate the ADD (average daily dose) and HQ (hazard quotient) values related with the ingestion pathway of seven heavy metals. These computations were carried out independently for adults and children. The absence of Mn was attributed to the lack of a reference dosage (RFD). In addition to Attention Deficit Disorder (ADD) and Headquarters (HQ), an estimate for the Hazard Index (HI) that results from accidental ingestion, inhalation, or cutaneous contact was made. Heavy metal levels, including chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), and iron (Fe), were found to be quite low in both adults and children. Nonetheless, children's values outweighed those of adults. The HQ values revealed in this study are consistent with earlier research findings provided by Wang et al. (2011) and Chen et al. (2011). The HI values for non-carcinogenic hazards were mostly less than 1×10^{-4}, indicating a low level of non-carcinogenic risk (insignificant health risk) associated with the examined RDS. Nonetheless, variations for the elements Fe and Ni were discovered. The inhalation pathway's health risk evaluation yielded low HI values, indicating little health risks. In contrast, the HI values related with skin contact showed a significant possibility for cancer risk, particularly in youngsters. The observed numerical values could be attributed to movements such as regular touch between the hands and the mouth, as well as a tendency to congregate in areas where there is direct contact with the ground.

Table 13. Carcinogenic risk (CR) of contaminants for Adult and Children through inhalation pathway.

Sample Code	AD/CH	Cr	Ni	Pb
PHR1	Adult	3.39×10^{-4}	2.53×10^{-4}	4.66×10^{-6}
	Children	9.92×10^{-8}	4.54×10^{-5}	1.36×10^{-3}
PHR2	Adult	1.59×10^{-3}	2.38×10^{-4}	4.11×10^{-8}
	Children	4.66×10^{-8}	4.28×10^{-5}	1.2×10^{-5}
PHR3	Adult	2.46×10^{-4}	2.48×10^{-4}	2.35×10^{-6}
	Children	7.21×10^{-8}	4.45×10^{-5}	6.88×10^{-2}
CR	TCR (AD)	2.18×10^{-8}	7.39×10^{-7}	7.05×10^{-5}
	TCR (CH	9.92×10^{-4}	1.32×10^{-4}	7.01×10^{-3}

Table 14. Carcinogenic risk (CR) of contaminants for Adult and Children through dermal pathway.

Sample Code	AD/CH	Cr	Ni	Pb
PHR1	Adult	1.61×10^{-5}	6.33×10^{-3}	9.43×10^{-7}
	Children	2.00×10^{-6}	1.81×10^{-6}	9.43×10^{-7}
PHR2	Adult	7.78×10^{-5}	5.95×10^{-3}	8.32×10^{-9}
	Children	9.80×10^{-6}	1.77×10^{-6}	8.32×10^{-9}
PHR3	Adult	1.17×10^{-6}	6.20×10^{-3}	4.76×10^{-7}
	Children	7.21×10^{-8}	4.45×10^{-5}	4.76×10^{-7}
CR	TCR (AD)	1.68×10^{-3}	7.20×10^{-2}	1.42×10^{-6}
	TCR (CH)	2.69×10^{-5}	2.13×10^{-5}	1.42×10^{-6}

5. Conclusion

The study looked at the quantities and sources of metallic contaminants in road deposited sediments (RDS) along main roads in Owerri. The study found substantial levels of chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and lead (Pb) in the RDS. It is worth noting that Ni, Cu, Cd, and Pb concentrations were found to be higher than their respective background levels. The Co concentration on Port Harcourt Road was 670 mg/l, which above the background level, indicating a significant anthropogenic influence. The enrichment factor calculations revealed that manganese (Mn) had little enrichment, but chromium (Cr) and zinc (Zn) had moderate to large enrichment. Furthermore, cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and lead (Pb) enrichment levels in RDS samples were quite high. The geoaccumulation index computations indicated varying degrees of contamination for the elements Nickel (Ni) and Lead (Pb), indicating the presence of anthropogenic accumulation. For the elements Cr, Fe, Co, Ni, Cu, Zn, and Pb, the contamination factors analysis revealed a range of contamination levels ranging from extremely low to very high. The pollution assessment indicated considerable levels of contamination on all three highways, with PHR1 having the worst pollution, followed by PHR3 and PHR2.

The investigation of prospective ecological risk indices found that the presence of cobalt (Co) on roadways significantly increased the ecological risk levels. The increased volume of traffic and vehicular operations in Owerri helped to deposit this metal on the road surfaces. As a result of high traffic-related activities, the health risk assessment found elevated levels of heavy metals in the Average Daily Doses (ADD) at PHR 1 to PHR 3. The Hazard Quotient (HQ) and Hazard Index (HI) values in these areas were found to be high, although the overall health risk was considered to be low.

The study discovered two major sources of heavy metal contamination: natural sources (including the Earth's crust) and transportation-related activities (including air deposition, corrosion, and vehicle degradation). The findings of this investigation shed light on the sources and quantities of metallic contaminants in sediments deposited on road surfaces. It is critical to understand the possibility of future heavy-metal contamination in the absence of effective management, particularly in respect to atmospheric depositions.

References

Adriano D.C., Wenzel W.W., Vangronsveld J. & Bolan N.S., 2004. Role of assisted natural remediation in environmental cleanup. Geoderma 122(2–4): 121–142.

Ahmed F., Bibi M.H. & Ishiga H., 2007, Environmental assessment of Dhaka City (Bangladesh) based on trace metal contents in road dusts. Environmental Geology 51(6): 975–985.

Akaolisa C.C., Agbasi O.E., Etuk S.E., Adewumi R. & Okoli E.A., 2023, Evaluating the Effects of Real Estate Development in Owerri, Imo State, Nigeria: Emphasizing Changes in Land Use/Land Cover (LULC). Journal of Landscape Ecology 16(2): 98–113. https://doi.org/10.2478/jlecol-2023-0012

Appleyard S., Wong S., Willis-Jones B., Angeloni J. & Watkins R., 2004, Groundwater acidification caused by urban development in Perth, Western Australia: source, distribution, and implications for management. Soil Research 42(6): 579–585.

Aryal R., Vigneswaran S., Kandasamy J. & Naidu R., 2010, Urban stormwater quality and treatment. Korean J Chem Eng 27: 1343–1359

Brown W. & Schueler T., 1997, National pollutant removal performance database of current urban stormwater best management practices. Center for Watershed Protection. Ellicott City, MD.

Charlesworth S., Everett M., McCarthy R., Ordonez A. & De Miguel E., 2003, A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. Environment international 29(5): 563–573.

Chen C., Lu X., Wang L. & Lei K., 2011, Health risk assessment of heavy metals in street dust in Baoji City. Urban Environment & Urban Ecology 24: 35–38.

Chen L., Zhang H., Ding M., Devlin A.T., Wang P., Nie M. & Xie K., 2021, Exploration of the variations and relationships between trace metal enrichment in dust and ecological risks associated with rapid urban expansion. Ecotoxicology and Environmental Safety 212, 111944.

Cui Y., Bai L., Li C., He Z. & Liu X., 2022, Assessment of heavy metal contamination levels and health risks in environmental media in the northeast region. Sustainable Cities and Society 80, 103796. https://doi.org/10.1016/j.scs.2022.103796

Dash S., Borah S.S. & Kalamdhad A., 2019, A modified indexing approach for assessment of heavy metal contamination in Deepor Beel, India. Ecological Indicators 106, 105444.

Davis A.P., Shokouhian M. & Ni S., 2001, Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 44(5): 997–1009.

Duong T.T.T. & Lee B., 2009, Partitioning and mobility behaviour of metals in road dusts from national-scale industrial areas in Korea. Atmos Environ 43: 3502–3509.

Egbueri J.C. & Unigwe C.O., 2020, Understanding the extent of heavy metal pollution in drinking water supplies from Umunya, Nigeria: an indexical and statistical assessment. Analytical Letters 53(13): 2122–2144.

Evans L.J., Spiers G.A. & Zhao G., 1995, Chemical aspects of heavy metal solubility with reference to sewage sludge amended soils. International Journal of Environmental Analytical Chemistry 59(2–4): 291–302.

Eze V.C., Onwukeme V. & Enyoh C.E., 2020, Pollution status, ecological and human health risks of heavy metals in soil from some selected active dumpsites in Southeastern, Nigeria using energy dispersive X-ray spectrometer. International Journal of Environmental Analytical Chemistry 102(6). Doi:10.1080/03067319.2020.1772778

Fakhri Y., Saha N., Ghanbari S., Rasouli M., Miri A., Avazpour M., Rahimizadeh A., Riahi S.M., Ghaderpoori M., Keramati H., Moradi B. & Khaneghah A.M., 2018, Carcinogenic and non-carcinogenic health risks of metal(oid)s in tap water from Ilam city, Iran. Food and Chemical Toxicology 118: 204–211.

Fuente D., Chico B. & Morcillo E., 2006, The effects of soluble salts at the metal/paint interface: advances in knowledge. Port Electrochim Acta 24: 191–206.

Guney M., Onay T.T. & Copty N. K, 2010, Impact of overland traffic on heavy metal levels in highway dust and soils of Istanbul, Turkey. Environmental Monitoring and Assessment, 164(1): 101–110.

Hakanson L., 1980, An ecological risk index for aquatic pollution control. Asedimentological approach. Water research 14(8): 975–1001.

Han Y.M., Du P.X., Cao J.J. & Posmentier E.S., 2006, Multivariate analysis of heavy metal contamination in urban dust of Xi'an, Central China. The Science of the Total Environment 355: 176–18

Hanfi M.Y., Seleznev A.A., Yarmoshenko I.V., Malinovsky G., Konstantinova E.Y., Alqahtani M.S. & Sakr A.K., 2023, Heavy metal contamination levels, source distribution, and risk assessment in fine sand of urban surface deposited sediments of Ekaterinburg, Russia. Environmental Geochemistry and Health 45(7): 4389–4406. https://doi.org/10.1007/s10653-023-01494-y

Hjortenkrans D., Bergbäck B. & Häggerud A., 2006, New metal emission patterns in road traffic environments. Environmental Monitoring and Assessment 117(1): 85–98.

Ibe F.C., Opara A.I., Ibe B.O., Adindu B.C. & Ichu B.C., 2018, Environmental and health implications of trace metal concentrations in street dusts around some electronic repair workshops in Owerri, Southeastern Nigeria. Environmental Monitoring and Assessment 190(12), 696.

Ibe F.C., Njoku P.C., Alinnor J. & Opara A.I., 2016, Evaluation of ambient air quality in parts of Imo State, Nigeria. Research Journal of Chemical Sciences 6(1): 41–52.

Ichu C.B., Ume J.I., Opara A.I. & Ibe F.C., 2021, Ecological Risk Assessment and Pollution Models of Trace Metal Concentrations in Road Dust in parts of Enugu, Southeastern Nigeria. Journal of Chemical Health Risks 11(2): 135–151.

Jeong H., Choi J.Y., Lim J., Shim W.J., Kim Y.O. & Ra K., 2020, Characterization of the contribution of road deposited sediments to the contamination of the close marine environment with trace metals: Case of the port city of Busan (South Korea). Marine Pollution Bulletin 161. Doi: 10.1016/j.marpolbul.2020.111717

Kartal Ş., Aydın Z. & Tokalıoğlu Ş., 2006, Fractionation of metals in street sediment samples by using the BCR sequential extraction procedure and multivariate statistical elucidation of the data. Journal of Hazardous Materials 132(1): 80–89.

Lecoanet H., Leveque F. & Ambrosi J.P., 2003, Combination of magnetic parameters: an efficient way to discriminate soil-contamination sources (south France). Environmental Pollution 122(2): 229–234.

Li X., Zhang S. & Yang M., 2014, Accumulation and risk assessment of heavy metals in dust in main living areas of Guiyang City, Southwest China. Chinese Journal of Geochemistry, 33(3): 272–276.

Loganathan P., Vigneswaran S. & Kandasamy J., 2013, Road-deposited sediment pollutants: a critical review of their characteristics, source apportionment, and management. Critical Reviews in Environmental Science and Technology 43(13): 1315–1348.
Loska K., Cebula J., Pelczar J., Wiechuła D. & Kwapuliński J., 1997, Use of enrichment, and contamination factors together with geoaccumulation indexes to evaluate the content of Cd, Cu, and Ni in the Rybnik water reservoir in Poland. Water, Air, and Soil Pollution 93(1): 347–365.
Lu X., Wang L., Lei K., Huang J. & Zhai Y., 2009, Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. Journal of Hazardous Materials 161(2–3): 1058–1062.
Lu X., Wang L., Li L.Y., Lei K., Huang L. & Kang D., 2010, Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China. Journal of Hazardous Materials 173(1–3): 744–749.
Maher B.A., Moore C. & Matzka J., 2008, Spatial variation in vehicle-derived metal pollution identified by magnetic and elemental analysis of roadside tree leaves. Atmospheric Environment 42(2): 364–373.
Mama C.N., Nnaji C.C., Igwe O., Ozioko O.H., Ezugwu C.K. & Ugwuoke I.J., 2020, Assessment of heavy metal pollution in soils: a case study of Nsukka metropolis. Environmental Forensics 23(3-4). Doi:10.1080/15275922.2020.1850567
Man Y.B., Sun X.L., Zhao Y.G., Lopez B.N., Chung S.S., Wu S.C., Cheung K.C. & Wong M.H., 2010, Health risk assessment of abandoned agricultural soils based on heavy metal contents in Hong Kong, the world's most populated city. Environment International 36(6): 570–576.
McKenzie E.R., Money J.E., Green P.G. & Young T.M., 2009, Metals associated with stormwater-relevant brake and tire samples. Science of the Total Environment 407(22): 5855–5860.
Meza-Figueroa D., De la O-Villanueva M. & De la Parra M.L., 2007, Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, México. Atmospheric Environment 41(2): 276–288.
Muller G., 1969, Index of geoaccumulation in sediments of the Rhine River. Geojournal 2: 108–118.
Muthukrishnan S., Madge B., Selvakumar A., Field R. & Sullivan D., 2004, The Use of Best Management Practices (BMPs) in Urban Watersheds. US Environmental Protection Agency. Office of Research and Development. EPA/600/R-04/184. Washington. 1.1–6.16.
NESREA, 2013, National Environmental Standards and Regulations Enforcement Agency. Soil Guideline Values, 25 pp.
Nkansah M.A., Agorsor P.I. & Opoku F., 2021, Heavy metal contamination and health risk assessment of mechanically milled delicacy called fufu. International Journal of Food Contamination 8(1). https://doi.org/10.1186/s40550-021-00085-y
Okoro U.K., Chen W., Chineke C. & Nwofor O., 2014, Comparative analysis of gridded datasets and gauge measurements of rainfall in the Niger Delta region. Research Journal of Environmental Sciences 8(7): 373–390.
Onyeagocha A.C., 1980, Petrography and depositional environment of the Benin Formation Nigeria. Journal of Mining and Geology 17(2): 147–151.
Rastmanesh F., Moore F., Kopaei M.K., Keshavarzi B. & Behrouz M., 2011, Heavy metal enrichment of soil in Sarcheshmeh copper complex, Kerman, Iran. Environmental Earth Sciences 62(2): 329–336.
Robertson D.J., Taylor K.G. & Hoon S.R., 2003, Geochemical and mineral magnetic characterisation of urban sediment particulates, Manchester, UK. Applied Geochemistry 18(2): 269–282.

Sezife T., Senol K. & Gokhan B., 2013, Comparison of three sequential extraction procedures for portioning of heavy metals in car park dust. Journal of Environmental Monitoring 5: 468–476.
Short K.C. & Stauble A.J., 1967, Outline of geology of Niger Delta. American Association of Petroleum Geologists Bull. 51(5): 761–729
Smith S.R. & Giller K.E., 1992, Effective Rhizobium leguminosarum biovar trifolii present in five soils contaminated with heavy metals from long-term applications of sewage sludge or metal mine spoil. Soil Biology and Biochemistry 24(8): 781–788.
Taşpınar F. & Bozkurt Z., 2018, Heavy metal pollution and health risk assessment of road dust on selected highways in Düzce, Turkey. Environmental Forensics 19(4): 298–314.
Taylor K.G., 2007, Urban environments, [in:] C. Perry, K. Taylor (eds.), Environmental sedimentology, p. 190–222. Oxford, England: Blackwell.
Taylor S. R., 1964, Abundance of chemical elements in the continental crust: a new table. Geochimica et Cosmochimica Acta 28(8): 1273–1285.
Uma K.O., 1989, An appraisal of the groundwater resources of the Imo River Basin, South eastern Nigeria. Journal of Mining and Geology 25(1–2): 305–315.
USEPA, 2001, Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355. 4–24. Office of Solid Waste and Emergency Response. US Environmental Protection Agency, Washington, DC, USA.
USEPA, 2011, Regional Screening Level Table (RSL) for Chemical Contaminants at Superfund Sites. U.S. Environmental Protection Agency, Washington, DC, USA.
Walkley A. & Black I.A., 1934, An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29–37.
Wang X., Ma J., Hou Q. & Duan H., 2011, Accumulation and health risk assessment of heavy metals in kindergarten surface dust in the city of Kaifeng. Acta Sci Circumst 31(3): 583–593.
Xie S., Dearing J.A., Bloemendal J. & Boyle J.F., 1999, Association between the organic matter content and magnetic properties in street dust, Liverpool, UK. Science of the Total Environment 241(1–3): 205–214.
Yang X., Cheng B., Gao Y., Zhang H. & Liu L., 2022, Heavy metal contamination assessment and probabilistic health risks in soil and maize near coal mines. Frontiers in Public Health 10. https://doi.org/10.3389/fpubh.2022.1004579
Yisa J., 2010, Heavy metals contamination of road-deposited sediments. American Journal of Applied Sciences 7(9), 1231.
Zhu W., Bian B. & Li L., 2008, Heavy metal contamination of road-deposited sediments in a medium size city of China. Environmental monitoring and assessment 147(1): 171–181.