



Research Article

Assessment of Environmental of Heavy Metal Contamination in Scrap Metal-Polluted and Flood-Affected Soils in Maiduguri and its Environs, North-Eastern Nigeria

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ABSTRACT

In this study, 31 soil samples from specific areas were examined for the levels of cadmium (Cd), chromium (Cr), and lead (Pb) and the dangers associated with them. The average values of Cd, Cr, and Pb were 0.033 mg/kg, 7.86 mg/kg, and 3.32 mg/kg, respectively. Individual samples did, however, show noticeably higher amounts of Cd (0.227 mg/kg in SL17), Cr (25.19 mg/kg in SL08), and Pb (15.73 mg/kg in SL10), suggesting localized pollution most likely caused by human activities such as industrial discharge, inadequate waste management, and the use of agrochemicals. Although mean concentrations were generally low, health risk screening indicated potential non-carcinogenic concern for Cr in localized hotspots. Several indices were used to evaluate the degree of contamination and the health concerns. Most soils were categorized as unpolluted by the Geoaccumulation Index (I_{geo}), which ranged from -1.750 to -0.297 for Cd, -2.155 to -0.729 for Cr, and -1.948 to -0.280 for Pb. Significant anthropogenic enrichment was suggested by samples with elevated I_{geo} values, such as SL07 and SL14. The Improved Nemerow Index (I_{IN}) revealed predominantly low-level heavy-metal pollution (1.028–1.942) across all sampling sites, with only a few locations exhibiting slightly elevated integrated contamination. Critical hotspots with multi-element contamination burdens, such as SL14, SL07, SL30, and SL31, were identified by additional analysis employing Pollution Load Index (P), Potential Ecological Risk Index (P_{ie}), and Contamination Degree Factor (D_{cont}). These results highlight the necessity of deliberate cleanup, localized risk assessment, and focused environmental monitoring. To reduce long-term ecological and public health effects, a complete management strategy that includes risk communication, pollution source identification, and regulatory enforcement is necessary.

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INTRODUCTION

Heavy metal contamination in the environment has become a significant global concern due to the

persistence, toxicity, and non-biodegradability of these elements. Among the most hazardous are cadmium (Cd), chromium (Cr), and lead (Pb), which pose serious risks

to human health and the ecosystem even at low concentrations (He *et al.*, 2015; Addis & Abebaw, 2017). These metals can persist in soils for long periods, accumulate in the food chain, and ultimately affect human populations through ingestion, inhalation, or dermal contact (Maleki *et al.*, 2014; Ripin *et al.*, 2014). Heavy metals like *Cd*, *Cr*, and *Pb* are particularly dangerous due to their bioaccumulative nature and chronic toxicity. *Cd* is known to affect kidney function, bone structure, and cardiovascular health, and has been linked to cancers of the lungs and prostate (Wu *et al.*, 2016; Amshi *et al.*, 2019). *Pb*, a neurotoxin, impairs cognitive development in children and is associated with kidney dysfunction, reproductive toxicity, and immune system impairment in adults (Addis & Abebaw, 2017; Hu *et al.*, 2017). *Cr*, particularly in its hexavalent form, is a recognized carcinogen and has been associated with respiratory disorders and liver damage (Achmad *et al.*, 2017). When these metals accumulate in soils, especially in flood-prone zones, they increase the risk of human exposure through various environmental pathways. Soil contamination, in particular, serves as a primary reservoir for heavy metals, and their mobilization can be triggered by human activities and environmental processes such as flooding (Harrison *et al.*, 1981; Osmani *et al.*, 2015).

Urbanization, industrial activities, and the informal recycling of scrap metals have contributed significantly to the increasing levels of heavy metals in soils, especially in developing countries (Ukpong *et al.*, 2013; Akpan & William, 2014). In regions such as Maiduguri, North-Eastern Nigeria, unregulated scrap metal operations and recurring flood events have resulted in substantial soil pollution. The lack of adequate environmental management strategies has made it easy for these contaminants to spread, threatening food safety, water quality, and public health (Kabir *et al.*, 2012; Proshad *et al.*, 2019). Informal scrapyards, common in many Nigerian cities, involve unsafe practices such as burning and open-air dismantling of metallic waste, which releases significant quantities of toxic substances into the environment (Al-Khashman & Shawabkeh, 2006; Lee *et al.*, 2005).

Maiduguri's geography and socio-economic activities make it uniquely vulnerable to heavy metal pollution. Located in a semi-arid region, the city experiences seasonal flooding that redistributes contaminants across agricultural fields and residential areas. Additionally, its position as a commercial hub near international borders contributes to high vehicular emissions and the proliferation of informal scrapyards (Fergusson & Kim, 1991; Charlesworth *et al.*, 2003). These factors, combined with inadequate waste regulation and environmental monitoring, create conditions conducive to soil contamination and long-term ecological damage. Despite the severity of the issue, data on heavy metal contamination in flood-affected and scrap metal-polluted soils in Maiduguri are scarce. Most existing studies in Nigeria have concentrated on industrialized areas, mining zones, or water pollution, with limited attention given to urban soil contamination from informal recycling and flood events (Kabir *et al.*, 2017; Mortvedt, 1996). Consequently, there is a critical need for localized investigations that assess the environmental burden of heavy metals in urban settings like Maiduguri and evaluate the associated human health risks.

METHODOLOGY

Study Area

This study was conducted in Maiduguri, the capital of Borno State, in North-Eastern Nigeria, located at approximately 11.85°N latitude and 13.08°E longitude with an elevation of about 354 meters above sea level. The area is characterized by arid and semi-arid climatic conditions, with pronounced dry and wet seasons. Maiduguri has witnessed recurrent flooding events in recent years, which have significantly affected urban land use and soil composition. The city is also home to multiple scrap metal markets and informal recycling sites, contributing to heavy metal contamination in the soil. Sampling sites were selected based on proximity to scrap metal activities and flood-prone zones using satellite imagery, reconnaissance surveys, and local knowledge.

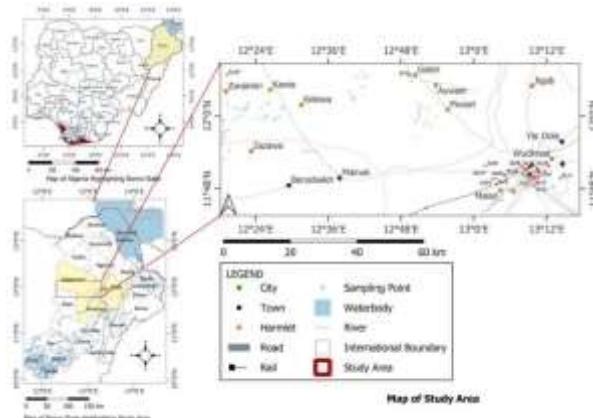


Figure 1: Geographical map of Borno state showing the sampling locations

Sample Collection

A total of 31 soil samples were collected from different flood-affected and scrap metal-contaminated sites across Mafa, Maiduguri, Magumeri, Jere and Konduga using a stainless-steel auger. At each location, composite soil samples were collected from four different points within 5 m radius, using a stainless-steel auger at a depth of 0–15 cm. Control samples were taken from non-impacted areas located at least 3 km away from the pollution sources. Several sampling locations were selected based on historical flood data, proximity to informal scrap metal markets, and

Table 1: The soil samples are from the following five Local Government Areas of Borno State, Nigeria

Sample ID	Sample Site	Latitude	Longitude
SL01	Njimtilo	11.862778	13.032222
SL02	Opp. BOSU	11.845000	13.031944
SL03	Gambari	11.829444	13.060833
SL04	Gambari II	11.826944	13.051111
SL05	Custom Area	11.850278	13.179444
SL06	Custom Mashamari	11.844444	13.178056
SL07	Gidan Dambe London	11.845556	13.180278
SL08	Moramti	11.835556	13.083889
SL09	Ayafe Junction Old Airport	11.840000	13.088056
SL10	Abba Street Gwange	11.833611	13.163611
SL11	Gwange Layin Gida Kifi	11.825278	13.162222
SL12	Gwange Barrack	11.808889	13.166944
SL13	Zanna Bukar Dipchari St.	11.828056	13.166111
SL14	Usman Tobacco Samaila Idris St.	11.843056	13.159722
SL15	Layin Kantin Yara	11.829167	13.177222
SL16	Gwange III Ward	11.826667	13.151667
SL17	Gwange II Ward Layin City Buba	11.828611	13.237500
SL18	Goni Kachallari	11.863056	13.207500
SL19	Gwange II Ward Layin Makaranta	11.833056	13.167222
SL20	Gwange I Ward Maijir St. Pom-Pom Zafi	11.834444	13.174722
SL21	Kasuwan Shanu	11.858056	13.174444
SL22	Gamboru	11.850278	13.172222
SL23	Gamboru Liberty	11.850278	13.172222

human activity levels. Each sample was stored in clean pre-labeled polyethylene bags, labeled accordingly, and transported to the laboratory for analysis. Sampling was done during the dry season to ensure accessibility and reduce variability due to moisture content. Soil digestion was performed using aqua regia ($\text{HNO}_3:\text{HCl}$ in a 1:3 ratio) following standard methods by the Association of Official Analytical Chemists (AOAC, 2005). The digested solutions were filtered and made up to 50 mL with deionized water in acid-washed volumetric flasks.

SL24	Post Office Bola	11.837222	13.147500
SL25	Baga Road Mechanical Workshop	11.863056	13.133611
SL26	Baga Road	11.863889	13.131667
SL27	West-End	11.853056	13.142778
SL28	Lamisula	11.855000	13.148611
SL29	Abbaganaram	11.857222	13.152500
SL30	Kajari	12.113611	12.166111
SL31	Opp. Vocational Center	12.110833	12.828333

Heavy Metal Analysis

In the laboratory, the soil samples were air-dried at room temperature for 6 days to reduce moisture content. The dried samples were then crushed, homogenized, and sieved through a 2 mm mesh to remove debris. Sub-samples were pulverized further and passed through a 0.5 mm sieve for elemental analysis. The concentrations of cadmium (*Cd*), chromium (*Cr*), and lead (*Pb*) in the soil samples were determined using Atomic Absorption Spectrophotometry (AAS). Calibration was done using certified reference standards, and blank samples were analyzed concurrently to ensure accuracy. Duplicate samples and standard reference materials were included to check accuracy and precision. The detection limits for *Cd*, *Cr*, and *Pb* were 0.001 mg/kg, 0.01 mg/kg, and 0.005 mg/kg, respectively. All glassware

$$A_i = \frac{C_i}{B_i} \quad (1)$$

where C_i is the measured concentration of the heavy metal in the sample (mg/kg), B_i is the geochemical baseline value and the values for each heavy metals i are: $B_{Cd} = 0.3 \text{ mg} \cdot \text{kg}^{-1}$, $B_{Cr} = 90 \text{ mg} \cdot \text{kg}^{-1}$, $B_{Pb} = 20 \text{ mg} \cdot \text{kg}^{-1}$ (Mohammed *et al.*, 2021; Ma *et al.*, 2022). The Degree of Contamination provides an overall

$$D_{cont} = \sum_{i=1}^n A_i = A_{Cd} + A_{Cr} + A_{Pb} \quad (2)$$

The Contamination factor helps to distinguish between natural (geogenic) and human-induced (anthropogenic) source of heavy metal contaminations. Though, it does not account for toxicity or ecological impact.

Toxicity and Ecological Risk

While the Contamination Factor, A_i provides insight into the pollution intensity, it does not account for the toxicity or ecological impact of the contaminants. To assess the degree of heavy metal contamination and its potential ecological risks in soils from flood-affected zones, the following indices were applied based on established protocols

$$P_l = \left(\prod_{i=1}^n A_i \right)^{\frac{1}{n}} = (A_{Cd} \cdot A_{Cr} \cdot A_{Pb})^{\frac{1}{3}} \quad (3)$$

where n is the number of metals, i , analyzed.

Potential Ecological Risk Index

The Potential Ecological Risk Factor, P_{ie} is an index applied to assess the ecological risk posed by a specific toxicity of heavy metal in an environmental medium. The P_{ie} for a specific contaminant is calculated using the formula,

and plastic containers were acid-washed using 10% HNO₃ and rinsed with deionized water before use. Duplicate samples, reagent blanks, and standard reference materials were included in each batch of analysis to assess precision, accuracy, and potential contamination.

Contamination Factor

The contamination factor, A_i is a key index used to assess the degree of contamination or pollution of a specific heavy metal in the top soil or sediments of the flood impacted region. It is a quantitative metric used to assess the degree of contamination of a particular element or pollutant in an environmental medium (e.g., soil, water, sediment). The A_i for each heavy metal, i , is calculated using the formula (Adu *et al.*, 2022; Helfnalis *et al.*, 2021; Šrbac *et al.*, 2017),

measure of the contamination level in a given area. It is calculated by summing the contamination factors, A_i of all the metals considered in the study. The Degree of Contamination, D_{cont} , of the i^{th} metal is calculated using the formula,

(Tomlinson *et al.*, 1980; Hakanson, 1980; Šrbac *et al.*, 2017):

Pollution Load Index Assessment

The Pollution Load Index, P_l is a metric that provides a comprehensive measure of the degree of heavy metal pollution status in the soil. It gives an overall indication of heavy metal pollution in a given area by integrating their individual contamination factors, A_i . The Pollution Load Index, P_l is computed as (Echeweozo *et al.*, 2025),

$$P_{ie} = A_i \cdot k_i \quad (4)$$

where k_i is the Toxic Response Factor for each contaminant, with typical values for common metals being: $k_{Cd} = 30$, $k_{Cr} = 2$, $k_{Pb} = 5$ (Echeweozo *et al.*, 2025). It reflects the toxicity and environmental sensitivity of the contaminant.

The P_{te} is the overall ecological risk index P_e for all

$$P_{te} = \sum_{i=1}^3 P_{ie} = P_{Cd_e} + P_{Cr_e} + P_{Pb_e} \quad (5)$$

The P_{te} is an integrated measure that evaluates the overall ecological risk posed by multiple contaminants (e.g., heavy metals) in an environmental medium (Guan *et al.*, 2014). It provides a cumulative measure of ecological and health risk posed by all heavy metals to aquatic and terrestrial ecosystem.

Geoaccumulation Index (I_{geo})

The Geoaccumulation Index (I_{geo}), introduced by Müller (1981), is a widely used metric for quantifying heavy metal enrichment in the soils/sediments/water samples from different locations in Maiduguri. It compares current heavy metal concentrations with pre-industrial or geochemical background levels, accounting for natural lithogenic variability. The I_{geo} is calculated using the following equation,

$$I_{geo} = \log_2 \left(\frac{C_i}{1.5 \cdot B_i} \right) \quad (6)$$

where 1.5 is the Correction factor accounting for natural variations in heavy metal concentration due to lithogenic effects and minor anthropogenic influences (Okoro *et al.*, 2018).

Improved Nemerow Index

Each sampling location's cumulative level of heavy-metal contamination is assessed using the Improved Nemerow Index (I_{IN}), a comprehensive pollution assessment measure. An integrated index offers a more reliable assessment of site-specific pollution conditions because various metals may have distinct effects on the environment and human health (Dey *et al.* 2021). It was calculated using,

$$I_{IN} = \frac{1}{\sqrt{2}} \sqrt{(I_{geomax}^2 + I_{geoave}^2)} \quad (7)$$

where I_{geomax} is the Maximum I_{geo} value among all metals in the sample and I_{geoave} is the Arithmetic mean of I_{geo} values for all metals. The following categories are commonly used to interpret I_{IN} readings: values < 1.0 indicate no pollution, values between 1.0 and 2.0 indicate mild pollution, values between 2.0 and 3.0 suggest moderate pollution, and values > 3.0 indicate high to severe pollution levels. The relative severity of heavy-metal pollution across sampling locations can be evaluated with the use of this gradation (Dey *et al.* 2021).

Statistical and Spatial Analysis

Geographic Information System (GIS) tools were used to map spatial distribution of metal concentrations using QGIS. Table 3 provides data on the concentrations of cadmium (Cd), chromium (Cr), and lead (Pb) in soil samples from various locations in Borno State, Nigeria.

contaminants,

The concentrations of heavy metals (Cd , Cr , Pb) were analyzed in 31 soil samples, revealing varying levels of contamination across the locations. The average concentrations obtained were 0.033 mg/kg for Cd , 7.86 mg/kg for Cr , and 3.32 mg/kg for Pb , with standard deviations of 0.036 , 7.26 , and 3.87 , respectively. According to WHO/FAO and USEPA guideline values, the acceptable limits for heavy metals in soil are 100 mg/kg for Pb , 60 mg/kg for Cr , and 3 mg/kg for Cd (Feyisa *et al.* 2025). While these averages fall within permissible limits recommended by international standards such as WHO and FAO, individual samples exhibited notable deviations, indicating potential environmental concerns in specific areas. Cd is a highly toxic heavy metal known for its detrimental effects on both human health and the environment, even at low concentrations. In this study, cadmium concentrations in the soil samples ranged from 0.008 mg/kg (SL09) to 0.227 mg/kg (SL17). Although most values were relatively low, sample SL17 recorded the highest concentration. This suggests that SL17 may represent a potential hotspot of cadmium contamination, possibly linked to nearby anthropogenic activities such as industrial discharge, improper waste disposal, or the use of phosphate fertilizers. Notably, the observed concentration in SL17 surpasses the WHO-recommended soil guideline values (0.01 – 0.05 mg/kg for agricultural soils), raising significant environmental and public health concerns for residents in the vicinity. Cr concentrations varied markedly across the samples, with values ranging from 0.944 mg/kg (SL20) to 25.19 mg/kg (SL08). Notably, samples SL08 (25.19 mg/kg) and SL31 (19.16 mg/kg) exhibited significantly elevated chromium levels, which could be indicative of point-source pollution. The concentrations in these hotspots are substantially higher than the typical maximum allowable limit for chromium in agricultural soils (approximately 0.1 mg/kg). This highlights an urgent need for risk mitigation strategies, especially in locations where residential or agricultural exposure pathways are likely. Pb levels also demonstrated significant variability, ranging from 0.338 mg/kg (SL09) to a maximum of 15.73 mg/kg (SL10). The elevated concentration in SL10 may reflect localized contamination. Thus, although the general soil quality appears to be within acceptable safety margins, the presence of elevated concentrations in several samples points to potential localized contamination hotspots. These findings call for targeted environmental monitoring, particularly in the affected zones, to prevent further accumulation of toxic metals. Additionally, community health awareness programs and remediation efforts should be considered to mitigate any long-term risks to human health and ecological systems.

RESULTS

Table 2: The mean concentration of *Cd*, *Cr*, and *Pb* (mean \pm SD) in soil samples

Sample ID	Concentration (mg/kg)		
	<i>Cd</i>	<i>Cr</i>	<i>Pb</i>
SL01	0.016 \pm 0.0011	17.31 \pm 0.045	0.867 \pm 0.0412
SL02	0.014 \pm 0.0009	1.796 \pm 0.0294	6.100 \pm 0.0418
SL03	0.012 \pm 0.0007	2.435 \pm 0.0112	0.620 \pm 0.0389
SL04	0.017 \pm 0.0013	19.91 \pm 0.050	1.283 \pm 0.0217
SL05	0.025 \pm 0.0001	4.433 \pm 0.0419	1.943 \pm 0.0097
SL06	0.015 \pm 0.0003	1.731 \pm 0.0466	0.607 \pm 0.0105
SL07	0.017 \pm 0.0016	15.26 \pm 0.035	1.089 \pm 0.0354
SL08	0.043 \pm 0.0013	25.19 \pm 0.102	0.918 \pm 0.0174
SL09	0.008 \pm 0.0012	1.601 \pm 0.0016	0.338 \pm 0.0276
SL10	0.057 \pm 0.0015	2.697 \pm 0.0514	15.73 \pm 0.064
SL11	0.025 \pm 0.0004	1.938 \pm 0.1088	7.230 \pm 0.0570
SL12	0.042 \pm 0.0016	3.139 \pm 0.0204	4.479 \pm 0.0592
SL13	0.040 \pm 0.0011	1.380 \pm 0.0328	7.516 \pm 0.0483
SL14	0.038 \pm 0.0006	6.469 \pm 0.0204	2.144 \pm 0.0461
SL15	0.044 \pm 0.0007	1.163 \pm 0.0176	4.296 \pm 0.0373
SL16	0.055 \pm 0.0011	5.155 \pm 0.0252	4.274 \pm 0.0208
SL17	0.227 \pm 0.0018	4.983 \pm 0.0064	14.06 \pm 0.039
SL18	0.013 \pm 0.0019	3.751 \pm 0.0473	0.540 \pm 0.0153
SL19	0.019 \pm 0.0017	14.59 \pm 0.046	0.789 \pm 0.0244
SL20	0.018 \pm 0.0003	0.944 \pm 0.0399	0.839 \pm 0.0214
SL21	0.018 \pm 0.0007	15.41 \pm 0.077	2.312 \pm 0.0131
SL22	0.021 \pm 0.0022	5.797 \pm 0.0076	1.895 \pm 0.0294
SL23	0.022 \pm 0.0001	2.355 \pm 0.0263	0.991 \pm 0.0137
SL24	0.016 \pm 0.0015	1.554 \pm 0.0517	1.774 \pm 0.0091
SL25	0.037 \pm 0.0017	4.768 \pm 0.0281	3.143 \pm 0.0253
SL26	0.032 \pm 0.0010	6.789 \pm 0.0007	1.427 \pm 0.0080
SL27	0.012 \pm 0.0010	20.86 \pm 0.073	0.560 \pm 0.0639
SL28	0.018 \pm 0.0021	20.47 \pm 0.049	2.130 \pm 0.0109
SL29	0.024 \pm 0.0006	3.574 \pm 0.0336	1.357 \pm 0.0302
SL30	0.107 \pm 0.0020	3.571 \pm 0.0358	6.131 \pm 0.0390
SL31	0.032 \pm 0.0008	19.16 \pm 0.020	6.241 \pm 0.0080
Average	0.033	7.86	3.32

Table 3 presents the geoaccumulation index (I_{geo}) values for *Cd*, which range from -1.750 to -0.297 , with an average of -1.240 . These values classify the area as unpolluted, indicating limited geochemical enrichment. However, values near the threshold—particularly in sample SL14—suggest possible anthropogenic contributions elevating *Cd* concentrations above natural background levels. For *Cr*, I_{geo} values span from -2.155 to -0.729 , with an average of -1.445 , suggesting that soils are generally “unpolluted to moderately polluted.” Nonetheless, elevated I_{geo} values in samples such as SL05, SL04, SL27, SL28, and SL31 imply anthropogenic influence—likely from scrap metal activities or effluent discharges. *Pb* exhibits I_{geo} values ranging from -1.948 to -0.280 , with an average of -1.173 . While this also falls within the “unpolluted to moderately polluted” range, the highest value (-0.280) at SL07 points to significant local contamination, aligning with elevated *Pb* concentrations in that area. Although the overall I_{geo} suggests minimal enrichment, localized pollution at SL07 and SL14 warrants concern. The Improved Nemerow Index (I_{IN}) values for 31 soil sampling sites in the research area are shown in Table 3. All locations fall into the low-pollution category ($I_{IN} > 1.0$ and < 2.0), with I_{IN} values ranging from 1.028 to 1.942. Several areas show comparatively significant levels of contamination,

even though none of the sites met the threshold for moderate or high pollution ($I_{IN} > 2.0$). Specifically, SL06 (1.912) and SL19 (1.942) had the greatest I_{IN} values, indicating somewhat higher cumulative heavy-metal contributions at these locations. SL31, on the other hand, has the lowest IIN rating (1.028), indicating less pollution than other places. Overall, the spatial pattern indicates that although contamination is generally minimal throughout the region, some sites could need additional observation because of slightly greater combined pollution pressures.

The dataset on Table 3 also reveals important insights into pollution levels in the analyzed samples through parameters like Pollution Load (P_L) and Individual Enrichment (P_{IE}). *Pb* shows exceptionally high enrichment in samples SL07, SL08, SL02, and SL31, with values reaching up to 78.65. These concentrations strongly suggest anthropogenic influence, likely from industrial operations or vehicular emissions. Similarly, *Cr* records notable pollution loads in SL05, SL04, and SL28, with enrichment values like 50.38 and 40.94, indicating localized industrial contamination—possibly from metal processing or tannery activities. *Cd*, though generally present in lower natural concentrations, exhibits significant pollution in SL14, SL30, SL07, and SL13. Given *Cd*’s high toxicity and mobility, even moderate enrichment poses ecological and health risks. The

contamination degree (D_{cont}) gives a clearer picture of total metal burden. Samples such as SL14 (1.5150), SL07 (1.0065), SL30 (0.7029), and SL31 (0.6316) exhibit elevated values, with SL14 exceeding the threshold of 1.0. This indicates multi-element contamination and points to critical pollution levels that could surpass permissible soil quality limits. The presence of multiple metals in harmful concentrations calls for immediate attention, especially as prolonged exposure in such environments can lead to toxic accumulation in plants, animals, and humans.

Table 3: Concentrations and Pollution Indices (D_{cont} , $P_{i\epsilon}$, $P_{t\epsilon}$) of Cd, Cr, and Pb in Soil Samples from Maiduguri

Sample ID	A_i			$D_{cont.}$	P_l			$P_{i\epsilon}$			$P_{t\epsilon}$	I_{geo}			I_{IN}
	Cd	Cr	Pb		Cd	Cr	Pb	Cd	Cr	Pb		Cd	Cr	Pb	
SL01	0.0533	0.1923	0.0434	0.2890	0.1341	0.480	34.620	4.335	39.435	-1.449	-0.892	-1.539	-1.421		
SL02	0.0467	0.0200	0.3050	0.3716	0.1313	0.420	3.592	30.500	34.512	-1.507	-1.876	-0.692	1.638		
SL03	0.0400	0.0271	0.0310	0.0981	0.0435	0.360	4.870	3.100	8.330	-1.574	-1.744	-1.685	1.706		
SL04	0.0567	0.2212	0.0642	0.3420	0.1693	0.510	39.82	6.415	46.745	-1.423	-0.831	-1.369	1.320		
SL05	0.1433	0.2799	0.0459	0.4691	0.1820	1.290	50.38	4.590	56.260	-1.020	-0.729	-1.514	1.318		
SL06	0.0267	0.0178	0.0169	0.0614	0.0264	0.240	3.202	1.690	5.132	-1.750	-1.926	-1.948	1.912		
SL07	0.1900	0.0300	0.7865	1.0065	0.2873	1.710	5.394	78.650	85.754	-0.897	-1.699	-0.280	1.379		
SL08	0.0833	0.0215	0.3615	0.4664	0.1537	0.750	3.876	36.150	40.776	-1.255	-1.843	-0.618	1.570		
SL09	0.1400	0.0349	0.2240	0.3988	0.1460	1.260	6.278	22.395	29.933	-1.030	-1.634	-0.826	1.418		
SL10	0.1333	0.0153	0.3758	0.5245	0.1446	1.200	2.760	37.580	41.540	-1.051	-1.990	-0.601	1.648		
SL11	0.1267	0.0719	0.1072	0.3057	0.1331	1.140	12.938	10.72	24.798	-1.073	-1.319	-1.146	1.251		
SL12	0.1467	0.0129	0.2148	0.3744	0.1013	1.320	2.326	21.48	25.126	-1.010	-2.065	-0.844	1.728		
SL13	0.1833	0.0573	0.2137	0.4543	0.1772	1.650	10.31	21.37	33.330	-0.913	-1.418	-0.846	1.251		
SL14	0.7567	0.0554	0.7030	1.5150	0.3892	6.810	9.966	70.30	87.076	-0.297	-1.433	-0.329	1.124		
SL15	0.0433	0.0417	0.0270	0.1120	0.0501	0.390	7.502	2.700	10.592	-1.539	-1.556	-1.745	1.680		
SL16	0.0833	0.0493	0.0972	0.2297	0.1032	0.750	8.866	9.715	19.331	-1.255	-1.484	-1.189	1.399		
SL17	0.0500	0.0192	0.0304	0.0996	0.0387	0.450	3.462	3.035	6.947	-1.477	-1.892	-1.694	1.793		
SL18	0.0633	0.1621	0.0395	0.2649	0.1192	0.570	29.18	3.945	33.695	-1.374	-0.966	-1.580	1.450		
SL19	0.0600	0.0105	0.0420	0.1124	0.0367	0.540	1.888	4.195	6.623	-1.398	-2.155	-1.553	1.942		
SL20	0.0567	0.1696	0.0545	0.2807	0.1374	0.510	30.52	5.445	36.475	-1.423	-0.947	-1.440	1.358		
SL21	0.0600	0.1712	0.1156	0.3468	0.1901	0.540	30.82	11.56	42.920	-1.398	-0.943	-1.113	1.281		
SL22	0.0700	0.0644	0.0948	0.2292	0.1118	0.630	11.59	9.475	21.699	-1.331	-1.367	-1.200	1.334		
SL23	0.0733	0.0262	0.0496	0.1491	0.0578	0.660	4.710	4.955	10.325	-1.311	-1.758	-1.481	1.642		
SL24	0.0533	0.0173	0.0887	0.1593	0.0625	0.480	3.108	8.870	12.458	-1.449	-1.939	-1.228	1.750		
SL25	0.1233	0.0530	0.1572	0.3335	0.1405	1.110	9.536	15.72	26.361	-1.085	-1.452	-0.980	1.320		
SL26	0.1067	0.0754	0.0714	0.2535	0.1109	0.960	13.58	7.135	21.673	-1.148	-1.299	-1.323	1.290		
SL27	0.0400	0.2318	0.0280	0.2998	0.1248	0.360	41.72	2.800	44.880	-1.574	-0.811	-1.729	1.560		
SL28	0.0600	0.2274	0.1065	0.3939	0.2121	0.540	40.94	10.65	52.130	-1.398	-0.819	-1.149	1.268		
SL29	0.0800	0.0397	0.0679	0.1876	0.0797	0.720	7.148	6.785	14.653	-1.273	-1.577	-1.345	1.490		
SL30	0.3567	0.0397	0.3066	0.7029	0.2045	3.210	7.142	30.66	41.007	-0.624	-1.578	-0.690	1.308		
SL31	0.1067	0.2129	0.3121	0.6316	0.3475	0.960	38.32	31.21	70.485	-1.148	-0.848	-0.682	1.028		
Average										-1.240	-1.445	-1.173			
Maximum										-0.297	-0.729	-0.280			

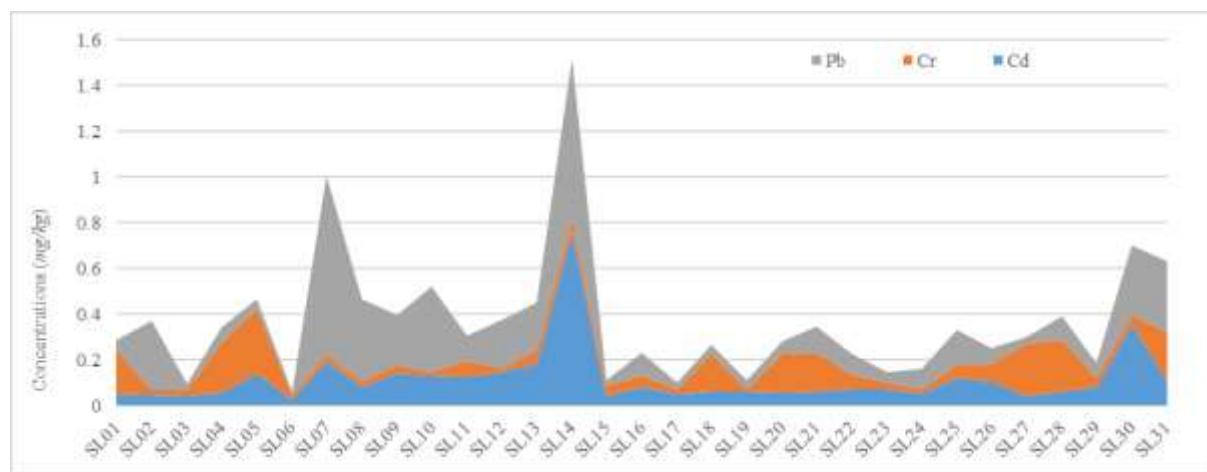
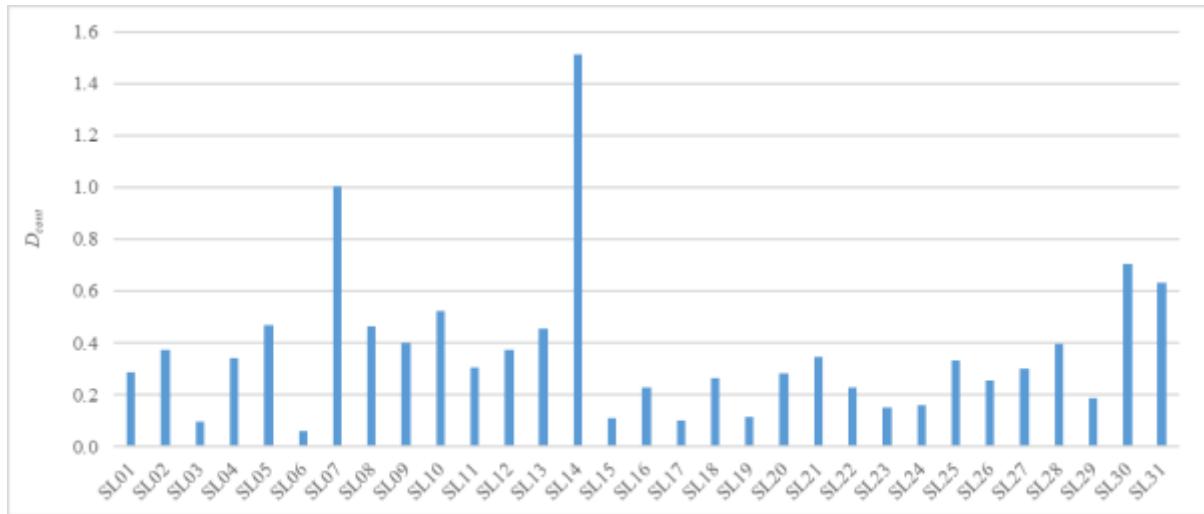
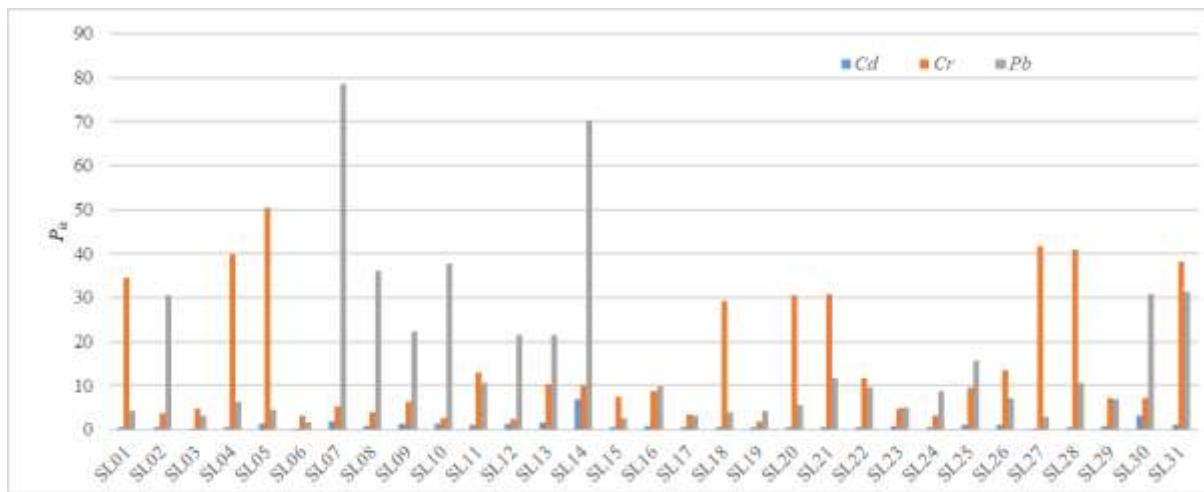
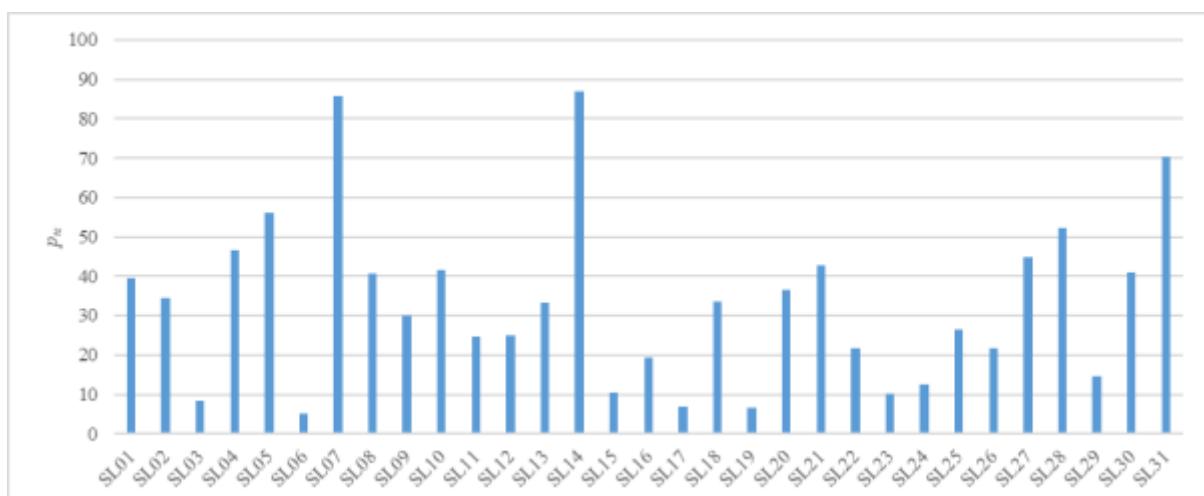


Figure 2: Concentrations of Cd, Cr, and Pb in Soil Samples from Maiduguri

**Figure 3:** Contamination Degree (D_{cont}) in Soil Samples from Maiduguri**Figure 4:** Individual Enrichment (P_{ie}) Levels of Cd, Cr, and Pb in Selected Soil Samples from Maiduguri**Figure 5:** Total Enrichment Potential (P_{te}) Across Soil Sampling Sites in Maiduguri

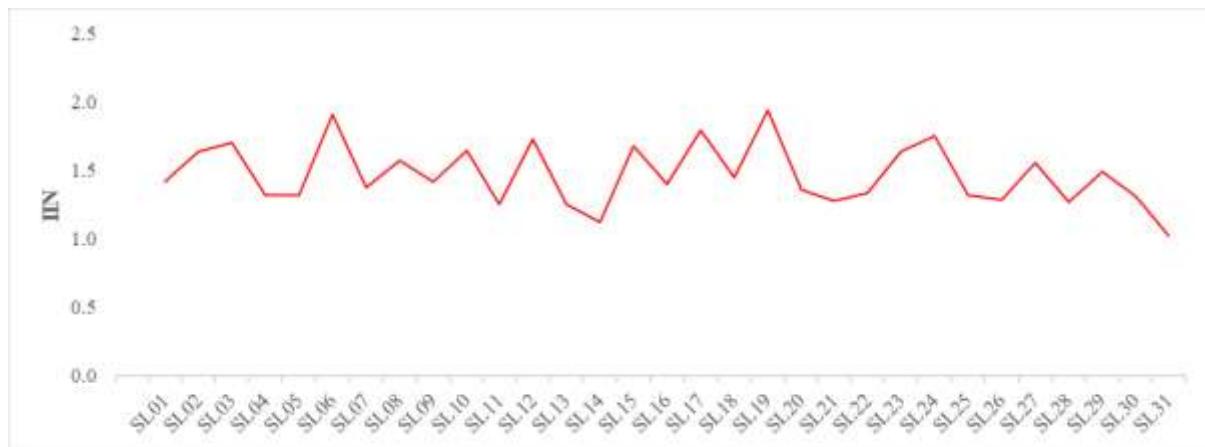


Figure 6: Improved Nemerow Index (I_{IN}) Values for Soil Samples Across the Study Area

Figure 2 is showing the measured concentrations of Cd , Cr , and Pb across all 31 sampling locations (e.g., SL01 to SL31). This figure illustrates the spatial variability in metal concentrations across the study area. Notable spikes in Cd at SL17, Cr at SL08 and SL31, and Pb at SL10 suggest localized hotspots likely influenced by anthropogenic activities such as industrial discharge, vehicular emissions, and scrap metal handling.

Figure 3 showed a bar graph of D_{cont} values across all 31 samples, highlighting values >1.0 . This figure presents an integrated view of cumulative contamination. SL14 (1.5150) and SL07 (1.0065) exceed the contamination threshold of 1.0, suggesting multi-elemental stress in these areas. The elevated D_{cont} values underscore the urgency for environmental intervention and long-term monitoring.

Figure 4 showed a bar chart illustrates the P_{te} values of Cd , Cr , and Pb across key sample locations. Notably high enrichment is observed in SL07, SL08, SL02, and SL31 for Pb , with values reaching up to 78.65. Similarly, Cr shows significant concentration in SL04, SL05, and SL28, suggesting localized anthropogenic influence likely related to industrial activities or scrap metal pollution. Cd , though generally lower in concentration, shows notable enrichment in SL14, SL30, SL07, and SL13—indicating ecological risk given its toxicity even at moderate levels. The chart underscores the spatial variability and potential health risk of heavy metal contamination in flood-affected soils.

Figure 5 presents the Total Enrichment Potential (P_{te}) values across the 31 soil sampling sites, highlighting locations with elevated cumulative contamination from

cadmium, chromium, and lead. Samples SL07, SL28, SL30, SL14, and SL31 exhibit the highest $P_{te} >$ values, indicating significant anthropogenic influence likely from scrap metal activities, improper waste disposal, and flood-borne pollutants. The spatial variation reveals localized hotspots of concern and underscores the necessity for site-specific environmental remediation and monitoring interventions. The P_{te} index offers an integrative assessment tool for prioritizing contaminated areas in environmental risk management.

Figure 6 illustrates the spatial variation of the Improved Nemerow Index (I_{IN}) across the 31 sampling locations. Overall, the distribution shows that all sites fall within the low-pollution range ($I_{IN} > 1.0$), with values clustering between 1.2 and 1.7. A few locations—particularly SL06, SL12, SL17, SL19, and SL24—display comparatively higher I_{IN} values, forming distinct peaks in the visual pattern. These elevated points indicate localized areas where cumulative heavy-metal input is relatively more pronounced. In contrast, the lower end of the distribution is represented by SL31, which exhibits the smallest I_{IN} value and appears as a clear trough in the figure. The generally narrow spread of values suggests a relatively uniform pollution profile across the study area, with only minor fluctuations. Visually, the figure supports the interpretation that while the region is broadly characterized by low-level contamination, certain hotspots may require closer monitoring or targeted mitigation.

Given the observed data, targeted remediation is crucial. Specific samples like SL07, SL14, SL30, and SL31, which display elevated

contamination across multiple metals, must be prioritized for cleanup efforts. This could involve soil washing, phytoremediation, or containment strategies depending on the severity and land use. Periodic monitoring should also be implemented to assess whether contaminant levels are increasing over time, thereby enabling early intervention. Lastly, a multi-faceted environmental management approach is essential. Isotopic and chemical speciation studies could help trace pollution sources, particularly for *Pb* and *Cr*. Comprehensive risk assessments that integrate ecological and human health models would guide mitigation strategies effectively. Additionally, local policies should emphasize stricter control over industrial emissions, promote the safe recycling of e-waste, and enhance awareness of heavy metal risks among residents and land users.

3. Discussion

In 31 soil samples, the concentrations and geographical distribution of cadmium (Cd), chromium (Cr), and lead (Pb) were evaluated. Significant regional variability and localized contamination hotspots were found, even though the average amounts of all metals were below international guideline values. Because mean values alone may conceal possible threats to the environment and public health, these findings highlight the significance of site-specific study and monitoring. With a mean of 0.033 mg/kg, cadmium concentrations varied from 0.008 mg/kg (SL09) to 0.227 mg/kg (SL17). Anthropogenic sources such phosphate fertilizers, industrial effluents, or inappropriate waste disposal are probably responsible for elevated Cd. Even these moderate levels present ecological and health problems because to the high mobility and toxicity of Cd, which can accumulate in plants and potentially enter the food chain. This interpretation is supported by the geoaccumulation index (I_{geo}) and enrichment factor (I_{IN}), where SL14, SL30, SL07, and SL13 exhibit significant enrichment, indicating discernible human involvement.

With a mean of 7.86 mg/kg, chromium concentrations ranged from 0.944 mg/kg (SL20) to 25.19 mg/kg (SL08). While USEPA permits up to 120 mg/kg, the WHO/FAO soil recommendation for Cr is 60 mg/kg. Hotspots like SL08, SL31, SL04, SL05, SL27, and SL28 show noticeably higher local concentrations compared to background levels,

indicating anthropogenic input, most likely from industrial effluents, metal processing, tanneries, or chromate-containing pesticides, even though all measured values are below these thresholds. At these locations, localized enrichment and mild pollution are confirmed by the I_{geo} and I_{IN} indices.

Pb values had a mean of 3.32 mg/kg and varied from 0.338 mg/kg (SL09) to 15.73 mg/kg (SL10). The USEPA suggests 400 mg/kg of lead in soils, but the WHO/FAO recommendation is 100 mg/kg. Enrichment study shows localized anthropogenic influence, especially at SL02, SL07, SL08, SL10, and SL31, even though mean concentrations are substantially below allowable levels. These hotspots could be caused by industrial processes, lead-based paints, automobile emissions, or past mining. The majority of soils were categorized as unpolluted to moderately polluted by the geoaccumulation index (I_{geo}). Notably, localized anthropogenic enrichment is indicated by Cd I_{geo} in SL14 and Pb I_{geo} in SL07. Although sites SL06 and SL19 exhibit comparatively higher cumulative contamination, the Improved Nemerow Index (I_{IN}) values varied from 1.028 to 1.942, suggesting that the research area is mainly in the low-pollution category. Multi-element contamination is most noticeable in SL14 (1.5150), SL07 (1.0065), SL30 (0.7029), and SL31 (0.6316), according to the contamination degree ($D_{cont.}$). Even when average concentrations are below international standards, these results emphasize the necessity of focused cleanup and monitoring. Localized hotspots of Cd, Cr, and Pb contamination present possible threats to human health and the environment even though the average soil quality is within WHO/FAO and USEPA guidelines. Bioaccumulation, organ toxicity, and developmental consequences may result from prolonged exposure through soil, crops, or dust. For hotspots like SL07, SL14, SL30, and SL31, targeted intervention techniques such soil washing, phytoremediation, or containment are advised. Lastly, to lessen continuing anthropogenic contributions, public awareness campaigns, stronger industrial emission regulations, and safe waste management techniques are crucial.

CONCLUSION AND RECOMMENDATION

The concentrations, spatial distribution, and pollution indicators of lead (Pb), chromium (Cr), and cadmium (Cd) in soils from Maiduguri, were evaluated in this study. Localized hotspots—such as SL17 for Cd, SL08 and SL31 for Cr, and SL07, SL10, and SL31 for Pb—indicate anthropogenic inputs from industrial activities, vehicle emissions, scrap metal handling, and agricultural practices, even though the average concentrations of Cd (0.033 mg/kg), Cr (7.86 mg/kg), and Pb (3.32 mg/kg) were below WHO/FAO and USEPA guidelines. Areas with moderate multi-metal contamination were found using pollution indices such as the geoaccumulation index, enrichment factor, contamination degree, and Improved Nemerow Index, which highlighted possible threats to the environment and public health. In addition to long-term environmental monitoring, more stringent industrial emission regulations, safe waste management techniques, and community awareness initiatives, specific remediation techniques are advised for hotspots that have been identified. Although Maiduguri's soil quality is generally under international safety limits, aggressive site-specific management and intervention are necessary to stop additional heavy-metal deposition and safeguard ecological and human health.

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REFERENCES

Achmad, R. T., Budiawan, & Auerkari, E. I. (2017). Effects of chromium on human body. *Annual Research & Review in Biology*, 13(2), 1–8. <https://doi.org/10.9734/ARRB/2017/33789>

Addis, A., & Abebaw, A. (2017). A review on environmental effects of heavy metals. *International Journal of Chemical Studies*, 5(6), 555–560.

Akpan, I. U., & William, M. E. (2014). Determination of heavy metals in soil and groundwater of scrap dumpsites in Akwa Ibom State, Nigeria. *Advances in Applied Science Research*, 5(6), 219–224.

Al-Khashman, O. A., & Shawabkeh, R. A. (2006). Metal distribution in street dust and roadside soil from selected highways of the Jordanian capital, Amman. *Environmental Geochemistry and Health*, 28(1–2), 13–22. <https://doi.org/10.1007/s10653-005-9027-4>

Amshi, M. A., Adamu, A. M., & Nggada, H. N. (2019). Assessment of heavy metals (Cd, Pb, Cr) and their health risks in vegetables irrigated with treated wastewater in Maiduguri. *Borno Journal of Geographical Research*, 6(1), 58–66.

Audu, Y., Aliyu, A. D., & Dadi-Mamud, N. J. (2022). Evaluation of heavy metals contamination in the sediments of some selected water bodies of South Senatorial District of Niger State, Nigeria. *Science World Journal*, 17(4).

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 large and small urban areas in the UK. *Environment International*, 29(5), 563–573. [https://doi.org/10.1016/S0160-4120\(03\)00015-1](https://doi.org/10.1016/S0160-4120(03)00015-1)

Dey, M., Akter, A., Islam, S., Dey, S. C., Choudhury, T. R., Fatema, K. J., & Begum, B. A. (2021). Assessment of contamination level, pollution risk and source apportionment of heavy metals in the Halda River water, Bangladesh. *Heliyon*, 7(8), e08625.

<https://doi.org/10.1016/j.heliyon.2021.e08625>

Echeweozo, E. O., Nworie, C. I., Ojobeagu, A. O., Otah, P. B., & Okoro, I. J. (2025). Health risk assessment due to environmental radioactivity and heavy metal contamination at the central solid waste dumpsite in Ebonyi State, Nigeria. *Journal of the Nigerian Society of Physical Sciences*, 7, 2160. <https://doi.org/10.46481/jnsp.2025.2160>

Fergusson, J. E., & Kim, N. D. (1991). Trace elements in street and house dusts: Sources and speciation. *Science of the Total Environment*, 100, 125–150. [https://doi.org/10.1016/0048-9697\(91\)90376-S](https://doi.org/10.1016/0048-9697(91)90376-S)

Feyisa, G., Mekassa, B., & Merga, L. B. (2025). Human health risks of heavy metals contamination of a water-soil-vegetables farmland system in Toke Kutaye of West Shewa, Ethiopia. *Toxicology Reports*, 14, 102061. <https://doi.org/10.1016/j.toxrep.2025.102061>

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. <https://doi.org/10.3390/ijerph110707286>

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. *Water Research*, 14(8), 975–1001.

Harrison, R. M., Laxen, D. P. H., & Wilson, S. J. (1981). Chemical associations of lead, cadmium, copper, and zinc in street dusts and roadside soils. *Environmental Science & Technology*, 15(11), 1378–1383. <https://doi.org/10.1021/es00093a006>

He, Z. L., Yang, X. E., & Stoffella, P. J. (2015). Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements in Medicine and Biology*, 19(2–3), 125–140. <https://doi.org/10.1016/j.jtemb.2005.02.010>

Hu, H., Téllez-Rojo, M. M., Bellinger, D., Smith, D., Ettinger, A. S., Lamadrid-Figueroa, H., ... & Hernandez-Avila, M. (2017). Fetal lead exposure: Mechanisms and evidence for health impacts. *Reviews on Environmental Health*, 23(2), 97–112. <https://doi.org/10.1515/REVEH.2008.23.2.97>

Kabir, A., Akinyemi, S. A., & Adedibu, A. A. (2017). Evaluation of soil heavy metal pollution from municipal waste dumpsites in Ilorin, Nigeria. *Environmental Research Journal*, 11(2), 75–84.

Kabir, E., Ray, S., Kim, K. H., Yoon, H. O., Jeon, E. C., Kim, Y. S., Cho, Y. S., & Yun, S. T. (2012). Current status of trace metal pollution in soils affected by industrial activities. *Scientific World Journal*, 2012, Article ID 916705. <https://doi.org/10.1100/2012/916705>

Lee, C. S. L., Li, X. D., Zhang, G., Li, J., Ding, A. J., & Wang, T. (2005). Heavy metals and Pb isotopic composition of urban soils in Hong Kong. *Science of the Total Environment*, 356(1–3), 20–33. <https://doi.org/10.1016/j.scitotenv.2005.03.024>

Ma, L., Wang, J., & Zhu, L. (2022). Geochemical baseline of heavy metals in topsoil on local scale and its application. *Polish Journal of Environmental Studies*, 31(6), 5805–5813. <https://doi.org/10.15244/pjoes/152449>

Maleki, A., Zaravand, M. A., & Javan, N. (2014). Pollution indices and health risk assessment of heavy metals in urban soil of Isfahan, Iran. *Iranian Journal of Health, Safety & Environment*, 1(1), 63–70.

Mohammed, A. I., Ahmed, A. A., & Jibrin, J. U. (2021). Index models assessment of heavy metal contamination in soil samples of selected motor parks within Maiduguri, Borno State, Nigeria. *Chemistry & Material Sciences Research Journal*, 3(1), 6–14. <https://doi.org/10.51594/cmsrj.v3i1.203>

Mortvedt, J. J. (1996). Heavy metal contaminants in inorganic and organic fertilizers. *Fertilizer Research*, 43(1–3), 55–61. <https://doi.org/10.1007/BF00747683>

Müller, G. (1981). The heavy metal pollution of the sediments of Neckars and its tributary: A stocktaking. *Chemie der Erde*, 40, 29–39.

Okoro, H. K., Ige, J. O., & Ngila, C. J. (2018). Characterization and evaluation of heavy metals pollution in river sediments from South Western Nigeria. *Journal of the Kenya Chemical Society*, 11(1), 18–27.

Osmani, M., Popoola, O. E., & Aina, B. A. (2015). Influence of flooding on soil contamination by heavy metals in selected parts of Lagos, Nigeria. *African Journal of Environmental Science and Technology*, 9(5), 460–467.
<https://doi.org/10.5897/AJEST2015.1883>

Proshad, R., Kormoker, T., Islam, S., Zhang, D., & Tusher, T. R. (2019). Heavy metal toxicity in agricultural soil due to e-waste dumping: A review. *Environmental Chemistry and Ecotoxicology*, 1, 22–35.
<https://doi.org/10.1016/j.enceco.2019.10.001>

Ripin, S. M., Radzi, M. S. M., & Talib, S. A. (2014). Human health risk assessment of heavy metals in soil of former tin mining catchment. *EnvironmentAsia*, 7(1), 130–137.

Štrbac, S., Kašanin Grubin, M., & Vasić, N. (2017). Importance of background values in assessing the impact of heavy metals in river ecosystems: Case study of Tisza. *Environmental Geochemistry and Health*.
<https://doi.org/10.1007/s10653-017-0053-0>

Tomlinson, D. L., Wilson, J. G., Harris, C. R., & Jeffrey, D. W. (1980). Problems in the assessment of heavy metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen*, 33(1), 566–575.

Ukpong, E. C., Antai, E. E., & Umoren, I. U. (2013). Assessment of heavy metals in surrounding soil of an automobile junk market in Uyo, Nigeria. *Environmental and Natural Resources Research*, 3(2), 128–134.
<https://doi.org/10.5539/enrr.v3n2p128>

United States Environmental Protection Agency (USEPA). (2011). Regional screening levels (RSLs) user's guide.

United States Environmental Protection Agency (USEPA). (2012). Integrated risk information system (IRIS). <https://www.epa.gov/iris>

UNSCEAR. (2000). Sources and effects of ionizing radiation: United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly with Scientific Annexes. United Nations.

World Health Organization (WHO). (2011). Guidelines for drinking-water quality (4th ed.). Geneva: WHO Press.

Wu, B., Zhao, D. Y., Jia, H. Y., Zhang, Y., & Zhang, X. X. (2016). Levels and health risk assessments of heavy metals in urban soils in a typical city in China. *International Journal of Environmental Research and Public Health*, 13(9), 881.