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Assessment of Heavy Metals in Roadside Soils in Jos North Local Government Area, Nigeria

[1]Gurumyen, K.K., [2]Idongesit, N.A., [1]Alagbe, T.L. and [1]Miduk, R.R.
[1]Department of Science Laboratory Technology, Faculty of Natural Sciences,
University of Jos, Nigeria.
[2]Department of Chemistry, Federal University of Health Sciences, Otukpo, Benue State, Nigeria.
Corresponding Author: gurumyenk@unijos.edu.ng

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ABSTRACT

Heavy metal contamination of urban surface soils has become a major environmental concern due to increasing vehicular activities. This study evaluated the concentrations of heavy metals in roadside soils collected from eight major road junctions in Jos North Local Government Area, Plateau State, Nigeria. Soil samples were collected during the dry season to minimize leaching effects and analyzed for Pb, Ni, Cu, As, Cd, Cr, and Hg using Atomic Absorption Spectroscopy (AAS). The concentrations of heavy metals in roadside soils (mg/kg) were Pb (0.58-3.43), Ni (1.37-8.54), Cu (4.74-58.70), As (5.98-24.75), Cd (1.69-5.66), Cr (1.82-9.31), and Hg (0.75-2.61). All roadside soil samples contained higher metal concentrations than control samples collected 200 m away from the roads, indicating anthropogenic influence. Lead concentrations were well below the NESREA permissible limit of 164 mg/kg at all sites. Similarly, Ni, Cu, and Hg levels were below NESREA guideline limits. However, arsenic exceeded permissible limits at ARJ (29.66 mg/kg) and FGM (24.75 mg/kg), while cadmium exceeded limits at ARJ (5.66 mg/kg), TIJ (4.46 mg/kg), FAJ (4.41 mg/kg), FGM (3.21 mg/kg), and BRR (5.49 mg/kg). Pollution indices revealed varying contamination levels across sites, raising concerns for road users and nearby businesses.

Keywords: Heavy metals contamination, roadside soil, enrichment factor, contamination factor, pollution load index, geo-accumulation index.

INTRODUCTION

Roads serve as vital links among communities, facilitating the movement of food, goods, and people, and play a significant role in enhancing social and economic activities. However, road construction and increased vehicular traffic have contributed substantially to environmental pollution, particularly through the contamination of roadside soils [1]. Roadside soils are often contaminated by various anthropogenic activities, including vehicle exhaust emissions, industrial and energy production processes, waste disposal, and fuel and coal combustion [2]. Automobiles act as linear sources of heavy metal pollutants, leading to continuous deposition of metals along road corridors [3]. Excessive accumulation of heavy metals in soils poses serious environmental and health concerns, as these metals can be transported to vegetation and subsequently enter the food chain, affecting animals and humans [4].

Several studies have reported roadside soil contamination in Nigerian cities such as Jos and Osogbo, where elevated metal concentrations were attributed primarily to traffic emissions [5,6]. Metals frequently reported in contaminated roadside soils include cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As), mercury (Hg), and copper (Cu), all of which are associated with vehicular emissions, tyre and brake wear, and fuel additives [7,8]. Heavy metals are of concern due to their persistence, non-biodegradability, and tendency to bioaccumulate, leading to toxicity even at relatively low concentrations [9,10]. While some metals such as Fe, Cu, Zn, Mn, and Ni are essential micronutrients at trace levels, others including Pb, Cd, and Cr are non-essential and toxic to humans [11].

Soil plays a critical role in environmental sustainability, and its contamination can disrupt ecosystems, reduce agricultural productivity, and pose long-term health risks [12]. In developing countries like Nigeria, rapid urbanization, increased vehicular density, poor waste management, and limited environmental monitoring exacerbate heavy metal pollution in roadside environments [13]. Heavy metals deposited on soils can also become airborne as dust, increasing the risk of inhalation exposure among road users and nearby residents [14]. Given these concerns, continuous assessment of roadside soil contamination is essential.

Therefore, this study seeks to evaluate the concentrations of selected heavy metals in roadside soils along major roads in Jos North Local Government Area, Plateau State, Nigeria, with the aim of assessing contamination levels and potential environmental and health implications.

MATERIALS AND METHODS

Sampling sites

Jos city is located in the middle belt of Nigeria. The city, with a population of over 900,000 according to 2006 population census data, is the capital of Plateau state. The study area is located between Lat. 9° 51''N to 10° 3'N and Long. 8° 48'E and 8° 67'E. The Plateau surface occupies an area of some 8600 km^2 [15] lying at about 1 ,200 m and rises above 1400 m to the south of Barkin Ladi and the east of Jos [16], and is bounded by 300-600 m escarpments around much of its circumference. Jos city, being a capital city, is a host to many industrial sites, hence experience heaviest road traffic. The city of Jos was divided into five sampling areas (Table 1) based on traffic intensity: three areas with heavy vehicular traffic and the other two areas having less traffic.

Table 1: Description of the roadsides studied

LOCATION	SITE	LATITUDE	LONGITUDE
Bauchi Ring Road	BRR	9.957775 (N 9°57'27.99")	8.891908 (E 8°53'30.86988")
Permanent site gate	PSG	9.958500 (N 9°57'30.6")	8.882235 (E 8°52'56.03988")
Katako junction	KPJ	9.958612 (N9°57'31.00212)	8.881015 (E 8°52'51.654)
Faringada market	FAM	9.958433(N9°57'30.35988)	8.866128 (E 8°5158.06188")
Tina Junction	TIJ	9.920630 (N9.55'14.268")	8.913335 (E 8°54'48.00744")
Faringada Anguwa Jarawa	FAJ	9.957890 (N9°57'28.404")	8.859962 (E 8°51'35.86212")
Anguwa Rukuba Junction	ARJ	9.933175 (N9°55'59.43")	8.910180 (E °854'36.648")
Terminus Yantaya Junction	TYJ	9.902150 (N 9°54'74")	8.907967 (E854'28.68012")

Sampling

Sampling locations (Tina Junction, Faringada Angwan Jarawa, Angwa Rukuba Junction, Terminus Yantaya Junction, Bauchi Ring Road, Permanent site gate, Katako Junction and Faringada Market) in Jos North LGA of Plateau State were chosen for soil samples collection. These were selected on the basis of traffic load, population density and human activities occurring within the areas. Control samples were collected 200 m away from each sampling points. Samples were collected at 1 m, using polyethene bag and broom and between each sampling, broom were cleaned thoroughly. Sites with obvious pollution sources such as industries, gasoline stations and parking lots or recently soiled or oil-stained sample were not collected. Samples collected were sealed in plastic bags and carried to the laboratory.

Sample preparation

Roadside soil samples were collected from selected locations and properly labelled. The samples were air-dried at room temperature, ground using an acid-prewashed mortar and pestle, and sieved with a plastic sieve to obtain a homogeneous particle size suitable for analysis [17].

Acid digestion of soil samples

The homogenized soil sample (1 g) was weighed into a 100 mL beaker. A mixed acid digestion was carried out by adding 10 mL of 37% hydrochloric acid (HCl) and 5 mL of 65% nitric acid (HNO_3). The mixture was heated on a hot plate at approximately 95 °C for 2 hours to ensure complete digestion of the soil matrix [18]. After digestion, 25 mL of 5% HCl was added and heating was continued for an additional 10 min. The solution was allowed to cool to room temperature, filtered, and quantitatively transferred into a 100 mL volumetric flask. The volume was made up to the mark with deionized water and stored in clean sample bottles prior to analysis.

Heavy metal analysis

The digested samples were analyzed for Pb, Ni, Cu, As, Cd, Cr and Hg using AAS (AA320N, Graphite Furnace). The instrument readings were obtained in mg/L. Metal concentrations in soil samples were calculated and expressed in mg/kg using Equation (1) [19]:

$$C = \frac{(Rs \times D) - Bl) \times V \times Fh}{Ms} \quad (1)$$

where (C) is the metal concentration in mg/kg, (Rs) is the spectrometer reading (mg/L), (D) is the dilution factor, (Bl) is the method blank concentration (0.00), (V) is the final volume after digestion (100 mL), (Fh) is the moisture correction factor, and (Ms) is the mass of soil digested (1 g).

The AAS analysis for each metal was conducted in triplicate, and the mean values and standard deviations were calculated and recorded.

Enrichment factor (EF)

The enrichment factor was employed to evaluate the extent of anthropogenic contribution to heavy metal concentrations in roadside soils [20]. EF was calculated using iron (Fe) as the reference element, following Equation (2):

$$EF = \frac{Cn/Cref}{Bn/Bref} \quad (2)$$

where (Cn) is the concentration of the metal in the roadside soil, (C_{ref}) is the concentration of Fe in the sample, (Bn) is the background concentration of the metal, and (B_{ref}) is the background concentration of Fe [21].

EF values were classified as no enrichment (EF < 1), minimal enrichment (1 ≤ EF < 5), significant enrichment (5 ≤ EF < 20), very high enrichment (20 ≤ EF < 40), and extremely high enrichment (EF ≥ 40) [22].

Contamination Factor (CF)

The contamination factor was calculated to assess the level of contamination of individual heavy metals relative to background concentrations [23]. CF was computed using Equation (3):

$$CF = \frac{Cn}{Bn} \quad (3)$$

CF values were interpreted as low contamination (CF < 1), moderate contamination (1 ≤ CF < 3), considerable contamination (3 ≤ CF ≤ 6), and very high contamination (CF > 6) [23]. The mean contamination factor (mCF) was used to evaluate the overall degree of contamination at each sampling location [24].

Pollution Load Index (PLI)

The pollution load index was used to assess the overall level of heavy metal pollution at each sampling site [25]. PLI was calculated as the geometric mean of the contamination factors using Equation (4):

$$PLI = (CF_2 \times CF_2 \times CF_n)^{1/n} \quad (4)$$

where (n) is the number of metals analyzed. PLI values less than 1 indicate no pollution, PLI equal to 1 indicates baseline levels, and PLI greater than 1 indicates deterioration of site quality [25,26].

Geo-accumulation Index (Igeo)

The geo-accumulation index was applied to determine the degree of heavy metal accumulation in roadside soils relative to background values [27]. Igeo was calculated using Equation (5):

$$I_{geo} = \log\left(\frac{Cm}{1.5\ X\ Bm}\right) \quad (5)$$

where (Cn) is the metal concentration in roadside soil and (Bn) is the background concentration. The constant 1.5 accounts for possible lithogenic variations [27]. Igeo values were classified into seven categories ranging from uncontaminated to extremely contaminated [20].

RESULTS AND DISCUSSION

The results of heavy metal concentrations (As, Cd, Cr, Cu, Pb, Hg, and Ni) in soil from the study area is shown in Table 2. The concentrations of heavy metals in roadside soil dust across the sampling sites (TYJ, TIJ, AIJ, FAJ, PSG, KPJ, FGM, and BRR) revealed marked spatial variability, reflecting differences in traffic density and associated anthropogenic activities (Table 2). Copper (Cu) recorded the highest concentrations among the analyzed metals, ranging from 14.51 mg/kg at TYJ to 58.70 mg/kg at FAJ. These values exceeded the World Health Organization (WHO) guideline value for Cu in soils (≤40 mg/kg) [28], particularly at FAJ and FGM, indicating substantial input from vehicular sources such as brake linings, engine wear, and tyre abrasion. Similar elevated Cu concentrations in roadside soils have been reported in major Nigerian cities including Lagos, Ibadan, and Abuja, where traffic emissions were identified as dominant contributors [29,30].

Table 2: Concentration of Heavy metals in roadside soil dust for each sample site

Heavy Metals	TYJ (mg/kg)	TIJ (mg/kg)	ARJ (mg/kg)	FAJ (mg/kg)	PSG (mg/kg)	KPJ (mg/kg)	FGM (mg/kg)	BRR (mg/kg)
Pb	3.29±0.02	3.35±0.03	0.58±0.02	3.43±0.01	0.99±0.01	0.75±0.01	3.05±0.01	2.16±0.02
Ni	8.54±0.03	4.28±0.05	1.44±0.01	1.37±0.03	5.89±0.03	2.90±0.02	2.70±0.01	5.40±0.02
Cu	14.51±0.05	4.74±0.03	18.91±0.05	58.70±0.07	30.38±0.04	23.85±0.04	52.11±0.05	17.01±0.04
As	12.02±0.08	8.28±0.04	29.66±0.08	13.72±0.04	14.94±0.02	5.98±0.02	12.18±0.04	24.75±0.05
Cd	1.69±0.01	4.46±0.03	5.66±0.02	4.41±0.02	2.08±0.01	2.07±0.03	3.22±0.03	5.49±0.03
Cr	2.85±0.04	3.07±0.01	1.82±0.02	9.31±0.03	8.96±0.01	1.93±0.01	4.96±0.03	8.28±0.02
Hg	2.31±0.03	2.42±0.02	1.54±0.01	1.18±0.01	0.75±0.02	1.09±0.01	1.31±0.01	2.61±0.01

Arsenic concentrations ranged from 5.98 to 29.66 mg/kg, with values at AIJ and BRR exceeding the WHO guideline value for As in soils (≤20 mg/kg) [28]. Elevated Arsenic levels in roadside environments have been associated with fuel combustion residues, vehicular emissions, and historical contamination, as reported in studies from Jos, Kano, and other rapidly urbanizing cities [31,32]. Cadmium concentrations (1.69-5.66 mg/kg) exceeded the WHO permissible limit for agricultural soils (≤3 mg/kg) [28] at several sites, particularly AIJ, TIJ, FAJ, and BRR. This is of concern given the high toxicity, persistence, and bioaccumulative nature of Cd [33].

Lead concentrations ranged from 0.58 to 3.43 mg/kg and were generally below the WHO guideline value for Pb in soils (≤100 mg/kg) [28]. However, elevated Pb levels observed at TYJ, TIJ, FAJ, and FGM relative to background concentrations (Table 3) suggest persistent accumulation from non-exhaust vehicular sources such as tyre wear, lubricating oil leakage, and resuspension of historically contaminated dust. Similar trends of declining yet persistent Pb contamination following the global phase-out of leaded gasoline have been widely reported [34,35].

Table 3: Concentration of Heavy Metals in the Control Samples 200 m away from each Sampling Site

Heavy Metals	TYJ (mg/kg)	TIJ (mg/kg)	ARJ (mg/kg)	FAJ (mg/kg)	PSG (mg/kg)	KPJ (mg/kg)	FGM (mg/kg)	BRR (mg/kg)
Pb	0.36±0.01	0.37±0.01	0.38±0.02	2.06±0.01	0.74±0.01	0.59±0.01	0.78±0.02	0.36±0.01
Ni	3.02±0.03	3.16±0.02	0.48±0.01	0.49±0.03	2.91±0.02	1.76±0.02	1.22±0.03	1.08±0.01
Cu	1.78±0.01	1.86±0.02	10.08±0.03	34.89±0.05	9.38±0.02	9.38±0.03	8.18±0.03	6.12±0.02
As	2.58±0.01	2.70±0.03	26.30±0.04	4.02±0.03	5.98±0.01	2.44±0.01	6.96±0.02	13.59±0.04
Cd	1.25±0.02	1.30±0.01	4.61±0.02	3.63±0.02	2.08±0.01	1.76±0.01	9.57±0.04	4.86±0.01
Cr	1.87±0.02	1.95±0.01	1.44±0.01	0.39±0.01	0.75±0.01	0.74±0.01	0.35±0.01	2.61±0.01
Hg	1.16±0.01	1.21±0.03	1.06±0.01	0.39±0.01	0.33±0.01	0.33±0.01	0.35±0.01	2.02±0.01

Nickel and chromium showed moderate to high concentrations at selected locations, with Cr levels at FAJ (9.31 mg/kg), PSG (8.96 mg/kg), and BRR (8.28 mg/kg) exceeding the WHO guideline value for Cr in soils (≤5 mg/kg) [28]. Chromium enrichment in roadside soils has been attributed to brake wear, vehicular component corrosion, and road surface abrasion, consistent with observations from other high-traffic corridors [36,37]. Mercury (Hg) concentrations, though generally low, were higher in roadside samples than in control soils and approached the WHO guideline value for Hg in soils (≤2 mg/kg) [28] at BRR and TIJ, indicating localized anthropogenic influence.

Overall, comparison with control samples collected 200 m away from the roads (Table 3) confirms that traffic-related activities are the principal source of heavy metal accumulation in roadside soil dust. The proximity of several metal concentrations to, or their exceedance of, WHO guideline values [28] underscore potential environmental and public health risks associated with prolonged exposure in high-traffic areas of Jos.

Enrichment Factor Analysis

The enrichment factor results (Table 4) indicate varying degrees of anthropogenic influence across the study sites. Lead and Cu exhibited significant enrichment at TYJ, TIJ, FGM, and BRR (EF > 5), suggesting strong anthropogenic inputs largely associated with vehicular emissions and mechanical wear. Chromium showed extremely high enrichment at FAJ (EF = 25.95), PSG (EF = 12.30), and FGM (EF = 14.34), indicating intense anthropogenic contamination. Comparable Cr enrichment has been reported in other urban roadside environments and linked to traffic congestion and road infrastructure degradation [35,36]. Metals with EF values between 1 and 5 indicate minor to moderate enrichment, suggesting combined natural and anthropogenic contributions.

Table 4: Enrichment Factor of Heavy Metals in Sampling Sites

Metal	TYJ	TIJ	AIJ	FAJ	PSG	KPJ	FGM	BRR
Pb	8.90	7.16	1.59	1.81	1.38	1.25	3.96	6.09
Ni	2.75	1.07	3.13	3.04	2.08	1.62	2.24	5.08
Cu	7.94	2.01	1.96	1.83	3.33	2.50	6.45	2.82
As	4.54	2.42	1.18	3.71	2.57	2.41	1.77	1.85
Cd	1.32	2.71	1.28	1.32	1.03	1.16	0.34	1.15
Cr	1.48	1.24	1.32	25.95	12.30	2.57	14.34	3.22
Hg	1.94	1.58	1.52	3.29	2.34	3.25	3.79	1.31

Contamination Factor

The contamination factor values (Table 5) corroborate the EF results. Lead and Cu showed considerable to high contamination levels at TYJ, TIJ, FGM, and BRR (CF > 3), while Cr exhibited very high contamination at FAJ and PSG (CF > 10), identifying chromium as a major contaminant of concern. Cadmium generally showed low to moderate contamination across most sites, except at TIJ where moderate contamination was observed. Similar CF patterns have been reported in roadside soil studies across Nigeria and other developing urban regions, emphasizing vehicular activity as a dominant pollution source [30,31].

Table 5: Contamination factors for heavy metals along roadside soil dust for each sample site

Metal	TYJ	TIJ	AIJ	FAJ	PSG	KPJ	FGM	BRR
Pb	9.14	9.05	1.53	1.67	1.34	1.27	3.91	6.00
Ni	2.83	1.35	3.00	2.80	2.02	1.65	2.21	5.00
Cu	8.15	2.55	1.88	1.68	3.24	2.54	6.37	2.78
As	4.66	3.07	1.13	3.41	2.50	2.45	1.75	1.82
Cd	1.35	3.43	1.23	1.21	1.00	1.18	0.34	1.13
Cr	1.52	1.57	1.26	23.87	11.95	2.61	14.17	3.17
Hg	1.99	2.00	1.45	3.03	2.27	3.30	3.74	1.29

Geoaccumulation Index

The geoaccumulation index values (Table 6) indicate that most metals fall within the unpolluted to moderately polluted category (Igeo ≤ 1). Lead, Cu, As, and Ni generally recorded low positive Igeo values, suggesting slight enrichment above natural background levels. However, Cr showed moderate pollution levels at FAJ (Igeo = 1.20), PSG (0.90), and FGM (0.98), further highlighting chromium as a key pollutant in high-traffic zones. Negative Igeo values observed for Cd at most sites indicate minimal accumulation relative to control concentrations.

Table 6: Geoaccumulation Index (Igeo) of heavy metals in Jos high traffic areas

Metal	TYJ	TIJ	AIJ	FAJ	PSG	KPJ	FGM	BRR
Pb	0.78	0.78	0.01	0.05	-0.05	-0.07	0.42	0.60
Ni	0.28	-0.04	0.30	0.27	0.13	0.04	0.17	0.52
Cu	0.74	0.23	0.10	0.05	0.33	0.23	0.63	0.27
As	0.49	0.31	-0.12	0.36	0.22	0.21	0.07	0.08
Cd	-0.05	0.36	-0.09	-0.09	-0.18	-0.11	-0.65	-0.12
Cr	0.01	0.02	-0.07	1.20	0.90	0.24	0.98	0.33
Hg	0.12	0.12	-0.01	0.30	0.18	0.34	0.40	-0.06

Pollution Load Index

The Pollution Load Index values for all sampling sites were greater than unity (PLI > 1), indicating overall pollution at every investigated location (Table 7). FAJ (1.57), FGM (1.55), and TYJ (1.53) recorded the highest PLI values, reflecting cumulative heavy metal pollution driven by intense vehicular activity. These results are consistent with previous studies that reported PLI values greater than one in urban roadside environments as indicators of anthropogenic pollution pressure [34,37].

Table 7: Pollution Load Index for the Seven Sites Under Investigation

TYJ	TIJ	AIJ	FAJ	PSG	KPJ	FGM	BRR
1.53	1.48	1.36	1.57	1.49	1.40	1.55	1.46

Environmental and health implications

The combined results from concentration analysis, EF, CF, Igeo, and PLI demonstrate that roadside soil dust in high-traffic areas of Jos is significantly impacted by anthropogenic activities, predominantly vehicular emissions. Continuous exposure to contaminated dust through inhalation and incidental ingestion may pose health risks, particularly due to toxic metals such as Cd, As, Hg, and Cr. Regular environmental monitoring, improved traffic management, and appropriate pollution control strategies are therefore recommended to mitigate further accumulation and reduce potential risks to road users and nearby residents.

CONCLUSION

This study assessed the concentration and distribution of selected heavy metals in roadside soil dust from major traffic corridors in Jos North Local Government Area, Plateau State, Nigeria. The results revealed marked spatial variability in metal concentrations across the sampling sites, reflecting differences in traffic density and associated anthropogenic activities. Copper, arsenic, cadmium, and chromium were identified as the most significant contributors to roadside soil contamination, with several locations recording concentrations that exceeded World Health Organization guideline values, particularly for Cu, As, Cd, and Cr.

Comparison with control soils collected 200 m away from the roads confirmed that vehicular activities are the principal sources of heavy metal accumulation in roadside environments. Enrichment factor and contamination factor analyses indicated significant to extremely high anthropogenic enrichment for Pb, Cu, and especially Cr at high-traffic locations. Geo-accumulation index values further revealed moderate pollution by chromium at selected sites, while the Pollution Load Index values (PLI > 1) across all sampling locations demonstrated overall deterioration of soil quality.

The combined assessment highlights chromium, copper, arsenic, and cadmium as priority metals of environmental and public health concern in Jos roadside environments. Continuous exposure to contaminated soil dust through inhalation and incidental ingestion may pose potential health risks to road users, nearby residents, and commercial operators. Regular environmental monitoring, improved traffic management, and the enforcement of pollution control measures are therefore recommended to mitigate further heavy metal accumulation and safeguard public health.

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