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Road Dust Concentration Profile of Traffic-Related Heavy Metals in Five Major Roads in Kano Metropolis, Nigeria.

Sani, H.T[1], Afolabi, J. A[2], Abba, M.J[3], Nura Yaro[4], U.K Afegbua[5], Farouk Hamzat[6]
Center for Geodesy and Geodynamics, Toro Bauchi State, Nigeria [1,3,5,6]
Geography Department, Faculty of social and Management sciences, Northwest University Kano, Nigeria. [2 & 4]

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ABSTRACT

This study assessed the contamination levels, spatial distribution, sources, and human health risks of heavy metals deposited in road dust along major traffic corridors in Kano Metropolis, Nigeria. Road dust samples were collected during the dry season from five major roads: Zaria Road, Katsina Road, Maiduguri Road, Hadejia Road, and Bayero University Kano Road. Concentrations of Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Sn, V, and Zn were determined using standard analytical methods. Pollution indices, including contamination factor (CF), enrichment factor (EF), geo-accumulation index (Igeo), pollution load index (PLI), and multimetal pollution index (MPI), were applied. Relationships between traffic density and metal concentrations were evaluated using correlation and regression analyses, while principal component and cluster analyses were used for source identification. Human health risks for children and adults were assessed via ingestion, inhalation, and dermal contact pathways following the USEPA model. Mean concentrations (mg/kg) across the study area ranged as follows: Al (4,210–9,865), Fe (6,540–18,230), Zn (145–612), Pb (68–284), Cu (42–196), Mn (210–845), Cr (31–118), Ni (27–96), Cd (1.9–8.6), As (3.4–21.7), and Hg (0.6–3.8). Pollution indices indicated moderate to very high contamination, with CF values for Pb, Cd, As, and Zn exceeding 6 at high-traffic locations, while PLI values ranged from 1.8 to 4.9, confirming substantial anthropogenic influence. Strong positive correlations (r = 0.62–0.88) were observed between traffic density and Pb, Zn, Cu, and Cd concentrations. Health risk assessment revealed elevated non-carcinogenic risks, with an overall Hazard Index of 7.94 for children and 2.79 for adults, indicating greater vulnerability among children. Carcinogenic risk estimates for As, Cd, and Pb ranged from 1.6×10^{-4} to 7.4×10^{-4}, exceeding acceptable thresholds. These findings highlight significant traffic-related heavy- metal contamination and associated health risks, revealing the need for targeted mitigation strategies and regulatory interventions in Kano Metropolis.

Keywords: Heavy metals, Road dust, Pollution, Contamination, Traffic, Kano

I. Introduction

Urbanization and rapid motorization in developing cities have increasingly intensified environmental contamination from heavy metals present in road dust. Road dust acts as both a sink and reservoir for toxic metals released from multiple anthropogenic sources, including vehicle exhaust emissions, brake and tyre wear, fuel combustion, lubricating oil leakage, industrial deposition, and resuspension of surrounding soil particles (Adamiec *et al*., 2021; Chen *et al*., 2025). Unlike gaseous pollutants, heavy metals are persistent, non-biodegradable, and bioaccumulative, posing long-term ecological risks and serious human health threats (WHO, 2022). Metals such as lead (Pb), cadmium (Cd), arsenic (As), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni) are of particular concern due to their toxicity, carcinogenicity, and potential to disrupt organ function even at low concentrations (Alloway, 2013; Tchounwou *et al*., 2012).

Kano Metropolis, the commercial and industrial hub of Northern Nigeria, experiences daily high- volume vehicular traffic, creating an environment conducive to heavy metal accumulation in roadside dust. Factors such as aging vehicle fleets, poorly maintained roads, roadside markets, open mechanic workshops, and weak emission enforcement exacerbate deposition of metals along transport corridors. Previous studies indicate that urban roads in developing countries are hotspots for metal contamination due to such anthropogenic pressures (Li *et al*., 2020; Chacha *et al*., 2019). Comparable patterns have been reported in cities like Accra, Ghana (Mensah *et al*., 2020), Nairobi, Kenya (Chacha *et al*., 2019), Mumbai, India (Garg *et al*., 2023), and Cairo, Egypt (El-Sherbiny *et al*., 2024), revealing a consistent regional trend of traffic-related heavy metal pollution in developing urban centers.

In Nigeria, several studies have documented mounting concentrations of heavy metals in road dust, though often with methodological limitations. Sadiq (2022) reported hazardous enrichment of Pb, Cd, Zn, and Cu along heavily trafficked roads in Northern Nigeria, highlighting the significant exposure risk for urban residents. Similarly, Garba *et al*. (2020) found contamination factors exceeding 6 (CF > 6) along major transport corridors in Kaduna, indicating considerable anthropogenic input. Despite these insights, many studies focus on a limited number of metals, lack spatially resolved sampling designs, or do not apply comprehensive pollution indices such as the enrichment factor (EF), geo-accumulation index (Igeo), pollution load index (PLI), or multi-metal pollution index (MPI), which are critical for evaluating the environmental quality and guiding regulatory interventions (Ihedioha *et al*., 2020; Osadebe *et al*., 2019).

Addressing these gaps, the present study assesses the concentration and spatial distribution of 15 heavy metals, Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Sn, V, and Zn, in road dust collected along five major traffic corridors in Kano Metropolis: Zaria Road, Katsina Road, Maiduguri Road, Hadejia Road, and Bayero University Kano Road. By integrating multiple contamination indices (CF, EF, Igeo, PLI, MPI), the study quantitatively characterizes pollution severity and identifies contamination hotspots. This holistic approach enables a better understanding of both the distributional patterns and potential sources of heavy metals, which is crucial for targeted environmental management.

This study focuses on three key questions: the levels and spatial patterns of heavy metals in Kano road dust, identification of pollution hotspots and their contributing factors, and how contamination indices (CF, EF, Igeo, PLI, MPI) reflect the extent of anthropogenic pollution. By addressing these questions, this research contributes critical empirical evidence to inform evidence-based urban environmental management strategies, traffic emission control, and public health protection policies in developing cities. Moreover, the study reveals the need for sustainable road design, stricter vehicular emission standards, and routine environmental monitoring to mitigate heavy metal pollution in urban centers.

II. Materials and Methods

2.1 Study Area

The study was conducted in Kano Metropolis, Northwestern Nigeria, a highly urbanized commercial hub characterized by dense vehicular activities, mixed land-use planning, and industrial clusters. Five major traffic corridors, Hadejia, BUK, Katsina, Maiduguri, and Zaria Roads were purposively selected based on traffic intensity, commercial activities, and settlement proximity as in (figure 1).

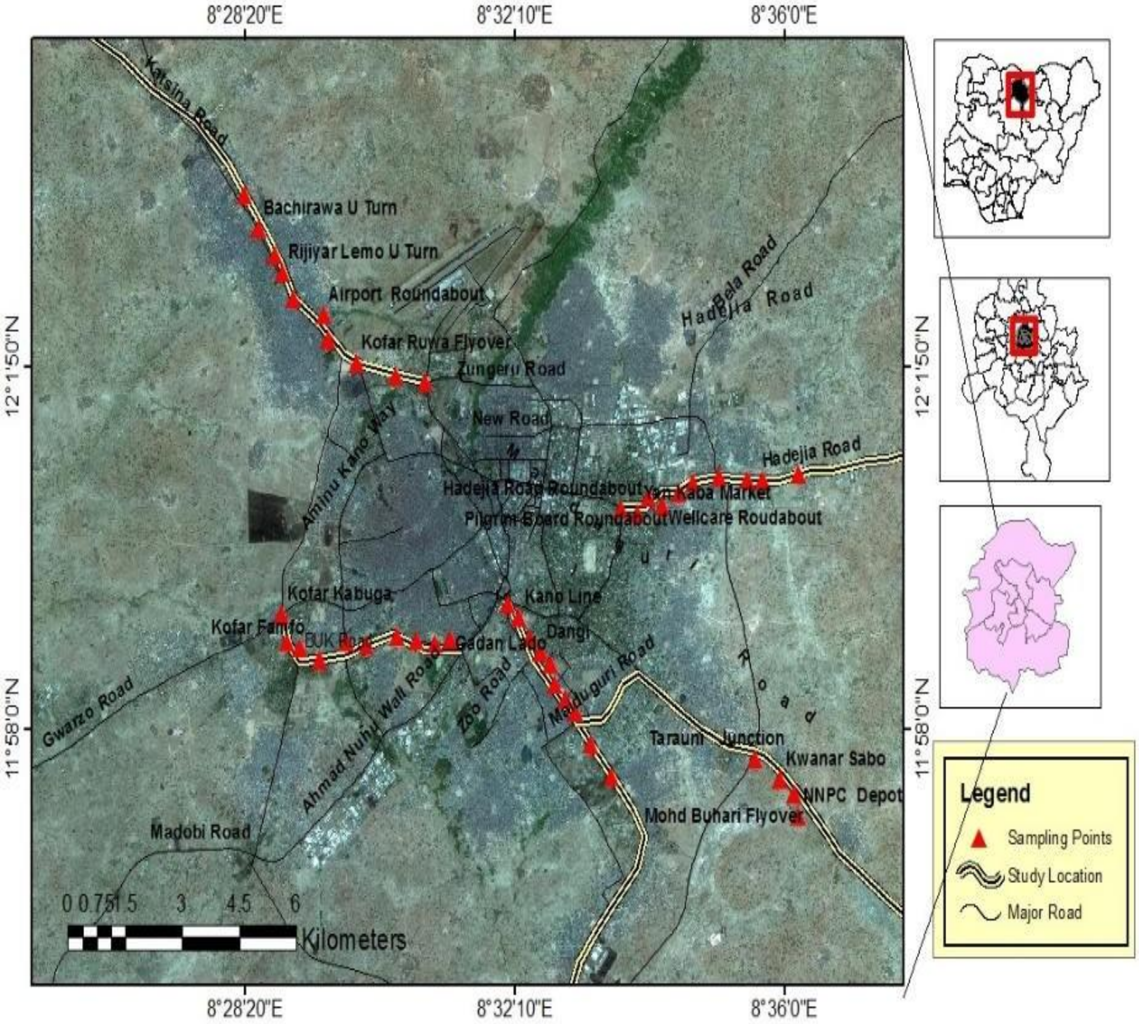

Figure 1: Map of The Study Area

Each corridor represents a high-exposure zone where road dust resuspension and pollutant dispersion are likely to occur due to congestion and road surface abrasion. Geographical coordinates were collected using a handheld GPS (Garmin eTrex 10). The study area experiences a tropical Savanna climate with a dry season (October–April) and wet season (May–September), conditions known to influence dust mobilization and deposition.

2.1 Traffic volume estimation

According to Kano state ministry of works Traffic volume was determined using tally sheets by manual counting motor vehicles passing the road on each side over 15 minutes-interval for every hour. Manual counting is one of the commonly and widely used methods for generating road traffic data (e.g. Leduc 2008; Jensen et al. 2017). The period within which the traffic head count was conducted was in the morning all through evening of week days. The number of vehicles passing per hour for each road was obtained as presented in Table 3.1.

Table 3.1: Mean Traffic Density/hour of The Study Area

Road	No. of Motorcycles	No. of Vehicles	No. of Trucks	Total
Hadejia	6870±2	6782±4	561±4	14213
BUK	10347±5	7182±2	343±6	17872

Katsina	5370±4	5635±3	658±4	11663
Maiduguri	8130±2	9453±7	1244±9	18827
Zaria	13918±6	8710±3	513±2	23141

Source: *Highways Department. KSMW, 2023*

2.2 Sampling Strategy and Sample Collection

A systematic transect sampling technique was adopted. Ten (10) sampling points per road were selected at 100–150 m intervals, resulting in a total of 50 samples. Road dust samples were collected during the dry season to minimize rainfall interference. A soft plastic brush and stainless-steel dustpan were used to sweep dust from the road shoulder (within 1 m from pavement edge). Approximately 200–250 g of surface dust (≤ 2 mm particle size) was collected from each location. Samples were transferred into pre-labelled polyethylene bags, sealed, and transported to the laboratory under ice-box conditions at 4°C to minimize contamination and chemical alteration. Samples were sieved at <75 µm, the respirable fraction most relevant for human exposure (USEPA, 2020).

2.3 Sample Preparation and Digestion

Samples were air-dried at room temperature for 48 hours to remove moisture; oven drying was done at 105°C for 2 hours. The dried samples were sieved using a 250 µm stainless-steel mesh, targeting respirable fractions most associated with human exposure. Acid Digestion Procedure (EPA 3050B) was adopted a**s** 1.0 g of sieved dust was weighed into a digestion vessel. About 10 mL of HNO_3 (65%) was added and heated at 95°C for 1 hour, while 5 mL of $HClO_4$ and 2 mL of H_2SO_4 were added sequentially. After evaporation to near dryness, residues were diluted with deionized water to 50 mL. A procedural blank and duplicate were included after every batch of ten samples.

$$CF = \frac{C_{metal}}{C_{background}}$$

2.4 Metal Analysis

Samples were digested using aqua regia (HCl:HNO_3, 3:1) and analyzed by using inductively coupled plasma optical emission spectroscopy (ICP-OES). for 15 metals: Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Sn, V and Zn. Calibration curves ($R^2 \geq 0.995$) were prepared using certified metal standards (Sigma-Aldrich, USA). Quality assurance included reagent blanks, calibration curves, duplicates, and certified reference material checks. Instrument drift correction was performed every 10 samples while glassware were acid-washed (10% HNO_3) to prevent contamination. Recovery range for QA/QC acceptance was between 80–120%.

2.5 Contamination Indices

To evaluate the extent of heavy metal pollution in road dust across the study area, quantitative contamination indices were applied. These indices enabled the assessment of metal enrichment levels, spatial pollution gradients, and the contribution of anthropogenic activities. Five major indices were computed: Contamination Factor (CF), Geo-accumulation Index (Igeo), Enrichment Factor (EF), Pollution Load Index (PLI), and Metal Pollution Index (MPI). All calculations were performed using Microsoft Excel 2019 and SPSS v26. Background reference values were obtained from NESREA (2016) regulatory soil thresholds and verified using control samples collected from non-traffic reference sites located ≥500 m away from road corridors.

2.5.1 Contamination Factor (CF)

The contamination factor measured the degree of metal accumulation relative to baseline levels and quantified the level of anthropogenic impact.

Where:

CF = Contamination Factor

Cmetal = Metal concentration in sampled road dust (mg/kg)

Cbackground = Background/control concentration or NESREA reference value

According to Hakanson (1980), Contamination Factor (CF) values are classified as follows: CF

< 1 indicates low contamination, 1 ≤ CF < 3 indicates moderate contamination, 3 ≤ CF < 6 indicates considerable contamination, and CF ≥ 6

signifies very high contamination.

2.5.2 Geo-Accumulation Index (Igeo)

The Igeo was used to determine the level of contamination and classify pollution severity based on background normalization following Müller (1969).

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n} \right)$$

Where:
C_n = Measured concentration of element n
B_n = Background/reference value (control or NESREA standard)

1.5 = Background correction factor accounting for natural variability

According to Müller (1969), the Igeo classification scale interprets pollution levels as follows: Igeo ≤ 0 denotes unpolluted, 0–1 unpolluted to moderately polluted, 1–2 moderately polluted, 2– 3 moderately to strongly polluted, 3–4 strongly polluted, 4–5 strongly to extremely polluted, and >5 indicates extremely polluted conditions.

2.5.3 Enrichment Factor (EF)

EF assessed the degree of anthropogenic enrichment compared to natural crustal sources. Fe was selected as the reference element due to its crustal stability and minimal anthropogenic variation.

$$EF = \frac{\left(\frac{C_{metal}}{C_{Fe}}\right)_{sample}}{\left(\frac{C_{metal}}{C_{Fe}}\right)_{background}}$$

Where Fe serves as the normalizing denominator.

According to Sutherland (2000), EF values are interpreted as follows: EF < 2 indicates deficiency to minimal enrichment from natural/geogenic sources, 2–5 reflects moderate enrichment from mixed inputs, 5–20 signifies significant anthropogenic enrichment, 20–40 denotes very high enrichment from strong anthropogenic activity, and EF > 40 represents extremely high enrichment typically linked to intensive industrial or traffic-related sources.

2.5.4 Pollution Load Index (PLI)

PLI provided an integrated measure of overall pollution status across all measured metals.

$$PLI = (CF_1 \cdot CF_2 \cdot CF_3 \ldots \cdot CF_n)^{\frac{1}{n}}$$

Where:

$CF_1 \ldots CF_n$ = contamination factors of each metal

n = number of metals analyzed

PLI values indicate environmental quality: 1 = baseline, <1 = no pollution, >1 = polluted.

2.5.5 Metal Pollution Index (MPI)

MPI quantified the cumulative metal burden across each sampling location and enabled ranking of road corridors according to pollution intensity.

$$MPI = (C_1 \cdot C_2 \cdot C_3 \ldots \cdot C_n)^{\frac{1}{n}}$$

Where $C_1 \ldots C_n$ represent concentrations of each metal in a sample.

Two categories of background/reference values were adopted. NESREA Soil Quality Guidelines (2016) and Control Soil Samples (≥500 m away from traffic and industrial activities). These reference values served as the baseline for CF, Igeo, and EF calculations, ensuring accuracy in distinguishing natural versus anthropogenic contributions.

2.6 Data Analysis

Descriptive statistics (mean ± SD, max–min range) were computed using SPSS v26. One-way ANOVA tested spatial variation across locations, while Tukey HSD identified significant pairwise differences. GIS-IDW spatial mapping identified hotspots. The mean concentrations (mg/kg) of heavy metals across roads were compared with NESREA (2011) Soil Contamination Guidelines and WHO (2022) Toxic Metal Exposure Framework.

III.Results And Discussion

3.1 Mean Concentrations (mg/kg) of Heavy Metals across Roads

The mean concentrations of heavy metals across the five major roads in Kano Metropolis indicate widespread contamination, with several metals exceeding both NESREA and WHO permissible limits (Table 1 and Figure 1). Arsenic (As) recorded notably high values on BUK (161.65 mg/kg) and Maiduguri Roads (156.43 mg/kg), far above the NESREA (20 mg/kg) and WHO (10–20 mg/kg) limits, while Cadmium (Cd) ranged between 31.72–43.92 mg/kg, significantly surpassing the 3.0 mg/kg threshold. Cobalt (Co), Nickel (Ni), and Lead (Pb) also exceeded regulatory standards, particularly along Hadejia, Katsina, and Zaria Roads, indicating influence from heavy traffic and anthropogenic activities. Although Zinc (Zn) and Iron (Fe) remained within regulatory margins, their elevated values reflect cumulative deposition from vehicular emissions and mechanical wear. Statistically significant variations ($p < 0.05$) were observed for As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sn, and Zn, confirming pollution hotspots along BUK, Maiduguri, and Zaria Roads that require urgent regulatory intervention.

Table 1: Mean Concentrations (mg/kg) of Heavy Metals across Roads

Metal	**Study Locations**					**Standards**		**F-Value**	**p-Value**
	Hadejia	**BUK**	**Katsina**	**Maiduguri**	**Zaria**	**NESREA**	**WHO**		
Aluminium (Al)	131.99 ± 19.43^{a}	114.98 ± 28.16^{ab}	107.37 ± 23.86^{b}	116.86 ± 37.18^{ab}	118.52 ± 39.08^{ab}	120	100	0.859	0.496
Arsenic (As)	129.88 ± 28.30^{b}	161.65 ± 41.55^{a}	119.85 ± 29.73^{b}	156.43 ± 10.30^{a}	135.70 ± 29.16^{b}	20	10–20	3.615	**0.012***
Cadmium (Cd)	43.92 ± 8.40^{a}	31.72 ± 5.21^{c}	34.70 ± 6.57^{bc}	37.60 ± 10.09^{bc}	41.75 ± 9.25^{ab}	3.0	3.0	3.793	**0.010***
Cobalt (Co)	127.33 ± 32.01^{a}	100.08 ± 10.78^{b}	68.69 ± 17.10^{c}	103.73 ± 15.06^{b}	109.78 ± 29.69^{ab}	50	50	8.944	**0.000***
Chromium (Cr)	91.57 ± 8.31^{b}	96.51 ± 8.24^{b}	91.08 ± 13.77^{b}	107.92 ± 26.79^{a}	109.01 ± 11.89^{a}	100	100	3.202	**0.021***
Copper (Cu)	138.74 ± 20.34^{b}	169.85 ± 40.87^{ab}	132.80 ± 28.95^{b}	143.28 ± 39.20^{b}	173.56 ± 15.31^{a}	70	70	3.737	**0.010***
Iron (Fe)	222.37 ± 60.71^{b}	228.98 ± 44.15^{b}	310.01 ± 42.53^{a}	253.43 ± 60.32^{ab}	283.02 ± 71.97^{ab}	350	500	4.190	**0.006***
Mercury (Hg)	60.25 ± 15.30^{b}	62.35 ± 15.10^{b}	50.53 ± 10.25^{c}	68.17 ± 19.65^{ab}	70.19 ± 13.50^{a}	2.0	1.0	2.636	**0.046***
Magnesium (Mg)	61.89 ± 14.55^{b}	64.67 ± 16.57^{b}	50.20 ± 12.90^{c}	71.83 ± 12.94^{a}	71.88 ± 14.00^{a}	200	150	3.920	**0.008***
Manganese (Mn)	105.73 ± 26.68^{b}	127.33 ± 32.01^{a}	122.76 ± 43.46^{ab}	110.88 ± 24.62^{b}	114.08 ± 28.87^{b}	200	200	0.763	0.555
Nickel (Ni)	159.50 ± 15.49^{a}	115.68 ± 33.42^{c}	158.14 ± 7.70^{a}	120.35 ± 25.92^{bc}	157.45 ± 37.92^{a}	75	70	6.970	**0.000***
Lead (Pb)	97.16 ± 13.64^{b}	98.00 ± 20.44^{b}	119.40 ± 15.08^{a}	113.20 ± 16.97^{a}	114.41 ± 21.28^{a}	70	50–70	3.297	**0.019***
Tin (Sn)	65.38 ± 14.95^{c}	77.89 ± 10.06^{b}	61.87 ± 16.69^{c}	81.97 ± 12.23^{b}	95.40 ± 29.99^{a}	100	100	5.497	**0.001***
Vanadium (V)	60.82 ± 12.08^{b}	62.74 ± 10.30^{b}	56.46 ± 15.83^{b}	66.19 ± 22.53^{b}	76.40 ± 12.32^{a}	150	140	2.428	0.061
Zinc (Zn)	244.23 ± 24.01^{b}	253.10 ± 43.10^{b}	203.37 ± 47.11^{c}	255.34 ± 61.19^{b}	267.72 ± 54.98^{a}	300	200–300	2.651	**0.045***

Note: Values represent mean ± standard deviation (mg/kg). Means followed by different superscript letters (^{a}, ^{b}, ^{c}) within the same row differ significantly at $p < 0.05$ (Tukey HSD test). National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011); World Health Organization (WHO, 2022).

3.2 Hotspot showing Concentration of Heavy Metal across the Study Area

The concentration of heavy metals across the study area, as presented in Plate (1–8a,b,c & d), reveals distinct patterns linked to traffic density, roadside activities, and urban land-use.

3.2.1 Aluminium (Al)

Aluminium(Al) (Plate 1) showed higher concentrations along high-traffic corridors such as Hadejia and BUK Roads, reflecting vehicular abrasion, pavement wear, and construction activities, while peripheral areas recorded lower values.

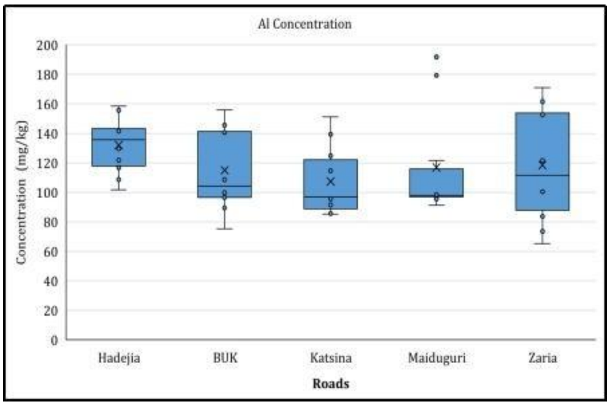

Plate 1: Concentration (mg/kg) of Aluminum (Al) across the Study Area

3.2.2 Arsenic (As)

Arsenic (As) (Plate 2) exhibited high concentration along BUK and Maiduguri Roads, indicating localized anthropogenic sources including fuel combustion, workshops, and commercial operations.

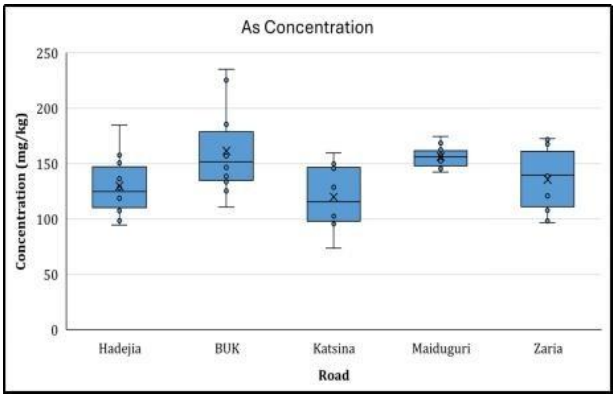

Plate 2: Concentration (mg/kg) of Arsenic (As) across the Study Area

3.2.3 Cadmium (Cd) and Cobalt (Co)

Cadmium (Cd) (Plate 3a) and Cobalt (Co) (Plate 3b) displayed elevated levels along Hadejia and Zaria Roads, suggesting influences from brake/tyre wear, engine emissions, and roadside waste handling.

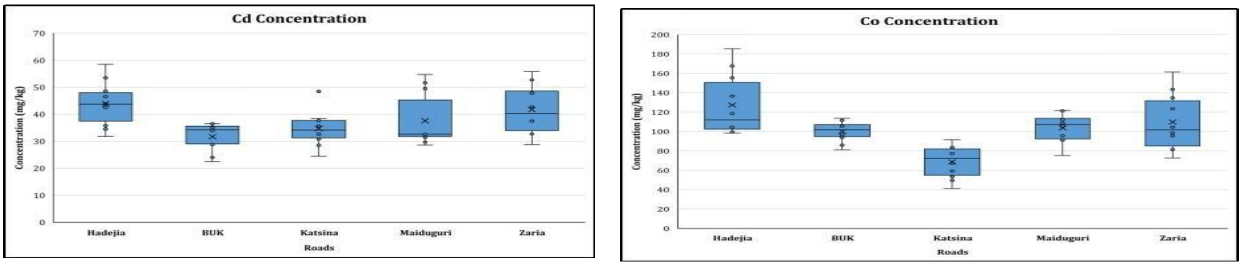

Plate 3a & b: Concentration (mg/kg) of Cadmium (Cd) and Cobalt (Co) across the Study Area

3.2.4 Chromium and Copper (Cu)

Chromium (Cr) (Plate 4a) and Copper (Cu) (Plate 4b) presented heterogeneous patterns, with enrichment along Maiduguri, Zaria, and BUK Roads, consistent with high traffic intensity and infrastructure degradation.

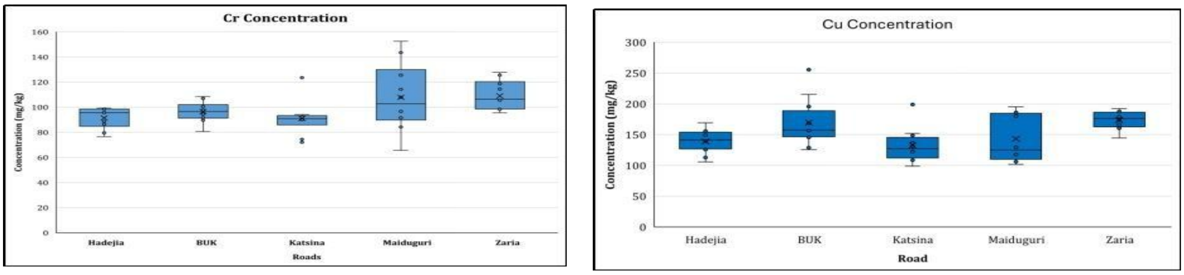

Plate 4a & b: Concentration (mg/kg) of Chromium (Cr) and Cupper (Cu) across the Study Area

3.2.5 Iron (Fe)

Iron (Plate 5) was concentrated around Katsina and Zaria Roads, reflecting both lithogenic sources and increased anthropogenic input.

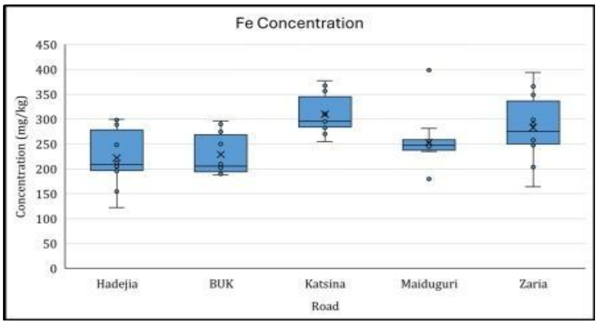

Plate 5: Concentration (mg/kg) of Iron (Fe) across the Study Area

3.2.5 Mercury (Hg)

Mercury (Plate 6) showed localized enrichment at Zaria and Maiduguri Roads, highlighting site- specific industrial or mechanical sources.

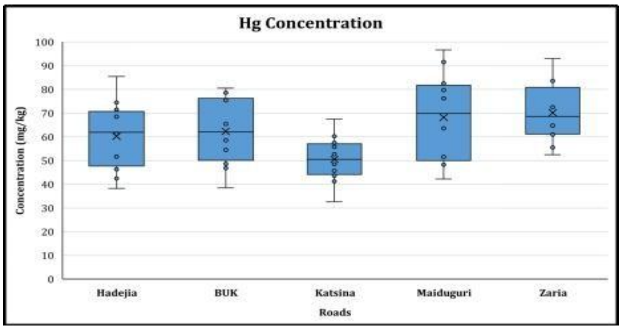

Plate 6: Concentration (mg/kg) of Mercury (Hg) across the Study Area

3.2.6 Magnesium (Mg), Manganese (Mn) and Vanadium (V)

Magnesium (Mg) (Plate 7a), Manganese (Mn) (Plate 7b), and Vanadium (V) (Plate 7c) demonstrated moderate concentration, correlating with urban activity gradients.

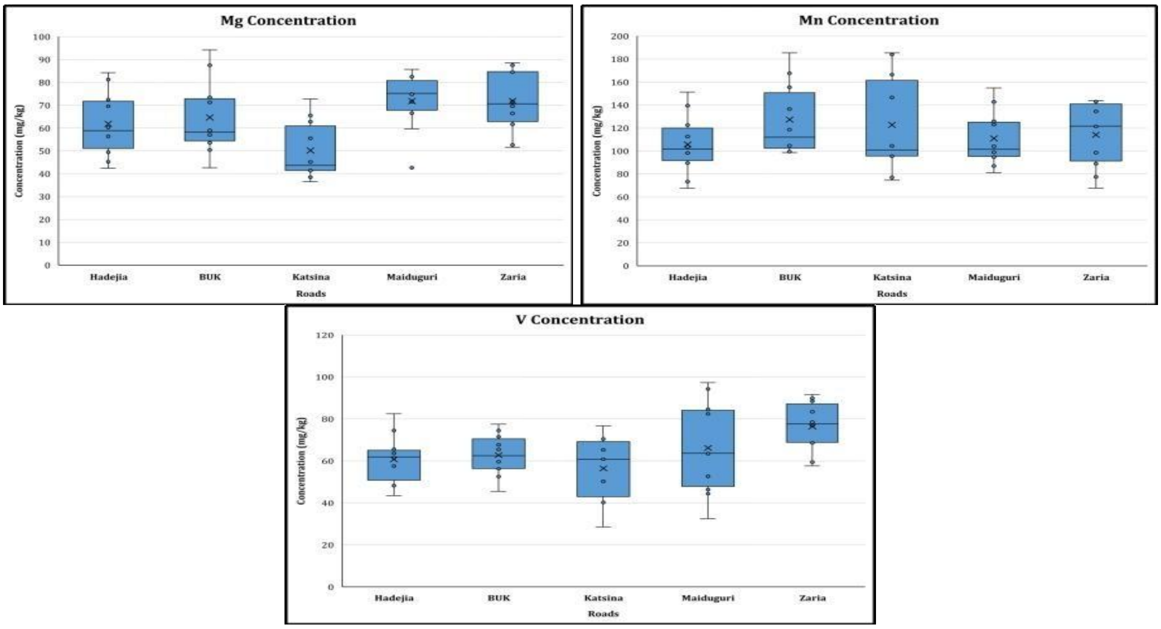

Plate 7a, b & c: Concentration (mg/kg) of Magnesium (Mg), Manganese (Mn) & Vanadium (V) across the Study Area

3.2.7 Nickel (Ni), Lead (Pb), Tin (Sn), and Zinc (Zn)

Nickel (Ni) (Plate 8a), Lead (Pb) (Plate 8b), Tin (Sn) (Plate 8c), and Zinc (Zn) (Plate 8d) showed strong heterogeneity, with maximum concentrations recorded along Katsina, Zaria, and Maiduguri Roads, aligning with commercial density, mechanical workshops, fuel stations, and high vehicular flow.

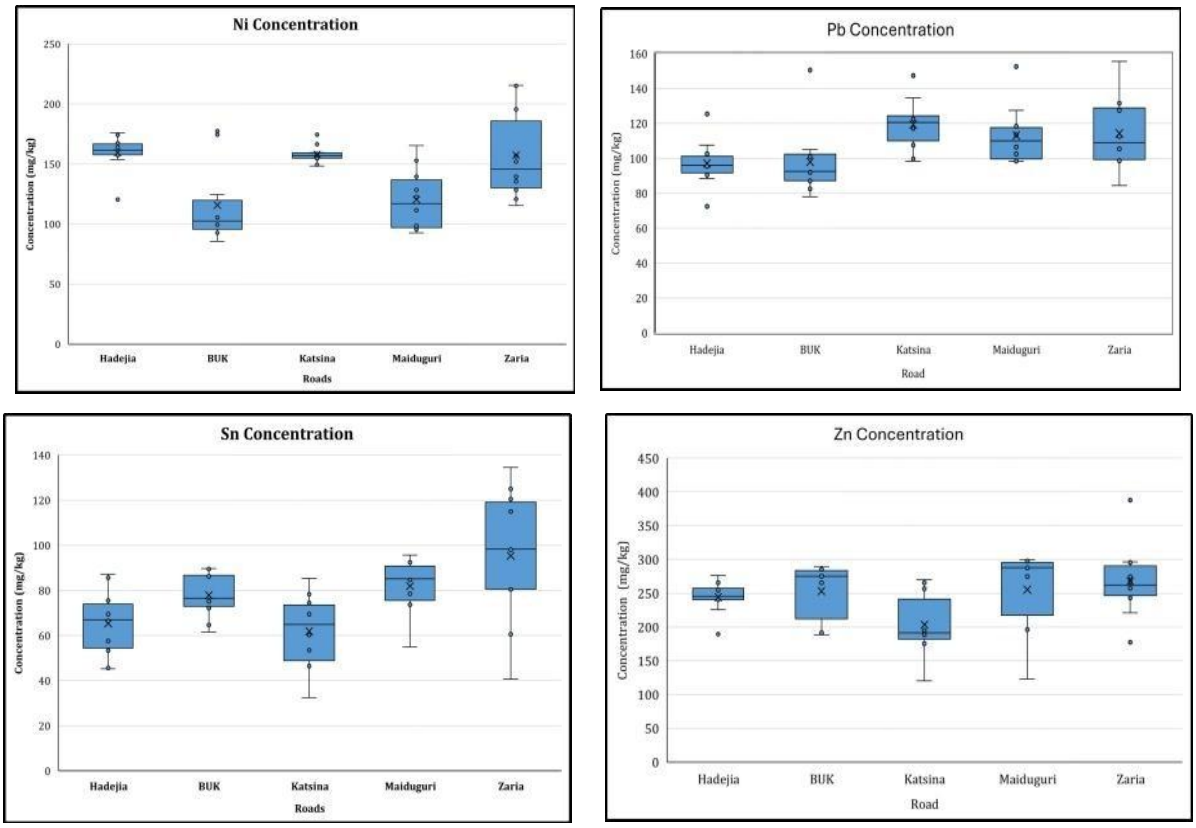

Plate 8a, b, c & d: Concentration (mg/kg) of Nickel (Ni), Lead (Pb), Tin (Sn) & Zinc (Zn) across the Study Area

IV. Discussion

4.1 Concentration Level of Heavy Metals in the Road Dust of the Study Area

The assessment of heavy metal concentrations in roadside dust across five major roads in Kano Metropolis reveals notable spatial variability, reflecting a combination of lithogenic inputs from soil and crustal sources and anthropogenic contributions from traffic, industrial activities, construction, and urban infrastructure.

Aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), tin (Sn), vanadium (V), and zinc (Zn) were detected at varying levels, with most metals displaying enhanced concentrations along high-traffic corridors. These findings align with regional and global evidence that road dust in rapidly urbanizing cities becomes a sink for pollutants derived from vehicle emissions, tyre and brake wear, lubricating oils, metallic corrosion, and the resuspension of contaminated particles (Vlasov *et al*., 2022; Rybak *et al*., 2020; Lei *et al*., 2025).

4.1.2 Aluminium (Al)

Aluminium exhibited mean concentrations from 107.37 to 131.99 mg/kg, with the highest values along Hadejia Road, slightly exceeding NESREA's reference threshold (120 mg/kg; NESREA, 2016). The pattern reflects inputs from natural crustal deposits and anthropogenic activities such as vehicle abrasion and construction. Comparable concentrations have been reported in Lagos, Ibadan, and Abuja, indicating a wider national trend of elevated Al in metropolitan areas (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Although not a primary carcinogen, chronic exposure to certain forms of aluminium has been associated with neurological, cognitive, and skeletal disorders, reinforcing the potential health implications of long-term dust exposure (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023).

4.1.3 Arsenic (As)

Arsenic concentrations ranged from 119.85 to 161.65 mg/kg, with the highest levels along BUK and Maiduguri Roads, reflecting dense traffic, commercial activity, and fuel combustion. The results are consistent with studies in Lagos and Abuja that report arsenic enrichment near commercial hubs and congested roadways (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). As a Group 1 carcinogen, arsenic exposure poses risks including neurological impairment, cardiovascular complications, skin lesions, and malignancies, particularly for children, vendors, and roadside workers (Skalny *et al*., 2021; Igbokwe *et al*., 2020). The hotspots observed indicate a need for targeted mitigation measures.

4.1.4 Cadmium (Cd)

Cadmium occurred at 31.72–43.92 mg/kg, with notable enrichment at Hadejia and Zaria Roads, associated with tyre and brake wear, fuel combustion, and informal waste incineration. Similar concentrations from other Nigerian cities highlight the metal's persistence in urban traffic corridors (Ojiodu *et al*., 2023; Kolawole *et al*., 2023). Cd is highly toxic, linked to kidney dysfunction, respiratory disorders, and bone demineralization in exposed populations (Skalny *et al*., 2021; Renke *et al*., 2023). These concentrations reveal the need for improved waste management and dust suppression practices.

4.1.5 Cobalt (Co)

Cobalt displayed concentrations between 68.69 and 127.33 mg/kg, with higher values near busy corridors, consistent with contributions from alloyed metal components, industrial emissions, and mechanical activities. Similar enrichment patterns were reported in Lagos and Abuja (Kolawole *et al*., 2023). Although an essential trace element, chronic exposure may lead to respiratory and cardiovascular complications, particularly in frequently exposed groups such as mechanics and vendors (Igbokwe *et al*., 2020; Renke *et al*., 2023).

4.1.6 Chromium (Cr)

Chromium concentrations ranged from 91.08 to 109.01 mg/kg, peaking along Zaria and Maiduguri Roads. The enrichment reflects stainless-steel abrasion, vehicular emissions, and construction residues, supporting global findings that Cr in road dust is both vehicular and lithogenic in origin (Vlasov *et al*., 2022; Lei *et al*., 2025). Given that Cr(VI) is carcinogenic while Cr(III) is nutritionally essential, speciation monitoring is important to determine health risk, particularly in traffic-dense zones (Skalny *et al*., 2021; Igbokwe *et al*., 2020).

4.1.7 Copper (Cu)

Copper registered 132.80–173.56 mg/kg, with hotspots along Zaria and BUK Roads due to brake wear, metallic corrosion, and electrical components. Similar patterns are reported in other African and global cities (Ojiodu *et al*., 2023; Lei *et al*., 2025). Though nutritionally relevant, long-term inhalation or ingestion may trigger hepatic and renal toxicity (Skalny *et al*., 2021; Renke *et al*., 2023). Mitigation strategies such as improved street cleaning are therefore warranted.

4.1.8 Iron (Fe)

Iron is a dominant crustal element, recorded values between 222.37 and 310.01 mg/kg, with the highest levels at Katsina and Zaria Roads, reflecting mixed natural and human sources including vehicle corrosion and soil resuspension. Similar abundances have been documented in Lagos and Ibadan (Kolawole *et al*., 2023). Inhaling Fe-laden particulates may induce respiratory irritation and oxidative stress in frequently exposed populations (Skalny *et al*., 2021; Renke *et al*., 2023).

4.1.8 Mercury (Hg)

Mercury concentrations of 50.53–70.19 mg/kg highlight anthropogenic contributions from fuel combustion, battery disposal, and industrial materials, particularly along Zaria and Maiduguri Roads. The findings correspond with documented Hg burdens in urban dust from Lagos and Port Harcourt (Kolawole *et al*., 2023). Mercury is neurotoxic even at low concentrations, posing risks of cognitive impairment and renal damage (Skalny *et al*., 2021; Igbokwe *et al*., 2020).

4.1.9 Magnesium (Mg)

Magnesium ranged from 50.20 to 71.88 mg/kg and reflects crustal origins augmented by construction and pavement abrasion. Although not highly toxic, repeated inhalation of Mg- bearing particles may exacerbate respiratory symptoms in vulnerable groups (Skalny *et al*., 2021).

4.1.10 Manganese (Mn)

Magnesium appeared at 105.73–127.33 mg/kg, aligning with findings that tie Mn to brake wear and traffic emissions (Rybak *et al*., 2020). While essential in trace amounts, excessive inhalation may contribute to neurotoxicity and motor impairment, especially among workers exposed daily (Renke *et al*., 2023).

4.1.11 Nickel (Ni)

Nickel concentrations of 115.68–159.50 mg/kg highlight the influence of corrosion, engine emissions, and alloyed components along high-traffic routes, consistent with national and international patterns (Ojiodu *et al*., 2023; Vlasov *et al*., 2022). Ni is a potential carcinogen and respiratory irritant, requiring continued monitoring in congested areas (Skalny *et al*., 2021; Renke *et al*., 2023).

4.1.12 Lead (Pb)

Lead values ranged from 97.16 to 119.40 mg/kg, with enriched levels along Katsina, Zaria, and Maiduguri Roads. Historical leaded gasoline legacy, tyre wear, and brake linings remain defining sources, consistent with research across Nigerian and global metropolitan areas (Kolawole *et al*., 2023; Lei *et al*., 2025). Pb is a major neurotoxin with no safe exposure threshold, particularly harmful to children (Igbokwe *et al*., 2020; Renke *et al*., 2023).

4.1.13 Tin (Sn) and Vanadium (V)

Tin and vanadium displayed moderate enrichment, particularly near industrial and mechanical zones, corresponding with international observations linking these metals to soldering residues, fuel combustion, and mechanical repairs (Vlasov *et al*., 2022; Olumayede *et al*., 2024). While Sn is relatively less toxic, certain organotin compounds pose endocrine risks (Skalny *et al*., 2021). V inhalation may induce respiratory and oxidative stress responses, especially among traffic- exposed populations (Renke *et al*., 2023).

4.1.14 Zinc (Zn)

Zinc concentrations of 203.37–267.72 mg/kg show clear enrichment near Zaria and Maiduguri Roads, attributed to tyre wear, lubricating oils, and construction residues. These values parallel elevated Zn reported in Lagos, Ibadan, and Abuja (Kolawole *et al*., 2023; Aturamu *et al*., 2024). Although nutritionally relevant, chronic exposure to Zn particulates may contribute to gastrointestinal and respiratory irritation (Skalny *et al*., 2021; Renke *et* *al*., 2023). The study confirms that Kano's roadside dust exhibits contamination profiles typical of fast-growing African cities, with metals reflecting combined lithogenic and traffic-driven anthropogenic sources. While some metals remain within expected urban ranges, others, particularly As, Cd, Ni, Pb, Hg, and Zn, indicate potential public health concerns due to chronic exposure from inhalation and ingestion. Urban planning interventions, dust suppression, street cleaning, traffic regulation, and public awareness are recommended to mitigate environmental and health risks.

V. Conclusion And Recommendations

This study demonstrates that road dust in the study area is contaminated with multiple heavy metals, primarily driven by anthropogenic sources such as vehicular emissions, brake and tyre wear, fuel combustion, and resuspension of roadside particulates. Contamination indices (CF, Igeo, PLI, EF, and MPI) consistently classify the study area as polluted, with particular contamination at Zaria and BUK Roads, confirming them as urban pollution hotspots. Arsenic emerged as the most critical pollutant due to its extreme enrichment and carcinogenic risk, while lead, zinc, copper, and iron also exceeded acceptable limits, indicating persistent environmental loading. The findings align with regional and international evidence of heavy metal accumulation in high-traffic corridors and reveal the need for urgent regulatory intervention, improved traffic and emission control, routine street cleaning, and public health risk mitigation to protect vulnerable populations and strengthen urban environmental management strategies.

Recommendations

Based on the findings, the following recommendations are proposed:

1. Establish routine surveillance of heavy metals in road dust and enforce NESREA/WHO air-quality and emission standards across high-traffic corridors.
2. Implement stricter vehicle inspection policies, promote low-emission transport options, and improve traffic flow to reduce particulate release.
3. Upgrade road infrastructure, introduce vegetation buffers, and conduct scheduled street cleaning to minimize dust resuspension.
4. Educate roadside residents, vendors, and commuters on exposure risks and promote hygiene practices to reduce ingestion and inhalation pathways.

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