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Spatial Distribution Profile of Traffic-Related Heavy Metals in Road Dust Across Some Five major Roads in Kano Metropolis, Nigeria

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Abstract

This study evaluates the spatial concentration and contamination profile 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. Samples were analyzed for Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Ni, Pb, Sn, V, and Zn using standard analytical techniques. Pollution indices, including contamination factor (CF), enrichment factor (EF), geo- accumulation index (Igeo), pollution load index (PLI), and multimetal pollution index (MPI), were applied. Mean concentration ranges recorded include: Al (107.37±23.86 – 131.99±19.43mg/kg), Fe (222.37±60.71 – 310.01± 42.53mg/kg), Zn (203.37±47.11 – 267.72±54.98 mg/kg), Pb (97.16±13.64 – 119.40±15.08 mg/kg), Cu (132.80±28.95 – 173.56±15.31 mg/kg), Mn (105.73±26.68 – 127.33±32.01 mg/kg), Cr (91.08±13.77 – 109.01±11.89 mg/kg), Ni (115.68±33.42 – 159.50±15.49 mg/kg), Cd (31.72±5.21 – 43.92±8.40 mg/kg), As (119.85±29.73 – 161.65±41.55 mg/kg), and Hg (50.53±10.25 – 70.19±13.50 mg/kg).

Pollution indices (CF, EF, Igeo, PLI) indicated moderate to very high contamination across several sites, with Pb, Cd, As, and Zn exceeding baseline thresholds. The result revealed that Arsenic CF ranged between 190.24–256.58 (very high contamination), Igeo: 3.14–3.35 (heavily contaminated), EF(As): 17.26–32.69 (significant–very high enrichment) and MPI: 99.40–115.61 (highest at Zaria Road). PLI values (13.40–15.61) and all >1 confirmed significant anthropogenic impact. Results identify Zaria and Katsina Roads as contamination hotspots due to persistent congestion and non-exhaust vehicular emissions. The study provides critical evidence of multimetal enrichment and emphasizes the need for strengthened regulatory controls on traffic emissions and roadside environmental quality management.

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).

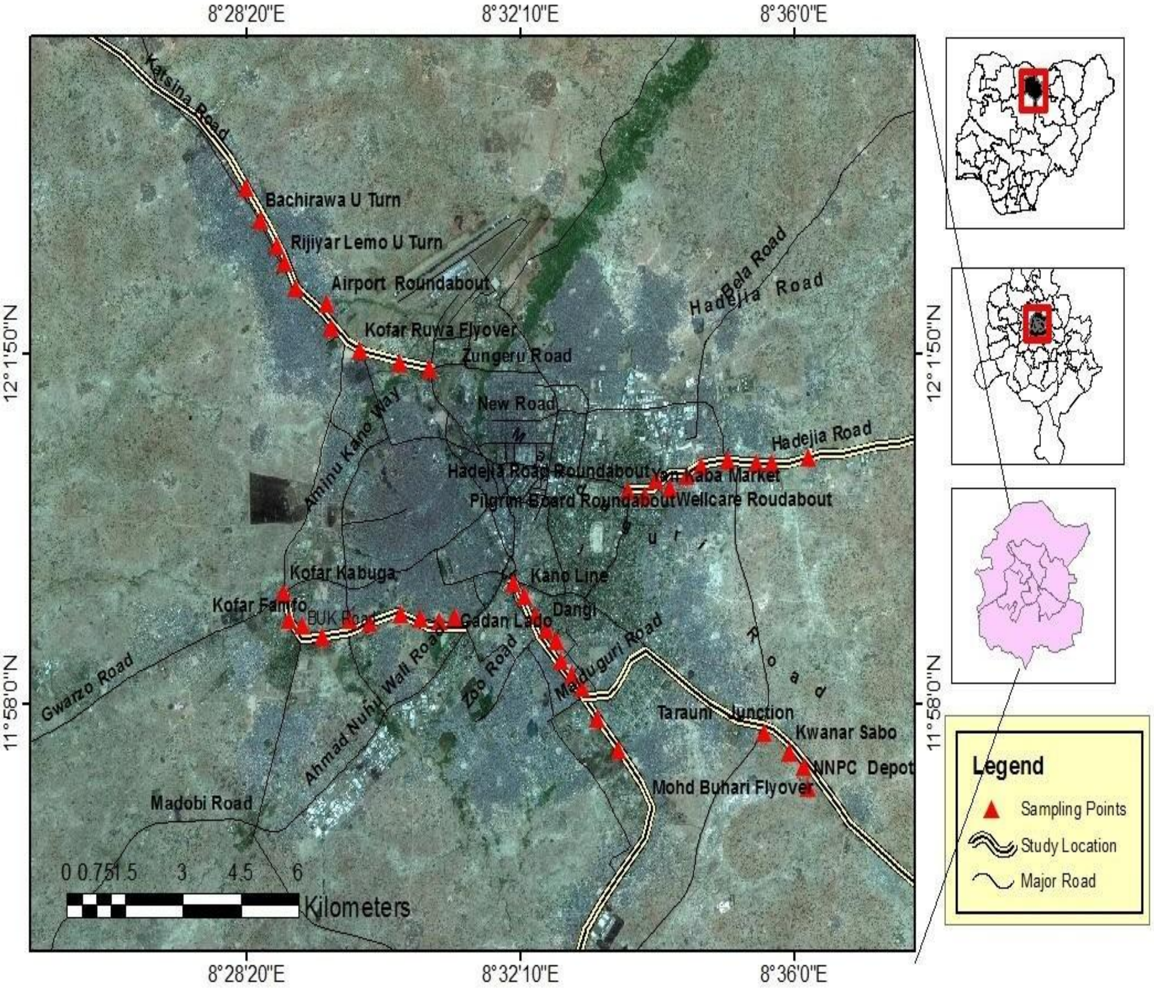

Figure 1: Map of The Study Area

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 ($\leq$ 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 as 1.0 g of sieved dust was weighed into a digestion vessel. About 10 mL of HNO3 (65%) was added and heated at 95°C for 1 hour, while 5 ml of HClO4 and 2 ml of H_2SO4 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.

2.4 Metal Analysis

Samples were digested using aqua regia (HCl:HNO3, 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, 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% HNO3) 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.

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

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 Spatial Variability of Heavy Metal across the Study Area

The spatial variability of heavy metals across the study area, as presented in Plate (4.1–4.15), reveals distinct patterns linked to traffic density, roadside activities, and urban land-use. 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.

3.2.1 Aluminium (Al)

Al concentrations in road dust showed marked spatial variability across the study area, with elevated levels observed along high-traffic corridors such as Hadejia and BUK roads, while comparatively lower concentrations were evident in peripheral areas, indicating the influence of traffic density and urban activities (Plate 4.1).

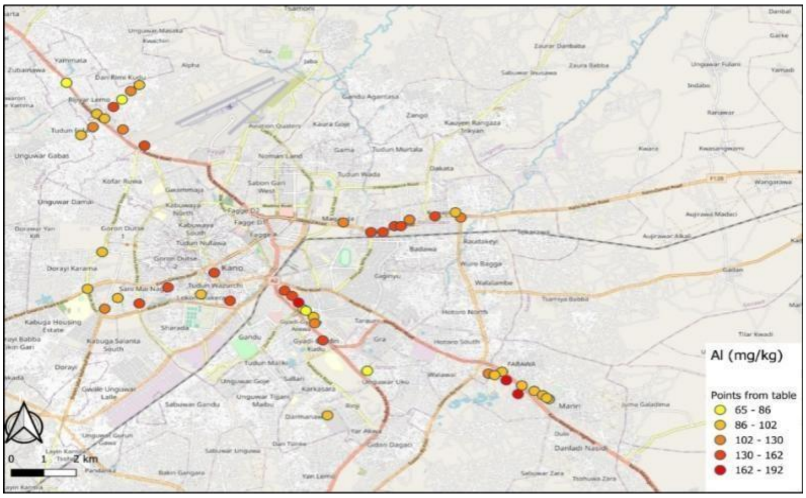

Plate 4.1: Spatial Distribution of Aluminium (Al) in Road Dust Across The Study Area

3.2.1 Arsenic (As)

Arsenic distribution exhibited clear spatial heterogeneity across the metropolis, with higher concentrations concentrated along BUK and Maiduguri roads, while relatively lower levels were observed in other locations, suggesting localized anthropogenic inputs (Plate 4.2).

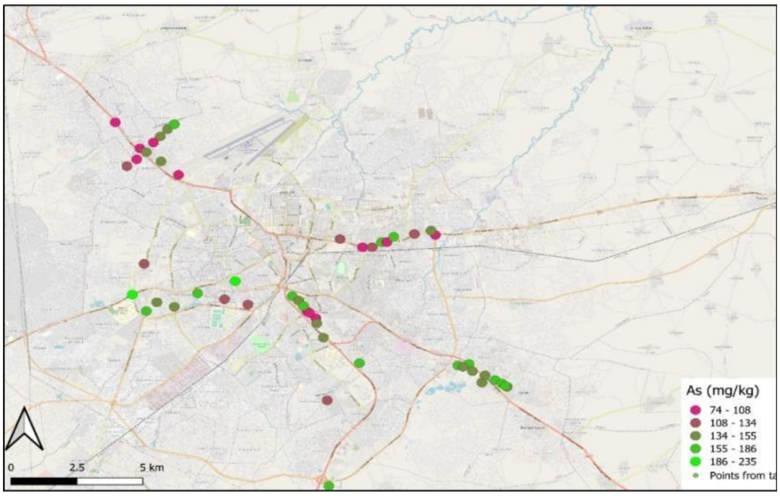

Plate 4.2: Spatial Distribution of Arsenic (As) in Road Dust Across The Study Area

3.2.3 Cadmium (Cd)

Cadmium concentrations displayed distinct spatial patterns, with elevated levels predominantly occurring along Hadejia and Zaria roads, whereas lower concentrations were recorded in less trafficked areas, reflecting variations in roadside activities (Plate 4.3).

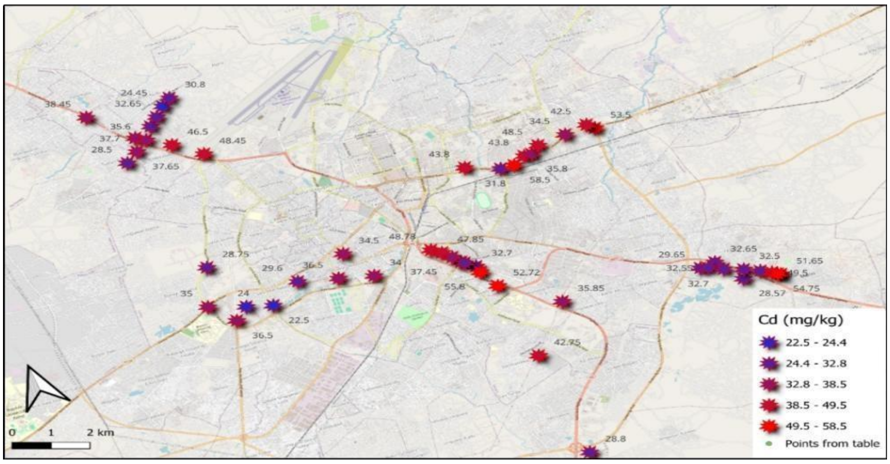

Plate 4.3: Spatial Distribution of Cadmium (Cd) in Road Dust Across The Study Area

3.2.4 Cobalt (Co)

Cobalt showed pronounced spatial variability, with higher concentrations observed along Hadejia and Zaria roads, while reduced levels were evident around Katsina Road, indicating site-specific sources of contamination (Plate 4.4).

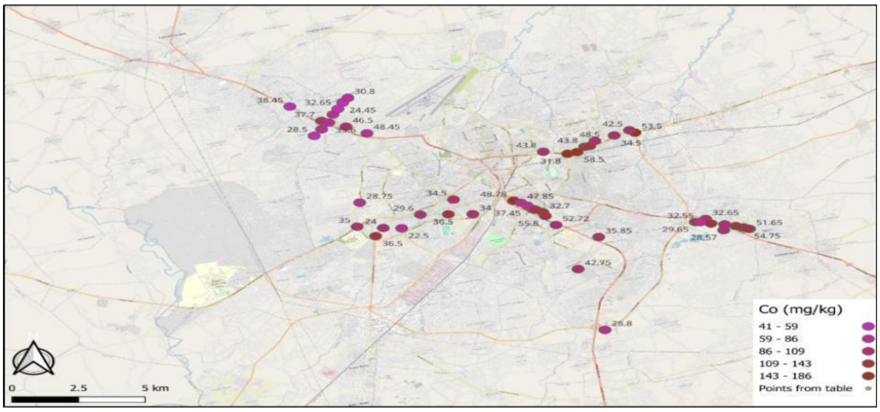

Plate 4.4: Spatial Distribution of Cobalt (Co) in Road Dust Across The Study Area

3.2.5 Chromium (Cr)

Chromium concentrations varied spatially, with noticeable enrichment along Maiduguri and Zaria roads, compared to other parts of Kano Metropolis, suggesting contributions from vehicular wear and urban infrastructure (Plate 4.5).

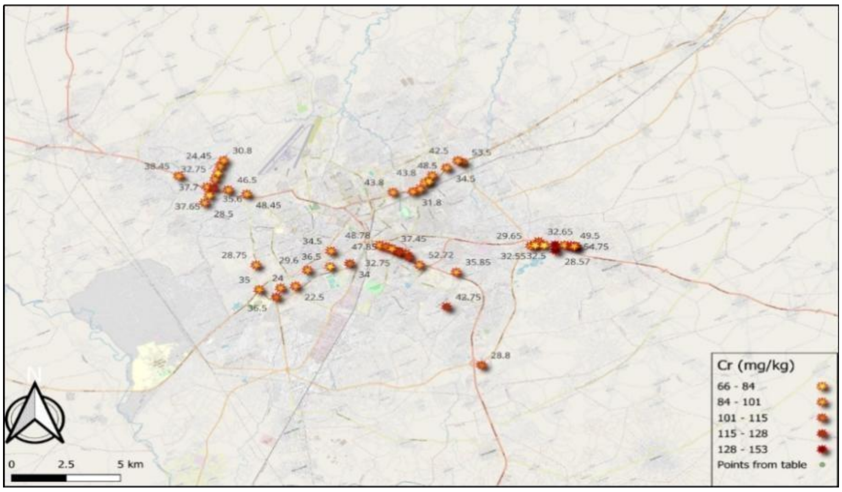

Plate 4.5: Spatial Distribution of Chromium (Cr) in Road Dust Across The Study Area

3.2.6 Copper (Cu)

Copper exhibited a heterogeneous spatial distribution, with elevated concentrations along BUK and Zaria roads, while relatively lower levels were observed in other locations, reflecting traffic-related sources (Plate 4.6).

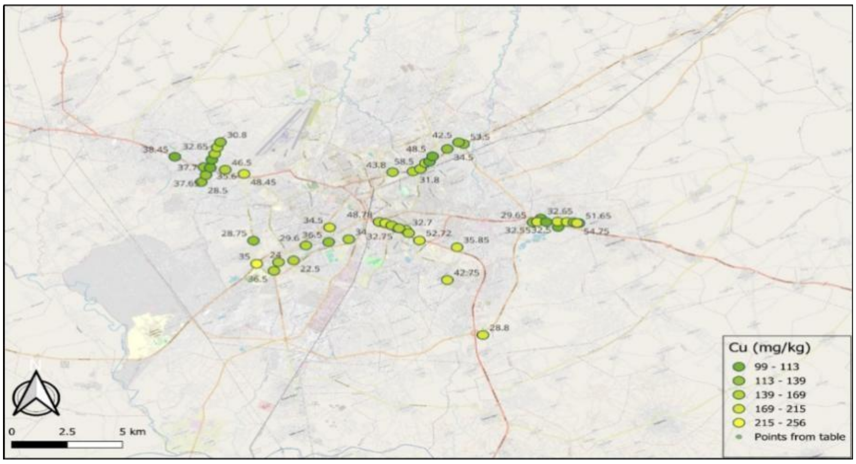

Plate 4.6: Spatial Distribution of Copper (Cu) in Road Dust Across The Study Area

3.2.7 Iron (Fe)

Iron distribution showed clear spatial differentiation, with higher concentrations observed around Katsina and Zaria roads, while comparatively lower levels were evident along Hadejia and BUK roads, indicating both natural and anthropogenic influences (Plate 4.7).

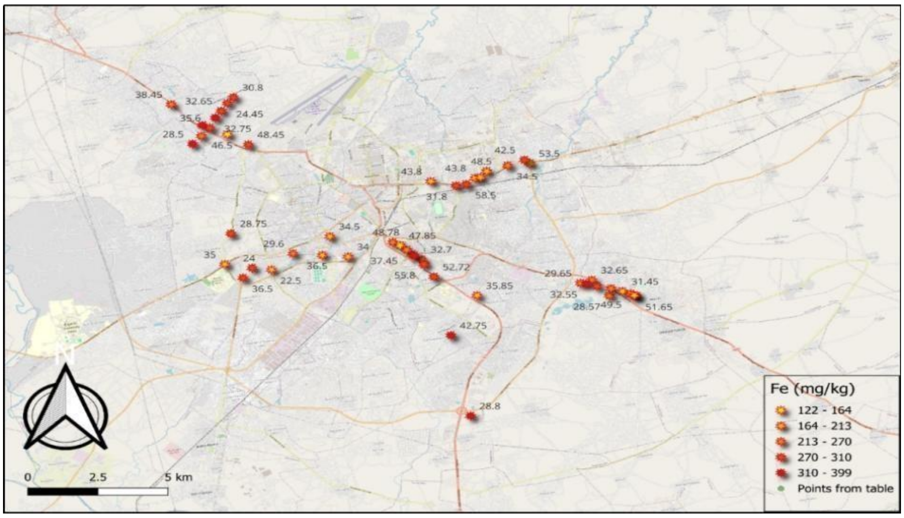

Plate 4.7: Spatial Distribution of Iron (Fe) in Road Dust Across The Study Area

3.2.8 Mercury (Hg)

Mercury concentrations displayed localized spatial enrichment, particularly along Zaria and Maiduguri roads, whereas lower concentrations were observed in other areas of the metropolis, suggesting site-specific contamination sources (Plate 4.8).

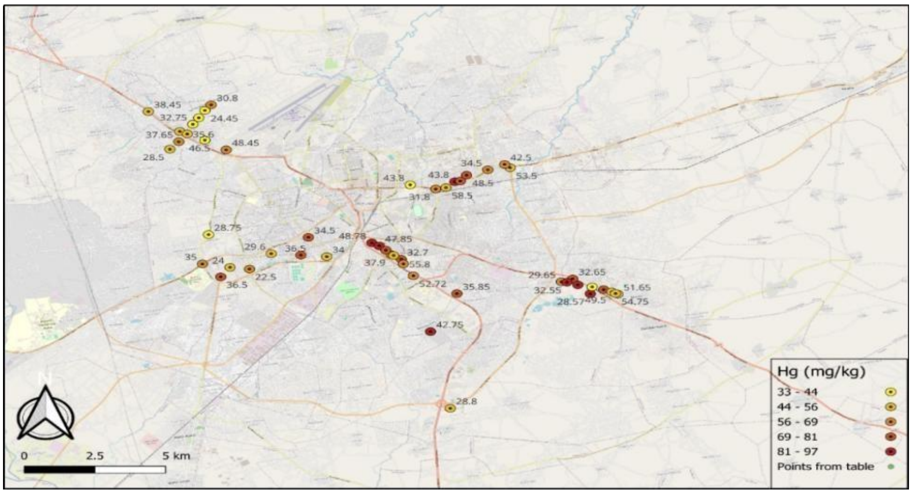

Plate 4.8: Spatial Distribution of Mercury (Hg) in Road Dust Across The Study Area

3.2.9 Magnesium (Mg)

Magnesium showed moderate spatial variability, with higher concentrations observed along Maiduguri and Zaria roads, while lower levels were recorded in less urbanized areas of Kano Metropolis (Plate 4.9).

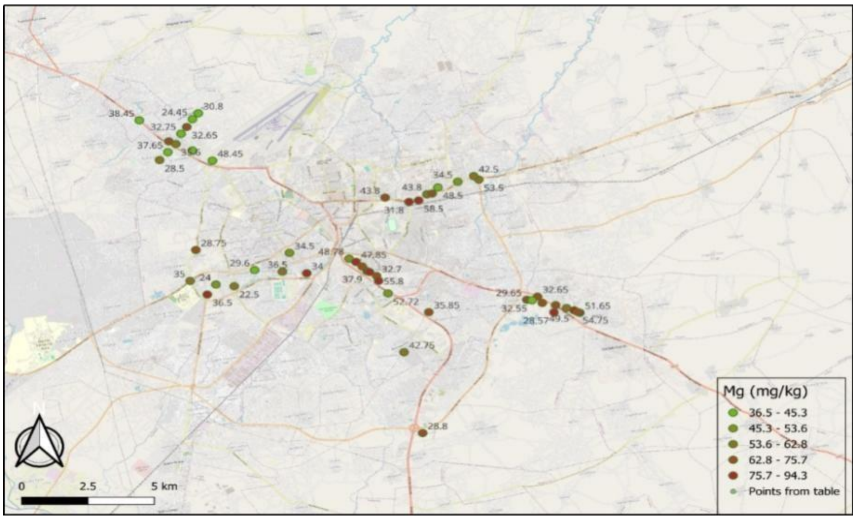

Plate 4.9: Spatial Distribution of Magnesium (Mg) in Road Dust Across The Study Area

3.2.10 Manganese (Mn)

Manganese concentrations exhibited relatively uniform spatial distribution across Kano Metropolis, with only slight enrichment along BUK and Katsina roads, indicating limited spatial differentiation (Plate 4.10).

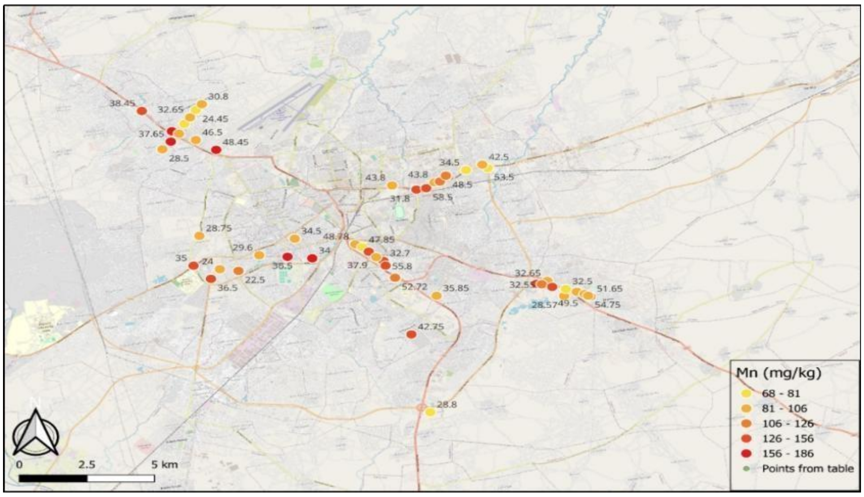

Plate 4.10: Spatial Distribution of Manganese (Mn) in Road Dust Across The Study Area

3.2.11 Nickel (Ni)

Nickel displayed distinct spatial variability, with elevated concentrations along Hadejia, Katsina, and Zaria roads, while comparatively lower levels were observed along BUK and Maiduguri roads, reflecting differences in anthropogenic inputs (Plate 4.11).

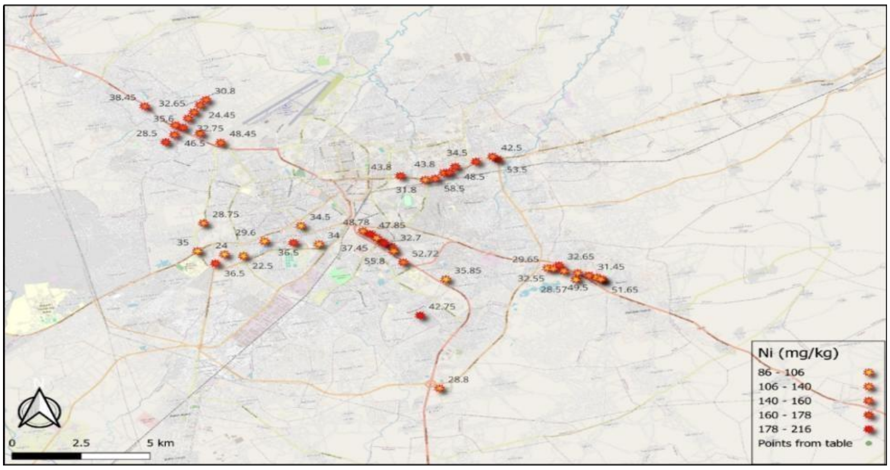

Plate 4.11: Spatial Distribution of Nickel (Ni) in Road Dust Across The Study Area

3.2.12 Lead (Pb)

Lead concentrations showed clear spatial variation, with higher levels concentrated along Katsina, Zaria, and Maiduguri roads, whereas lower concentrations were observed along Hadejia and BUK roads, consistent with traffic-related deposition patterns (Plate 4.12).

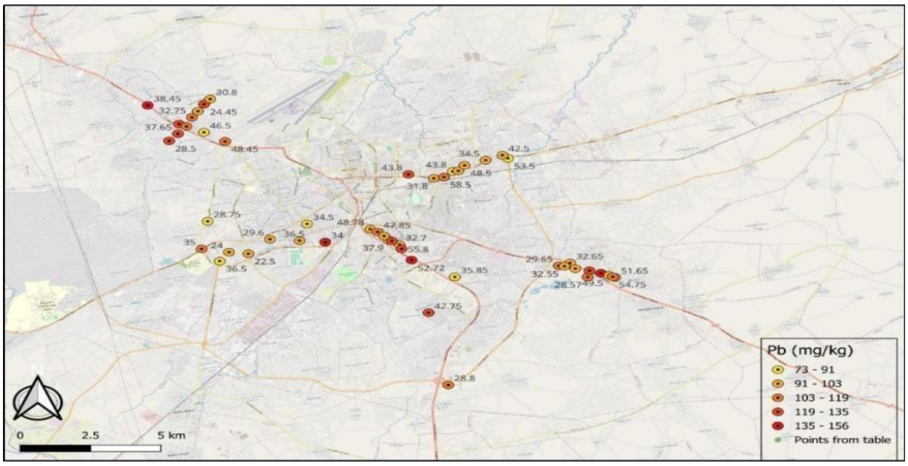

Plate 4.12: Spatial Distribution of Lead (Pb) in Road Dust Across The Study Area

3.2.13 Tin (Sn)

Tin exhibited strong spatial heterogeneity, with elevated concentrations along Zaria and Maiduguri roads, while lower levels were observed in other parts of Kano Metropolis, indicating localized sources (Plate 4.13).

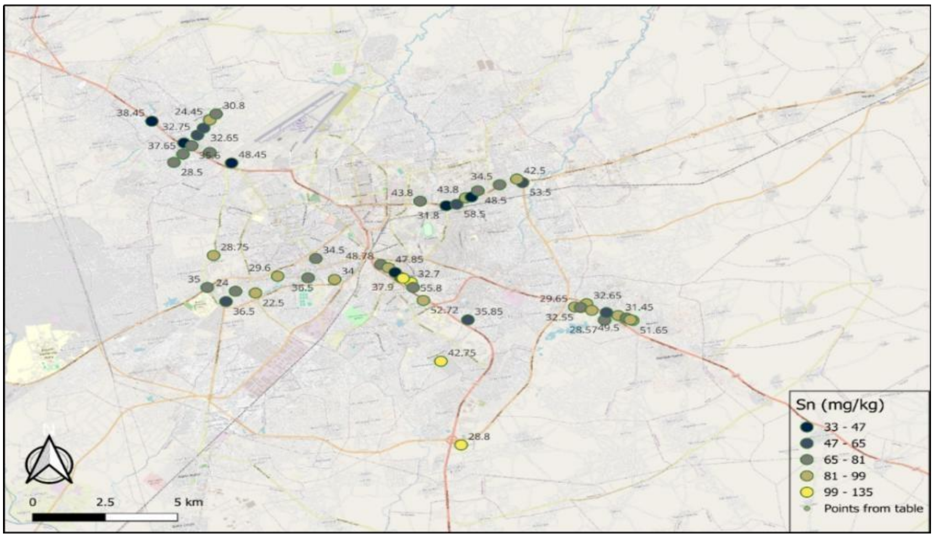

Plate 4.13: Spatial Distribution of Tin (Sn) in Road Dust Across The Study Area

3.2.14 Vanadium (V)

Vanadium concentrations showed relatively subtle spatial variation, with slightly higher levels observed along Zaria Road, while other areas displayed more uniform distribution across the metropolis (Plate 4.14).

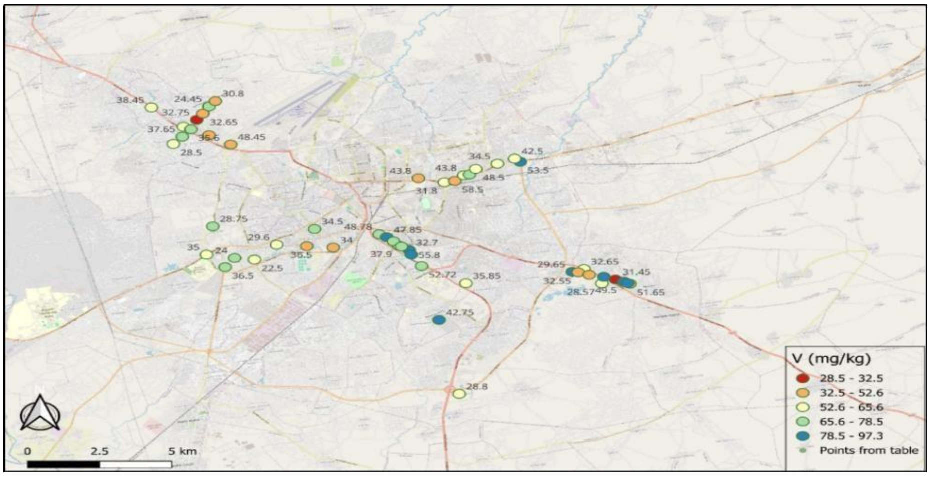

Plate 4.14: Spatial Distribution of Vanadium (V) in Road Dust Across The Study Area

3.2.15 Zinc (Zn)

Zinc distribution was spatially heterogeneous, with elevated concentrations occurring along Zaria and Maiduguri roads, while lower levels were evident around Katsina Road, highlighting the influence of vehicular and urban activities (Plate 4.15).

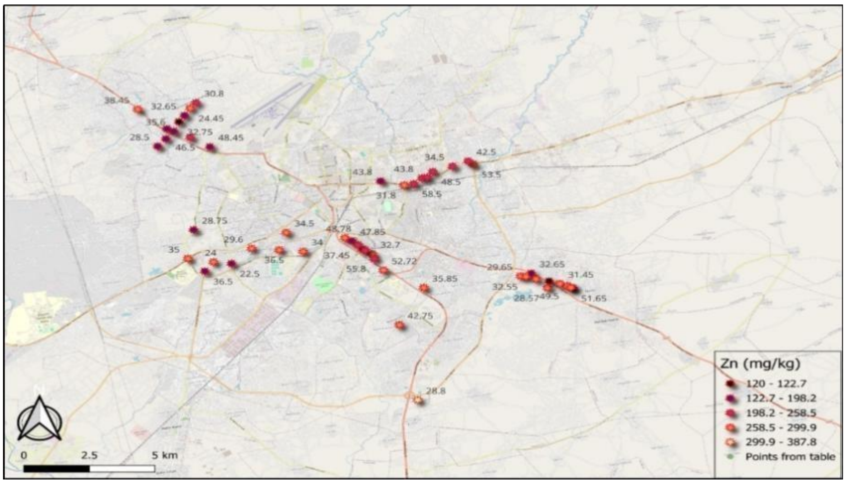

Plate 4.15: Spatial Distribution of Zinc (Zn) in Road Dust Across The Study Area

4.1 Discussion

4.1.2 Aluminium (Al)

Aluminium was ubiquitous in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 107.37 ± 23.86 mg/kg (Katsina Road) to 131.99 ± 19.43 mg/kg (Hadejia Road). The Hadejia mean slightly exceeds the maximum permissible / background reference shown in this study's MPL column (120 mg/kg; NESREA, 2016), while the other roads fall close to or below that reference. This pattern, elevated Al where traffic, construction and pavement abrasion are greatest, is consistent with the literature: Al is abundant in crustal materials and in road dust it commonly reflects both natural (soil/rock) and anthropogenic (vehicle abrasion, building materials, cement, brake and tyre wear, construction activities) inputs (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparing the present results with other Nigerian and regional studies shows broadly similar findings. Urban road-dust surveys in Lagos, Ibadan and other Nigerian cities have likewise reported detectable and often elevated Al in roadside dust, attributing variations to traffic intensity, local geology and construction activity (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). For example, multi-site studies in major Nigerian cities frequently detect Al among the most abundant elements in dust, with spatial "hotspots" near busy corridors and construction zones (Rybak, 2020; Olumayede *et al*., 2024). Internationally, urban studies and reviews also report Al as a dominant crustal tracer in road dust and link higher road-side Al concentrations to unpaved sections, road resurfacing, and re-suspension of soil and construction debris (Vlasov *et al*., 2022; Lei *et al*., 2025). Thus, your Kano findings fit the expected pattern for mixed lithogenic– anthropogenic sources in fast-growing West African cities.

From an exposure and health standpoint, aluminium is not classed as a classic "priority" carcinogen, but it is biologically active and can produce adverse effects if internalized in sufficient quantities over time. Toxicology and epidemiological reviews indicate that chronic high exposure to certain forms of aluminium (e.g., soluble Al^{3+}) has been associated with neurological effects, including cognitive impairment and concerns over neurodevelopmental vulnerability in children, as well as bone and dialysis-related encephalopathy in occupational or medical settings (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). Urban road dust is an exposure medium primarily via inhalation of resuspended fine particulates, incidental ingestion (hand-to-mouth behaviour, important for children), and dermal contact.

4.1.3 Arsenic (As)

Arsenic was detected in road dust across all five study roads, with mean concentrations ranging from 119.85 ± 29.73 mg/kg at Katsina Road to 161.65 ± 41.55 mg/kg at BUK Road. Elevated As levels along BUK and Maiduguri Roads (156.43 ± 10.30 mg/kg) indicate localized anthropogenic inputs, consistent with traffic density, commercial activities, and fuel combustion. Lower concentrations at Katsina and Hadejia Roads reflect comparatively lighter traffic and fewer roadside emissions. This spatial pattern aligns with the literature, as arsenic in urban dust commonly originates from vehicle emissions, industrial activity, and resuspension of contaminated dusts (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparing the present results with other Nigerian urban studies shows broadly similar findings. Roadside dust surveys in Lagos, Ibadan, and Abuja reported arsenic concentrations ranging from 100–180 mg/kg, with higher levels near busy roads and commercial hubs (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, urban studies in Asia and Europe also report arsenic enrichment in road dust along major traffic corridors and near industrial zones (Lei *et al*., 2025; Vlasov *et al*., 2022). Thus, the Kano findings reflect the expected pattern of mixed lithogenic–anthropogenic sources in fast-growing West African cities. From a health standpoint, arsenic is a Group 1 human carcinogen. Chronic exposure through inhalation of resuspended fine particles and incidental ingestion of dust can cause skin lesions, cardiovascular disorders, neurological impairments, and cancers. Children, roadside vendors, and traffic personnel are especially vulnerable (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). The relatively high arsenic levels along BUK and Maiduguri Roads reveal the need for targeted interventions such as traffic regulation, street cleaning, and public-awareness campaigns to mitigate exposure risks in these urban hotspots.

4.1.4 Cadmium (Cd)

Cadmium was detected in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 31.72 ± 5.21 mg/kg at BUK Road to 43.92 ± 8.40 mg/kg at Hadejia Road. Elevated Cd levels along Hadejia and Zaria Roads suggest influence from traffic emissions, vehicle wear (particularly tyres and brake linings), and possible waste incineration, whereas lower levels at BUK and Katsina Roads indicate comparatively lighter anthropogenic input. This distribution pattern is consistent with urban road-dust studies, where Cd is often linked to vehicular and industrial activities (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparisons with other Nigerian cities show similar trends. Surveys in Lagos, Ibadan, and Abuja reported Cd concentrations ranging from 25–45 mg/kg, with hotspots near heavily trafficked and commercial areas (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, urban dust studies also highlight Cd enrichment along major roads and industrial zones, reflecting anthropogenic deposition on top of natural background levels (Lei *et al*., 2025; Vlasov *et al*., 2022). Thus, the present Kano results reflect typical patterns of mixed lithogenic– anthropogenic sources in growing West African cities.

From a health perspective, cadmium is highly toxic, with chronic exposure linked to kidney damage, bone demineralization, and respiratory disorders. Children and roadside workers are particularly vulnerable due to hand-to-mouth contact and inhalation of fine dust particles (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). The elevated Cd levels along Hadejia and Zaria Roads reveal the need for urban dust management strategies, including street cleaning, traffic regulation, and public education to minimize exposure risks.

4.1.5 Cobalt (Co)

Cobalt was present in road dust across all five major roads in Kano Metropolis, with mean concentrations ranging from 68.69 ± 17.10 mg/kg at Katsina Road to 127.33 ± 32.01 mg/kg at Hadejia Road. Higher Co levels along Hadejia and Zaria Roads likely reflect intense vehicular traffic, wear of alloyed metal parts, and localized industrial emissions, whereas lower levels at Katsina Road suggest comparatively reduced anthropogenic inputs. Such spatial variability aligns with studies showing Co enrichment in urban road dust near high-traffic corridors and industrial hotspots (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparative assessments with other Nigerian cities demonstrate similar patterns. Urban dust surveys in Lagos and Abuja reported Co concentrations ranging between 60–120 mg/kg, with the highest levels detected near busy roads and auto-repair workshops (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Globally, urban studies indicate that Co, though a trace element, is often enriched in roadside dust due to vehicular emissions and anthropogenic surface deposition (Lei *et al*., 2025; Vlasov *et al*., 2022). Therefore, the observed distribution in Kano is consistent with mixed lithogenic and anthropogenic contributions typical of fast-growing West African cities.

From a toxicological perspective, cobalt is an essential trace element but can be hazardous at elevated levels. Chronic exposure may lead to respiratory, cardiovascular, and thyroid-related effects, while inhalation of Co-containing dust poses risks to street vendors, roadside mechanics, and children (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). The relatively high Co concentrations along Hadejia and Zaria Roads highlight the need for preventive measures, including dust suppression, traffic management, and public awareness campaigns to reduce exposure to sensitive populations.

4.1.6 Chromium (Cr)

Chromium was detected in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 91.08 ± 13.77 mg/kg at Katsina Road to 109.01 ± 11.89 mg/kg at Zaria Road. Elevated levels along Zaria and Maiduguri Roads likely reflect intensive traffic, brake and tyre wear, and urban infrastructure-related inputs, whereas lower levels at Katsina and Hadejia Roads indicate areas with less anthropogenic disturbance. This spatial pattern is consistent with previous studies that link Cr accumulation in road dust to both vehicular emissions and abrasion of stainless-steel components in vehicles and construction materials (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparisons with other Nigerian cities show broadly similar findings. Urban dust surveys in Lagos, Abuja, and Ibadan reported Cr concentrations generally ranging from 85 to 120 mg/kg, with hotspots typically observed along heavily trafficked routes and near industrial zones (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, studies also note that Cr is a common constituent in urban dust, often enriched in areas with high vehicular density and construction activities (Lei *et al*., 2025; Vlasov *et al*., 2022). Therefore, the Kano results align with global observations of Cr as a tracer of mixed lithogenic–anthropogenic sources in urban environments.

From a health perspective, chromium exists in several oxidation states, with Cr(VI) being highly toxic and carcinogenic, while Cr(III) is an essential nutrient in trace amounts. Prolonged exposure to Cr(VI) via inhalation or ingestion may lead to respiratory, dermatological, and gastrointestinal issues, emphasizing the risk for children and roadside workers (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). Although the measured total Cr concentrations in Kano are within ranges reported for urban dust elsewhere, ongoing monitoring and assessment of Cr speciation are recommended to accurately evaluate public health risks, particularly in high-traffic corridors like Zaria and Maiduguri Roads.

4.1.7 Copper (Cu)

Copper was present in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 132.80 ± 28.95 mg/kg at Katsina Road to 173.56 ± 15.31 mg/kg at Zaria Road. Higher concentrations along Zaria and BUK Roads likely reflect intensive traffic, brake and tyre wear, corrosion of metal parts, and contributions from electrical and construction materials, while lower levels along Katsina and Hadejia Roads suggest relatively lower anthropogenic inputs. This distribution pattern is consistent with the literature, which identifies Cu as a common contaminant in urban dust, originating from vehicular emissions, industrial activities, and infrastructure degradation (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparative studies in Nigeria and other West African cities show similar trends. For instance, urban road dust in Lagos, Abuja, and Ibadan often reports Cu concentrations between 120 and 180 mg/kg, with hotspots near busy traffic corridors and industrial sites (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, Cu is frequently observed as a traffic-related pollutant in urban dust, often linked to brake wear, tyre abrasion, and corrosion of metallic infrastructure (Lei *et al*., 2025; Vlasov *et al*., 2022). Therefore, the present Kano results reflect typical mixed lithogenic and anthropogenic contributions characteristic of rapidly urbanizing cities.

Regarding exposure and health implications, copper is an essential trace element but can be toxic at elevated concentrations. Chronic ingestion or inhalation of Cu-rich dust can cause gastrointestinal disturbances, liver and kidney damage, and oxidative stress (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). Although the mean Cu levels recorded in Kano are within ranges commonly observed in urban dust studies, the relatively high values along Zaria and BUK Roads indicate that sensitive populations, including children, traffic police, and street vendors, may be at higher risk. Monitoring and mitigation measures, such as controlling dust resuspension and regular street cleaning, are recommended to reduce exposure in these hotspots.

4.1.8 Iron (Fe)

Iron was abundant in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 222.37 ± 60.71 mg/kg at Hadejia Road to 310.01 ± 42.53 mg/kg at Katsina Road. Elevated concentrations along Katsina and Zaria Roads likely reflect combined natural and anthropogenic sources, including soil and crustal material, vehicular wear, corrosion of metallic structures, and construction debris. Lower levels along Hadejia and BUK Roads suggest reduced anthropogenic input or better dispersion conditions. This distribution pattern aligns with previous studies indicating Fe as a dominant element in urban dust due to both crustal origin and traffic-related contributions (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparative studies in other Nigerian cities, such as Lagos and Ibadan, report Fe concentrations in road dust ranging from 200 to 350 mg/kg, with higher values near busy traffic corridors and construction zones (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, Fe is consistently identified as a major constituent of urban dust, often linked to resuspension of soil, corrosion of vehicles, and industrial emissions (Lei *et al*., 2025; Vlasov *et al*., 2022). The Kano results, therefore, fit the expected pattern of mixed lithogenic and anthropogenic sources in a rapidly urbanizing West African city.

From a health perspective, iron is an essential nutrient but excessive exposure can have toxic effects, particularly through inhalation of fine particulate matter. Chronic inhalation of Fe-laden dust has been associated with respiratory irritation, oxidative stress, and in extreme cases, pulmonary fibrosis (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). Although the Fe levels in Kano's road dust are generally within ranges observed in other urban studies, individuals frequently exposed to roadside dust, such as traffic personnel and street vendors, may face increased health risks. Measures to minimize dust resuspension, including regular street cleaning and vegetation buffers along roadsides, could mitigate exposure in high-concentration areas.

4.1.9 Mercury (Hg)

Mercury was detected across all five study roads in Kano Metropolis, with mean concentrations ranging from 50.53 ± 10.25 mg/kg at Katsina Road to 70.19 ± 13.50 mg/kg at Zaria Road. Elevated Hg levels along Zaria and Maiduguri Roads suggest localized anthropogenic inputs, potentially from vehicular emissions, industrial activities, battery waste, and improper disposal of mercury- containing materials. Lower concentrations along Katsina and Hadejia Roads indicate either fewer sources or greater dispersion. This spatial heterogeneity is consistent with urban dust studies, where Hg often displays site-specific enrichment due to its affinity for fine particulate matter and susceptibility to deposition from anthropogenic activities (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparisons with other Nigerian cities show broadly similar patterns. For instance, studies in Lagos and Port Harcourt report road dust Hg concentrations ranging from 45 to 75 mg/kg, with higher levels near industrial areas, busy traffic corridors, and waste disposal sites (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024).

Internationally, urban Hg in dust is commonly linked to combustion of fossil fuels, artisanal metal processing, and improper waste handling (Lei *et al*., 2025; Vlasov *et al*., 2022). The Kano results, therefore, reflect both natural background and human-induced contamination in rapidly urbanizing regions.

From a health perspective, Hg is highly toxic even at low concentrations. Chronic exposure, primarily through inhalation of fine Hg-laden dust particles or ingestion of contaminated materials, can lead to neurological impairment, renal dysfunction, and developmental effects in children (Skalny *et al*., 2021; Igbokwe *et al*., 2020; Renke *et al*., 2023). Given the observed concentrations, populations frequently exposed to road dust, such as street vendors, traffic police, and roadside residents, may be at elevated risk. Mitigation strategies, including regular street cleaning, proper waste management, and public education on exposure avoidance, are recommended to reduce potential health impacts.

4.1.10 Magnesium (Mg)

Magnesium was present across all road dust samples, with mean concentrations ranging from 50.20 ± 12.90 mg/kg at Katsina Road to 71.88 ± 14.00 mg/kg at Zaria Road. Elevated levels along Zaria and Maiduguri Roads suggest contributions from both natural sources, such as soil and crustal material, and anthropogenic activities, including traffic-related dust resuspension, concrete abrasion, and construction debris. Lower concentrations along Katsina and Hadejia Roads likely reflect less intense urban activity and lower traffic density. This spatial distribution aligns with prior studies indicating that Mg in urban dust often mirrors underlying geology while being amplified by human activities (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparatively, road dust studies in other Nigerian cities report Mg concentrations between 45 and 75 mg/kg, with higher values typically recorded near busy commercial roads and construction sites (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Similarly, international research identifies Mg as a prevalent crustal element in urban dust, where vehicular abrasion, cement handling, and pavement wear can elevate its concentrations locally (Lei *et al*., 2025; Vlasov *et al*., 2022). Thus, the observed Kano values reflect the expected lithogenic and mixed anthropogenic inputs typical of rapidly developing West African cities.

From a health standpoint, magnesium is generally considered an essential micronutrient, and environmental exposure through dust is unlikely to pose direct toxicity under normal circumstances. However, fine Mg-containing particulates can contribute to respiratory irritation when inhaled repeatedly, particularly among sensitive populations such as children, the elderly, and individuals with pre-existing respiratory conditions (Skalny *et al*., 2021; Renke *et al*., 2023).

4.1.11 Manganese (Mn)

Manganese was detected in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 105.73 ± 26.68 mg/kg at Hadejia Road to 127.33 ± 32.01 mg/kg at BUK Road. The spatial distribution shows slight enrichment along BUK and Katsina Roads, likely due to higher traffic density, vehicular brake wear, and resuspension of soil and construction debris. Lower concentrations along Hadejia Road suggest comparatively less intensive anthropogenic input in that corridor. These patterns are consistent with previous research indicating that Mn in urban dust originates from both natural lithogenic sources and anthropogenic activities such as road abrasion, industrial emissions, and vehicle exhaust (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparative studies from Nigerian cities have reported Mn concentrations in road dust ranging from 95 to 140 mg/kg, with hotspots typically located near busy roads, commercial hubs, and construction zones (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). International studies similarly confirm that Mn is a common constituent of urban dust and that higher levels are often linked to traffic intensity, brake wear, and urban infrastructure (Lei *et al*., 2025; Vlasov *et al*., 2022). The Kano findings fit within this regional and global context, reflecting mixed lithogenic and anthropogenic sources.

In terms of health implications, manganese is an essential trace element required for enzymatic functions, but excessive exposure, particularly through inhalation of fine particles, may pose neurological risks, including cognitive impairment and motor dysfunction in children and occupationally exposed adults (Skalny *et al.*, 2021; Renke *et al.*, 2023). Urban road dust exposure pathways primarily include inhalation, incidental ingestion, and dermal contact.

4.1.12 Nickel (Ni)

Nickel was present in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 115.68 ± 33.42 mg/kg at BUK Road to 159.50 ± 15.49 mg/kg at Hadejia Road. Elevated concentrations along Hadejia, Katsina, and Zaria Roads suggest contributions from traffic emissions, vehicular wear (especially from engines and tires), and potential industrial inputs, whereas lower levels along BUK and Maiduguri Roads indicate comparatively lower anthropogenic loading. Nickel's presence in urban dust typically reflects a combination of lithogenic sources (soil, rock) and human activities, particularly those associated with vehicles and urban infrastructure (Vlasov *et al.*, 2022; Rybak *et al.*, 2020).

Comparison with other Nigerian studies shows similar concentrations in urban road dust, with reported mean values ranging from 110 to 165 mg/kg, often peaking near busy traffic corridors or industrial zones (Ojiodu *et al.*, 2023; Kolawole *et al.*, 2023; Aturamu *et al.*, 2024). Globally, urban dust surveys indicate that Ni is commonly enriched near highways, manufacturing sites, and areas with frequent use of nickel-containing alloys, revealing the importance of anthropogenic contributions (Lei *et al.*, 2025; Vlasov *et al.*, 2022). The Kano results align with these patterns, highlighting the role of high-traffic roads as hotspots for Ni accumulation.

From a toxicological perspective, nickel is classified as a priority pollutant due to its potential carcinogenicity and ability to induce respiratory, dermatological, and systemic effects following chronic exposure (Skalny *et al.*, 2021; Renke *et al.*, 2023). In urban road dust, inhalation of fine particles is the primary route of exposure, while incidental ingestion and dermal contact also contribute. Children, traffic police, and roadside vendors are particularly vulnerable. Although the observed concentrations are within ranges reported in other Nigerian cities, continued monitoring is recommended to prevent long-term exposure risks, especially in high-traffic corridors.

4.1.13 Lead (Pb)

Lead was detected across all five study roads in Kano Metropolis, with mean concentrations ranging from 97.16 ± 13.64 mg/kg at Hadejia Road to 119.40 ± 15.08 mg/kg at Katsina Road. Higher levels along Katsina, Zaria, and Maiduguri Roads suggest substantial contributions from traffic emissions, particularly from older vehicles, vehicular wear (brake linings, tires), and historical use of leaded gasoline. Lower concentrations along Hadejia and BUK Roads may reflect reduced traffic density or better road management practices. Lead in urban road dust generally reflects both natural lithogenic sources and anthropogenic inputs, with the latter dominating in high-traffic corridors (Rybak *et al.*, 2020; Vlasov *et al.*, 2022).

Comparisons with previous studies in Nigeria indicate that the observed Pb concentrations are consistent with urban road dust values reported in Lagos, Ibadan, and Abuja, where heavy traffic and industrial activities contribute to roadside enrichment (Ojiodu *et al.*, 2023; Kolawole *et al.*, 2023; Aturamu *et al.*, 2024). Internationally, urban dust surveys in fast-growing cities often record Pb as one of the priority metals in road dust, with hotspots along major traffic routes and industrial areas (Lei *et al.*, 2025; Olumayede *et al.*, 2024). Thus, the current findings in Kano align with expected patterns of anthropogenic Pb accumulation in metropolitan settings.

From a health perspective, lead is a well-established toxicant, with no safe level of exposure. Chronic exposure via inhalation, incidental ingestion (particularly in children), and dermal contact can lead to neurodevelopmental deficits, hematological disorders, kidney damage, and cardiovascular problems (Skalny *et al.*, 2021; Renke *et al.*, 2023; Igbokwe *et al.*, 2020). Children are particularly susceptible due to hand-to-mouth behaviors and higher absorption rates. The mean concentrations observed in this study, while within ranges reported in other Nigerian cities, highlight the need for exposure mitigation measures, including street cleaning, dust suppression, and public awareness campaigns for residents and roadside workers.

4.1.14 Tin (Sn)

Tin was present in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 61.87 ± 16.69 mg/kg at Katsina Road to 95.40 ± 29.99 mg/kg at Zaria Road.

Elevated levels along Zaria and Maiduguri Roads suggest localized anthropogenic sources, likely including industrial activities, vehicle parts, soldering residues, and corrosion products, while lower concentrations along Hadejia and Katsina Roads reflect comparatively less urban or industrial influence. Spatial heterogeneity indicates that Sn contamination in road dust is influenced more by site-specific sources than by general lithogenic input (Rybak *et al*., 2020; Vlasov *et al*., 2022).

Comparing these findings with other Nigerian studies shows similar patterns of tin accumulation in urban environments. For example, studies in Lagos and Abuja report Sn in road dust ranging from moderate to elevated levels, with hotspots associated with industrial zones and dense traffic corridors (Ojiodu *et al*., 2023; Kolawole *et al*., 2023). Internationally, urban surveys often detect tin as a minor yet significant trace metal in road dust, particularly in areas with mechanical workshops, tin-based construction materials, and electronic waste recycling activities (Lei *et al*., 2025; Olumayede *et al*., 2024). Thus, the Kano results are consistent with expected anthropogenic contributions in fast-growing cities.

From a toxicological perspective, tin is generally considered low in acute toxicity but certain organotin compounds can be harmful to human health and aquatic systems. Chronic exposure via dust inhalation or incidental ingestion could potentially affect the endocrine and immune systems, though typical roadside dust concentrations rarely reach critical levels (Skalny *et al*., 2021; Renke *et al*., 2023). Nevertheless, urban populations, especially children and roadside workers, remain at risk from repeated exposure. Mitigation strategies should focus on dust management, control of industrial emissions, and public education to minimize incidental ingestion and inhalation.

4.1.15 Vanadium (V)

Vanadium was detected in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 56.46 ± 15.83 mg/kg at Katsina Road to 76.40 ± 12.32 mg/kg at Zaria Road. The spatial pattern indicates moderate enrichment along major traffic and urban activity corridors, particularly Zaria Road, while other roads recorded relatively lower values. This distribution suggests that vanadium in road dust originates from both natural crustal sources and anthropogenic inputs, including fuel combustion, oil residues, industrial emissions, and vehicular wear (Vlasov *et al*., 2022; Rybak *et al*., 2020).

Comparative studies within Nigeria show broadly similar vanadium levels in urban dust. For instance, surveys in Lagos and Abuja report vanadium concentrations in road dust ranging from moderate to elevated, often linked to heavy traffic, diesel vehicle emissions, and local industrial activities (Ojiodu *et al*., 2023; Kolawole *et al*., 2023). Globally, urban road dust studies also identify vanadium as a marker of fossil fuel combustion and industrial sources, with hotspots occurring near busy roads, refineries, and metallurgical operations (Lei *et al*., 2025; Olumayede *et al*., 2024). Thus, the observed pattern in Kano aligns with mixed lithogenic–anthropogenic sources in rapidly urbanizing West African cities.

From a health perspective, vanadium exposure is generally low through incidental ingestion and dermal contact with road dust, but chronic inhalation of fine vanadium-containing particulates can impact the respiratory system and may contribute to oxidative stress or cardiovascular effects in sensitive populations (Skalny *et al*., 2021; Renke *et al*., 2023). Children, street vendors, and traffic personnel are particularly vulnerable due to higher exposure frequency. While the mean values observed are below widely cited hazardous thresholds, repeated exposure reveals the need for dust control measures, proper road maintenance, and public awareness regarding potential risks.

4.1.16 Zinc (Zn)

Zinc was present in road dust across all five study roads in Kano Metropolis, with mean concentrations ranging from 203.37 ± 47.11 mg/kg at Katsina Road to 267.72 ± 54.98 mg/kg at Zaria Road. The highest values were recorded along Zaria and Maiduguri Roads, reflecting areas of intense traffic and urban activity. The spatial distribution suggests that zinc in road dust arises from both natural sources, such as soil and crustal materials, and anthropogenic activities, including vehicular wear (tires and brake linings), lubricating oil residues, industrial emissions, and construction activities (Vlasov *et al*., 2022; Rybak *et al*., 2020).

When compared to other Nigerian studies, these levels of zinc are consistent with observations in urban centers such as Lagos, Ibadan, and Abuja, where road dust surveys reported elevated zinc concentrations, particularly along major transport corridors and industrial zones (Ojiodu *et al*., 2023; Kolawole *et al*., 2023; Aturamu *et al*., 2024). Internationally, urban studies also identify zinc as a common road dust contaminant, often enriched near high-traffic areas and locations with industrial emissions (Lei *et al*., 2025; Olumayede *et al*., 2024). The Kano data fit the expected profile for mixed lithogenic and anthropogenic contributions in growing urban environments.

Regarding health implications, zinc is an essential trace element but can produce adverse effects when exposure exceeds tolerable levels. Urban road dust serves as an exposure medium via incidental ingestion, inhalation of resuspended dust particles, and dermal contact, particularly for children, street vendors, and roadside workers. Excessive or repeated exposure to zinc in particulate form may contribute to gastrointestinal disturbances and respiratory irritation, although the concentrations observed in this study are generally below the limits considered hazardous (Skalny *et al*., 2021; Renke *et al*., 2023). Nonetheless, the relatively elevated concentrations along Zaria and Maiduguri Roads highlight the need for localized dust mitigation measures, including street cleaning, traffic management, and awareness campaigns to reduce exposure.

V. Conclusion And Recommendation

This study demonstrates that road dust in Kano Metropolis 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, particularly 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.

VI. 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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