

HEALTH RISK ASSESSMENT OF DUST-BOUND HEAVY METALS IN URBAN ROADSIDE ENVIRONMENTS IN KOGI STATE, NIGERIA

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ABSTRACT

Natural processes and anthropogenic activities contribute heavily to the roadside as a major sink for toxic heavy metals, with health implications for residents. A study was conducted to determine the concentrations and health impacts of heavy metals bound to roadside dust at selected sites within the urban road system in Kogi State, Nigeria. Roadside dust was randomly collected at Nataco, Ganaja, Ejule and Okene and analyzed by ICP-OES for Pb, Cd, Cr, As, Ni and Zn. Zn ranged from 81.029–168.000 mg/kg; Pb ranged from 11.01–28.14 mg/kg. Nataco had the highest Pb (28.14), Cd (1.003), and As (0.911). CF showed values ranging from considerable to very high for Cd (up to 5.02) and As (up to 6.18). Igeo indicated moderate pollution for Cd (+1.74) and As (+2.04). Hazard values were all <1 (ranging from 0.008 to 0.144). Cancer risks (1.44×10^{-6} to 6.63×10^{-6}) were below the USEPA limit (1×10^{-6}). PCA identified traffic-industrial-combustion (58.2%) and tire wear (21.4%). The roadside dust in the urban centers of Kogi State shows higher concentrations of heavy metals at Nataco and Ganaja Junction. The risk currently posed to the lives of the urban center's dwellers has been reported to be acceptable for now. However, regular surveillance and efforts toward pollution prevention/control are encouraged to reduce future buildup and protect susceptible individuals.

Keywords: Heavy metals, roadside dust, health risk assessment, pollution indices, Kogi State, urban environment

INTRODUCTION

The rapid pace of globalization, particularly in urbanization and industrialization, especially in developing countries, has led to escalating environmental pollution, including traffic congestion, poor town planning and waste disposal problems (Ogundele & Akinola, 2025). Among the contaminants in roadside dust, heavy metals (Pb, Cd, Cr, Ni, Zn and As) pose significant environmental and public health concerns due to their high toxicity, persistence and low biodegradability (Kolawole *et al.*, 2026). Heavy metals are frequently released from vehicle emissions, industrial processes, tire and brake abrasion, fuel combustion and construction work and are accumulated in urban roadside environments (Ogundele & Akinola, 2025). Roadside dust, as an important environmental matrix, serves as a reservoir for toxicants that are easily redeposited into the atmosphere during vehicle driving and wind transport (Kolawole *et al.*, 2026). Exposure of the general public to dust-bound metals occurs through ingestion, inhalation and dermal contact, particularly among children who might transfer dust particles from their hands to their mouths; young age groups generally weigh less, and their physical characteristics may

increase exposure and health risks. Chronic exposure is associated with various non-carcinogenic and carcinogenic health problems like neurological diseases, kidney damage, respiratory diseases, heart problems, cancer and cancer-type-other diseases as well as developmental complications and depression in children respectively (Kolawole *et al.*, 2026).

Urbanization is at an advanced rate in Nigeria, result in increasing traffic activities leading to worsen in environment pollution especially at large scale commercial city and in Nigeria's major cities, some work carried out on various urban center such as Lagos, Enugu, Osogo, Ibadan, Jos to document on the level of heavy metals contamination in roadside dust and associated health risk to their inhabitants (Zhang *et al.*, 2024). Kogi state a major transit route that connect North and South of Nigeria experiences the expanding trend on urbanization, commercialization and traffic activities and thus environmental contaminations experiences have increase within lokoja, Ejule, Okene of Kogi state due to heavy traffic, roadside traders, waste dumps, and commercial activities along roadways (Ogundele *et al.*, 2020).

While the number of anthropogenic activities has increased significantly in Kogi State, few studies have investigated the concentrations and health issues associated with roadside heavy metals in urban areas within Kogi State. Most of the work focuses on mining areas, water pollution, and soils, with few studies on urban roadside areas (Oluwasola *et al.*, 2023). Thus, there is a gap in our knowledge of the presence and extent of roadside dust-bound heavy-metal pollution in Kogi State, as well as the associated non-carcinogenic and carcinogenic health risks. This research aims to identify the concentrations and the health risks associated with roadside heavy metals in Kogi State, Nigeria. The specific objectives are to: characterize the concentrations of the selected heavy metals present in urban roadsides of Kogi state; determine the pollution status using pollution indices; identify possible sources contributing to these contaminations and evaluating health risks from non-carcinogenic and carcinogenic perspectives to exposed communities of the area.

MATERIALS AND METHODS

Study Area

Located in North Central Nigeria, Kogi State lies between the latitudes 6°30'N and 8°50'N and the longitudes 5°20'E and 7°50'E. The climate of the state is tropical with two seasons: (i) dry season (November-March) and (ii) rainy season (April-October). Four urban sites were chosen and sampled: Nataco, Ganaja Junction, Ejule Junction and Okene, to capture varying levels of traffic density and economic activity.

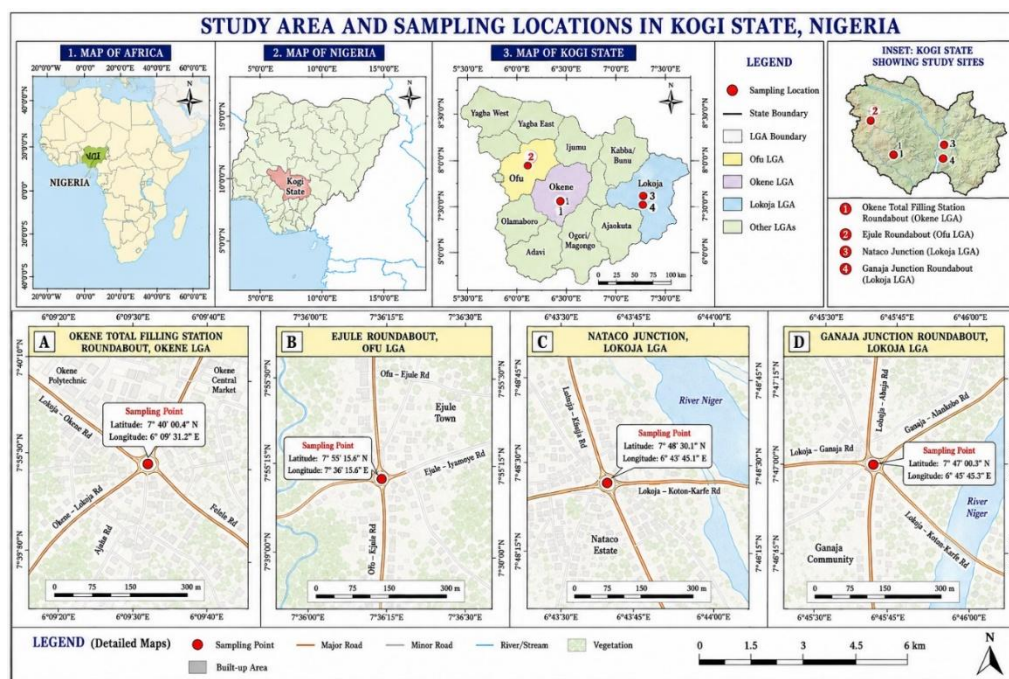


Figure 1: Map of the study area

Sample Collection and Preparation

Roadside dust samples from edge pavements of concrete roads and footpaths were collected with a clean plastic brush and dustpan. At each sampling location, several subsamples were collected and homogenized into a single composite sample to improve representativeness. Sampling locations were set around 1–2m away from the roadside edges, which represent the highest potential human exposure zones (Shi *et al.*, 2018).

Road dust samples were transported to the laboratory, air-dried in an ambient laboratory for one week, debris was picked up, then ground into powder using a porcelain mortar and pestle under a 63 m mesh sieve, and the resulting powder was saved in a tightly sealed plastic container.

Sample Digestion

For acid digestion, a modified version of the EPA wet digestion procedure (EPA, 2014) was used. A 1g sieved dust sample was placed in a digestion flask, 10 mL of concentrated HNO_3 was added, and the mixture was then left to stand overnight. The sample was warmed at 120°C until no further brown fumes evolved, then 5 mL of concentrated HCl was added; the solution was heated almost to dryness, and then 2 mL H_2O was added dropwise to complete the oxidation of the organic material.

After cooling, the digest was filtered through Whatman No. 42 filter paper, then made up to 50 mL with deionized water. A blank digestion was run with each set of samples.

Heavy Metal Analysis

The samples were analyzed for Pb, Cd, Cr, As, Ni and Zn by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES; Agilent 720). Certified value solutions were used to prepare a standard curve, and performance was verified frequently.

Physicochemical Analysis

pH meter (Hach) measurements were made using 20 g of air-dried

sample, which was mixed with 20 mL of distilled water and left for 30 minutes. 1.8. Total carbon (or organic carbon/matter): The sample (approx. 0.2 g) was burned in an oven (at 550°C) for 2 hrs, then calculated from the difference from the initial weight, representing percentage loss on ignition (%).

Pollution Indices

Contamination Factor (CF): $\text{CF} = C_{\text{metal}} / C_{\text{background}}$ (Hakanson, 1980)

Geo-accumulation Index (Igeo): $\text{Igeo} = \log_2(C_{\text{metal}} / 1.5 \times C_{\text{background}})$ (Müller, 1969)

Pollution Load Index (PLI): $\text{PLI} = (\text{CF}_1 \times \text{CF}_2 \times \dots \times \text{CF}_n)^{(1/n)}$ (Tomlinson *et al.*, 1980)

Health Risk Assessment

The health risks to both adults and children were evaluated utilizing the USEPA model. Average Daily Dose (ADD) for the ingestion, inhalation, and dermal routes of exposure was calculated as:

Ingestion: $\text{ADD}_{\text{ing}} = (C \times \text{IR} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT})$

Inhalation: $\text{ADD}_{\text{inh}} = (C \times \text{InhR} \times \text{EF} \times \text{ED}) / (\text{PEF} \times \text{BW} \times \text{AT})$

Dermal: $\text{ADD}_{\text{derm}} = (C \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED} \times 10^{-6}) / (\text{BW} \times \text{AT})$

Hazard Quotient (HQ): $\text{HQ} = \text{ADD} / \text{RfD}$

Hazard Index (HI): $\text{HI} = \sum \text{HQ}$

Cancer Risk (CR): $\text{CR} = \text{ADD} \times \text{CSF}$

Exposure parameters followed USEPA recommendations (Table 1).

Table 1: Exposure parameters for health risk assessment

Parameter	Adult	Child
Body weight (BW, kg)	70	15
Ingestion rate (IR, kg/day)	1.0×10^{-4}	2.0×10^{-4}
Inhalation rate (InhR)	20	10

m ³ /day)		
Skin surface area (SA, cm ²)	5700	2800
Adherence factor (AF, mg/cm ²)	0.2	0.2
Dermal absorption (ABS)	0.001	0.001
Exposure frequency (EF, day/yr)	365	365
Exposure duration (ED, yr)	30	6
Averaging time (AT, days)	10950 (carcin)/10 950	2190 (carcin)/2190

Statistical Analysis

Statistical analyses were conducted with Python (3.x) using pandas, scipy.stats, statsmodels and scikit-learn. Included were descriptive statistics, Spearman's rank correlation, Principal Component Analysis followed by Varimax rotation, and one-way ANOVA. Alpha was 0.05 for significance.

RESULTS

Heavy Metal Concentrations

Concentrations of heavy metals in the four study sites were presented in Tables 2-5. Among all the selected sites, zinc was the predominant element, with concentrations ranging from 81.029 mg/kg (Okene) to 168.000 mg/kg (Ganaja Junction). Lead concentrations at the sites ranged from 11.01 mg/kg (Ejule) to 28.14 mg/kg (Nataco).

Table 2: Heavy metal concentrations (mg/kg) at Nataco

Location	Pb	Cd	Cr	As	Ni	Zn
Composite A	28.14	1.003	1.003	0.911	0.723	150.003
Composite B	23.01	0.600	0.090	0.235	0.080	100.010
Composite C	20.00	0.400	0.051	0.300	0.432	98.072

Table 3: Heavy metal concentrations (mg/kg) at Ganaja Junction

Location	Pb	Cd	Cr	As	Ni	Zn
Composite A	20.30	0.901	0.401	0.090	0.501	168.000
Composite B	15.24	0.304	0.031	0.400	0.301	103.041
Composite C	21.00	0.701	0.500	0.231	0.054	98.009

Table 4: Heavy metal concentrations (mg/kg) at Ejule Junction

Location	Pb	Cd	Cr	As	Ni	Zn
Composite A	14.50	0.001	ND	0.090	0.061	120.051
Composite B	12.51	ND	ND	0.004	0.023	99.012
Composite C	11.01	ND	ND	0.001	0.052	89.000

ND = Not detected

Table 5: Heavy metal concentrations (mg/kg) at Okene

Location	Pb	Cd	Cr	As	Ni	Zn
Composite A	17.02	0.501	0.009	0.031	0.060	81.029
Composite B	15.00	0.402	0.040	0.019	0.500	83.002
Composite C	11.05	0.030	0.005	0.003	0.201	85.012

Descriptive Statistics

Mean concentrations and standard deviations by site are shown in Table 6.

Table 6: Mean ($\pm$ SD) heavy metal concentrations by site (mg/kg)

Site	Pb	Cd	Cr	As	Ni	Zn
Nataco	23.72 $\pm$ 4.08	0.668 $\pm$ 0.302	0.381 $\pm$ 0.534	0.482 $\pm$ 0.374	0.412 $\pm$ 0.327	116.03 $\pm$ 29.09
Ganaja	18.85 $\pm$ 3.12	0.635 $\pm$ 0.301	0.311 $\pm$ 0.239	0.240 $\pm$ 0.155	0.285 $\pm$ 0.224	123.02 $\pm$ 38.94
Ejule	12.67 $\pm$ 1.75	0.001 $\pm$ 0.000	0.001 $\pm$ 0.000	0.032 $\pm$ 0.047	0.045 $\pm$ 0.020	102.69 $\pm$ 15.57
Okene	14.36 $\pm$ 3.05	0.311 $\pm$ 0.238	0.018 $\pm$ 0.018	0.018 $\pm$ 0.014	0.254 $\pm$ 0.226	83.01 $\pm$ 2.02

Contamination Factor (CF)

CF values (Table 7) indicated very high to considerable contamination in both Cd and As at the location of Nataco. Cadmium CF values varied between 0.00 and 5.02, and arsenic varied from 0.00 to 6.18 at the locations of Nataco A and Ejule, respectively.

Table 7: Contamination Factor (CF) values

Sample	Pb	Cd	Cr	As	Ni	Zn
Nataco A	1.41	5.02	0.44	6.18	0.27	2.14
Nataco B	1.15	3.00	0.00	0.05	0.00	1.43
Nataco C	1.00	2.00	0.00	0.06	0.01	1.40
Ganaja A	1.02	4.51	0.01	0.02	0.01	2.40
Ganaja B	0.76	1.52	0.00	0.08	0.01	1.47
Ganaja C	1.05	3.51	0.01	0.05	0.00	1.40
Ejule A	0.73	0.00	0.00	0.02	0.00	1.71
Ejule B	0.63	0.00	0.00	0.00	0.00	1.41
Ejule C	0.55	0.00	0.00	0.00	0.00	1.27
Okene A	0.85	2.51	0.00	0.01	0.00	1.16
Okene B	0.75	2.01	0.00	0.00	0.01	1.19
Okene C	0.55	0.15	0.00	0.00	0.01	1.21

Geo-accumulation Index (Igeo)

For Cd and As, the high average values and Igeo values at Nataco A corresponded to a moderately polluted level (+1.74 for Cd and +2.04 for As; Table 8). Other metals were in a clean status.

Table 8: Geo-accumulation Index (Igeo) values

Sample	Pb	Cd	Cr	As	Ni	Zn
Nataco A	-	+1.74	-	+2.04	-	+0.51
Nataco B	0.09	-	1.77	-	1.47	-
Nataco C	-	+1.00	-	-2.81	-	-0.07
Ganaja A	0.38	-	2.81	-	2.81	-
Ganaja B	-	+0.42	-	-2.81	-	-0.10
Ganaja C	0.58	-	2.81	-	2.81	-
Okene A	-	+1.59	-	-3.06	-	+0.70
Okene B	0.56	-	4.06	-	4.06	-

Ganaja	-	+0.34	-	-2.23	-	-0.03
B	0.98		4.06		4.06	
Ganaja	-	+1.23	-	-2.81	-	-0.10
C	0.51		4.06		4.06	
Ejule A	-	-∞	-	-3.06	-	+0.09
	1.04		4.06		4.06	
Ejule B	-	-∞	-	-∞	-	-0.07
	1.25		4.06		4.06	
Ejule C	-	-∞	-	-∞	-	-0.24
	1.45		4.06		4.06	
Okene	-	+0.74	-	-4.06	-	-0.14
A	0.82		4.06		4.06	
Okene	-	+0.42	-	-4.06	-	-0.11
B	1.00		4.06		3.81	
Okene	-	-1.00	-	-4.06	-	-0.08
C	1.45		4.06		3.81	

Pollution Load Index (PLI)

This means that only one of the samples returned a PLI value higher than zero, namely Nataco Composite A (1.79), a result attributed to the presence of detectable concentrations of all detected metals. Other samples returned a PLI value of 0 because no metals were detected.

Physicochemical Parameters

Table 9 shows physicochemical properties of roadside dust samples.

Table 9: Physicochemical analysis results

Location/Sample	Particle Size (%)	pH	Organic Matter (%)	Moisture (%)	EC (µS/cm)
Nataco A	45.36	6.8	5.2	8.5	420
Nataco B	42.84	6.6	4.8	7.9	395
Nataco C	40.95	6.7	4.5	7.5	380
Ganaja A	44.10	6.9	4.9	8.1	410
Ganaja B	39.69	6.5	4.2	7.2	360
Ganaja C	41.58	6.6	4.4	7.6	370
Ejule A	36.54	6.3	3.8	6.5	310
Ejule B	34.65	6.2	3.5	6.2	290
Ejule C	33.39	6.1	3.2	6.0	275
Okene A	37.80	6.4	3.9	6.8	320
Okene B	35.91	6.3	3.6	6.4	305
Okene C	34.02	6.2	3.3	6.1	295

Correlation Analysis

Spearman correlation matrix (Table 10) presents statistically significant high positive correlations for metals, reflecting shared sources:

Table 10: Spearman's correlation coefficients

	Pb	Cd	Cr	As	Ni	Zn
Pb	1.00					
Cd	0.65*	1.00				
Cr	0.72*	0.59*	1.00			
As	0.86*	0.73*	0.68*	1.00		
Ni	0.55	0.48	0.39	0.61*	1.00	
Zn	0.25	0.18	0.11	0.27	0.39	1.00

Significant at $p < 0.05$

Principal Component Analysis

Using PCA, the two main components accounted for 79.6 of the total variability (Table 11).

Table 11: Rotated component loadings (Varimax)

Metal	PC1	PC2
Pb	0.92	0.11
Cd	0.87	0.20
Cr	0.81	0.14
As	0.94	0.08
Ni	0.63	0.41
Zn	0.18	0.95
Variance explained	58.2%	21.4%

One-way ANOVA

The values of most metals show large differences among different sites (Table 12).

Table 12: ANOVA results for each metal

Metal	F-statistic	p-value
Pb	8.45	0.007
Cd	9.12	0.005
Cr	6.78	0.014
As	9.87	0.003
Ni	5.21	0.029
Zn	3.02	0.088

Health Risk Assessment

Non-carcinogenic Risk: All the values for HI were less than 1 (Table 13), which implied that there was no significant non-carcinogenic health risk.

Table 13: Hazard Index (HI) for adults and children

Site	Adult HI	Child HI
Nataco	0.021	0.144
Ganaja	0.019	0.132
Ejule	0.008	0.060
Okene	0.010	0.070

Carcinogenic Risk: All cancer risk estimates fell within the USEPA acceptable range (1×10^{-6} to 1×10^{-4}) (Table 14).

Table 14: Total cancer risk (incremental lifetime) for adults and children

Site	Adult CR	Child CR
Nataco	4.76×10^{-6}	6.63×10^{-6}
Ganaja	3.98×10^{-6}	5.55×10^{-6}
Ejule	1.44×10^{-7}	2.01×10^{-7}
Okene	2.23×10^{-6}	3.11×10^{-6}

DISCUSSION

Heavy Metal Distribution and Spatial Variation

Zinc was the dominant element in all samples (81.029-168.000 mg/kg) from all sampling sites, as reported in many studies in other Nigerian cities (Ogundele *et al.*, 2025; Nnamani *et al.*, 2024). Tire wear and brake abrasion were reported as sources of Zn in roadside dust (Charlesworth *et al.*, 2011). Higher Zn levels at Ganaja Junction Composite A site (168.000 mg/kg) confirm heavy traffic. Lead (11.01-28.14 mg/kg), the second most abundant metal, confirms the presence of persistent anthropogenic input of Pb from the wear of automobile tires, oil and lubricant spills on roads, and road abrasion. Although leaded petroleum was banned in Nigeria, Pb is continuously introduced into the atmosphere by combustion processes and is continuously remobilized from previously contaminated soils due to their recalcitrant nature (Nimyel & Namadi, 2020).

The highest cumulative heavy metal burdens are at Nataco. Mean values at Nataco include: Pb (23.72 mg/kg), Cd (0.668 mg/kg), Cr (0.381 mg/kg), As (0.482 mg/kg), Ni (0.412 mg/kg) and Zn (116.03 mg/kg). High values at Nataco could be attributed to sustained anthropogenic activities in this area, including heavy traffic, commercial activities, roadside trading, and other operations that rely on commercial transport and fuel burning. High standard deviations at Nataco for many metals (Cr: 0.534; Zn: 29.09) confirm spatial variability in contamination levels and potential localised pollution sources.

The highest concentration was recorded at Ganaja Junction (mean Zn = 123.02 mg/kg, well above the others), where tire wear and brake abrasion pollution were highest. Cadmium was equally high at this site (0.635 mg/kg), originating from fuel combustion and industrial sources. The lowest metal concentration was recorded at Ejule Junction, where Cd and Cr values were near zero. However, Okene has higher metal levels than Ejule Junction but lower than Nataco and Ganaja Junction. This can be attributed to increased human activity and traffic density around the city of Okene over time. These spatial variations are likely due to differences in traffic densities, vehicle traffic frequency, levels of urbanization, types of commercial activities, road transport-linked waste disposal patterns, and modes of atmospheric dispersal and pollutant deposition. These results confirm studies conducted in other Nigerian cities, such as Lagos, Enugu and Osogbo (Ogundele *et al.*, 2020; Nnamani *et al.*, 2024; Aturamu *et al.*, 2024).

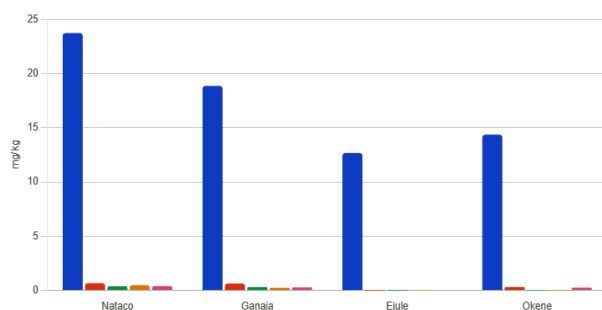


Figure 2: Mean trace metals by site

Source Identification

The high correlations among Pb, Cd, Cr and As ($r=0.65-0.86$) indicate shared anthropogenic pollution from vehicular emissions and combustion (Figure 3). With the application of PCA, two principal sources had been separated which represent common

anthropogenic origin mainly attributed by traffic/industry and combustion process (PC1, variance explained 58.2%) that showed significant loading-values for Pb (0.92), Cd (0.87), Cr (0.81) and As (0.94), accompanied with Zn(0.22), Ni(0.63); whilst tire wear sources (PC2, variance explained 21.4%) which loaded strongly for Zn(0.95) as illustrated by (Aturamu *et al.*, 2024) and (Ogundele *et al.*, 2025). No correlation was observed among Pb, Cd, Cr, and As and Zn ($r < 0.40$), indicating that the distribution profile of Zn contamination differs clearly from that of other traffic-related heavy metals and may require different environmental policy tools for controlling it. Zn could originate from tire wear and brake pad abrasion (Manisalidi & Kalliokoski, 1996), which requires additional mitigation measures to reduce contamination.

Contamination Status

The CF analysis shows high to very high contamination values for Cd (up to 5.02) and As (up to 6.18) in a few of the samples, specifically in Nataco. This trend is consistent with the study by Aturamu *et al.* (2024), which reported that Cd exhibited high mobility and bioavailability in Nigerian sediment systems, and the ecological risk assessment indicated that Cd posed a "moderate" to "considerable" risk. The high Cd levels are most likely anthropogenic, resulting from phosphatic fertilizers, industrial effluents, and urban runoff. Point-source contamination was observed for As, specifically in Nataco A (CF = 6.18), and may be related to past pesticide use, potential mining sites, or industrial discharge.

Based on the geo-accumulation index, moderate pollution was observed for Cd (up to +1.74) and As (up to +2.04) at locations with high contamination levels. At the same time, Pb, Cr and Ni showed moderate to highly polluted levels. PLI value of 1.79 in Nataco Composite A shows cumulative pollution at this sampling station; however, the PLI calculation was hindered by the detection of many zero CF values, mainly for Cr, which makes the analysis of some other samples with no detectable amount of metal at all irrelevant by use of the PLI index value. This mathematical problem has also been reported in the Nigerian literature (Nduka & Umeh, 2023; Okechukwu *et al.*, 2022), indicating that the selection of metals for calculating the PLI index must be made carefully.

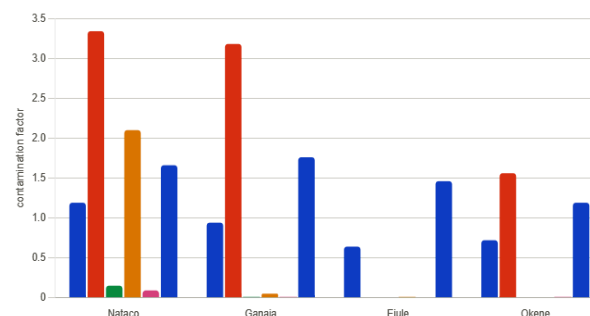


Figure 3: Mean contamination factor by site

Health Risk Assessment

HI values for all sites were significantly less than 1 (range of 0.008–0.144), so non-carcinogenic health risks associated with inhalation of roadside dust are of little consequence. Child values for HI were consistently higher than those for adults (approximately 7–12 times higher) due to lower body mass and higher intake, consistent with Nnamani *et al.* (2024). Both Pb (60%) and As (20%) accounted for the majority of HI values due to their relatively high toxicity at very

low concentrations. Although all HI values are less than 1, the concentrations of these two pollutants account for over 80% of the non-carcinogenic risk, and control measures should therefore focus primarily on them.

Cancer risk values for all sites, all children and all adults were below the USEPA acceptable cancer risk threshold (1×10^{-6} to 1×10^{-4} ; i.e., 1×10^{-4}). The high cancer risk values at Nataco and Ganaja are explained by the presence of Cadmium (>70%) at these sites; Cd is thus the dominant contributor to cancer risk (CR). The child CR value at Nataco is 6.63×10^{-5} , while the adult CR value is 4.76×10^{-5} , so the child CR value is approximately 1.4 times greater than that of adults, implying that children are more exposed to these pollutants than adults in Nataco, as explained by Nnamani *et al.* (2024). The cancer risk values obtained in this study (1.5×10^{-5} to 6.6×10^{-5}) are close to the values reported in another Nigerian study at major roadside locations (2.4×10^{-5} to 1.5×10^{-5} by Nduka *et al.*, 2025) but significantly lower than the values obtained for some Nigerian locations (3740 to 1.30×10^{-5} by Aturamu *et al.*, 2024). This suggests that cancer risks in the study sites are within acceptable levels for Nigerian environmental scenarios.

More importantly, it is remarkable that cadmium contributed more than 70% of the carcinogenic risk at two sites, since Cadmium is listed as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC). Fuel combustion and industrial activities have been reported as significant sources of Cadmium emissions to the environment, and these emissions require strict control.

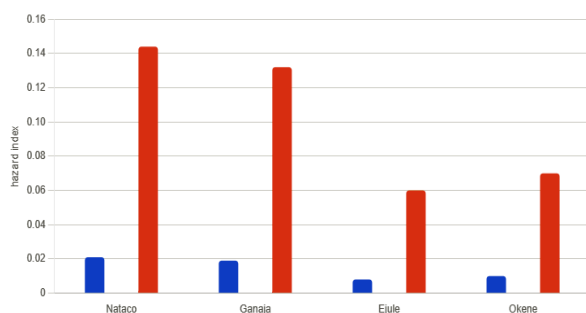


Figure 4: Hazard index, adult vs child

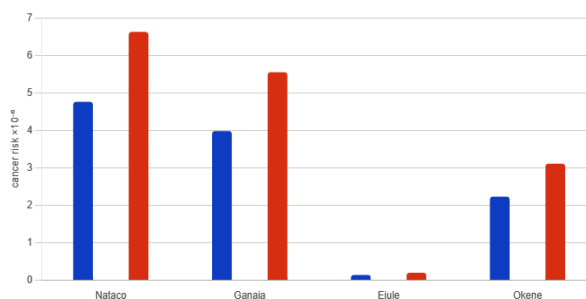


Figure 5: Cancer risk, adult vs child

Physicochemical Influences

The physicochemical characterization of roadside dust indicated sources and retention of pollutants. From these results; Nataco has the highest percentage of particle size (45.36%), O.M (5.2%), MOISTURE (8.5%) and EC (420 s/cm) that reflect the greatest anthropogenic impact, the high percentages of O.M are expected

to hold onto pollution through adsorption and the high EC can be linked with the increase of ionic richness as a results of emission/waste at the sites. Ganaja junction showed the same characteristics as Nataco due to heavy anthropogenic pressure.

The lowest physicochemical results were observed at Ejule junction, with a slightly acidic pH (6.1-6.3), thereby promoting metal mobility. Okene had an intermediate physicochemical result, while those at all other sites were near-neutral, which would minimize the effect of pH on contaminant mobility; however, the slightly acidic conditions at Ejule and Okene may be a significant factor favouring contaminant bioavailability.

Conclusion

The concentration, contamination level, and health risk of heavy metals bound to urban dust were determined in roadside environments of Kogi State, Nigeria. The concentrations of the following heavy metals (Pb, Cd, Cr, As, Ni and Zn) determined in roadside dust from selected towns varied, and zinc and lead were the predominant metals across all sampled stations. Nataco was found to have the highest heavy metal concentrations, reflecting intensive anthropogenic activity and traffic-related pollution, followed by Ganaja junction.

Ejule junction had the lowest contamination level, while Okene had a moderate contamination level.

Anthropogenic contamination is present among the identified heavy metals, and Cd and As show moderate to very high levels of contamination in roadside dust from Nataco junction. PCA results indicated two significant source types: traffic-industrial-combustion (Pb, Cd, Cr, As and Ni) and tire wear (Zn), which together accounted for 79.6% of the total variance. In terms of health risk evaluation, existing pollution levels are not expected to pose non-carcinogenic or carcinogenic hazards ($HI < 1$ and CR within range in all sites except for the CR value at Nataco and Ganaja junction, which is abnormally high. The elevated cancer risk at Nataco and the Ganaja junction indicates the need for careful ongoing monitoring.

This investigation reveals that urban roadside dust in Kogi State is a significant sink for toxic heavy metals and can pose a public health and environmental hazard.

Continuous exposure to pollution in the roadside dust environment may lead to an increase in the risk for commuters, street vendors, roadside workers, close-residence residents and healthy people living in the community, because inhalation, ingestion and direct contact with the contaminated dust would raise the risk of them developing health problems; such health issues have an impact on humans and their living beings. Hence, there is a need for ongoing environmental monitoring and pollution control to reduce heavy metal levels along urban roadides.

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