

Contamination Level and Health Risk Assessment of Heavy Metals Deposited in Street Dust in Some Part of Kano Metropolis

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ABSTRACT

Street dust is a critical medium and a reliable indicator for the environmental quality. This study assessed the contamination level and health risk associated with heavy metals (As, Cr, Pb, Ni, Fe, Al, Cu and Zn) in street dust of some major roads of Kano Metropolis. A total of 25 dust samples were systematically collected from the five major roads considered for this research (Zaria Road, BUK Road, Hadejia Road, Katsina road and Maiduguri road). The selection of the roads were based on the foreknowledge of their relative traffic density. The geo-accumulation index (Igeo) was used for contamination assessment, while the health risk was scored using a hazard quotient (HQ) and health index (HI) for non-carcinogenic heavy metals as well as a life time average daily dose (LADD) for carcinogenic heavy metals. The results revealed that the concentration values of all the studied heavy metals were higher than the background values with exception of Fe (106.1/114.1) in Zaria road, Cr (31.90/38.20) and Pb (20.90/46.66) in Hadejia Road. Furthermore, the Igeo value signified "uncontaminated to heavily contaminated" street dust in the Zaria road, BUK road and Katsina road. The results also revealed that among the three exposure pathway for human health (ingestion, dermal contact and inhalation), inhalation was estimated to be the main contributor for health risk. Each value of HQ and HI indicated that street dust heavy metals of studied roads were at a safe level (< 1). In addition, the potential health risk for children was greater than for adults, where HI for children had a high value compared to adults. It is concluded that, generally there is absence of significant health risk in the area. However, continuous monitoring and assessment of contamination level of heavy metals at time interval is recommended in order to keep a check and take preventive measures to safeguard human and environment.

Keywords: Heavy Metals, Street Dust, Health Risk, Kano Metropolis, Geo-accumulation index.

1. INTRODUCTION

Street dust is a critical environmental medium and it is one of the reliable indicators for the quality of the environment in general and the quality of air in particular (Prokofeva *et al.* 2017). Number of heavy metals are introduced in to the atmosphere as a results of vehicle emissions and other anthropogenic activities such as industrial discharges, oil lubricants, and

automobile parts, corrosion of building materials, bush burning, wastes incineration and mining operations. This significantly changes the composition of the atmosphere. Atmospheric dust suspended in the air will eventually deposit on the surface of the water and topsoil, thus introducing toxic substances into the biosphere (Wolterbeek, 2002) and causing potential problems such as toxicity to

plants and animals, accumulation in food chain, perturbation of the ecosystem and adverse health effects.

It was estimated that the annual amount of dust emitted into the air by vehicles in Nigerian was 612,000 tons and 187,000 tones for unpaved and paved roads respectively (Ubwa *et al.*, 2013). Also the total harmattan dust load over Nigeria was estimated to have increased from 160,000 tone in year 2000 to between 300,000 to 600,000 tons in 2006. It was also investigated by (Egwuatu, 1998) that, about 584,000 tone of smoke particles was estimated to be emitted annually into the atmosphere from the burning of about 80million cubic meters of fuel wood. The burning of an estimated 18.5 million tone of domestic waste is also said to be capable of throwing about 58,400 tone of dust into the air annually (Ubwa *et al.*, 2013).

Kano metropolis is one of the most densely populated cities in Nigeria and is considered as the nerve center of northern Nigeria. The major form of transportations within Kano metropolis as reported by Okunola *et al.* (2015), is by road and most common transport modes used include cars, buses, motorcycles, and tricycles (locally called Keke NAPEP). Components and quantity of street dusts are important environmental pollution indicators. Rapid growth of industries, population, and transportation system can contribute to increasing pollution levels in nearby

surrounding area including heavy metals in dust (Levy *et al.*, 2002).

Humans are always exposed to the natural levels of trace elements. Under normal circumstances; the body is able to control some of these amounts. However, continuous exposure to elevated levels of metals could cause serious illness resulting in death (Moja *et al.*, 2002; Okonkwo and Mothiba, 2005; Rollin *et al.*, 2005; Gupta *et al.*, 2019). Increased exposure may occur through inhalation of airborne particles or through ingestion of contaminated soil by children or by absorption through the skin (U.S. EPA, 2021). Due to the growing nature of population in Kano metropolis many environmental challenges posed by the proliferation of human activities have become evident in the industrial and high traffic density areas of the city. Despite that there is dearth of baseline data on the levels of heavy metal pollutants in dust over the areas. Thus, this study sought to provide information on contamination levels and health risk associated with some heavy metals in street dust especially over the high traffic density areas of Kano metropolis.

2. MATERIALS AND METHODS

2.1 Study Area

Kano metropolis is located between Latitudes $11^{\circ}53'20''N$ and $12^{\circ}0'40''N$ and Longitudes $8^{\circ}23'20''E$ and $8^{\circ}46'40''E$ (Figure 1). It occupies an area of about 683km^2 , with approximate

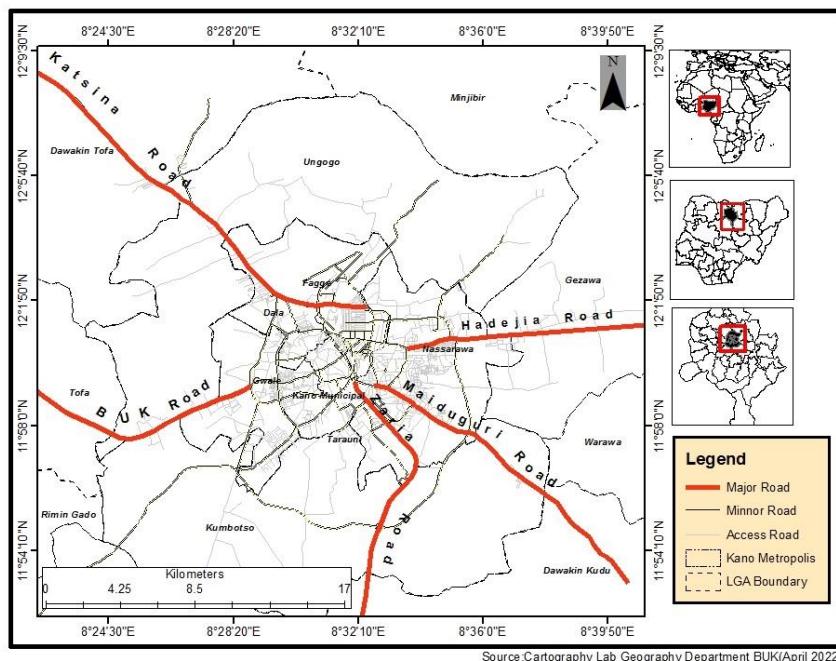


Figure 1: Metropolitain map of kano showing road network.

distance of 25km from east to west and about 2 1km from north to South. It is the largest urban center in the Hausa land and most influential commercial town in the Sudan region. Kano metropolis is the second largest industrial and commercial centre in Nigeria after Lagos and it is experience rapid population growth rate, the population of metropolis at 2006 was 2.8million (Mohammed et al., 2016) and projected in 2022 to over 4million.

2.2 Sampling Technique

Dust samples were systematic collected, by considering the intensity of traffic congestion, commercial and industrial activities along the selected major roads (Zaria Road, Katsina Road, Maiduguri Road, Hadejia Road and BUK Road). Using a plastic mat (6 cm length and 37.5cm width) along the roadside, four sample points were considered along each road at 1km distance and samples were collected at interval of one hour during the day. Therefore, a total number of 20 street dust samples were collected. Dust samples were also collected in another location's adjacent to the roads, which are basically residential areas, free from traffic, commercial and industrial activities as a controls, making total number of samples to be 25. The samples (dust) were then transferred to a clean labeled polythene bags and was directly taken to the laboratory for analysis.

2.3 Samples Treatments

The dust samples collected were dried at 100 – 110°C to drive out moisture. On cooling, each sample was passed through 2mm sieve to remove the coarse fragment. The digestion of the dust samples was done using 1:1 ratio distilled water to trioxonitrate (v) acid. 1grm of each of oven dried dust samples were weighed and transferred into 250 ml beaker. The samples were heated to boil for 30 minutes and was acid washed to pass through (what's man filter paper) and then was filtered into 100 ml volumetric flask. Calibration standard was prepared from the stock solution by dilution and was matched with the acid concentration of the digested samples. The digested samples were then analyzed for the levels of Iron (Fe), Copper (Cu), Lead (Pb), Asenic (As), Zinc (Zn), Aluminum (Al), Chromium (Cr) and Nickel (Ni), and using Microwave Plasma Atomic Emission Spectroscopy (MP - AES).

2.4 Data Analysis

The geo-accumulation index (Igeo) developed by Muller (1979) as reported by (Birch, 2013 and Pan et al., 2017) was used in the street dust contamination assessment, while the health risk was scored using a hazard quotient (HQ) and health index (HI) for non-carcinogenic heavy metals, as well as a life time average daily dose (LADD) for carcinogenic heavy metals.

I_{geo} of each metal was measured through the following equation:

$$I_{geo} = \log_2 \frac{C_i}{1.5B_i} \dots \dots \dots (1)$$

Where, C_i is the calculated heavy metal's concentration in the sample; B_i is the heavy metals' geochemical background value. For this present study, B_i is the background value of local soil. The constant 1.5 is to bring down the consequence of likely deviation in the background values. The I_{geo} for every heavy metal was computed and categorized as indicated in the table 1 below:

Table1: The Evaluation Grading Standard of the Geo-accumulation Index.

VALE	QUALITYGRADE
$I_{geo} \leq 0$	Uncontaminated
$<I_{geo} \leq 1$	Uncontaminated to moderately contaminated
$<I_{geo} \leq 2$	Moderately contaminated
$<I_{geo} \leq 3$	Moderately to heavily contaminated
$<I_{geo} \leq 4$	Heavily contaminated
$<I_{geo} \leq 5$	Heavily to extremely contaminated
$<I_{geo} \geq 5$	Extremely Contaminated

2.4.1 Health Risk Assessment and Exposure Dose

The risk assessment methodology introduced by the Environmental Protection Agency of the United States (USEPA, 2007) was used to evaluate the health risk in relation to the contamination level of heavy metals in the study area. According to the Exposure Factors Hand book, the average daily dose (ADD) (mg/kg/day) of three exposure pathways; ingestion, inhalation and dermal contact can be estimated using Equations (2)-(4):

$$ADD_{ing} = C \times R_{ing} \times E_f \times ED / BW \times AT \dots \dots \dots (2)$$

$$ADD_{inh} = C \times R_{inh} \times E_f \times ED / PEF \times BW \times AT \dots \dots \dots (3)$$

Where, ADDing is daily exposure amount of metals through ingestion (mg/kg/day), ADD_{inh} is daily exposure amount of metals through inhalation (mg/kg/day), and ADD_{derm} is daily exposure amount of metals through dermal contact (mg/kg/day). The exposure factors for these models are shown in Table 2 with reference to the USEPA and environmental site assessment guidelines. The values of these factors include the standards from USEPA and data from this study.

2.4.2 Non-Carcinogenic Risk Assessment

After the calculations of ADD, the three exposure pathways was then calculated, a hazard quotient (HQ) based on the non-carcinogenic toxic risk was then calculated by dividing the daily dose by a particular reference dose (RfD), as in Equation (5):

$$HQ = ADD/RfD \dots \dots \dots \quad (5)$$

Using the threshold of RfD value, it is possible to evaluate whether there are existing adverse Health effects to humans, and if RfD value is higher than the ADD, there would be no adverse health effect. If the hazard quotient (HQ) value indicates lower than 1, there are no adverse health effects; whereas, if HQ is higher than 1, it means there is likely adverse health effects.

The hazard index (HI) can then be calculated by adding HQs of a mix of metal elements:

i=1

HI is equal to the sum of the HQs and gives the total risk of being non-carcinogenic for a single element. If the value of $HI \leq 1$, it is considered that “no significant risk” or no carcinogenic effects exists. However, if $HI > 1$, there is a probability of carcinogenic effects occurring, and the probability increases with a rising value of HI (USEPA, 2021). For this study, HI was utilized in assessing the human health risk of exposure from eight heavy metals considered in the study area.

2.4.3 Carcinogenic Risk Assessment

For carcinogens, the lifetime average daily dose (LADD) (inhalation exposure route for As, Cr, and Ni) was utilized in the evaluation of carcinogenic risk, and according to the classification developed by the International Agency for Research on Cancer (IARC) (Plummer *et al.*, 2016), to investigate the three heavy metals for their carcinogenic risks. The lifetime average daily dose for these three metals will be calculated using:

$$LDD = \frac{C \times EF}{PEF \times AT} \times \left(\frac{CRchild \times EDchild}{BWchild} + \frac{CRadults \times EDadults}{BWadults} \right) \dots \dots \dots (7)$$

Where, all the variables are the same as in Equations (2) - (6).

CR is the inhalation (CR=Rinh) rate. The interpretations and values of other parameters are listed in Table 2. The life time cancer risk was then calculated using:

Where, SF is the corresponding slope factor. The level of cancer risk associated with exposure to those metals in dust is the range of threshold values (10^{-6} – 10^{-4}), above which

Table 2: Exposure Factors for Dose Models used for this Study (USEPA, 2007; 2021)

Factor	Definition	Unit	Value	
			Children	Adult
C	Concentration of an element in soil (UCL ¹ 95%)	mg/kg	--	
Ring	Ingestion rate of soil	mg/day	200	100
EF	Exposure frequency	days/year	180	180
ED	Exposure duration	Years	6	24
BW	Average body weight	Kg	15	70
AT	Average time	Days	365×ED	365×ED
CF	Conversion factor	kg/mg	1×10^{-6}	1×10^{-6}
Rinh	Inhalation rate	m ³ /day	7.6	20×10^9
PEF	Particle emission factor	m ³ /kg	1.36×10^9	1.36×10^9
SA	Surface area of the skin that contacts the dust	cm ²	2800	5700
SL	Skin adherence factor for the dust	mg/cm ²	0.07	0.2
AT	Average time carcinogenic	Days	25,550	25,550

¹UCL: Upper Confidence Level

environmental and regulatory agencies considered as unacceptable risk.

3. RESULTS AND DISCUSSION

The mean concentration of eight elements (As, Cr, Pb, Ni, Fe, Al, Cu and Zn) in street dust samples along the major roads of the study area with their background values were presented in (Table 3). The mean values revealed significant diversity in the concentration of Fe, Zn, Cr and Pb predominating among the studied metals and followed by As, Ni, Al, and Cu. Moreover, the concentration values of all the studied heavy metals were higher than the background values with exception of Fe (106.1/114.1) in Zaria road, Cr (31.90/38.20) and Pb (20.90/46.66) in Hadejia Road. The concentration ranges of the metals in mg/kg (Table 3) are also observed to be As (3.33 – 28.04), Cr (16.09 – 164.64), Pb (20.90 – 125.09), Ni (16.07 – 155.80), Fe (55.08 – 343.09), Al (15.40 – 34.12), Cu (7040 – 42.60) and Zn (16.40 – 52.40). The concentration of Pb in Katsina Road was found be higher than maximum permissible concentration (MPC). Similarly Cr and Ni in Katsina Road was found to be higher than the background values and MPC (Table 3).

3.1 Contamination Level of Heavy Metals

Table 3: Summary of heavy metal mean concentration with their background values (mg/kg).

Major Roads	Indication	As	Cr	Pb	Ni	Fe	Al	Cu	Zn
Zaria Road	Concentration	28.04	61.56	43.11	21.26	106.1	18.05	7.40	52.40
	Background	14.17	13.04	37.91	14.74	114.10	11.20	3.00	34.60
BUK Road	Concentration	12.78	65.70	28.06	29.30	155.17	34.12	42.6	24.80
	Background	4.00	60.00	15.00	18.60	77.80	25.40	16.4	6.25
Hadejia Road	Concentration	3.33	31.90	20.90	19.49	67.26	15.40	32.1	18.40
	Background	3.31	38.20	46.66	12.73	52.30	12.10	20.5	5.60
Katsina Road	Concentration	19.02	164.64	125.09	155.8	343.09	20.56	33.52	16.4
	Background	17.03	41.05	53.05	43.06	66.03	16.00	23.4	11.30
Maiduguri Road	Concentration	5.80	16.09	22.04	16.07	55.08	17.23	19.62	17.05
	Background	3.07	56.60	34.09	26.06	76.05	14.40	12.50	9.07
	MPC	6.00	150.00	100.00	150.00	300.00	20.00	160.0	720.0

MPC: Maximum Permissible Concentration

Table 4: Geo-accumulation Index of Heavy metals in Five Major Roads investigated (mg/kg)

Metals	Zaria Road			BUK Road			Hadejia Road			Katsina Road			Maiduguri Road.		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
As	-1.60	0.26	1.68	-0.29	0.84	2.00	-1.37	-0.67	0.16	-1.50	-0.50	1.00	-2.43	-0.43	2.50
Cr	-3.29	-0.46	1.07	-2.03	-0.59	1.14	-4.13	-1.10	-0.04	-3.50	-0.67	1.67	-1.60	-0.50	1.04
Pb	-2.37	-0.76	1.55	-2.20	-0.69	1.53	-2.89	-1.91	-0.08	-2.30	-0.45	1.80	-1.40	0.67	1.77
Ni	-2.14	-0.21	1.44	-1.47	-0.08	2.97	-1.06	-0.28	0.64	-1.70	-0.24	1.09	-1.35	-0.30	1.73
Fe	-1.90	-0.78	0.29	-1.48	-0.02	1.03	-1.71	-0.29	1.75	-0.65	0.60	2.65	-1.65	0.60	2.09
Al	-1.45	-0.56	0.45	-1.56	-0.34	1.13	-1.65	-0.54	1.05	-1.56	0.40	1.10	-1.60	0.45	1.65
Cu	-1.63	0.25	1.34	0.56	0.85	2.40	-1.46	-0.65	0.75	-1.60	-0.75	1.75	1.54	-0.65	1.55
Zn	-1.75	0.43	1.45	-1.75	-0.65	1.56	0.65	-0.45	1.35	-2.65	-0.65	1.45	1.65	-0.76	1.43

The minimum, maximum, and geometric mean values of Igeo were presented in Table 4. Igeo values were calculated on each major road considered. The aim was to evaluate the overall contamination levels of all sites.

3.1.1 Zaria Road

From Table 4, the mean Igeo values were in the range from -0.78 to 0.43, indicating that dust along Zaria road was uncontaminated with those elements (Cr, Pb, Ni, Fe and Al) except for As (0.26), Cu(0.25) and Zn (0.43) which showed uncontaminated to moderately contaminated value. The high (Max) Igeo values for As, Cr, Pb, Ni and Zn also showed that the dust was moderately contaminated, whereas the Fe (0.29) and Al (0.45) values indicated uncontaminated to moderately contaminated dust. In terms of the high Igeo value, some sampling sites were slightly impacted by anthropogenic factors. As, Cr, Pb, and Ni are 1.68, 1.07, 1.55 and 1.44 respectively. However, studies have shown the implication of being exposed to high concentration these elements. For example, ingestion of arsenic-rich water leads to skin lesions in exposed populations which are also subject to increased incidence of cancers of the skin (NAS, 2009). This result has conformed to

the results of the study carried out by (Hsu *et al.*, 2007) in the northern and southern China Sea. And also results of Mandal *et al.*, 2008) carried out in West Bengal, India. In addition, it has been suggested that exposure to arsenic-rich water increases the risk of vascular disease, hypertension and diabetes. Likewise, Chromium (Cr) can cause allergic reactions such as skin rashes and after breathing chromium (vi) in air, nose irritation and bleeding are quite common.

3.1.2 BUK Road

The mean Igeo values for Cr, Pb, Ni, Fe, Al and Zn were all lower than 0 indicating uncontaminated, while As (0.84) and Cu (0.85) were within uncontaminated to moderately contaminated. The maximum Igeo values for each element were higher than 1 (Table 4). For instance, Ni (2.97) was the highest followed by Cu (2.40) and As (2.00) which showed moderately to heavily contaminated value. Cr, Pb, and Zn were 1.14, 1.53 and 1.56, respectively indicating uncontaminated to moderately contaminated values. However, Nickel with the highest value is one of ubiquitous elements and ranks 23rd in order of abundance. The highest value of nickel observed in this case may be as a result of geochemical emission, and anthropogenic activities such as high vehicular movement, vulcanizes, mechanical workshops and metal works activities along the road side. High exposure to nickel varies from skin irritation to damage to lungs, the nerve system and mucous membranes. This result is also in agreement with the findings of Laughlin *et al.* (2010).

3.1.3 Hadejia Road

As presented in Table 4. The mean values for each element was lower than 0. This means that dust sample from Hadejia road was uncontaminated by all elements used for this study. Whereas the highest value is estimated to be 1.75 (Fe), 0.64 (Ni) and 0.16 (As), which indicated uncontaminated to moderately contaminated dust with respect to them. Other elements like, Cr and Pb have -0.04 and -0.08 values respectively. The general low mean value of elements especially, chromium (Cr) might be as a result of its low level in air and for lead (Pb) may be as a result of low human activities that could cause high concentration of it, the main sources of lead (Pb) pollution are lead smelters, battery manufacturers, paper and bulb industries which have been observed not

to be much in the area. Similar results were reported in the work carried out by Abdallah *et al.* (2012) at Kaduna metropolis on the assessment of heavy metals from refuse dump sites.

3.1.4 Katsina Road

The mean Igeo values for As, Cr, Pb, Ni, and Zn were lower than 0 indicating uncontaminated, while Fe and Al were 0.6 and 0.40 respectively and this represent uncontaminated to moderately contaminated dust with respect to them. The maximum Igeo values for each element were higher than 1 except for As. For instance, Fe showed the highest values of 2.65, which indicate moderate to heavily contamination. As, Cr, and Ni were also 1.00, 1.67, and 1.09, respectively (Table 4). These results are similar with the works reported by (Wahab *et al.*, 2012) with metal concentrations ranging from 2.20 – 14.00 mg/kg and very high compared with the works reported by (Adekola and Dosumu, 2001) with metal concentrations ranging from 0.190 – 1.990 mg/kg.

3.1.5 Maiduguri Road

Reference to Table 4. The mean values for each element were lower than 0 with exceptions for Pb, Fe and Al, this means that dust sample from Maiduguri road was uncontaminated by all elements in this study. Whereas the highest values are estimated at 2.50 and 2.09 for As and Fe respectively which indicated moderately contaminated to heavily contaminated dust with respect to them, other elements like Cr and Ni are 1.04 and 1.73 respectively.

3.2 Health Risk Assessment

3.2.1 Non-Carcinogenic Risk

The reference dose (*RfD*), upper confidence level (95%UCL), and results of the hazard quotient (*HQ*) and hazard index (HI) Calculations from five major roads in some part of Kano metropolis are listed in (Appendix 1). HQ and HI values for both children and adults have the same patterns. The *HQ* of the inhalation of dust particles for all metals was much higher than those of ingestion of re-suspended dust particles and dermal absorption with dust particles. HQ of inhalation of dust particles for all metals was much higher than those of the ingestion and dermal absorption exposure pathways. The values of *HQ* and HI for those pathways of this study decreased in order of inhalation > dermal contact > ingestion.

The contribution of HQinh to HI was the highest in exposure pathways and accounted more for the total risk. The result shows that the inhalation is a principal pathway of heavy metals damaging to human health around the study area. Conversely, the ingestion and the dermal contact had relatively low values. The non-cancer risk of As was the major contribution to HI (from 2.04×10^{-4} to 4.15×10^{-3}) lower than the safe level. Therefore, the potential health risks for children and adults can be overlooked. Meanwhile, the health risk for adults was lower compared to the risk for children. The HI values of these metals for children were higher than those for adults.

3.2.2 Carcinogenic Risk

The carcinogenic risks according to inhalation exposure to As, Cr, and Ni are presented in (Table 5). Results showed that the risks for As, Cr, and Ni decreased in the sequence of Ni > As >> Cr for Zaria road, whereas it was in the order of Ni > Cr > As for BUK road and Hadejia road.

Table 5: Carcinogenic risks for heavy metal in the dust sample collected along the study area in some parts of Kano Metropolis.

Heavy Metal Elements	As	Cr	Ni
InhSF*	15.1	42	0.0421
Risk—Zaria Road	2.54×10^{-10}	5.51×10^{-11}	7.99×10^{-9}
Risk—BUK Road	1.20×10^{-10}	2.16×10^{-10}	4.61×10^{-9}
Risk—Hadejia Road	1.25×10^{-11}	4.58×10^{-10}	2.43×10^{-9}
Risk---Katsina Road	2.45×10^{-10}	5.25×10^{-10}	3.63×10^{-9}
Risk---Maiduguri Road	1.52×10^{-11}	2.64×10^{-11}	4.16×10^{-9}

Likewise, it was also in order of Ni > Cr > As for both Katsina and Maiduguri road. Level of carcinogenic risks for those elements were lower than the tolerable range (10^{-6} – 10^{-4}), above which the environmental and regulatory agencies perceived as an unacceptable risk.

4. CONCLUSION AND RECOMMENDATIONS

The study concentrated on some five major roads of high volume of traffic density in parts of Kano metropolis thereby finding the contamination level and risk assessment of heavy metal deposited in street dust in these areas. Results showed some differences and similarities among the five major roads put under study. In most cases, the heavy metal

contamination was higher than their background values. The contamination of elements generally increased in the order of As < Cr < Ni < Pb < Fe. The results also revealed that hazard quotient (HQ) of the inhalation of dust particles for all metals was much higher than those of ingestion of re-suspended dust particles and dermal absorption with dust particles. HQ of inhalation of dust particles for all metals was much higher than those of the ingestion and dermal absorption exposure pathways. The values of HQ and HI for those pathways of this study decreased in order of inhalation > dermal contact > ingestion.

It is concluded that, generally there is absence of significant health risk in the study area. However, it is recommended that a continuous monitoring and assessment of contamination level of heavy metals should be carried out at time interval in order to keep a check and take preventive measures to safeguard human and environment.

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Appendix 1

Table 6: HQ's and HI's from heavy metals with their concentration and reference dose in the study area.

Metals	C (UCL95%)	RfDing ¹ mg/kg*d	RfDinh ² mg/kg*d	RfDderm ³ mg/kg*d	HQing ⁴		HQinh ⁵		HQderm ⁶		HI ⁷	
					Children	Adults	Children	Adults	Children	Adults	Children	Adults
Zaria Road												
As	32.99	3.00x10 ⁻⁴	3.01x10 ⁻⁴	1.23x10 ⁻⁴	4.00x10 ⁻³	4.28x10 ⁻⁴	3.91x10 ⁻⁵	2.20x10 ⁻⁵	1.17x10 ⁻⁴	2.84x10 ⁻⁴	4.15x10 ⁻³	7.34x10 ⁻⁴
Cr	19.83	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.97x10 ⁻⁷	1.42x10 ⁻⁷	3.43x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
Pb	57.12	3.50x10 ⁻³	3.52x10 ⁻³	5.25x10 ⁻⁴	5.99x10 ⁻⁴	6.2x10 ⁻⁵	5.86x10 ⁻⁶	5.30x10 ⁻⁶	3.87x10 ⁻⁷	1.42x10 ⁻⁶	6.06x10 ⁻⁴	6.89x10 ⁻⁵
Ni	25.49	2.00x10 ⁻²	2.06x10 ⁻²	1.00x10 ⁻³	4.65x10 ⁻⁵	4.9x10 ⁻⁶	4.55x10 ⁻⁷	4.56x10 ⁻⁷	2.56x10 ⁻⁸	1.10x10 ⁻⁷	4.70x10 ⁻⁵	5.35x10 ⁻⁶
Fe	21.5	3.00x10 ⁻¹	3.00x10 ⁻¹	4.00x10 ⁻²	3.48x10 ⁻⁵	1.59x10 ⁻⁶	1.45x10 ⁻³	3.18 x10 ⁻⁸	1.45x10 ⁻⁸	1.51x10 ⁻⁸	1.50x10 ⁻⁵	1.71x10 ⁻⁶
Al	17.83	1.00x10 ⁻⁴	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	3.50x10 ⁻³	1.50x10 ⁻⁶	3.70x10 ⁻⁷	1.40x10 ⁻⁷	3.40x10 ⁻⁷	3.46x10 ⁻⁴	1.50x10 ⁻⁵
Cu	21.83	1.00x10 ⁻²	2.86x10 ⁻⁵	1.50x10 ⁻⁴	2.45x10 ⁻⁴	2.55x10 ⁻⁵	3.41x10 ⁻⁴	1.60x10 ⁻⁷	1.50x10 ⁻⁷	2.42x10 ⁻⁷	2.40x10 ⁻⁴	2.60x10 ⁻⁵
Zn	42.83	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	1.20x10 ⁻¹	1.41x10 ⁻⁶	7.40x10 ⁻⁷	2.42x10 ⁻⁷	3.43x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
BUK Road												
As	12.78	3.00x10 ⁻⁴	3.01x10 ⁻⁴	1.2x10 ⁻⁴	1.88x10 ⁻³	2.01x10 ⁻⁴	1.84x10 ⁻⁵	1.04x10 ⁻⁵	5.52x10 ⁻⁵	1.3x10 ⁻⁴	1.95x10 ⁻³	3.45x10 ⁻⁴
Cr	65.7	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	5.68x10 ⁻⁴	6.08x10 ⁻⁵	5.55x10 ⁻⁶	1.3x10 ⁻⁶	5.56x10 ⁻⁷	1.4x10 ⁻⁶	5.74x10 ⁻⁴	6.53x10 ⁻⁵
Pb	18.06	3.50x10 ⁻³	3.5x10 ⁻³	5.25x10 ⁻⁴	2.47x10 ⁻⁴	2.64x10 ⁻⁵	2.41x10 ⁻⁶	1.36x10 ⁻⁶	2.42x10 ⁻⁷	5.84x10 ⁻⁷	2.49x10 ⁻⁴	2.84x10 ⁻⁵
Ni	29.3	2.00x10 ⁻²	2.06x10 ⁻²	1.00x10 ⁻³	6.05x10 ⁻⁵	6.48x10 ⁻⁶	5.92x10 ⁻⁷	3.34x10 ⁻⁷	5.93x10 ⁻⁸	1.43x10 ⁻⁷	6.11x10 ⁻⁵	6.96x10 ⁻⁶
Fe	15.17	3.00x10 ⁻¹	3.00x10 ⁻¹	6.00x10 ⁻²	2.75x10 ⁻⁵	2.95x10 ⁻⁶	2.69x10 ⁻⁷	1.52x10 ⁻⁷	2.70x10 ⁻⁸	6.52x10 ⁻⁸	2.78x10 ⁻⁵	3.17x10 ⁻⁶
Al	11.83	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.97x10 ⁻⁷	1.42 x10 ⁻⁷	3.43x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
Cu	32.8	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.97x10 ⁻⁷	1.42x10 ⁻⁷	4.3x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
Zn	16.83	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.97x10 ⁻⁷	1.42x10 ⁻⁷	3.43x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
Hadejia Road												
As	13.99	3.00x10 ⁻⁴	3.01x10 ⁻⁴	1.23x10 ⁻⁴	1.96x10 ⁻⁴	2.10x10 ⁻⁵	1.92x10 ⁻⁶	1.08x10 ⁻⁶	5.77x10 ⁻⁶	1.39x10 ⁻⁵	2.04x10 ⁻⁴	3.60x10 ⁻⁵
Cr	39.52	5.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻⁴	1.20x10 ⁻⁴	1.29x10 ⁻⁵	1.17x10 ⁻⁶	6.62x10 ⁻⁷	1.18x10 ⁻⁷	2.84x10 ⁻⁷	1.21x10 ⁻⁴	1.38x10 ⁻⁵
Pb	28.03	3.50x10 ⁻³	3.52x10 ⁻³	5.25x10 ⁻⁴	1.44x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.95x10 ⁻⁷	1.41x10 ⁻⁷	3.42x10 ⁻⁷	1.46x10 ⁻⁴	1.66x10 ⁻⁵
Ni	27.64	2.00x10 ⁻²	2.06x10 ⁻²	1.00x10 ⁻³	3.18x10 ⁻⁵	3.41x10 ⁻⁶	3.11x10 ⁻⁷	1.75x10 ⁻⁷	3.12x10 ⁻⁸	7.54x10 ⁻⁸	3.22x10 ⁻⁵	3.66x10 ⁻⁶
Fe	79.44	3.00x10 ⁻¹	3.00x10 ⁻¹	6.00x10 ⁻²	3.23x10 ⁻⁶	3.46x10 ⁻⁷	3.16x10 ⁻⁸	1.78x10 ⁻⁸	3.17x10 ⁻⁹	7.66x10 ⁻⁹	3.27x10 ⁻⁶	3.72x10 ⁻⁷
Al	19.83	5.00x10 ⁻⁴	1.86x10 ⁻⁵	1.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	7.97x10 ⁻⁷	1.42 x10 ⁻⁷	2.43x10 ⁻⁷	1.30x10 ⁻⁴	1.60x10 ⁻⁵
Cu	34.83	4.00x10 ⁻³	4.80x10 ⁻⁵	4.50x10 ⁻³	2.45x10 ⁻⁴	6.55x10 ⁻⁵	1.11x10 ⁻⁶	3.20x10 ⁻⁷	2.42x10 ⁻⁷	3.33x10 ⁻⁷	2.44x10 ⁻⁴	1.55x10 ⁻⁵
Zn	18.83	7.00x10 ⁻³	2.48x10 ⁻⁵	2.50x10 ⁻⁴	4.45x10 ⁻⁴	1.45x10 ⁻⁵	2.41x10 ⁻⁶	7.90x10 ⁻⁷	1.52x10 ⁻⁷	4.43x10 ⁻⁷	1.50x10 ⁻⁴	2.66x10 ⁻⁵

Metals	RfDing ¹		RfDderm ³ mg/kg*d	HQing ⁴		HQinh ⁵		HQderm ⁶		HI ⁷		
	C (UCL95%) mg/kg*d			Children	Adults	Children	Adults	Children	Adults	Children	Adults	
	Katsina Road											
As	19.83	4.00x10 ⁻³	2.86x10 ⁻⁵	2.50x10 ⁻¹	1.45x10 ⁻⁴	1.66x10 ⁻⁵	1.40x10 ⁻⁶	7.97x10 ⁻⁷	1.40x10 ⁻⁷	3.43x10 ⁻⁷	1.43x10 ⁻⁴	
Cr	22.83	6.00x10 ⁻⁵	2.66x10 ⁻⁵	1.50x10 ⁻³	5.45x10 ⁻⁴	3.55x10 ⁻⁶	2.51x10 ⁻²	6.47x10 ⁻⁷	2.52x10 ⁻⁷	5.23x10 ⁻⁷	4.60x10 ⁻⁴	
Pb	19.83	1.00x10 ⁻¹	2.96x10 ⁻⁵	7.50x10 ⁻⁶	4.45x10 ⁻³	2.56x10 ⁻²	1.60x10 ⁻⁶	2.67x10 ⁻⁷	3.42x10 ⁻⁷	2.43x10 ⁻⁷	2.55x10 ⁻⁴	
Ni	43.83	5.00x10 ⁻⁴	4.86x10 ⁻⁶	4.50x10 ⁻⁴	2.45x10 ⁻⁷	1.58x10 ⁻³	6.30x10 ⁻⁶	3.97x10 ⁻⁷	7.44x10 ⁻⁷	1.34x10 ⁻⁷	6.22x10 ⁻⁴	
Fe	20.83	7.00x10 ⁻¹	3.86x10 ⁻¹	2.60x10 ⁻⁴	1.35x10 ⁻¹	1.80x10 ⁻⁴	1.45x10 ⁻⁴	6.90x10 ⁻⁷	1.46x10 ⁻⁷	7.25x10 ⁻⁷	1.44x10 ⁻⁴	
Al	54.83	9.00x10 ⁻³	6.86x10 ⁻⁵	2.55x10 ⁻²	1.55x10 ⁻⁴	2.45x10 ⁻²	2.60x10 ⁻¹	4.93x10 ⁻⁷	6.42x10 ⁻⁷	4.40x10 ⁻⁷	1.30x10 ⁻⁴	
Cu	31.83	6.00x10 ⁻⁴	1.86x10 ⁻⁴	2.50x10 ⁻⁴	1.45x10 ⁻⁶	4.55x10 ⁻⁵	3.50x10 ⁻⁴	7.94x10 ⁻⁷	3.20x10 ⁻⁷	6.44x10 ⁻⁷	2.40x10 ⁻⁴	
Zn	16.83	5.00x10 ⁻²	2.86x10 ⁻⁶	2.50x10 ⁻¹	1.65x10 ³ ⁴	1.55x10 ⁻³	1.41x10 ⁻⁶	7.07x10 ⁻⁷	4.42x10 ⁻⁷	3.23x10 ⁻⁷	1.46x10 ⁻⁴	
Maiduguri Road												
As	12.83	2.00x10 ⁻⁵	2.86x10 ⁻⁵	3.50x10 ⁻⁴	1.45x10 ⁻⁴	1.55x10 ⁻⁵	1.41x10 ⁻⁶	5.97x10 ⁻⁹	1.42x10 ⁻⁷	6.43x10 ⁻⁷	3.46x10 ⁻⁶	
Cr	16.3	4.00x10 ⁻¹	3.86x10 ⁻⁵	6.50x10 ⁻²	2.45x10 ⁻¹	1.66x10 ⁻⁵	4.41x10 ⁻⁶	2.97x10 ⁻⁷	5.42x10 ⁻⁷	1.43x10 ⁻⁷	1.46x10 ⁻³	
Pb	10.83	2.00x10 ⁻³	5.86x10 ⁻⁵	7.50x10 ⁻⁶	1.45x10 ⁻⁸	1.57x10 ⁻⁵	2.41x10 ⁻⁴	4.97x10 ⁻¹	1.42x10 ⁻⁷	3.43x10 ⁻⁷	9.46x10 ⁻⁴	
Ni	19.83	1.00x10 ⁻³	2.86x10 ⁻⁵	1.50x10 ⁻⁴	1.55x10 ⁻⁷	5.55x10 ⁻⁵	1.41x10 ⁻⁵	7.97x10 ⁻²	8.42x10 ⁻⁷	6.43x10 ⁻⁷	7.46x10 ⁻¹	
Fe	14.33	5.00x10 ⁻⁷	7.86x10 ⁻⁵	2.50x10 ⁻¹	1.65x10 ⁻¹	1.55x10 ⁻⁵	6.41x10 ⁻⁷	1.97x10 ⁻⁷	6.42x10 ⁻⁷	1.43x10 ⁻⁷	2.46x10 ⁻¹	
Al	11.23	6.00x10 ⁻⁴	1.86x10 ⁻⁵	6.50x10 ⁻⁵	3.45x10 ⁻²	7.55x10 ⁻⁵	1.41x10 ⁻¹	6.97x10 ⁻³	7.42x10 ⁻⁷	4.43x10 ⁻⁷	5.46x10 ⁻⁶	
Cu	15.23	4.00x10 ⁻³	2.86x10 ⁻⁵	2.450x10 ⁻³	6.45x10 ⁻⁴	1.55x10 ⁻⁵	4.61x10 ⁻⁶	7.97x10 ⁻⁷	2.42x10 ⁻⁷	8.43x10 ⁻⁷	1.46x10 ⁻³	
Zn	25.23	2.00x10 ⁻²	4.86x10 ⁻⁵	2.50x10 ⁻⁴	1.45x10 ⁻⁴	3.55x10 ⁻⁵	1.41x10 ⁻⁶	2.97x10 ⁻⁵	4.42x10 ⁻⁷	3.43x10 ⁻⁷	1.46x10 ⁻⁴	

¹Reference dose—Ingestion. ²Reference dose—Inhalation. ³Reference dose—Dermal contact. ⁴Hazard quotient—Ingestion. ⁵Hazard quotient—Inhalation.

⁶Hazard quotient—Dermal contact. ⁷Hazard index.