Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 54 (2024) 83-101 EISSN 2543-5426

Potential Human Health Risk Assessment of Heavy Metals in Road Dusts Collected From Three Urban Roads of Enugu State, Nigeria

Amarachukwu Rebecca Nnamani*, **John Kanayochukwu Nduka**, and **Akudu Adaobi Ukamaka**

Department of Pure and Industrial Chemistry, Faculty of Physical Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria

*E-mail address: princessamarachi98@gmail.com

ABSTRACT

Dust samples from roads classified based on traffic volumes (low, medium and high traffic) were collected from three different urban roads in Enugu South LGA, Enugu State, Nigeria followed by assessment of human health risks of each heavy metals. The concentrations of heavy metals in road dust were determined using computerized Agilent FS240AA Atomic Absorption Spectrophotometer. The heavy metal concentrations were dominated by Fe and Mn with mean concentration of 247.03 mg/kg and 26.43 mg/kg respectively. Other dominant elements were Cu and K with mean concentrations of 121.85 mg/kg and 73.39 mg/kg, respectively. The results revealed that the highest heavy metals in road are highest in industrial road site and commercial road while the dust from residential area has the lowest heavy metal concentration. Contrary to most metals detected, mercury (Hg) shows no detection. The health risk assessment through ingestion, dermal and inhalation contact was conducted according to the United States Environmental Protection Agency's (USEPA) model for children and adults. The assessment of health risk indicated that there were mainly three exposure pathways for people: ingestion, dermal contact and inhalation. The main exposure pathway of heavy metals to both children and adults is ingestion. The values of HQ and HI are lower than the safe level (HI< 1), indicating no health risk exists in present condition. The cancer risk (CR) for children and adults from exposure to Pb, As, Ni, and Cr was found to be negligible ($\leq 1 \times 10^{-6}$). Meanwhile, the HI value for children is higher than that for adults, indicating that children have higher potential health risk than adults in the studied areas in Enugu state.

***Keywords*:** Heavy metals, hazard quotient, hazard index, average daily intake, cancer risk, health risk assessment

(Received 17 March 2024; Accepted 15 April 2024; Date of Publication 16 April 2024)

1. INTRODUCTION

Rapid growth in global road transportation is a source of heavy metal emissions (Świetlik *et al.,* 2015). Though roads play a significant role in social and economic development, road dust contaminated with heavy metals is a growing environmental concern due to its impact on human health and ecosystems (Rajaram *et al.,* 2014; Huang *et al.,* 2016). In urbanized areas particularly cities, studies have shown that main anthropogenic sources for heavy metals are traffic emissions, industrial processes and agricultural activities (Rajaram *et al.*, 2014; Kamani *et al.*, 2018). Road dust, released from both engine exhaust and other non-exhaustible releases, may act as a temporary source of heavy metals which may be considered as sink and a source of pollution in the urban environment (Apeagyei *et al.*, 2011; Soltani *et al.*, 2015; Rastegari Mehr *et al.*, 2016; Song *et al.*, 2018). They may eventually accumulate in the human body with increased risk of several undesirable effects including reproductive defects and cardiovascular problems (Christoforidis and Stamatis, 2009).

Road dust is comprised of solid particles which accumulate on impervious, hard road surfaces, such as cement and sidewalks in urban areas (Liu *et al.*, 2014). Road dust plays an active role as a "sink and source" of pollutants due to enhanced levels of metals and other pollutants and frequent interactions of dust with the atmosphere and other mediums through resuspension and deposition of dust particles (Moreno *et al.,* 2013). Therefore, road dust can contribute significantly to environmental pollution in urban areas and is considered an indicator of heavy metal contamination from atmospheric deposition (Zheng *et al.*, 2010). Moreover, heavy metal elements in road dust are known to easily enter the human body through ingestion, inhalation, and dermal contact (Cook *et al.*, 2005).

The exposure of humans to metals in dust via inhalation, ingestion and dermal contact can consequently result in undesirable responses in the respiratory system, particularly at higher concentrations, or get deposited in circulation and/or accumulated in tissues (Lu et al. 2014; Bian *et al.* 2015). According to Chen *et al.* (2017), living nearby traffic zones is a multifaceted concern representing sensitive exposure to heavy metals and other pollutants. Therefore, people who live near roadways or who use sidewalks in urban areas are likely to be more exposed to heavy metals and other traffic-related pollutants (Duong and Lee 2011; Chen *et al.*, 2017).

Worldwide, heavy metals have been frequently reported in road dust samples (Huang *et al.*, 2016; Rastegari Mehr *et al.*, 2016; Song *et al.*, 2018; Kamani *et al.*, 2018), but limited studies have been carried out in Enugu urban roads. The city also needs to do better at maintaining the air quality around the road vicinities concerning elevated heavy metals as highlighted in the sustainable development goals (SDGs) report (SDGs 2019). This paper therefore determined the concentrations level of Lead (Pb), Manganese (Mn), Nickel (Ni), Copper (Cu), Chromium (Cr), Arsenic (As), Mercury (Hg), Iron (Fe) in road dust samples of different traffic road categories. And also to evaluates their potential health risks to the human health.

2. METHODS

2. 1. Study Area

The study area is Enugu, the capital of Enugu State, Nigeria. The city of Enugu is made up of three Local Government Areas (LGAs) Enugu East, North and South LGAs. The city lies approximately between latitude 6°21' N and 6°30' N and between longitude 7°26' E and 7°37' E of the Equator and Greenwich Meridian respectively. It is bounded in the east by Nkanu LGA, in the West by Udi LGA, in the North by Igbo-Etiti and Isiuzor and in the south by Nkanu West LGA. "It lies on the plains close to the foot of the east facing escarpment of Enugu-Awgu Cuesta" (Okoye, 1975). It has a total area of 612 square kilometers with a population of 722,664 individuals according to 2006 census (National Population Commission, 2007). It records a lot of transportation activities due to high population density, industrialization and commercial businesses in the town. The improved standard of living had also led to high number of vehicles in the city. Most of these vehicles are imported into the country and they can be described as second hand and fairly used with low internal fuel combustion efficiency and some other problems. Although a rail track passed through city, but the major means of transportation is by road where vehicles of all sorts including motor cycle, mini bus, trucks, commuters, taxi, and private cars are used. Also, a significant number of people walk on the roadside depending on their destinations and hawking activities. Automobile repair workshops, welding and metal construction works by the roadside are common phenomena in the major urban roads of the state. Through these activities, heavy metal pollutants are also emitted into the atmosphere and deposited in the roadside soil.

2. 2. Sampling and preparation

Fifteen road dust samples were collected from three major traffic roads within the city. The sampling roads for the study were selected according to traffic density, industrial activities, business activities and residential. These areas were busy within the hours of 7.00 – 8.30 am when offices and commercial activities commences and 4.00 – 7.30 pm in the evening at the close of work and market activities. The traffic density was determined by counting the number of motor vehicles passing the sampling sites for a period of an hour in the morning and in the evening each day for three days. The average number of vehicles passing the site per day was then calculated. Table 1 shows the description of each traffic road and nature of the roads.

The samples were sampled using brush and plastic scoop to collect the settled dust on polyethylene sheets placed along the roads in each of the study areas. Samples were collected from December, 2022 to April, 2023 to avoid rain-washing out the heavy metals. Dust samples were collected and transferred to clean polyethylene bags and transported to the laboratory for onward analysis. All the samples were dried at 100 – 105 °C to drive out moisture.

Table 1. Description of the sampling locations

Sample sites	Name of site	Vehicular description	Ave. traffic Vol./day	Road description
Industrial Road	Enugu/PH express road	heavy duty vehicles (heavy trucks, fuel tankers, 18 tyres truck)	8782	Heavy traffic, automobile repair workshops, welding and metal construction works, car transport terminals, schools, religious organization, mini-markets, health care & medical laboratories centers, car dealers, gas plant and filling stations, companies and industries, military

				check-points, POS centers, car wash centers, auto-body scraps centers, car parking lots.
Commercial road	Agbani road	Three-wheelers(keke) and local buses, four-wheelers (car/van/911)	7893	Heavy traffic, stores, restaurant, supermarket, plaza complexes, markets, banks, gas plant and filling stations, health care & medical laboratories centers religious organization, schools, hotels, military barracks, offices, car transport terminals, POS centers, phone and laptop repair centers, car-wash centers, computer sales and accessories, cyber café, car parking lots.
Residential Road	Ogui new layout road	Mainly private cars, school buses, three wheelers (Keke) and buses	4046	Medium traffic, schools, offices, health care & medical laboratories centers, banks, religious organization, hotels, stores, plaza and shopping centers, market, phone and laptop repair centers, car-wash centers, phone sales and accessories, cyber café, POS centers, car-wash centers

2. 3. Sample Digestion Procedure

The collected dust samples were air-dried to constant weight and sieved through a stainless mesh wire. Portions of two gram of each of each air-dried dust sample were ashed in a muffle furnace at 180 °C for 4 hours. The ash were digested in 20 ml freshly prepared aqua-regia (1:3 HNO_3:HCl) according to (Praveena *et al.*, 2015). After the digestion, the digests were first centrifuged and were acid washed to pass through whatman 540 filter paper and then filtered into 100 ml volumetric flask then made up to the volume with distilled water. Calibration standards were prepared from the stock solution of the elements to be determined by serial dilution and were matrix matched with the acid concentration of the digested samples (Radojevic and Bashkin 2013). The digested samples were then analyzed for heavy metal using computerized Agilent FS240AA Atomic Absorption Spectrophotometer. All the measurements were in duplicate analyses. Statistical analysis of mean and standard deviation were obtained, using a Microsoft Excel 2007 spreadsheet.

2. 4. Human health risk assessment model

Health risk assessment models were used to quantify the health risk (carcinogenic and non-carcinogenic) for children and adults exposed to heavy metals in road dust. They are based on those developed by the United States Environmental Protection Agency (USEPA) (USEPA, 2009; USEPA, 2002)

Local residents are exposed to metals in road dust through three main exposure pathways: direct ingestion, inhalation through mouth and nose, and dermal absorption. The total non-carcinogenic risk was calculated for each metal in road dust by the summation of the individual risks calculated for the three exposure pathways (USEPA, 2002; Shi *et al.*, 2011). The average daily intake (ADI) (mg $kg^{-1}day^{-1}$) for heavy metals in road dust through the three exposure pathways was calculated according to Exposure Factors Handbook (USEPA, 2009) and the Technical Report of USEPA (USEPA, 1989) using the following equations.

2. 4. 1. Average daily intake (ADI) (mg/kg/day) of heavy metals in dust media

$$\text{ADI}-\text{ingestion} = \left(\frac{\text{CS} \times \text{IRing} \times \text{EF} \times \text{ED} \times \text{TR}}{\text{BW} \times \text{AT}}\right) \quad (1)$$

$$\text{ADI}-\text{inhalation} = \left(\frac{\text{CS} \times \text{IRinh} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}}\right) \quad (2)$$

$$\text{ADI}-\text{dermal} = \left(\frac{\text{CS} \times \text{AF} \times \text{SA} \times \text{DAF} \times \text{EF} \times \text{ED} \times \text{TR}}{\text{BW} \times \text{AT}}\right) \quad (3)$$

where: ADIingestion, ADIinhalation, and ADIdermal are the average daily intake or amount of exposure to heavy metals (mg (kg day)$^{-1}$) via ingestion or oral intake, inhalation and dermal contacts, respectively. Cs is the concentration of the heavy metals in soil (mg kg^{-1}); IR_{ing} is the ingestion rate (mg day^{-1}); EF is the exposure frequency of the people (day year^{-1}); ED is the exposure duration (years); TR is the conversion factor in kg/mg, IR_{inh} is the inhalation rate (m^3 day^{-1}); EF is the particulate emission factors (m^3 kg^{-1}); SA is the skin surface area (cm^2); AF is the skin adherence factor (mg cm^{-2}); DAF is the dermal absorption factor; BW and AT are the body weight (kg) and average exposed time (years), respectively (USEPA, 2009; USEPA, 2002). The detailed description of the values of exposure factors for children and adults applied to the above models (Equations 5-7) are given in Table 2.

Table 2. Definition and reference value of some parameters for health risk assessment of heavy metal.

Indicators	Parameters	Definition	Units	Adult	Children	References
Exposure factors	EF	Exposure frequency	days year^{-1}	350	350	USEPA (2002)
	ED	Exposure duration	Years	30	6	USEPA (2002)
	BW	Body weight	Kg	70	20	USEPA (2002)
	TR	Conversion factor	mg kg^{-1}	1×10^6	1×10^6	
	Cs	Concentration of heavy metals	mg kg^{-1}	-	-	present study
	IR_w	daily water ingestion rate	L/day	2.5L/day	0.78L/day	USEPA (2002)
Ingestion	IR_{ing}	Ingestion rate	mg day^{-1}	100	200	USEPA (2002, 1989)
Inhalation	IR_{inh}	Inhalation rate	m^3 day^{-1}	20	10	USEPA (2009)
	PEF	Particle emission factor	m^3 kg^{-1}	1.36×10^9	1.36×10^9	USEPA (2009)
Skin contact	SA	Exposed skin surface area	cm^2	5800	2100	USEPA (2002)

	AF	Skin adherence factor	mg cm^2	0.7	0.2	USEPA (2002)
	DAF	Dermal absorption factor	-	0.1	0.1	USEPA (2002)
	AT	Average time Carcinogens Non-carcinogens	days $year^{-1}$	70 × 365 ED × 365	70 × 365 ED × 365	USEPA (2002)

2. 4. 2. Non-carcinogenic risk assessment

Reference dose (RfD) is a key factor to estimate the non-carcinogenic health risk of a single heavy metal which is traditionally characterized by the hazard quotient (HQ). Therefore, HQ is computed as the ratio of the average daily dose (ADD) and a reference dose (RfD). The equitation of HQ is defined as follows (USEPA 1989, 2002):

$$\mathrm{HQ} = \frac{\mathrm{ADI}}{\mathrm{RfD}} \tag{4}$$

where ADI is the average daily intake of heavy metals n through e exposed (ingestion, inhalation, and dermal contact) pathways (mg (kg day)$^{-1}$) and RfD is the reference dose of heavy metal n through (ingestion, inhalation, and dermal contact) pathways (mg (kg day)$^{-1}$). The reference dose (RfD) for the selected heavy metals is listed in Table 3.

Eventually, to assess the overall non-carcinogenic risk of six heavy metals that can be evaluated by the sum of the HQ values of multiple exposure pathways is also expressed as a hazard index (HI). The equation of HI is as follows:

$$\mathrm{HI} = \mathrm{HQ_{der}} + \mathrm{HQ_{ing}} + \mathrm{HQ_{inh}} = \left(\left[\frac{\mathrm{ADI(Der)}}{\mathrm{RfD}}\right] + \left[\frac{\mathrm{ADI(ing)}}{\mathrm{RfD}}\right] + \left[\frac{\mathrm{ADI(inh)}}{\mathrm{RfD}}\right]\right) \tag{5}$$

where: HI = sum total of more than one hazard quotient of multiple exposure pathway, HQ = hazard quotient is a unit-less number for expressing the probability of an adverse health effect, ADI (E) = average daily intake (exposure), RfD = reference dose of heavy metals (mg/kg/day). There is no non-carcinogenic health risk for humans if the value of HI is less than one, while if it is greater than one, it is assumed to be an adverse non-carcinogenic health risk occur (Adimalla and Wang 2018; USEPA, 2002).

2. 4. 3. Carcinogenic risk assessment

The carcinogenic risk is assessed by calculating the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (USEPA, 2004). Carcinogenic risk and total carcinogenic risks are computed using the following equation:

$$\mathrm{CR} = \mathrm{ADI\ X\ SF} \tag{6}$$

$$\mathrm{TCR} = \mathrm{CR}_{der} + \mathrm{CR}_{ing} + \mathrm{CR}_{inh} = \left([\mathrm{ADI}_{ing} \times \mathrm{CSF}] + [\mathrm{ADI}_{inh} \times \mathrm{CSF}] + [\mathrm{ADI}_{derm} \times \mathrm{CSF}]\right) \tag{7}$$

where: CR(ing), CR(inh), and CR(dermal) are risks contributions through ingestion, inhalation and dermal pathways respectively. CR is the carcinogenic risk; ADI is the average daily intake; TCR is the total carcinogenic risk; and SF is the carcinogenicity slope factor over a lifetime (mg $(kg\ day)^{-1}$); TCR is the total excess lifetime cancer calculated from risk pathway. Carcinogenic risk values ranging from 1×10^{-6} to 1×10^{-4} are typically considered as a safe limit for human health (USEPA 1989, 2009). If carcinogenic risk value exceeds the limit of 1×10^{-4}, it will result in a lifetime cancer risk to the human body (USEPA 1989).

Both non-carcinogenic and carcinogenic risk assessment of heavy metals are calculated using RfD and CSF values derived largely from USEPA as shown in Table 3.

Table 3. Reference doses (RfD) in (mg/kg-day) and Cancer Slope Factors (CSF) for the different heavy metals

Heavy metals ($mg\ kg^{-1}$)	**Reference dose (RfD)**			**Slope factor (SF)**		
	RfD_{Ing}	**RfD_{Inh}**	**RfD_{dermal}**	**Oral SF**	**Inhal.SF**	**Dermal SF**
Cu	4.00E-02	4.02E-02	1.20E-02	-	-	-
Fe	8.40E+00	2.20E-04	7.00E-02	-	-	-
Cr	3.00E-03	2.86E-05	3.00E-03	5.01E-01	4.20E+01	2.00E+01
As	3.00E-04	3.01E-04	1.23E-04	1.50E+00	4.30E-03	3.66E+00
Hg	3.00E-04	8.57E-05	2.10E-05	-	-	-
Pb	3.50E-03	3.52E-03	5.25E-04	8.50E-03	4.20E-02	-
Mn	4.60E-02	1.43E-05	1.84E-03	-	-	-
Ni	2.00E-02	2.06E-02	5.40E-03	1.70E+00	8.40E-01	4.25E+01

Source: http://www.epa.gov/ncea/efh.NA: not available

3. RESULTS AND DISCUSSION

3. 1. Concentrations of heavy metals in dust samples

Table 4 presents the mean concentrations of some pollutants determined in the roadside dust samples in Enugu south LGA, Enugu state from December, 2022 to April, 2023. High elemental concentration was observed in Fe, followed by Mn, Cu, Pb, Ni, Cr and As in all the three different sampling roads while Hg shows no detection. The high concentration of Fe in the roadside dust samples may be attributed to metal construction works, iron bending and welding of metals, which is a common practice along the urban roads in Enugu city. The heavy metals in urban roadside dust take their origin from sources such as vehicles, road wear, activities of roadside artisans (battery charging, vehicle repairs, iron-bending, vehicle painting and panel beating) and emissions and or discharges from industries (Abechi *et al.*, 2010). Pb, Cr and Ni come mainly from vehicular activities such as tyre wear, wear of brake linings and studded tyres may be the sources for Ni, Cr, and Pb (Muschack, 1990) and Fe, Ni, Cr and Cu respectively (Viklander, 1998). Corrosion of bushings, brake wires and radiators and friction materials used on road surfaces for slipperiness control could expose metals such Cu, Fe, Ni and Cr into the environment (Viklander, 1998). Motor oil also tends to accumulate metals as it comes into contact with surrounding parts as the engine runs, so oil leaks become another pathway by which metals enter the environment. Studies have shown that, steel and alloy steel contain Fe, Cr, Co, Al and Cu and that exhaust emission from both gasoline and diesel fueled vehicles contain variable quantities of these elements (Chong, 1986; Yu *et al.*, 2003).

Table 4. Mean concentrations and standard deviation of heavy metals (mg/kg) in roadside dusts samples between December, 2022 to April, 2023 at the various urban roads of Enugu State, Nigeria.

Sample roads	Sample/month	Cr	As	Ni	Cu	Hg	Fe	Pb	Mn
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Enugu/PHexpress road	Dec	ND	ND	1.98 ±0.14	4.54 ±0.05	ND	137.36 ±2.95	0.88 ±0.18	17.65 ±0.21
	Jan	0.13 ±0.07	2.33 ±0.11	2.05 ±0.07	16.93 ±0.11	ND	165.54 ±5.85	3.54±0.12	25.75 ±0.18
	Feb	0.01 ±0.02	0.3 ±0.07	1.13 ±0.11	10.68 ±0.07	ND	197.1 ±3.39	4.99 ±0.12	20.08 ±0.11
	March	0.03 ±0.04	ND	1.58 ±0.12	6.45 ±0.11	ND	247.03 ±1.4	1.68 ±0.25	26.43 ±0.25
	April	0.18 ±0.04	ND	0.85 ±0.14	5.68 ±0.07	ND	218.25 ±1.91	1.5 ±0.14	20.3 ±0.42
Agbani road	Dec	ND	ND	0.85 ±0.14	8.43 ±0.25	ND	159.23 ±1.41	3.1±0.07	19.15 ±0.21
	Jan	ND	2.85 ±0.14	0.71 ±0.19	121.8 ±1.24	ND	197.48 ±0.07	4.93 ±0.25	15.95 ±0.18
	Feb	ND	ND	1.2 ±0.11	10.08 ±0.11	ND	187.66 ±1.39	14.63 ±13.97	23.44 ±0.27
	March	ND	ND	4.68 ±0.11	4.94 ±0.27	ND	189.48 ±5.13	0.59 ±0.09	15.05 ±0.07
	April	ND	ND	0.99 ±0.16	9.53 ±0.11	ND	203.7 ±0.35	3.89 ±0.07	21.7 ±0.28
Ogui road	Dec	ND	ND	2.38 ±0.18	4.48 ±0.04	ND	155.71 ±1.22	1±0.11	14.13 ±0.14
	Jan	0.14 ±0.05	2.33 ±0.11	1.43 ±0.07	4.25 ±0.11	ND	189.16 ±7.87	2.3 ±0.07	18.63 ±0.18
	Feb	ND	ND	2.8 ±0.07	6.95 ±0.11	ND	157.90 ±3.04	3.41 ±0.23	20.71 ±0.30
	March	ND	ND	1.08 ±0.11	5.54 ±0.05	ND	152.84 ±0.05	1.75 ±0.11	15.91 ±0.23
	April	ND	ND	4.45 ±0.21	5.7 ±0.14	ND	207.66 ±1.29	1 ±0.14	23.18 ±0.25

All values represent mean±SD (Standard Deviation). ND: Not Detected; Industrial road = Enugu/PH express road; Commercial road = Agbani road; Residential road = Ogui new layout road

3. 2. Health risks assessment results

Table 5-7 shows the results of the non-carcinogenetic effects via inhalation, ingestion, and dermal exposure pathways of metals in the road dust on children and adults. Ingestion appeared to be the major exposure pathway of heavy metals in the road dust to the adults. This is followed by dermal contact and inhalation. Most adults engaged in roasting of food items like maize, plantain and hawker, vendors, artisan such as vulcanizer around the traffic roads in Enugu city and the nature of these activities could lead to exposure to heavy metals in the road dust emitted from to traffic activities.

The exposure by dermal contact could be as a result of particle from traffic activities that settled on the exposed skin of the road users, pedestrians and other people around the road environment. Exposure to dust particles through ingestion could be associated to hand to mouth transfer of contaminated items by the road dust particles. A negligence of hand washing before eating after daily activities by the adults could increase the ingestion of heavy metals (Olujimi *et al.*, 2012). Outdoor artisans, road sweepers, taxi drivers and pedestrian could be exposed to heavy metals in the road dust and suffer severe health implications due to the nature of their activities. For the children, inhalation also showed to be a most exposure route. The inhalation rate of the children is about 200 m^3 /day and high proportion of the volume of air breath in might be contaminated with road dust (Du *et al.*, 2013).

Table 5. Non-carcinogenic health risks assessment of dust for the selected elements at Enugu/PH express road

Elements (mg/kg)	Samples	ADULT			CHILDREN			HI =∑HQ	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL		
	Months	HQ_{ING}	HQ_{INH}	HQ_{DERM}	HQ_{ING}	HQ_{INH}	HQ_{DERM}	ADULT	CHILD
Cu	Dec	1.56E-04	1.84E-08	5.80E-06	1.45E-03	3.96E-08	3.68E-05	1.61E-04	1.49E-03
	Jan	5.80E-04	6.87E-08	2.16E-05	5.40E-03	1.49E-07	1.37E-04	6.02E-04	5.54E-03
	Feb	3.65E-04	4.33E-08	1.36E-05	3.40E-03	9.35E-08	8.67E-05	3.79E-04	3.49E-03
	March	2.21E-04	2.61E-08	8.24E-06	2.06E-03	5.65E-08	5.23E-05	2.29E-04	2.11E-03
	April	1.94E-04	2.30E-08	7.26E-06	1.82E-03	4.98E-08	4.59E-05	2.02E-04	1.86E-03
Fe	Dec	2.25E-05	1.02E-04	3.01E-05	2.10E-05	2.21E-04	1.91E-04	1.55E-04	4.33E-04
	Jan	2.70E-05	1.23E-04	3.63E-05	2.52E-05	2.65E-04	2.30E-04	1.86E-04	5.21E-04
	Feb	3.21E-05	1.46E-04	4.31E-05	3.00E-04	3.16E-04	2.74E-04	2.22E-04	8.90E-04
	March	4.02E-05	1.83E-04	5.41E-05	3.76E-04	3.96E-04	3.43E-04	2.78E-04	1.11E-03
	April	3.56E-05	1.62E-04	4.79E-05	3.32E-04	3.50E-04	3.03E-04	2.45E-04	9.85E-04
Cr	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	1.39E-05	2.15E-07	7.80E-06	3.25E-05	1.25E-07	1.24E-05	2.20E-05	4.50E-05
	Feb	7.83E-08	1.21E-09	4.38E-08	1.83E-07	7.04E-10	6.94E-08	1.23E-07	2.53E-07
	March	3.91E-06	6.04E-08	2.19E-06	9.13E-06	3.52E-08	3.47E-06	6.17E-06	1.26E-05

	April	1.61E-05	2.49E-07	9.03E-06	3.76E-05	1.45E-07	1.43E-05	2.54E-05	5.21E-05
As	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	3.60E-03	5.28E-07	9.84E-05	8.40E-03	3.08E-07	1.56E-04	3.70E-03	8.56E-03
	Feb	4.70E-04	6.88E-08	1.28E-05	1.10E-03	4.02E-08	2.03E-05	4.83E-04	1.12E-03
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	Dec	1.17E-04	1.72E-08	8.77E-06	2.74E-04	1.00E-08	1.39E-05	1.26E-04	2.88E-04
	Jan	4.75E-04	6.94E-08	3.54E-05	1.11E-03	4.05E-08	5.61E-05	5.10E-04	1.16E-03
	Feb	6.69E-04	9.79E-08	5.00E-05	1.56E-03	5.71E-08	7.91E-05	7.19E-04	1.64E-03
	March	2.25E-04	3.29E-08	1.68E-05	5.24E-04	1.92E-08	2.66E-05	2.42E-04	5.51E-04
	April	2.01E-04	2.94E-08	1.50E-05	4.70E-04	1.72E-08	2.38E-05	2.16E-04	4.93E-04
Mn	Dec	5.26E-04	2.01E-04	1.47E-04	4.91E-03	4.35E-04	9.35E-04	8.75E-04	6.28E-03
	Jan	7.67E-04	2.94E-04	2.15E-04	7.15E-03	6.35E-04	1.36E-03	1.28E-03	9.15E-03
	Feb	5.98E-04	2.29E-04	1.67E-04	5.59E-03	4.95E-04	1.06E-03	9.95E-04	7.14E-03
	March	7.87E-04	3.01E-04	2.20E-04	7.35E-03	6.52E-04	1.40E-03	1.31E-03	9.40E-03
	April	6.04E-04	2.31E-04	1.69E-04	5.63E-03	5.01E-04	1.07E-03	1.00E-03	7.20E-03
Ni	Dec	4.64E-05	6.62E-09	1.92E-06	1.08E-04	3.86E-09	3.05E-06	4.83E-05	1.11E-04
	Jan	4.81E-05	6.87E-09	2.00E-06	1.12E-04	4.01E-09	3.16E-06	5.01E-05	1.15E-04
	Feb	2.64E-05	3.77E-09	1.10E-06	6.16E-05	2.20E-09	1.74E-06	2.75E-05	6.34E-05
	March	3.70E-05	5.28E-09	1.53E-06	8.63E-05	3.08E-09	2.43E-06	3.85E-05	8.87E-05
	April	2.00E-05	2.85E-09	8.28E-07	4.66E-05	1.66E-09	1.31E-06	2.08E-05	4.79E-05

NA: Indicates that reference doses were not available for calculation; ‘’0’’ means the detectable concentration is zero; Industrial road = Enugu/PH express road.

Table 6. Non-carcinogenic health risks assessment of dust for the selected elements at Agbani road

Elements (mg/kg)	Samples	ADULT			CHILDREN			HI =∑HQ	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL		
	Months	HQ_{ING}	HQ_{INH}	HQ_{DERM}	HQ_{ING}	HQ_{INH}	HQ_{DERM}	ADULT	CHILD
Cu	Dec	2.88E-04	3.41E-08	1.08E-05	2.70E-03	7.39E-08	6.83E-05	2.98E-04	2.77E-03
	Jan	4.18E-03	4.95E-07	1.56E-04	3.90E-02	1.07E-06	9.83E-04	4.33E-03	3.99E-02
	Feb	3.45E-04	4.08E-08	1.29E-05	3.23E-03	8.83E-08	8.16E-05	3.58E-04	3.31E-03
	March	1.69E-04	2.00E-08	6.32E-06	1.58E-03	4.33E-08	3.99E-05	1.75E-04	1.62E-03
	April	3.25E-04	3.86E-08	1.22E-05	3.05E-03	8.36E-08	7.72E-05	3.37E-04	3.13E-03
Fe	Dec	2.60E-05	1.18E-04	3.49E-05	2.43E-04	2.55E-04	2.21E-04	1.79E-04	7.19E-04
	Jan	3.23E-05	1.46E-04	4.33E-05	3.00E-04	3.16E-04	2.74E-04	2.22E-04	8.91E-04

	Feb	3.06E-05	1.39E-04	4.11E-05	2.85E-04	3.01E-04	2.60E-04	2.11E-04	8.45E-04
	March	3.08E-05	1.40E-04	4.16E-05	2.88E-04	3.04E-04	2.63E-04	2.13E-04	8.55E-04
	April	3.32E-05	1.51E-04	4.47E-05	3.10E-04	3.26E-04	2.83E-04	2.29E-04	9.19E-04
Cr	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	4.46E-03	6.54E-07	1.22E-04	1.04E-02	3.81E-07	1.93E-04	4.58E-03	1.06E-02
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	Dec	4.16E-04	6.08E-08	3.11E-05	9.71E-04	3.55E-08	4.92E-05	4.47E-04	1.02E-03
	Jan	6.61E-04	9.66E-08	4.93E-05	1.54E-03	5.64E-08	7.81E-05	7.10E-04	1.62E-03
	Feb	1.96E-03	2.87E-07	1.47E-04	4.58E-03	1.67E-07	2.32E-04	2.11E-03	4.81E-03
	March	7.88E-05	1.15E-08	5.89E-06	1.84E-04	6.72E-09	9.32E-06	8.47E-05	1.93E-04
	April	5.20E-04	7.60E-08	3.88E-05	1.21E-03	4.44E-08	6.15E-05	5.59E-04	1.27E-03
Mn	Dec	5.70E-04	2.18E-04	1.60E-04	5.33E-03	4.72E-04	1.01E-03	9.48E-04	6.81E-03
	Jan	4.74E-04	1.82E-04	1.33E-04	4.43E-03	3.93E-04	8.42E-04	7.89E-04	5.67E-03
	Feb	6.98E-04	2.67E-04	1.95E-04	6.50E-03	5.78E-04	1.24E-03	1.16E-03	8.32E-03
	March	4.48E-04	1.72E-04	1.26E-04	4.17E-03	3.71E-04	7.93E-04	7.45E-04	5.34E-03
	April	6.46E-04	2.48E-04	1.81E-04	6.02E-03	5.35E-04	1.15E-03	1.07E-03	7.71E-03
Ni	Dec	2.00E-05	2.85E-09	8.28E-07	4.66E-05	1.66E-09	1.31E-06	2.08E-05	4.79E-05
	Jan	1.67E-05	2.39E-09	6.94E-07	3.90E-05	1.39E-09	1.10E-06	1.74E-05	4.01E-05
	Feb	2.82E-05	4.02E-09	1.17E-06	6.58E-05	2.35E-09	1.85E-06	2.94E-05	6.76E-05
	March	1.10E-04	1.57E-08	4.55E-06	2.56E-04	9.14E-09	7.21E-06	1.14E-04	2.63E-04
	April	2.32E-05	3.31E-09	9.62E-07	5.41E-05	1.93E-09	1.52E-06	2.42E-05	5.56E-05

NA: Indicates that reference doses were not available for calculation; ‘’0’’ means the detectable concentration is zero; Commercial road = Agbani road

Table 7. Non-carcinogenic health risks assessment of dust for the selected elements at Ogui road

Elements (mg/kg)	Samples	ADULT			CHILDREN			HI =∑HQ	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL		
	Months	HQ_{ING}	HQ_{INH}	HQ_{DERM}	HQ_{ING}	HQ_{INH}	HQ_{DERM}	ADULT	CHILD
Cu	Dec	1.53E-04	1.82E-08	5.73E-06	1.43E-03	3.93E-08	3.63E-05	1.59E-04	1.47E-03

	Jan	1.46E-04	1.72E-08	5.43E-06	1.36E-03	3.71E-08	3.44E-05	1.51E-04	1.39E-03
	Feb	2.38E-04	2.81E-08	8.92E-06	2.22E-03	6.09E-08	5.63E-05	2.47E-04	2.28E-03
	March	1.90E-04	2.25E-08	7.08E-06	1.77E-03	4.85E-08	4.48E-05	1.97E-04	1.81E-03
	April	1.95E-04	2.31E-08	7.29E-06	1.82E-03	5.00E-08	4.62E-05	2.03E-04	1.87E-03
Fe	Dec	2.54E-05	1.15E-04	3.41E-05	2.37E-04	2.50E-04	2.16E-04	1.75E-04	7.02E-04
	Jan	3.08E-05	1.40E-04	4.14E-05	2.88E-04	3.03E-04	2.63E-04	2.13E-04	8.54E-04
	Feb	2.57E-05	1.17E-04	3.46E-05	2.40E-04	2.53E-04	2.19E-04	1.78E-04	7.12E-04
	March	2.49E-05	1.13E-04	3.34E-05	2.32E-04	2.45E-04	2.13E-04	1.71E-04	6.90E-04
	April	3.38E-05	1.54E-04	4.56E-05	3.17E-04	3.33E-04	2.89E-04	2.33E-04	9.38E-04
Cr	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	1.40E-05	2.16E-07	7.85E-06	3.27E-05	1.26E-07	1.24E-05	2.21E-05	4.52E-05
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	3.64E-03	5.34E-07	9.94E-05	8.49E-03	3.11E-07	1.57E-04	3.74E-03	8.65E-03
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	Dec	1.34E-04	1.96E-08	1.00E-05	3.13E-04	1.14E-08	1.59E-05	1.44E-04	3.29E-04
	Jan	3.09E-04	4.51E-08	2.30E-05	7.20E-04	2.63E-08	3.65E-05	3.32E-04	7.57E-04
	Feb	4.58E-04	6.70E-08	3.42E-05	1.07E-03	3.91E-08	5.41E-05	4.92E-04	1.12E-03
	March	2.35E-04	3.43E-08	1.75E-05	5.48E-04	2.00E-08	2.78E-05	2.52E-04	5.76E-04
	April	1.34E-04	1.96E-08	1.00E-05	3.13E-04	1.14E-08	1.59E-05	1.44E-04	3.29E-04
Mn	Dec	4.20E-04	1.61E-04	1.18E-04	3.93E-03	3.48E-04	7.45E-04	6.98E-04	5.03E-03
	Jan	5.54E-04	2.13E-04	1.55E-04	5.17E-03	4.59E-04	9.84E-04	9.22E-04	6.62E-03
	Feb	6.17E-04	2.36E-04	1.73E-04	5.76E-03	5.10E-04	1.09E-03	1.03E-03	7.36E-03
	March	4.74E-04	1.81E-04	1.33E-04	4.41E-03	3.92E-04	8.42E-04	7.88E-04	5.65E-03
	April	6.89E-04	2.64E-04	1.93E-04	6.43E-03	5.71E-04	1.22E-03	1.15E-03	8.23E-03
Ni	Dec	5.58E-05	7.96E-09	2.31E-06	1.30E-04	4.65E-09	3.66E-06	5.81E-05	1.34E-04
	Jan	3.35E-05	4.78E-09	1.39E-06	7.81E-05	2.79E-09	2.20E-06	3.49E-05	8.03E-05
	Feb	6.58E-05	9.39E-09	2.73E-06	1.53E-04	5.48E-09	4.32E-06	6.85E-05	1.58E-04
	March	2.52E-05	3.60E-09	1.05E-06	5.89E-05	2.10E-09	1.66E-06	5.11E-07	1.19E-06
	April	1.05E-04	1.49E-08	4.33E-06	2.44E-04	8.70E-09	6.86E-06	2.11E-06	4.91E-06

NA: Indicates that reference doses were not available for calculation; ‘’0’’ means the detectable concentration is zero; Residential road = ogui road.

The results showed that, the Hazard Index (HI) values of the selected metals, in all the locations of the urban roads in Enugu city were mostly less than one. Cu, Mn and As where the elements that recorded high HI values greater than other elements, which occurred mostly at the industrial road and commercial road and mostly for children. Their values are below the acceptable value HI=1 (safe level for non-cancerous effect). As is cumulative poison and neurotoxic hence prolong exposure can trigger neurological and developmental disorders in children (Atiemo *et al.*, 2010). The sample locations generally recorded the least health indexes less than one, indicating little or no adverse health risk.

However due to heavy metals accumulation in the body, long time exposure can have possibly adverse health effect. It is also observed that the exposure route with the highest risk of non-cancerous is ingestion, while inhalation recording the least route of exposure. This indicates that ingestion was the main pathway exposure to the measured heavy metals in urban road dusts of Enugu city in the two population groups. These results are consistent with those reported in other studies (Liu *et al.*, 2014; Wei *et al.*, 2015; Mohmand *et al.*, 2015; Li *et al.*, 2018; Shi *et al.*, 2011; and Ali *et al.*, 2017). It was observed that the children are exposed to higher risk than adults as their HI and HQing values are consistently higher than that of the adult. Children are more vulnerable to dust exposure because of their playing habits ingestion of dust through mouth, hand licking, toys and other household objects (Mohmand *et al.*, 2015; Martin and Griswold, 2009). Special attention should be paid for children exposure. The high value of HI for children than adults indicates that children face more potential harmful health risk through both ingestion and inhalation of heavy metals in urban road dusts of Enugu state.

The carcinogen risk for ingestion, inhalation and dermal exposure routes was estimated for Cr, Ni, As and Pb for both adults and the children. All CR values for both populations are within the global threshold limit of 10^{-4} to 10^{-6} recommended by United States Environmental Protection Agency and International Agency for Research on Cancer (USEPA, 2011; IRAC, 2011), with higher values in children, suggesting that the carcinogenic risk from exposure to these metals is negligible. These results are similar to those reported in literature (Keshavarzi *et al.*, 2015; Liu *et al.*, 2014; Ali *et al.*, 2017). The present study deduced that there is no serious risk from heavy metals in road dusts of Enugu-port Harcourt road, Agbani road and Ogui road via different exposure routes. However, the possibility that these metals can cause serious health effects by their accumulation in body tissues persists. Particularly As with TCR values of 1.88E-06 and 1.04E-05 for adult and children respectively should be paid more attention to the potential occurrence of cancer risk to the local residents along the urban roads of Enugu.

Table 8. Cancer risk (CR) values for heavy metals in dust for adults and children from Enugu/PH express road

Elements (mg/kg)	Samples	ADI and cancer risk (CR) values							
		ADULT			CHILDREN			TCR	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL	ADULT	CHILD
	Months	CR_{ING}	CR_{INH}	CR_{DERM}	CR_{ING}	CR_{INH}	CR_{DERM}		
Cr	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	2.09E-08	2.58E-10	9.36E-09	4.88E-08	1.51E-10	1.48E-08	3.05E-08	6.37E-08
	Feb	1.17E-10	1.45E-12	5.26E-11	2.74E-10	8.46E-13	8.33E-11	1.71E-10	3.58E-10
	March	5.87E-09	7.25E-11	2.63E-09	1.37E-08	4.23E-11	4.16E-09	8.57E-09	1.79E-08
	April	2.42E-08	2.99E-10	1.08E-08	5.64E-08	1.74E-10	1.72E-08	3.53E-08	7.38E-08
As	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	Jan	1.62E-06	6.83E-13	4.43E-08	3.78E-06	3.98E-13	7.01E-08	1.66E-06	3.85E-06
	Feb	2.11E-07	8.91E-14	5.78E-09	4.93E-07	5.20E-14	9.14E-09	2.17E-07	5.02E-07
	March	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	April	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb	Dec	3.49E-09	2.54E-12	NA	8.15E-09	1.48E-12	NA	3.49E-09	8.15E-09
	Jan	1.41E-08	1.03E-11	NA	3.30E-08	5.99E-12	NA	1.41E-08	3.30E-08
	Feb	1.99E-08	1.45E-11	NA	4.65E-08	8.44E-12	NA	1.99E-08	4.65E-08
	March	6.69E-09	4.86E-12	NA	1.56E-08	2.83E-12	NA	6.69E-09	1.56E-08
	April	5.99E-09	4.35E-12	NA	1.40E-08	2.54E-12	NA	5.99E-09	1.40E-08
Ni	Dec	1.58E-06	1.15E-10	4.42E-07	3.68E-06	6.68E-11	6.99E-07	2.02E-06	4.38E-06
	Jan	1.64E-06	1.19E-10	4.58E-07	3.82E-06	6.94E-11	7.26E-07	2.10E-06	4.54E-06
	Feb	8.98E-07	6.53E-11	2.52E-07	2.10E-06	3.81E-11	3.98E-07	1.15E-06	2.49E-06
	March	1.26E-06	9.14E-11	3.52E-07	2.93E-06	5.33E-11	5.58E-07	1.61E-06	3.49E-06
	April	6.79E-07	4.93E-11	1.90E-07	1.58E-06	2.88E-11	3.01E-07	8.69E-07	1.88E-06

NA: Indicates that dermal slope factor of Pb were not available for calculation; ''0'' means the detectable concentration is zero.

Table 9. Cancer risk (CR) values for heavy metals in dust for adults and children from Agbani road

Elements (mg/kg)	Samples	ADI and cancer risk (CR) values							
		ADULT			CHILDREN			TCR	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL	ADULT	CHILD
	Months	CR_{ING}	CR_{INH}	CR_{DERM}	CR_{ING}	CR_{INH}	CR_{DERM}		
Cr	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Feb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	March	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	April	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
As	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	2.01E-06	8.46E-13	5.49E-08	4.68E-06	4.94E-13	8.69E-08	2.06E-06	4.77E-06
	Feb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	March	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	April	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb	Dec	1.24E-08	8.99E-12	NA	2.89E-08	5.25E-12	NA	1.24E-08	2.89E-08
	Jan	1.97E-08	1.43E-11	NA	4.59E-08	8.33E-12	NA	1.97E-08	4.59E-08
	Feb	5.84E-08	4.24E-11	NA	1.36E-07	2.47E-11	NA	5.84E-08	1.36E-07
	March	2.35E-09	1.70E-12	NA	5.47E-09	9.94E-13	NA	2.35E-09	5.49E-09
	April	1.55E-08	1.12E-11	NA	3.61E-08	6.56E-12	NA	1.55E-08	3.61E-08
Ni	Dec	6.79E-07	4.93E-11	1.90E-07	1.58E-06	2.88E-11	3.01E-07	8.69E-07	1.88E-06
	Jan	5.69E-07	4.13E-11	1.59E-07	1.33E-06	2.41E-11	2.52E-07	7.28E-07	1.58E-06
	Feb	9.58E-07	6.96E-11	2.68E-07	2.24E-06	4.06E-11	4.25E-07	1.23E-06	2.66E-06
	March	3.73E-06	2.71E-10	1.05E-06	8.71E-06	1.58E-10	1.65E-06	4.78E-06	1.04E-05
	April	7.88E-07	5.73E-11	2.21E-07	1.84E-06	3.34E-11	3.50E-07	1.01E-06	2.19E-06

NA: Indicates that dermal slope factor of Pb were not available for calculation; ''0'' means the detectable concentration is zero.

Table 10. Cancer risk (CR) values for heavy metals in dust for adults and children for from Ogui road

ADI and cancer risk (CR) values									
Elements (mg/kg)	Samples	ADULT			CHILDREN			TCR	
		INGESTION	INHALATION	DERMAL	INGESTION	INHALATION	DERMAL	ADULT	CHILD
	Months	CR_{ING}	CR_{INH}	CR_{DERM}	CR_{ING}	CR_{INH}	CR_{DERM}		
Cr	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	2.10E-08	2.60E-10	9.42E-09	4.90E-08	1.51E-10	1.49E-08	3.07E-08	6.41E-08
	Feb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	March	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	April	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
As	Dec	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Jan	1.64E-06	6.91E-13	4.48E-08	3.82E-06	4.03E-13	7.09E-08	1.68E-06	3.89E-06
	Feb	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	March	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	April	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb	Dec	3.99E-09	2.90E-12	NA	9.32E-09	1.69E-12	NA	3.99E-09	9.32E-09
	Jan	9.18E-09	6.67E-12	NA	2.14E-08	3.89E-12	NA	9.18E-09	2.14E-08
	Feb	1.36E-08	9.90E-12	NA	3.18E-08	5.77E-12	NA	1.36E-08	3.18E-08
	March	6.99E-09	5.08E-12	NA	1.63E-08	2.96E-12	NA	6.99E-09	1.63E-08
	April	3.99E-09	2.90E-12	NA	9.32E-09	1.69E-12	NA	3.99E-09	9.32E-09
Ni	Dec	1.90E-06	1.38E-10	5.31E-07	4.42E-06	8.04E-11	8.41E-07	2.43E-06	5.27E-06
	Jan	1.14E-06	8.27E-11	3.19E-07	2.65E-06	4.82E-11	5.04E-07	1.46E-06	3.16E-06
	Feb	2.24E-06	1.62E-10	6.26E-07	5.22E-06	9.48E-11	9.91E-07	2.86E-06	6.21E-06
	March	8.58E-07	6.24E-11	2.40E-07	2.00E-06	3.64E-11	3.81E-07	1.10E-06	2.38E-06
	April	3.55E-06	2.58E-10	9.95E-07	8.29E-06	1.51E-10	1.58E-06	4.55E-06	9.87E-06

NA: Indicates that dermal slope factor of Pb were not available for calculation; ''0'' means the detectable concentration is zero

4. CONCLUSIONS

The concentrations of Lead (Pb), Manganese (Mn), Nickel (Ni), Copper (Cu), Chromium (Cr), Arsenic (As), Mercury (Hg), Iron (Fe), in the road dust samples collected from different traffic road categories were measured by employing AAS. The HQs and HI values for the different exposure pathways of measured heavy metals in children and adults decreased in the following order: ingestion > dermal contact > inhalation. The average daily exposure dose indicated ingestion as the major exposure pathway of heavy metals in the road dust to both adults and children followed by dermal contact and inhalation. The values of HQs for all heavy metals in all the three urban roads were below the safe level (<1) indicating that no significant potential health risk posed to inhabitants (children and adults) from exposure to heavy metals in road dusts. The carcinogenic risk assessment for heavy metals in three urban roads of Enugu state was found to be within the safe limits for children and adults, suggesting no potential harm from exposure to these metals in road dusts. Meanwhile, carcinogenic risk values of heavy metals were higher in children than adults indicating that children have higher potential health risk than adults in the study road sites. The present study deduced that there is no serious risk from heavy metals in road dusts of Enugu/PH express road, Agbani road and Ogui road via different exposure routes. However, the possibility that these metals can cause serious health effects by their accumulation in body tissues persists. Particularly As with TCR values of 1.88E-06 and 1.04E-05 for adult and children respectively should be paid more attention to the potential occurrence of cancer risk to the local residents along the urban roads of Enugu.

References

[1] Abechi, E.S., Okunola, O.J., Zubairu, S.M.J., Usman, A.A. and Apene E. (2010). Evaluation of heavy metals in roadside soils of major streets in Jos metropolis, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology,* 2(6): 98-102

[2] Adimalla, N. and Wang, H. (2018). Distribution, contamination, and health risk assessment of heavy metals in surface soils from northern Telangana. India. *Arabian Journal of Geosciences,* 11(21), 684. https://doi.org/10.1007/s12517- 018-4028-y

[3] Ali, M.U., Liu, G., Yousaf, B., Abbas, Q., Ullah, H., Munir, M.A.M. and Fu, B. (2017). Pollution characteristics and human health risks of potentially (eco)toxic elements (PTEs) in road dust from metropolitan area of Hefei, China. *Chemosphere*, 181: 111–121

[4] Apeagyei, E., Bank, M.S. and Spengler, J.D. (2011). Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts. *Atmospheric Environment,* 45(13): 2310–2323

[5] Atiemo, S.M., Ofosu, F.G., Aboh, I.J.K. and Yeboah, P.O. (2010). Determination of Heavy Metals and Human health risk assessment of road dust on the Tema Motorway and Tetteh Quarshie Interchane in Accra, Ghana. *Journal of the Ghana Science Association,* 12, (2), 76-85

[6] Bian, B., Lin, C. and Wu, H.S. (2015). Contamination and risk assessment of metals in road-deposited sediments in a medium-sized city of China. *Ecotoxicol Environ Saf.* 112: 87–95

[7] Chen, H., Kwong, J.C., Copes, R., Tu, K., Villeneuve, P.J., van Donkelaar, A. and Burnett, R.T. (2017). Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. *Lancet* 389(10070): 718–726

[8] Chong, C. (1986). Determination of silver, bismuth, cadmium, copper, iron, nickel and zinc in lead and tin base solder and white metal bearing alloys by atomic absorption spectrophotometer. *Talanta.* 33: 91-94

[9] Christoforidis, A. and Stamatis, N. (2009). Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. *Geoderma*, 151(3–4): 257–263

[10] Cook, A.G., Weinstein, P. and Centeno, J.A (2005). Health effects of natural dust. *Biological Trace Element Research*, 103(1): 1–15

[11] Du, Y., Gao, B., Zhou, H., Ju, X., Hao, H. and Yin, S. (2013). Health risk assessment of heavy metals in road dusts in urban parks of Beijing, China. *Procedia Environ. Sci.* 18: 299–309. Doi:10.1016/j.proenv.2013.04.039

[12] Duong, T.T.T. and Lee, B.K. (2011). Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. *J Environ Manage*, 92(3): 554–562

[13] Huang, J., Li, F., Zeng, G., Liu, W., Huang, X., Xiao, Z., Wu, H., Gu, Y., Li, X. and He, X. (2016). Integrating hierarchical bioavailability and population distribution into potential eco-risk assessment of heavy metals in road dust: A case study in Xiandao District, Changsha city, China. *Sci Total Environ.* 541: 969–976

[14] IRAC (2011). International Agency for Research on Cancer. Agent Classified by the IARC Monograph 2011-102.

[15] Kamani, H., Mirzaei, N., Ghaderpoori, M., Bazrafshan, E., Rezaei, S. and Mahvi, A.H. (2018). Concentration and ecological risk of heavy metal in street dusts of Eslamshahr, Iran. *Hum Ecol Risk Assess.* 24(4): 961–970

[16] Li, X., Zhang, M., Gao, Y., Zhang, Y., Zhang, X., Yan, X., Wang, S., Yang, R., Liu, B. and Yu, H. (2018). Urban street dust bound 24 potentially toxic metal/ metalloids (PTMs) from Xining valley-city, NW China: spatial occurrences, sources and health risks. *Ecotoxicol Environ Saf*, 162: 474–487

[17] Liu, E., Yan, T., Birch, G. and Zhu, Y. (2014). Pollution and health risk of potentially toxic metals in urban road dust in Nanjing, a mega-city of China. *Sci. Total Environ.*, 476–477: 522–531. Doi:10.1016/j.scitotenv.2014.01.055

[18] Martin, S. and Griswold, W. (2009). Human Health Effects of Heavy Metals; Center for Hazardous Substance Research, Kansas State University: Manhattan, KS, USA, pp. 1–6, 15.

[19] Mohmand, J., Eqani, S.A.M.A.S., Fasola, M., Alamdar, A., Ali, N., Mustafa, I., Liu, P., Peng, S. and Shen, H. (2015). Human exposures to toxic metals via contaminated dust: Bioaccumulation trends and risk assessment. *Chemosphere*, 132, 142–151.

[20] Moreno, T., Karanasiou, A. and Amato, F. (2013). Daily and hourly sourcing of metallic and mineral dust in urban air contaminated by traffic and coal-burning emissions. *Atmospheric Environment*, 68: 33–44

[21] Muschack, W.R. (1990). Pollution of street run-off traffic and local condition. *Sci Total Environ.* 93: 419–424

[22] National Population Commission. (2007). Population Census of the Federal Republic of Nigeria, Official Gazette, Lagos, 94(24).

[23] Okoye, T.O. (1975). Enugu, in GEK Ofomata (ed) Nigeria in Maps: Eastern States Ethope Publishing House Benin City Nigeria.

[24] Olujimi O., Steiner O. and Goessler W. (2012). Pollution indexing and health risk assessment of trace elements in indoor dust from classroom, living rooms and offices in Ogun State, Nigeria. *J. Afr. Earth Sci.* 101: 396– 404. Doi:10.1016/j.jafrearsci.2014.10.007

[25] Praveena, S. M., Pradhan, B. and Ismail, S. N. S. (2015). Spatial assessment of heavy metals in surface soil from Klang District (Malaysia): An example from a tropical environment. *Human and Ecological Risk Assessment: An International Journal*, 21(7), 1980–2003. doi:10.1080/ 10807039.2015.1017872

[26] Radojevic, M. and Bashkin, V. (2013). Practical environmental analysis, *Royal Society of Chemistry,* Vol. 53. doi:10.1017/ CBO9781107415324.004

[27] Rajaram, B,S., Suryawanshi, P.V., Bhanarkar, A.D. and Rao, C.V.C. (2014). Heavy metals contamination in road dust in Delhi city, India. *Environ Earth Sci.* 72(10): 3929–3938

[28] Rastegari, Mehr, M., Keshavarzi, B., Moore, F., Sacchi, E., Lahijanzadeh, A.R., Eydivand, S., Jaafarzadehe, N., Naseriang, S., Setti, M. and Rostami, S. (2016). Contamination level and human health hazard assessment of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in street dust deposited in Mahshahr, southwest of Iran. *Hum Ecol Risk Assess.* 22: 1726–1748

[29] Shi, G., Chen, Z. and Xu, S. (2008). Potentially toxic metal contamination of urban soils and roadside dust in Shanghai. China. *Environmental Pollution,* 156: 251–260

[30] Shi, G.T., Chen, Z.L., Bi, C.J., Wang, L., Teng, J.Y., Li, Y.S. and Xu, S.Y. (2011). A comparative study of health risk of potential metals in urban and sub urban road dust in the most populated city of China. *Atmos. Environ.* 45, 764–771

[31] Soltani, N., Keshavarzi, B., Moore, F., Tavakol, T., Lahijanzadeh, A.R., Jaafarzadeh, N. and Kermani, M. (2015). Ecological and human health hazards of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in road dust of Isfahan metropolis, Iran. *Sci Total Environ.* 505: 712–723

[32] Song, B., Guo, G., Lei, M. and Wang, Y. (2018). Assessments of contamination and human health risks of heavy metals in the road dust from a mining county in Guangxi, China. *Hum Ecol Risk Assess.* 24(6): 1606–1622

[33] Świetlik, R., Trojanowska, M., Strzelecka, M. and Bocho-Janiszewska, A. (2015). Fractionation and mobility of Cu, Fe, Mn, Pb and Zn in the road dust retained on noise barriers along expressway – A potential tool for determining the effects of driving conditions on speciation of emitted particulate metals. *Environ Pollut.* 196: 404–413

[34] USEPA. (2004). Risk Assessment Guidance for Superfund Volume I: human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). Washington (D.C): Office of Superfund Remediation and Technology Innovation.

[35] USEPA. (2009). Risk Assessment Guidance for Superfund Volume I: human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment). Washington (D.C):Office of Superfund Remediation and Technology Innovation

[36] USEPA.(1989). Risk assessment guidance for superfund, vol I., Human health evaluation manual (Part A) Office of Emergency and Remedial Response, Washington, DC.

[37] USEPA.(2002). Supplemental guidance for developing soil screening levels for superfund sites. Washington, DC: U. S. Environmental Protection Agency, Office of Emergency and Remedial Response

[38] Viklander, M. (1998). Particle size distribution and metal content in street sediments. *J Envir Engr, ASCE* 124(8): 761-766.

[39] Wei, B. and Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Michro J* 94: 99–107. Doi:10.1016/j.microc.2009.09.014

[40] Yu, K.N., Yeung, Z.L. and Kwok, R.C.W. (2003). Determination of Multi-element profiles of soils using Energy Depressive X-Ray Fluorescence (EDXRF). *Appl Radiat Isot.* 58: 339-346

[41] Zheng, N., Liu, J. and Wang, Q. (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, northeast of China. *Science of the Total Environment*, 408(4): 726–733