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Assessment of Heavy Metals Contamination using Geochemical Indices and Potential Risks in Road Dust of an Urban Environment in Delta State, Nigeria

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ABSTRACT: This study assessed heavy metals (HMs) contamination in road dust using geochemical indices and their potential risks from an urban environment in Delta State, Nigeria. Fifteen road dust samples were sampled, digested in aqua regia and their HMs concentrations determined using atomic absorption spectrometry. The concentrations of the HMs in the road dust ranged from 0.25 to 3.55 mg/kg for Cd, 8.91 to 15.9 mg/kg for Pb, 17.1 to 33.3 mg/kg for Cr, 0.10 to 2.50 mg/kg for Ni, 1.63 to 5.84 mg/kg for Cu, 0.40 to 2.0 mg/kg for Co, 42.7 to 263 mg/kg for Mn, 39.5 to 240 mg/kg for Zn and 1127 to 8380 mg/kg for Fe. The geochemical indices of contamination/pollution index, geoaccumulation index, enrichment factor, contamination factor and potential ecological risk index suggested that the road dusts were impacted with Cd and Zn. The hazard index (HI) and cancer risk values relating to children and adults exposure to HMs in the road dust were within safe limits.

Keywords: Road dust, heavy metals, geochemical indices, risks, Delta State

Introduction

The presence of heavy metals (HMs) in dust has elicited substantial consideration in modern times because of their toxic and non-degradable character under natural settings (Iwegbue *et al*., 2021). Human beings come in contact with dust regularly making it a possible source of exposure to HMs via dermal contact, ingestion and inhalation (Iwegbue *et al*., 2020). Dust particles differ in size and shape, however, a good amount have diameters that are < 100 mm (Pedersen *et al*., 2001). Dust can amass larger concentrations of HMs and can be used as an indicator for long-term monitoring of environmental quality (Cheng *et a*l., 2018; Men *et al*., 2018; USEPA, 2011a). Long-term exposure of individuals to low or high levels of HMs can cause their accumulation in the body, and result in various health challenges including dermatitis, cancer etc. Furthermore, some of these HMs can interferes in the operations of endocrine glands or even act as respiratory toxins (Iwegbue *et al*., 2015). For example, lead (Pb) can cause eternal harm to the neurological system, abnormal behavioural and developmental problems in toddlers (Hassan, 2012). Cadmium and Pb can interrupt DNA replication, repair, and upset gene expression by meddling with the activities of essential metals (Menzie *et al*., 2009).
Urban environments are strongly influenced by anthropogenic activities which results in the significant inputs of HMs into the environment (Yang *et al*., 2016). Road dust are the particles from atmospheric dust and other non-point sources such as released from both engine exhaust and other non-exhaustible releases deposited on the impervious pavement of the street by gravity, hydraulics and wind which have become one of the most widespread pollutants carriers on the surface (Acosta *et al*., 2015). Although, roads play a significant role in social and economic development, road dust contaminated with HMs is a growing environmental concern due to its impact on human health and ecosystems (Rajaram *et al*.. 2014; Huang *et al*., 2016). Road dust contains mainly products of vehicular emission, mechanical wear of cars parts like pads, brake and tyres and particles re-

suspended from the pavement and unpaved shoulder. In addition to traffic related particles, road dust integrates contaminated soil, geogenic material, and settled airborne particles. Thus, road dust is very varied and has an intricate chemical configuration in terms of HMs (Li *et al*., 2013; Shi *et al*., 2011).

HMs have been reported in road dust in many countries of the world (e.g. Dytłow and Go´rka-Kostrubiec, 2021; Kamari *et al*., 2021; Al-Shidi *et a*l., 2020; Song *et al*., 2018; Huang *et al*., 2016; Suryawanshi *et al*., 2016; Yang *et al*., 2016; Adu *et al*., 2014; Duong and Lee, 2011) including Nigeria (e.g. Adewumi, 2022; Taiwo *et al*., 2020; Ogundele *et al*., 2019; Chellube *et al*., 2018; Mafuyai *et al*., 2015). However, no such study has been reported in Delta State, Nigeria. In addition, earlier studies have offered an extensive record of absolute concentrations of HMs in road dust. However, using total concentrations to assess the level of pollution requires using the geochemical background, which is a function of geological settings. The application of varied geochemical indices normalized to the background values is a more dependable method to compare the environmental quality (Dytłow and Go´rka-Kostrubiec, 2021; Chen *et al*. 2019). Depending on the method of computation, the following indices provide useful data about the level of contamination: (1) geoaccumulation index (Igeo) to compare the current and pre-industrial concentration of HMs (2) contamination factor (CF) as the level of pollution caused by the individual HMs, (3) enrichment factor (EF) to detect the source of HMs contamination and (4) potential ecological risk index (PERI) as the source of harmful effects on the environment (Dytłow and Go´rka-Kostrubiec, 2021). The aforementioned indices are computed with respect to baseline values of HMs occurring naturally in soils or sediments and they depend on the composition and mineralogy of local geogenic material (Barbieri *et al*., 2015). Thus, this study assessed HMs contamination in road dust using these geochemical indices and their potential risks from an urban environment in Delta State, Nigeria.

Materials and methods

Description of the study area: The study area is an urban area of Warri in Delta State. Warri is the commercial capital of Delta State and one of the hubs of petroleum related businesses in the southern Nigeria. It lies between latitude 5°31N and longitude 5°45E. Warri is a densely populated city with a population of 943,000 in 2022 based on the United Nations – World Population Prospect (Tesi *et al*., 2022). Warri and its environs have a Refinery and Petrochemicals company, international and local oil companies, Gas plants and Sea port.

Sample collection: A total of fifteen dust samples were collected from roads in selected areas of Warri. The dusts were collected in adequate quantities by gentle sweeping of the roads with a soft plastic brush into a plastic dust pan and transferred into a polyethylene bag. After each sampling, brush and dust pans were cleaned with paper towels. The samples were properly labelled and taken to the laboratory for analysis.

HMs determination in the dusts: The method of Radojevic and Bashkin (1999) as described by Tesi *et al*. (2020) was used. Briefly, one gram of dust was weighed into a digestion tube and digested with 20 mL of aqua regia at 120 °C for 2 h. Thereafter, the digest was cooled, filtered and made up to mark with 0.25 mol/L HNO_3. The samples solution was subsequently analysed for Cd, Pb, Cr, Ni, Cu, Co, Mn and Zn using atomic absorption spectrophotometry (GBC Explorer).

Calculations:

$$\text{Metal concentration (mg kg}^{-1}\text{)} = \frac{(Sc - Bc) \times V}{Ms}$$

Where: Sc = instrumental response of sample (mg / L)
Bc = Instrumental response for sample blank (mg / L)
V = Final volume of digest (mL)
Ms = Mass of sample digested

Quality control and assurance: Sample containers were washed and rinsed with metal detergent and distilled water and then soaked overnight with 10 percent HNO_3. Procedural blank and a sample spiked standard were used for monitoring interferences and cross contamination and all results were blank-corrected. All chemicals and reagents used were of analytical grade.

Statistical analysis: Analysis of variance (ANOVA) was used to determine whether the concentrations of HMs varied significantly among sampling points with $p<0.05$ consider statistically significant. The statistical analysis was performed using SPSS version 23.

Contamination/pollution index: The contamination/pollution index (CPI) of HMs in the dust was obtained by using the CPI equation given by Lacutusu (2002).

$$\text{CPI} = \frac{\text{Concentration of metals in dust}}{\text{Reference value}}$$

The reference value of HMs used in this study was the Department of Petroleum Resources (DPR) of Nigeria target value of HMs in soil (DPR, 2012). The interpretation of CPI is shown in Table 1.

Index of geoaccumulation (Igeo): The Igeo was obtained by using the equation given by Muller (1969).

$$\text{Igeo} = \log_2\left(\frac{\text{Measured concentrations of HMs in the dust}}{1.5 \times \text{Background concentrations of HMs}}\right)$$

The background concentrations of HMs used were the crustal abundance values (CAV) for the respective metals (Turiekian and Wedepohl, 1961). The interpretation of Igeo according to Muller (1961) is shown in Table 1.
Enrichment Factor (EF): The EF of HMs in the dust was obtained using the equation of Reimann and De Caritat (2000).

$$EF = \frac{(\text{Concentration of a particular HM})}{(\text{Concentration of reference HM})} \div \frac{(\text{Background concentration of a particular HM})}{(\text{Background concentration of reference HM})}$$

Iron (Fe) being the most abundant in the earth crust among the HMs analysed was used as the reference HM. The CAV for the individual HMs were also used as background concentrations in computing the EF. Five enrichment categories are recognized on the basis of the enrichment factor (Loska and Wiechula, 2003) and these are shown in Table 1.

Table 1: Significance of the contamination/pollution index, geoaccumulation index and enrichment factor

Metals	DPR (2012)	CAV	CPI values	Significance	Igeo Values	Significance	EF Values	Significance
Cd	0.8	0.3	<0.1	Very slight contamination	<0	Practically unpolluted (Class 1)	<2	Deficiency to minimal enrichment
Pb	85	20	0.10-0.25	Slight contamination	0-1	Unpolluted to moderately polluted (Class 2)	2-5	Moderate enrichment
Cr	100	90	0.26-0.50	Moderate contamination	1-2	Moderately polluted (Class 3)	5-20	Significant enrichment
Ni	35	68	0.51-0.75	Severe contamination	2-3	Moderately to strongly polluted (Class 4)	20-40	Very high enrichment
Cu	36	45	0.76-1.00	Very severe contamination	3-4	Strongly polluted (Class 5)	>40	Extremely high enrichment
Co	20	19	1.10-2.00	Slight pollution	4-5	Strongly polluted to very polluted (Class 6)		
Mn	-	850	2.10-4.00	Moderate pollution	>5	Extremely polluted (Class 7)		
Zn	140	95	4.10-8.00	Severe pollution				
Fe	-	47000	8.10-16.0	Very severe pollution				
			>16.0	Excessive pollution				

Ecological risk factor and potential ecological risk index of HMs in the dusts: The ecological risk of HMs in the dust was obtained using the equation given by Hakanson (1980).

$$RI = \sum_{i=1}^{n} E_r^i$$

Where $E_r^i = T_f^i \times C_f^i$, and

$$C_f^i = \frac{C_s^i}{C_r^i},\ C_d = \sum_{i=1}^{n} C_f^i$$

Where C_r^i = concentration of HMs in dust,
C_s^i = background concentration of HMs,
E_r^i = ecological risk factor,
C_f^i = contamination factor of a given HM,
T_f^i = toxic response factor of HMs = 30, 5, 2, 5, 5, 1, and 1 for Cd, Pb, Cr, Ni, Cu, Mn, and Zn respectively.
RI = potential ecological risk factor for all the HMs. The CAV of the HMs were also utilized as the background concentrations. The interpretation of the ecological risk is presented in Table 2.

Health risk assessment of HMs in dust: The non-cancer and cancer risks of HMs in the road dusts were assessed as hazard index (HI) and total cancer risk (TCR) respectively using the three routes of exposure; ingestion, dermal and inhalation (IDI) (USEPA, 1989). The HI and TCR were obtained by summing up the individual hazard quotients (HQs) and Risks via each route of exposure. The equations used are given below (USEPA, 1989).

$$\text{Hazard index (HI)} = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{derm}$$

Where $HQ_{ing} = \frac{CDI_{nc}}{RfD}$;

$$HQ_{inh} = \frac{CDI_{nc}}{RfCinh};$$

$$HQ_{derm} = \frac{CDI_{nc}}{RfD \times GIABS}$$

$$CDI_{ing\text{-}nc} = \frac{C \times IngR \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6}$$

$$CDI_{inh\text{-}nc} = \frac{C \times InhR \times EF \times ET \times ED}{PEF \times 24 \times AT_{nc}}$$

$$CDI_{derm\text{-}nc} = \frac{C \times SA \times AF \times ABS_d \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6}$$

Table 2: Indices for interpretation of potential ecological risk for metal pollution

Contami-nation factor (C_f)	**Contami-nation factor for an individual metal**	**Degree of contami-nation (C_d)**	**Degree of contami-nation of the environment**	E_r	**Ecological risk factor for an individual metal**	**Potential ecological risk index (*RI*)**	**Pollution Degree**
$C_f < 1$	Low	$C_d < 5$	Low contamination	$E_r < 40$	Low risk	$RI < 65$	Low risk
$1 \leq C_f < 3$	Moderate	$5 \leq C_d < 10$	Moderate contamination	$40 \leq E_r < 80$	Moderate risk	$65 \leq RI < 130$	Moderate risk
$3 \leq C_f < 6$	Considerable	$10 \leq C_d < 20$	Considerable contamination	$80 \leq E_r < 160$	Considerable risk	$130 \leq RI < 260$	Considera ble risk
$C_f \geq 6$	High	$C_d \geq 20$	High contamination	$160 \leq E_r < 320$	High risk	$RI \geq 260$	Very high risk
				$E_r \geq 320$	Very high risk		

$$\text{Total Cancer Risk} = Risk_{ing} + Risk_{inh} + Risk_{derm}$$

$$Risk_{ing} = \frac{Csoil \times IngR \times EF \times ED \times CF \times SFO}{BW \times AT}$$

$$Risk_{inh} = \frac{Csoil \times EF \times ED \times IUR}{PEF \times AT*}$$

$$Risk_{derm} = \frac{Csoil \times SA \times AF \times ABS \times EF \times ED \times CF \times SFO \times GIABS}{BW \times AT}$$

The definition and values of all variables can be found in Iwegbue *et al*. (2018) and Iwegbue *et al*. (2021). Generally, HI < 1 indicate no adverse non-cancer risk and but > 1 indicate adverse non-carcinogenic risk while TCR <1 × 10^{-6} indicate no cancer risk but >1 × 10^{-6} indicates cancer risk (USEPA, 2011b). However, cancer risk values <1 × 10^{-4} are regarded as insignificant considered to be within the acceptable and safe limit (US EPA, 1997; Guney *et al*., 2010; Iwegbue *et al*., 2021).

Results

The concentrations of the HMs in the dusts are shown in Table 3 while comparisons of the HMs in this study with others reported elsewhere are shown in Table 4.

Table 3: Heavy metals concentrations in the road dusts

Samples	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn	Fe
RD1	2.55	9.95	19.4	1.65	3.94	0.65	58.5	151	3480
RD2	3.50	11.8	17.1	1.30	3.63	1.20	58.1	239	1127
RD3	3.10	11.0	24.1	1.25	3.61	0.85	58.1	177	5662
RD4	2.25	11.3	24.1	1.65	3.75	1.40	63.7	168	3029
RD5	2.45	13.8	22.1	1.70	4.72	1.90	42.7	240	5278
RD6	3.55	8.91	28.8	1.30	3.95	1.95	78.8	176	5934
RD7	3.45	9.32	27.5	1.85	4.25	1.75	76.9	179	2824
RD8	1.70	12.3	27.0	1.15	1.96	2.00	88.4	170	4222
RD9	0.30	11.1	30.8	1.65	1.67	1.25	88.3	172	6701
RD10	0.75	14.3	29.7	0.10	2.12	1.75	84.7	237	8380
RD11	0.85	14.0	23.5	1.40	2.38	1.95	86.1	180	2794
RD12	0.25	9.15	26.8	0.45	2.40	0.40	213	41.9	4222
RD13	0.40	13.9	33.0	0.70	1.63	0.55	222	40.2	5151
RD14	0.90	15.9	32.4	2.50	2.16	1.45	263	39.5	4224
RD15	0.25	11.5	33.3	1.10	5.84	1.25	224	42.4	3060

The concentrations of the HMs ranged from 0.25 to 3.55 mg/kg for Cd, 8.91 to 15.9 mg/kg for Pb, 17.1 to 33.3 mg/kg for Cr, 0.10 to 2.50 mg/kg for Ni, 1.63 to 5.84 mg/kg for Cu, 0.40 to 2.0 mg/kg for Co, 42.7 to 263 mg/kg for Mn, 39.5 to 240 mg/kg for Zn and 1127 to 8380 mg/kg for Fe. Sample RD2 contains the lowest concentration of Cr and Fe. Sample RD5 contain the lowest and highest concentrations of Mn and Zn respectively. Sample RD6 has the highest and lowest concentrations Cd and Pb respectively while RD8 has the highest concentrations of Co. Furthermore, RD10 contain the lowest Ni and highest Fe concentrations. Sample RD12 contain the lowest Cd and Co concentrations. Sample RD14 has the highest concentrations of Pb, Ni, Mn and lowest lowest concentration of Zn while RD15 has the highest concentrations of Cr and Cu.

Table 4: Mean HMs concentrations (mg/kg) in this study with others reported elsewhere

Country	City	Cd	Pb	Cr	Ni	Cu	Mn	Zn	Fe	References
Nigeria	Warri	1.75	11.9	26.6	1.32	3.20	114	150	4406	This study
Nigeria	Akure	3.02	32.3	3.17	12.4	37.7	-	72.5	115	Adewumi (2022)
Nigeria	Lagos	8.79	39.7	41.3	2.90	13.8	18.1	346	1458	Taiwo *et al.* (2020)
Nigeria	Lagos	0.12	35.2	41.0	3.00	9.16	12.1	85.3	1212	Taiwo *et al.* (2020)
Nigeria	Enugu	2.80	31.0	-	0.40	64.0	-	-	690	Ekere and Ukoha (2013)
China	Panzhihua	0.59	63.2	235	53.0	149	2136	274	90738	Yang *et al*. (2016)
China	Panzhihua	0.68	65.1	513	70.5	76.5	2327	388	113599	Yang *et al*. (2016)
China	Panzhihua	0.87	111	232	46.5	101	1854	345	101180	Yang *et al*. (2016)
China	Panzhihua	0.98	73.1	196	46.7	98.4	1658	289	103506	Yang *et al*. (2016)
China	Shanghai	1.23	295	159	83.9	197	-	734	-	Shi *et al.* (2008)
Spain	Murcia Region	1.07	117	39.3	41.7	134	-	203	-	Acosta *et al*. (2015)
Spain	Murcia Region	1.55	85.7	28.7	37.1	75.4	-	149	-	Acosta *et al*. (2015)
Spain	Murcia Region	1.28	75.3	23.0	38.4	68.7	-	105	-	Acosta *et al*. (2015)
Spain	Murcia Region	1.19	27.8	20.4	33.0	19.5	-	50.3	-	Acosta *et al*. (2015)
China	Urumqi	1.97	187	186	290	179	-	227	-	Zhang *et a*l. (2014)
Australia	Clearview Estate	0.51	32.5	14.8	7.92	131	200	297	7220	Chandima *et al.* (2011)
Australia	Nerang	0.19	25.7	3.96	6.11	65.5	90.0	176	4230	Chandima *et al.* (2011)
Australia	Benowa	0.35	29.1	9.37	7.01	98.4	60.0	237	5730	Chandima *et al.* (2011)
Australia	Surfers Paradise	0.54	38.4	3.16	4.53	70.8	370	90.4	2980	Chandima *et al.* (2011)
India	Delhi	2.65	121	149	36.4	192	-	285	-	Duong and Lee (2011)
Italy	Gela	-	69.0	20.0	29.0	49.0	400	218	-	Emanuela *et al*. (2006)
Italy	Gela	-	35.0	38.0	38.0	48.0	380	196	-	Emanuela *et al*. (2006)
Italy	Gela	-	72.0	43.0	36.0	1.4	-	220	-	Emanuela *et al*. (2006)
Angola	Luanda	-	351	26.0	10	42.0	-	317	-	Ferreira Baptista and de Miguel (2005)
England	Birmingham	1.62	48.0	-	41.1	467	-	534	-	Charlesworth *et al.* (2003)
Canada	Ottawa	0.37	39.1	43.3	15.2	65.8	-	113	-	Rasmussen *et al.* (2001)
Hong Kong	Hong Kong	3.77	181	-	-	173	-	1450	-	Li *et al.* (2001)

The CPI of the HMs in the dusts is shown in Table 5.

Table 5: Contamination/Pollution Index (CPI) of HMs in the dusts

Sample	Cd	Pb	Cr	Ni	Cu	Co	Zn	Mn	Fe
RD1	3.19	0.12	0.19	0.05	0.11	0.03	1.08	0.07	0.07
RD2	4.38	0.14	0.17	0.04	0.10	0.06	1.71	0.07	0.02
RD3	3.88	0.13	0.24	0.04	0.10	0.04	1.27	0.07	0.12
RD4	2.81	0.13	0.24	0.05	0.10	0.07	1.20	0.07	0.06
RD5	3.06	0.16	0.22	0.05	0.13	0.10	1.71	0.05	0.11
RD6	4.44	0.10	0.29	0.04	0.11	0.10	1.26	0.09	0.13
RD7	4.31	0.11	0.28	0.05	0.12	0.09	1.28	0.09	0.06
RD8	2.13	0.14	0.27	0.03	0.05	0.10	1.22	0.10	0.09
RD9	0.38	0.13	0.31	0.05	0.05	0.06	1.23	0.10	0.14
RD10	0.94	0.17	0.30	0.00	0.06	0.09	1.69	0.10	0.18
RD11	1.06	0.17	0.24	0.04	0.07	0.10	1.28	0.10	0.06
RD12	0.31	0.11	0.27	0.01	0.07	0.02	0.30	0.25	0.09
RD13	0.50	0.16	0.33	0.02	0.05	0.03	0.29	0.26	0.11
RD14	1.13	0.19	0.32	0.07	0.06	0.07	0.28	0.31	0.09
RD15	0.31	0.14	0.33	0.03	0.16	0.06	0.30	0.26	0.07

The CPI of the HMs varied from 0.31 to 4.44 for Cd, 0.10 to 0.19 for Pb, 0.17 to 0.33 for Cr, 0.0 to 0.07 for Ni, 0.05 to 0.16 for Cu, 0.02 to 0.10 for Co, 0.28 to 1.71 for Mn, 0.05 to 0.31 for Zn and 0.02 to 0.18 for Fe.

The Igeo and EF of the HMs in the dusts are shown in Tables 6 and 7 respectively.

Table 6: Index of geoacumulation (Igeo) of HMs in the road dust samples

	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn	Fe
RD1	2.50	-3.84	-2.80	-5.95	-4.10	-5.45	-4.45	0.09	-4.34
RD2	2.96	-3.60	-2.98	-6.29	-4.22	-4.57	-4.46	0.75	-5.97
RD3	2.78	-3.70	-2.49	-6.35	-4.23	-5.07	-4.46	0.32	-3.64
RD4	2.32	-3.66	-2.49	-5.95	-4.17	-4.35	-4.32	0.24	-4.54
RD5	2.45	-3.37	-2.61	-5.91	-3.84	-3.91	-4.90	0.75	-3.74
RD6	2.98	-4.00	-2.23	-6.29	-4.10	-3.87	-4.02	0.31	-3.57
RD7	2.94	-3.93	-2.30	-5.79	-3.99	-4.03	-4.05	0.33	-4.64
RD8	1.92	-3.54	-2.32	-6.47	-5.11	-3.83	-3.85	0.26	-4.06
RD9	-0.59	-3.68	-2.13	-5.95	-5.34	-4.51	-3.85	0.27	-3.40
RD10	0.74	-3.32	-2.18	-10.0	-4.99	-4.03	-3.91	0.73	-3.07
RD11	0.92	-3.34	-2.52	-6.19	-4.83	-3.87	-3.89	0.33	-4.66
RD12	-0.85	-3.96	-2.33	-7.83	-4.81	-6.16	-2.58	-1.77	-4.06
RD13	-0.17	-3.36	-2.03	-7.19	-5.37	-5.70	-2.52	-1.82	-3.77
RD14	1.00	-3.17	-2.06	-5.35	-4.97	-4.30	-2.28	-1.85	-4.06
RD15	-0.85	-3.63	-2.02	-6.54	-3.53	-4.51	-2.51	-1.75	-4.53

Table 7: Enrichment Factor (EF) of HMs in the road dust samples

	Cd	Pb	Cr	Ni	Cu	Co	Mn	Zn
RD1	115	6.72	2.90	0.33	1.18	0.46	0.93	21.5
RD2	486	24.55	7.92	0.80	3.36	2.63	2.85	105
RD3	85.8	4.57	2.22	0.15	0.67	0.37	0.57	15.5
RD4	116	8.76	4.15	0.38	1.29	1.14	1.16	27.5
RD5	72.7	6.15	2.19	0.22	0.93	0.89	0.45	22.5
RD6	93.7	3.53	2.53	0.15	0.70	0.81	0.73	14.7
RD7	191	7.76	5.09	0.45	1.57	1.53	1.51	31.4
RD8	63.1	6.83	3.33	0.19	0.48	1.17	1.16	20.0
RD9	7.01	3.90	2.40	0.17	0.26	0.46	0.73	12.7
RD10	14.0	4.00	1.85	0.01	0.26	0.52	0.56	14.0
RD11	47.7	11.8	4.39	0.35	0.89	1.73	1.70	31.8
RD12	9.28	5.09	3.31	0.07	0.59	0.23	2.79	4.91
RD13	12.2	6.35	3.35	0.09	0.33	0.26	2.39	3.86
RD14	33.4	8.83	4.00	0.41	0.53	0.85	3.45	4.63
RD15	12.8	8.86	5.68	0.25	1.99	1.01	4.04	6.86

The Igeo of the HMs varied from -0.85 to 2.98, -4.0 to -3.17, -2.98 to -2.02, -10.0 to -5.35, -5.37 to -3.53, -6.16 to -3.83, -4.90 to -2.28, -1.85 to 0.75 and -5.97 to -3.07 for Cd, Pb, Cr, Ni, Cu, Co, Mn, Zn and Fe respectively. However, the EF of the HMs ranged from 7.01 to 486, 3.53 to 24.6, 1.85 to 7.92, 0.01 to 0.80, 0.26 to 3.36, 0.23 to 2.63, 0.45 to 4.04 and 3.86 to 105 for Cd, Pb, Cr, Ni, Cu, Co, Mn and Zn respectively.

The contamination factor, degree of contamination and contamination level of HMs in dust in the dusts are shown in Tables 8 while the ecological risk factor, potential ecological risk index and pollution degree are shown in Table 9.

Table 8: Contamination factor, degree of contamination and contamination level due to metals in dust

	Contamination factor (C_f)								Degree of Contamination (C_d)	Contamination level
	Cd	**Pb**	**Cr**	**Ni**	**Cu**	**Co**	**Mn**	**Zn**		
RD1	8.50	0.50	0.22	0.02	0.09	0.03	0.07	1.59	11.02	Considerable
RD2	11.67	0.59	0.19	0.02	0.08	0.06	0.07	2.52	15.19	Considerable
RD3	10.33	0.55	0.27	0.02	0.08	0.04	0.07	1.87	13.23	Considerable
RD4	7.50	0.56	0.27	0.02	0.08	0.07	0.07	1.77	10.36	Considerable
RD5	8.17	0.69	0.25	0.03	0.10	0.10	0.05	2.53	11.91	Considerable
RD6	11.83	0.45	0.32	0.02	0.09	0.10	0.09	1.86	14.76	Considerable
RD7	11.50	0.47	0.31	0.03	0.09	0.09	0.09	1.89	14.46	Considerable
RD8	5.67	0.61	0.30	0.02	0.04	0.11	0.10	1.79	8.64	Moderate
RD9	1.00	0.56	0.34	0.02	0.04	0.07	0.10	1.81	3.94	Low
RD10	2.50	0.71	0.33	0.00	0.05	0.09	0.10	2.49	6.28	Moderate
RD11	2.83	0.70	0.26	0.02	0.05	0.10	0.10	1.89	5.96	Moderate
RD12	0.83	0.46	0.30	0.01	0.05	0.02	0.25	0.44	2.36	Low
RD13	1.33	0.70	0.37	0.01	0.04	0.03	0.26	0.42	3.16	Low
RD14	3.00	0.79	0.36	0.04	0.05	0.08	0.31	0.42	5.04	Moderate
RD15	0.83	0.58	0.37	0.02	0.13	0.07	0.26	0.45	2.70	Low

Table 9: Ecological risk factor, potential ecological risk index and risk level of HMs in the dusts

	Ecological Risk Factor (E_r^i)								Potential Risk Index (RI)	Risk Level
	Cd	**Pb**	**Cr**	**Ni**	**Cu**	**Co**	**Mn**	**Zn**		
RD1	255	2.49	0.43	0.12	0.44	0.07	0.07	1.59	260	Very high
RD2	350	2.95	0.38	0.10	0.40	0.13	0.07	2.52	357	Very high
RD3	310	2.75	0.53	0.09	0.40	0.09	0.07	1.87	316	Very high
RD4	225	2.82	0.53	0.12	0.42	0.15	0.07	1.77	231	Considerable
RD5	245	3.45	0.49	0.13	0.52	0.20	0.05	2.53	252	Considerable
RD6	355	2.23	0.64	0.10	0.44	0.21	0.09	1.86	361	Very high
RD7	345	2.33	0.61	0.14	0.47	0.18	0.09	1.89	351	Very high
RD8	170	3.07	0.60	0.08	0.22	0.21	0.10	1.79	176	Considerable
RD9	30.0	2.78	0.68	0.12	0.19	0.13	0.10	1.81	35.8	Low
RD10	75.0	3.57	0.66	0.01	0.24	0.18	0.10	2.49	82.3	Moderate
RD11	85.0	3.51	0.52	0.10	0.26	0.21	0.10	1.89	91.6	Moderate
RD12	25.0	2.29	0.60	0.03	0.27	0.04	0.25	0.44	28.9	Low
RD13	40.0	3.48	0.73	0.05	0.18	0.06	0.26	0.42	45.2	Low
RD14	90.0	3.97	0.72	0.18	0.24	0.15	0.31	0.42	96.0	Moderate
RD15	25.0	2.89	0.74	0.08	0.65	0.13	0.26	0.45	30.2	Low

From Table 7, the C_f of Cd, Pb, Cr, Ni, Cu, Co, Mn and Zn ranged from 0.83 to 11.83, 0.45 to 0.79, 0.19 to 0.37, 0.0 to 0.04, 0.04 to 0.13, 0.02 to 0.11, 0.05 to 0.31 and 0.42 to 2.53 respectively while the C_d of all the HMs ranged from 2.36 to 15.2. As shown in Table 8, the E_r^i of the individual HMs ranged from 25 to 355, 2.23 to 3.97, 0.38 to 0.74, 0.01 to 0.18, 0.18 to 0.65, 0.04 to 0.21, 0.05 to 0.31 and 0.42 to 2.53 for Cd, Pb, Cr, Ni, Cu, Co, Mn and Zn respectively while the RI of all the HMs ranged from 28.9 to 361.

The results of the non-cancer and cancer risks computed as HI and TCR respectively are shown in Tables 10 and 11 respectively.

Table 10: Hazard index (HI) values of HMs in the dust for child and adult exposures

	Child				**Adult**			
	HQIng	**HQInh**	**HQDerm**	**HI**	**HQIng**	**HQInh**	**HQDerm**	**HI**
RD1	0.26	0.005	0.02	0.28	0.03	0.02	0.004	0.06
RD2	0.25	0.006	0.02	0.28	0.03	0.02	0.004	0.06
RD3	0.34	0.006	0.03	0.37	0.04	0.02	0.005	0.07
RD4	0.30	0.006	0.03	0.33	0.04	0.02	0.004	0.07
RD5	0.37	0.005	0.02	0.40	0.05	0.02	0.004	0.07
RD6	0.41	0.007	0.03	0.45	0.05	0.03	0.006	0.09
RD7	0.34	0.007	0.03	0.38	0.04	0.03	0.005	0.08
RD8	0.36	0.008	0.03	0.40	0.05	0.03	0.005	0.08
RD9	0.37	0.007	0.03	0.40	0.05	0.03	0.005	0.08
RD10	0.43	0.007	0.03	0.47	0.05	0.03	0.005	0.09
RD11	0.31	0.007	0.02	0.34	0.04	0.03	0.004	0.07
RD12	0.27	0.013	0.02	0.31	0.03	0.05	0.004	0.09
RD13	0.34	0.014	0.03	0.38	0.04	0.06	0.005	0.11
RD14	0.37	0.017	0.03	0.42	0.05	0.07	0.005	0.12
RD15	0.32	0.014	0.03	0.37	0.04	0.06	0.005	0.11

Table 11: Total cancer risk (TCR) values of HMs in the dust for child and adult exposures

	Child				**Adult**			
	RISKIng	**RISKInh**	**RISKDerm**	**Total Cancer Risk**	**RISKIng**	**RISKInh**	**RISKDerm**	**Total Cancer Risk**
RD1	3.48×10^{-5}	2.01×10^{-6}	2.69×10^{-7}	3.71×10^{-5}	9.59×10^{-6}	4.61×10^{-6}	2.65×10^{-8}	1.42×10^{-5}
RD2	3.56×10^{-5}	1.79×10^{-6}	2.39×10^{-7}	3.76×10^{-5}	9.82×10^{-6}	4.12×10^{-6}	2.35×10^{-8}	1.40×10^{-5}
RD3	4.10×10^{-5}	2.49×10^{-6}	3.34×10^{-7}	4.38×10^{-5}	1.13×10^{-5}	5.73×10^{-6}	3.29×10^{-8}	1.71×10^{-5}
RD4	4.15×10^{-5}	2.48×10^{-6}	3.35×10^{-7}	4.43×10^{-5}	1.14×10^{-5}	5.70×10^{-6}	3.29×10^{-8}	1.72×10^{-5}
RD5	4.37×10^{-5}	2.29×10^{-6}	3.08×10^{-7}	4.63×10^{-5}	1.21×10^{-5}	5.25×10^{-6}	3.03×10^{-8}	1.73×10^{-5}
RD6	4.21×10^{-5}	2.98×10^{-6}	3.99×10^{-7}	4.55×10^{-5}	1.16×10^{-5}	6.85×10^{-6}	3.92×10^{-8}	1.85×10^{-5}
RD7	4.16×10^{-5}	2.85×10^{-6}	3.81×10^{-7}	4.48×10^{-5}	1.15×10^{-5}	6.55×10^{-6}	3.75×10^{-8}	1.80×10^{-5}
RD8	4.59×10^{-5}	2.77×10^{-6}	3.75×10^{-7}	4.90×10^{-5}	1.26×10^{-5}	6.36×10^{-6}	3.68×10^{-8}	1.90×10^{-5}
RD9	4.76×10^{-5}	3.13×10^{-6}	4.27×10^{-7}	5.12×10^{-5}	1.31×10^{-5}	7.20×10^{-6}	4.19×10^{-8}	2.04×10^{-5}
RD10	5.18×10^{-5}	3.03×10^{-6}	4.13×10^{-7}	5.52×10^{-5}	1.43×10^{-5}	6.96×10^{-6}	4.06×10^{-8}	2.13×10^{-5}
RD11	4.54×10^{-5}	2.40×10^{-6}	3.28×10^{-7}	4.81×10^{-5}	1.25×10^{-5}	5.52×10^{-6}	3.22×10^{-8}	1.81×10^{-5}
RD12	4.06×10^{-5}	2.73×10^{-6}	3.72×10^{-7}	4.37×10^{-5}	1.12×10^{-5}	6.27×10^{-6}	3.65×10^{-8}	1.75×10^{-5}
RD13	5.43×10^{-5}	3.36×10^{-6}	4.59×10^{-7}	5.81×10^{-5}	1.50×10^{-5}	7.72×10^{-6}	4.50×10^{-8}	2.27×10^{-5}
RD14	5.69×10^{-5}	3.31×10^{-6}	4.50×10^{-7}	6.07×10^{-5}	1.57×10^{-5}	7.60×10^{-6}	4.42×10^{-8}	2.33×10^{-5}
RD15	5.07×10^{-5}	3.39×10^{-6}	4.62×10^{-7}	5.46×10^{-5}	1.40×10^{-5}	7.79×10^{-6}	4.54×10^{-8}	2.18×10^{-5}

From Table 9, the HQIng, HQInh and HQDerm values ranged from 0.25 to 0.43, 0.01 to 0.02, 0.02 to 0.03 respectively for child exposure and 0.03 to 0.05, 0.02 to 0.07 and 0.004 to 0.01 respectively for adult exposure. However, the HI values ranged from 0.28 to 0.47 and 0.06 to 0.12 for child and adult respectively. From Table 10, the RiskIng, RiskInh and RiskDerm values varied from 3.48×10^{-5} to 5.69×10^{-5}, 1.76×10^{-6} to 3.39×10^{-6}, 2.39×10^{-7} to 4.62×10^{-7} respectively for child and 9.59×10^{-6} to 1.57×10^{-5}, 4.12×10^{-6} to 7.79×10^{-6}, 2.35×10^{-8} to 4.54×10^{-8} respectively for adult. However, the TCR values varied from 3.71×10^{-5} to 6.07×10^{-5} and 1.40×10^{-5} to 2.33×10^{-5} for child and adult respectively.

Discussion

HMs concentrations in Dust: The HMs concentrations in these road dust showed significant ($p<0.05$) spatial variation. The order of HMs concentration for the road dusts was Fe > Zn > Mn > Cr > Pb > Cu > Cd > Co > Ni. The concentrations of Cd and Zn in 67% and 73% of the dusts respectively were above their DPR target values. However, the concentrations of other HMs were generally below their DPR and CAV values.

CPI and MPI of HMs in the Dusts: The CPI of Cd and Zn in 67% and 73% of the road dusts were > 1 and fall into the pollution range. On the average the CPI of Cd and Zn fall into the moderate and slight pollution respectively. The CPI values of Pb, Cr, Ni, Cu, Co, Mn and Fe were < 1 in all the dusts and fall into the contamination range. One the average, the CPI of Pb and Mn falls into the slight contamination, Cr falls into the moderate contamination while Ni, Cu, Co and Fe fall into the very slight contamination category. On the average, the MPI of the HMs suggests moderate pollution with significant impact from Cd and Zn.

Igeo of HMs in the Dusts: The Igeo of Cd in 27%, 20%, 7% and 47% of the dust samples falls into the class 1 (unpolluted), 2 (unpolluted – moderately polluted), 3 (moderately polluted) and 4 (moderately – strongly polluted) respectively. The Igeo of Pb, Cr, Ni, Cu, Co, Mn and Fe fall into the class 1. However, the Igeo of Zn in 27% and 73% of the dust samples fall into the class 1 and 2 respectively.

EF of HMs in the Dusts: The EF values of Cd fall into the range of significant to extremely high enrichment while those of Pb fall into the moderate to very high enrichment. The EF values of Cr fall into the minimal to significant enrichment while those of Ni, Cu, and Co falls into the minimal enrichment except for sample RD2 for Cu and Co which falls into moderate enrichment. The EF of Mn falls into minimal to moderate enrichmnet whereas that of Zn falls into moderate to extremely high enrichment.

Ecological Risk Assessment of HMs in the Dusts: On the average, the C_f of the HMs followed the order: Cd > Zn > Pb > Cr > Mn > Cu = Co > Ni. The C_f of Cd and Zn falls into the considerable and moderate risks respectively while those of other HMs falls into the low risk. The contamination level indicate that samples RD1 to RD7 has considerable contamination, RD8, RD10, RD11 and RD14 have moderate contamination while RD9, RD12, RD13 and RD15 have low contamination. Cd significantly contributed to the contamination level of HMs in these road dusts.

Ecological Risk Factor and Potential Ecological Risk Index of HMs in the Dusts: On the average, the E_r^i of the HMs followed the order: Cd > Pb > Zn > Cr > Cu > Co > Mn > Ni. The E_r^i of all the HMs falls into the low risk whereas that of Cd falls into the considerable risk. Also, the ecological risk index of HMs indicated that samples RD1, RD2, RD3, RD6 and RD7 have very high ecological risk, RD4, RD5 and RD8 have considerable ecological risk, RD10, RD11 and RD14 have moderate ecological risk while RD9, RD12, RD13 and RD15 have low ecological risk. Cadmium was a major contributor to the risk index.

Non-cancer and cancer risks: The results of the non-carcinogenic risk computed as hazard index due to metal exposure to adult and children in the soils are shown in Table 4.8. The hazard quotient (HQ) for human exposure to metals in the soils profiles followed the order: $HQ_{Ing} > HQ_{Derm} > HQ_{Inh}$. The HQ values for the three routes of exposure were < 1. Also, the HI values for all the dust samples were < 1. This indicates that there are no adverse non-cancer risks for human exposure to the HMs in the road dusts. The HI values for the child's exposure were higher than that of the adult's exposure. This is because of the smaller body weight and exposure duration of the child. Like the non-cancer risk, the risk values of the road dusts also followed the order; $HQ_{Ing} > HQ_{Derm} > HQ_{Inh}$. The risk through inhalation was greater in adult than children exposure. This is because of the longer exposure duration of 30 years for adult (Tesi *et al.*, 2016). The USEPA regards a TCR value of 1×10^{-6} as negligible and 1×10^{-4} as limit at which some remedial actions are necessary. The total cancer risk values obtained in this study were less than 1×10^{-4} suggesting that the TCR values of the road dusts were within the acceptable and/or safe limit.

Conclusion

This study has provided information on the heavy metals (HMs) contamination in road dust using geochemical indices and their potential risks from an urban environment in Delta State, Nigeria. The study showed that the concentrations of the HM were below their respective DPR and CAV values except Cd. The geochemical indices of contamination/pollution index, geoaccumulation index, enrichment factor, contamination factor and potential ecological risk index (PERI) suggested that the road dusts were impacted with Cd and Zn. The hazard index (HI) and cancer risk values relating to children and adults exposure to HMs in the road dust were within safe limits.

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