Contamination and Hazard Risk Assessment of Potentially Toxic Elements in Road Dust Lagos, Southwest, Nigeria.

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Abstract

The purpose of this study was to determine the concentration, sources of pollution and health risks associated with 16 potentially toxic elements (PTEs) in 120 urban road dust samples in the city environ of Lagos, southwest, Nigeria. For all road dust samples, Zn, Se, Mo, Ag, Cd and Pb were higher than background values as defined by Upper Continental Crust (UCC) values, whilst 50, 96, 3, 20, 20, 5 and 5% of the samples showed higher values for U, Cu, V, As, Cr, Ti and Fe, respectively. The spatial distribution maps showed that pollution hotspots for Pb, Zn, Cu, Cr, Se, Ag, Cd and Mo were concentrated in densely populated areas with a high volume of traffic and industrial areas such Ikeja, Ojo, Alimosho and Kosofe regions. Ninety five percent of the samples provided a Pollution Load Index (PLI) greater than 1, indicating the presence of pollution inputs. The calculated Contamination Degree (CD) was between 10 - 174 for PTE's with an average of 58, exhibiting a moderate to very high degree of contamination. The potential ecological risk index (RI) ranged from 39 – 3496, with a mean value of 678 where 7% of the samples provided a low ecological risk index, 5% a moderate risk, 34% and 38% a considerable and very high ecological risk. The non-carcinogenic health risk index showed that Mo, Pb and Co accounted for 87% of the Heath risk index value for both children and adults with a low to moderate exposure risk following the order: dermal > ingestion > inhalation. The carcinogenic risk showed that Ni posed no carcinogenic risk in the dust, Co and As were within low risk, Pb and Cd posed a low and moderate carcinogenic risk to both children and adults in the study area. Road dusts from industrial and densely populated residential areas with high traffic influx exhibited a higher pollution and health risk index compared to less densely populated residential areas in Lagos. This confirmed vehicular traffic as the main source of the PTEs in the dust samples of the study area.

Keywords; Dust; Road; health risk; Lagos; Pollution.

1. Introduction

Road dust is increasingly recognised as an environmental pollution indicator in urban cities worldwide [1]. The generation of dust has been linked to mining, construction, farming, vehicular traffic, industrial emitters and natural sources and its chemical composition by these anthropogenic activities, specifically chemical plants, fuel combustion, wearing of tyre, brake and road surfaces and household waste [2], [3], [4], [5], [6]. Road dust can be referred to as the accumulation of impervious solid particles with a very short half-life of between 190 to 370 days [7] owing to the ease of resuspension into the atmosphere [8] or washed away as street run off through precipitation to become an important component of suspended and dissolved solids [9].

A good road network is vital to urban development to drive economic and social activities as well as goods and service delivery [10], [11]. However, most of the urban roads in Lagos, Nigeria is poorly managed and characterized by a high volume of daily traffic leading to emissions of toxic elements associated with health hazards and environmental degradation [12]. This problem is particularly pertinent to a large number of the Lagos population that spend a significant proportion of their working lives in close proximity to the roadside. Elevated concentrations of Pb and other trace elements such as Zn, Cu, Cd and Ba in road dust have been connected with emissions of car exhaust from vehicular traffic [13], [14], [15]. Most developed countries have shifted from the use of leaded petrol to unleaded petrol, drastically reducing the concentration of Pb in the street dusts [16]. For example, the concentration of Pb in road dusts from Birmingham, U.K had reduced over almost 30 years' period (1973-2003) from 1,300 mg/kg to 48 mg/kg [17], [18].

Airborne Pb was the main source of Pb accumulation in humans from developing countries and 90% of this came from leaded gasoline. Nigeria still depends on leaded gasoline which contains Pb in the concentration range of 0.65 to 0.74 mg/l [19]. There was an initiative to reduce Pb content in gasoline to 0.15 mg/l, by the end of the year 2002 and the total phase-out of leaded gasoline in Nigeria by the year 2004 (National Conference on the Phase-out of Leaded Gasoline in Nigeria). However, the continued dependency of Nigeria on leaded gasoline has resulted in persistent environmental problems demonstrated by the concentration of Pb in the blood levels of roadside automobile technicians where 40% were elevated above 10 µg/dl safe level [20]. Lead exposure via vehicular emissions presents a hazard to young children, which can be aggravated by malnutrition or poor dietary quality/nutrient intake in developing countries, such as Nigeria. Associated health problems include aneamia, neurobehavioural deficits, renal impairment, reproductive abnormalities and suppressed body defence system, as well as neurological harm in children [21]. For example, in Nigeria, the high concentration of Pb in blood has been linked with those living close to high traffic areas [20], [22]. Another negative effect of Pb is the reduction in the Intelligent Quotients (IQs), hearing and physical growth in children, along with an increase in blood pressure, hypertension and cance1r in adults [20].

Many similar studies have established road dusts contamination with both organic and inorganic pollutants that could be hazardous to human health and result in a reduction in life expectancy [23], [24], [25], [26], [27]. The small size (2.5 μm) of dust particles increases exposure via their inhalation, ingestion and adsorption [28]. A report by the Health Effects Institute (2019) concluded that road dust pollution contributed to more than one million global premature deaths in 2017, being a major health concern in many developing countries [29]. An approach to human health risk assessment is therefore important, to estimate the possible hazard to health effects from exposure to metals in dust particles over a specific period of time [30], [31].

[25] assessed the spatial distribution, pollution index, receptor modelling and health risk of metals in road dust/soil samples collected from parts of Lagos metropolis, Southwestern Nigeria. The work only focused on few industrial areas in Lagos and nothing was done in the residential areas while PTEs like V, Se, Mo and Ag were not assessed in the study and all these were addressed in this study. The results indicated high levels of As, Ca, Cd, Cr, Cu, Fe, Mg and Mn in the study area. Chromium was the major contributor to carcinogenic effects in road dusts and control soil, while ingestion was the major pathway for entry to adults and children. Human hazard assessments can be used to quantify and estimate the potential for adverse human health effects to better inform government and regulatory agencies in mitigation.

The aim of this study was to determine the hazard to human health associated with exposure to PTEs via road dust from both residential and industrial areas within Lagos, Southwest Nigeria. The objectives to achieve this aim are: (1) to determine the concentration of comprehensive PTEs in the road dust collected from residential and industrial areas in Lagos, Southwest Nigeria, (2) to identify the possible sources of the PTEs pollution using multivariate statistical analysis;

and (3) assess the hazard to human health associated with the measured PTEs. The residential areas included both high and less populated with high and low influx of vehicular traffic respectively.

2. Material and Methodology

2.1. Study Area

The study area was located in Lagos, southwest Nigeria, with a longitude 06˚38.011'- 06˚38.011' and latitude 003˚11.038' - 003'20.608' (Figure 1). Lagos is a commercial and industrial hub for Nigeria, with about 300 industries It has a population of more than 20 million people [32]. There are approximately 2,600 km of roads in Lagos that are frequently congested with over 1 million vehicles per day [32]. The average vehicular density in Lagos is 222 vehicles/km, compared to the Nigerian average of 11/km. Travel corridors with predominantly heavy vehicular traffic are the Lagos-Abeokuta road, the Lagos-Badagry road axis and the Ikorodu road [33]. Public transport in Lagos is inadequate, and this, coupled with bad road networks causes traffic congestion and gridlock which can lead to commuters losing up to 75% of their weekly working hours [34]. This also increases the duration and severity of exposure of Lagos residents to PTEs in road dust, particularly for street vendors and inner city dwellings.

There are two main types of vegetation in the study area which include tropical rain forest and guinea savanna vegetation which is made up of trees, grasses and occasionally shrubs [35]. The climate falls within a tropical climate with alternating wet and dry season. The wet season is from April to October when the effect of the southwest monsoon wind overwhelms that of the northeast trade wind and usually results in dry seasons from November to April. The wet season is characterised by heavy rainfall and lower temperatures.

The geology of the study area is characterised by two bands of sand with silty mud alternation lying within the Dahomey Basin. Dahomey Basin, a combination of inland/coastal/offshore basin that stretches from southeastern Ghana through Togo and the Republic of Benin to southwestern Nigeria has been variously described by many workers [36], [37], [38], [39]. Lagos mainland is underlain by sediment of Cretaceous through Tertiary to Quaternary origin. Quaternary sediments are alluvial deposits, covering most part of the Lagos Coastal areas and river valleys. The geomorphic feature of the study area bears a relationship with the geology. The topographical higher areas are underlain by more resistant sandstone formation while the lowland areas are largely underlain by low resistant silt/mud stones. The undulating topography trends NW-SE, probably resulted from differential weathering and erosion of the various rock types.

2.2. Sampling and Analysis

120 road dust samples were collected from both the Mainland and hinterland part of Lagos, Southwest, Nigeria during the period of January and March, 2020. The sample areas represented different land uses such as residential, industrial and highway associated with low and high influx of traffic (Figure 1). The characteristics of the road and land use within the sample sites were noted and recorded as well as the coordinates of the sample location. About 500g of road dust were collected from unpaved surface area in 1-2m^2 using polyethylene brush and plastic packer. The samples were stored in the sealed polyethylene bags, labelled and transported to the laboratory. The samples were air dried (40ºC) while the coarse parts like stone, plastic and leaves were removed before passing through a 63 µm sieve. The samples were digested for total elemental determination using the method based on an HF-based mixed acid attack [40], [41]. Road dust digests were analysed by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 8900) for 50 elements which included major, trace and rare earth elements. For this study, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Pb and U were considered due to their significant abundance and environmental impacts, whilst the overall dataset along with data for multiple reference materials, blanks and duplicate samples is presented in Supplementary Table 1, with the limits of detection.

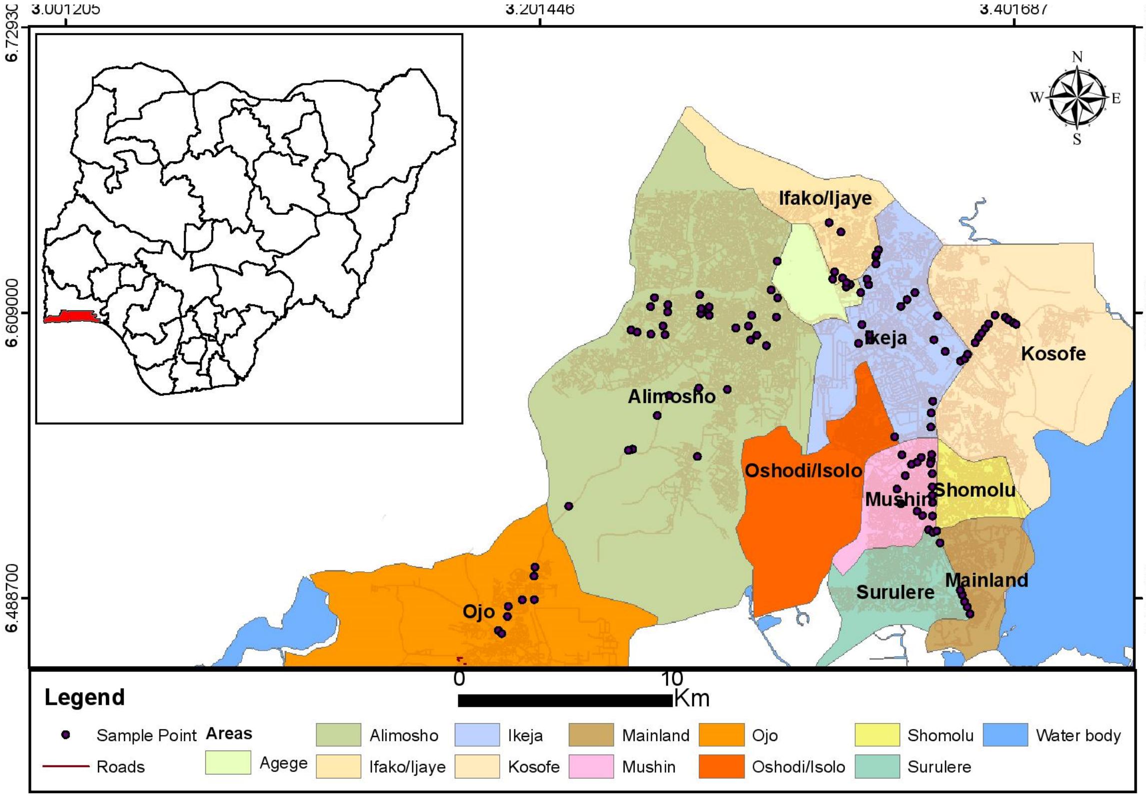


Figure 1. Sample Location Map of the Study Area

2.3. Data and statistical analysis

SPSS for Windows version 22.0 was used for data analysis to determine simple descriptive measurement (mean, median, standard deviation, minimum and maximum) and Pearson correlation analysis. Multivariate statistical analysis was done using principal component analysis (PCA) and hierarchical cluster analysis (CA), the most commonly used multivariate statistical methods in environmental studies were also used for multivariate statistical analysis [42], [43].

2.4. Spatial distribution map of Potential Toxic Elements

The Spatial maps of different potential toxic elements in road dusts from Lagos, Southwest Nigeria as well as different pollution indices were produced using ArcGIS 10.3 (ESRI, 2012) and Quantum GIS1.7.0 (QGIS).

2.5. Pollution Indices. Different pollution indices such as anthropogenic enrichment factor, contamination factor and degree, pollution index and ecological risk index were carried out using different calculations. Detailed procedures are presented in supplementary Tables 2 and 3, Equations 1-4.

2.6. Human health assessment – The human health risk assessment based on the US EPA quantitative model (44) was calculated using risk and hazard indices shown in full in Supplementary Tables 4 and 5, Equations 5-11 following previously described methods [45], [46], [6].

3. Results and discussion

3.1. Concentration of Potentially Toxic Elements in road dust

Geochemical analysis of 120 unpaved and paved road dust from Lagos, southwest Nigeria were carried out to determine 50 elements. These roads were located within industrial and residential areas of the city with both high and low traffic situations. Sixteen potentially toxic elements (PTEs) were considered in this study based on their significant abundance and environmental impacts. They include Ti, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ni, Co, Ag, Cd, Pb and U. The summary and descriptive statistics of the PTEs and the values for the upper continental crust (UCC) [47] that were used as background values and world soil average [48] are presented in Table 1, alongside the median and concentration range of PTEs in road dust samples.

Table 2 shows a comparison between the concentration of PTEs in the study area and other urban cities both within Nigeria and outside Nigeria. These cities included Lagos and Abeokuta both in Nigeria, Kolkata in India, Ahvaz in Iran, Northwest China and Accra in Ghana. The values of Pb, Cu, Co and Cr were higher in the study area compared to their values from other urban cities mentioned above. The road dust in the study area also showed higher values for As, Cd, Zn, Fe and Mn than other urban cities studied earlier except for Kolkata in India, Northwest China and Iran respectively and presented in Table 2. All of the road dust samples in this study for Lagos exhibited up to 10 times higher concentrations for Zn, Se, Mo, Ag, Cd and Pb compared to UCC values. Fifty, 96 and 3% of the dust samples also showed higher values for U, Cu and V, respectively when compared with background values while 20% of samples for As and Cr, as well as 5% of the samples for Ti and Fe, were higher than background values (Table 1). Most of the PTEs in the study area also showed higher values compared to world soil average values [48]. The concentration of the toxic elements in the road dust of the study area followed the decreasing order Fe>Ti>Mn>Zn>Pb>Cu>Cr>V>Ni>Co>As>Mo>U>Cd>Ag>Se based on both the mean and maximum values (Table 1).

Table 1. Descriptive statistics of PTEs concentrations (mg/kg) in street dust of Lagos, southwest Nigeria

PTEs	N	Range	Mean	Std. Deviation	Coefficient of variation	Skewness	Kurtosis	UCC Values (47)	World Average (48)
Ti	120	2829-8866	4864	1212	0.25	0.99	1.25	6400	-
V	120	18.2-170	59.3	19.8	0.33	1.83	8.08	97	60
Cr	120	30.6-218	87.31	25.03	0.29	1.41	7.46	92	42
Mn	120	164-1217	612.25	201.79	0.33	0.74	1.32	1000	418
Fe	120	11178-92752	36826	10644	0.29	1.15	5.68	50400	47000
Co	120	1.49-20.30	8.24	2.53	0.31	1.04	5.54	17.31	6.91
Ni	120	5.60-52.60	25.23	7.67	0.30	0.31	1.10	47	18
Cu	120	11.80-492	97.28	64.62	0.66	3.42	16.44	28	14
Zn	120	68-1504	472.94	224.95	0.48	1.11	3.31	67	62
As	120	0.90-8.50	4.08	1.45	0.36	0.44	0.47	4.8	4.8
Se	120	0.08-1.77	0.42	0.21	0.50	2.91	15.14	0.09	-
Mo	120	0.67-10.60	3.88	1.72	0.44	1.15	2.42	1.1	1.8
Ag	120	0.06-4.89	0.47	0.56	1.19	4.81	32.7	0.053	-
Cd	120	0.08-8.79	1.75	1.40	0.80	2.82	10.69	0.09	1.1
Pb	120	20.30-1478	137.42	147.45	1.07	7.07	60.17	17	25
U	120	0.39-9.73	3.26	1.42	0.44	1.37	3.83	2.7	-

Table 2 A comparison of toxic metals values (mg/kg) in dusts of Lagos and other cities

PTEs	This Study Lagos	Lagos (some industrial areas. [25]	Abeokuta [49]	Kolkata, India [41]	Ahvaz, Iran [45]	Northwest China [50]	Accra, Ghana [51]
Ti	2829-8866	649-2037	-	-	-	-	-
V	18.2-170	-	0.77-2.98	46-104	43-860		171-221
Cr	30.6-218	9.8-211	7.2-63.8	42-129	26.9-105.9	12.7-140	83-180
Mn	164-1217	0.75-25.05	38.6-72.6	503-1027	332-1933	231-773	170-384
Fe	11178-92752	883-2994	1597-9364	23422-59309	13500-293600		1790-2580
Co	1.49-20.3	0.05-0.55	-	8-18	6.4-21.3		-
Ni	5.6-52.6	0.05-0.05	1.4-2.0	18-75	42.7-83.5	19.3-118	-
Cu	11.8-492	3.2-32.2	1.8-17.3	28-279	22.8-326.9	37.5-118	24.8-55.9
Zn	68-1504	20.4-233	24.6-216.4	121-1258	74.3-2589.1	257-844	81.1-260.4
As	5.6-52.6	15.6-116	-	2-16	-	29.8-226	-
Se	0.08-1.77	-	-	-	-		-
Mo	0.0-10.6	-	-	0.4-17	1.0-10.7		-
Ag	0.06-4.89	-	-	-	-		-
Cd	0.08-8.79	0.05-1.40	0.4-1.2	0.28-8.03	0.2-1.3	2.5-11.7	-
Pb	20.3-1478	10.65-741	3.4-126.4	77-551	16-878.1	70.1-384	26.7-45.5
U	0.39-9.73	-		-	-		-

3.2. Sources of PTEs in street dust

The median concentrations of Cu, Zn, Se, Mo, Ag, Cd, Pb and U were higher than the background values and may likely indicate that PTEs in half of the samples were from anthropogenic sources (Table 1). The high values of standard deviation and coefficient of variation (CV= Standard deviation / Mean) especially CV > 0.3 also confirmed that spatial distribution of some PTEs listed above in the study area was heterogeneous indicating mixed origins (Table 1) [52]. Coefficient of Variance < 0.3 were found in Ti, Cr and Fe which indicated same origin likely to be natural or geogenic since they are crustal elements. The values of kurtosis for all the toxic elements except As were greater than zero. The results of skewness and kurtosis for toxic urban elements (Cu, Zn, Se, Mo, Ag, Cd, U and Pb) were higher than other elements and showed the possible existence of highly contaminated spots in the study area.

Correlation analyses were used to provide considerable information on the sources and pathways of toxic elements within the road dust of the study area [53]. The results of the spearman's correlation coefficients of toxic elements showed positive and strong correlation between Cu-Zn-Pb-Fe-Co-Mo-Ni-Cr-As-V, Ti-V-Fe and U-Fe-As at 0.01 significance level (Table 3). Iron showed a strong positive correlation with all other elements. Potentially toxic elements are bound to ferric iron minerals such as goethite and hematite with high adsorption capacities for many toxic elements and occur in oxidized soil and dust [54]. Strong positive correlated elements also suggest a similar source or origin [55].

Factor analysis was also used to classify the PTEs in the road dust of part of Lagos, southwest Nigeria based on their origin and sources. The method adopted followed the previous articles of [56], [57]. The result of the varimax rotated Principal Component Analysis (PCA) of the road dust in the study area was presented in Table 4 and Figure 2. From the result, four factors were identified based on 69% of the total variance. Factor 1 showed significant values for Ti-V-Fe-As-Se, with a cumulative percentage of 25%, Cr-Mn-U as Factor 2, with 41%. Factors 3 and 4 showed that Ni-Cu-Zn-Mo-Pb and Co-Ag-Cd were 59% and 67%, respectively. The four factors confirmed both the geogenic and anthropogenic sources of the PTEs in the study area. The anthropogenic sources could include vehicular emission, especially leaded fuel, industrial, domestic and commercial activities that dominate the study area.

Vehicular traffic is one of the most relevant point sources of toxic elements in the street or road dust of both residential and industrial areas in Lagos, southwest, Nigeria [13]. The exhaust from car emissions was responsible for the high concentration of Cu, Cd, Zn and Pb. There is a gradual shift from the use of leaded petrol to unleaded petrol in most of the developed nations, significantly reducing the concentration of Pb road dust [58], [59]. The leaded petrol is still in use in Lagos, Nigeria hence, the increase in the concentration of Pb in the road dust, which was greater than those in other urban cities like Iran, India, Accra and Russia. Tyre wear is associated with a high concentration of Zn and Cd [60]. The corrosive action of lubricating oil used in the automobiles can lead to the release of Zn, Cu, Ni, Mo and Cd-bearing alloys to the urban environment and their accumulation in street dust [61], [62]. Oil combustion is associated with Ni and V in the street dust [63]. Other sources of these PTEs are road maintenance and weathering, construction activities and incineration. High levels of Zn, Cd and Pb have also been found in the finest fraction of refuse incineration fly ash [64], [65].

Table 3. Correlation Analysis of PTEs in the study area

	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Pb	U
Ti	1.00															
V	**.501****	1.00														
Cr	.432**	**.591****	1.00													
Mn	.319**	.376**	**.504****	1.00												
Fe	**.571****	**.853****	**.725****	.496**	1.00											
Co	0.14	**.573****	.386**	.497**	**.627****	1.00										
Ni	.399**	**.751****	**.698****	.454**	**.819****	**.702****	1.00									
Cu	.230**	.461**	**.577****	.334**	**.563****	**.533****	**.683****	1.00								
Zn	0.10	.355**	.392**	.407**	.390**	**.540****	**.572****	**.708****	1.00							
As	.401**	**.782****	**.589****	.374**	**.766****	**.542****	**.673****	.496**	.412**	1.00						
Se	.495**	**.795****	**.519****	.226**	**.696****	.421**	**.641****	.433**	.422**	**.744****	1.00					
Mo	.228**	**.566****	**.721****	.363**	**.669****	.487**	**.746****	**.728****	**.665****	**.529****	.498**	1.00				
Ag	0.06	.256**	.207*	.249**	.234**	.337**	.275**	.269**	.304**	.336**	.347**	.314**	1.00			
Cd	-0.11	0.14	-0.04	0.06	0.10	.367**	.164*	.371**	.393**	0.14	.227**	.188*	.401**	1.00		
Pb	0.15	.437**	**.542****	.415**	**.542****	**.590****	**.669****	**.763****	**.733****	.499**	.411**	**.714****	.416**	.313**	1.00	
U	0.15	.491**	.466**	.307**	**.504****	.419**	.481**	.385**	.208*	**.601****	.327**	.466**	.205*	-0.05	.439**	1.00

Table 4. Factor Analysis of PTEs in the study area

	Component			
	1	2	3	4
Ti	**.767**	.174	-.182	-
V	**.916**	.205	-	-
Cr	.405	**.691**	.375	-
Mn	.114	**.692**	-	.273
Fe	**.679**	.511	.287	-
Co	.266	.389	.375	**.425**
Ni	.527	.503	**.552**	.119
Cu	-	.254	**.672**	
Zn	-	.191	**.724**	.195
As	**.689**	.441	.180	.200
Se	**.882**		.155	.110
Mo	.238	.492	**.633**	
Ag	-	.118	-.124	**.825**
Cd	.136	-.391	.463	**.527**
Pb	-	-	**.608**	-
U	.118	**.666**	.198	-
Total Eigenvalues	3.765	2.845	2.782	1.335
% of Variance	23.53	17.78	17.34	8.3
Cumulative %	23.53	41.31	58.70	67.04

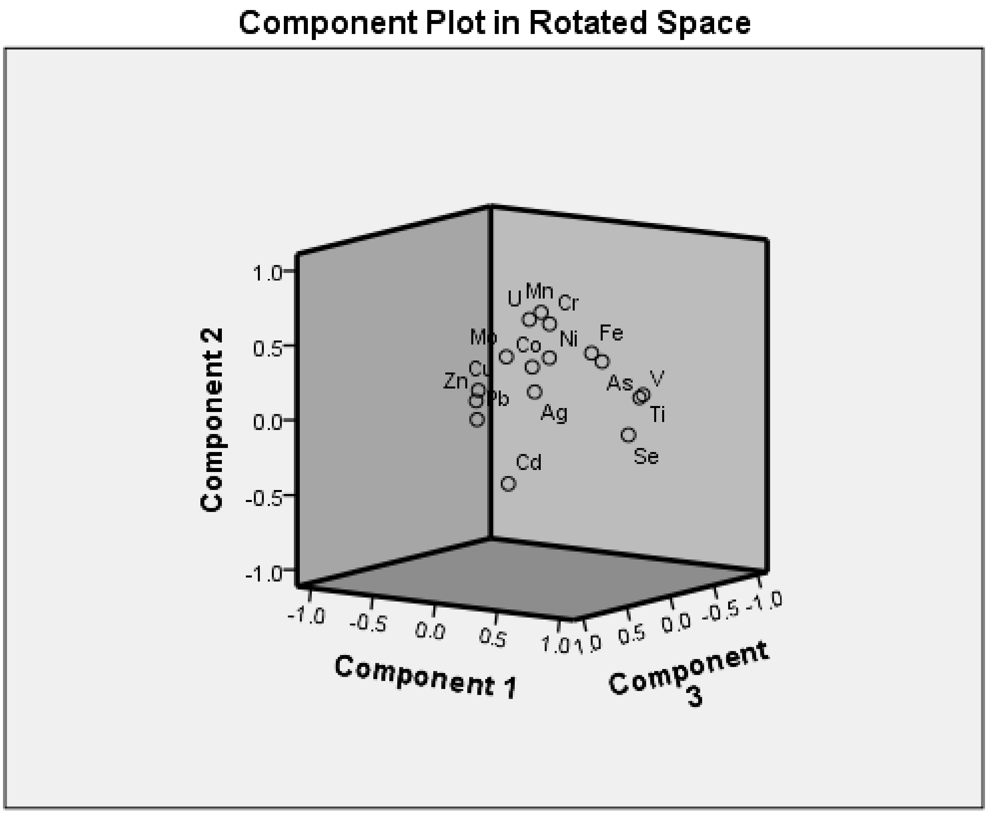
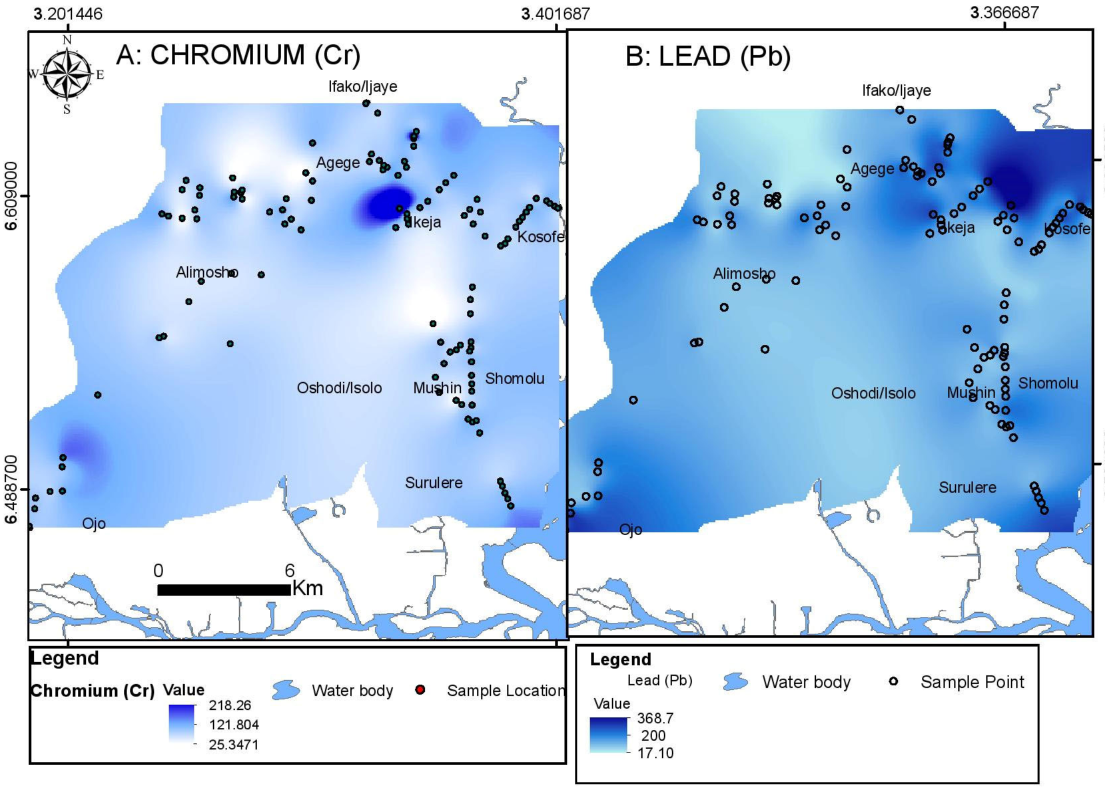
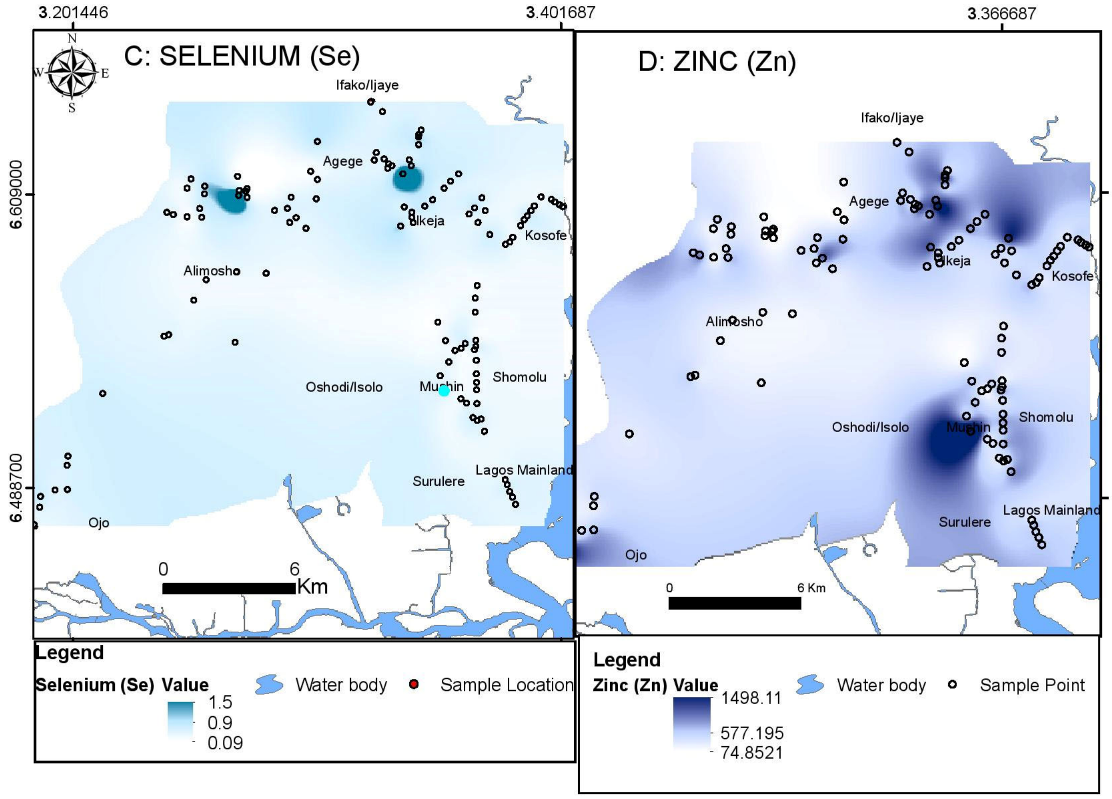


Figure 2. Component plots of Factor analyses in the study area

3.3. Geospatial distribution of PTEs in the Road Dust

The geospatial maps of PTE distribution in road dust of the study area are presented in Figures 3a-f). The maps showed pollution hotspots for Pb, Zn, Cu, Cr, Se, Ag, Cd and Mo. These hotspot areas were concentrated in the areas with densely populated areas associated with a high volume of traffic and some industrial areas. All of the PTEs except Ag and As showed high concentration in the regions like Ikeja, Ojo, Kosofe, Alimosho and sometimes Mushin. These areas fall within industrial and densely populated residential areas that also attract a high influx of traffic. Silver and As showed low concentration in Ikeja area that is associated with industries and high concentration in Kosofe, Agege and Ifako that are more of residential areas but with also a high influx of vehicular movement. It is also pertinent to note that despite the fact that most of the industries within these areas had been closed down since 2015 due to the recession Nigeria has been experiencing, the values of PTEs in road dusts were still elevated in some of the area. However, all of the PTEs showed relatively low concentrations for road dusts within less populated residential areas as would be expected.




C: SELENIUM (Se)
3.201446
3.401687
6.609000
6.488700
Ifako/Ijaye
Agege
Ikeja
Kosofe
Alimosho
Oshodi/Isolo
Mushin
Shomolu
Lagos Mainland
Surulere
Ojo
0
6
Km
Legend
Selenium (Se) Value
1.5
0.9
0.09
Water body
Sample Location
D: ZINC (Zn)
3.366687
6.626500
6.501200
Ifako/Ijaye
Agege
Ikeja
Kosofe
Alimosho
Oshodi/Isolo
Mushin
Shomolu
Lagos Mainland
Surulere
Ojo
0
6 Km
Legend
Zinc (Zn) Value
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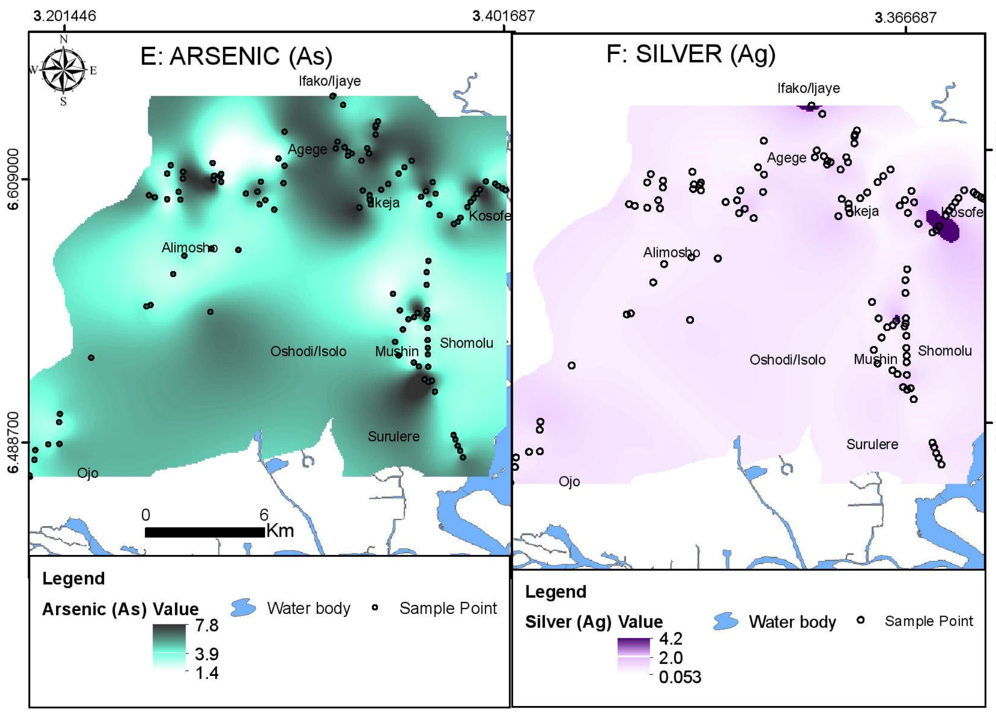
577.195
74.8521
Water body
Sample Point


E: ARSENIC (As)
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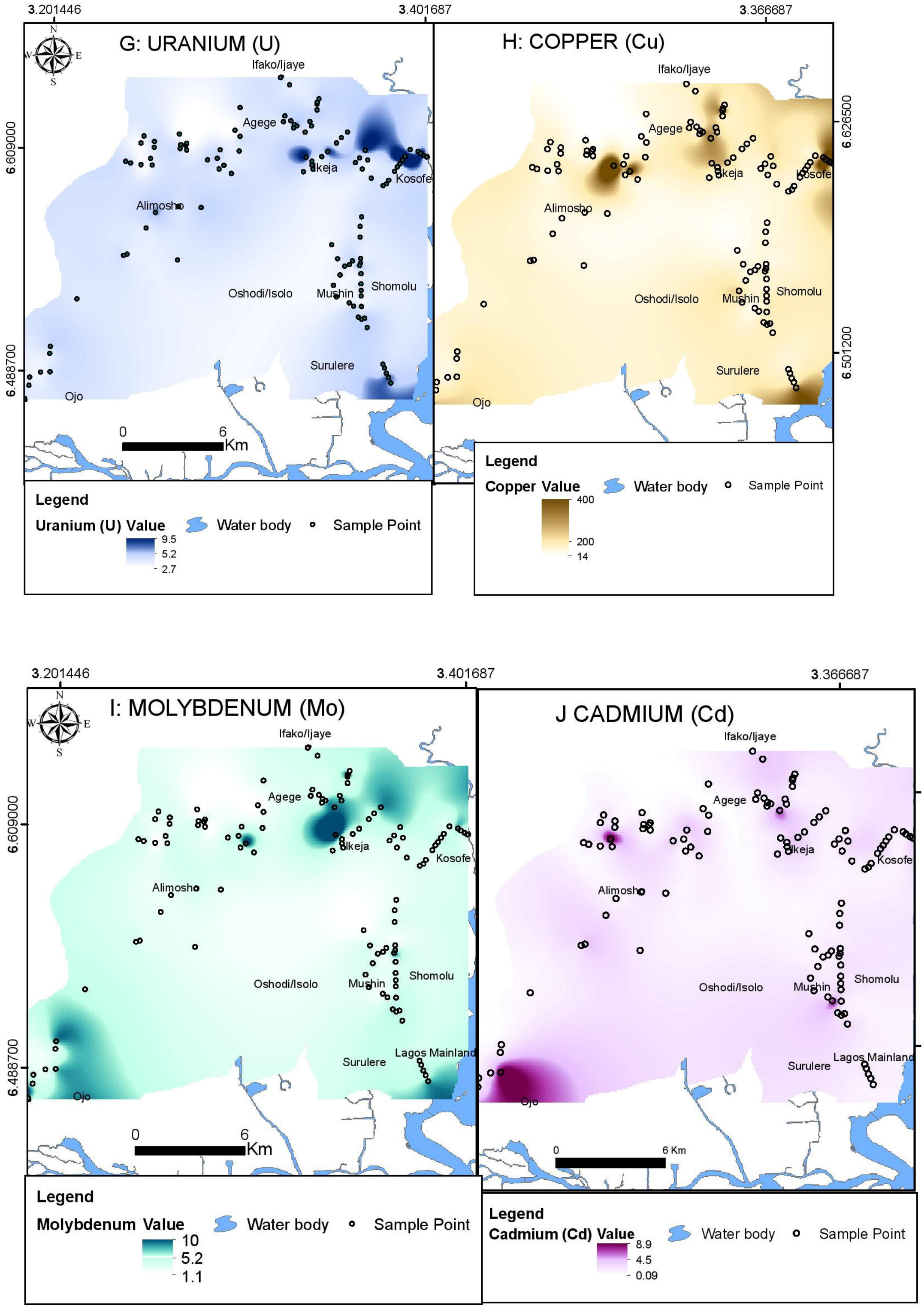
3.401687
6.609000
6.488700
Ifako/Ijaye
Agege
Ikeja
Kosofe
Alimosho
Oshodi/Isolo
Mushin
Shomolu
Surulere
Ojo
0
6
Km
Legend
Arsenic (As) Value
7.8
3.9
1.4
Water body
Sample Point
F: SILVER (Ag)
3.366687
6.626500
6.501200
Ifako/Ijaye
Agege
Ikeja
Kosofe
Alimosho
Oshodi/Isolo
Mushin
Shomolu
Surulere
Ojo
Legend
Silver (Ag) Value
4.2
2.0
0.053
Water body
Sample Point



Figures 3A-J. Geospatial Distribution Maps of PTEs in the study area

3.4. Contamination Indices in the dust

3.4.1. Enrichment Factor (EF)

The Enrichment Factor was calculated for all of the PTEs considered in this study. The results of PTE enrichment factors for road dust samples is presented in Figures 4a and 4b. There are different degrees of PTE enrichment in the study area above local background from minimal to extremely severe enrichment. The enrichment order of PTEs based on median values followed the order Cd>Zn>Pb>Ag>Se>Mo>Cu>U>Cr>As>Fe>V>Mn>Ti>Ni>Co. Enrichment Factor values for Ti, V, Cr, Mn, Fe, Co and Ni showed background enrichment (0-2) as shown in Figure 4a. Arsenic fell within background to moderate enrichment, Se and Mo fell within background to significant enrichment. Copper, Zn and U exhibited background to very high enrichments for all of the samples in the study area as shown in Figure 4b. Some samples within industrial and high traffic area showed extremely high enrichment for Pb and Cd. The larger percentage of the samples were within moderate to high enrichment for most of the elements that are linked to urban pollution such as Pb, Zn, Cu, Cd and Mo, as shown in Figures 4a and 4b). Ti, V and Ni showed EF < 1.5 which indicated natural or geogenic sources. The EF values for all other PTEs were >1.5 and indicated anthropogenic sources [66].

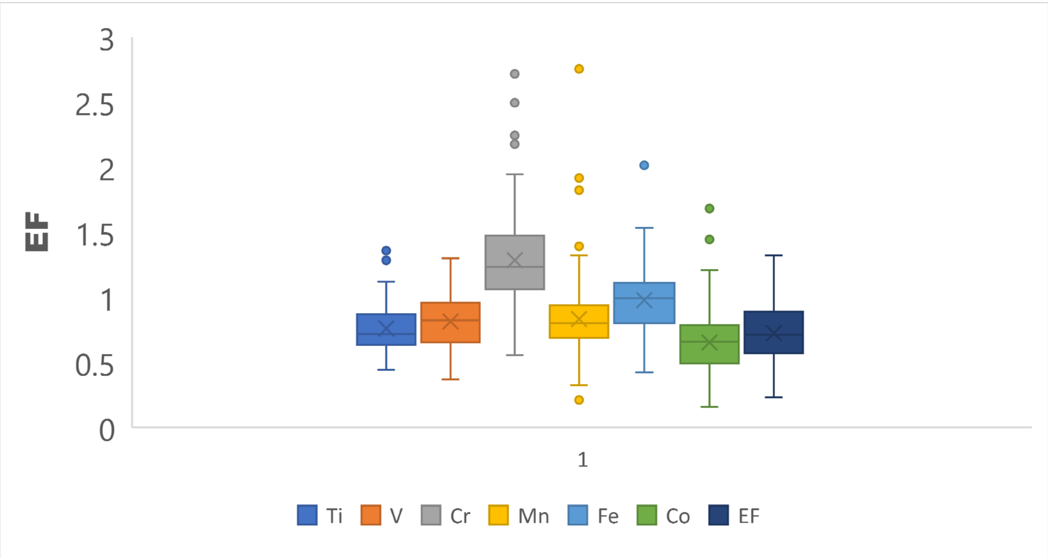


Figure 4a. Enrichment Factor of PTEs in the study area

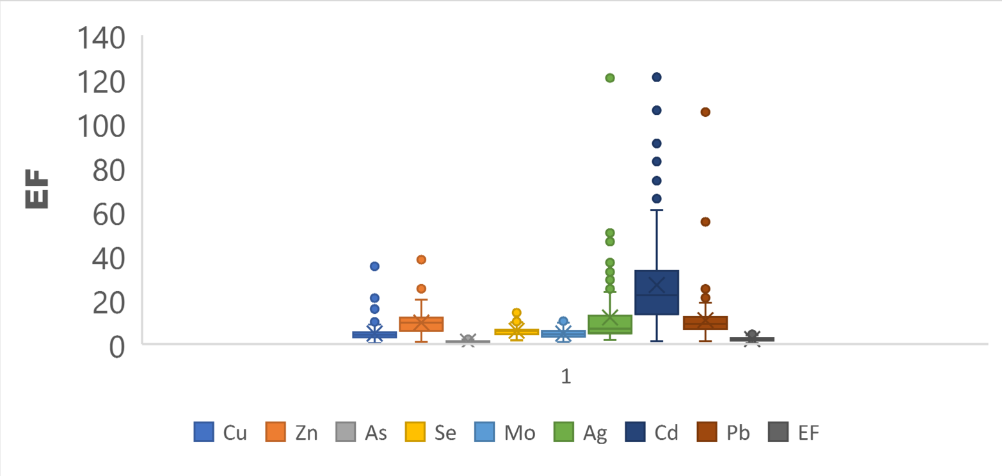


Figure 4b. Enrichment Factor of PTEs in the study area

3.4.2. Contamination Factor (CF), Pollution Load Index (PLI) and Contamination Degree (CD)

The result of the Contamination Factor (CF) showed that the dust samples in the study area fell within low to moderate contamination factor with respect to Fe, Cu and Cr. All other PTEs which included Zn, As, Se, Mo, Ag, Cd, Pb and U showed very high contamination in the dust of the study area (Table 4). The Contamination Degree (CD) of the dust in the study area based on the PTEs ranged between 10 - 174, with an average of 58 and were within a moderate to very high degree of contamination as shown in Table 4.

The Pollution Load index (PLI) of the road dusts in Lagos, southwest Nigeria ranged from 0.7 to 5.95 with mean value of 3.34 and confirmed pollution in most of the samples. Only 5% of the samples showed PLI < 1 and were within residential areas with very low traffic situation. Figures 5 and 6 showed that PLI and CD values followed the order Industrial area > High traffic > Residential area.

Table 5. Results of PTEs Contamination Assessment and Ecological Risk in Road Dust

Contamination Indicies	Fe	Cu	Zn	As	Se	Mo	Ag	Cd	Pb	U	Cr
EF	0.42-2.01	0.43-35.15	1.05-38.18	0.37-2.21	1.75-16.24	0.87-12.96	1.77-120.49	1.21-120.81	1.23-105.03	0.38-7.89	0.55-2.72
CF	0.22-1.84	0.42-17.5	1.01-22.45	0.19-1.77	0.89-19.67	0.61-9.63	1.07-92.25	0.91-97.64	1.19-86.94	0.14-3.60	0.33-2.37
Eir		2.10-87.89	1.01-22.45	1.87-17.71					5.96-434.74		0.67-4.74
CD	9.55-173.95 (58.02)										
PLI	0.71-5.95 (3.34)										
RI	38.96-3496-86 (677.54)										

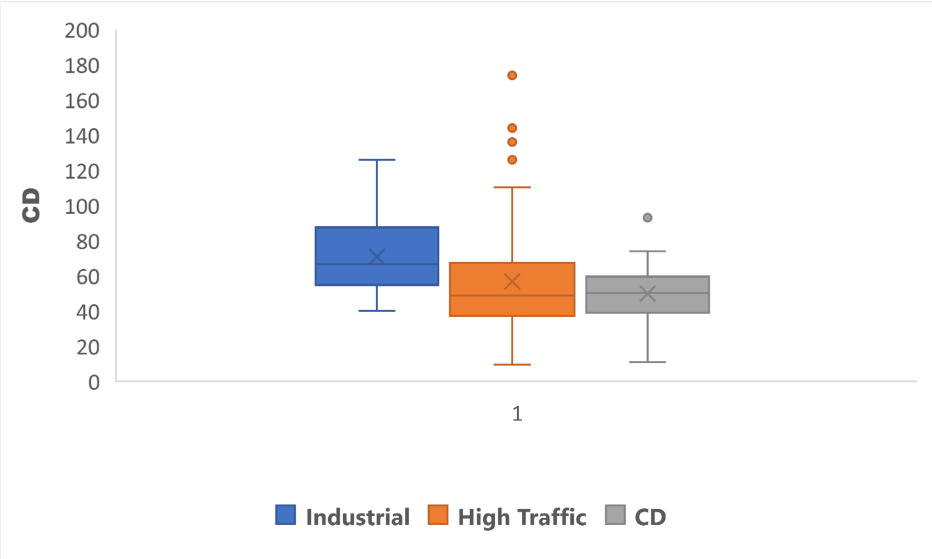


Figure 5. CD in Road Dust of the study area

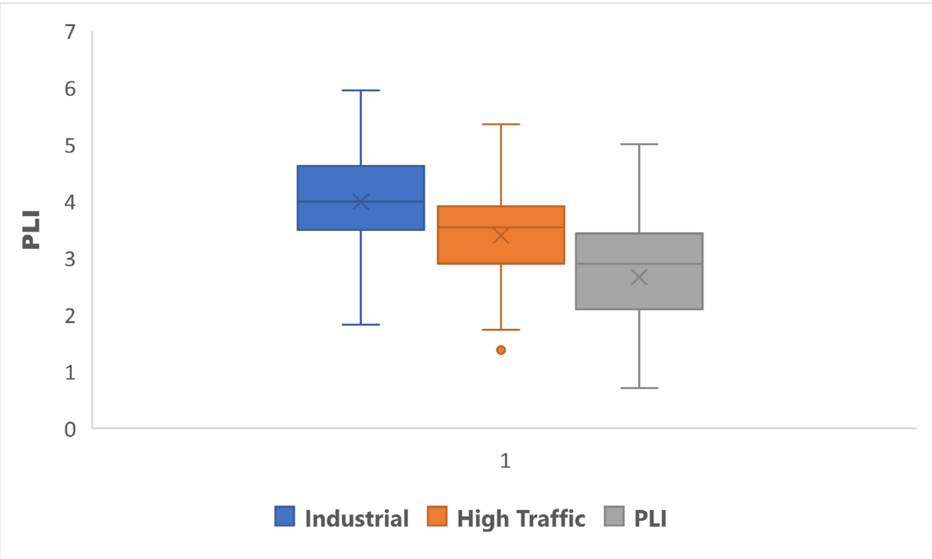


Figure 6. PLI in Road Dust of the study area

3.4.3. Ecological Risk ($E^i r$) and Potential Ecological Risk Index (RI)

The environmental effects of elemental pollution in road dust of the study area was also determined using ecological risk (Er) for individual element and total potential ecological risk index (RI) based on [67]. The result of ecological risk showed that As, Cr and Zn were within low ecological risk, Cu fell within low to moderate while Cd and Pb can be classified as between low to very high ecological risk and presented in Table 4. Figure 7 showed that samples within very high ecological risk were taken from both industrial and high traffic areas of the study area.

The potential ecological risk index (RI) in the road dust samples ranged from 39 - 3496 with mean value of 678. RI values were determined as low ecological risk index for 7% of the samples, 5% as moderate risk, 34% and 38% as considerable and very high risk, respectively as shown in Figure 8.

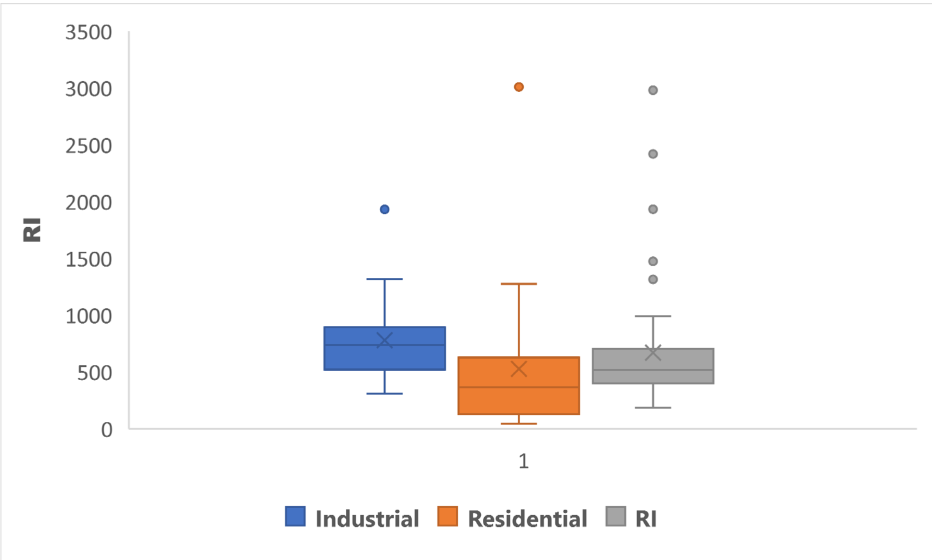


Figure 7. RI in Road Dust of the study area

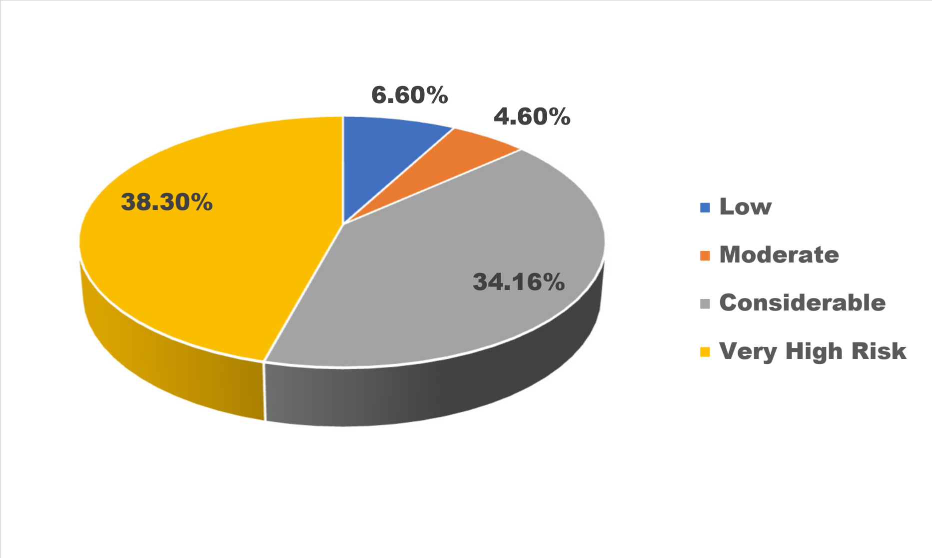


Figure 8. Classification of potential ecological risk index (RI) in the road dust

3.5. Human health risk (Non carcinogenic and Carcinogenic) of PTEs in Road dust

The human health risk index of road dust exposure was evaluated using Hazard Quotients (HQs) and Hazard Indices (HIs) derived using the US EPA quantitative models (68). The model was based on calculating both non-carcinogenic and carcinogenic risks for residents resulting from exposure to the PTEs in the road dust. The exposure to the PTEs in the road dust may be from direct ingestion through mouth, inhalation through nose and adsorption through dermal contact. The formulae and parameters used to calculate both the non-carcinogenic and carcinogenic health risks were explained in [41] and summarised in Supplementary Tables 3 and 4. Based on [69], interpretation guidelines, both HQ and HI can be interpreted as <0.1 = No Hazard, 0.1-1.0 = Low Hazard, 1.1-10 = Moderate Hazard and >10 = High Hazard. The carcinogenic risks were calculated based on the probability that an individual can develop cancer over a lifetime as a result of exposure to a potential carcinogen [70]. According to 70 US EPA, 1989 and as explained in [41]. The interpretation for individual cancer risk for PTEs and Total Cancer Risk is described in Table 6.

Table 6. Cancer Risk and Total Cancer Risk Interpretation Guidelines (71, 72)

Values	Interpretation
1 x 10^{-6} to 1 x 10^{-4}	low risk level,
1 x 10^{-4} to 1 x 10^{-3}	medium risk
1 x 10^{-3}	Unacceptable

3.5.1. **Non-carcinogenic Health Risk**

The result of non-carcinogenic health risk index showed that dust exposure pathways of PTEs for both children and adults decreased as follows: skin contact (dermal) > ingestion > inhalation with the following ranges and mean values 0.28-5.1 (1.53), 0.13-2.99 (0.61), 0.004-0.04 (0.02) and 0.09-4.99 (0.82), 0.16-2.5 (0.50), 0.004-0.04 (0.02), respectively as shown in Table 7 and Figure 9). The total hazard quotient (THQ) results also showed low to moderate hazard for exposure from skin contact and ingestion routes while inhalation route fell within no hazard for both children and adults (69). All the PTEs considered for health risk index except Cu showed the same order of HQ in children and adults suggesting that both dermal contact and ingestion of dust were the important pathway exposures of dust in the study area that can be hazardous to human health (73). Earlier work of [27] similarly indicated dermal contact as the main exposure pathway to dust for children and adults in Russian road dust while [25,] [41] indicated ingestion routes as the main exposure route for some street dust in some industrial parts of Lagos in Nigeria and Kolkata in India.

The HQ value in the street dust decreased as follows: Mo>Pb>Co>Cu>As>Ni>Zn for children and adults with a greater risk for children who are more prone to play with dust especially from Nigeria and presented in Figures 10a and 10b. They also exhibit certain behaviour like pica and hand or finger sucking [56], [74]. The HQ of Mo, Pb, and Co for dust samples accounted for 87% of the whole HI values for both children and adults. Additionally, the total percentage of Cu, As, Cd, Ni and Zn for the total HI value was lower than 20%. The HI range and mean values of the studied metals for children and adults were 0.41-8.08 (2.16) and 0.25-7.48 (1.34), respectively as shown in Figure 11. The result also showed that the children and adults exposed to road dusts in part of Lagos were within low to moderate health risks based on the PTEs, especially Mo, Pb and Co. Also, the higher values were observed within industrial areas as also confirmed by [25] and in addition, densely populated residential areas with high traffic influx.

3.5.2. Cancer Risk

The Cancer Risk (CR) was calculated for Co, Ni, As, Pb and Cd in the road dust of Lagos, Southwest Nigeria and was presented in Table 7. The CR showed that Ni posed no carcinogenic risk, Co and As were within a low risk while Pb and Cd posed a low to moderate carcinogenic risk based on [71], [72] classification. The Total Cancer Risk (TCR) ranged between 5.8×10^{-5} - 6.4×10^{-4} with a mean value of 3×10^{-4}. The children and adults that are exposed to the road dusts in the study area had a low to moderate carcinogenic risk based on Pb, Cd, As, Ni and Co. The pathway for the exposure risk followed the order inhalation>dermal>ingestion as can be clearly observed in Figure 12.

Table 7. Human health risk (Carcinogenic and Non-carcinogenic) of PTEs in Road dust

Metals	Children				Adults			
	HQing	HQderm	HQinh	HI	HQing	HQderm	HQinh	HI
Cu	0.32	7.86	0.0002	8.18	0.06	1.32	0.0002	1.38
Zn	0.03	0.05	0.000002	0.08	0.006	0.02	0.000002	0.026
As	0.18	0.05	0.00005	0.23	0.03	0.03	0.00009	0.06
Mo	0.01	0.05	0.0004	0.06	0.003	0.007	0.0005	0.01
Cd	0.06	0.02	0.02	0.11	0.01	0.03	0.02	0.06
Pb	2.63	3.73	0.00000001	6.36	4.92	1.78	0.00000002	6.7
Co	0.43	0.61	0.03	1.07	0.08	0.88	0.03	0.99
Ni	0.05	0.06	0.01	0.12	0.006	0.03	0.006	0.04
HI	3.71	12.43	0.06	16.20	5.12	4.11	0.06	9.27
TCR	5.89E-05 - 0.0007 (0.0003)							

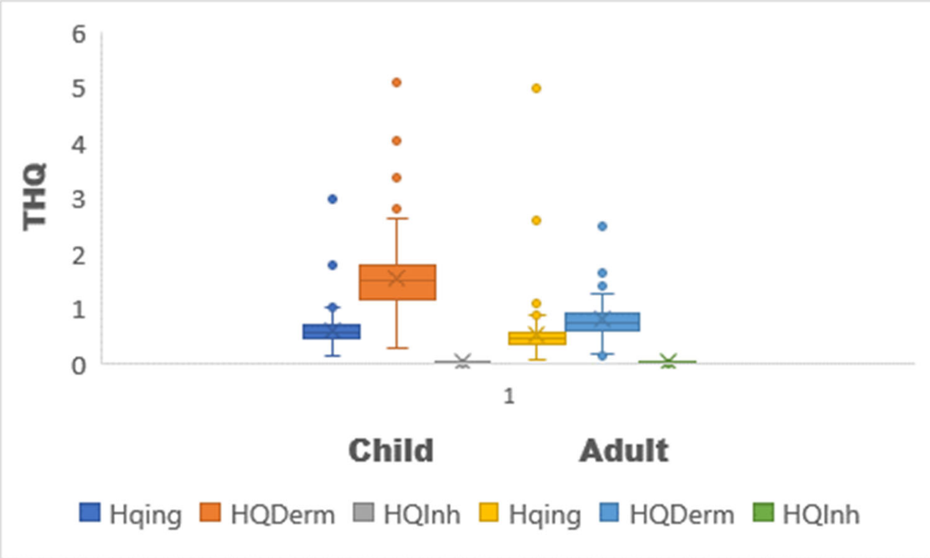


Figure 9. Hazard Quotient in the three Exposure for children and adults

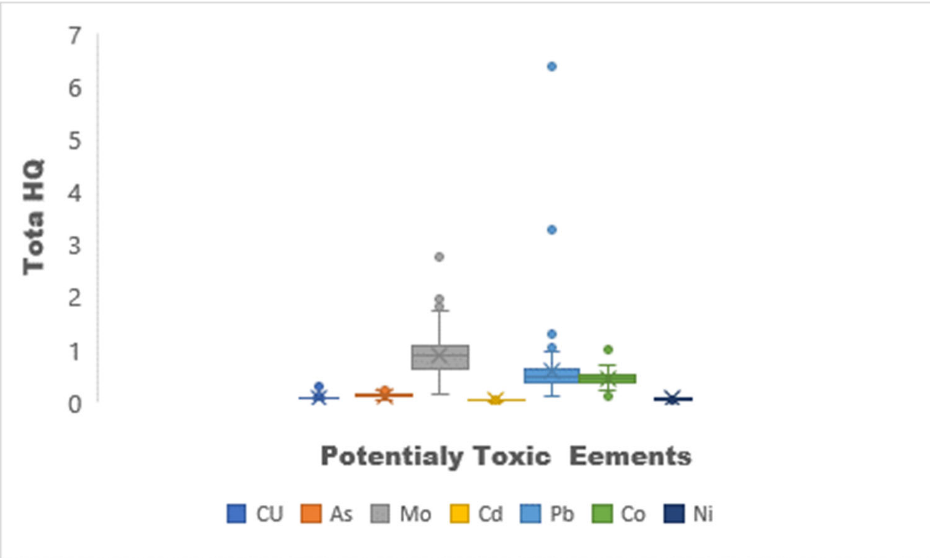


Figure 10a. THQ for Different PTEs In Road Dust For Children

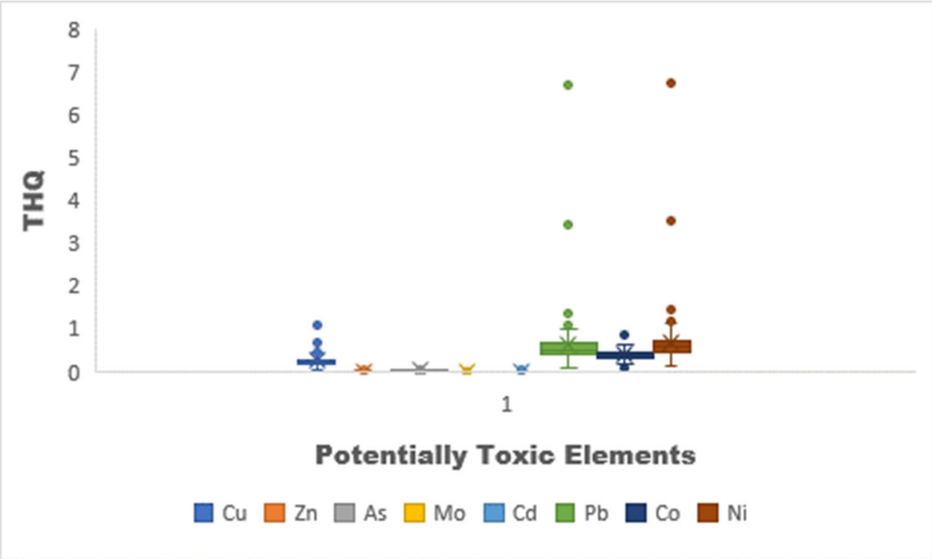


Figure 10b. THQ for Different PTEs In Road Dust For Adults

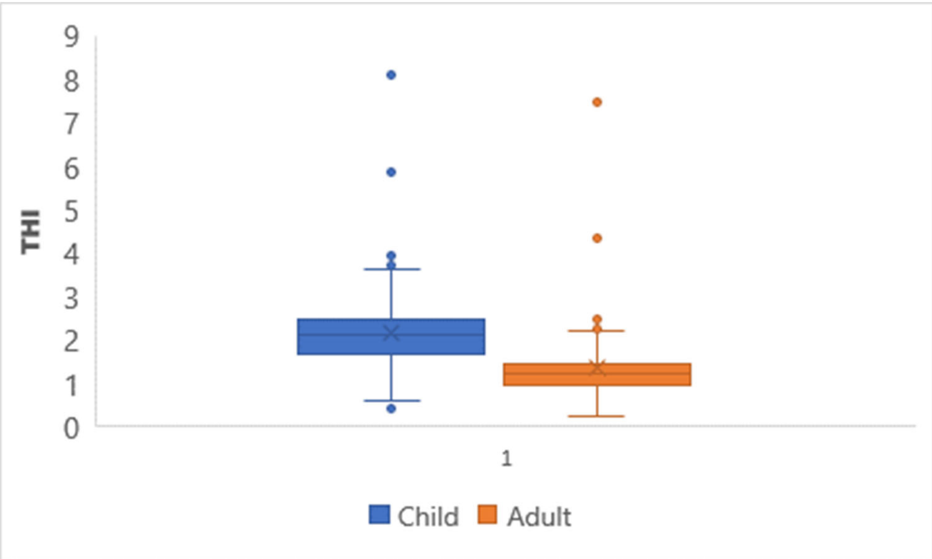


Figure 11. THI in Children and Adults

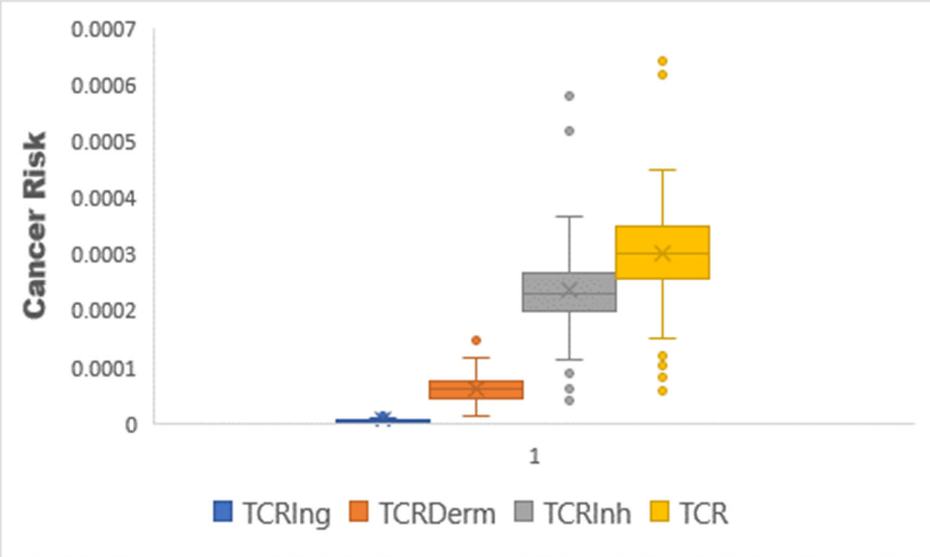


Figure 12. Total Cancer Risk in the study Area

4.0. **Conclusion**

The purpose of this study was to determine the concentration, contamination levels and human health risk associated with PTEs in street dust from both residential and industrial areas within Lagos, Southwest Nigeria which is the most populated and industrialised city in Nigeria. All of the road dust samples in the study area showed higher concentration for Zn, Se, Mo, Ag, Cd and Pb compared to their background values. 50%, 96% and 3% of the dust samples also showed higher values for U, Cu and V respectively when compared with background values while 20% of samples for As and Cr, as well as 5% of the samples for Ti and Fe, showed higher values than background values. The concentration of Pb, Cu, Co and Cr were higher in the study area compared to their values from other urban cities like Kolkata in India, Ahvaz in Iran, Northwest China, Accra in Ghana, Abeokuta in Nigeria and previous work in Lagos, Nigeria.

Ninety five percent of the samples exhibited a Pollution Load Index (PLI) greater than 1, indicating the presence of pollution inputs. The calculated Contamination Degree (CD) was between 10 - 174 for PTE's with an average of 58, exhibiting a moderate to very high degree of contamination. The non-carcinogenic health risk showed that HQ of Mo, Pb, and Co in dust samples accounted for 87% of HI values for both children and adults. Additionally, the total percentage of Cu, As, Cd, Ni and Zn for the total HI value was lower than 20%. The exposure of children and adults to road dust in parts of Lagos were within low to moderate health risks, especially Mo, Pb and Co. Also, high values were within some industrial areas as well as densely populated areas with high traffic influx and this confirmed that vehicular traffic is the main source of the PTEs in the study area. The pathway for the exposure risk followed the order dermal> ingestion > inhalation. The children and adults exposed to the road dust in the study area have between low to moderate carcinogenic risk based on Pb, Cd, As, Ni and Co. The pathway for the cancer exposure risk followed the order inhalation>dermal>ingestion. Lagos is a densely populated city with inadequate road and public transport networks leading to traffic congestion and exposure of residents and drivers to traffic pollution for many hours every day. Better road networks in Lagos will reduce traffic congestion, hence, reduce the exposure of the residents to both non carcinogenic and carcinogenic risks of PTEs in the road dust.

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Author contributions AMO: investigation, writing-original draft preparation, resources. SMA: Sampling, Data Analysis. MJW: writing reviewing and editing, visualization. All authors approved the manuscript in the present form and gave the permission to submit the manuscript for publication.

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Data availability- All the data generated and analyzed during the study are included in the main manuscript. Compliance with ethical standards

Conflict of interest - The authors declare that they have no conflict of interest.

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Supplementary Table 1. Result of Geochemical Analysis of Street Dust

PTEs	Ti	V	Cr	Mn	Fe	Cu	Zn	As	Se	M
Unit	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/
Detection Limit	0.7	0.2	0.2	0.5	8	0.2	2	0.006	0.03	0.0
1	4207	50.8	77.7	524	33640	98.0	548	4.22	0.34	3.
2	5235	93.7	88.2	501	46768	101	576	6.15	0.75	4.
3	4824	61.9	68.8	576	37171	79.4	541	3.95	0.40	2.
4	4912	73.5	85.7	507	40741	149	499	4.83	0.61	3.
5	5116	74.2	90.1	512	43798	156	498	4.92	0.62	3.
6	5924	72.7	110	656	44038	109	465	4.96	0.52	4.
7	3622	60.4	69.8	477	33198	70.4	440	2.95	0.40	3.
8	5669	86.3	92.5	687	44233	84.1	505	6.60	0.64	4.
9	5259	68.0	82.6	700	46554	117	464	3.34	0.32	3.
10	5158	69.3	98.0	743	43577	136	949	4.73	0.44	5.
11	6267	93.6	113	693	50073	120	712	5.73	0.54	6.
12	6338	68.4	110	696	38876	85.2	569	4.03	0.52	5.
13	4501	66.2	82.3	572	35885	102	687	3.86	0.41	5.
14	5580	64.7	218	1124	46629	168	816	5.23	0.44	9.
15	5300	76.7	112	666	48468	207	636	5.37	1.21	6.
16	4190	64.9	90.9	587	45108	145	1097	6.39	0.80	6.
17	4572	80.7	111	672	51381	165	842	4.80	0.48	5.
18	4585	70.2	122	689	55329	174	970	5.13	0.51	6.
19	4384	52.7	87.6	544	39010	104	643	4.55	0.46	4.
20	4639	62.3	77.7	599	38959	118	591	5.94	0.40	3.
21	4961	75.8	84.1	815	40546	69.9	554	5.66	0.45	3.
22	4859	74.7	85.6	818	42346	64.9	536	5.44	0.46	3.
23	4349	63.4	73.2	517	38540	86.8	390	4.38	0.36	3.
24	6029	87.8	97.4	668	49942	95.6	539	5.76	0.65	4.
25	4676	60.6	101	605	44490	263	946	4.45	0.88	4.
26	5192	55.4	87.2	598	38632	102	478	4.87	0.50	4.
27	4167	59.2	73.3	720	35704	97.8	586	3.93	0.39	4.
28	5199	56.5	83.6	571	38772	105	489	4.22	0.48	3.
29	5848	70.9	189	1208	92752	152	679	6.15	0.49	8.
30	5391	60.3	110	670	37639	94.7	600	4.79	0.39	3.
31	4544	62.4	81.2	720	39478	108	757	4.84	0.41	4.
32	3256	18.2	33.6	164	11178	24.7	140	0.90	0.08	0.
33	5977	64.1	88.1	767	36867	86.8	578	4.39	0.46	3.
34	6881	70.4	80.6	579	33815	115	406	4.12	0.54	2.
35	8692	118	89.2	1014	50115	55.4	332	5.96	0.75	2.

36	8537	116	89.6	1012	51862	54.8	324	5.92	0.77	2.
37	4950	39.6	59.8	342	26625	53.8	190	2.41	0.24	2.
38	5993	59.1	80.5	511	33717	85.0	416	3.73	0.46	3.
39	4457	41.0	35.6	347	23717	22.5	69	1.28	0.28	0.
40	6205	48.0	49.5	204	20678	11.8	68	1.85	0.38	1.
41	8866	170	127	349	62030	30.5	137	8.50	1.77	3.
42	2914	22.8	35.3	198	14372	15.4	130	1.21	0.10	1.
43	5561	42.0	93.4	971	59439	52.4	194	2.73	0.21	3.
44	5940	50.9	67.5	419	31806	84.6	186	2.77	0.28	1.
45	8217	100	99.7	557	45209	50.2	214	4.99	0.68	2.
46	3345	25.4	33.0	193	13607	12.1	79	1.25	0.15	0.
47	7081	47.2	76.6	515	30282	57.8	194	4.57	0.32	2.
48	5554	64.6	80.2	1064	35032	102	609	4.45	0.46	2.
49	3944	55.7	66.1	554	33303	72.9	447	4.24	0.36	3.
50	6262	70.3	111	739	50940	97.4	469	5.71	0.48	5.
51	4220	58.5	74.6	527	36616	293	822	3.36	0.39	7.
52	4646	64.9	93.6	607	52161	422	411	4.38	0.40	3.
53	6228	60.9	91.6	616	38955	81.1	349	3.61	0.38	3.
54	6413	63.1	98.0	592	41600	82.4	351	3.83	0.36	3.
55	4229	48.6	83.5	418	29238	51.4	258	4.95	0.40	2.
56	5400	48.3	67.2	436	30910	57.4	189	3.04	0.28	2.
57	3931	52.6	59.9	445	31366	61.5	219	2.54	0.29	3.
58	3728	46.3	59.4	430	28685	46.5	218	3.39	0.25	2.
59	3725	46.5	61.4	426	29252	46.1	217	2.16	0.25	2.
60	4457	57.9	61.0	514	33579	68.9	317	3.00	0.41	2.
61	4978	57.3	82.3	660	37222	85.5	503	3.59	0.33	3.
62	7159	89.2	109	528	45306	77.2	303	4.50	0.57	4.
63	6310	67.6	127	677	40265	101	422	3.68	0.49	6.
64	6176	51.1	98.2	468	35849	71.6	264	2.72	0.46	3.
65	5818	70.7	114	819	45997	108	622	4.26	0.48	6.
66	6151	56.9	76.8	841	33560	53.1	453	3.18	0.36	2.
67	6763	68.8	94.6	540	35664	83.9	376	3.73	0.58	4.
68	5215	58.1	95.4	766	38683	105	1067	3.76	0.42	5.
69	4755	41.1	101	568	32356	94.5	510	2.79	0.30	10
70	5298	47.4	90.5	541	35579	148	581	3.38	0.30	4.
71	3067	22.9	30.6	239	16188	32.7	144	1.47	0.14	1.
72	5663	36.8	89.1	491	30399	69.8	588	2.73	0.28	3.
73	5606	35.9	86.1	483	30121	71.2	594	2.73	0.31	3.
74	4721	39.3	71.0	402	25162	146	534	4.14	0.35	3.
75	3762	39.0	66.8	426	24462	90.8	1504	3.46	0.41	2.

76	3101	32.3	38.8	297	20007	30.0	277	1.74	0.19	1.
77	4158	64.9	81.3	534	40935	63.4	382	5.12	0.39	3.
78	4548	89.6	112	493	52303	112	320	7.44	0.50	5.
79	4514	88.6	111	494	52583	103	328	7.48	0.54	5.
80	4207	60.5	109	706	38313	98.5	522	5.74	0.40	4.
81	4124	37.6	70.8	780	25143	48.7	232	2.59	0.21	1.
82	3245	30.5	85.1	971	20415	79.4	198	1.87	0.17	1.
83	5512	55.1	79.8	1198	36206	82.6	557	7.73	0.61	2.
84	3352	55.7	67.0	447	29087	66.8	582	3.90	0.57	3.
85	3355	59.5	93.7	451	32891	97.5	697	5.04	0.34	7.
86	3983	54.6	84.4	412	31542	75.4	406	3.79	0.36	2.
87	4043	54.3	85.6	471	33916	79.4	523	3.89	0.56	3.
88	3499	61.2	74.0	764	31446	69.7	574	4.76	0.37	3.
89	4234	58.7	80.9	623	34565	69.9	380	4.02	0.31	3.
90	4900	44.0	71.2	526	30753	56.8	302	3.56	0.25	2.
91	4490	57.2	86.9	663	35961	76.2	509	4.42	0.38	3.
92	3732	51.2	85.8	486	28917	69.2	442	3.89	0.33	3.
93	3750	49.9	89.1	546	32848	85.0	444	4.50	0.78	4.
94	6672	56.8	107	803	44004	121	448	6.73	0.35	4.
95	6594	57.6	109	811	45058	128	442	7.77	0.31	4.
96	3389	49.4	69.9	536	28609	68.5	332	2.80	0.25	2.
97	4488	59.1	122	724	41644	159	611	4.53	0.39	7.
98	3200	51.1	100	416	25944	492	240	3.93	0.29	2.
99	4237	61.1	111	720	39001	105	523	5.33	0.40	5.
100	3674	41.5	67.7	618	26501	57.7	389	2.93	0.28	2.
101	4301	37.1	74.8	788	25807	57.8	277	2.30	0.17	2.
102	4211	46.4	62.8	521	27763	53.2	342	2.50	0.24	2.
103	4336	47.5	63.8	536	29167	70.4	366	2.51	0.27	3.
104	3744	33.3	99.1	1066	22890	48.6	206	2.25	0.15	1.
105	2829	39.5	101	1217	24645	68.7	354	2.22	0.22	3.
106	4477	50.3	83.5	662	33226	79.7	589	2.90	0.28	3.
107	4620	42.3	83.2	642	31859	115	644	2.77	0.23	3.
108	4563	49.8	82.0	623	33655	103	568	3.05	0.27	3.
109	4622	45.3	83.4	619	32088	106	632	2.91	0.29	4.
110	3959	61.2	101	578	36212	109	686	4.11	0.32	4.
111	5057	79.7	121	800	49313	223	581	4.93	0.43	6.
112	4456	60.1	102	683	38853	113	566	3.51	0.36	4.
113	4152	70.7	110	683	40157	94.6	524	4.58	0.36	5.
114	3897	54.2	95.0	649	35918	101	650	3.54	0.61	5.
115	3929	56.7	78.8	550	36382	74.0	314	3.51	0.32	4.

116	4059	52.5	88.7	698	44093	87.7	402	4.12	0.29	3.
117	4128	60.2	89.9	653	38589	91.3	525	4.11	0.35	3.
118	3576	53.5	72.6	511	32685	77.4	475	3.68	0.31	3.
119	3628	54.3	80.5	455	30613	64.8	403	3.50	0.28	3.
120	3534	53.4	79.2	452	30511	79.0	389	3.25	0.28	3.

$$CF = \frac{Concentration\ of\ PTEs\ in\ Dust}{Background\ Value}$$ Equation 1

$$CD = \sum CF$$ Equation 2

Supplementary Table 2. Classification of contamination indices

Contamination Factor		Contamination Degree	
Value	Interpretation	Value	Interpretation
Cf < 1	Low contamination factor	Cd < 7	Low degree of contamination
1 ≤ Cf < 3	Moderate Contamination factor	7 ≤ Cd < 14	Moderate degree of contamination
3 ≥ Cf < 6	Considerable Contamination factor	14 ≤ Cd < 21	High degree of Contamination
Cf ≥ 6	Very high contamination factor	Cd ≥ 21	Very high degree of contamination

Ei r = Tr* Cf Equation 3

CF is the contamination factor

Tr as a ‘‘toxic response factor’’ for a given substance and demonstrated this value for

Cd, As, Cu, Pb, Ni, Cr, Zn, Mn to be 30, 10, 5, 5, 5, 2, 1, 1, respectively. Based on Hakanson (1980)

Supplementary Table 3. Grades of the environment by potential ecological risk index (Ren et al 2007)

Grade	E i r value	Grade of ecological risk of single metal	RI Value	Grade of potential ecological risk of the environment
A	E i r < 5	Low Risk (LR)	RI < 30	Low Risk (LR)
B	5 ≤ E i r < 10	Moderate Risk (MR)	30 ≤ RI ≤ 60	Moderate Risk (MR)
C	10 ≤ E i r < 20	Considerable Risk (CR)	60 ≤ RI ≤ 120	Considerable Risk (CR)
D	20 ≤ E i r < 40	High Risk (HR)	RI ≥ 120	High Risk (HR)
E	∑ir ≥ 40	Very High Risk (VHR)		

$$PLI = \sqrt[n]{CF1 * CF2 * CF3 * \ldots\ldots\ldots CFn} \quad \text{Equation 4}$$

where PLI is the pollution load index, CF is contamination factor and n is the number of elements. A PLI value >1 indicates polluted road dust, whereas <1 indicates no pollution (Tomlinson et al. 1980).

$ADDing = Ci * IRS * FI * EF * ED * CF/BW * AT$ Equation 5

$ADDderm = Ci * SA * AF * ABSd * EF * ED * CF/BW X AT$ Equation 6

$ADDinh = Ci * IRA * EF * ED/ BW * AT * PEF$ Equation 7

$LADDing = Ci * FI * EF * CF/LT (EDchild * IRs / BW + EDadult * IRSadult / BWE$
Equation 8

LADDinh = Ci EF/ LT* PEF *(IRAchild* EDchild/BWchild + IRAadult* EDadult/ BWadult)
Equation 9

$HQ = ADD/RFD$ Equation 10

$HI = \sum_{k=1}^{n} HQk = \sum_{n} k = 1 (ADDing/ RFDing + ADDderm/ RFDderm + ADDinh/ RFDinh) k$ Equation 11

Supplementary Table 4. Exposure Parameters used for the health risk assessment

Parameter		Unit	Children	Adults	References
ABS_d	Dermal absorption fraction	unitless	Fe, Be, V, Mn, Co, Cu, Zn, Sr, Mo, Sn, Sb, Ba, W, and Pb 0.03;		OEHHA (2012)
			Cr 0.02; Ni 0.04; As 0.06; Cd 0.002; PAHs 0.13		
AF	Soil adherence factor	mg/cm^2	0.2	0.07	US EPA (2014)
AT	Average time	days	ED_{child} 9 365	ED_{adult} 9 365	US EPA (1989)
BW	Body weight	kg	15	80	US EPA (2014)
CF	Conversion factor	kg/mg	$1\ 9\ 10^{-6}$		US EPA (1989)
ED	Exposure duration	years	6	20	US EPA (2014)
EF	Exposure frequency	days/year	350		US EPA (2014)
FI	Fraction Ingested	unitless	1		US EPA (1989)
IRa	Inhalation rate	m^3/day	10	20	US EPA (2014)
IRs	Ingestion rate	mg/day	100	60	US EPA (2017)
LT	Lifetime	days	365 9 70		US EPA (1989)
PEF	Particulate emission factor	m^3/kg	$1.36\ 9\ 10^9$		US EPA (2002)
SA	Skin surface area	cm^2	2373	6032	US EPA (2014)

Supplementary Table 5 Reference doses (RfD, mg kg^{-1} day^{-1}) and cancer slope factors (SF, kg day^{-1} mg^{-1}) of PTEs and PAHs

	RfD_{ing}	RfD_{derm}[a]	RfD_{inh}[b]	SFing	Sf_{derm}[c]	SF_{inh}[d]	References
Fe	0.7	0.07	–	–	–	–	US EPA (2020b)
V	0.007	1.82 9 10^{-4}	2.86 9 10^{-5}	–	–	–	US EPA (1997, ATSDR (2020)
Mn	0.14	8.4 9 10^{-3}	1.4 9 10^{-5}	–	–	–	US EPA (2020a)
Co	3.0 9 10^{-4}	3.0 9 10^{-5}	1.7 9 10^{-6}	–	–	31,500	US EPA (2020b)
Ni	0.011	4.4 9 10^{-4}	2.57 9 10^{-5}	–	–	0.84	ATSDR (2020, OEHHA (2020), US EPA (2020a)
Cu	0.01	5.7 9 10^{-3}	–	–	–	–	ATSDR (2020)
Zn	0.3	0.03	–	–	–	–	US EPA (2020a)
As	3.0 9 10^{-4}	2.85 9 10^{-4}	4.29 9 10^{-4}	1.5	1.58	15.05	US EPA (2020a), OEHHA (2020)
Mo	0.005	5.0 9 10^{-4}	1.14 9 10^{-4}	–	–	–	US EPA (2020a), ATSDR (2020)
Cd	0.001	2.5 9 10^{-5}	2.86 9 10^{-6}	–	–	6.3	US EPA (2020a, ATSDR (2020)
Pb	3.6 9 10^{-3}	3.6 9 10^{-4}	–	8.5 9 10^{-3}	0.085	0.042	OEHHA (2020), RIVM (2001)