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Concentrations, source identification and human health risk of heavy metals in the road dust collected from busy junctions in Osogbo Southwest, Nigeria

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Abstract

The study determined the concentrations of heavy metals in the road dust samples collected in some selected busy traffic junction in Osogbo, southwest, Nigeria. This was to identifying the sources of heavy as well as the evaluating the associated human health risks. The concentrations of Pb, Cu, Cd, Ni, Co, Cr, Zn, Mn, and Fe were determined by employing Atomic Absorption Spectrophotometer. The sources were identified using non-negative constraint Positive Matrix Factorization receptor model and the health implication were assessed using risk indices consist of average daily doses via: dermal, inhalation and ingestion; Hazard Quotient (HQ); hazard index (HI); and lifetime average daily dose (LADD). The total average concentrations of Fe, Mn, Cu, Zn, Cr, Cd, Pb, Ni, and Co were 5030.0, 80.52, 15.14, 49.0, 6.81, 2.80, 1.77, 1.31, 1.98 μg/g, respectively and they were few order higher than their values in the local background site. The inhalation appeared to be the major exposure pathway of heavy metals in the road dust to the adults and children followed by dermal contact and ingestion. The sequences of HQ values are Cd < Ni < Zn < C u < Pb < Cr and Cu < Cd < Pb < Cr < Ni < Zn for adults and children. The HI values for the adults and children are 0.2 and 0.5, showing that any of Cu, Zn, Cr, Cd, Pb and Ni will unlikely cause negative human health effect through multiple exposure routes. The cumulative value of LADD for Cu, Zn, Cr, Cd, Pb and Ni is 1.70 x 10^{-5} which falls within the acceptable limit value of 10^{-4} to 10^{-6}. The four main sources resolved by PMF and their relative contributions were vehicular components wear (36 %), fuel and lubricating oil (30 %), tyre particles wear (23 %), and battery corrosion and leakage (11 %).

Keywords
Traffic, Road dust, Exposure, Health risks

Introduction

Globally, a good road network is highly desirable in urban centers as it drives the economic processes, stimulates social activities, improves services delivery, facilitates exchange of goods, and enhances dissemination of information among the people (Omole et al., 2012; Taiwo et al., 2016). Most roads in urban centers are poorly maintained and they are characterized with vehicular congestion on daily basis, leading to emission of potentially toxic pollutants with varying human health implications and environmental degradation (Olajire et al., 2011; Bernardino et al., 2019). Among the pollutants, heavy metals are frequently encountered along the traffic corridors (Tchounwou et al., 2012). Road dust consists of settled solid particles on the road surfaces, pavement, gutter and they serve as temporary sinks for heavy metals and they had been considered as a useful indicator of environmental pollution (Timofeev et al., 2019).

Heavy metals have potential to be accumulated in human body after entering via dermal absorption of dust adhered to exposed parts of the body, direct ingestion of airborne substrate and the inhalation of suspended particles through mouth and nose (Du et al., 2013; Taiwo et al., 2016; Ogundele et al., 2019). They can

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also be transported from the diverse points and mobile sources finally enter the food chain by plant uptake. Exposure to road dust riched with heavy metals had been linked to several health issues (Wei et al., 2015; Taiwo et al., 2016). Heavy metals have no biochemical functions and physiological relevance in human body even at low concentrations. At high concentrations and increased accumulation in the living organism, they may induce severe health implications among the healthy group. People with existing ill-health issues may also suffer worsen health conditions (Ogundele et al., 2017). Some of the detrimental health consequences of heavy metals in human body are liver damage, airway constriction, bone defects, lung cancer, pulmonary disease, decreased lung function, hormones disorders and several dysfunction in human body (Sofuoglu and Sofuoglu, 2017). Human health risks assessment is an approach that gives the quantitative estimate of the likelihood as well as the nature of adverse human health effects and presentation of risk information to the decision makers (Du et al., 2013). It has been extensively employed by governmental agencies, scientific researchers and regulatory authorities to define the inherent risks of various environmental pollutants. The risk-based equations developed by the United State Environmental Protection Agency (USEPA, 1989) and Dutch National Institute of Public Health and Environmental Protection formed the basis for human health risk assessment studies.

The source identification of heavy metal is a crucial step for decision making in order to develop effective management strategies in improving the environmental quality, reduction of heavy metal pollution and human health protection and safety (Huang et al., 2015; Hu et al., 2018). Most studies were based on the model calculations, enrichment analysis, statistical analysis, isotope ratio analysis, index of geoaccumulation as well as comparison of measured elemental concentrations data with the literature data (Hu et al., 2018). Over the past few years, a number of classical approaches had been developed by employing multivariate statistical methods to identify and quantify environmental pollutants to their sources. Among the recently developed multivariate statistical methods, Positive Matrix Factorization (PMF) model had been widely used for source identification of not only the heavy metals but also the elemental contents of atmospheric particulate matter, sediment, water, soils and biomonitors (Ogundele et al., 2016; Vaccaro et al., 2007; Jiang et al., 2017; Hu et al., 2018; Rodenburg et al., 2011; Li et al., 2015). In these studies, sources were identified on the basis of the concentrations of the fingerprints of the pollution sources. A recent study by Taiwo et al. (2018) ascertained Cr, Pb and Cd (few numbers of heavy metals) as metals of serious health risks with respected to the road dust. Also, no effort was made towards identification of sources responsible for heavy metals contents in the road dust. In the present study, PMF was used to define the sources of selected heavy metals in road dust samples. The objectives of the present study are: (1) to determine the concentration of Pb, Zn, Fe, Mn, Cu, Ni, Cr and Cd in the road dust collected from major traffic junctions in Osogbo; (2) to identify the possible sources of the measured metals pollution using multivariate statistical analysis; and (3) assess the human health risks associated with the measured heavy metals.

Materials and Methods

Study area

Osogbo is the capital of Osun State in Southwestern Nigeria. The city is situated within the geographical grid reference of 7.460º - 7.767° N and 4.340º - 4.567º E and over 500 m above sea level. It has two has two Local Governments areas: Osogbo and Olorunda Local Government areas, state secretariat, electricity power transmission substation, several parastatals and non-governmental organizations, some main market centers as well as other financial institutions (Fig, 1).

The traffic in Osogbo exhibits a typical week days diurnal volume variation pattern with the morning and afternoon rushing hours on a daily basis. The recent infrastructural development, construction of road networks and dualization of major roads by the immediate past administration had increased the transportation services in Osogbo. Moreover, the current population in Osogbo is believed to be some order of magnitude higher than 300,000 people (Adedotun, 2015), which was previously reported in the 2006 census. 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, private cars are used. Also, a significant number of people walk on the roadside depending on their destinations and hawking activities.

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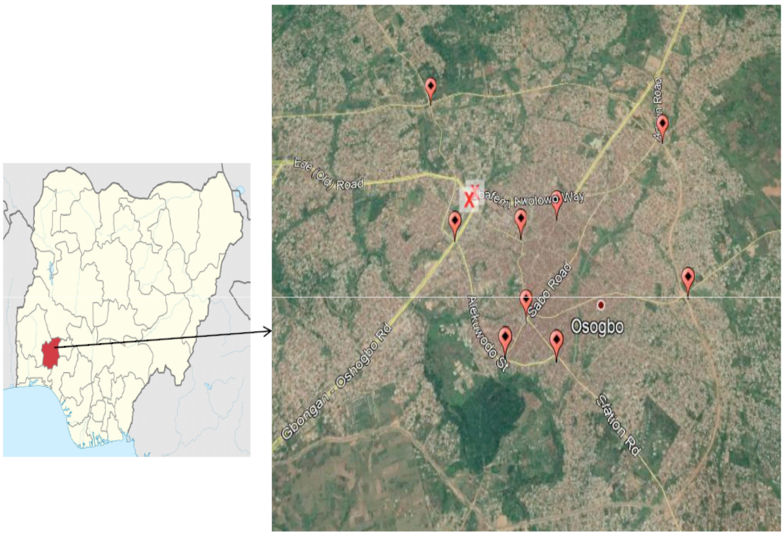

Figure 1. *Map of the study area showing sampling locations (Osogbo and Olorunda).*

Sampling and preparation

Forty two (42) road dust samples were collected from 9 major traffic junctions within the city. Table 1 shows the description of each traffic junction, and nature of adjoining roads. The road dust samples were collected in the non-active lanes and sidewalk ways by gently sweeping an area of about 1 m^2 at the roadside with a plastic hand brush and parker to avoid metal contaminations.

Table 1. *Description of the sampling locations*

S/N	Site	No	Site Description
1	Olaiya	5	paved dualized roads with busy traffic all the time of the day
2	Okefia	5	unpaved road with some portions under construction
3	Old garage	5	paved road with some portions of road under construction and high traffic volume
4	Abere	5	paved, dualized road with busy traffic activities
5	Stadium	6	newly constructed paved roads with busy vehicular activities
6	Lamecom	4	dual road with low vehicular mobility
7	Dele yes sir	4	the roads are under construction with slow vehicular mobility
8	Oja Oba	4	high traffic congestion around the junction due to market activities
9	Ilesha garage	4	paved road with some portions under construction and less traffic volume

The sample were kept in the well labeled polythene bags and transferred into the laboratory for further preparation and chemical analysis. All the samples were collected in the same day and at the peak of the dry season when the dust remobilization rate were very high and no rain fell in about a month before sampling. The road dust samples were sieved to remove the coarse particles and other organic debris such as small pieces of nylon, grass and paper. The fine samples were later obtained and sent for digestion and analysis. A four soil samples were collected from forest area (undisturbed site) and they were used as control (local background) for this study.

Chemical analysis

A 2.0 g of each sample was accurately weighed into a pre-cleaned digestion flask followed by the addition of 2 ml of concentrated H_2SO_4. The whole content was heated on the Tectactor digestion vessel for about 1 hour until the solution become clear and it was left to cool to room temperature. The digested samples were made up to mark (50 mL) with distilled water and filtered using a filter membrane (Whatman no 1, φ = 0.45 μm) prior to chemical analysis. The concentration of Pb, Cu, Cd, Ni, Cr, Zn, Mn, Fe and Co were measured using Atomic Absorption Spectrophotometer (Perkin Elmer 400 model) based on flame atomization, using air-acetylene flame and single element hollow cathode

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lamp (Ayeku et al., 2019; Ogundele et al., 2019). To verify the accuracy of the analytical procedures and to check the reliability of the analytical results, IAEA SOIL-7 standard reference material was analyzed in the same experimental conditions as the regular samples. The certified values were closed to the measured values for each element and the recovery rates were obtained: 94 % for Cu; 96 % for Cr, Pb and Zn; 102 % for Fe; and 105 % for Mn showing the reliability of the instrumental analysis. The detection limits of the measured metals ranged from Cd (0.01 µg g^{-1}) to Mn (0.05 µg g^{-1}). The average mean of elemental of the measured heavy metals were presented by descriptive statistics (mean and standard deviation) using with Statistical Package for Social Sciences (20.0).

Health risks assessment

Human health risk assessment connects the concentrations of environmental pollutants with the probability of toxic effects on the exposed population (Jiang et al., 2017). For non-carcinogenic effects, the health risks of the vulnerable parts of the exposed population (children and adults with existing health issues) were quantitatively characterized by employing risks-based models (equations) developed by the United States Environmental Protection Agency (USEPA, 1989) and previously used in several studies (Ferreira-Baptista and De Miguel, 2005; Sun et al., 2010; Du et al., 2013; Zheng et al., 2015; Ogundele et al., 2016; Jiang et al., 2017; Ogundele et al., 2019). The models assumed that human beings are exposed to heavy metals through oral ingestion, dermal contact and inhalation routes; similarity of the exposure parameters; combination of individual risk due to each measured metal; and summation of the individual risks from each exposure pathways (Wei et al., 2015; USEPA, 2011a; Jiang et al., 2017). The average daily exposure doses (µg kg^{-1}day^{-1}) through ingestion (D_{ing}), inhalation (D_{inh}) and dermal absorption (D_{der}) pathways were estimated as follows equations 1, 2 and 3:

$$D_{ing} = \frac{C * IingR * EF * ED * CF}{BW * AT} \quad [1]$$

$$D_{inh} = \frac{C * IingH * EF * ED}{PEF * BW * AT} \quad [2]$$

$$D_{der} = \frac{C * SL * SA * ABS * EF * ED * CF}{BW * AT} \quad [3]$$

where C is the concentration of heavy metals; $IingR$ is ingestion rate; EF is the exposure frequency; ED is exposure duration; CF is conversion factor; BW is average body weight; AT is average time; $IinhR$ is the inhalation rate; PEF is particle emission factor; SL is skin adherence factor; SA is skin surface area of contact; and ABS is dermal absorption factor.

The definitions of the exposure parameters and their respective values used for the estimation average daily dose for each exposure pathways are presented in Table 2.

The non-carcinogenic hazard quotient (HQ) for each heavy metal for the three exposure pathway was calculated by dividing the average daily dose of each heavy metal by their specific reference dose as:

$$HQ = \frac{ADD}{Rf_oD} \quad [4]$$

The reference dose (Rf_oD) (µg kg^{-1}day^{-1}) is the maximum daily permissible risk on the exposed population (Du et al., 2013) used to indicate the tendency of adverse health effect during a life time.

Table 2. *Exposure Parameters for Average Dose Estimation*

Exposure Parameters	Definition	Units	Adult	Children	References
C	concentration of heavy metals	µg/g			
I*ingR*	ingestion rate	mg/day	100	200	USEPA (2011a)
I*inhR*	inhalation rate	m^3/day	20	5	Wei et al. (2015)
EF	exposure frequency	days/year	365	365	Ferreira-Baptista and De Miguel (2005)
ED	exposure duration	years	24	6	USEPA (2011a)
CF	conversion factor	kg/mg	10–6	10–6	Liu et al. (2014)
AT	average time	days	365 * ED	365 * ED	Zheng et al. (2015)

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BW	average body weight	kg	60	15	WHO (2015)
PEF	particle emission factor	m^3/kg	$1.32 * 10^{-9}$	$1.32 * 10^{-9}$	USEPA (2011a)
SL	skin adherence factor	mg/cm^2	1	1	WHO (2015)
SA	skin surface area of contact	cm^2	3300	1800	Wei et al. (2015)
ABS	dermal absorption factor		0.001	0.001	Du et al. (2013)

Heavy metals such as Cr, Ni, Cu, Zn, Cd, and Pb are listed as potential carcinogen and they were considered in estimation HQ (IRAC, 2011). The Rf_oD values Cr, Ni, Cu, Zn, Cd, and Pb were 0.003, 0.02, 0.04, 0.3, 0.001 and 0.003 mg/kg/day, respectively (Sofuoglu and Sofuoglu, 2018). If ADD $<Rf_oD$, then no adverse health effect is expected. However, if the ADD $>Rf_oD$, it is likely that the exposure pathway will cause negative human health effect. The HQ value of 1 means no adverse health effects (USEPA, 2011a,b). The Hazard Index (HI), which is the overall potential for non-carcinogenic effects from different pathways was estimated as summation of all the individual hazard quotient using:

$$HI = \sum_{1}^{3} HQ \qquad [5]$$

According to USEPA (2010), HI value less than 1 and greater than 1 signify no significant risk of non-carcinogenic effects and the probability for non-carcinogenic effects to occur in the exposed population. The tendency of experiencing long-term health hazard effect increases as HI values increases (Olujimi et al., 2012). For carcinogenic effects, the average, which lifetime average daily dose (*LADD*) ($\mu g^{-1}day^{-1}$) which indicates incremental probability of an individual developing cancer over a lifetime due to inhalation exposure route of specific carcinogen in the road dust was estimated as follows (USEPA, 2011a):

$$LADD = \frac{C * EF}{AT}\left[\left(\frac{I_{inh} * ED}{BW}\right)_{Children} + \left(\frac{I_{inh} * ED}{BW}\right)_{Adults}\right] \qquad [6]$$

The International Agency for Research on Cancer (IRAC, 2011) listed Cu, Zn, Cr, Cd, Pb and Ni as part of the major players for carcinogenic health implication among the exposed population and they had been previously reported in other studies as having potential carcinogen (Ma and Singhirunnusorn, 2012; Ogundele et al., 2019). Therefore, the cumulative values of LADD for Cu, Zn, Cr, Cd, Pb and Ni were of concern in this study. The LADD values were compared with the risk values of 1.0×10^{-6} to 1.0×10^{-4}) which had been judged to be acceptable or tolerable risk for regulatory purposes (Du et al., 2013).

Positive Matrix Factorization

Positive Matrix Factorization (PMF) is a multivariate form of factor analysis developed by (Paatero, 1997; Paatero and Hopke, 2009) based on the assumption of mass conservation between sources and receptor. The unique features of PMF are non-negativity constraint and the use of uncertainty to weigh each data point (Norris et al., 2014). Also, a remarkable advantage of PMF over some other traditional receptor model such as Chemical Mass Balance (CMB) is that it can be used without the knowledge of the source profiles as part of the inputs. Briefly, the elemental concentrations matrix X (i x j), where i and j are number of samples and chemical species can be decomposed into a contribution matrix, G (i x k), and source profile F (k x j) and residual error matrix E (i x j) as:

$$X_{ij} = \sum_{k=1}^{p} G_{ik}F_{kj} + E_{ij} \qquad [7]$$

where X_{ij} is the concentration of the j^{th} element in the i^{th} sample, G_{ik} is the contribution of the k^{th} source for i^{th} number of samples; and F_{kj} is the concentration of the j^{th} element in the k^{th} source. The uncertainty for the PMF run was computed as follows (Jiang et al., 2017):

$$U_{ij} = \sqrt{(\sigma * C)^2 + MDL^2} \qquad [8]$$

where σ, C and MDL are relative standard deviation, concentration of the measured element and method detection limit, respectively. Based on the residual matrix E_{ij} (analytical uncertainty and variation in source composition) and U_{ij}, the main task of the PMF model is to obtain factor profiles and contributions by fitting the solution that minimizes the objective function Q, which is the sum of the square of the residual E_{ij} weighted inversely with uncertainty estimate, U_{ij} associated with j^{th} element for the i^{th} sample data point:

$$Q = \sum_{n=1}^{n}\sum_{m=1}^{m}\left[\frac{X_{ij} - \sum_{k=1}^{p} G_{ik}F_{kj}}{U_{ij}}\right]^2 \qquad [9]$$

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$$Q=\sum_{n=1}^{n}\sum_{m=1}^{m}\left[\frac{E_{ij}}{U_{ij}}\right]^2 \qquad [10]$$

In this study, the heavy metal concentrations data of the nine sites were merged to obtain a large data set requires for PMF model run. These consist of concentration and uncertainty data files of dimension 9 by 42 matrix (9 elements by 42 samples). More details about the PMF model procedures had been reported elsewhere (Norris et al., 2014; Owoade et al., 2015; Ogundele et al., 2016; Jiang et al., 2017). The standalone USEPA PMF 5.0 software was used for the modeling. The factor profiles (mixture of source signatures in each factor profile) in the model output were interpreted by using specific tracers information and emission inventory and sources were assigned by the considering the percentage contribution of each species in the each factor.

Results and discussion

Average heavy metal concentrations results (μg g^{-1})

Table 3 shows the average concentrations of Mn, Fe, Cu, Zn, Cr, Cd, Pb, Ni, and Co in the 9 sites and the control site of the study area. The results showed similar compositions of heavy metals in all the sites as well as site. Among the measured heavy metals, it was observed that Fe had the highest average concentrations in all the sites which ranged from 2480.66 μg g^{-1} (Ilesa garage) to 5870.48 μg g^{-1} (Dele yes sir). The average high concentrations of Fe in all the sites might be attributed to anthropogenic contributions from construction debris such as broken brick, plaster, cement and concrete.

Table 3. *Mean (standard deviation) of heavy metal concentrations in road dusts* (μg g^{-1})

Location		Mn	Fe	Cu	Zn	Cr	Cd	Pb	Ni	Co
Olaiya	Mean	59.41	4335.32	8.86	29.80	8.13	2.87	3.15	2.68	2.35
	SD	13.86	418.77	2.26	8.99	1.47	0.90	1.48	1.96	1.66
Okefia	Mean	67.88	2416.38	22.19	15.14	3.84	2.43	2.83	1.72	1.95
	SD	5.76	1312.30	2.52	4.10	1.30	1.50	1.90	0.40	0.92
Old garage	Mean	78.27	5832.86	12.77	45.19	9.64	4.46	4.20	1.79	1.31
	SD	13.64	1643.63	4.94	6.30	2.57	3.81	1.88	0.16	0.57
Abere	Mean	77.46	5400.74	45.64	39.26	3.60	1.63	1.16	1.13	0.5
	SD	4.11	559.18	6.12	8.25	1.92	2.08	1.65	0.30	0.75
Stadium	Mean	61.38	3412.42	14.36	41.25	3.61	3.10	0.59	0.90	0.98
	SD	9.28	870.54	3.14	3.81	1.51	1.22	0.50	0.30	0.20
Lamecum	Mean	93.52	6543.86	11.31	33.40	7.66	1.98	0.50	0.54	1.55
	SD	36.11	3631.15	8.74	3.41	1.96	0.28	0.22	0.40	0.60
Dele yes sir	Mean	113.22	5870.48	10.54	52.65	9.72	1.11	0.32	1.75	0.45
	SD	25.83	2141.33	3.73	32.76	4.44	1.20	0.24	1.64	0.36
Oja Oba	Mean	82.38	2684.98	7.50	28.7	3.2	0.60	1.24	0.98	2.42
	SD	24.03	1289.51	7.57	23.79	3.20	0.39	1.71	1.02	1.15
Ilesha garage	Mean	72.82	2480.66	17.36	107.15	1.62	0.39	0.34	1.56	1.94
	SD	11.69	995.68	15.01	102.13	1.19	0.57	0.27	1.76	1.52
Over all	Mean	80.52	5030.00	15.14	49.0	6.81	2.80	1.77	1.31	1.98
	SD	7.54	1100.86	4.0	5.31	1.24	0.43	0.23	0.45	0.53
Control	Mean	56.04	2240.00	7.14	28.0	3.78	1.30	0.30	0.41	0.58
	SD	6.14	980.00	1.23	1.30	1.30	0.50	0.06	0.10	0.12

SD = Standard deviation

Also, geogenic activities involving weathering of parent materials could also contribute to Fe content in the road dust (Bernardino et al., 2019). The average concentration of Mn was high at Dele yes sir compared to other sites. The concentrations of Pb were 4.20 and 3.15 μg/g at Old garage and Olaiya sites, respectively. The concentrations of Zn, Cr, and Cd were 107.2, 9.7, and 4.2 μ g/g at Ilesha garage, Dele yes sir and Old garage sites, respectively. The average concentrations of Pb, Co, Ni, Fe, Cd, Cu, Cr, Zn, and Mn were 6.0, 3.4, 3.2, 2.2, 2.2, 2.1, 1.8, 1.8, and 1.4 times their respective average values in the control site. These strongly suggested that the road dust collected at various traffic junctions are moderately polluted with

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respect to the measured metals due to traffic and other man made activities around the junctions. Largely, the variation in the average concentrations of the various metals in the studied traffic junctions might be related to volume of traffic, vehicle speed, nature of road, vehicle load, acceleration, braking and steering (Kreider et al., 2010) and other anthropogenic activities around each junction. The average concentrations of Zn, Cd and Pb reported by Taiwo et al. (2018) around some busy traffic junctions in Abeokuta, Nigeria were slightly different to the average concentrations reported in this study. The probable reasons for the differences in the values of the measured concentrations might base on the fact that each city has its unique characteristics with respect to traffic density, nature and age of the road and fuel combustion efficiency of vehicles (Ma and Singhirunnusorn, 2012). Despite the fact that effort is being made worldwide to phase out the use of Pb in Tetraethyl lead as octane enhancer in gasoline, the presence of Pb in this study indicates that leaded gasoline is still in use and phasing out of Pb has not been fully implemented. The average value of Pb/Cd ratio was 2.2, implying traffic emission was the dominant sources of heavy metals (Razos and Christides, 2010; Taiwo et al., 2019).

Health risks assessment results

Table 4 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 junctions in Osogbo and the nature of these activities could lead to exposure to heavy metals in the road dust emitted from to traffic activities.

Table 4. *Hazard quotient and hazard indices values of heavy metals in the road dust*

Heavy metal	Adults			Children			Adult	Children
	D_{ing}	D_{inh}	D_{der}	D_{ing}	D_{inh}	D_{der}	HI	HI
Mn	1.21E-03	1.90E-04	4.60E-03	5.10E-03	1.90E-03	9.10E-03	1.86E-03	2.50E-03
Fe	6.88E-03	1.08E-02	2.60E-2	2.87E-02	1.08E-02	5.16E-02	1.06E-02	1.41E-02
Cu	2.07E-04	3.24E-05	7.84E-05	8.63E-05	3.24E-04	1.56E-05	3.18E-04	4.26E-04
Zn	6.83E-04	1.07E-04	2.58E-04	2.84E-04	1.07E-03	5.12E-05	1.05E-03	1.40E-03
Cr	1.02E-04	1.60E-05	3.86E-05	4.25E-05	1.60E-04	7.66E-06	1.57E-04	2.10E-04
Cd	3.73E-05	5.84E-06	1.41E-05	1.55E-05	5.84E-05	2.80E-06	5.73E-05	7.67E-05
Pb	2.77E-05	4.33E-06	1.05E-05	1.15E-05	4.33E-05	2.08E-06	4.25E-05	5.69E-05
Ni	2.34E-05	3.65E-06	8.83E-06	9.72E-06	3.65E-05	1.75E-06	3.58E-05	4.80E-05
Co	2.55E-05	3.99E-06	9.65E-06	1.06E-05	3.99E-05	1.91E-06	3.92E-05	5.24E-05

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 junctions. 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). The inhalation exposure pathway is followed by dermal contact. The ingestion occurred to be the least exposure pathway. However, some other studies indicated inhalation as the primary exposure pathway to heavy metals in the road dust to the children (Ferreira-Baptista and De Miguel, 2005; Du et al., 2013; Wei et al., 2015; Taiwo et al., 2016). The sequences of HQ values for the measured metals are Cd < Ni < Zn < Cu < Pb < Cr and Cu < Cd < Pb < Cr < Ni < Zn for adults and children, respectively. The HI values for the adults and children are 0.2 and 0.5, indicating an unlikely condition of negative human health effect from multiple exposure pathways. The carcinogen risk for inhalation exposure route was estimated for Cr, Ni, Cu, Zn, Cd and Pb for both adults and the children. Each of Zn, Ni, Cd, Cr, and Pb could produce individual risks as well as aggregate health implications resulting in high toxicological

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risks among the exposed population. The mixture of Zn, Cr, Cd, Ni and Pb, if contact in large dose might triggered neurological and developmental disorder and be responsible for respiratory issues, cardiac symptoms, lung injury and human mortality (Liu et al., 2014). It was also observed that the non-carcinogenic health risks through multiple exposure routes for adults was less than the values for children with respect to heavy metals consideration, making children to be more vulnerable among the exposed population.

The average values of LADD for Cu, Zn, Cr, Cd, Pb and Ni were 7.57 x 10^{-5}, 2.49 x 10^{-5}, 3.73 x 10^{-5}, 1.36 x 10^{-5}, 1.01 x 10^{-5} and 8.53 x 10^{-6}, respectively and the cumulative value of 1.70 x 10^{-5}. These values 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, 2011b; IRAC, 2011). This implies that the life time average exposure dose due to inhalation of road dust that contains Cu, Zn, Cr, Cd, Pb and Ni in the study is judged to be acceptable and pose non cancer risk to human health. Children had higher non-carcinogenic risks than adults in the three exposure pathways considered, indicating that they are more vulnerable to health implication heavy metals in the road dust. The children frequently engaged in hand-to-mouth activities and various outdoor plays. They also experience high respiration rate per unit body weight, hence breathing more deeply into lung road dust containing heavy metals with systematic toxicity and health risks.

PMF results

Figure 2 showed percentage concentrations distribution of heavy metal in the identified factor in each of the stacked bar charts. Four sources were resolved for the merged elemental concentrations data of the nine junctions under consideration. The first factor is characterized with Co, Ni, Cu, Mn, Cr and Zn with percentage species concentrations of 63.6, 51.8, 50.1, 46.7, 34.6 and 32.6 %, respectively and 36 % as percentage source contribution. Co, Ni, Cu, Mn, Cr and Zn are typical marker elements for vehicular fuel (McKenzie et al., 2009; Amato et al., 2009). On daily basis, a significant amount fuel (gasoline and diesel) is being consumed by all sorts of vehicle during transportation services.

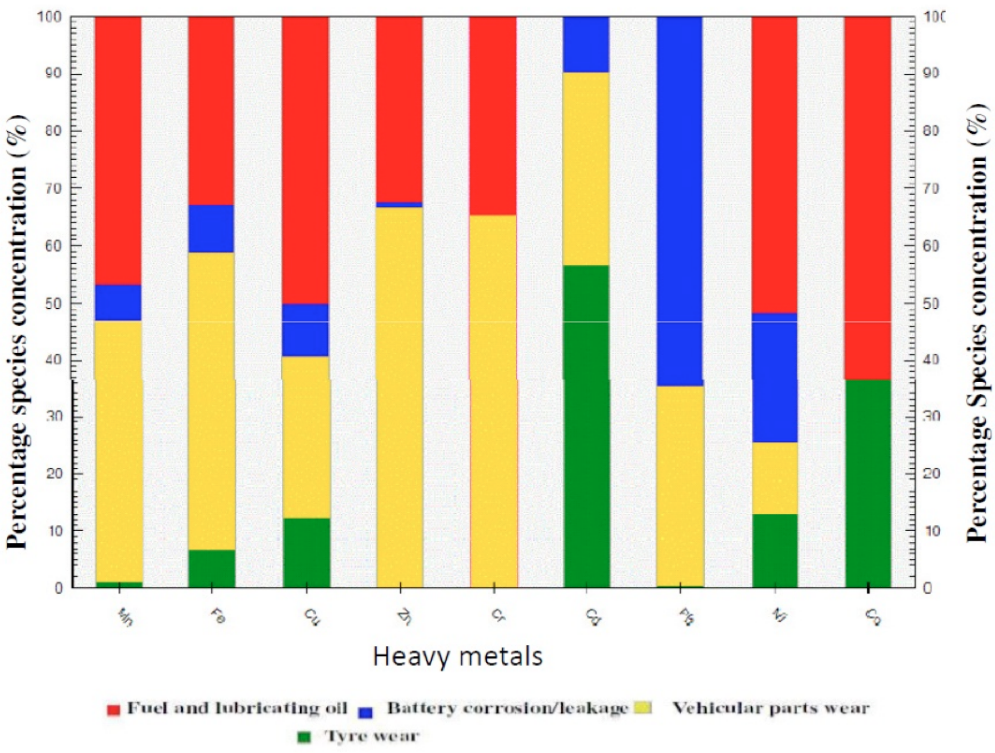

Figure 2. *PMF factor fingerprint of the heavy metals.*

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These metals are still retained in the exhaust emission and they might settle and incorporated in the roadside dust. Moreover, the tendency is high for leakage of the lubricating oil residues and other vehicular fluids. Ni and Mn are typical signatures for lubricating and engine oil (Wawer et al., 2015; Bernardino et al., 2019). They might also be contributed to the road dust from the unintentional discharge of spent fuel during repairing of some faulty car along the road. Previous studies indicated that substantial amount of Pb in urban roadside soil came from traffic emission, involving fuel combustion (Taiwo et al., 2018; Al-Taani et al., 2019). This factor is identified as fuel and lubricating oil. The second factor contains Pb and Ni with respective percentage species concentrations of 64.4 and 24.7 % with 30 % as the percentage source contribution. Pb is a principal component of most batteries while Ni is frequently used in large quantity as trace additives in the molding and casting processes of batteries (Ogundele et al., 2019). Pb and Ni might be added to the road dust from battery corrosion and leakage of the electrolyte (Novo et al., 2017; Bernardino et al., 2019). This factor is attributed to battery corrosion and leakage.

The third factor featured Zn, Cr, Fe, Mn, Pb and Cd with 66.6, 65.2, 52.3, 45.9, 35.2, and 33.6 % as the percentage species concentrations, respectively and contributed 23.0 % as percentage source contributions. The combination of the elements in this factor reflects vehicular body wear and break lining wear. Zn and Cu are peculiar tracers for brake wears (Khan et al., 2011; Kluge and Wessolek, 2012). The source of Zn in road dust was indicated by previous studies as wearing of the galvanized metals used in vehicular body parts. The rate of corrosion and wear from old vehicle is very high as a result of high patronage of imported and fairly used cars). This could account significantly to the levels of Ni in the road dust. About 70% of the all the vehicular parts are made of Zn, and the corrosion of galvanized structures might introduce scraps which contribute to Fe and Zn content in to the road dust. Fe and Mn had been reported as parts the naturally abundant elements in the soil. Weathering and mechanical attrition of the crustal materials due to vehicular mobility could also contribute to Fe loading in the road dust (Lu et al., 2009). Iron Oxide (FeO) is used as abrasion agents in tire treads, brake linings, and other vehicle components and it may end up in road dust after wearing (Saeedi et al., 2009; Wawer et al., 2015). Hence, the third factor is linked to vehicular components wear. The fourth factor contains Cd and Co and their percentage species concentrations are 56.6 and Co 36.4 % and percentage source contribution of 11.0 %. Cd is a major constituent of vulcanization agent in vehicles tyre. During high temperature, the wearing rate could be high, leading to the contribution of high Cd contents in the road dust. In a similar way, wearing of automobile tyre was related to non-point sources of Co in the road dust and it is adopted as fingerprint for vehicular tyre wearing (Amato et al., 2009; McKenzie et al., 2009; Wang et al., 2012). Therefore, this factor is considered as tyre particles wear.

Generally, the results of PMF were pivotal to infer potential sources of heavy metal in the road dust of the study area and it indicated four major sources. Considering the pace of urbanization and industrial growth in addition to high volume of traffic on daily basis within Osogbo, the heavy metal contents of road dust might also be from municipal wastes disposal activities, urban runoff, atmospheric deposition from industrial emissions and urban land use types. Studies involving bio-indicators such as urine, hair, blood of the road users and people living close to the busy traffic junctions and other exposure parameters like air, food and water could also be conducted in order to establish the bioaccumulation contents of heavy metals.

Conclusion

The concentrations Mn, Fe, Cu, Zn, Cr, Cd, Pb, Ni, and Co in the road dust samples collected from busy traffic junctions and control sites had been measured by employing AAS. The total average concentrations of measured metals were slightly higher than the control site. This showed a pollution conditions due to traffic activities. The average daily exposure dose indicated inhalation as the major exposure pathway of heavy metals in the road dust to both adults and children followed by dermal contact and ingestion. The HQ values of Cd, Ni, Zn, Cu, Pb, and Cr were less than 1 for adults and children. Cd in the road dust showed to be mostly contributed to non-cancer effects among the exposed population. The Cd had the highest HQ for the adults. The overall LADD value for Cu, Zn, Cr, Cd, Pb and Ni was 1.70 x 10^{-5}. This was within the global threshold limit of 10^{-4} to 10^{-6} recommended as acceptable risk for human protection and safety. The four sources identified by PMF to be responsible for heavy metals in the road dust of the study area are vehicular components wear, fuel and lubricating oil, tyre particles wear, and battery corrosion and leakage. The vehicular components wear and vehicular fluid and

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fuel constitute the dominant sources that contributed to heavy metals in the road dust.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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