REPORT

Heavy metals in soils along unpaved roads in south west Cameroon: Contamination levels and health risks

Veronica M. Ngole-Jeme

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Abstract Soils enriched with heavy metals from vehicular emission present a significant exposure route of heavy metals to individuals using unpaved roads. This study assessed the extent of Cd, Cr, Co, Cu, Ni, Pb and Zn contamination of soils along unpaved roads in Cameroon, and the health risks presented by incidental ingestion and dermal contact with the soils using metal contamination factor (CF) pollution load index, hazard quotients (HQ) and chronic hazard index (CHI). CF values obtained (0.9–12.2) indicate moderate to high contamination levels. HQ values for Cr, Cd and Pb exceeded the reference doses. Moderate health hazard exists for road users in the areas with intense anthropogenic activities and high average daily traffic (ADT) volume according to CHI values (1–4) obtained. The economy and quality of life in cities with unpaved roads could be threatened by health challenges resulting from long-term exposure to heavy metal derived from high ADT volumes.

Keywords Incidental soil ingestion · Vehicular emission · Hazard quotients · Chronic hazard index · Contamination factor

INTRODUCTION

Heavy metals have been receiving increasing concerns because of their potential negative effects on various environmental sectors. Their origin in the environment could be of natural or anthropogenic source including industrial, mining, agricultural and waste disposal activities, as well as vehicular emissions. The role of vehicular emissions in the introduction of heavy metals into the environment is well known. Lead (Pb), copper (Cu), iron (Fe), zinc (Zn) and cadmium (Cd) are some of the heavy

metals that have been reported in vehicular emissions. According to Hopke et al. (1980), Jaradat and Momani (1999), Davis et al. (2001), Nouri and Naghipour (2002), Sternbeck et al. (2002), Wang et al. (2003), Walsh (2004), Ugwu et al. (2011) and Raj and Ram (2013), these metals originate from the wear and tear of tires, alloys, wires and brake parts. Vehicular emission combine with suspended soil particles especially in areas with unpaved roads to form secondary particles which are eventually deposited along roadsides (Baptista and De Miguel 2005) and on the exposed body parts of individuals using these roads. Roadside soils are therefore expected to have elevated concentrations of heavy metals derived from vehicles. These soil and dust particles constitute a secondary source of health threat to individuals residing along unpaved roads due to possible incidental inhalation and ingestion of resuspended soil particles. Vehicular emission has consequently been implicated in several human health conditions including heart disease, respiratory illnesses and cancer (Han et al. 2007; Allen et al. 2009).

Exposure of individuals to heavy metals through incidental ingestion and dermal contact with dust and soil particles along unpaved roads constitute an important and unnoticed exposure route of heavy metals. The health threats presented by these exposure routes have been presented in Agency for Toxic Substances and Disease Registry (ATSDR) toxic substances profiles (ATSDR 2015). Cd and Pb, for example, are carcinogenic and prolonged exposure to low concentrations could lead to kidney disease, lung damage, fragile bones for Cd, and nervous disorder in the case of Pb. The health effects of Cr depend on the valence state of the Cr ingested but according to ATSDR (2015), Cr may cause gastrointestinal, nasal and lung irritation, ulceration of stomach and small intestines, dermatitis and decreased sperm counts. Dermatitis, lung inflammation and cancer

have all been associated with Ni. Co has been implicated in cardiomyopathy and lung irritation. The most commonly reported adverse health effect of Cu and Zn is gastrointestinal distress including nausea, vomiting and/or abdominal pain but irritation of the respiratory system is also common (ATSDR 2015). The type of effects and their intensity however differ depending on whether heavy metal exposure is through oral or dermal route.

Poor roads, driving patterns, passenger and goods overloads, and engine revving are some conditions which promote high vehicular emissions (Kean et al. 2003). According to Sjödin et al. (1998), vehicular emissions increase by a factor of 10 during traffic congestion compared to smooth driving conditions. Similar observations were made by Hopke et al. (1980), Davis et al. (2001), Nouri and Naghipour (2002), Sternbeck et al. (2002) and Kean et al. (2003). Unpaved roads and lack of road maintenance are still common in developing countries despite the apparent contributions of an established road infrastructure to the economy of a nation (World Bank 2003; Burningham and Stankevich 2005). Whereas most developed countries have set emission standards which are closely monitored to reduce vehicular emissions, that has not been the case with developing countries where

regulations on the roadworthiness of vehicles are not strictly enforced. These lapses in compliance have resulted in an increase in the health risk to which populations spending time along unpaved roads are exposed.

In Kumba (Fig. 1), one of the largest Anglophone cities in Cameroon, more than 80 % of the roads are untarred and are plied by old vehicles and motorbikes (Fig. 2), most of which still make use of leaded gasoline. These vehicles are also frequently overloaded with goods and passengers (Fig. 2). There are no measures such as application of oil or other materials on these roads to reduce the amount of dust generated by vehicular traffic in the city. The sale of both raw and ready to eat foodstuffs and other merchandise along roadsides is characteristic of the city. The city also has one main market serving the population of over 200 000 people, three quarters of which fall within the youthful age group. The characteristics of Kumba typifies many cities in developing countries hence its selection as a study area.

Several studies including those of Hopke et al. (1980), Davis et al. (2001), Nouri and Naghipour (2002), Sternbeck et al. (2002), Walsh (2004) and Raj and Ram (2013) have focused on the concentrations of heavy metals present in roadside soils/dust. Whereas these studies present the risk to which individuals are exposed, they provide little

Fig. 1 Locations of Cameroon (a), Kumba (b) and the sampling points (c)

Fig. 2 Photograph showing private vehicles, taxis and motorbikes along the unpaved Kumba-Market Mbonge Road (Photos by Emmanuel Etonde)

information on what concentrations of these metals are available for assimilation by individuals ingesting these particles. Information on the bioaccessible fraction of heavy metals in roadside soils may shed more light on the potential of incidental ingestion of road side soil as a significant heavy metal exposure route. Therefore the major objectives of this study are to: (1) determine the concentrations and contamination levels of heavy metals in soils along unpaved roads and (2) assess the risk levels of these metals to human health.

MATERIALS AND METHODS

Samples collection and characterisation

Using a plastic hand trowel, roadside soil samples were collected at different locations (Table 1) along a 10 km stretch of the Kumba market-Mbonge highway in Kumba Cameroon (Fig. 1) at depths of between 0 and 10 cm. The distances of the sampling points from the high way ranged between 5 and 10 m. These sampling sites were chosen based

Table 1 Human activities near each soil sampling site

Sampling site	Activity
KA1	Mainly a residential area
KA2	Various commercial activities including motor mechanic workshops, blacksmith workshops, carpentry workshops and bars
KA3	
KA4	
KA5	
KA6	
KA7	Various commercial activities including motor mechanic workshops, blacksmith workshops, carpentry workshops and bars
KA8	Various retail shops, plumbing workshops, kiosks
KA9	Control site (not shown in Map)
KA10	Various small scale private businesses including banks, bookshops, offices
KA11	Brewery depot
KA12	Brewery depot

on the different anthropogenic activities along the road (Table 1). A total of 12 sampling sites were identified in this study. From each site, two samples weighing between 800 and 1000 g were collected. Each sample was air-dried, sieved through a 500- μm sieve, and then their pH, organic matter (OM) content, electrical conductivity (EC) and cation exchange capacity (CEC) were determined using the methods described in van Reeuwijk (2002). The <500 μm fraction of the samples was used for these analyses because finer particles are more easily resuspended and constitute a greater risk to individuals along the road compared to the coarse fractions of soil. Particle size analyses of the soil samples were done with a Malvern Mastersizer 2000 laser particle size analyser fitted with Hydro 2000 G dispersion unit after removal of cementing agents with sodium hexametaphosphate ($\text{Na}_4\text{P}_2\text{O}_7$), 30 % H_2O_2 and 10 % HCl as described in Ngole and Ekosse (2012). Samples were run in duplicate with three runs per replicate. The weight percent (wt%) of sand, silt, and clay was plotted in a textural triangle to determine the texture of the samples.

Determination of average daily traffic volume in study area

To estimate the extent to which the Kumba market-Mbonge road is being used and to establish the possible occurrence of high vehicular emissions in the study area, the short-term average daily traffic (ADT) volume at different sections of the road was determined manually. Using a customised traffic volume tally sheet, the number of vehicles and motorbikes crossing specific sampling sites per unit time was recorded in the morning, at noon and in the evening. Traffic volume data was collected for 7.5 h day^{-1} from sites KA1, KA2, KA5, KA7, KA8, KA9 and KA12 representing different activities along the road (Table 1). This was done for 5 days in a week for 3 weeks.

An estimate of the short-term ADT volume was determined by dividing the total number of vehicles counted at each site during these period by the number of days (15) during which counting was done. Details of the procedure are found in Leduc (2008).

Determination of heavy metal concentrations

1 g of each sample was digested with aqua regia (9 ml HNO_3 + 3 ml HCl) in a Perkin Elmer Multiwave 3000 Microwave unit. The temperature of the microwave was raised to 160 $^{\circ}\text{C}$ over 10 min and held for 15 min at a power of 800 W and pressure of 30 bar. The digestion was carried out for 35 min at a rate of 0.5 bar s^{-1} (Lin et al. 2007). After the microwave-assisted digestion, the samples were filtered, transferred into 50 mL volumetric flask and made to volume using distilled deionized water (DDW). The concentrations of Cd, Cr, Co, Cu, Ni, Pb and Zn in each digest were determined using a Perkin Elmer Nexion 300 Q ICP-MS. These metals were selected because they have been reported in vehicular emissions in several studies (Hopke et al. 1980; Jaradat and Momani 1999; Davis et al. 2001; Nouri and Naghipour 2002; Sternbeck et al. 2002; Wang et al. 2003; Walsh 2004; Ugwu et al. 2011; Raj and Ram 2013).

Assessment of soil contamination by heavy metals

The extent of heavy metal contamination of the samples was determined using the contamination factor (CF) (ratio of the concentration of a given metal in soil to the background concentration of the given metal in the specific environment) and pollution load index (PLI). The CF for each metal was calculated as indicated in Eq. 1 (Hakanson 1980).

$$CF = C_m/B_m, \quad (1)$$

where C_m is the measured concentration of heavy metal in the soil and B_m = local background concentration value of a given metal which in this study was taken as the concentration of the respective metals in the control sample. PLI for each site was calculated using Eq. 2 (Seshan et al. 2010). PLI values < 1 indicate no pollution, whereas values > 1 indicate pollution.

$$PLI = \sqrt[n]{CF_{Co} \times CF_{Cd} \times CF_{Cr} \times CF_{Cu} \times CF_{Ni} \times CF_{Pb} \times CF_{Zn}}, \quad (2)$$

where CF contamination factor; n number of elements.

Determination of bioaccessibility of heavy metals

To determine the concentrations of the heavy metals in the soil which were bioaccessible, the physiologically based extraction test (PBET) as described by Li and Zhang (2013) was used. Gastric juice was prepared using 2.5 g pepsin (Pocrine gastric mucosa), 1 g tri-sodium citrate, 1 g DL Malic acid and 840 μ L lactic acid syrup. These were diluted with DDW, acidified to pH 1.5 using concentrated hydrochloric acid and made up to 2 L (Intawongse and Dean 2008; Sialelli et al. 2010; Li and Zhang 2013). The intestinal phase solution comprised 500 mg pancreatin and 175 mg of bile salts per litre of gastric juice solution neutralised to pH 7 with solid sodium hydrogen carbonate (NaHCO_3) (Sialelli et al. 2010 and Li and Zhang 2013). All reagents used were Merck KgaA analysed reagents.

To 0.5 g of each roadside soil sample weighed into 125 mL HDPE bottles, 100 mL of gastric solution was added. Each mixture was allowed to shake for 2 h at a temperature of 37 °C after which, 5 mL was pipetted from each HPDE bottle into 60 mL polypropylene centrifuge tubes and centrifuged for 10 min at 3500 rpm. The supernatant was transferred into 25 mL volumetric flasks and made up to volume using DDW. This solution represented the stomach phase. To the residue in the HDPE bottle, 5 mL of gastric juice was added to restore the original sample:solution ratio. The pH of the mixture was then adjusted to 7 using NaHCO_3 , after which 175 mg of bile salts and 50 mg pancreatin was added into each bottle. The mixture was also allowed to shake for 2 h at 37 °C after which 5 mL of the mixture was also transferred into separate 25 mL flasks and made up to volume with DDW. This represented the intestinal phase. The remaining sample residue was digested with aqua regia and the digest

collected, made up to 100 mL volume with DDW and labelled residual phase. Each sample was extracted in duplicate. The concentrations of Cd, Co, Cr, Cu, Ni, Pb and Zn in the extracts were determined using a Perkin Elmer Nexion 300 Q ICP-MS. The ratio of the bioaccessible fraction of the metal to its total concentration was taken as the fraction of the metal that an individual is exposed to and used to determine the health risk. Percent bioaccessibility of each metal was determined as in Eq. 3 (Bruce et al. 2007).

%Bioaccessibility

$$\frac{\text{Conc of metal in stomach phase} + \text{intestinal phase}}{\text{Conc of metal in stomach} + \text{intestinal} + \text{residual phase}} \times 100. \quad (3)$$

Determination of health risks

The risk presented to both children and adults by continuous exposure to soils on the roadside was determined as detailed in Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A) (USEPA 2010; Qu et al. 2012). Whereas Eq. 4 was used to determine risk from incidental ingestion, Eq. 5 was used for the determination of risk resulting from dermal contact with the soils. Dermal intake was determined separately for exposed body parts including, head, hands, arms legs and feet for both adult and children, and the values summed up to represent the total dermal intake for an individual. The health risk posed by exposure of individuals to heavy metals in road side soil was determined by calculating the hazard quotients (HQ) using Eq. 6 (Qu et al. 2012). According to Qu et al. (2012), HQ values < 1 are assumed to be safe, whereas HQ values > 1 present potential health risks associated with over exposure. HQ values were then used to determine chronic hazard index (CHI) according to Qu et al. (2012) and Ogunkunle et al. (2013) (Eq. 7). The various risk assessment parameters used in Eqs. 4, 5, 6 and 7 are presented in Table 2. These values were then compared with documented reference dose (RfD) for each heavy metal analysed as detailed in Agency for Toxic Substances and Disease Registry Toxic Substances Profiles (ATSDR 2015).

$$\text{Oral intake (mg/kg/day)} = \frac{C \times IR \times CF \times FI \times EF \times ED}{BW \times AT}, \quad (4)$$

$$\begin{aligned} \text{Dermal intake (mg/kg/day)} \\ = \frac{C \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}, \end{aligned} \quad (5)$$

Table 2 Health risk parameters and values used

Parameters	Unit	Definition	Values used	
			Children	Adults
C	mg kg ⁻¹	Site-specific heavy metal concentration		
IR	mg k ⁻¹	Ingestion rate	200	100
EF	Days year ⁻¹	Exposure frequency	350	350
ED	Years	Exposure duration	6	30
BW	kg	Body weight	15	70
CF	kg mg ⁻¹	Correction factor	10 ⁻⁶	10 ⁻⁶
FI	–	The fraction of soil or dust contacted that is presumed to be contaminated	Ratio of bioaccessible fraction of metals to total concentration	Ratio of bioaccessible fraction of metals to total concentration
AT	Days	Average time over which exposure is averaged	ED × 365	ED × 365
SA	cm ²	Skin surface area available for exposure	600 (head) 1060 (arms) 370 (hands) 1950 (legs) 490 (feet)	1250 (head) 2760 (arms) 960 (hands) 6400 (legs) 1300 (feet)
AF	mg cm ² ⁻¹ day ⁻¹	Adherence factor	0.04	0.02
ABS	–	Dermal absorption factor	0.13	0.13

Sources of values: USEPA (1989, 2011), Chen and Liao (2006), Shi et al. (2014)

Fig. 3 Particle size distribution of soil samples

$$\text{Non-Cancer Hazard quotient (HQ)} = \frac{\text{Daily metal intake (mg/kg/day)}}{\text{Chronic reference dose for element (RfD)}}, \quad (6)$$

$$\text{Total chronic hazard index} = \sum_{i=1}^n \text{HQ}. \quad (7)$$

Quality assurance and control

All samples were analysed in duplicate. Two reagent blanks were included in each batch of samples for microwave digestion and determination of bioaccessibility. In The PBET experiment, the sum of the concentrations of

Table 3 Concentrations of heavy metals in each soil sample

Sample	pH	EC ($\mu\text{S cm}^{-1}$)	CEC (cmol kg^{-1} soil)	OM (%)	Metal concentrations (mg kg^{-1})						
					Cr	Cu	Cd	Co	Ni	Pb	Zn
KA1	6.3	13.7	4.0	4.4	183	36	2.2	22.7	5	27	77
KA2	6.6	14.0	13.1	3.5	213	32	2.6	27	11	40	76
KA3	7.1	49.0	14.3	4.3	191	29	2.5	28	11	63	87
KA4	6.8	26.3	7.7	3.2	140	29	2.4	24	28	91	81
KA5	6.7	19.4	5.2	4.4	160	75	2.6	22	7	61	491
KA6	6.6	3.2	9.1	2.0	147	23	2.6	25	8	52	93
KA7	7.3	12.3	9.8	3.0	124	35	3.0	29	10	143	108
KA8	6.7	10.8	12.1	3.1	163	29	2.8	28	11	109	98
KA9	6.8	18.7	4.3	3.4	44	11	2.5	20	5	26	40
KA10	4.9	4.7	17.0	2.0	75	15	2.7	24	10	37	60
KA11	7.3	13.7	5.2	3.3	69	10	2.7	20	4	88	48
KA12	5.8	14.4	11.5	2.0	78	18	3.1	33	13	31	43
Beijing*	–	–	–	–	61.9	29.7	0.2	–	26.7	35.4	92.1
Toronto**	–	–	–	–	197.9	162.2	0.5	–	58.8	182.8	232.8
UAE***	–	–	–	–	–	15.5	0.9	–	13.3	284.9	72.4
Greece**** (dust)	–	–	–	–	193.2	42.79	0.2	–	58.2	359.4	137.8

* Chen et al. (2010)

** Nazzal et al. (2014)

*** Aslam et al. (2013)

**** Christofordis and Stamatis (2009)

metals contained in the stomach, intestinal and residual phases were summed up and compared with those of the single aqua regia extract. Percentage recovery of each metal was determined by comparing the measured concentration with certified values of a Perkin Elmer Pure Plus Multi element standard.

RESULTS AND DISCUSSION

Physicochemical properties of soil samples

The soil particles comprised of medium to fine sand (50–500 μm). Clay-sized particles in all the samples were less than 10 % by volume, whereas silt-sized particles ranged from 6 to 60 % (Fig. 3). Except for samples KA 11 and KA 12 which were acidic, the samples had circum-neutral pH values (Table 3). The electrical conductivity of the soils were all $<4000 \text{ mS cm}^{-1}$ indicating non-saline condition. With a range of 4.0–14.3 cmol kg^{-1} soil, the CEC values were relatively low though the OM content seemed high (Table 3).

The high OM values obtained in these samples when compared with soils generally could have been due to fine particles of plant litter mixed in the soil particles. These plant materials may not be chemically bound to the soil and

therefore might not have contributed to the surface charge density of the particles, hence the low CEC despite the high OM content of the samples.

Short-term average daily traffic along Kumba market-Mbonge road

Values for the short-term traffic volume per day obtained in this study were 583, 1105, 1713, 1230, 915, 229 and 894 for sites KA1, KA2, KA5, KA7, KA8, KA9 and KA12, respectively. The ADT volume obtained for the study site (953 vehicles day^{-1}) is slightly higher than the annual average daily traffic (AADT) volume of the Kumba-Mbonge-Ekondo Titi highway (794 vehicles day^{-1}) which is an extension of the Kumba Market-Mbonge road (MINEPAT 2012). Higher values are justified by the location of the study area which is in the central business district of Kumba and along where the single market serving the city is located. These values could be higher in the dry season (October–February) which also includes the festive season (December) during which there is usually an increase in supply and demand of goods and commodities from the market. Whereas the traffic type at sites KA1, KA2, KA5, KA7 and KA8, comprised sedans and pick-up trucks, sedans and heavy duty trucks (3 axles) dominated

Table 4 Contamination factors and pollution load index of metals in soils along the highway

Sample site	Contamination Factor							PLI
	Cr	Cu	Cd	Co	Ni	Pb	Zn	
KA1	4.2	3.2	0.9	1.1	1.1	1.0	1.9	1.6
KA2	4.9	2.9	1.0	1.3	2.4	1.5	1.9	2.0
KA3	4.4	2.5	1.0	1.4	2.3	2.4	2.2	2.1
KA4	3.2	2.5	1.0	1.2	5.9	3.5	2.0	2.3
KA5	3.7	6.7	1.0	1.1	1.4	2.4	12.2	2.7
KA6	3.4	2.0	1.0	1.2	1.6	2.0	2.3	1.8
KA7	2.8	3.1	1.2	1.4	2.0	5.5	2.7	2.4
KA8	3.7	2.6	1.1	1.4	2.4	4.2	2.4	2.3
KA10	1.7	1.3	1.1	1.2	2.0	1.4	1.5	1.4
KA11	1.6	0.9	1.1	1.0	0.7	3.4	1.2	1.2
KA12	1.8	1.6	1.2	1.6	2.8	1.2	1.1	1.5

CF < 1 = low contamination, 1 < CF < 3 = moderate contamination, 3 < CF < 6 = considerable contamination; CF > 6 = very high contamination

the traffic at sites KA9 and KA12, respectively. The activities of motor bikes were mostly at sites KA2, KA5, KA7, KA8 and KA12 with an average of 5238 bikes per day at site KA5. Considering that Kumba market is the main market serving the whole city of Kumba with a population of 200 000 people, the impact of heavy metal exposure could be significant in the city's economy which is driven by the young people.

Heavy metal concentration in roadside soil

Percent recovery of heavy metals from samples was between 87 and 102 %. A comparison of the sum of the concentrations of the heavy metals in the stomach, intestinal and residual phases with total concentrations from the single aqua regia extraction showed an agreement of between 72 and 107 %. Varied amounts of heavy metals were identified in the samples (Table 3). Zn and Cr had the highest mean values among all metals analysed, whereas Cd and Ni had the lowest (Table 3). Mean values for Cr, Ni and Zn concentrations were within the range of those reported in studies by Christofordis and Stamatis (2009), Chen et al. (2010), Aslam et al. (2013) and Nazzal et al. (2014), whereas values for Cd concentrations were slightly higher (Table 3). The concentrations of Cd were similar along the road with values of Cd concentration in the different sites being close to those of the control site (KA 9).

Cu, Cr, Zn and Pb concentrations in the soils from all sites were higher than values from the control site (KA9), indicating enrichment of the soils with these metals. High concentrations of Co were also observed in samples KA3, KA7, KA8 and KA12. The concentrations of Pb obtained were lower than those reported by Aslam et al. (2013) and

Nazzal et al. (2014), but higher than those of Chen et al. (2010) from other roadside soils as indicated in Table 3. Cu concentrations in this study were also within the range of those reported by Chen et al. (2010) and Aslam et al. (2013) but lower than those reported by Christofordis and Stamatis (2009) and Nazzal et al. (2014) in soils from Beijing China, Dubai, United Arab Emirates, Totonto Canada and Kavala region in Greece (Table 3).

The sites (KA3, KA7, KA4 and KA8) with higher concentrations of most of the metals were those found in areas with motor mechanic and blacksmith workshops as well as the main market where traffic density and ADT volumes were highest. High volumes of traffic and revving of engines along these sections of the road because of the traffic congestion may have resulted in increased vehicular emissions with a consequent heavy metals enrichment of soil samples from these sections of the road. Anthropogenic activities around these areas (Table 1) may also have made significant inputs into the heavy metal concentrations of the soils. Frequent use of the roads by delivery trucks running on diesel could explain the high concentrations of heavy metals in sites KA10, KA11 and KA12. According to Krivosht et al. (2008), diesel fuel and the products of its combustion constitute one of the most common toxins to which inhabitants of both urban and rural areas are exposed. Studies by Wang et al. (2003) have also indicated that consumption of metal contents in diesel fuel contributes to high concentrations of heavy metals in exhaust emission.

Extent of contamination of the roadside soils

CF values < 1 indicated low contamination, 1 < CF value < 3 indicates moderate contamination, 3 < CF value < 6

Table 5 Descriptive statistics of daily oral and dermal intake of heavy metals by adult and children and hazard quotients (HQ)

Heavy metal	Descriptive statistics	Daily intake (mg kg ⁻¹ day ⁻¹)		RfD (mg kg ⁻¹ day ⁻¹)*	Hazard quotient	
		Child	Adult		Child	Adult
Cr	Minimum	1.90E-04	1.10E-04	3E-3	0.06	0.035
	Maximum	7.60E-04	4.90E-04		0.25	0.16
	Mean (<i>n</i> = 12)	5.20E-04	3.10E-04		0.17	0.10
Cu	Minimum	5.00E-05	2.10E-05	4E-2	1.3E-3	5.2E-4
	Maximum	1.90E-04	1.70E-04		4.7E-3	4.2E-3
	Mean (<i>n</i> = 12)	1.10E-04	6.50E-05		2.6E-3	1.6E-3
Cd	Minimum	4.60E-06	4.70E-06	1E-3	4.5E-3	4.8E-3
	Maximum	5.90E-06	6.70E-06		5.9E-3	6.7E-3
	Mean (<i>n</i> = 12)	5.20E-06	5.70E-06		5.2E-3	5.7E-3
Co	Minimum	1.20E-04	5.40E-05		**	**
	Maximum	2.00E-04	8.60E-05		**	**
	Mean (<i>n</i> = 12)	1.60E-04	6.60E-05		**	**
Ni	Minimum	1.50E-05	9.40E-06	2E-2	7.5E-4	4.7E-4
	Maximum	7.10E-05	6.20E-05		3.6E-4	3.1E-3
	Mean (<i>n</i> = 12)	3.10E-05	2.30E-05		1.6E-4	1.2E-3
Pb	Minimum	5.90E-05	6.00E-05	1.4E-4	0.42	0.43
	Maximum	5.10E-04	3.30E-04		3.62	2.38
	Mean (<i>n</i> = 12)	2.30E-04	1.50E-04		1.63	1.06
Zn	Minimum	1.40E-04	9.40E-04	3E-1	4.7E-4	3.1E-4
	Maximum	1.10E-03	1.10E-03		3.8E-3	3.6E-3
	Mean (<i>n</i> = 12)	4.00E-04	2.50E-04		1.3E-3	8.5E-4

* The Agency for Toxic Substance and Disease Registry, USA

** No RfD values have been established for Co yet

implies considerable contamination, whereas CF value > 6 indicates very high contamination (Seshan et al. 2010). Contamination of the roadside soils with Cd and Co was moderate in all sites (Table 4). Except for Pb in site KA11, soil samples from sites KA10, KA11 and KA12 also showed moderate contamination with the heavy metals studied (Table 4). There was considerable contamination of the soils around site KA1–KA6 with Cr, KA4 with Ni, and KA4, KA7, KA8 and KA11 with Pb. High contamination with Cu and Zn was observed at site KA5 (Table 4). Contamination of soils by metals followed the order Cr > Zn > Cu > Pb > Ni > Co > Cd. Values for PLI showed that all the sites were contaminated but the most contaminated were KA2, KA3, KA4, KA5, KA7 and KA8 (Table 5). These sites also had the highest ADT volumes which may implicate vehicular emission as a source of the heavy metals in the soils along these sections of the road.

Bioaccessibility of heavy metals in roadside soil samples

Bioaccessibility was highest in Co with a range of 24–50 % and lowest in Cd with a range of 3–5 %. Mean percentage

bioaccessibility of the metals followed the order Co > Cu > Zn > Cr > Ni > Pb > Cd (Fig. 4) with values of 38.0 ± 2.30 , 22.7 ± 2.82 , 20.3 ± 3.04 , 19.2 ± 0.98 , 14.3 ± 2.05 , 13.9 ± 2.54 , and 3.8 ± 0.10 %, respectively. Whereas bioaccessibility of Cd, Cu, Ni, Pb and Zn was higher in the stomach, Co and Cr had higher bioaccessibility in the intestinal phase. Similar results have been reported by Bruce et al. (2007), Navarro et al. (2008) and Li and Zhang (2013). Higher availability of metals in the stomach can be explained by the acidic conditions which result in dissociation of metal cations from binding substances. Protonation of hydrolytic heavy metals like Zn and Cu under acidic environments could also be responsible (Whitehead et al. 1996; Bruce et al. 2007). Neutralisation in the stomach caused by pancreatic juices reduces bioaccessibility of metals. Hydrolytic metals like Cu and Zn would lose a proton to form hydroxyl-metal species which polymerise, liberating further protons (Whitehead et al. 1996). Low molecular weight ligands like malate and citrate in the intestines also form chelates with these metals, binding them with a resultant decrease in their bioaccessibility (Whitehead et al. 1996).

Fig. 4 Percentage of bioaccessible metal fraction relative to total metal

Fig. 5 Total chronic hazard index of the different sites for children and adults

Health risk associated with incidental ingestion of the soil samples

Mean values for both dermal and oral intake of heavy metals indicated that dermal intake was higher than oral intake for Cd, Co, Ni, Pb and Zn in adults, whereas for children, oral intake was higher for Cr, Co, Pb and Zn. Heavy metal intake was generally higher in children than in adults except for Cd (Table 5). Values for hazard quotients followed the order Pb > Cr > Cd > Zn > Cu > Ni (Table 5). Mean HQ values for Cu, Cr, Pb and Zn in children were higher than those for adults, whereas those for Cd and Ni were higher in adults (Table 5). Except for Cr, Cd and Pb, the HQ values for all the elements were lower than the RfD values (Table 5) indicating that the chronic daily intake for these metals exceeds the safe dose.

Chronic hazard index (CHI) values for sites KA3, KA4, KA5, KA6, KA7, KA8 and KA11 were all between 1 and 10 indicating that these sites presented moderate oral heavy metal exposure hazards to residents and frequent users at these sites (Lemly, 1996). The exposure hazard was greater for children than for adults at all except sites KA10 and KA12 (Fig. 5). Considering that this is a hidden contribution of heavy metals to individuals because it is incidentally ingested, it may in the long-term contribute towards bioaccumulation of heavy metals in residents who ingest these particles over a long period of time.

Implication of heavy metal exposure on the health of residents in the study area

The health risks posed by these heavy metals are determined by the intensity, duration and pathways of exposure, how readily the soil particles are physically or chemically cleared from the system, and how they are absorbed, distributed, metabolised, and eliminated (Plumlee and Ziegler

2007). Heavy metals are absorbed directly by dermal tissues but oral intake of heavy metals may be slightly lower than revealed by bioaccessible studies because not the entire bioaccessible fraction of the heavy metal ingested is absorbed in the gastrointestinal tract (GIT). The kinds of food and microorganisms present in the GIT may reduce absorption through chelation processes (Whitehead et al. 1996; Monachese et al. 2012). GIT microflora like *Lactobacillus* and *Bifidobacterium* are known to bind Cd, Pb and other metals in solution (Monachese et al. 2012). Ligands of high molecular weight compounds like proteins and albumins contained in human diets also bind heavy metals in the GIT, reducing their absorption (Whitehead et al. 1996). Chromium for example is poorly absorbed in the stomach because of amino acid binding (Nelson et al. 1973).

Despite these natural absorption inhibitors, there are indications that incidental ingestion of soil particles from along highways with high vehicular emissions over a long time may result in bioaccumulation of these heavy metals. The extent of contamination of the soils from unpaved roadsides in this study as well as the HQ and CHI values indicate that frequent users of these roads may suffer from Pb-related health complications in the long term. Whether inhaled or ingested, Pb targets the nervous system. Cobalt could be beneficial or harmful depending on its concentration. It has been documented as a carcinogen (ATSDR 2015). Fragile bones and kidney diseases have been associated with prolonged exposure of low levels of Cd. Chromium toxicity depends on the species present.

The young people who make up more than half of the population of Kumba Town are the main drivers of the economy of the city. Taxis which constitute more than 70 % of the vehicular traffic in the city are driven mostly by these young people. There are more than 15 000 motor bikes serving as taxis in the city, which are also ridden by

young people. These young people are consequently exposed daily to the heavy metals contaminated soil particles. A compromise on their health as a result of heavy metal exposure will negatively affect the economy of the city and the quality of life in the South West Region of the nation. Considering that the amount of heavy metals ingested with roadside dust is not factored into daily intake from food ingested, long-term exposure of residents of Kumba to soil from roadsides may result in health complications associated with high intake of heavy metals.

CONCLUSION

Soil particles along unpaved roads are enriched with heavy metals derived from vehicular emissions. The extent of contamination of the soils increases with ADT volume and the kinds and density of anthropogenic activities along a roadside, being higher in areas with high ADT volumes than in others. Heavy metal exposure risks along these roads are higher for children than for adults and vary with the specific heavy metal. Pb and Cr were found to present significant risks of overexposure especially at sites along the road with anthropogenic activities like welding and motor mechanic workshops. Considering that this is a hidden source of heavy metal intake by individuals frequenting unpaved roads, there is a potential for health complications due to long-term exposure. The economy of Kumba Town and similar cities in developing countries around the world could be threatened because the health of the young people who make up majority of the population will in the long term be compromised by constant exposure to heavy metals contaminated soil and dust particles. Governments in areas with unpaved roads should consider improving road infrastructure in these area because health threats associated with heavy metal exposure may increase the medical burden of poor communities. In addition, town planning should reconsider locating certain activities in areas with high vehicular emissions as this further increases human health risks.

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AUTHOR BIOGRAPHY

Veronica M. Ngole-Jeme (✉) holds Ph.D. and M.Sc. degrees in Environmental Science and is an Associate Professor at North West University (Mafikeng Campus). Her research interests include behaviour of heavy metals in soils, uptake of heavy metals by plants from soils, soil pollution due to mining and waste disposal activities, and the health risks associated with contaminated soils.
Address: Department of Crop Science, Faculty of Agriculture, Science and Technology, North West University (Mafikeng Campus), Private Bag X2046, Mmabatho 2735, South Africa.
e-mail: vm.ngole@gmail.com