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Health risk assessment of heavy metals in soil samples from an abandoned industrial waste dumpsite in Ibadan, Nigeria

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Abstract This study was carried out to determine the concentrations of heavy metals in the soil samples collected from an abandoned lead acid battery (LAB) industrial waste dumpsite in Ibadan, southwestern Nigeria. This was to assess the potential risks of the heavy metals on human due to exposure among local residents (children and adults) of the area. Forty (40) soil samples were collected over the entire dumpsite at 0–20 cm depth. The elemental concentrations of Pb, Cr, Cd, Zn, Cu, and Ni were measured using an atomic absorption spectrophotometer (AAS) technique. The contamination load was estimated by employing index of geoaccumulation (I_{geo}) and potential human health risks due to multiple exposure pathways (inhalation, dermal absorption, and ingestion) were estimated using the risk-based equations and exposure parameters developed by the United States Environmental Protection Agency (USEPA). The average concentrations (± standard deviation) of Pb, Cr, Cu, Mn, Cd, Ni, and Zn were 3.79 ± 2.16, 8.36 ± 3.90, 7.77 ± 2.70, 7.75 ± 3.10, 4.31 ± 0.82, 3.09 ± 2.29, and 3.07 ± 1.74 μg/g, respectively. The mean values of I_{geo} follow the order of Mn < Cr < Pb = Ni < Zn < Cu < Cd. The dermal contact with the heavy metals appeared to be the major route of exposure to children followed by inhalation and ingestion. Inhalation is the main route of exposure for the adults. The hazard quotients (HQ) of all the heavy metals are lower than 1, implying that the adverse health impact on the children and adult exposed to heavy metals from the dumpsite was relatively moderate. The hazard index (HI) values of Cd were 2.0 and 1.2 for exposed adults and children, respectively. The carcinogen risks for inhalation exposure ranged from 2.3×10^{-6} to 6.4×10^{-6}, which falls within the acceptable limit of 10^{-4} to 10^{-6}. There is concern over the potential health risk of the local residents, most especially the children living in the vicinity of the dumpsite due to the possibility of dispersal of heavy metals to the entire community, leading to long-life exposure and residents' detrimental health.

Keywords Lead acid battery · Industrial waste · Heavy metals · Exposure · Risks · Human health

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Introduction

The industrial sector contributes immensely to the rapid growth and urban development of a nation. Among various industries, lead acid battery (LAB) industry is one of the most capital- and energy-intensive industries. LAB production processes consist of extraction of Pb-containing minerals, purification of used Pb plates, glass fiber, plastic casing, and replacement of electrolyte (corrosive sulfuric acid and water). The LAB products are used mostly in vehicles for lighting and ignition purposes, photovoltaic solar installations, and telecommunication systems for storing energy and as a backup for computer, television, lighting of rural and urban household bulbs, and other electrical appliances where power supplies are often inconsistent (Gottesfeld and Pokhrel 2011). In LAB production activities, huge quantities of wastes either from Pb extraction (primary sources) or recycling processing (secondary sources) are generated. The uncontrolled disposal of LAB industrial wastes in an open space in the peripheries of many cities serve as a source which introduces Pb into various environmental media such as ambient air, duct/soil, and ground and surface water (Ogundiran et al. 2012; Tsering et al. 2013; Cao et al. 2015; Zhang et al. 2016; Cao et al. 2016). Apart from Pb, other potentially toxic metals such as Cu, Cd, Cr, and Ni could also be released in large quantity as part of LAB wastes since they are used frequently as trace additives in the molding and casting processes in LAB production (Onianwa and Fakayode 2000).

The studies of human exposure to heavy metals and the associated health risks have attracted attention of many researchers worldwide because of their potential toxicity (Zheng et al. 2013; Zhu et al. 2013; Olujimi et al. 2014; Cao et al. 2014; Khanna et al. 2015; Osipova et al. 2015; Cao et al. 2015). In most studies, the recognized exposure pathways are dermal absorption of heavy metals in particles that stick to exposed skin, direct ingestion of airborne substrate of the particles, and the inhalation of suspended particles through the mouth and nose (Du et al. 2013; Zheng et al. 2013; Li et al. 2013; Olujimi et al. 2014; Zheng et al. 2015; Ihedioha et al. 2017; Gu and Gao 2018). The toxicological and epidemiological studies had indicated that heavy metals have no beneficial physiological functions but rather potential and deleterious health implications in the human body (Olujimi et al. 2014; Osipova et al. 2015; Cao et al. 2016). The adverse health effects are not reversible once they occurred in the human body and their implications vary from subclinical symptoms to death (Wasserman et al. 2008). The health risk assessment of soil of the LAB (Exide brand) industrial dumpsite was premised on the fact that the industrial wastes were initially dumped haphazardly in open space in Lalupon village located along Iwo-Ibadan road in Ibadan, Nigeria. Currently, the factory is no longer in operation and the dumpsite abandoned. However, the urban development is very rapid in the area such that residential houses and primary schools are built very close to the dumpsite. This poses a great health risk to the residents around the area.

Several studies had been conducted on the level of heavy metals in some environmental matrices of the study area (Ogundiran and Osibanjo 2009; Adegoke et al. 2009; Ogundiran et al. 2012; Afolayan and Hassan 2017). These studies ascertained the pollution conditions of the dumpsite. To date, no studies had been carried out on the assessment of the possible human health risks linked with the contamination due to heavy metals in the soil from the study area. Therefore, assessing the aggregated risks through multiple exposures to various heavy metals in the area would be of great relevance for providing basis for human health protection. In the present study, the main objectives were to determine the concentrations of Pb, Zn, Cu, Ni, Mn, Cr, and Cd, and estimate the level of contamination and multiple exposure and the associated health risks of the local residents in the soil samples from the abandoned LAB dumpsite in Ibadan, southwestern Nigeria.

Materials and methods

The study area, sampling, preparation, and chemical analysis

The study was conducted in Ibadan, the state capital of Oyo State, Nigeria. Ibadan, as a typical metropolitan city, has 11 local governments with five in urban and six semi-urban areas of the city. The study area is located at Lalupon in Lagelu Local Government area along Ibadan-Iwo road. It has geographic grid reference of 7° 24′ 28.1″ N and 4° 00′ 52.2″ E and 174 m above the sea level. Climatically, it experiences mainly tropical climate with an estimated average annual rainfall of about 1250 mm, mean temperature range of 21.42–26.46 °C, and the relative humidity about 74.55% (Ogundiran and Osinbanjo 2009). The study site was a large and bare expanse of land characterized with scanty vegetation. The satellite map of the study location is presented in Fig. 1. Forty (40) topsoil samples were collected over the entire dumpsite using Dutch hand soil auger at 0–20 cm depth. For each sample, four subsamples were taken within an area of 1 m^2, then mixed thoroughly to achieve homogeneity before a representative sample was obtained. The soil samples were kept in the polythene bags, properly labeled and transported to the laboratory for further preparation. Before chemical analysis, the soil samples were air-dried at room temperature for 2 weeks. Small stone, sand, gravel, and plant fragments were removed from the samples, then grounded with agate pestle and mortar. The grounded samples were sieved through nylon mesh to restrain the analysis to fine samples. The fine soil samples were then stored in a ziplock sample bags prior to analysis. Two grams (2.0 g) of each soil sample was accurately weighed into a 50-ml Pyrex volumetric flask. A concentrated H_2SO_4 (2 ml) was added to the sample and covered with watch glass before transferring the whole content into the digestion vessel, maintained at 450 °C for 6 h, until the solution becomes clear. The resulting digest was allowed to cool and diluted with distill water to appropriate concentrations (50 ml) and filtered using Whatman Grade 41 filter paper for instrumental analysis. The concentrations of Ni, Zn, Cr, Cu, Mn, Cd, and Pb were determined using flame atomic absorption spectrophotometer (Bulk Scientific 210VGP USA and Perkin Elmer A Analyst 200 model). All chemical reagents used in this study were of analytical grade. The instrument detection limits for measured metals ranged from 1.2 to 49.8 μg/g. The analysis was carried out in triplicate and the average concentration values were recorded.

Contamination assessment method

The index of geoaccumulation (I_{geo}) was originally proposed by Muller (1979). The I_{geo} is a quantitative index which is widely used to verify the magnitude of the contamination of an individual element in various environmental samples such as soil, sediment, and water (Olujimi et al. 2014). It is based on the ratio of the measured concentration, C_m, of the element in a given sample with the geochemical background concentrations B_m of the element m in the sample. The I_{geo} was calculated using the logarithmic function:

$$I_{geo} = \log_2 \left[\frac{C_m}{1.5 \times B_m} \right] \tag{1}$$

In the present study, Taylor and McLennan's (1985) continental crustal average data was used as the background concentrations. The concentrations of the measured heavy metals were used as C_m. The factor 1.5 was introduced to minimize the effect of possible variations in the background values, B_m, which may be attributed to the lithogenic variations in the soil (Gupta et al. 2014; Olujimi et al. 2014). The I_{geo} values of < 0, 0–1, 1–2, 2–3, 3–4, 4–5, and > 5 indicate practically unpolluted, unpolluted to moderately polluted, moderately polluted, moderately to strongly polluted, strongly polluted, strongly to extremely polluted, and extremely polluted, respectively (Muller 1979).

Health risk assessment via dermal, ingestion, and inhalation routes

The human health risk assessment involves estimation of the probability of occurrence of an event and likely magnitude of the adverse health effects as a result of exposure to harmful substances over a specified period of time (Wongsasuluk et al. 2014; Boateng et al. 2015; Osipova et al. 2015). It is an effective scientific tool which forms basis for making decision on environmental hazard in any particular location or activity. The numerous exposure (dermal, ingestion, and inhalation) pathways necessitate modification in most traditional risk assessment approaches (e.g., enrichment factor analysis, contamination factor, pollution index factor) that are based on relative ratio of the determined concentrations of various elements in the sample to a background values (Sun et al. 2010; Chen et al. 2008; Gu et al. 2016). In the present study, the potential human health risk assessment equations (models) and exposure parameters developed by the United States Environmental Protection Agency (USEPA) and previously employed by Du et al. (2013), Li et al. (2013), Wongsasuluk et al. (2014), Cao et al. (2014), Olujimi et al. (2014), Cao et al. (2015), Boateng et al. (2015), Cao et al. (2016), and other authors were used. Generally, the USEPA risk assessment equations assumed that human beings are exposed to heavy metals via oral ingestion, dermal contact and inhalation, and similar parameters for the exposed population. The individual daily doses from each exposure pathway and heavy metals were also cumulative in nature and the total risk was determined for each heavy metal by the addition of individual risk estimated from each exposure pathways (USEPA 1989; Olujimi et al. 2014; Wei et al. 2015). The health risk assessment was conducted by substituting the respective exposure parameters and the average concentrations of the measured heavy metal into the United States Environmental Protection Agency' risk equations. The average daily doses (ADD) received through dermal, ingestion, and inhalation were calculated using Eqs. (2–4) (USEPA 2011a):

Fig. 1 Maps of Nigeria and Oyo State indicating the study location

$$D_{\mathrm{ing}} = C \times \frac{I_{\mathrm{ingR}} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \tag{2}$$

$$D_{\mathrm{inh}} = C \times \frac{I_{\mathrm{inhR}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}} \tag{3}$$

$$D_{\mathrm{der}} = C \times \frac{\mathrm{SL} \times \mathrm{SA} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \tag{4}$$

where $\mathrm{ADD_{ing}}$, $\mathrm{ADD_{inh}}$, and $\mathrm{ADD_{der}}$ (μg/kg/day) are average daily exposure dose through ingestion, inhalation, and dermal absorption, respectively. The exposure parameters for estimating the average daily exposure dose for adults and children are defined in Table 1.

Non-carcinogen risk estimation

The non-carcinogenic hazard quotient (HQ) for each heavy metal for the three exposure pathways was calculated by dividing the average daily dose (ADD) of each heavy metal by its specific reference dose ($\mathrm{Rf_0D}$) using Eq. 5:

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{Rf}_o\mathrm{D}} \tag{5}$$

The reference dose ($\mathrm{Rf}_o\mathrm{D}$) is the maximum permissible risk on the affected population through daily exposure (Du et al. 2013) and can be used to specify the possibility of adverse health effects. The $\mathrm{Rf}_o\mathrm{D}$ (μg/g/day) values for the heavy metals under consideration were obtained from USEPA (2011b) and Wongsasuluk et al. (2014). If ADD < $\mathrm{Rf}_o\mathrm{D}$, this implies absence of adverse health effect. However, if the ADD > Rf*o*D, it is likely that the exposure pathway will cause negative human health effect. The HQ value of 1 signifies

Table 1 Exposure parameters for average dose estimation

Parameters	Definition	Units	Adult	Children	References
C	Concentration of heavy metals	μg/g			
I_{ingR}	Ingestion rate	mg/day	100	200	USEPA (2011b)
I_{inhR}	Inhalation rate	m^3/day	20	5	Cao et al. (2014)
EF	Exposure frequency	Days/year	365	365	Ferrira-Baptista and Miguel (2017)
ED	Exposure duration	Years	24	6	WHO (2015)
CF	Conversion factor	kg/mg	10^{-6}	10^{-6}	Zheng et al. (2015)
AT	Average time	Days	365 * ED	365 * ED	USEPA (2001)
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 (2011b)
SL	Skin adherence factor	mg/cm^2	1	1	USEPA (2001)
SA	Skin surface area of contact	cm^2	3300	1800	USEPA (2001)
ABS	Dermal absorption factor		0.001	0.001	Du et al. (2013)

adverse health effects (USEPA 2011b, c). The hazard index (HI), which is the overall potential for non-carcinogenic risk from multiple exposure pathways, was calculated as summation of all the individual hazard quotients (Eq. 6):

$$HI = \sum_{1}^{3} HQ_i \tag{6}$$

HI value less than 1 implies no significant risk of non-carcinogenic effects and greater than 1 means the probability for non-carcinogenic effects to occur in the exposed population. The probability of experiencing long-term health hazard effects increases as HI value increases (Wang 2012). Based on the multiple carcinogenic contaminants, the lifetime average daily dose (LADD) in the assessment of cancer risk was calculated as the sum (assuming additive effects) of carcinogen (Cr, Cd, and Ni) through the inhalation exposure route using Eq. 7 (Ma and Singhirunnusorn 2012; Ferrira-Baptista and Miguel 2017). The USEPA grouped the chance of carcinogenic risks as $< 10^{-6}$, 10^{-4}–10^{-6}, and $> 10^{-6}$ to be negligible, acceptable, and sufficiently large, requiring remediation (Gu and Gao 2018).

$$LADD = \frac{C \times EF}{AT}\left[\left(\frac{I_{inh} \times ED}{BW}\right)_{children} + \left(\frac{I_{inh} \times ED}{BW}\right)_{adult}\right] \tag{7}$$

Results and discussion

Heavy metal concentration results (μg/g)

The descriptive statistics of the concentrations of Pb, Cr, Cu, Mn, Cd, Ni, and Zn in soil samples from LAB industrial dumpsite is presented in Table 2. The distribution pattern of the average concentrations of the heavy metals studied is Cr > Cu > Mn > Cd > Pb > Ni > Zn. Chromium, copper, and manganese exhibited high values of 21.5, 26.0, and 22.8 μg/g. The high concentrations of Cr, Cu, and Mn could be linked to the wastes from LAB production activities since the dumpsite is solely meant for LAB industrial waste and there are no major industrial activities around the study area. Thus, the study location might be polluted with Cr, Cu, and Mn based on their levels in the industrial wastes. The result was in accordance with some previous studies, which reported a pollution condition of the soil of the study dumpsite by Cr and Cu due to waste from LAB production activities (Adegoke et al. 2009; Ogundiran et al. 2012). The low concentrations of Pb can be ascribed to the fact that Pb is a major element being extracted during recycling of spoilt battery and it is utilized in the LAB production; hence, the content in the industrial wastes might be very low. Also, solid waste product (slag) discarded alongside with the other waste during smelting/refining might be the sources of Pb. In this study, the average concentration of Pb is found to be much lower than the values reported earlier by Ogundiran et al. (2012), but it is in agreement with

Table 2 Descriptive statistic of the heavy metal concentration results

Metals	Pb	Cr	Cu	Mn	Cd	Ni	Zn
Mean	3.79 ± 2.16	8.36 ± 3.90	7.77 ± 2.70	7.75 ± 3.10	4.31 ± 0.82	3.09 ± 2.29	3.07 ± 1.74
Range	0.70–8.30	2.16–21.49	0.90–26.00	2.07–22.80	3.40–7.00	0.87–12.23	0.17–7.05

the results of Afolayan and Hassan (2017). The concentration of Cd ranged between 3.40 and 7.00 μg/g which is similar to the range value (2.24–11.70 μg/g) obtained by Ogundiran and Osibanjo (2009). The different concentration of the measured heavy metals could be traced to their presence as impurities or alloy in Pb used during secondary lead smelting processing. Among the heavy metals, Cd, Pb, and Cr had been highlighted to be potentially detrimental to human health and pose serious environmental concern, even at low concentration as obtained in this study.

Index of geoaccumulation results

The results of I_{geo} of heavy metals in the LAB dumpsite soil are displayed in Fig. 2. The mean values of I_{geo} follow the order of Cd > Cu > Zn > Ni = Pb > Cr > Mn. The I_{geo} values of Cd range from 2.0 to 3.1 with the mean of 2.4 signifying moderately to strongly polluted classification. The mean and maximum I_{geo} values of Cr and Mn were less than zero (< 0) and one (< 1), signifying practically unpolluted and unpolluted to moderately polluted classifications (Muller 1979). Copper and nickel had the maximum I_{geo} values of 2.6 meaning moderately to strongly polluted while maximum I_{geo} of Pb was 1.7 interpreted as moderately polluted. On the basis of I_{geo}, the overall characteristic of heavy metals in the present work showed varying degree of I_{geo} classifications which can be traced to the wastes from replacement of electrolyte, battery assembly, oxide and grid processing, and secondary recycling during the LAB production activities. The increased accumulation and enrichment of the heavy metal concentration in the soil of the dumpsite might also occur from parent material and geogenic sources.

Health risk assessment results

The results of the non-carcinogenetic effects via inhalation, ingestion, and dermal exposure pathways of LAB dumpsite soil on children and adult are presented in Table 3. The dermal contact appeared to be the major route of exposure to children. This is followed by inhalation and ingestion. Most children engaged in outdoor play both in the school and at home and crawling activities, which promote exposure to heavy metals through dermal contact while ingestion exposure might be from frequent hand-to-mouth

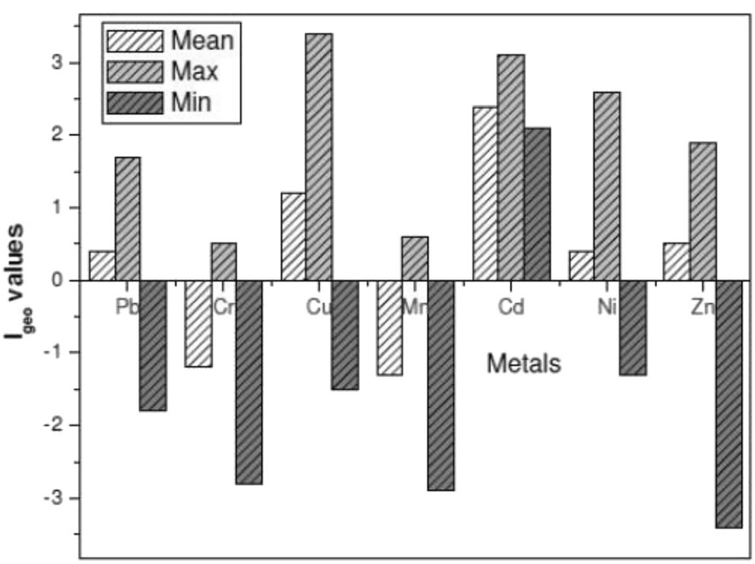

Fig. 2 *I*geo values of the measured heavy metals

Table 3 Results of exposure assessment via inhalation, ingestion, and dermal

Metals		ADD_{ing}		ADD_{inh}		ADD_{der}	
		Children	Adult	Children	Adult	Children	Adult
Pb	Mean	3.04E−05	3.04E−05	9.56E−04	8.35E−02	4.55E−03	6.41E−03
	Max	6.64E−05	6.64E−05	2.09E−03	1.83E−01	9.96E−03	1.40E−02
	Min	5.60E−06	5.60E−06	1.76E−04	1.54E−02	8.40E−04	1.18E−03
Cr	Mean	6.69E−05	1.25E−03	2.11E−03	1.84E−01	1.00E−02	1.41E−02
	Max	1.72E−04	3.22E−03	5.42E−03	4.73E−01	2.58E−02	3.63E−02
	Min	1.73E−05	3.24E−04	5.45E−04	4.75E−02	2.59E−03	3.65E−03
Cu	Mean	6.22E−05	1.17E−03	1.96E−03	1.71E−01	9.33E−03	1.31E−02
	Max	2.08E−04	3.90E−03	6.55E−03	5.72E−01	3.12E−02	4.39E−02
	Min	7.20E−06	1.35E−04	2.27E−04	1.98E−02	1.08E−03	1.52E−03
Mn	Mean	6.20E−05	1.16E−03	1.95E−03	1.71E−01	9.30E−03	1.31E−02
	Max	1.82E−04	3.42E−03	5.75E−03	5.02E−01	2.74E−02	3.85E−02
	Min	1.66E−05	3.11E−04	5.22E−04	4.55E−02	2.48E−03	3.50E−03
Cd	Mean	3.45E−05	6.47E−04	1.09E−03	9.48E−02	5.17E−03	7.28E−03
	Max	5.60E−05	1.05E−03	1.76E−03	1.54E−01	8.40E−03	1.18E−02
	Min	2.72E−05	5.10E−04	8.57E−04	7.48E−02	4.08E−03	5.75E−03
Ni	Mean	2.47E−05	4.63E−04	7.77E−04	6.79E−02	3.70E−03	5.21E−03
	Max	9.78E−05	1.83E−03	3.08E−03	2.69E−01	1.47E−02	2.07E−02
	Min	6.96E−06	1.31E−04	2.19E−04	1.91E−02	1.04E−03	1.47E−03
Zn	Mean	2.45E−05	4.60E−04	7.73E−04	6.75E−02	3.68E−03	5.18E−03
	Max	5.64E−05	1.06E−03	1.78E−03	1.55E−01	8.46E−03	1.19E−02
	Min	1.36E−06	2.55E−05	4.28E−05	3.74E−03	2.04E−04	2.87E−04

activity. Moreover, the average height of most children in the nearby resident and schools is around 70–80 cm above the ground; this increases the possibility of exposure through inhalation route most especially in the dry season. The exposure through inhalation of the re-suspended soil by nose and mouth ranged from 10^{-3} to 10^{-5} lower than the other two exposure pathways. For adults, inhalation appeared to be the main route of exposure. On the average per day, the volume of air breathe in by an adult is 20 m^3/day (0.014 m^3/min) that would increase with vigorous activities (Ogundele et al. 2017). A large amount of the breath-in air might contain heavy metals emitted from the dumpsite and enter the human body through inhalation route. Adults could also be exposed to heavy metals simply through negligence of hand washing before eating after daily activities (Olujimi et al. 2014).

The results of the hazard quotient of the measured heavy metals for the children and adult are presented in Table 4. Cadmium and lead were the major elements which have comparatively HQ values very close to 1 for the children and adult in the three exposure pathways. The HQs of all the heavy metals are lower than 1, except Cd and Pb. This implies the possibility of adverse health effects due to Pb and Cd on the children and adults. The HI values of the measured heavy metals are presented in Fig. 3. Regarding non-cancer effects, Cd exhibits HI values of 2.0 and 1.2 for exposed adults and children, respectively. These values were greater than the safe limit of 1 and it indicates that Cd has a huge potential risk on the health of the local residents. Similar study by Wang et al. (2014) found Cd as the most potent health risks among the measured heavy metals. The HI values of Pb were 1.1 and 0.8 (≈ 1) for children and adult. The HI values of Zn, Cr, Mn, Cu, and Ni were far below one. Depending on the level of exposure, Pb and Cd had been reported as potent toxins that are responsible for

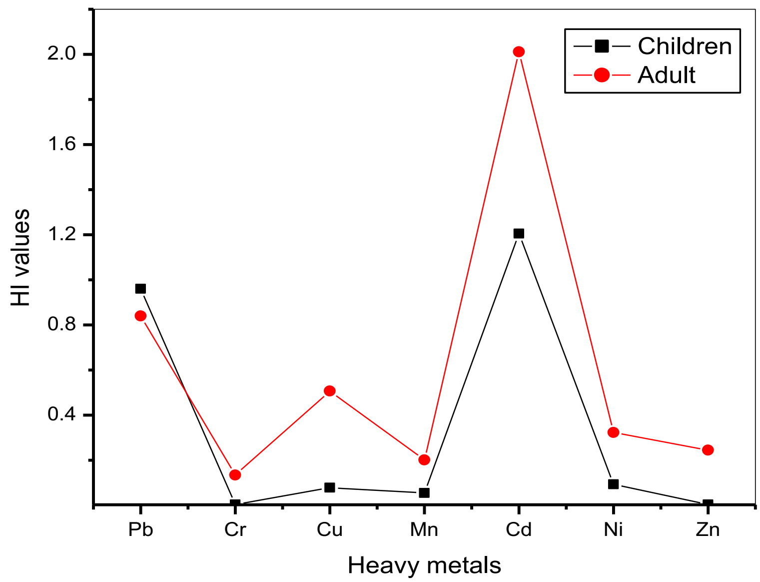

Fig. 3 HI values for the measured heavy metals

serious health risk if contacted by children and adults. In children, neurological dysfunction, impairment of cognitive function, cellular DNA damage, and brain retardation can be triggered (Tsering et al. 2013; Gu et al. 2016). The children with no fully developed organs and body system might also suffer disruption in growth and development (Li et al. 2013). The detoxification abilities of children are very low especially under 7 years of age and under continued exposure; Pb and Cd accumulate in the body tissue of the children leading to more severe effects. The probable health risks that could be experienced by the adults are liver damage, miscarriage in pregnant women, intestinal irritation, blood diseases, kidney failure, respiratory disorder, weakness of the joints, declined fertility in men, behavioral disruption, and drastic reduction in life expectancy (Zheng et al. 2013; Khanna et al. 2015; Osipova et al. 2015). Adults with existing health challenges that are related to heavy metal might experience worst situation. Only carcinogen risks for inhalation exposure was considered for both adults and the children. The level of cancer risks associated with exposure to the studied heavy metals ranged from 2.3×10^{-6} to 6.4×10^{-6}, which falls within the global threshold limit of 10^{-4} to 10^{-6} that had been judged to be acceptable by environmental and regulatory agencies (USEPA 2011b; IARC 2011). This shows that the carcinogenic risk due to inhalation exposure pathway of heavy metals in the soil of the LAB

Table 4 Non-carcinogenic risk assessment results

Metals	HQ_{ing}		HQ_{inh}		HQ_{der}	
	Children	Adults	Children	Adults	Children	Adults
Pb	6.83E−01	5.29E+00	2.17E−01	2.45E+00	6.00E−02	4.66E−01
Cr	1.41E−03	1.23E−01	4.46E−05	8.36E−04	1.73E−0E	9.76E−03
Cu	4.90E−02	4.28E+00	1.55E−03	2.92E−02	2.70E−02	3.49E−01
Mn	2.35E−02	2.05E+00	7.47E−04	1.40E−02	2.99E−02	1.66E−01
Cd	1.09E+00	9.48E−01	3.45E−02	6.47E−01	8.00E−02	4.15E−01
Ni	3.89E−02	3.39E+00	1.23E−03	2.31E−02	5.22E−02	2.86E−01
Zn	2.58E−03	2.25E−01	8.18E−05	1.53E−03	6.80E−04	1.75E−02
HI	1.88E+00	1.63E+01	2.55E−01	3.16E+00	2.52E−01	1.71E+00

dumpsite soil was acceptable. The results of this study suggest the occurrence of multiple exposure pathways to the residents around the LAB waste dumpsite. The risk equations were based on the conservative assumptions and the exact human health impact is advocated among the local residents, most especially the children due to developmental stages and long-life multiple exposures.

Conclusions

The concentrations of Pb, Cr, Cd, Zn, Cu, and Ni in the soil samples from abandoned LAB industrial waste dumpsite had been determined. The sequential order of the average concentrations of the measured heavy metals is Cr > Cu > Mn > Cd > Pb > Ni > Zn. The dumpsite was classified moderately polluted with respect to Cd and Cu. The major route of exposure to heavy metals by the children is through dermal contact, followed by ingestion while inhalation is the main exposure route for adults followed by ingestion. The estimated hazard quotients of all the heavy metals are less than 1. Cadmium is a major contributor to non-cancer effects in children and adults in the soil of the dumpsite. For all the measured heavy metals, the carcinogen risks varied from 2.3×10^{-6} to 6.4×10^{-6} which falls within the acceptable limit of 10^{-4} to 10^{-6} for inhalation exposure. There is a concern for health issues among the local residents around the dumpsite.

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