International Journal of Environmental Science and Technology (2020) 17:2385–2400
https://doi.org/10.1007/s13762-020-02637-9

ORIGINAL PAPER

Potential environmental and human health risk of soil and roadside dust in a rapidly growing urban settlement

C. N. Mama[1] · C. C. Nnaji[1,2] · P. C. Emenike[3] · C. V. Chibueze[1]

Received: 6 October 2019 / Revised: 17 December 2019 / Accepted: 16 January 2020 / Published online: 25 January 2020

Abstract

The rate of urbanisation in Nsukka, Nigeria, is a trending phenomenon that is characterised by an overwhelming influence on the environment. Twenty-one dust and soil samples were collected from points strategically located on major roadsides in Nsukka and analysed for hazardous trace elements. The ecological and potential human health risks of the samples were estimated, and the pollution source was deduced with hierarchical cluster analysis. The relative abundance of the trace elements followed the order of Fe > As > Ni > Cr > Pb > Zn > Mn > Cu > Cd in roadside dust and Fe > As > Pb > Ni > Zn > Cr > Mn > Cu > Cd in roadside soil. Results obtained highlighted the impact of anthropogenic activities on soil and dust, as the multi-element contamination indices for the different groups of samples were below unity. The health risk assessment revealed that Cr was 120 times more likely to cause health problems than Pb and 450 times more than Ni. The agglomerated cancer risk (CR) for all exposure pathways estimated for children was about 1.2 times higher than that of adults, and the CR value for roadside dust was slightly higher than that of soil. All values of CR obtained were within the acceptable range of 10^{-6} and 10^{-4}. Nevertheless, it is noteworthy to state that a significant health risk is bound to occur if adequate measures are not taken to curb the current rate of metal accumulation in the soil.

Keywords Cancer risk · Exposure pathways · Heavy metals · Ingestion · Pollution

List of symbols

ADI_{dermal}	Average daily intake of heavy metals by dermal contact
ADI_i	Average daily intake of *i*th heavy metal
ADI_{inh}	Average intake of heavy metals though inhalation
ADI_{ing}	Average intake of heavy metals though direct oral ingestion
C_b^i	Background concentration of *i*th heavy metal in the soil
C^i	Concentration of *i*th heavy metal in the soil
E_r^i	Monomial ecological risk index for *i*th heavy metal
T_r^i	Toxicity factor of *i*th heavy metal

Abbreviations

ABS	Dermal absorption factor
AF	Adherence factor
AT	Average time
BW	Body weight
ED	Exposure duration
EF	Exposure frequency
HI	Hazard index
HQ	Hazard quotient
IngR	Ingestion rate
InhR	Inhalation rate
mCD	Degree of contamination
MEC	Multi-element contamination
NPI	Nemerow pollution index
PEF	Particle emission factor
PI	Pollution index
PLI	Pollution load index

Editorial responsibility: M. Abbaspour.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s13762-020-02637-9) contains supplementary material, which is available to authorized users.

✉ C. C. Nnaji
chidozie.nnaji@unn.edu.ng

[1] Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

[2] Faculty of Engineering and Built Environment, University of Johannesburg, Johannesburg, South Africa

[3] Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria

RfD_i	Reference dose for *i*th heavy metal
RI	Potential ecological risk
SA	Exposed skin surface area
SF	Slope factor

Introduction

The devastating impact of anthropogenic activities has been gaining the global attention of researchers from both governmental and non-governmental organisations. One of the most threatening environmental menace that has taken a central stage in global discussions is the upward trajectory of heavy metal concentrations in the immediate environment of man. Numerous research papers have reported the occurrence of concentrations of heavy metals in soil and water which far exceed stipulated standards. Even though this is a global problem, developing countries are more at risk from exposure to heavy metals especially because of non-enforcement and non-adherence to effluent standards. In a bid to catch up with the rest of the world, developing countries pursuing industrial revolution are prone to environmental dilapidation due to emissions from toxic chemicals derived from industrialisation and urbanisation (Tian et al. 2015; Kobza and Geremek 2017). Specifically, aggressive industrialisation and rapid urbanisation have resulted in a substantial release of heavy metals to the environment (Najmeddin and Keshavarzi 2018; Pateraki et al. 2019; Sun et al. 2019).

Soils in industrialised and urbanised region have been receiving attention in recent times because they can be contaminated with various hazardous substances among which heavy metals play a significant role (Woszczyk et al. 2018). These trace elements can be transferred to the soil through atmospheric deposition of industrial particles emanating from metal smelting, sweltering of fossil fuels and releases from gasoline (Ettler 2015; Alsbou and Al-Khashman 2018; de Carvalho Aguiar et al. 2018). Trace elements are of particular interest to researchers because of their conservative nature, propensity to accumulate in soils and their persistence in the environment (Nazzal et al. 2013). In this regard, various investigators have attributed heavy metals (HM) release into the environment to a “chemical time bomb” caused by environmental changes due to the sudden release of strata-stored elements (Morton-Bermea et al. 2009; Dao et al. 2010).

Environmental concerns have been triggered by the spinoff impacts of urbanisation and industrialisation (Liu et al. 2018). On a global evaluation, 74% of Pb released from anthropogenic sources are derived from gasoline, and 70–73% of Cd, Cu and Zn are from non-ferrous metallurgy. But on a regional perspective, different sources contribute substantial amount of trace elements to the environment. Vehicular emission, industrial waste disposal and municipal waste incineration contribute significant amounts of HM such as Zn, Pb, Cu and Cd to urban soils (Ajmone-Marsan and Biasioli 2010; Martínez and Poleto 2014). Street dust, comprising of particulates emanating from construction materials, vehicular emission, industrial airborne particles deposited over time, soil and soot, has become a major sink for heavy metals (Zhang et al. 2019; Ghanavati et al. 2019). Heavy metals released into the environment also accumulate in the soil, plants, aquatic animals, water sediments and groundwater from which they are transferred to humans by the process of bioaccumulation and biomagnification. Heavy metals released into the environment via anthropogenic activities have specifically been reported to accumulate in tobacco leaves, freshwater fish, rice, tomatoes, leafy vegetables and corn (Wuana and Okieimen 2011; Ali et al. 2019). Street dusts pose particular danger to human beings because these are much more mobile than normal soil particle and other kinds of sinks. In developing countries where massive urban development is a continuous process, thousands of tons of dust particles are generated and dispersed into the environment during road construction, erection of industrial/residential buildings and demolition. These dust particles are distributed in the atmosphere and thus form part of the air that people inhale daily. They are also deposited on human and animal skins, as well as plants which are eventually consumed without much of a precaution. Heavy metals accumulated in urban soils can also be mobilised by a combination of complex chemical processes causing them to be transferred to the food chain and groundwater aquifers, thereby causing environmental hazards to humans and soil biota (Ettler 2015). Humans are exposed to the health hazards resulting from exposure to heavy metals through various routes such as inhalation, ingestion and dermal contact of street dust and urban soils laden with toxic HM.

Urban soils and street dust have attracted the attention of researchers because they constitute the largest sink of heavy metals emanating from diverse forms of anthropogenic activities (Lin et al. 2017). However, in the current investigation, we aimed at investigating the distribution and health risk assessment of nine HM (As, Cr, Cu, Fe, Mn, Ni, Pb, Zn and Cd) in street dust and urban soils of Nsukka. Nsukka is a growing city located in the eastern part of Nigeria characterised by small- and medium-scale food processing industries, metal craft industries, non-ferrous metallurgy, agricultural activities and high vehicular traffic. Local occupants are exposed to toxic emissions originating from direct and indirect anthropogenic sources. With a view to evaluate the variability of trace element origin, composition, as well as their toxicity, investigations related to urban soil, street dust and vehicular traffic are of public interest within the study region. As a result of a shortage of the literature on the subject area, this study investigated the pollution status of roadside soil and dust with the following objectives: (1)

to ascertain the metal variability in urban soils and street dust in regions of high commercial activities within Nsukka; (2) to determine the pollution load indices in relation to the chemical constituents of soil and associated potential health risks via inhalation, ingestion and dermal pathways; and (3) to obtain the ecological risk and spatial variation of hazard indices within the study region. This research was conducted between February and August 2019.

Materials and method

Sample collection

The study area, Nsukka, Nigeria, is a rapidly expanding urban settlement characterised by a proliferation of commercial/industrial settings located along the roadsides. Solid waste is improperly dumped by the roadsides, and the local waste management authority is already overwhelmed by the sheer size of waste generated. Twenty-one strategically and adequately staggered points located by the roadsides were selected for investigation. The coordinates of each location were taken using GPS instrument (Infinix S4; model Infinix X626) while digital camera (model Inepix s2980 fujifilm camera semiprofessional) was used in taking pictures of activities that take place at each location. Dust samples were collected from the surface of the roadside while soil samples were collected at a depth of 0.5 m. Suitable samples that served as control were collected at 400 m away from the influence of the road at three different locations. The samples were immediately transported to the National Center for Energy Development, University of Nigeria, Nsukka.

Laboratory analyses

Soil and dust samples were subjected to spectrophotometric analyses using Atomic Absorption Spectrometer model AA-7000 Shimadzu, Japan ROM version 1.01, S/N A30664700709. All glassware used was soaked in 3 M HNO_3 overnight and washed with de-ionised water to reduce the chances of interferences. Three grams each of the samples were weighed into digestion flask, and 30 cm^3 of aqua regia was added and digested in a fume cupboard until clear solution was obtained; it was cooled, filtered and made up to 50 ml in a standard volumetric flask with de-ionised water. A blank sample was prepared to zero the instrument before running other series of samples. Standards (2 ppm, 4 ppm and 6 ppm) were prepared from 1000 ppm stock solution of the metals and used to obtain the calibration curve. Each metal/mineral was analysed using its respective wavelength (Ni—232 nm, Pb—283.3 nm, Fe—248.3 nm, As—193.7 nm, Mn—279.5 nm, Cr—357.9 nm, Cu—324.8, Zn—213.9 nm) after which its concentration was generated from the standard graph by the instrument.

Data analyses

First, the dataset obtained from laboratory analyses of soil and roadside dust samples was subjected to descriptive statistical analyses to determine the mean, minimum and maximum values of the metals as well as the standard deviation, skewness and coefficient of variation. The data were further subjected to analyses to determine the degree of pollution. The single pollution index (PI) was used to ascertain the degree of contamination of soil and dust by individual metal with reference to background concentrations (Eq. 1). The normalised contribution of all the metals was computed using the pollution load index (PLI) as given in Eq. 2. Related to PLI is the modified degree of contamination (mCD) which allows an assessment of the overall heavy metal contamination (Kowalska et al. 2018) as shown in Eq. 3. Cheng et al. categorised mCD as follows: $\text{mCD} \leq 1.5$—unpolluted, $1.5 < \text{mCD} \leq 2$—slightly polluted, $2 < \text{mCD} \leq 4$—moderately polluted, $4 < \text{mCD} \leq 8$—considerably polluted, $8 < \text{mCD} \leq 16$—highly polluted, $16 < \text{mCD} \leq 32$—strongly polluted and $\text{mCD} > 32$—extremely polluted (Cheng et al. 2018). The soil is categorised as highly polluted if $\text{PLI} > 1$ and unpolluted (low pollution) if $\text{PLI} < 1$ (Rabee et al. 2011; Abdelhafez et al. 2015). The multi-element contamination (MEC) factor was computed for all sampling points using Eq. 4. The Nemerow pollution index (NPI) was also calculated using Eq. 5 and applied to the data using the following categorisation: $\text{NPI} \leq 0.7$ (clean or uncontaminated), $0.7 \leq \text{NPI} < 1$ (warning limit), $1 \leq \text{NPI} < 2$ (slightly polluted), $2 \leq \text{NPI} < 3$ (moderately polluted) and $\text{NPI} > 3$ (heavily polluted) (Cheng et al. 2018; Nazarpour et al. 2019). A general risk assessment was performed using the monomial ecological risk factor E_r^i and potential ecological risk (RI) index (Eqs. 6, 7). This was accomplished using the toxicity factor of the various metals, thus As—10, Cd—30, Cr—2, Cu—5, Ni—5, Pb—5 and Zn—1 (Akoto et al. 2018). Ecological risks are categorised as follows: $E_r^i \leq 40$ (low risk), $40 < E_r^i \leq 80$ (moderate risk), $80 < E_r^i \leq 160$ (considerable risk), $160 < E_r^i \leq 320$ (high risk) and $E_r^i > 320$ (very high risk) for monomial ecological risk and $\text{RI} \leq 150$ (low risk), $150 < \text{RI} \leq 300$ (moderate risk), $300 < \text{RI} \leq 600$ (considerable risk) and $\text{RI} > 600$ (very high risk) (Li 2018).

$$\text{PI} = \frac{C^i}{C_b^i} \tag{1}$$

$$\mathrm{PLI} = \sqrt[n]{\prod_{i}^{n} \mathrm{PI}} \quad (2)$$

$$\mathrm{mCD} = \frac{\sum_{i}^{n} C^{i}}{n} \quad (3)$$

$$\mathrm{MEC} = \frac{\sum_{i}^{n} \left(\frac{C^{i}}{T}\right)}{n} \quad (4)$$

$$\mathrm{NPI} = \sqrt{\frac{\mathrm{PI}_{\mathrm{ave}}^{2} + \mathrm{PI}_{\max}^{2}}{2}} \quad (5)$$

$$E_{\mathrm{r}}^{i} = T_{\mathrm{r}}^{i} \times \mathrm{PI} \quad (6)$$

$$\mathrm{RI} = \sum_{i}^{n} E_{\mathrm{r}}^{i} \quad (7)$$

The human health risks associated with heavy metals are triggered when these metals enter the human body through the three major routes of ingestion, inhalation and dermal contact. The potential of a particular contaminant to induce health problems is directly proportional to the quantity that enters the body through the various pathways and the toxicity of the contaminant. The health risk posed individually and collectively by heavy metals was estimated using the hazard quotient (HQ) as given in Eq. 8, while the hazard index (HI) which represents the total non-carcinogenic risk associated with the intake of contaminants by the three aforementioned pathways was calculated with Eqs. 9–12. A number of heavy metals and metalloids such as As, Cr, Cd, Pb and Ni have been linked to various forms of cancers, with As, Cd, Cr and Ni being categorised as group 1 carcinogens (Mulware 2013; Kim et al. 2015; Alahabadi et al. 2017; Mohammadi et al. 2019). Hence, the probability of inducing carcinogenic health conditions in humans was estimated using the cancer risk (CR) measure as given in Eq. 13. Specific values of the different parameter used for calculating the health risk assessment are documented in Table 1 as obtained from the relevant literature.

$$\mathrm{HQ} = \sum \frac{\mathrm{ADI}_{i}}{\mathrm{RfD}_{i}} \quad (8)$$

$$\mathrm{ADI}_{\mathrm{ing}} = \frac{C^{i} \times I_{\mathrm{ng}}R \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \quad (9)$$

$$\mathrm{ADI}_{\mathrm{inh}} = \frac{C^{i} \times I_{\mathrm{nh}}R \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}} \quad (10)$$

$$\mathrm{ADI}_{\mathrm{dermal}} = \frac{C^{i} \times \mathrm{SA} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \quad (11)$$

$$\mathrm{HI} = \sum \mathrm{HQ}_{i} \quad (12)$$

$$\mathrm{CR} = \sum \mathrm{ADI}_{i} \times \mathrm{SF}_{i} \quad (13)$$

Table 1 Factors used to estimate the average daily intake of heavy metals and human health risk indices

ADI parameters[a]			Heavy metal	Reference dose[b] (10^{-3} mg/kg/day)			ABS[c]	Slope factor[a,b,c, d] (SF) (mg/kg/day)		
Parameter	Child	Adult		Oral	Dermal	Inhalation		Ingestion	Dermal	Inhalation
AF (mg/cm^2)	0.2	0.07	As	0.3	0.123	0.301	0.03	1.5	1.5	15.1
BW (kg)	15	70	Cd	1	0.01	0.0024	0.14	–	–	4.1
ED (years)	6	24	Cr	3	0.06	0.0286	0.04	0.5	–	6.3
EF (days/year)	180	350	Ni	20	5.4	20.6	0.35	–	–	0.84
IngR (mg/day)	200	100	Pb	3.5	0.525	3.52	0.006	8.5E–03	8.5E–06	0.042
InhR (mg/day)	7.6	20	Cu	40	12	40.2	0.1			
AT* (days)	2190	8760	Zn	300	60	300	0.02			
AT** (days)	25,550	25,550								
SA (cm^2)	2800	3300								
PEF (m^3/kg)	1.36E–09	1.36E–09								

[a] Johnbull et al. (2019)

[b] Liang et al. (2017)

[c] Jia et al. (2018)

[d] Johnbull et al. (2019), Kamunda et al. (2016) and Liang et al. (2017)

*AT** average time for non-carcinogenic effect, *AT*** average time for carcinogenic effect

Finally, in order to investigate the spatial distribution of heavy metals in soil and roadside dust, an interpolation scheme was used. The inverse distance weighting interpolation function was implemented on all the heavy metals investigated using the SAGA IDW plug-in in Quantum GIS 2.18.11

$$C_n \frac{\sum_i^n \frac{C_i}{\delta_i^n}}{\sum_i^n \frac{1}{\delta_i^n}} \tag{14}$$

Results and discussion

Concentration of heavy metals in roadside dust and soil

The average concentration of metals in roadside dust samples was 3.348, 0.572, 0.082, 97.552, 0.250, 0.593, 0.476, 0.406 and 0.027 mg/kg for As, Cr, Cu, Fe, Mn, Ni, Pb, Zn and Cd while the corresponding values for soil were 3.33, 0.381, 0.075, 108.570, 0.278, 0.547, 0.583, 0.399 and 0.050 mg/kg. The order of abundance of these metals in roadside dust varied slightly from their abundance in roadside dust as follows: Fe > As > Ni > Cr > Pb > Zn > Mn > Cu > Cd for roadside dust and Fe > As > Pb > Ni > Zn > Cr > Mn > Cu > Cd for roadside soil (Table 2). Fe and As were the most abundant while Cu and Cd were the least abundant in both roadside dust and soil samples analysed. Of all the trace metals investigated, As had the highest concentration in both roadside dust and soil. However, these values were similar to those obtained by New Castle (UK), Shiraz (Iran), Baoding City (China), Ahvaz City (Iran), Tehran (Iran) and Kirkuk City of Northern Iraq with arsenic concentration ranges of 4.4–8.6, 5.3–8.6, 13.16–67.26, 0.5–18.3, 5.6–9.87 and 8.29–10.4 mg/kg, respectively (Okorie et al. 2012; Keshavarzi et al. 2015; Al-Jumaily 2016; Xie et al. 2017a; Nazarpour et al. 2019; Taghavi et al. 2019). This can be attributed to metal input from the construction works and other anthropogenic activities like vehicular emission, agriculture, aerosols, burning of tire and burning of heavy duty oils which release particulates that are subsequently deposited on to the surface soil (Al-Jumaily 2016). The percentage increase in metal concentrations from background levels was evaluated in order to ascertain the trend of metals build-up in dust and soil. Results revealed that the highest change in concentration from background level was associated with Cd with 2842% and 1861% increase in roadside dust and soil, respectively, followed by Zn with corresponding values of 47% and 600%, respectively, and then As with 456% and 454%, respectively. Though the concentration of these metals in soil and roadside dust was within tolerable limits, current trend of build-up suggests that these metals will eventually attain unacceptable levels in both soil and dust. The average concentration of As, Cr, Cu, Ni and Zn in roadside dust was higher than those in the soil. This can be attributed to vehicle emissions and the interaction between automobile tyres and the road surface leading to wearing and eventual deposition of particulate metals on the road which then mingles with the dust. However, the concentrations of Fe, Mn, Pb and Cd in the soil were higher than those in roadside dust. The concentration of Cd in the soil was about twice its concentration in roadside dust collected from the same spots. The higher concentration of Fe in the soil can be attributed to the lateritic nature of the soil under investigation, and lateritic soils are known to be very rich in

Table 2 Descriptive statistics of heavy metals in roadside dust and soil

Sample		As	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Cd
Roadside dust	Min	ND	ND	ND	15.162	0.032	0.103	ND	0.147	0.000
	Max	6.548	1.333	0.323	139.140	0.519	3.077	1.250	1.195	0.078
	Mean	3.348	0.572	0.082	97.522	0.250	0.593	0.476	0.406	0.027
	SD	1.986	0.382	0.073	36.154	0.149	0.642	0.387	0.278	0.025
	Skewness	−.217	−.039	1.789	−.870	.226	3.109	.892	1.833	.492
	CV	0.534	0.303	0.741	0.371	0.596	1.082	0.706	0.683	0.698
Soil	Min	.226	ND	ND	62.970	.032	.103	.000	.113	.000
	Max	7.000	1.333	.226	135.350	.551	1.333	1.750	1.212	.106
	Mean	3.333	.381	.075	108.570	.278	.547	.583	.399	.050
	SD	1.794	.451	.068	21.238	.123	.306	.428	.267	.028
	Skewness	.417	.787	.968	−.358	.081	.785	1.139	1.453	−.122
	CV	0.874	2.735	2.840	0.472	1.217	2.764	2.725	2.930	2.938
Background concentration of metals in the soil	0.602	0.019	0.043	62.804	0.076	0.274	0.083	0.237	0.023	

Fe. There was also significant spatial variation of metals in both soil and roadside dust (Fig. 1a, b).

Pollution indices as a measure of soil degradation

The values of pollution index (PI) computed for various metals showed varying degrees of soil and dust pollution by metals (Fig. 2). The highest ranges of PI obtained were 34.32–68.59 (Cr), 3.0–15.0 (Pb), 0.75–10.88 (As) and 0.43–6.85 (Mn) for dust and 34.32–68.59 (Cr), 3.0–21.0 (Pb), 0.375–11.63 (As) and 0.429–7.29 (Mn) for roadside dust. Considering all the samples and pollutants analysed, 71% were greater than 1.0 for roadside dust and 77% were greater than 1.0 for soil samples. Following standard classification of pollution index (Kowalska et al. 2018; Salman et al. 2019), the degree of pollution of roadside dust was partitioned as follows: low contamination (29.3%), moderate contamination (39.9%), considerable contamination (18.2%) and high contamination (12.6%). The corresponding values for soil were 23.2%, 41.9%, 24.8% and 10.1%, respectively. Further analysis showed that both roadside dust and soil were moderately contaminated with Cu, Fe, Ni, Zn and Cd; considerably contaminated with As, Mn and Pb; and highly contaminated with Cr. Though it would appear from the preceding that the soil samples were more polluted than roadside dust, the average pollution index (API) aggregated for all sampling points suggests otherwise. The API for roadside dust was 6.17 (highly polluted) while the API for soil was 5.2 (considerably polluted). Soil samples from different locations displayed wide variations in metal concentration. Table 2 shows that the coefficient of variation for all metal concentrations in the soil was higher than those in roadside dust. This is because the soil restricts the mobility of metals while dust particles allow easy distribution of metals on the ground surface due to the mixing action of wind and man. The values of Nemerow pollution index (NPI) show that all dust and soil samples from all locations were heavily polluted with values ranging from 5.23 to 49.59 and 2.47 to 49.22, respectively. This confirms the adverse impact of anthropogenic activities on the quality of the soil samples. These values of NPI are far above the values reported by Nazarpour et al. (2019) for urban soils of Ahvaz City in southwest Iran. The extreme values of NPI obtained in this study were due to the high concentrations of Cr in both soil and roadside dust. However, there was a drastic drop in NPI average values to 6.31 and 6.52 for roadside dust and soil when computed without Cr.

The soil and dust samples were further assessed using the pollution load index (PLI), which is a measure of the degree of soil deterioration due to anthropogenic activities (Kowalska et al. 2018). The average range of PLI obtained for roadside dust was 1.40–4.67 while that obtained for soil was 1.81–5.38. These values indicate an extensive anthropogenic impact on soil and roadside dust. The modified degree of contamination (mCd) was used to provide a broader classification of the degree of environmental pollution by heavy metals. For roadside dust, 20% of the samples was moderately polluted ($2 < mCd < 4$), 65% was considerably polluted ($4 < mCd < 8$) while the remaining 15% was highly polluted ($8 < mCd < 16$). Soil samples exhibited a different distribution with respect to categorisation of the degree of pollution with 5% being slightly polluted ($1.5 < mCd < 2.0$), 45% moderately polluted ($2 < mCd < 4$), 40% considerably polluted ($4 < mCd < 8$) and 10% highly polluted ($8 < mCd < 16$). However, on the average, both soil and roadside dust were considerably polluted by metals with average mCd values of 5.2 and 6.17, respectively. Though mCd provides a broader classification of level of pollution, the derived values can be misleading because it simply takes an overall average of the concentrations of pollutants in the soil without due consideration to the background concentration as well as the potential of individual heavy metal to cause environmental and health damage. This drawback is catered for by the ecological risk index (ERI) which integrates both the background concentration of individual metal and their toxicity factor. While all the pollution indices considered so far give an indication of the build-up of pollutants in the soil as a result of anthropogenic activities, ER goes a step further to associate a degree of risk with the concentrations of these pollutants. In this study, the various degrees of risk identified were distributed as follows: low risk (69.7%), moderate risk (24.5%) and considerable risk (5.8%) for roadside dust. The corresponding values for soil were 68%, 22.7% and 9.3%, respectively. At an elemental level, the degree of risk was in this order: Cr (82.4) > Cd (70.9) > As (55.4) > Pb (36.8) > Cu (10.8) > Ni (10) > Mn (3.7) > Zn (1.7) for soil. Hence, Cr posed considerable risk in the soil, Cd and As posed moderate risk while the other elements posed low risk. The level of risk posed by pollutants in roadside dust was of the same order as that of soil, but with a slight difference in ER values except for Cd whose ER value was far less (42.6). Hence, the corresponding ER values for roadside dust were: Cr (77.2) > As (58.4) > Cd (42.7) > Pb (28.6) > Cu (11.0) > Ni (10.8) > Mn (3.3) > Zn (1.7). As, Cu, Ni and Zn posed slightly greater risks in roadside dust than in soil. Table 3 shows that Cr posed considerable risk in 10% of the samples while Cd posed considerable risk in 5% of the roadside dust samples. Cd posed considerable risk in 33.3% of soil samples, As posed considerable risk in 19%, while Cr posed considerable risk in 10% of the soil samples. On a global scale, the risk index (RI) was used to aggregate the collective risk posed by all pollutants identified in the samples. The RI values for soil and roadside dust were 236 and 202, respectively, representing moderate risk. Concerning soil, 60% of the samples exhibited moderate risk while 20%

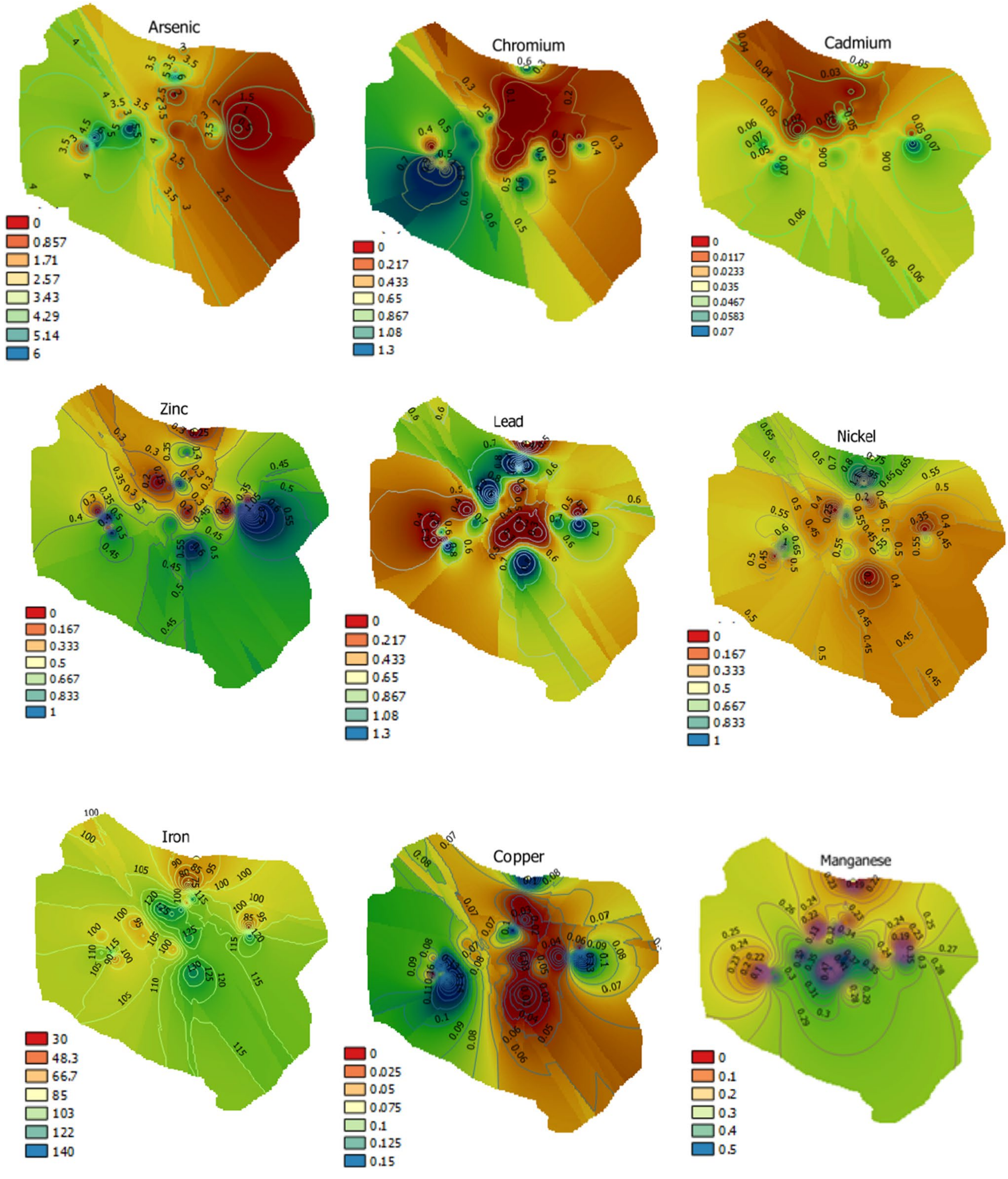

Fig. 1 Spatial distribution of heavy metals in roadside dust

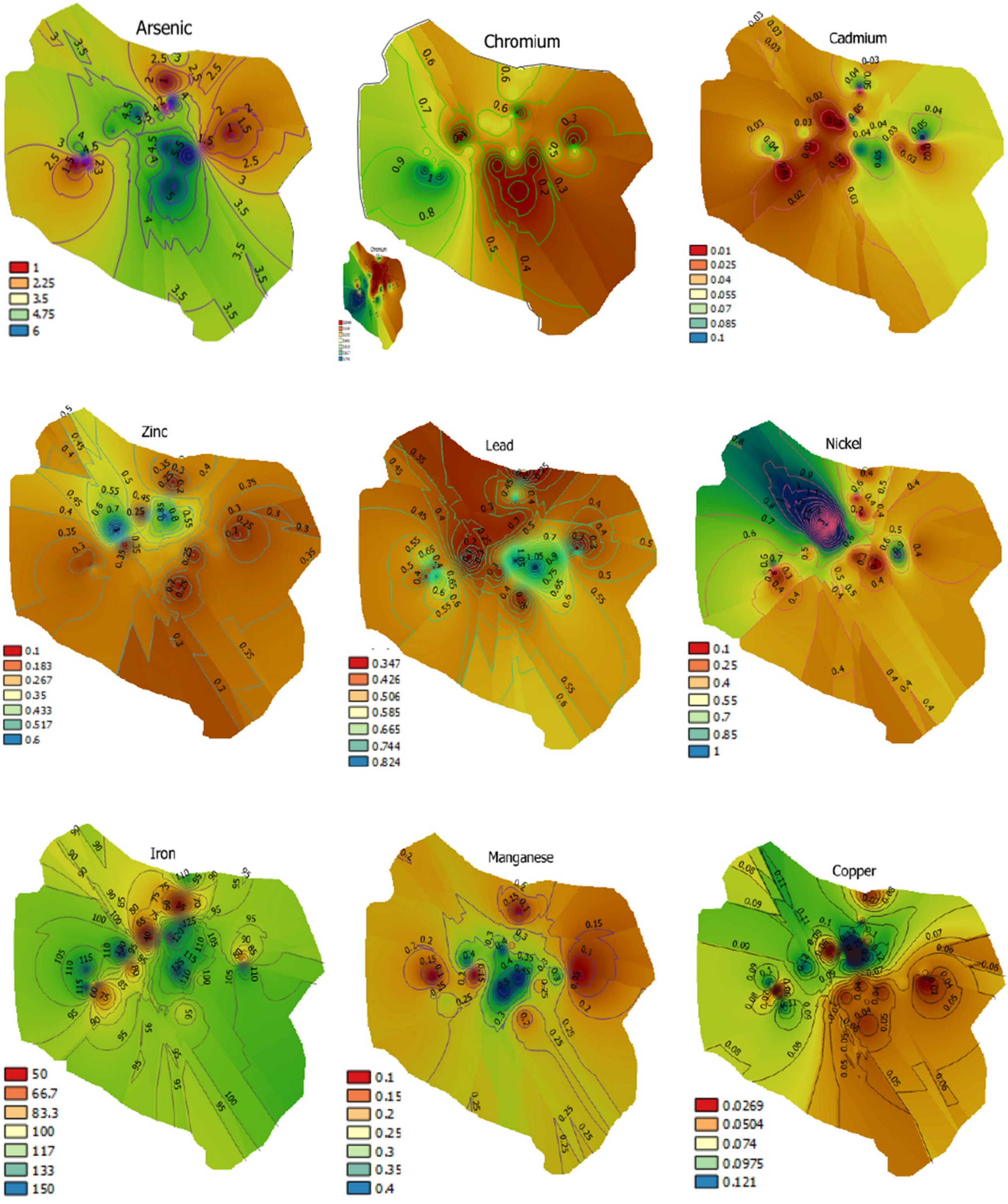

Fig. 2 Spatial distribution of heavy metals in the soil

Table 3 Distribution of ecological risks according to heavy metals

Source	Class (level of risk)	Metal							
		As (%)	Cr (%)	Cu (%)	Mn (%)	Ni (%)	Pb (%)	Zn (%)	Cd (%)
Dust	ER < 40 (low)	62	24	100	100	95	67	100	57
	40 < ER < 80 (moderate)	38	67	0	0	5	33	0	38
	80 < ER < 160 (considerable)	0	10	0	0	0	0	0	5
Soil	ER < 40 (low)	29	52	100	100	100	62	100	29
	40 < ER < 80 (moderate)	52	38	0	0	0	33	0	38
	80 < ER < 160 (considerable)	19	10	0	0	0	5	0	33

each represented low risk and considerable risk, respectively (Table 1). For roadside dust, 76.2% of the samples exhibited moderate risk while 19% represented low risk and 4.8% represented considerable risk. Hence, it can be seen that soil represented a slightly higher ecological risk than roadside dust. This can be explained by the fact that the concentration of pollutants in dust is constantly being redistributed and leached into the soil by surface runoff and rainwater. Figure 3a shows that there is a nearly uniform distribution of ecological risk due to pollutants in dust, while there is a more sporadic pattern with respect to soil with wider spatial ER range of 120–330 as opposed to roadside dust with a range of 150–250. This again confirms that soil pollutants display a wider range of spatial variation than pollutants in dust considering the results obtained from the hierarchical cluster analysis. It is worth mentioning at this stage that while all the pollution assessment indices considered so far clearly indicate that both soil samples and roadside dust samples were being considerably impacted by anthropogenic activities, the multi-element contamination indices (MEC) obtained for both soil and roadside dust were far below 1.0, with a mean of 0.034 for soil and 0.033 for roadside dust.

Human health risk associated with soil and dust contaminants

The release of toxic pollutants into the environment has been linked to a countless number of human health hazards. Heavy metals cause chronic diseases by disrupting the normal functioning of body cells and organs (Järup 2003; Jaishankar et al. 2014; Jan et al. 2015). Heavy metals can enter the body through three major pathways namely: ingestion, inhalation and dermal contact (Liang et al. 2017; Sun et al. 2017; Xie et al. 2017b). Table 4 shows that the highest concentration of heavy metals enters the body by ingestion with values of 7.49E−04 and 1.56E−04 mg/day of soil for children and adult, respectively, while the daily intake of metals through dust by the same pathway was 6.69E−04 and 1.39E−04 mg/day for children and adults, respectively. The next route of chronic intake of heave metals was by dermal contact with intake values ranging from 2.45E−07 to 2.62E−05, while the least was by inhalation with values ranging from 1.95E−08 to 2.18E−08. Results clearly show that the intake of heavy metals by children through dermal contact was about 6 times more than the intake by adults via the same pathway. But the intake through ingestion is about 5 times higher than that of adults via the same pathway, while intake through inhalation was 1.1 times lower for children than for adults. The daily combined intake of metals through the three routes of exposure was 7.75E−04 and 1.56E−04 for children and adults, respectively, for soil, while the corresponding values for dust was 6.93E−04 and 1.60E−04. These values indicate children take in 5 times more quantities of metals than adults.

The hazard quotients (HQs) were used to assess the probability of non-carcinogenic health effects associated with the intake of metals though the major exposure pathways for various pollutants. HQ is a proportion of the probable exposure to an element and the level at which no negative impacts are expected (Kacholi and Sahu 2018). In terms of exposure pathway, the order of non-carcinogenic health risk was ingestion > dermal > inhalation with average HQ of 3.98E−02, 7.12E−03 and 1.17E−06, respectively, for children; and 8.30E−03, 1.24E−03 and 1.28E−06, respectively, for adults considering only pollutants in roadside dusts (Table 5). The corresponding values for soil were 4.27E−02, 9.96E−03 and 1.25E−06 for children and 8.90E−03, 5.93E−04 and 1.37E−06 for adults. The hazard quotients for children were far above those for adults with respect to ingestion and dermal contact, but slightly lower than those of adults with respect to inhalation. The highest HQ of 1.31E−02 was obtained for the ingestion for ingestion of roadside dust for children. In order to identify the pollutants that posed the greatest cumulative non-carcinogenic

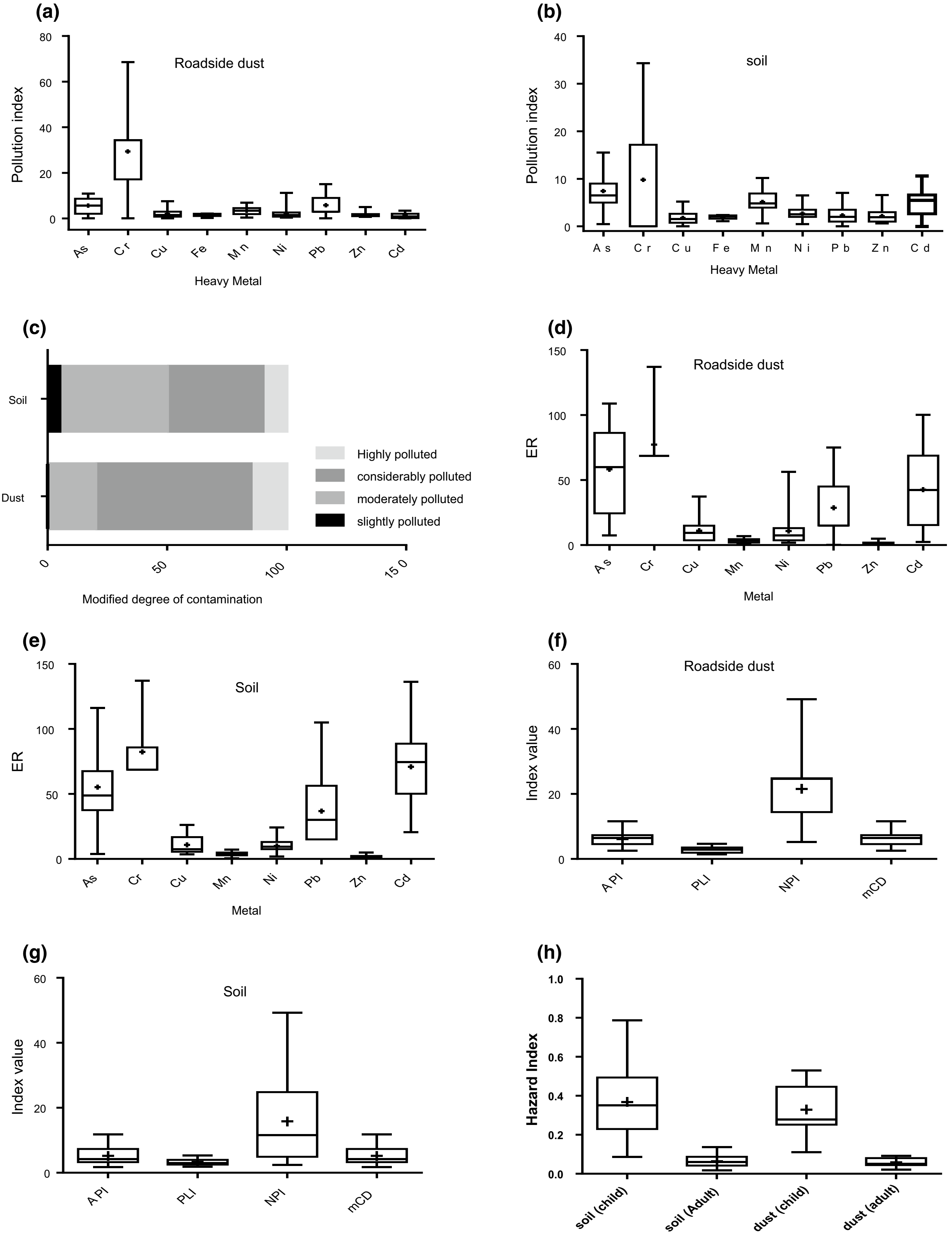

Fig. 3 Indices of pollution for roadside dust and soil

Table 4 Summary of hazard quotients for soil and roadside dust

HM	Roadside dust						Soil					
	Children			Adult			Child			Adult		
	Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal
As	2.14E−06	7.31E−02	6.14E−03	2.34E−06	1.52E−02	1.07E−03	2.13E−06	7.28E−02	6.12E−03	2.33E−06	1.52E−02	3.64E−04
Cr	3.84E−06	1.31E−01	1.47E−02	4.21E−06	2.74E−02	2.55E−03	2.56E−06	8.76E−02	9.81E−03	2.81E−06	1.83E−02	5.83E−04
Cu	3.90E−10	1.33E−05	3.74E−06	4.28E−10	2.78E−06	6.48E−07	3.61E−10	1.23E−05	3.46E−06	3.96E−10	2.57E−06	2.05E−07
Ni	5.53E−09	1.89E−04	1.86E−04	6.07E−09	3.94E−05	3.22E−05	5.1E−09	1.75E−04	1.71E−04	5.6E−09	3.64E−05	1.02E−05
Pb	2.60E−08	8.90E−04	1.49E−05	2.85E−08	1.85E−04	2.59E−06	3.19E−08	1.09E−03	1.83E−05	3.49E−08	2.27E−04	1.09E−06
Zn	2.60E−10	8.90E−06	4.98E−07	2.85E−10	1.85E−06	8.65E−08	2.56E−10	8.75E−06	4.90E−07	2.8E−10	1.82E−06	2.91E−08
Cd	2.15E−06	7.36E−02	2.88E−02	2.36E−06	1.53E−02	5.00E−03	4E−06	1.37E−01	5.36E−02	4.38E−06	2.85E−02	3.19E−03

risk, the pollutants were ranked in decreasing order of HQ as follows: Cr > Cd > As > Pb > Ni > Cu > Zn for roadside dust and Cd > Cr > As > Pb > Ni > Cu > Zn for soil regardless of age category. It can be seen that Cr, Cd and As ranked highest in both soil and roadside dust. This calls for serious concern because all three metals are confirmed carcinogens and also have the potentials to induce other forms of chronic health problems. However, the values of HQ obtained for all cases were less than 1.0 which indicates that the probability of inducing health problems is very low. But considering the trend of pollutants build-up in the soil and roadside dust as depicted by the pollution indices aforementioned, a significant health risk will most likely exist in the future unless drastic measures are taken to retard the rate of metal accumulation in the soil. Further investigation of the hazard quotients showed that Cr was 120 times more likely to cause health problems than Pb and 450 times more than Ni. Cr and Cd exhibited nearly equal likelihood of causing non-carcinogenic health problems. Several studies have reported that Cr and Cd posed the highest potential health in soil (Elnazer et al. 2015; Liang et al. 2017; Ramdani et al. 2018). Many others reported potentially significant health hazards for As and Pb (Huang et al. 2018; Cai et al. 2019; Rinklebe et al. 2019). Cd is particularly dangerous because it provokes cell invasion in human gastric cancer cells due to the overexpression of uPAR via the ERK-1/2, NF-κB, and AP-1 signalling pathways (Yuan et al. 2016).

The hazard index (HI) is a cumulative of the hazard quotient for all the metals. Ingestion had the highest HI with values of 2.79E−01 and 5.82E−02 for children and adults, respectively, for roadside dust and 2.98E−01 and 6.22E−02 for children and adult, respectively, for soil (Table 5). This shows that the hazard index for children with respect to ingestion was 5 times higher than that for adults. Jia et al. (2018) also reported that HI for heavy metals was 5.5 times higher for children than for adults. Ingestion of heavy metals can occur by consumption of plants cultivated in contaminated soil or cultivated with untreated effluents as is the case in many developing countries. Hence the quantity of pollutants that enters the body through direct ingestion is higher than other routes. In this study, the value of hazard index for the ingestion pathway was 6 times higher than that which occurs though dermal contact for adults. However, farmers and other categories of individuals that have constant contact with the soil might be exposed to a significant chance of heavy metals intake by the dermal route. The value of hazard index associated with the ingestion pathway was 5 times higher than that of the dermal pathway for children. It should be noted that in many developing countries, children are usually exposed to higher than average level of heavy metals intake though the dermal pathway because of longer outdoor times and higher degree of exposure to bare soil. This is opposed to many developed countries where paved

Table 5 Hazard index

Pathway	Hazard index				Cancer risk			
	Roadside dust		Soil		Roadside dust		Soil	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Ingestion	2.79E−01	5.82E−02	2.98E−01	6.22E−02	2.99E−06	2.49E−06	2.93E−06	2.44E−06
Dermal	4.99E−02	8.70E−03	6.97E−02	1.21E−02	2.38E−07	1.65E−07	2.37E−07	1.64E−07
Inhalation	8.16E−06	8.95E−06	8.72E−06	9.57E−06	8.83E−10	3.87E−09	8.68E−10	3.81E−09
Total	0.329	0.067	0.368	0.074	3.23E−06	2.66E−06	3.17E−06	2.61E−06

and grassed surfaces are more prevalent, thus reducing the amount of loose soil particles in the environment. Generally, the additive HI of contaminated soil in this study was 0.368 and 0.074 for children and adults, respectively; and 0.329 and 0.067 for children and adults, respectively, for roadside dust. Moghtaderi et al. (2018) reported that children faced more health risk in their daily lives than adult via unconscious ingestion of soil and dermal contact. HI values are generally less than 1.0, indicating that no lifetime risks are envisaged if the concentrations of these metals in both roadside dust and soil remain the same going forward. But this is most unlikely as anthropogenic activities that release these contaminants into the environment are on the rise. Besides, a spatial characterisation of hazard indices shows that while the risk for adults are very low for adults throughout the study area, values much higher than the average values are possible at some locations for children (Fig. 4). A hazard index of 0.7 was recorded for a spot around the southeast flank of the study area. The hazard indices for soil were generally higher than those for dust at corresponding spots (Fig. 5). Another important issue worth mentioning is that the risk due to inhalation in this study was grossly underestimated. Again the prevalence of bare soils and untarred roads give rise to the release of large amounts of soil particles into the air especially during the dry season.

The lifetime risk of developing cancer due to exposure to soil and roadside dust was investigated using cancer risk (CR). It provides an estimate of the probability of a person developing any form of cancer over a lifetime as a result of exposure to potential carcinogens (Enuneku et al. 2018). All values of CR obtained for all cases were within the acceptable range of 10^{-6} and 10^{-4}. Specifically, children stand a higher chance (1.2 times) of suffering from cancer due to dermal contact. On the other hand, adults are 4.4 times more likely to develop cancer induced by the inhalation of soil and dust particles than children. The aggregate CR values for all exposure pathways obtained for children were about 1.2 times higher than those for adults. Interestingly, though soil posed a higher non-carcinogenic risk than roadside dust as earlier noted, the reverse is the case with respect to carcinogenic risk. CR value for roadside dust is slightly higher than that for soil. This can be traced to the fact that most carcinogenic metals such as As, Cr and Ni had higher average concentrations in roadside dust than in the soil samples. These particular carcinogenic metals (As, Cr, Ni) can evoke posttranslational histone modifications and modulate histone-modifying enzymes including iron- and

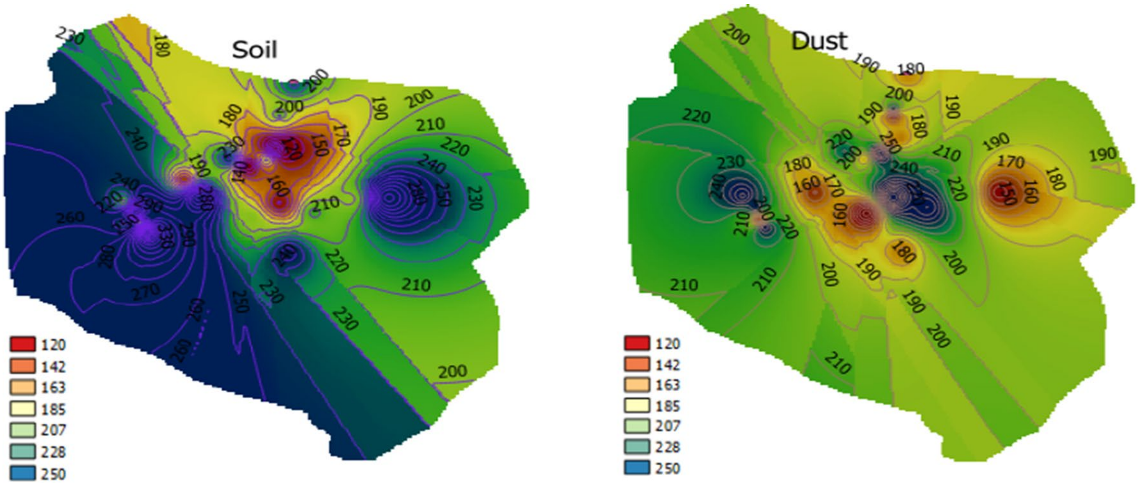

Fig. 4 Ecological risk for soil and dust

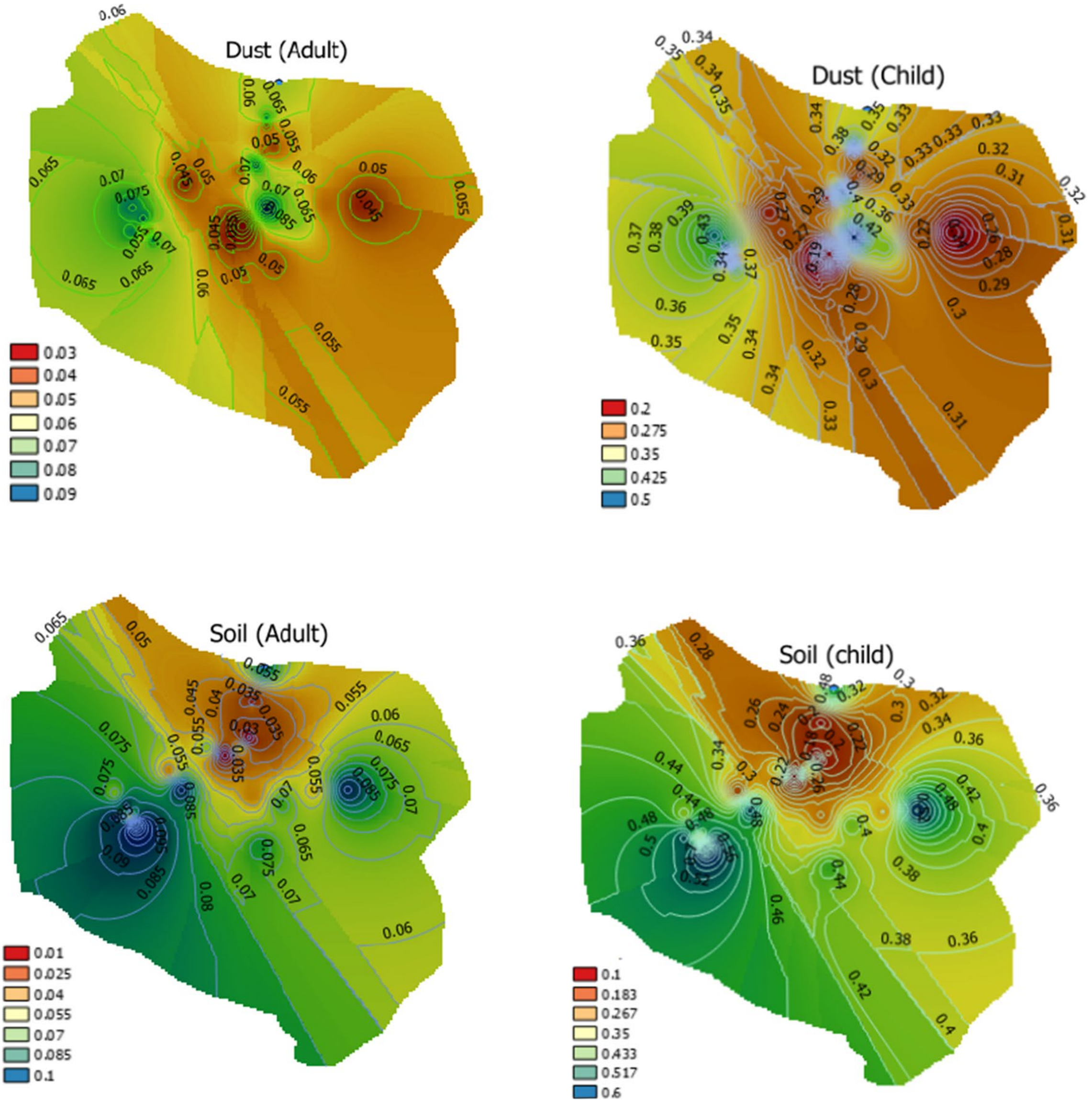

Fig. 5 Spatial variation of human hazard indices

2-oxoglutarate-dependent dioxygenase family enzymes, DNA repair enzymes ABH3 and ABH2, and histone methyltransferases, which may affect the epigenome (Chervona et al. 2012). Though the CR values fall within the acceptable range, the cancer risk associated with dust particle might violate acceptable limits when adjusted for excessive inhalation of dust particles prevalent in developing countries.

Conclusion

In the current paper, the concentrations of these metals in soil and roadside dust were within tolerable limits, but current trend of build-up will eventually attain unacceptable levels in both soil and dust. The results also revealed that the highest change in concentration from background level was associated with Cd in roadside dust and soil, respectively, followed by Zn and then As. The pollution index (PI) showed that both roadsides dust and soil were moderately contaminated with Cu, Fe, Ni, Zn and Cd, considerably contaminated with As, Mn and Pb and highly contaminated with Cr. Conversely, the average pollution index (API) aggregated for all sampling points suggests otherwise. The values of Nemerow pollution index (NPI) and PLI showed that all dust and soil samples from all locations were heavily polluted. The values of HQ showed that children take in 5 times more quantities of metals than adults. Meanwhile, the highest value of HQ was obtained for the ingestion of roadside dust for children. Furthermore, the aggregate CR values for all exposure pathways obtained for children were about 1.2 times higher than those for adults. CR value for roadside dust was 1.3 times higher than that of soil. All values of CR obtained for all cases were within the acceptable range. The cancer risk associated with dust particle might violate acceptable limits when adjusted for excessive inhalation of dust particles prevalent in the study area.

Acknowledgements The authors would like to appreciate the management of the University of Nigeria, Nsukka, for the enabling environment to conduct the research.

Compliance with ethical standards

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

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

Abdelhafez A, Abbas M, Attia T (2015) Environmental monitoring of heavy-metals status and human health risk assessment in the soil of Sahl El-Hessania Area, Egypt. Pol J Environ Stud 24(2):459–467

Ajmone-Marsan F, Biasioli M (2010) Trace elements in soils of urban areas. Water Air Soil Pollut 213(1–4):121–143. https://doi.org/10.1007/s11270-010-0372-6

Akoto O et al (2018) Characterization, spatial variation and risk assessment of heavy metals and a metalloid in surface soils in Obuasi, Ghana. J Health Pollut 8(19):180902. https://doi.org/10.5696/2156-9614-8.19.180902

Alahabadi A et al (2017) A comparative study on capability of different tree species in accumulating heavy metals from soil and ambient air. Chemosphere 172:459–467. https://doi.org/10.1016/j.chemosphere.2017.01.045

Ali H, Khan E, Ilahi I (2019) Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. J Chem 2019:1–14. https://doi.org/10.1155/2019/6730305

Al-Jumaily HAA (2016) An evaluation performance of potential pollution of arsenic, chromium and cadmium in the road side soil of Kirkuk City, Northern Iraq. J Geosci Environ Prot 04(09):80–94. https://doi.org/10.4236/gep.2016.49007

Alsbou EME, Al-Khashman OA (2018) Heavy metal concentrations in roadside soil and street dust from Petra region. Environ Monit Assess, Jordan. https://doi.org/10.1007/s10661-017-6409-1

Cai L-M et al (2019) Heavy metal contamination and health risk assessment for children near a large Cu-smelter in central China. Sci Total Environ 650:725–733. https://doi.org/10.1016/j.scitotenv.2018.09.081

Cheng X et al (2018) Pollution assessment of trace elements in agricultural soils around copper mining area. Sustainability 10(12):4533. https://doi.org/10.3390/su10124533

Chervona Y, Arita A, Costa M (2012) Carcinogenic metals and the epigenome: understanding the effect of nickel, arsenic, and chromium. Metallomics 4(7):619. https://doi.org/10.1039/c2mt20033c

Dao L, Morrison L, Zhang C (2010) Spatial variation of urban soil geochemistry in a roadside sports ground in Galway, Ireland. Sci Total Environ 408(5):1076–1084. https://doi.org/10.1016/j.scitotenv.2009.11.022

de Carvalho Aguiar VM et al (2018) Environmental assessment concerning trace metals and ecological risks at Guanabara Bay, RJ, Brazil. Environ Monit Assess. https://doi.org/10.1007/s10661-018-6833-x

Elnazer AA et al (2015) Assessment of some heavy metals pollution and bioavailability in roadside soil of Alexandria-Marsa Matruh Highway, Egypt. Int J Ecol 2015:1–7. https://doi.org/10.1155/2015/689420

Enuneku A et al (2018) Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. Appl Water Sci 8(8):224. https://doi.org/10.1007/s13201-018-0873-9

Ettler V (2015) Soil contamination near non-ferrous metal smelters: a review. Appl Geochem 64:56–74. https://doi.org/10.1016/j.apgeochem.2015.09.020

Ghanavati N, Nazarpour A, Watts W (2019) Status, source, ecological and health risk assessment of toxic metals and polycyclic aromatic hydrocarbons (PAHs) in street dust of Abadan, Iran. Catena 177:246–259. https://doi.org/10.1016/j.catena.2019.02.022

Huang S et al (2018) Distribution and health risk assessment of trace metals in soils in the golden triangle of Southern Fujian Province, China. Int J Environ Res Public Health 16(1):97. https://doi.org/10.3390/ijerph16010097

Jaishankar M et al (2014) Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol 7(2):60–72. https://doi.org/10.2478/intox-2014-0009

Jan A et al (2015) Heavy metals and human health: mechanistic insight into toxicity and counter defense system of antioxidants. Int J Mol Sci 16(12):29592–29630. https://doi.org/10.3390/ijms161226183

Järup L (2003) Hazards of heavy metal contamination. Br Med Bull 68:167–182. https://doi.org/10.1093/bmb/ldg032

Jia Z, Li S, Wang L (2018) Assessment of soil heavy metals for eco-environment and human health in a rapidly urbanization area of the upper Yangtze Basin. Sci Rep 8(1):1–14. https://doi.org/10.1038/s41598-018-21569-6

Johnbull O, Abbassi B, Zytner RG (2019) Risk assessment of heavy metals in soil based on the geographic information system-kriging technique in Anka, Nigeria. Environ Eng Res 24(1):150–158. https://doi.org/10.4491/eer.2018.130

Kacholi DS, Sahu M (2018) Levels and health risk assessment of heavy metals in soil, water, and vegetables of Dar es Salaam, Tanzania. J Chem 2018:1–9. https://doi.org/10.1155/2018/1402674

Kamunda C, Mathuthu M, Madhuku M (2016) Health risk assessment of heavy metals in soils from witwatersrand gold mining basin, South Africa. Int J Environ Res Public Health. https://doi.org/10.3390/ijerph13070663

Keshavarzi B et al (2015) Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban street dust of Shiraz, Iran. Atmos Environ 119:1–10. https://doi.org/10.1016/j.atmosenv.2015.08.001

Kim HS, Kim YJ, Seo YR (2015) An overview of carcinogenic heavy metal: molecular toxicity mechanism and prevention. J Cancer Prev 20(4):232–240. https://doi.org/10.15430/JCP.2015.20.4.232

Kobza J, Geremek M (2017) Do the pollution related to high-traffic roads in urbanised areas pose a significant threat to the local population? Environ Monit Assess. https://doi.org/10.1007/s10661-016-5697-1

Kowalska JB et al (2018) Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination—a review. Environ Geochem Health 40(6):2395–2420. https://doi.org/10.1007/s10653-018-0106-z

Li F (2018) Heavy metal in urban soil: health risk assessment and management. Heavy Met. https://doi.org/10.5772/intechopen.73256

Liang Y et al (2017) Heavy metal contamination and health risk assessment in the vicinity of a tailing pond in Guangdong, China. Int J Environ Res Public Health 14(12):1557

Lin M et al (2017) Pollution characteristics, source apportionment, and health risk of heavy metals in street dust of Suzhou, China. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-016-7934-0

Liu L et al (2018) Remediation techniques for heavy metal-contaminated soils: principles and applicability. Sci Total Environ 633:206–219. https://doi.org/10.1016/j.scitotenv.2018.03.161

Martínez LLG, Poleto C (2014) Assessment of diffuse pollution associated with metals in urban sediments using the geoaccumulation index (Igeo). J Soils Sediments 14(7):1251–1257. https://doi.org/10.1007/s11368-014-0871-y

Moghtaderi T et al (2018) Heavy metals contamination and human health risk assessment in soils of an industrial area, Bandar Abbas–South Central Iran. Hum Ecol Risk Assess Int J 24(4):1058–1073. https://doi.org/10.1080/10807039.2017.1405723

Mohammadi AA et al (2019) Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX 6:1642–1651. https://doi.org/10.1016/j.mex.2019.07.017

Morton-Bermea O et al (2009) Assessment of heavy metal pollution in urban topsoils from the metropolitan area of Mexico City. J Geochem Explor 101(3):218–224. https://doi.org/10.1016/j.gexplo.2008.07.002

Mulware SJ (2013) Trace elements and carcinogenicity: a subject in review. 3 Biotech 3(2):85–96. https://doi.org/10.1007/s13205-012-0072-6

Najmeddin A, Keshavarzi B (2018) Health risk assessment and source apportionment of polycyclic aromatic hydrocarbons associated with PM 10 and road deposited dust in Ahvaz metropolis of Iran. Environ Geochem Health. https://doi.org/10.1007/s10653-018-0209-6

Nazarpour A et al (2019) Source, spatial distribution and pollution assessment of Pb, Zn, Cu, and Pb, isotopes in urban soils of Ahvaz City, a semi-arid metropolis in southwest Iran. Sci Rep 9(1):1–11. https://doi.org/10.1038/s41598-019-41787-w

Nazzal Y, Rosen MA, Al-Rawabdeh AM (2013) Assessment of metal pollution in urban road dusts from selected highways of the Greater Toronto Area in Canada. Environ Monit Assess 185(2):1847–1858. https://doi.org/10.1007/s10661-012-2672-3

Okorie A, Entwistle J, Dean JR (2012) Estimation of daily intake of potentially toxic elements from urban street dust and the role of oral bioaccessibility testing. Chemosphere 86(5):460–467. https://doi.org/10.1016/j.chemosphere.2011.09.047

Pateraki S et al (2019) The traffic signature on the vertical PM profile: environmental and health risks within an urban roadside environment. Sci Total Environ 646:448–459. https://doi.org/10.1016/j.scitotenv.2018.07.289

Rabee AM et al (2011) Using Pollution Load Index (PLI) and geoaccumulation index (I-Geo) for the assessment of heavy metals pollution in Tigris river sediment in Baghdad Region. J Al-Nahrain Univ Sci 14(4):108–114. https://doi.org/10.22401/JNUS.14.4.14

Ramdani S et al (2018) Assessment of heavy metal pollution and ecological risk of roadside soils in Tlemcen (Algeria) using flame-atomic absorption spectrometry. Anal Lett 51(15):2468–2487. https://doi.org/10.1080/00032719.2018.1428985

Rinklebe J et al (2019) Health risk assessment of potentially toxic elements in soils along the Central Elbe River, Germany. Environ Int 126:76–88. https://doi.org/10.1016/j.envint.2019.02.011

Salman SA et al (2019) Soil characterization and heavy metal pollution assessment in Orabi farms, El Obour, Egypt. Bull Natl Res Centre 43(1):42. https://doi.org/10.1186/s42269-019-0082-1

Sun G et al (2017) Metal exposure and associated health risk to human beings by street dust in a heavily industrialized city of Hunan Province, Central China. Int J Environ Res Public Health 14(3):261. https://doi.org/10.3390/ijerph14030261

Sun L et al (2019) Levels, sources, and spatial distribution of heavy metals in soils from a typical coal industrial city of Tangshan, China. Catena 175:101–109. https://doi.org/10.1016/j.catena.2018.12.014

Taghavi SN et al (2019) Assessment of heavy metals in street dusts of Tehran using enrichment factor and geo-accumulation index. Health Scope. https://doi.org/10.5812/jhealthscope.57879 **(in press)**

Tian HZ et al (2015) Quantitative assessment of atmospheric emissions of toxic heavy metals from anthropogenic sources in China: historical trend, spatial distribution, uncertainties, and control policies. Atmos Chem Phys 15(17):10127–10147. https://doi.org/10.5194/acp-15-10127-2015

Woszczyk M, Spychalski W, Boluspaeva L (2018) Trace metal (Cd, Cu, Pb, Zn) fractionation in urban-industrial soils of Ust-Kamenogorsk (Oskemen), Kazakhstan—implications for the assessment of environmental quality. Environ Monit Assess. https://doi.org/10.1007/s10661-018-6733-0

Wuana RA, Okieimen FE (2011) Heavy Metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecol 2011:1–20. https://doi.org/10.5402/2011/402647

Xie J-J et al (2017a) Bioavailability and speciation of arsenic in urban street dusts from Baoding city, China. Chem Speciat Bioavailab 29(1):135–142. https://doi.org/10.1080/09542299.2017.1366281

Xie W et al (2017b) Health risk assessment of trace metals in various environmental media, crops and human hair from a mining affected area. Int J Environ Res Public Health 14(12):1595. https://doi.org/10.3390/ijerph14121595

Yuan W, Yang N, Li X (2016) Advances in understanding how heavy metal pollution triggers gastric cancer. Biomed Res Int 2016:7825432. https://doi.org/10.1155/2016/7825432

Zhang M et al (2019) Multipotential toxic metals accumulated in urban soil and street dust from Xining City, NW China: spatial occurrences, sources, and health risks. Archiv Environ Contam Toxicol 76(2):308–330. https://doi.org/10.1007/s00244-018-00592-8