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Human exposure of hazardous elements from different urban soils in Bangladesh

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Abstract. In order to evaluate the contamination and health risk, levels of six hazardous elements i.e., Cr, Ni, Cu, As, Cd and Pb in soils of 12 different land-uses were measured. The average concentration of Cu, Cr, Ni, Pb, As and Cd in soils were 267, 239, 206, 195, 58 and 16 mg/kg, respectively. Levels of each metal exceeded the environmental action level for soils, which could pose significant risk to human. The metal concentrations were subsequently used to establish hazard indices (for adults and children) where the 5th and 95th percentile values were used to derive the hazard index through different exposure pathways (ingestion, dermal contact and inhalation). Considering the total exposure through each of the three pathways, the hazard index elucidates that there was a potency of non-cancer risk at most of the sites for both the adults and children. The findings of this study suggested that different land-use soils were severely contaminated with hazardous elements and attention is needed on the potential health risks to the exposed inhabitants.

Keywords: hazardous elements; land use; exposure pathways; health risk; Bangladesh

1. Introduction

Metal contaminations in soils are of great concern because of their persistence, non-biodegradable and toxicity to human and other organisms (Radha *et al*. 1997, Zhao *et al*. 2014). Naturally, hazardous elements can exist in the environment as trace elements in rocks and soils; furthermore, they are released into the environment as the result of human activities (Karakus 2012). Dhaka, the capital of Bangladesh is facing serious threats from pollution caused by the city's rapid expansion, congestion and industrial activities. Increasing air, water and soil pollution emanating from traffic congestion and industrial waste are serious problems that affect public health in the city (Islam *et al*. 2014a, b). Urban soils are an important indicator for the quality assessment of urban environment as they act as a sinks for metals and other pollutants (Mielke *et*

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al. 1999). In the urbanized areas, hazardous elements may originate from various activities such as emissions from vehicular exhaust, sewage sludge, wastewater irrigation and discharges from industrial activities (Thornton 1991).

In the last few decades, urbanization and industrialization has created environmental pollution due to the intensive nature of human activities in the urban area (Shi *et al*. 2011, Xia *et al*. 2011, Thornton *et al*. 2008, Wong *et al*. 2006). Urban soils are generally regarded as being continuous recipients of hazardous elements and other pollutants (Wei and Yang 2010). Excessive inputs of hazardous elements and synthetic chemicals into urban soils may lead to the deterioration of the soil biology and functions, changes in the soil physicochemical properties and create other environmental problems (Papa *et al*. 2010). Recently, in the urban area, lands have been changed by the owners for more profitable uses such as open storage sites, construction of stations, metal and car workshops, etc. Depending on the nature, the non-conforming land uses are potentially dangerous to the surrounding environment and may jeopardize human health (Man *et al*. 2010). In addition, urbanized megacities have been considered as regional sinks for resource consumption and sources of chemical emissions. In the urban areas, metal contaminated soil can pose significant human health risks due to soil ingestion (Luo *et al*. 2011a, Okorie *et al*. 2011), inhalation of volatiles and fugitive soil particulates (Laidlaw and Filippelli 2008), and dermal contact (Siciliano *et al*. 2009), especially in the public parks and playgrounds (Li *et al*. 2011, DEFRA 2002) (Fig. 1). The general public (especially children and senior citizens) are most susceptible to the hazardous elements from soil (Ljung *et al*. 2007, Luo *et al*. 2012a). However, study on possible health risk due to the contamination by hazardous elements in soil of urban area is very important. Measurement of metal concentrations in soils of the urban and industrial regions is critical for making policies to reduce the pollution level and improvement of soil functions.

Although a number of studies have reported for assessing human health impact due to metal contamination from urban soil in some regions of the world (Chen *et al*. 2005, Luo *et al*. 2007,

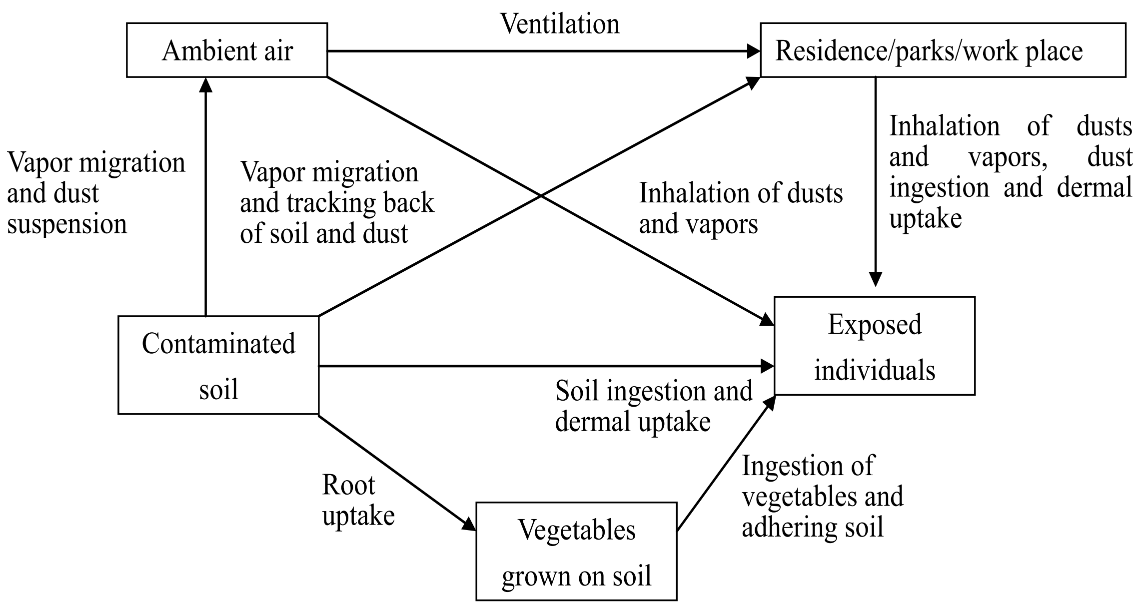

Fig. 1 Routes of heavy metal exposure to human from soil (DEFRA 2002)

Man *et al*. 2010, 2013), to the best of our knowledge, no such study has been conducted in Bangladesh. Therefore, the objectives of this study are to evaluate the contamination of hazardous elements (Cr, Ni, Cu, As, Cd, and Pb) in soils of different land uses, to assess non-cancer and cancer risks of hazardous elements through three exposure pathways: ingestion, dermal contact and inhalation of both adults and children.

2. Materials and methods

2.1 Study area and sampling

This study was conducted in the urban area of Dhaka City, Bangladesh covering 12 different land uses: agriculture farm (AF), tannery waste (TW), gas and petrol station (GPS), playground (PG), metal workshop (MW), electric waste (EW), waste burning site (BS), household waste (HW), garments waste (GW), construction site (CS), park area (PA) and brick field (BF) (Fig. 2). The metropolitan area of Dhaka is about 815.8 km^2 and located at the centre of Bangladesh. The Dhaka City is one of the most densely populated cities in the world, home to approximately twelve million people (Islam *et al*. 2014a, b, 2015). Numerous industries (leathers, textiles, metals processing, paper mills, electronic goods, power plant, fertilizers, pharmaceuticals, dyeing, battery manufacturing, ink manufacturing, Pb-Zn smelting, brick fields, etc.) are situated near the study area (Rahman *et al*. 2012). The basic information of the study area is presented in Table S1. About 70 composite soil samples were collected during February-March, 2012 and August-September, 2013. Sampling sites were selected depending on the current land use for different purposes. At each sampling sites soil samples (up to 10 cm) were collected in the form of sub-samples and were

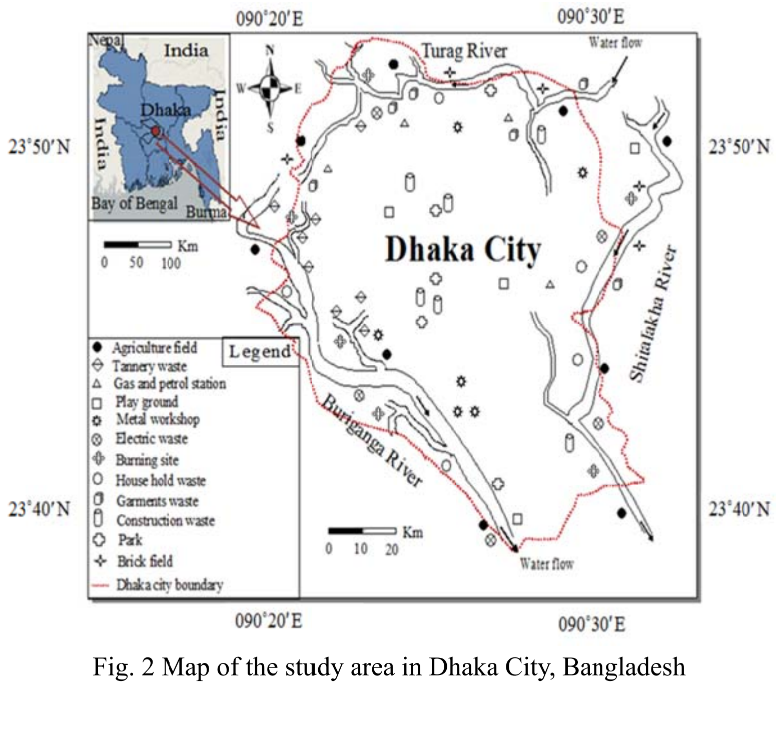

Fig. 2 Map of the study area in Dhaka City, Bangladesh

Table S1 Descriptions of different assorted land uses and their respective number of sites under present investigation

Land types	Number of sites	Description about the sampling sites
Agriculture field (AF)	9	Traditional farming systems, grown different types of foods with chemical fertilizers and pesticides
Tannery waste (TW)	8	Disposal site of tannery waste with leather products and some chemical materials
Gas and petrol station (GPS)	4	Gas and petrol filling station, dispose of some waste from the car around the station.
Play ground (PG)	4	The field for play to the children, adults and other residents as a regular basis
Metal workshop (MW)	6	Recycling of heavy metals with some machinery activities, metal smelting and preparing new products
Electric waste (EW)	5	Breaking down of electronic components such as computers, refrigerators and printers on the land.
Waste burning site (BS)	6	Burning of house hold waste, farm waste and mixture of industrial waste to the open field
Household waste (HW)	5	Disposal site of the mixture of house hold waste from the city
Garments waste (GW)	6	Disposal site of the garments waste with small cloths, polybag and dyeing materials
Construction waste (CW)	6	Open field for construction, demolishing building materials, wood, scrap metal, concrete and bamboo etc.
Park area (PA)	5	The area for recreation for the people which also surrounded by some industry
Brick field (BF)	6	Brick kiln field, burning of coal and wood for making bricks

mixed to form a composite sample. Soil samples were air-dried at room temperature for two weeks, then ground and homogenized. The dried soil samples were crumbled and pulverized with a porcelain mortar and pestle and sieved through 2 mm nylon sieve and stored in airtight clean Ziploc bag until chemical analysis was carried out.

2.3 Sample analysis

All chemicals were analytical grade reagents and Milli-Q (Elix UV5 and MilliQ, Millipore, USA) water was used for solution preparation. For element analysis, 0.5 g of the soil sample was treated with 1.5 mL 69% HNO_3 (Kanto Chemical Co, Tokyo, Japan) and 4.5 mL 35% HCl (Kanto Chemical Co, Tokyo, Japan) in a closed Teflon vessel and was digested in a Microwave Digestion System (Berghof Speedwave®, Eningen, Germany). The digested soil samples were then transferred into a Teflon beaker and total volume was made up to 50 mL with Milli-Q water. The digested solution was then filtered using a syringe filter (DISMIC® - 25HP PTFE, pore size=0.45 μm) Toyo Roshi Kaisha, Ltd., Tokyo, Japan and stored in 50 mL polypropylene tubes (Nalgene, New York).

2.4 Instrumental analysis and quality control

For hazardous elements, samples were analyzed using inductively coupled plasma mass spectrometer (ICP-MS). Multi-element Standard XSTC-13 (Spex CertiPrep® Metuchen, USA) solutions was used to prepare calibration curve. Multielement solution (Agilent Technologies, USA) 1.0 μg/L was used as tuning solution covering a wide range of masses of elements. All test batches were evaluated using an internal quality approach and validated if they satisfied the defined Internal Quality Controls (IQCs). Before starting the analysis sequence, relative standard deviation (RSD, <5%) was checked using a tuning solution purchased from the Agilent Technologies.

2.5 Human exposure and health risk assessment

Risk assessment is a multi-step procedure (USDOE 2011, USEPA 1989) comprising data collection and evaluation, exposure assessment, toxicity assessment and risk characterization. For the assessment of non-carcinogenic and carcinogenic risk, the mathematical expressions were taken from the US Environmental Protection Agency "Exposure factors handbook" (USEPA 1997). In this study six elements i.e., Cr, Ni, Cu, As, Cd and Pb were identified as potential hazardous to human health. Human exposure to hazardous elements in the urban soils can occur via three main pathways (Luo *et al*. 2012b, De Miguel *et al*. 2007): (I) direct ingestion of substrate particles ($CDI_{ingestion}$); (II) inhalation of resuspended particulates emitted from soil through the mouth and nose ($CDI_{inhalation}$); and (III) dermal absorption of hazardous elements in particles adhered to exposed skin (CDI_{dermal}). Both non-carcinogenic and carcinogenic risks of these exposure routes were considered. In the step of exposure assessment, a specific approach characteristic for human exposure from soil in the urban residential areas was applied, taking particularly care of the non-carcinogenic hazard exposure for children. The carcinogenic risk was calculated for the lifetime exposure, estimated as the incremental probability of an individual developing cancer over a lifetime as a result of total exposure to the potential carcinogen. The dose received (chronic daily intake, CDI; i.e., average daily dose, ADD) through each of the three exposure routes were considered and was calculated using Eqs. (1)-(9) adapted from USEPA (1989, 1997, 2001, 2009) and USDOE (2011). The definition of symbols, used values of Bangladesh-specific variables and parameters are shown in Tables 1-3.

Non-carcinogenic risk

$$CDI_{ing-nc} = \frac{C_{soil} \times IngR \times EF \times ED}{BW \times AT} \times CF \tag{1}$$

$$CDI_{dermal-nc} = \frac{C_{soil} \times SA \times AF_{soil} ABS_{d} \times EF \times ED}{BW \times AT} \times CF \tag{2}$$

$$CDI_{inh-nc} = \frac{C_{soil} \times InhR \times EF \times ED}{PEF \times BW \times AT} \tag{3}$$

$$HQ = \frac{CDI_{nc}}{RfD} \tag{4}$$

$$HI = \sum HQ = HQ_{ingestion} + HQ_{dermal} + HQ_{inhalation}$$

$$= \frac{CDI_{ing-nc}}{RfD_{ingestion}} + \frac{CDI_{dermal-nc}}{RfD_{ingestion} \times ABS_{GI}} + \frac{CDI_{inh-nc}}{RfC_{inhalation}} \tag{5}$$

Carcinogenic risk

$$CDI_{ing-ca} = \frac{C_{soil} \times IngR \times EF \times ED}{BW \times AT} \times CF \times CSF_{ing} \quad (6)$$

$$CDI_{dermal-ca} = \frac{C_{soil} \times SA \times AF_{soil} ABS_{d} \times EF \times ED}{BW \times AT} \times CF \times CSF_{ing} \times ABS_{GI} \quad (7)$$

$$CDI_{inh-ca} = \frac{C_{soil} \times ET \times EF \times ED}{PEF \times 24 \times AT} \times IUR \times 10^{3} \quad (8)$$

$$Totalrisk = \sum Risk = Risk_{ingestion} + Risk_{dermal} + Risk_{inhalation} \quad (9)$$

The chronic daily intake (CDI) for each metal and exposure pathway ($CDI_{ingestion,}$ CDI_{dermal} and $CDI_{inhalation}$) were subsequently divided by the corresponding reference dose to yield a hazard quotient [HQ, or non-carcinogenic risk; Eq. (4)] for systemic toxicity. For carcinogens, the dose for As and Pb was multiplied by the corresponding slope factor (Table 3) to produce a level of excess lifetime cancer risk Eqs. (6) and (7). Though the effect from interactions between some elements might occur in a synergistic manner (Luo *et al*. 2012b, Xu *et al*.2011), it was assumed

Table 1 Values of the variables for the estimation of human exposure of hazardous elements from soils of different land types in the urban area

Variables	Value	References
IngR (mg/d): Soil ingestion rate for receptor	Resident, 200 for children and 100 for adult	USDOE 2011; USEPA 1997
EF (d/yr): Exposure frequency	75 for residents	USDOE 2011
ED (yr): Exposure duration	30 for adult resident and 6 for children	USDOE 2011
BW (kg): Average body weight	15 for child and 60 for adult resident	FAO 2006; Man et al. 2010
ATnc (d): Averaging time for non-carcinogenic effects	ED × 365 for residents	USDOE 2011
ATca (d): Averaging time for carcinogenic effects	LT × 365 for residents	USDOE 2011; USEPA 1997
LT (yr): Lifetime	70 for adult residents	USEPA 2009; WHO 2014
ET (h/d): Exposure time	1 for residents for the site specific	USDOE 2011
CF (kg/mg): Conversion factor	1×10^{-6}	Man et al. 2010, 2013
SA (cm^2): Skin surface that are available for exposure	Resident, 2800 for child and 3300 for adult	USDOE 2011
AF (mg/cm^2): Soil to skin adherence factor	Resident, 0.2 for child and 0.007 for adult	USDOE 2011
ABS_d (unitless): Dermal absorption factor	0.03 for As and 0.001 for other metals	USEPA 2011
InhR (m^3/d): Inhalation rate	20 for both adult and child	USEPA 1997
PEF (m^3/kg): Particle emission factor	1.36×10^{9}	USDOE 2011; USEPA 2011

Table 2 Definitions of the parameters for the human health risk assessments

Symbol (units)	Definition
C (mg/kg)	Concentration of metal in soil;
ABS_{GI}	Gastrointestinal absorption factor;
CDI_{ing}, CDI_{inh}, and CDI_{dermal}	Chronic daily intake or dose contacted through oral ingestion (mg/kg/d), inhalation of (mg/m^3 for non-cancer and $\mu g/m^3$ for cancer), and dermal contact (mg/kg/d) with soil particles, respectively;
$CSF_{ing}(mg/kg/d)^{-1}$	Chronic oral slope factor;
CSF_{dermal}	Chronic dermal slope factor, $= CSF_{ing}/ABS_{GI}$
IUR $(\mu g/m^3)^{-1}$	Chronic inhalation unit risk;
RfD_{ing}(mg/kg/d)	Chronic oral reference dose;
RfC_{inh} (mg/m^3)	Chronic inhalation reference concentration;
RfD_{dermal}	Chronic dermal reference dose, $=RfD_{ing} \times ABS_{GI}$

Table 3 Some toxicological characteristics of the investigated hazardous elements used for health risk assessments

Metals	$RfD_{ingestion}$ (mg/kg/day)	ABS_{GI}	$RfC_{inhalation}$ (mg/m^3)	$CSF_{ingestion}$ $(mg/kg/day)^{-1}$	IUR $(\mu g/m^3)^{-1}$
Cr	0.003[a]	0.013	2.86E-05		
Ni	0.02	0.04	0.00009		
Cu	0.04	1	0.002		
As	0.0003	0.41	3.01E-04	1.5[b]	4.30E-03
Cd	0.001	0.025	1.00E-05		
Pb	0.004	1	3.00E-04	8.50E-03	1.20E-05
References	USDOE 2011	USEPA 2011	USDOE 2011	USDOE 2011	USDOE 2011

[a]USEPA 2002; [b]USEPA 2010

that all the hazardous elements risks were additive, hence, it is possible to calculate the cumulative non-carcinogenic risk expressed as the hazard index [HI, Eq. (5)], and carcinogenic risk expressed as the total cancer risk Eq. (9).

Reference toxicity values for dermal absorption were calculated as in Risk Assessment Information System (RAIS) (USDOE 2011). Oral reference doses were multiplied and slope factors divided by a gastrointestinal absorption factor to yield the corresponding dermal values. The reference dose (RfD) (mg/kg/day) is an estimation of maximum permissible risk on human population through daily exposure, taking into consideration sensitive group (children). In general, there are two RfD for two exposure pathways: RfD (mg/kg/day) for ingestion, RfD (mg/kg/day)×gastrointestinal absorption factor (ABSGI) for dermal contact. If the CDI is less than the RfD, HQ≤1, it is considered that there will be no adverse health effects, whereas, if the CDI exceeds the RfD, HQ>1, it is likely that there will be adverse health effects (USEPA 1989, 2001). Furthermore, the guidelines for health risk assessment of chemical mixtures assumed that "simultaneous sub threshold exposures to several chemicals could result in an adverse health effect" and "the magnitude of the adverse effect will be proportional to the sum of the ratios of the sub threshold exposures to acceptable exposures" (USEPA 1986). Hence, HQs can be added and generate a hazard index (HI) to estimate the risk of mix contaminants Eq. (5) (USEPA 1989). The guidelines also states that any single chemical with an exposure level greater than the toxicity value will cause the hazard index to exceed unity, for multiple chemical exposures the HI can also exceed unity even if no single chemical exposure exceeds its RfD. In general, the excess cancer risks lower than 10^{-6} (a probability of 1 chance in 1,000,000 of an individual developing cancer) are considered to be negligible, cancer risks above 10^{-4} are considered unacceptable by most international regulatory agencies (Guney *et al*. 2010, USEPA 1989) and risks lying between $10^{-6}$and 10^{-4} are generally considered an acceptable range, depending on the situation and circumstances of exposure (Fryer *et al*. 2006, Hu *et al*. 2012). The value 10^{-6} is also considered the carcinogenic target risk by USEPA (2011).

2.6 Statistical analysis

The data were statistically analyzed using the statistical package, SPSS 16.0 (SPSS, USA). The means and standard deviations of the metal concentrations in soils were calculated. The 5th and 95th percentile values were also calculated.

3. Results and discussion

3.1 Metal contamination in soil

The concentration of six hazardous elements (Cr, Ni, Cu, As, Cd and Pb) in soil samples of different land uses are presented in Fig. 3. The mean concentration of hazardous elements in soils were in the following decreasing order of Cu (267) > Cr (239) > Ni (206) > Pb (195) > As (58) > Cd (16 mg/kg). The levels of hazardous elements varied among the land types and followed the descending order of TW > MW > EW > AF > GW > BS > CW > BF > HW > GPS > PG > PA. Among the sites, soil sample from metal workshop and electric waste disposal sites showed the highest values of Ni, Cu, Cd and Pb, whereas, tannery waste (TW) disposal site contained the highest amounts of Cr (1112 mg/kg) and As (276 mg/kg) (Fig. 3). High level of Cr in soil of TW site can be due to the waste from chromate smelters (Srinivasa *et al*. 2010) and As due to the use of ground water containing As (Neumann *et al*. 2010, Hug *et al*. 2011, Islam *et al*. 2014b), some chemicals especially arsenic sulfide (Bhuiyan *et al*. 2011). The highest Cu and Pb concentrations were observed in soil of metal workshop, electric waste and waste burning sites; which can be due to the emission of Cu and Pb from burning activities (Luo *et al*. 2011b, Srinivasa *et al*. 2010). The highest mean concentration of Cd was obtained in soil of EW disposal site (34 mg/kg) and Pb at BS site (365 mg/kg). The notable industrial activities observed at the sampling sites were tanneries, lead smelting, battery manufacturing, metal processing etc. where, solid and liquid wastes emanating from the tanning industry were known to contain various toxic metals (McMartin *et al*. 1999, Islam *et al*. 2015). Metal processing, battery manufacturing and smelting industries cause severe metal pollution have been reported from areas surrounding smelters in many countries (Martley *et al*. 2004, Rawlins *et al*. 2006). During our sampling, we observed leachates from defused Ni-Cd batteries, Cd plated items, casting lead and lead products manufacturing at these sites. According to Srinivasa *et al*. (2010), huge amount of Cr is released from tannery industry, Cu from steel manufacturing industry, Pb from smelting, motor-vehicle

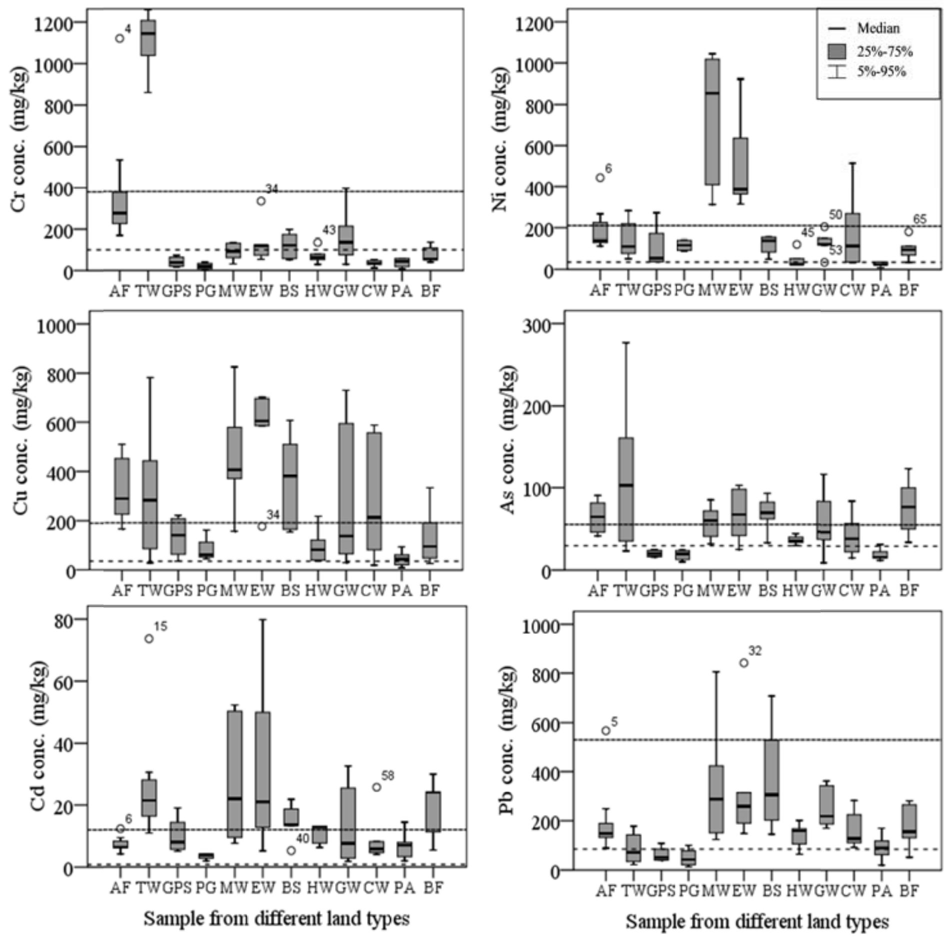

Fig. 3 Metal concentrations in soils of 12 different land types in Dhaka City, Bangladesh. The horizontal dash lines indicate Dutch soil quality standards for target and intervention value

exhaust fumes and from corrosion of lead pipe work. Textile and garments industries can act as one of the major sources of metal pollution in the environment (Kashem and Singh 1999, Islam *et al*. 2014b, 2015). Some hazardous elements showed higher standard deviation among the sites and such high deviation may be indicative of the lack of uniformity of the elemental distribution across the sites. This might possibly due to varied land use activities and disturbances such as digging, excavation and construction, as well as other natural processes such as weathering and erosion (Amuno 2013).

In the present study we used Dutch soil quality standards (VROM 2000) for hazardous elements in soil to understand the current situation of metal contamination, since in Bangladesh there was no locally-derived environmental standard for hazardous elements contamination in soil. Mean concentrations of Ni, Cu, As, Cd and Pb of different land uses soils were higher than the Dutch soil quality standards (Fig. 3). The level of pollution from Cr at the tannery waste site and the other metals in soil of metal workshop and electric waste disposal sites was high and potentially detrimental to the surrounding ecosystems.

3.2 Health risk assessment

Hazardous elements in the contaminated soils might have a serious impact on human health. In the urban areas, the risks of hazardous elements in playground, residential, traffic, industrial, waste burning sites and brick fields are especially significant taking into consideration the exposure through ingestion, dermal contact and inhalation (De Miguel *et al*. 2007, Zheng *et al*. 2010). According to the human health risk assessment approach for hazardous elements in soil, the non-carcinogenic and carcinogenic risk, the cumulative HI and risk of multi-pathway exposure and combined metals in urban soils of Dhaka City were characterized.

3.3 Non-carcinogenic risk

In this study, mean concentrations of hazardous elements from individual site were used for estimating the non-cancer risk on human through the ingestion, dermal contact and inhalation of soils. The hazard quotients (HQs) and hazard index (HI) for both adults and children are presented in Fig. 4 and Table 4. Considering the single exposure media, there was no non-cancer risk on adults and children, whereas, children posed non-carcinogenic risk of hazardous elements (HI>s1) at AF, TW, GPS and BS sites through ingestion (Fig. 4). However, when considering the total exposure HI of ingestion, dermal contact and inhalation; there was a chance of having non-cancer risk at most of the sites on adults and children. In general, the selected land types in this study were more detrimental to children than adults, mainly through ingestion of soil. Children might be exposed to soil bounded contaminants, including hazardous elements, at elevated levels due to

Table 4 Total exposures [Hazard Index (HI)] of ingestion, dermal contact and inhalation of soils on adult and child in 12 different land types at 5th, median and 95th percentiles

	Total exposure Hazard Index (HI) of ingestion, dermal contact and inhalation					
Sites	Adult			Child		
	5th Percentile	Median	95th Percentile	5th Percentile	Median	95th Percentile
AF	0.24	0.36	0.57	0.79	**1.2**	**2.1**
TW	0.51	0.98	**2.9**	**1.4**	**2.6**	**4.8**
GPS	0.19	0.30	0.65	0.28	0.36	0.45
PG	0.09	0.16	0.18	0.21	0.30	0.35
MW	0.41	0.85	**1.8**	0.91	**1.2**	**1.4**
EW	0.28	0.86	**2.7**	0.87	**1.6**	**1.8**
BS	0.25	0.63	0.81	0.70	**1.2**	**1.8**
HW	0.26	0.49	0.50	0.55	0.60	0.70
GW	0.11	0.36	**1.2**	0.44	0.96	**1.8**
CW	0.19	0.26	0.90	0.31	0.70	**1.3**
PA	0.11	0.27	0.50	0.28	0.37	0.39
BF	0.25	0.90	**1.2**	0.66	**1.1**	**1.7**

Note: Hazard Index>1=Bold

their behaviors, increasing indirect ingestion by way of hand-to-mouth activities, touching and mouthing of various dust-contaminated objects (Mielke *et al.* 1999). Moreover, the ingestion of greater amounts of small soil particles would have a greater impact on children because of their smaller body-weight compared to adults (Beamer *et al.* 2008). Through ingestion, children tend to be exposed to greater amount of soil than adults due to pica and play behavior (Murgueytio *et al.* 1998, CDC 2005). The HI values for children were higher than adults and total exposure of metals through the three pathways were greater than 1 for both groups of population at AF, TW, MW, EW, BS, GW, CW and BF sites (Table 4). Hence, soil samples from the urban areas of Bangladesh were detrimental to both adults and children. According to Fig. 4 the HQ of ingestion for children indicated that soil samples in these land types were detrimental through ingestion. Approximately 67% of soil samples at these land types were harmful to children due to ingestion pathway.

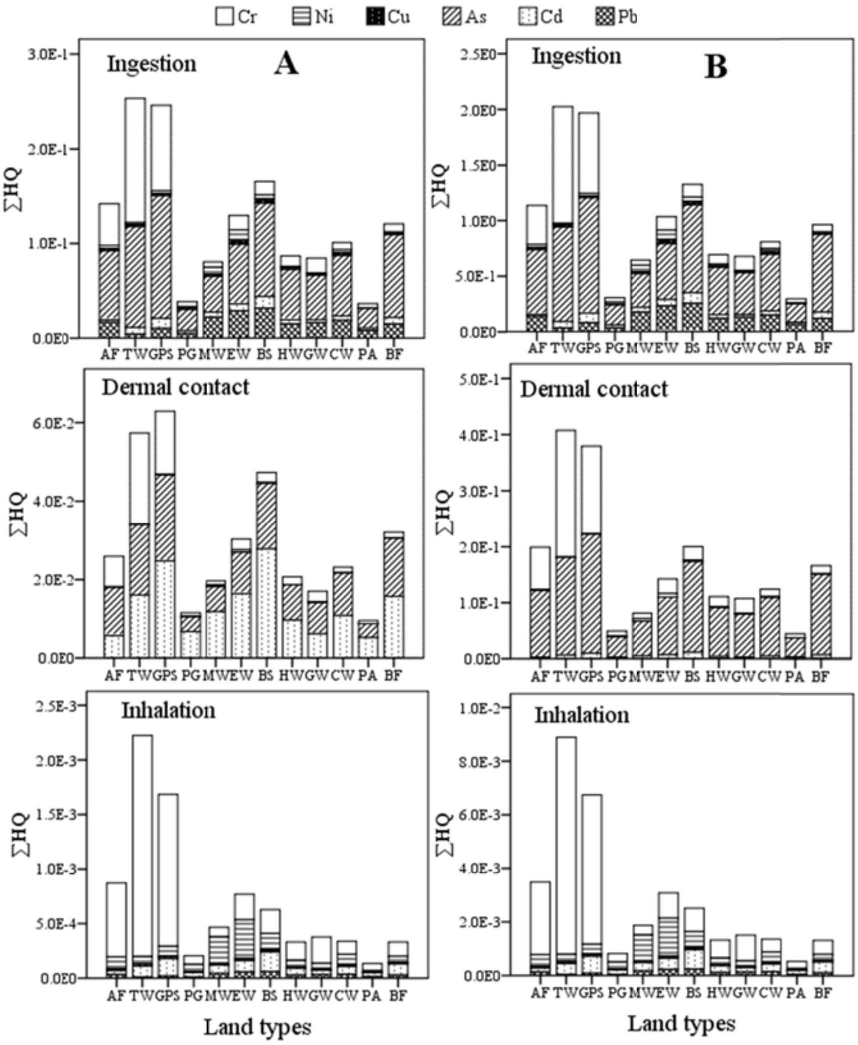

Fig. 4 Hazard index (∑HQ) of metals through ingestion, dermal contact and inhalation of soils for adult (A) and child (B) in 12 different land types in Dhaka City, Bangladesh

Table 5 Carcinogenic risk of arsenic and lead due to ingestion, dermal contact and inhalation of soil in Dhaka City, Bangladesh

	Arsenic (As)			Sum of all	Lead (Pb)			Sum of all
	Ingestion	Dermal	Inhalation	pathways	Ingestion	Dermal	Inhalation	pathways
AF	1.4×10^{-5}	6.9×10^{-7}	7.4×10^{-10}	1.5×10^{-5}	2.5×10^{-7}	9.9×10^{-10}	6.4×10^{-12}	2.5×10^{-7}
TW	2.0×10^{-5}	1.2×10^{-6}	1.3×10^{-9}	2.6×10^{-5}	1.1×10^{-7}	4.3×10^{-10}	2.8×10^{-12}	1.1×10^{-7}
GPS	4.3×10^{-6}	2.1×10^{-7}	2.3×10^{-10}	4.6×10^{-6}	7.8×10^{-8}	3.1×10^{-10}	2.0×10^{-12}	7.8×10^{-8}
PG	3.9×10^{-6}	1.9×10^{-7}	2.1×10^{-10}	4.1×10^{-6}	6.2×10^{-8}	2.5×10^{-10}	1.6×10^{-12}	6.2×10^{-8}
MW	1.3×10^{-5}	6.3×10^{-7}	6.7×10^{-10}	1.3×10^{-5}	4.3×10^{-7}	1.7×10^{-9}	1.1×10^{-11}	4.3×10^{-7}
EW	1.5×10^{-5}	7.2×10^{-7}	7.7×10^{-10}	1.5×10^{-5}	4.4×10^{-7}	1.7×10^{-9}	1.1×10^{-11}	4.4×10^{-7}
BS	1.5×10^{-5}	7.4×10^{-7}	7.9×10^{-10}	1.6×10^{-5}	4.6×10^{-7}	1.8×10^{-9}	1.2×10^{-11}	4.6×10^{-7}
HW	7.9×10^{-6}	3.9×10^{-7}	4.2×10^{-10}	8.3×10^{-6}	1.7×10^{-7}	6.9×10^{-10}	4.5×10^{-12}	1.7×10^{-7}
GW	1.2×10^{-5}	6.1×10^{-7}	6.5×10^{-10}	1.3×10^{-5}	3.1×10^{-7}	1.2×10^{-9}	8.1×10^{-12}	3.1×10^{-7}
CW	9.3×10^{-6}	4.6×10^{-7}	4.9×10^{-10}	9.7×10^{-6}	2.0×10^{-7}	8.0×10^{-10}	5.2×10^{-12}	2.0×10^{-7}
PA	4.2×10^{-6}	2.1×10^{-7}	2.2×10^{-10}	4.4×10^{-6}	1.2×10^{-7}	4.6×10^{-10}	3.0×10^{-12}	1.2×10^{-7}
BF	1.7×10^{-5}	8.3×10^{-7}	8.9×10^{-10}	1.8×10^{-5}	2.2×10^{-7}	8.7×10^{-10}	5.6×10^{-12}	2.2×10^{-7}

3.4 Carcinogenic risk

The carcinogenic risk of As and Pb for adults are presented in Table 5. The cancer risks from As and Pb at all other sites via the different pathways were within acceptable levels. The range of carcinogenic risk for As was (3.9×10^{-6} to 2.5×10^{-5}), (1.9×10^{-7} to 1.2×10^{-6}) and (2.1×10^{-10} to 1.3×10^{-9}) and Pb (6.2×10^{-8} to 4.6×10^{-7}), (2.5×10^{-10} to 1.8×10^{-9}) and (1.6×10^{-12} to 1.2×10^{-11}) for ingestion, dermal contact and inhalation (Table 5). For all sampling sites, carcinogenic risk posed by Pb was lower than 10-6 through different exposure pathways. The carcinogenic risks of As following exposure from urban soil via ingestion, dermal contact and inhalation pathways cannot be negligible in Dhaka City, Bangladesh, as some sites exceeding the target value 10^{-6} (USEPA 2011).

Among the three exposure pathways, the ingestion of soil seems to be the major pathway of exposure to hazardous elements followed by dermal contact and inhalation. Hazardous elements could be accumulated in human for a long time and especially non-cancer adverse effects of these metals to the tissues of adult population can become more serious. Therefore, based on the results of the present study, the potential health risk for adults and children due to metal exposure through soil could not be overlooked.

4. Conclusions

This study showed that the examined soils were heavily contaminated by hazardous elements. Although the individual hazardous elements through single pathway did not show considerable health risk, their combined effects were of particular concern. The soil ingestion and dermal contact for both the adults and children were the major routes with high substantial values based on HI value greater than 1 indicating potential non-cancer risk at most of the sites on adults and children due to the exposure to hazardous elements.

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