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Trace elements in different land use soils of Bangladesh and potential ecological risk

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Abstract Bogra city is highly susceptible to environmental pollution due to overpopulation, rapid industrialization, and urbanization during the last decades. The levels of six trace elements (chromium, nickel, copper, arsenic, cadmium, and lead) in seven different land use soils in Bangladesh were assessed. The ranges of Cr, Ni, Cu, As, Cd, and Pb in studied soils were 6.3–256, 8.3–271, 13–279, 7.5–87, 0.09–29, and 5.3–624 mg/kg, respectively. The pollution load index (PLI) values for all land uses were higher than 1, indicating the progressive deterioration of soil due to trace elements contamination. In view of the potential ecological risk (PER), soils from all land uses showed moderate to very high potential ecological risk. Among the elements, As and Cd showed a higher potential ecological risk than the others.

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Introduction

The contamination of soil by trace elements is a global problem that is greatly influenced by anthropogenic activities (Han et al. 2002; Vare 2006). Soil is a dynamic natural resource for the survival of human life and regarded as the key receiver of the relentless pollutants like trace elements (Luo et al. 2007; Karim et al. 2014). High concentrations of trace elements in soil have significant negative impacts on crop growth, as these elements are responsible for metabolic dysfunctions in plants, inhibition of photosynthesis, respiration, and degeneration of main cell organelles, even leading to death of plants and creates other environmental problems (Papa et al. 2010; Atafar et al. 2010; Schwartz et al. 2003). Indeed, problems relating to the presence of trace elements in agricultural soils are well known and their adverse impacts have already been studied in many parts of the world (Kheir 2010; Sun et al. 2010), including

Bangladesh (Islam et al. 2014a; Ahmed et al. 2015a). In recent decades, there has been a significant concern regarding soil contamination by various toxic elements due to rapid industrialization and urbanization, especially in developing countries (Chen et al. 2010; Sun et al. 2010; Islam et al. 2014b; Ahmed et al. 2015b). However, in the urban areas, trace elements may originate from various sources of which are industrial activities, power generation, mining, smelting, waste spills, or fossil fuel combustion and waste disposal (Wei and Yang 2010; Li and Feng 2012; Rodríguez Martín et al. 2014; Karim et al. 2014; Islam et al. 2015a). However, the accumulation of trace elements in soils is a big concern due to their potential ecological risk and detrimental effects on soil ecosystems (Cui et al. 2004; Li et al. 2009; Yu et al. 2012; Yuan et al. 2014).

Different methods have been widely used to assess the ecological risks of trace elements in soil, such as enrichment factor (EF), contamination factor (CF), and geoaccumulation index (I_{geo}) (Rashed 2010; Liu et al. 2014). To evaluate the combined risk of multiple trace elements in soil, the pollution load index (PLI) and potential ecological risk index (PER) have also been developed (Huang et al. 2013). The EF of an area indicates the relative enrichment in any contaminant when compared to pre-industrial soils from the same environment (Sayadi and Sayyed 2011; Dias et al. 2014; Hower et al. 2013).

As a pioneer of industrialization and urbanization in Bangladesh, the study area have raised attention due to its environmental pollution which is facing serious threats due to elemental pollution originated from the district's rapid expansion, congestion, and activities from industries (Islam et al. 2015b). Several studies have reported the concentration of trace elements in the urban agricultural soils in Bangladesh (e.g., Kashem and Singh 1999; Ahmad and Goni 2010; Rahman et al. 2012; Islam et al. 2014). Nevertheless, these studies did not consider the land use aspect as an indicator which could have a strong influence on the concentration of trace elements in urban soils (Cerqueira et al. 2012; Saikia et al. 2014; Martinello et al. 2014). Therefore, in this study the variations of trace elements in soils of different land uses were investigated. The hypothesis of the present study states that trace element concentrations of urban soils depend on land uses. The objectives of this study are to address the problem of Cr, Ni, Cu, As, Cd, and Pb in soils and to assess the ecological risk of trace elements in soils of different land uses in Bangladesh.

Materials and methods

Study area and sample collection

This study focused on seven different land uses (agriculture field, dairy farm, railway station, waste disposal, market, hatchery, and poultry farm sites) of urban soils of Bogra city, Bangladesh (Fig. 1). The area of Bogra district is about 71.56 km^2, the total population of this district is about 350,397. The study area is located at the northern part of Bangladesh, and the coordinates of Bogra district is 24° 84′ 91.82″ N and 89° 37′ 29.57″ E. Bogra is one of the newly industrially based areas of Bangladesh, which is highly susceptible to environmental pollution due to overpopulation, rapid industrialization, and urbanization in last 10 years. There are several types of industrial units, including aluminum factory, tannery, pharmaceutical industry, cosmetics industry, diesel plant, ceramics factory, packaging industry, brick field, and garments (Anonymous 2007). The basic information of the study area is presented in Table S1. About 48 composite soil samples (up to 20 cm) were collected during February–March and August–September 2013. For considering the pre-industrial sample, soil was taken by means of percussion hammer corer (50–80 cm in length) for trace elements analysis (Schottler and Engstrom 2006). Lead-210 dating by alpha spectrometry method was used to determine the soil age and accumulation rates (Islam et al. 2015c). Samples were air-dried at room temperature for 2 weeks and then sieved through 2-mm nylon sieve to discard the gravel or mineral fraction. Before physical or chemical analysis, the dried samples were crumbled with a porcelain mortar and pestle and stored in airtight clean Ziploc bag and kept frozen.

Sample analysis

All chemicals were analytical grade reagents, and Milli-Q (Elix UV5 and Milli-Q, Millipore, USA) water was used for the preparation of solution. For trace elements analysis, 0.5 g of 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 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).
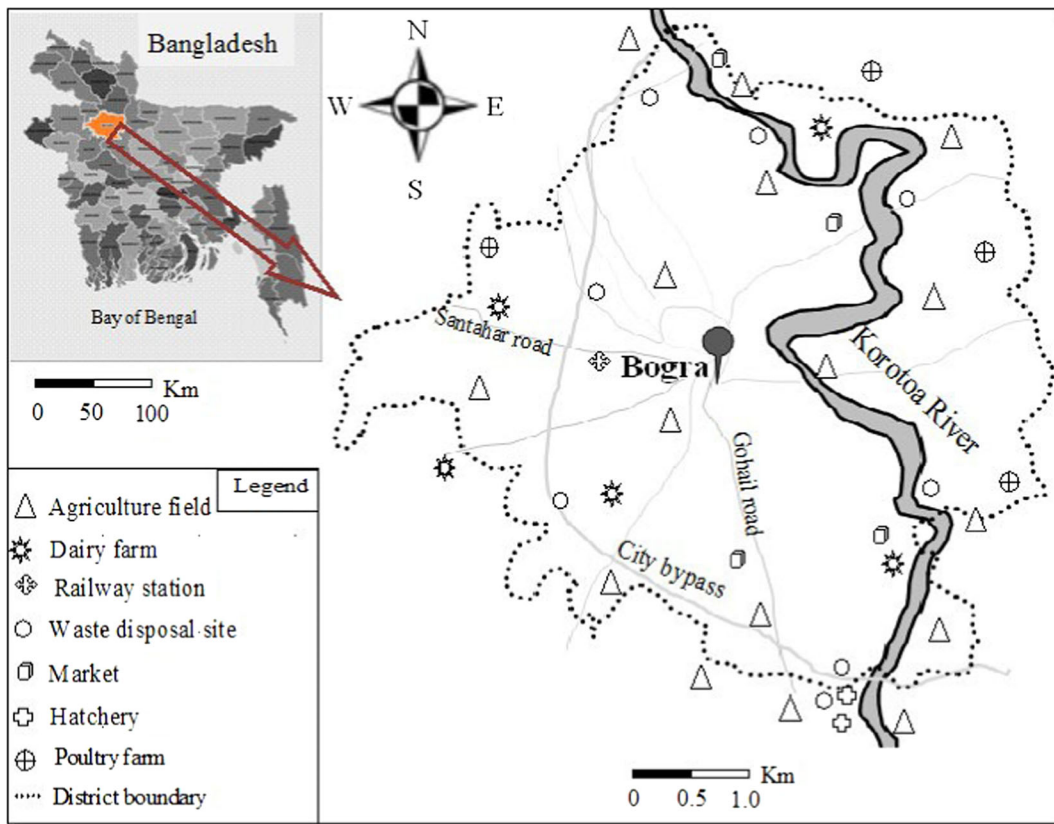
Fig. 1 Map of the study area of Bogra district in Bangladesh

Instrumental analysis and quality control

The samples were analyzed using inductively coupled plasma mass spectrometer (ICP-MS). Multi-element Standard XSTC-13 (Spex CertiPrep®, Metuchen, USA) solution was used to prepare calibration curve. Multi-element solution (Agilent Technologies, USA) of 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. Instrument operating conditions and parameters for metal analysis are presented in Table S2.

Calculation of soil pollution indexes

Enrichment factors (EFs)

EF is a good methodology to differentiate the metal source of anthropogenic origin from those occurring naturally in the environment (Zhang et al. 2009). The enrichment factor of trace elements is measured by normalizing the given concentration of trace elements in soils to the percentage of aluminum, iron, or organic carbon concentrations (Luoma and Rainbow 2008; Islam et al. 2015c). The EF is calculated according to the following equation:

$$\mathrm{EF} = \left(C_M \big/ C_{Al} \right)_{\mathrm{sample}} \Big/ \left(C_M \big/ C_{Al} \right)_{\mathrm{background}} \qquad (1)$$

where $(C_M/C_{Al})_{\mathrm{sample}}$ is the ratio of concentration of trace elements (C_M) to that of aluminum (C_{Al}) in the soil sample, and $(C_M/C_{Al})_{\mathrm{background}}$ is the same reference ratio in the pre-industrial sample. Generally, an EF value of about 1 suggests that a given element may be entirely from crustal materials or natural weathering processes (Rashed 2010). Samples having enrichment factor >1.5 was considered indicative of human influence, and (arbitrarily) an EF of 1.5–3, 3–5, 5–10, and >10 is considered the evidence of minor, moderate, severe, and very severe modifications, respectively (Islam et al. 2015c).

Table 1 Concentrations of trace elements (mg/kg) in soils of different land uses and guideline values

Sites		Al	Cr	Ni	Cu	As	Cd	Pb
Agriculture field ($n=16$)	Mean±SD	15±7.0	54±29[a]	83±69[a]	57±64[a]	36±21[ab]	6.3±3.8[a]	97±81[ab]
	Range	5.5–29	20–130	21–271	12–279	8.7–87	1.3–16	5.3–362
Dairy farm ($n=5$)	Mean±SD	17±10	81±33[ab]	57±5.5[a]	33±23[a]	11±3.8[a]	2.0±2.4[a]	18±12[a]
	Range	7.2–17	41–130	50–65	13–68	7.5–16	0.09–5.9	5.8–36
Railway station ($n=4$)	Mean±SD	18±4.2	97±40[ab]	116±95[a]	85±27[ab]	31±22[ab]	4.5±5.6[a]	226±60[bc]
	Range	12–22	47–138	21–232	64–122	13–63	0.81–13	162–298
Waste disposal site ($n=7$)	Mean±SD	17±7.7	118±64[b]	107±80[a]	166±34[b]	46±19[b]	15±8.3[b]	375±206[c]
	Range	9.1–31	68–256	27–223	105–213	24–71	6.9–29	123–624
Market ($n=5$)	Mean±SD	15±4.8	45±8.3[ac]	40±17[a]	104±28[ab]	44±15[b]	2.3±1.1[a]	97±59[ab]
	Range	12–23	38–59	16–55	75–133	32–60	0.71–3.5	47–174
Hatchery site ($n=4$)	Mean±SD	18±3.5	71±29[a]	89±40[a]	76±35[ab]	57±7.2[b]	3.2±1.1[a]	119±41[ab]
	Range	14–22	37–108	52–141	39–124	49–66	2.3–4.7	69–162
Poultry farm ($n=7$)	Mean±SD	17±5.7	81±57[a]	53±35[a]	106±60[ab]	42±24[ab]	5.4±2.4[a]	131±69[ab]
	Range	12–29	6.3–179	8.3–95	22–191	25,538	2.0–7.9	21–204
Background value of Bangladesh soil[a]		NA	22	27	3	0.01–0.2	20.0	
Dutch soil quality standard (target value)[b]		100	35	36	29	1	85	
Dutch soil quality standard (intervention value)[b]		380	210	190	55	12	530	
Canadian Environmental Quality Guidelines[c]		64	50	63	12	1.4	70	
Department of Environmental Protection, Australia[d]		50	60	60	20	3	300	

Vertical letters *a*, *b*, and *c* show statistically significant differences at ($P<0.05$) among the land uses of each element

[a] Kashem and Singh (1999)

[b] VROM (2000)

[c] CCME (2003)

[d] DEP (2003)

Contamination factor (C_f^i)

The C_f^i is the ratio obtained by dividing the concentration of each element in the soil by the baseline or background value (trace elements in the pre-industrial soil of the study area):

$$C_f^i = \frac{C_{\text{trace element}}}{C_{\text{background}}} \qquad (2)$$

The contamination levels may be classified based on their intensities on a scale ranging from 1 to 6 (Luo et al. 2007; Rashed 2010; Islam et al. 2015b) (Table 4). The C_f^i values can monitor the enrichment of one given metal in soils over a period of time.

Pollution load index (PLI)

To assess the quality of soil in terms of trace elements contamination, an integrated approach of pollution load index of the six trace elements is calculated according to Rashed (2010). The PLI is defined as the *n*th root of the multiplications of the contamination factor (C_f^i) of trace elements (Bhuiyan et al. 2010; Islam et al. 2015b, c).

$$\text{PLI} = \left(C_{f1}^i \times C_{f2}^i \times C_{f3}^i \times \ldots \ldots \times C_{fn}^i \right)^{1/n} \qquad (3)$$

The PLI gave an assessment of the overall toxicity status of the sample and also it is a result of the contribution of the six trace elements.
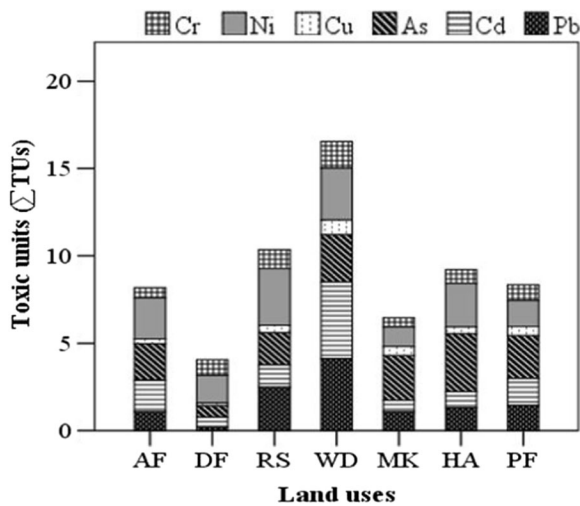
Fig. 2 Sum of the toxic units ($\sum$TUs) of trace elements in different land uses soils

Potential ecological risk (PER)

PER index is introduced to assess the degree of trace elements contamination in soils. The equations used for calculation of PER were proposed by Guo et al. (2010) and are as follows:

$$C_f^i = \frac{C^i}{C_n^i}, \qquad C_d = \sum_{i=1}^{n} C_f^i \qquad (4)$$

$$E_r^i = T_r^i \times C_f^i, \quad \mathrm{PER} = \sum_{i=1}^{m} E_r^i \qquad (5)$$

where C_f^i is the single element contamination factor, C^i is the content of the trace elements in samples, and C_n^i is the background value of trace elements. The background values (pre-industrial samples of the study area) of Cr, Ni, Cu, As, Cd, and Pb in soils were 29,

32, 27, 6.5, 0.82, and 23 mg/kg, respectively (Islam et al. 2015b). The sum of C_f^i for all trace elements represents the integrated pollution degree (C_d) of the environment. E_r^i is the potential ecological risk index, and T_r^i is the biological toxic factor of an individual element. The toxic-response factors for Cr, Ni, Cu, As, Cd, and Pb were 2, 6, 5, 10, 30, and 5, respectively (Xu et al. 2008; Guo et al. 2010; Islam et al. 2015b, c). PER is the comprehensive potential ecological risk index, the sum of E_r^i. It represents the sensitivity of the biological community to the toxic substance and illustrates the potential ecological risk caused by the overall contamination.

Statistical analysis

The data were statistically analyzed using the statistical package, SPSS 16.0 (SPSS, USA). The means and standard deviations of trace elements concentrations in soils were calculated. Multivariate post hoc Tukey test was performed to detect significant differences in concentration of trace elements for different land use soil.

Results and discussion

Trace element concentrations in soil

The concentrations of trace elements (Cr, Ni, Cu, As, Cd, and Pb) in soils are presented in Table 1. The levels of trace elements were varied among the sampling sites and followed the descending order of waste disposal (WD)>railway station (RS)>poultry farm (PF)>hatchery (HA)>agriculture field (AF)> market (MK)>dairy farm (DF). It was observed that some trace elements in soils of some sites showed higher standard deviation. Such high deviation may

Table 2 Enrichment factor of trace elements in different land uses soils of Bogra district, Bangladesh

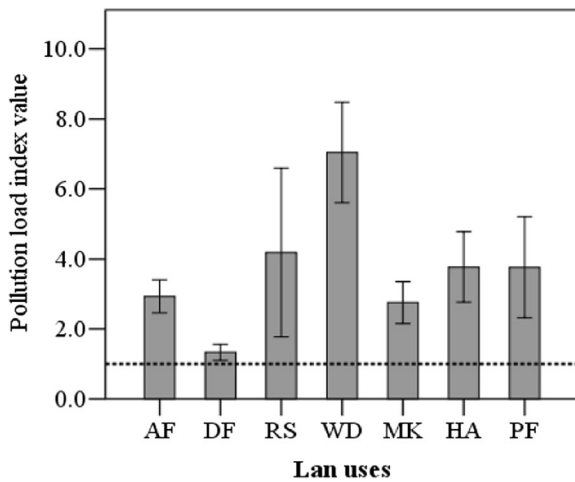|	Cr	Ni	Cu	As	Cd	Pb
AF	1.0±0.57	1.5±1.2	1.2±1.3	3.1±1.8	4.3±2.6	2.4±2.0
DF	1.4±0.57	0.90±0.09	0.62±0.44	0.85±0.30	1.2±1.5	0.40±0.27
RS	1.7±0.69	1.8±1.5	1.6±0.50	2.4±1.7	2.8±3.4	5.0±1.3
WD	2.4±1.1	1.7±1.3	3.1±0.64	3.6±1.5	9.5±5.1	8.3±4.5
MK	0.79±0.14	0.64±0.27	1.9±0.53	3.4±1.2	1.4±0.70	2.1±1.3
HA	1.2±0.51	1.4±0.63	1.4±0.66	4.4±0.56	2.0±0.67	2.6±0.90
PF	1.4±1.0	0.84±0.56	2.0±1.1	3.2±1.9	3.4±1.5	2.9±1.5

Fig. 3 Pollution load index (PLI) of trace elements in different land uses soils (*error bar* represents±SE)

be indicative of the lack of uniformity of the elemental distribution across the site such as digging, excavation, and construction, as well as other natural processes, such as weathering and erosion, which could alter the stabilization of the soil environment (Amuno 2013; Arenas-Lago et al. 2013, 2014; Cerqueira et al. 2011, 2012; Silva et al. 2011; Quispe et al. 2012). The mean concentration of Cr in soil of WD site was higher than the Department of Environmental Protection, Australian guideline values (DEP 2003) (Table 1). The highest concentration of Cr was obtained at the WD site followed by RS which could be resulted from the disposal of untreated waste from the districts' urban area (Srinivasa et al. 2010). Statistically significant difference ($P<0.05$) was observed for Cr concentration among some land uses in the study area (Table 1). The highest mean concentration of Ni was observed in soil at RS site (116±95 mg/kg) followed by WD site (107±80 mg/kg). The high level of Ni in soils of RS, WD, AF, and HA sites might be the result from localized additions or accidental spillages of highly concentrated materials that might contain Ni (Krishna and Govil 2007).

Elevated levels of Cu were observed in soils at WD site (166±34 mg/kg) followed by the PF site (106±60 mg/kg) which could be due to the emission from different waste burning activities at these sites (Kashem and Singh 1999; Srinivasa et al. 2010). The highest mean concentration of As was found in soil collected from HA site (57±7.2 mg/kg) followed by the WD site (46±19 mg/kg).

Table 3 Indices and grades of potential ecological risk of trace elements pollution (Luo et al. 2007)

Contamination factor (C_f^i)	Contamination degree of individual metal	Degree of contamination (C_d)	Contamination degree of the environment	E_r^i	Grade of ecological risk of individual metal	Potential ecological risk (PER)	
$C_f^i<1$	Low	$C_d<5$	Low contamination	$E_r^i<40$	Low risk	PER<65	Low risk
$1\leq C_f^i<3$	Moderate	$5\leq C_d<10$	Moderate contamination	$40\leq E_r^i<80$	Moderate risk	$65\leq$PER<130	Moderate risk
$3\leq C_f^i<6$	Considerable	$10\leq C_d<20$	Considerable contamination	$80\leq E_r^i<160$	Considerable risk	$130\leq$PER<260	Considerable risk
$C_f^i\geq6$	High	$C_d\geq20$	High contamination	$160\leq E_r^i<320$	High risk	PER≥260	Very high risk
				$E_r^i\geq320$	Very high risk		

Statistically significant difference ($P<0.05$) was observed for As concentration among the land uses in the study area. Most of samples exceeded the Dutch target value and Canadian as well as Australian guidelines values (Table 1). In general, huge amount of As-contaminated ground water (Polizzotto et al. 2013; Neumann et al. 2010) is being used for irrigation in agricultural fields along with various As-enriched fertilizers and pesticides (Bhuiyan et al. 2011; Alam et al. 2003). Moreover, emission and waste from hatchery and incineration activities might contribute to the high concentration of As in the study area (Olawoyin et al. 2012). It was also observed that individual concentration of some metals (Ni, Cu, As, Pb, and Cd) in some sites exceeded the Bangladesh background values, as well as the Dutch, Canadian, and Australian soil quality guidelines values (Table 1), indicating potential risks to the surrounding ecosystems.

Ecological risk assessment

The potential toxicity of trace elements in soils can be estimated as the sum of toxic units ($\sum$TUs), defined as the ratio of the determined concentration of trace elements in soil to probable effect levels (PELs) (Zheng et al. 2008; Islam et al. 2015b). Toxic unit (TU) and $\sum$TUs for trace elements in different land uses soils were presented in Fig. 2. Toxic units of trace elements in soils of land uses were decreased in the order of WD>RS>HA>PF>AF> MK>DF. The sum of toxic units for most land uses soils was higher than 4, indicating a moderate to serious toxicity of trace elements in soils (Bai et al. 2011).

In this study, the EF, PLI, contamination factor (C_f^i), and degree of contaminations (C_d) were applied to assess trace elements contamination in soils. The EF values for different land use soils are presented in Table 2. Among the sites, the descending order of EFs were as WD>PF>RS> AF>HA>MK>DF. As a whole, the EF of all the studied metals for all sites were in the descending order of Cd>Pb>As>Cu>Cr>Ni. For most of the sites EF of As, Cd, and Pb were higher than 1.5 (Table 2), indicating strong human influence from various urban activities of Bogra district (Rashed 2010). Generally, studies have observed that low enrichment values indicate a great contribution for crusted source to the soil, while high EFs indicate a significant contribution from anthropogenic sources (Yadao and Rajamani 2006; Rashed 2010).

The value of PLI equal to zero indicates perfection, 1 indicates the presence of only baseline level of contaminants, and value above 1 indicates progressive contamination of soil by trace elements (Rashed 2010; Islam et al. 2015b). As per above grade, soils from different land uses were polluted considerably, since the PLI values were higher than 1 (Fig. 3). Among the land uses, the highest PLI values were observed at WD site (7.0) followed by RS (4.2), HA (3.8), and PF (3.5) sites. An elevated level of PLI for WD, RS, HA, and PF sites suggested that the activities from waste burning and disposal from hatchery and poultry farm and emission from rail way station might caused some extent ecological risk of the urban area (Bhuiyan et al. 2010; Liu et al. 2014; Islam et al. 2015c).

The four categories of C_f^i, four categories of C_d, five categories of E_r^i, and four categories of PER are shown

Table 4 Contamination factor, degree of contamination, and contamination level of trace elements

Sites	Contamination factor (C_f^i)						Degree of contamination	Contamination level
	Cr	Ni	Cu	As	Cd	Pb		
Agriculture field ($n=16$)	1.9	2.6	2.1	5.5	**7.7**	4.2	*24*	Very high
Dairy farm ($n=5$)	2.8	1.8	1.2	1.7	2.4	0.79	11	Considerable
Railway station ($n=4$)	3.4	3.6	3.1	4.8	5.4	*9.8*	*30*	Very high
Waste disposal site ($n=7$)	4.8	3.3	*6.1*	*7.1*	*19*	*16.3*	*56*	Very high
Market ($n=5$)	1.6	1.3	3.9	6.7	2.8	4.2	*20*	Very high
Hatchery site ($n=4$)	2.5	2.8	2.8	*8.7*	3.9	5.2	*26*	Very high
Poultry farm ($n=7$)	2.8	1.7	3.9	*6.4*	6.6	5.7	*27*	Very high

Values in *italics* indicate very high contamination ($C_f^i>6.0$)

Table 5 Potential ecological risk factor, risk index, and pollution degree of trace elements in soils

Sites	Potential ecological risk factor (E_r^i)						Potential ecological risk (PER)	Pollution degree
	Cr	Ni	Cu	As	Cd	Pb		
Agriculture field ($n=16$)	3.7	16	11	55	*230*	21	*336*	Very high risk
Dairy farm ($n=5$)	5.6	11	6.1	17	73	4.0	116	Moderate risk
Railway station ($n=4$)	6.7	22	16	48	*163*	49	*305*	Very high risk
Waste disposal site ($n=7$)	9.55	20	31	71	*561*	81.6	*774*	Very high risk
Market ($n=5$)	3.1	7.5	19	67	85	21	203	Considerable risk
Hatchery site ($n=4$)	4.9	17	14	87	117	26	*266*	Very high risk
Poultry farm ($n=7$)	5.6	10	20	64	*199*	28	*326*	Very high risk

Values in *italics* indicate very high contamination ($E_r^i > 320$)

in Table 3. Among the land uses WD site showed very high contamination ($C_f^i > 6$) for Cu, As, Cd, and Pb in soil (Table 4), indicating that these metals might pose potential risk to the surrounding ecosystems (Rashed 2010). Overall, the C_f^i for studied elements was the descending order of Cd>Pb>As>Cu>Cr>Ni. The assessment of overall contamination was based on the degree of contamination (C_d) where most of the sites showed very high degree of contamination ($C_d > 20$) (Table 4).

According to the potential ecological risk index of individual metals (E_r^i) and the PER index of the environment (Table 5), soils from AF, RS, WD, HA, and PF sites were classified as very high potential ecological risk. The order of E_r^i in soils were in the following descending order of Cd>As>Pb>Cu>Ni>Cr. Considerable variations were observed for the potential ecological risk index (E_r^i) of individual metals, indicating that ecological risk of trace elements varied with different land uses (Table 5). Cadmium contributes significantly to the PER index of the environment which can be due to the effect from anthropogenic activities (application of phosphate fertilizers and industrial activities) (Rodríguez Martín et al. 2013). PER represents the sensitivity of various biological communities to different toxic substances and illustrates the potential ecological risk caused by trace elements. The PER of the environment for the different land uses can be ranked in the following order: WD>PF>AF>RS>HA>MK>DF. As a whole, the ranges of PER for all kinds of lands were 116–774, indicating moderate to very high ecological risk. The maximum value of PER (774 in soil at WD site in Table 5) denotes very high potential ecological risk for land receiving waste from waste disposal activities.

Conclusions

Concentrations of Ni, Cu, As, Pb, and Cd in some sites exceeded background values, as well as the Dutch, Canadian, and Australian soil quality guidelines values, suggesting that soils were contaminated by trace elements. The study also confirmed that trace element concentrations in urban soils were varied with different land uses in Bangladesh. Trace elements from different land uses soils showed moderate to high degree of contamination. Considering individual metal, only Cd had very high ecological risk for AF, RS, WD, and PF sites, whereas the potential ecological risk indexes of these metals indicate very high potential ecological risk of the study area. However, further study is needed to explain the reasons for the higher potential ecological risk caused mainly by Cd in soils of different land uses.

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