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Apportionment of Hazardous Elements in Agricultural Soils Around the Vicinity of Brick Kiln in Bangladesh

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Abstract

Natural and anthropogenic factors affect soil pollution which significantly reduces environmental quality. In this study, six hazardous elements namely Chromium (Cr), Nickel (Ni), Arsenic (As), Cadmium (Cd) and Lead (Pb), in 12 different sampling sites around brick kiln vicinity from Bangladesh were assessed. The ranges of Cr, Ni, Cu, As, Cd and Pb in studied soils were 0.77-21.71, 4.74-27.67, 3.08-38.56, 2.51-28.44, 1.03-8.06 and 2.23-18.31 mg/kg, respectively. Presence of these hazardous elements in soils is indicating a potential risk to the environment. Certain indices, including the enrichment factor (EF), pollution load index (PLI) and contamination factor (Cⁱ_t), geoaccumulation index (I_{geo}), toxic unit analysis and principal component analysis (PCA) were used to assess the ecological risk posed by hazardous elements in soils. The Cⁱ_t values of As (15.34) and Cd (37.89) revealed that the examined soils were strongly impacted by As and Cd where Pollution load index in As (1.01) and Cd (2.61) indicating progressive deterioration of soil due to metal contamination. In view of the above results, soils from all sampling sites showed considerable to very high potential ecological risk.

Keywords: Heavy metals; Arsenic; Cadmium; Soil; Brick kiln; Enrichment factors; Pollution load index

Introduction

Brick kiln have adverse effect to soils which causes soil pollution. Soil is an in born resource for the survival of living being which concerned as the explanation receiver of the merciless pollutants like hazardous elements [1]. Hazardous elements are of great concern due to their wide sources, toxicity, non-biodegradable properties and accumulative behaviors [2]. Trace metals such as Chromium (Cr), Nickel (Ni), Arsenic (As), Cadmium (Cd) and Lead (Pb) have been considered as the most toxic elements in the environment by the US Environment Protection Agency (EPA) [1,3]. Brick production in brick kiln is traditional and fast growing industry in many parts of Asia like Bangladesh. Due to industrialization, use of bricks are increasing day by day as attractive building materials and for this an ample amount of brick kiln industries are set up here and there in Bangladesh. For very speedy urbanization, to meet the requirement of brick in construction industry there produce about 8.6 billion bricks per year. The annual rate of demand for the bricks rising is about 5.28% and which is rapidly increasing every year [4]. Hazardous elements may originate in soils around brick kiln area from different sources of which are industrial activities, fuel and coal combustion, wood burning, tyres and furnace oil in the brick kiln [5]. From brick kilns, ambient hazardous elements are being brought forward every year which are mixed up with air causes air pollution and rest are being stored in soils and create soil toxicity [6]. Therefore, the accumulation of hazardous elements in soils is of increasing concern due to their potential risk, and detrimental effects on soil ecosystems [7,8]. In brick kiln area, there should be concern about the soil pollution and ecological risks because the rate of emission of toxic substance is very high in developing countries, especially in Bangladesh as the rules and regulations are being broken which should be maintained for brick kiln. Different methods are usually used to determine hazardous elements contamination in soil like contamination factor (C_i) , enrichment factor (EF), geoaccumulation index (I_{eeo}), pollution load index (PLI) etc. [9]. The EF of an area indicates the relative enrichment in any contaminant when compared to pre-industrial soils from the same environment [10,11]. As soil pollution arising from brick kiln, the study area have raised attention due to its environmental pollution which is facing serious threats due to elemental pollution originated from the rapid expansion, congestion, and activities from brick kilns [12]. Several studies have reported the concentration of hazardous elements in agricultural soils due to brick kiln in Bangladesh [13-15]. The main aim to present research are to address the problem of hazardous elements like Cr, Ni, Cu, As, Cd, and Pb around brick kiln area soils and to find out the ecological risk of such hazardous elements in soils around brick kiln area in Bangladesh.

Materials and Methods

Study area and sampling

Twelve different sampling sites were selected for this study in Tangail district, Bangladesh (Figure 1). The area of Tangail district is 3414.28 km2 and located at the center point in Bangladesh. Tangail district is one of the most densely polluted areas in Bangladesh where the density of population is 1.100/km² (2011 census). The study area is situated between 24° 01' and 24° 47' north latitudes and between 89° 44' and 90° 18' east longitudes (Wikipedia). During March- April, 2016 soil samples were collected. Twelve sampling sites were selected around the brick kiln area. In every sampling site, agricultural soil samples (surface soils) were accumulated in the form of three subsamples. To make a composite sample, three subsamples were mixed together. Samples were kept in cool place and dried in air at room temperature for two weeks, then these were ground and homogenized for determination of hazardous elements. A porcelain mortar and pestle was used to crumble the soils and 2 mm nylon sieve was used to sieve the soils and stored in an airtight clean Ziploc bag and kept frozen until chemical analysis.

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Received February 13, 2017; Accepted February 22, 2017; Published February 27, 2017

Citation: Proshad R, Ahmed S, Rahman M, Kumar T (2017) Apportionment of Hazardous Elements in Agricultural Soils Around the Vicinity of Brick Kiln in Bangladesh. J Environ Anal Toxicol 7: 439. doi: 10.4172/2161-0525.1000439

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Sample analysis

For sample analysis, analytical grade reagents were used and for solution preparation Milli-Q (Elix UV5 and MilliQ, Millipore, USA) water was used. 0.3 g of the soil sample was mixed with 1.5 mL 69% HNO₃ (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) for metal analysis. By using a syringe filter (DISMIC^{*}-25HP PTFE, pore size=0.45 μ m) [11] Toyo Roshi Kaisha, Ltd., Tokyo, Japan the solution was digested and 50 mL polypropylene tubes (Nalgene, New York) were used for storing.

Quality control and instrumental analysis

Inductively coupled plasma mass spectrometer (ICP-MS, 7700 series) was used for sample analysis. To prepare calibration curve, Multi-element Standard XSTC-13 (SpexCertiPrep^{*}, Metuchen, USA) solutions were used. Due to cover more range of masses of elements, 1.0 μ g/L multi-element solution was used as tuning solution. An internal quality system was used for evaluation every test batches. Once defined Internal Quality Controls (IQCs) was satisfied than it was validated.

Ecological risk assessment for soil pollution

Contamination factor (\mathbf{C}_{i}^{t}): The (\mathbf{C}_{i}^{t}) may be defined as the ratio of the metal concentration in the soil to that of baseline or background value (background value is considered as toxic elements in the pre-industrial soil around research vicinity)

$$C_{f}^{i} = C_{heavy metal} / C_{background}$$
 (1)

According to the intensities of contamination, the levels of contamination may be divided on six categories which range from 1 to 6: very high degree ($C_{f}^{i} \ge 6$), considerable degree ($3 \le C_{f}^{i} < 6$), moderate degree ($1 \le C_{f}^{i} < 3$) and low degree ($C_{f}^{i} < 1$) [16,17]. Thus, the enrichment of each metal may be monitored by C_{f}^{i} values over a long time in soils.

Enrichment factor (EF)

For assessing the magnitude of hazardous elements in the

environment, enrichment factor is assumed impressive tool [18]. For determination anthropogenic influences of hazardous elements in soil, enrichment factor was calculated using the following formula [19].

$$EF = (C_M / C_{Al})_{sample} / (C_M / C_{Al}))_{background}$$
(2)

Where, $(C_M/C_{Al})_{sample}$ is assumed as ratio of hazardous element concentration of (C_M) to that of aluminum (C_A) in the soil sample, and $(C_M/C_{Al}))_{background}$ is the same reference ratio in the background sample. If the EF value of heavy metals is 1, it means that metal may be entirely from crustal materials or natural weathering processes [20]. It is stating a fact of human interference if enrichment factor of samples is more than 1.5. An EF of 1.5–3, 3–5, 5–10 and >10 is considered the evidence of minor, moderate, severe, and very severe modification [21].

Geoaccumulation index (I_{geo})

 $I_{\rm geo}$ may be considered as an effective tool for assessing degree of contamination from hazardous element. It use universally for determination of soil concentration now a days [22]. One of the most important purposes for assessing $I_{\rm geo}$ is to characterize the level of pollution from soil. $I_{\rm geo}$ can be determined adopting following equation

$$I_{geo} = \log_2 (C_n / 1.5B_n)$$
 (3)

Where, C_n is the assessed metal (n) concentration in the soil and B_n is considered as the geochemical baseline value of metal n in the baseline sample [23-25]. For reducing the probable variations in the baseline values of metal n, factor 1.5 is used that can be ascribed to lithogenic effects. I_{geo} values were categorized as: $5 < I_{geo}$ – extremely contaminated; $4 \leq I_{geo} \leq 5$ -heavily to extremely contaminated; $3 \leq I_{geo} \leq 4$ -heavily contaminated; $2 \leq I_{geo} \leq 3$ - moderately to heavily contaminated; $1 \leq I_{geo} \leq 2$ -moderately contaminated; $0 \leq I_{geo} \leq 1$ -uncontaminated to moderately contaminated; and $I_{geo} \leq 0$ -practically uncontaminated.

Pollution load index (PLI)

Pollution load index act as an integrated approach which assess soil quality. of the six metals is calculated according to Suresh et al. [26] pollution load index may be assessed from six hazardous elements (Cr, Ni, Cu, As, Cd and Pb). The PLI can be calculated by using following formula

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Sampling sites	pH (1:2.5 H2O)	EC(dS/m)	Organic carbon (%)	Sand (% in <2 mm)	Silt	Clay	Soil type ^a
S1	6.54	0.43	3.566	35.1	46.6	18.3	Loam
S2	6.78	0.13	1.343	41	45	14	Loam
S3	6.95	0.1	3.607	55	30	15	Sandy loam
S4	6.44	0.08	1.335	39.7	45	15.3	Loam
S5	6.02	0.07	3.650	35	51	14	Silt loam
S6	6.25	0.18	1.352	44	37.5	18.5	Loam
S7	6.05	0.06	0.553	34	47.5	18.5	Loam
S8	6.93	0.17	0.551	34.7	45	20.3	Loam
S9	6.83	0.15	0.552	34.9	47.5	17.6	Loam
S10	6.45	0.12	2.547	48.5	39.1	12.4	Loam
S11	7.87	0.47	0.545	44.7	37.5	17.8	Loam
S12	6.81	0.1	0.537	36.5	45	18.5	Loam

^aAccording to the United states Department of Agriculture soil classification system.

Table 1: Physiochemical properties of soil from Tangail district brick manufacturing area, Bangladesh.

Sampling sites	Cr	Ni	Cu	As	Cd	Pb
S1	11.23	4.74	10.75	4.67	1.18	5.99
S2	10.12	11.39	9.66	11.12	7.2	6.24
S3	21.71	12.21	29.56	7.61	2.01	10.99
S4	11.93	9.75	14.08	14.94	2.01	3.98
S5	17.25	5.34	6.0	19.07	2.49	3.24
S6	0.77	25.71	3.08	2.69	2.76	2.23
S7	10.86	9.11	8.26	28.44	8.06	17.93
S8	9.41	27.67	6.93	2.51	1.03	8.62
S9	8.21	18.77	26.93	13.36	2.82	18.32
S10	1.57	12.40	29.30	7.51	2.01	10.96
S11	1.88	9.80	38.56	14.77	2.08	3.89
S12	19.62	5.45	5.86	18.99	2.26	3.24
Dutch standard ^a	100	35	36	29	0.80	85
Canadian guidelines ^b	64	50	63	12	1.4	70
Australian guidelines ^c	50	60	60	20	3.0	300

^aVROM (2000); ^bCCME (2003); ^cDEP (2003)

Table 2: Metal concentration (mg/kg) in soil collected from Tangail district brick manufacturing area, Bangladesh.

(4)



$$PLI=(CF1 \times CF2 \times CF3 \times \ldots \times CFn)^{1/n}$$

The overall toxicity status of heavy metals in soils may be assessed from Pollution load index (PLI) calculation. PLI is the share of conclusion of six heavy metals.

Statistical analysis

The data were statistically analysed using the statistical package, SPSS 20.0 (SPSS, USA). The means of the hazardous element concentrations in soils were calculated. Multivariate methods in terms of principal component analysis (PCA) were used to interpret the potential sources of hazardous element in soil. Other calculations were performed by Microsoft Excel 2010.

Results and Discussion

Physicochemical Properties and Metals in Soil

The physicochemical properties of soil are presented in Table 1. The studied soils were slightly acidic to neutral excluding the S11 site that was alkaline (Table 1) because of decomposition of organic matter and subsequent formation of carbonic acid [27]. Electrical conductivity (EC) value of the soil was non saline (0-2 dS/m; SRDI soil salinity class) for all sampling sites which mean the salinity effect is negligible on crop plants. Organic carbon (%C) ranging 0.551-3.65 where the highest value was observed in soil collected from the S5 site. The textural class of the soil were loam, sandy loam and silt loam (Table 1) according to the United States soil texture classification. The concentrations of heavy metals were measured to estimate the Contamination Factor (Figure 5) and enrichment factors with pollution load index of soil. Mean concentrations of Cr, Ni, Cu, As, Cd, and Pb in soil were 10.41, 12.69, 15.66, 12.15, 3.1, and 7.98 mg/kg, respectively (Table 2 and Figure 2) found around brick kiln area of Tangail district, Bangladesh. Metals in soils were compared with the other studies in Bangladesh and other countries. Arsenic and cadmium concentrations of the present study were higher than those of the study conducted in Bangladesh, India, Spain, and Turkey (Table 3), pointing out that soils were contaminated by As and Cd. The mean concentrations of As was above

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District (Country)	Cr	Ni	Cu	As	Cd	Pb	References
Tangail, Bangladesh	10.41	12.69	15.66	12.15	3.1	7.98	Present study
Bogra (Bangladesh)	41	45	42	10	4.2	44	Islam et al. 2014
Maharashtra (India)	164	171	155	2.8	30	42	Bhagure and Mirgane (2011)
Murcia (Spain)	18	14	11	NA	0.22	49	Acosta et al. (2011)
Kayseri (Turkey)	29	45	37	NA	2.5	75	Tokalıoğlu and. Kartal (2006)
Dutch soil quality standard (Target Value)	100	35	36	29	0.8	85	VROM (2000)
Dutch soil quality standard (Intervention Value)	380	210	190	55	12	530	VROM (2000)
Canadian Environmental Quality Guidelines	64	50	63	12	1.4	70	CCME (2003)
Department of Environmental Protection, Australia	50	60	60	20	3	300	DEP (2003)

Table 3: Comparison of metal concentration (mg/kg) in soil of present study with other study and guideline values.

Initial Eigenvalues				Extrac	tion Sums of Squ	ared Loadings	Rotation Sums of Squared Loadings			
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	
1	2.154	35.9	35.9	2.15	35.9	35.9	1.82	30.45	30.45	
2	1.485	24.74	60.64	1.48	24.74	60.64	1.72	28.78	59.23	
3	1.169	19.48	80.12	1.16	19.48	80.14	1.25	20.88	80.12	
4	0.739	12.31	92.43							
5	0.266	4.42	96.86							
6	0.188	3.13	100							
Elements	Elements Component matrix				Rotated Component Matrix					
	PC1	PC2	PC3		PC1	PC2	PC3			
Component	Component matrix			0.73						
Cr	0.55	-0.52			-0.91					
Ni	-0.70	0.38	-0.45					0.97		
Cu		0.43	0.85		0.64					
As	0.89					0.64				
Cd	0.65	0.45	-0.450			0.87				
Pb		0.81				0.73		0.40		

 Table 4: Total variance explained and component matrices for the hazardous elements in surface soils collected from Tangail district, Bangladesh Extraction Method:

 principal component analysis.



Figure 3: Principle component analysis (PCA) of heavy metals in soils of brick kiln area of Tangail district, Bangladesh.

the Canadian guideline and Cd in the present study were above the Dutch soil quality standard [28], Canadian guideline and Australian guideline (Table 2). The contaminations of these agricultural fields' soils are a major concern because foods are still being grown on these soils. The Dutch soil quality standard is regarded as the most suitable guideline indicating all possible exposure pathways for protecting humans, plants, and animals. If any metal concentration in soil is below its respective Dutch Target Value, the soil is considered clean. If the concentration level lies between the target values and intervention values, the soil is regarded to be slightly to moderately contaminated. In contrast, if the value is above the Dutch Intervention Value, the soil

is considered detrimental to humans, plants, and animals. According to Table 2, Cd was in the worst situation among the studied metals as the mean concentration of Cd was more than 4 times higher than the Dutch Target value.

Source analysis of hazardous elements in soil

Principal component analysis (PCA) was carried out to associate the source of heavy metals in soils of several sampling site of the Tangail district, Bangladesh. PCA is assumed ideal act for identification of sources [29,30]. Due to source analysis of hazardous element, there



Figure 4: Estimated sum of the toxic unit in soils of brick kiln area of Tangail district, Bangladesh.

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prevalent three principal components (Table 4 and Figure 3). Total variation was computed for 80.12% of source analysis. First principal component (PC1) comprised Cr, As and Cd describing the largest variance (35.9%); Ni and Cu comprised second principal component (PC2) which expound 24.74% of the variance. Only Pb comprised third principal component (PC3), describing 19.48% of the total variance









	рН	EC	Organic carbon	Cr	Ni	Cu	As	Cd
EC	0.604*	1						
Organic carbon	-0.320	0.021	1					
Cr	-0.148	-0.419	0.347	1				
Ni	0.081	-0.081	-0.383	-0.459	1			
Cu	0.652*	0.361	0.052	-0.243	-0.094	1		
As	-0.209	-0.335	-0.272	0.312	-0.576*	-0.060	1	
Cd	-0.291	-0.341	-0.295	-0.003	-0.149	-0.235	0.564	1
Pb	-0.106	-0.264	-0.177	-0.011	0.149	0.287	0.261	0.382

*=Correlation is significant at the 0.05 level (two-tailed)

**=Correlation is significant at the 0.01 level (two-tailed)

 Table 5: Correlation coefficient matrix for physiochemical properties of soil and heavy metals collected from Tangail district brick manufacturing area, Bangladesh.



Figure 7: Geo accumulation index (I_{geo}) value of heavy metals in soils of brick kiln area of Tangail district, Bangladesh.



(Figure 3 and Table 4).

Toxic unit analysis

Aggregation of Toxic units (Σ TUs) can comprise potential acute toxicity of heavy metals. Toxic units may be defined as the ratio of the determined concentration of metal in soil to probable effect levels (PELs) [30,31]. Toxic unit (TU) and sum of toxic units (Σ TUs) for heavy metals in different soil sampling sites were shown in Figure 4. If the sum of toxic units of soils was more than 4, toxicity of heavy metals is moderate to serious [32]. In the present study, sum of toxic units (Σ TUs) for the sampling sites SS-7 was higher than 4 as well as the other sites, which indicate serious toxicity of heavy metals.

Metal pollution determination in soils

The EF values of several soils are given in Figure 6 and Table 5. Average EF values of metals in the present study indicate enrichments in soils of various sampling sites in Tangail district, Bangladesh. As and Cd showed the highest EF value indicate the soil pollution for all the sampling sites.

 I_{geo} values of present study were presented in Figure 7. For all heavy metals, the I_{geo} values indicated the decreasing order of Cd>As>Cu>Ni>Pb>Cr. The mean of I_{geo} values for Cd was 3.104 indicating the soils were heavily contaminated with Cd.

Pollution load index (PLI) value is zero means perfection. If PLI value is equal to 1, it indicates the pollutants are in background level and PLI values more than 1 comprise the soil is in progressive deterioration contamination of heavy metals [31,33]. The pollution state is proportional to numerical PLI value. As per above mentioned value, studied soils were contaminated by Cd and it was noticed that PLI values of all sampling sites were more than one (Figure 8).

Conclusions

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This study presented that soils of all sampling sites were severely contaminated by heavy metals like As and Cd (around 80% samples crossed the Dutch soil quality target value). The study also assured that concentrations of heavy metal in brick kiln area soils of Bangladesh were varied with different sampling sites. The heavy metals enrichment in soil is also cause of anthropogenic and geogenic elements. As and Cd had very Severe ecological risk for most of the sites for individual heavy metals and the study area comprises ecological risk indexes of these heavy metals were too high. However, it is necessary to conduct further study for describing the causes for the higher potential ecological risk caused primarily by As and Cd in several sampling sites around brick kiln area in Bangladesh.

Acknowledgment

The authors thank the authority of Patuakhali Science and Technology University (PSTU), Bangladesh and Yokohama National University, Japan for providing laboratory facilities to complete this study. The authors also delighted to express their gratefulness and sincerest thanks to Dr. Md. Saiful Islam, Associate Professor, Department of Soil Science Patuakhali Science and Technology University, for his valuable suggestions and cooperation to carry out this research.

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