JCBPS; Section D; August 2017 – October, 2017, Vol. 7, No. 4; 835-850. E- ISSN: 2249 –1929
[DOI: 10.24214/jcbps.D.7.4.83550.]

Journal of Chemical, Biological and Physical Sciences

An International Peer Review E-3 Journal of Sciences

Available online atwww.jcbsc.org

Section D: Environmental Sciences

CODEN (USA): JCBPAT

Research Article

Metallic pollution in top soils of an urban industrialized city: a case study of Chittagong city, Bangladesh

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Received: 05 August 2017**; Revised:** 14 August 2017; **Accepted:** 20 August 2017

Abstract: Top soils of Chittagong city is highly susceptible to environmental pollution due to over population, rapid industrialization, urbanization and disposal of different types of solid and liquid waste without any treatment. Total 22 top soil samples were collected from different locations of Chittagong city to assess metallic pollution level and concentrations of metals in samples were determined by an Atomic Absorption Spectrophotometer (AAS). The mean total concentrations of Cu, Zn, Cr, Fe and Pb in soil were 60.56, 108.05, 238.63, 37153.69 and 254.05 µg g^{-1}, respectively, while the concentrations of Ni in most sampling sites were trace. The study revealed that the average Cu, Zn, Cr and Pb contents in soils were higher compared with several other industrial areas in home and abroad as well as geochemical background. The geoaccumulation index (I_{geo}) values for Pb ranged from 3.49-4.02, indicating I_{geo} class 4-5, which means strongly to extremely polluted soil quality. But the calculated I_{geo} for Cr at all locations and Zn at 50% sites exhibited I_{geo} class: 1-2, indicating uncontaminated to moderately polluted soil quality. As regards to enrichment factors (EFc), all sampling sites had EFc values > 5.0 for Pb, which indicates anthropogenic load of the metal to the city. Estimated pollution load index (PLI) of all sites showed values >1.0, indicates significant pollution load at the study area. The comprehensive potential ecological risk index (RI) values ranged from 98.37-134.93 and the potential ecological risk index of single element (E_R^i) values of Pb ranged from 85.61-123.46 means Pb was the most important metal leading to risk. The study results concluded that the top soil of the city is significantly polluted with Pb followed by Cr and Zn.

Keywords: Metallic pollution, soil, ecological risk index, Chittagong, Bangladesh

INTRODUCTION

Pollution typically refers to the presence of chemicals or other substances in concentrations greater than the value that would occur in natural conditions. A major environmental issue across the world is diffuse pollution of the land and water by heavy metals. Different kinds of anthropogenic activities have greatly increased the various metal burdens in the environment all over the world. The list of sites contaminated with various metals increases every year, presenting a serious problem for human health and formidable danger to the environment[1-2].

Naturally different metals are present in soils but their concentration is generally low. Enhance concentration are found in soil from naturally mineralized areas, but more commonly arise where metals have become dispersed as a result of anthropogenic activities such as industrialization, urbanization, underground deposition of waste, discharge of effluent without treatment and others[3-4]. Environment is seriously polluted by increasing industrialization and urbanization which create huge amount of waste. During the last few years a remarkable number of research work reported severe metallic contamination to soil, water and sediments of Bangladesh[1-2, 5-11].

Chittagong city is situated on the bank of the Karnaphully river and the city is surrounded by rich natural resources like the green Hilly Terrain and the Bay of Bengal on the west. Chittagong is the second largest city, prime sea port and the heart of all commercial and business activities in Bangladesh. Accordingly the government of the country has already declared Chittagong as the "Commercial Capital" of the country by this time. After the independence of Bangladesh in 1971, Chittagong has earned a significant status of the second important city because of the Chittagong port, diversified economic activities, natural beauties, industrial activities and because of its suitable geographical location factor in the regional map[12].

Numerous industries are the major source of soil and water pollution in Chittagong City. The important industries in Chittagong include tanneries, garments, ship breaking, pulp and paper, refineries, food, fertilizer, textile, pharmaceuticals, steel, chemical and other agro-based industries[12]. In Chittagong, industries are located mainly at Fauzdarhat, Kaptai, Nasirabad, Barabkunda, Bhatiary, Sholashahar, Patenga and Kalurghat area. Undoubtedly, metallic pollution is a problem associated with disposal of untreated sewage discharges, industrial pollutants, land washout, city run-off and urban garbage. In these circumstances, this study was conducted to determine the concentration of different metals and to evaluate the present status of metallic pollution in soils of some selected industrial areas of Chittagong.

MATERIAL AND METHODS

Soil Sampling: Soil samples were collected from 22 sites randomly considering 400 to 500 meters distance from one station to another station of the Chittagong city, Bangladesh. The sampling location and a list of sampling sites along with possible sources of contamination are shown in Fig. 1 and Table 1, respectively. The sampling was done on 15-16th January, 2016.

Preparation of Soil Samples for Analysis: After collection, the soil sample was placed in a thin layer on a clean piece of brown paper on a shelf in the laboratory and left until it was air dried. Visible garbage, stones, fragments of weeds and roots etc. were removed from the soil samples and discarded. Then the samples were ground and subsequently sieved by using a 2 mm stainless steel sieve. Each sample was then kept in a separate clean polythene bag with appropriate marking for physical and chemical analyses. The chemical analyses of soil were accomplished in the laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

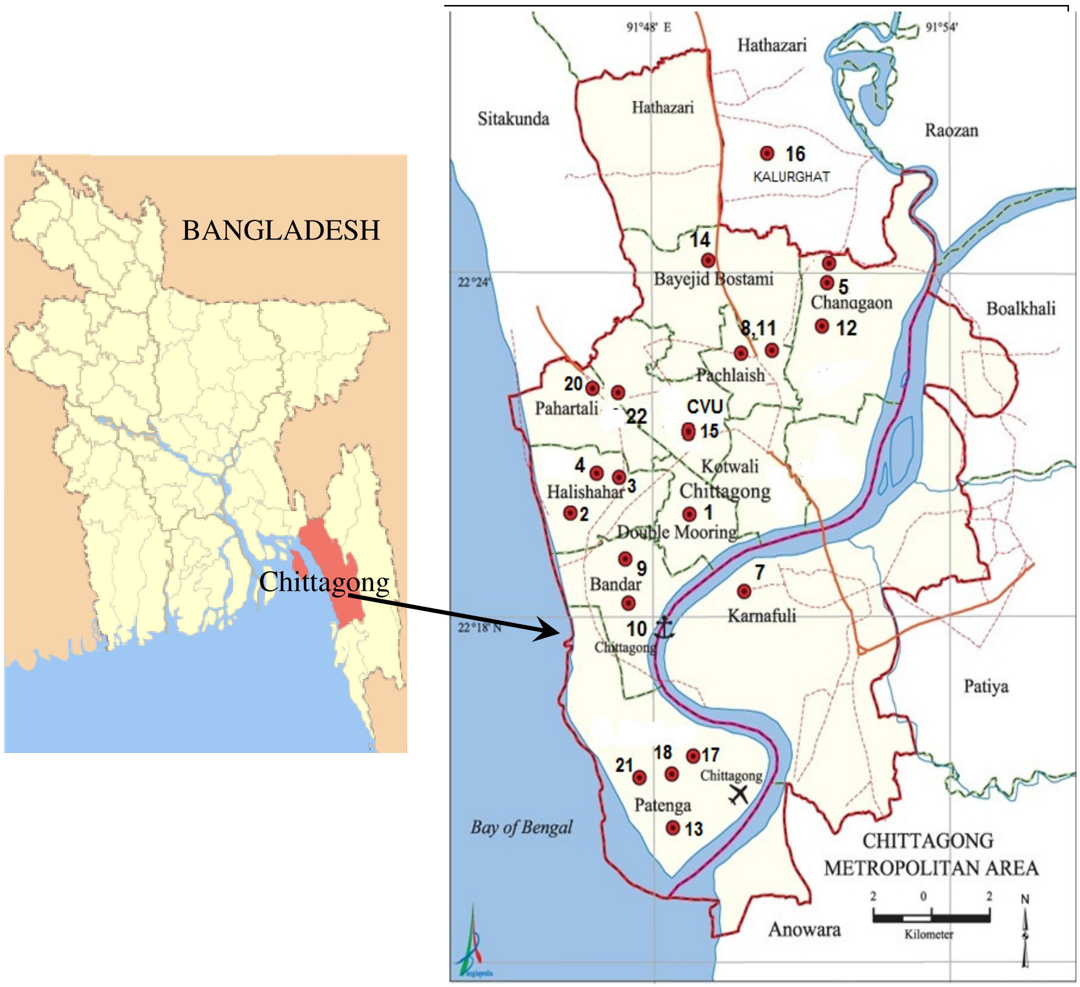

Fig. 1: Map showing details of soil sampling locations in Chittagong city, Bangladesh

Analytical Methods: Soil pH was determined by glass electrode bench top pH meter (SensION^{TM}+EC5, HACH, USA) as described by Ghosh *et al.*[13] and the result was reported as soil pH measured in water (soil: water ratio being 1:2.5). On the other hand, the electrical conductivity (EC) of collected soil samples was determined electrometrically (soil water ratio was 1:5) by a conductivity meter (SensION^{TM} + EC5, HACH, USA) as described by Singh *et al.*[14]. The organic carbon content in soil was measured following the method outlined by Ghosh *et al.*[13]. For the determination of total metal concentration, exactly 1.00 g of powdered soil sample was digested with 10 mL of HF and 2 mL $HClO_4$ as described by Tessier *et al.*[15]. Then concentrations of different metals (Cu, Zn, Pb, Cr, Ni and Fe) in aqueous extracts were measured by an atomic absorption spectrophotometer (AAS) (Shimadzo, AA7000, Japan).

DOI:10.24214/jcbps.D.7.4.83550.]

Table 1: List of soil sampling sites of Chittagong city, Bangladesh along with possible sources of contamination

Sample ID	Sampling Area	Possible Sources of contamination
01	CEPZ	Young One T-Shirt Factory
02	Patenga, Zeti # 15	Jamuna Oil Company, Ltd.
03	Dewanhat Link Road Area	Rahim Uddin Steel Mills
04	KEPZ	Young One Shoe Factory
05	Chittagong Railway Station	Rail Wagon
06	Shah Amanat Airport	Waste and Dusts
07	Nimtala Biswa Road, Under bridge	Chittagong Container Depot and Oil Factory
08	CEPZ	Young One T-Shirt Factory
09	Kalurghat Industrial Area	Rahman Industries Ltd.
10	Kalurghat Industrial Area	Sarwar Thread Ltd.
11	CEPZ	Young One Shoe Factory
12	Patenga, Chittagong Container Depot	Container and Other Vehicles
13	Baized Bostami Lake	Waste and Vehicles
14	Probortok, Pachlaish	Al-Amin Wash Ltd. and Household Waste
15	Chittagong Veterinary University	Office and Residential area and Veterinary Clinic.
16	Chandgong, Baddarhat	Ravino Industries Ltd
17	CEPZ	Young One Jacket Factory
18	KEPZ	Young One Shoe Factory
19	Patenga, Zeti # 7	Rubi Cement Factory
20	Kalurghat Industrial Area	Rahman Dyeing Factory
21	Nasirabad Industrial Area	Saleh Steel Industries Ltd.
22	Nasirabad Industrial Area	Saydur Factory Ltd.

Assessment of Soil Pollution

Geoaccumulation index: The index of geoaccumulation (I_{geo}) is a quantitative measure of metal pollution, using the relationship between concentration of the element in soil/ sediment (fraction <2 µm) and the background as introduced by Muller[16], which can be calculated by the following formula:

$$I_{geo} = \log_2 (Cn/1.5\times Bn)$$

where, Cn is measured concentration of metal in the soil and Bn is the geochemical background for the same element. Average earth's crust value of the metal described by Taylor[17] was used as background value. The factor 1.5 is introduced by Muller[16] to include possible variations of the background values that are due to lithologic variations. There are seven I_{geo} classes based on the numerical value of the index viz. class 0 ($0 \geq I_{geo}$) unpolluted; class 1 ($0 \leq I_{geo} \leq 1$) uncontaminated/ moderately polluted; class 2 ($1 \leq I_{geo} \leq 2$) moderately polluted; class 3 ($2 \leq I_{geo} \leq 3$) moderately/ strongly polluted; class 4 ($3 \leq I_{geo} \leq 4$) strongly polluted; class 5 ($4 \leq I_{geo} \leq 5$) strongly/ extremely polluted and the class 6 is an open class and comprises all values of I_{geo} higher than 5, which indicates extremely polluted soil quality[16].

Enrichment factors: Crustal enrichment factors (EFc) of elements are frequently used to determine the degree of modification in soil composition[18], which is usually computed relative to the abundance of species in source material to that found in the Earth's crust. The following equation was used to calculate the EFc:

$$EFc = (C_M/C_{Fe})_{\text{sample}} / (C_M/C_{Fe})_{\text{Earth's crust}}$$

where, $(C_M/C_{Fe})_{\text{sample}}$ is the ratio of concentration of metal (C_M) to that of Fe (C_{Fe}) in the soil sample and $(C_M/C_{Fe})_{\text{Earth's crust}}$ is the same reference ratio in the Earth's crust. The average abundance of metal in the reference Earth's crust was taken from Taylor[17] and Fe was selected as the reference element, due to its crustal dominance and its high immobility.

Pollution load index (PLI): The pollution load index (PLI) proposed by Tomlinson *et al.*[19] has been calculated for surface soils of Chittagong city, Bangladesh. The PLI is used to know the pollution level for a single site, which is the *n*th root of *n* number of multiplied together contamination factor (CF) values. The CF is measured as follows:

$$CF = C_{\text{Metal concentration}} / C_{\text{Background concentration of the same metal}}$$ and

PLI for a site = *n*th√CF1 × CF2 ……….. × CFn,

where, n = the number of contamination factors and sites, respectively. First a number of contamination factors are derived for different metals at each site, and then a site pollution index is calculated by taking the five highest contamination factors and deriving the fifth root of the five factors multiplied together[19].

Ecological risk assessment: Potential ecological Risk Index (RI) proposed by Hakanson[20] was calculated to evaluate the potential ecological risk of heavy metals to the study area. This index is formed by three basic modules: degree of contamination (C_D), toxic-response factor (T_R) and potential ecological risk factor (E_R)[20]. According to this method, the potential ecological risk index of a single element (E_R^i) and comprehensive potential ecological risk index (RI) were calculated by the following equations:

$$C_f^i = C_D^i / C_R^i \quad \text{(i)}$$

$$E_R^i = T_R^i \times C_f^i \quad \text{(ii)}$$

$$RI = \sum_{i=1}^{4} E_R^i \quad \text{(iii)}$$

where C_D^i is the measured concentration of toxic metal in each sampling point; C_R^i is the reference value, here the earth's crust average is used[17]; C_f^i is the contamination factor of a single element; E_R^i is the potential ecological risk index of a single element; T_R^i is the biological toxic-response factor of a single element, which is determined for Zn = 1, Cr = 2, Cu = 5 and Pb = 5[20]; RI is a comprehensive potential ecological risk index. Original RI method proposed by Hakanson[20] considers eight pollutants, including PCBs, Hg, Cd, As, Pb, Cu, Cr and Zn. However, we did not consider PCBs, Hg, Cd and As in this study.

RESULTS AND DISCUSSION

Physicochemical Properties of Soils: The pH values of soil samples ranged from 5.74 to 9.60 with a mean value of 7.17 (Table 2). Various materials such as wastes, effluents, chemicals, salt etc. discharged from different industries might be responsible for such pH variation. According to Wang and Qin[21] soil pH is the key factor that governs the concentration of soluble metals and the solubility tends to increase at

DOI:10.24214/jcbps.D.7.4.83550.]

lower pH and decrease at higher pH. Thus acidic nature of soil of the study area may enhance toxic metal distribution and availability to plants.

The electrical conductivity (EC) of soil samples collected from different locations of Chittagong city are presented in Table 2. The EC of soil samples ranged from 2.09 to 2160 µS cm^{-1}. According to Costa *et al.*[22], high EC value in soil, might be due to huge quantities of salt, solid wastes and effluents of tannery and other industries. In general, EC of soils varied markedly with soil salinity. The high salt affected soils of contaminated sites account for the higher EC.

Table 2: Some physicochemical properties of soils collected from different areas of Chittagong city, Bangladesh.

Sample ID	pH	EC (µS cm^{-1})	Organic carbon (%)	Organic matter (%)
01	7.20	1213.00	0.10	0.17
02	7.59	197.30	0.10	0.18
03	6.57	696.00	0.10	0.17
04	6.97	2.09	0.07	0.12
05	7.00	768.00	0.10	0.18
06	5.74	198.00	0.11	0.20
07	7.60	3.10	0.08	0.14
08	7.37	2.81	0.10	0.17
09	6.64	1313.00	6.52	11.29
10	9.60	2160.00	0.10	0.17
11	7.75	947.00	0.10	0.18
12	7.43	5.50	0.05	0.08
13	7.47	597.00	0.08	0.15
14	7.06	9.34	0.10	0.17
15	7.76	9.02	0.07	0.12
16	7.80	557.00	0.08	0.14
17	6.33	1260.00	6.66	11.52
18	6.34	147.10	0.06	0.11
19	6.25	588.00	0.10	0.18
20	6.49	7.63	0.04	0.08
21	7.18	1337.00	0.04	0.07
22	7.80	485.00	0.11	0.19
Range	5.74 - 9.60	2.09 - 2160	0.04 - 6.66	0.07 - 11.52
Mean	7.17	568.30	0.68	1.17
SD	0.79	595.60	1.91	3.31

The organic matter content in soils ranged from 0.07 to 11.52% with a mean value of 1.17% (Table 2). The deposition and decomposition of huge quantities of solid wastes and sewage sludge might be responsible for higher organic matter enrichment in some soil[7]. Organic matter along with clay contents of the soils had a significant influence on metal accumulation[21] and retention which could have implications on metal mobility and bioavailability[3, 23]. Furthermore, the variations of organic matter might be due to fluctuation in temperature, rainfall, topography, soil textural class, soil pH and soil profile.

Metallic Contents in Soils: The concentration of Cu in soils of different sites of Chittagong city ranged from 51.58 to 84.75 µg g^{-1}, having an average value of 60.56 µg g^{-1} (Table 3). According to Kabata and Pendias[24] the maximum acceptable concentration of Cu for crop production is 100 µg g^{-1}. But the present study results of Cu was several times higher than those reported by Domingo and Kyuma[25], they stated that the Cu status in some selected Bangladesh paddy soils ranged from 6.0 to 48.0 μg g^{-1}. The total concentration of Zn in top soils of the city ranged from 20.71 to 307.5 μg g^{-1} having an average value of 108.05 μg g^{-1} (Table 3). Jahiruddin *et al.*[26] reported that the mean concentration of Zn in Gangetic alluvium and Brahmaputra alluvium soils were 78.50 and 66.4 μg g^{-1}, respectively. Similarly, Domingo and Kyuma[25] reported that Zn content in Bangladesh soils ranged from 10-110 μg g^{-1} with a mean of 68 μg g^{-1}. However, this study revealed that the average Cu and Zn levels in top soils of Chittagong city were higher compared with most other industrial areas in home, abroad and geochemical background value of continental crust (Table 4).

Table 3: Concentration of total toxic metal in soil samples collected from different areas of Chittagong City, Bangladesh.

Sample ID	Total metal concentrations (μg g^{-1})					
	Fe	Cu	Zn	Ni	Cr	Pb
01	37022.80	56.22	166.19	Trace	263.41	214.03
02	39679.20	60.61	152.05	Trace	249.04	236.68
03	38878.40	57.68	110.72	Trace	243.87	228.03
04	39388.00	56.86	123.38	Trace	259.26	234.68
05	35169.40	53.20	22.07	Trace	228.49	230.02
06	36225.40	51.58	22.04	Trace	230.54	228.69
07	38417.80	56.78	33.42	4.02	226.44	230.68
08	40269.40	62.07	93.00	10.03	270.54	266.00
09	37258.60	68.93	307.46	Trace	247.98	254.01
10	37290.20	55.72	52.05	Trace	230.54	238.01
11	36984.00	55.81	88.73	Trace	226.44	239.00
12	38847.00	60.93	57.58	Trace	237.72	259.34
13	37201.40	57.59	95.15	Trace	225.42	253.34
14	37118.40	74.99	120.93	0.48	235.67	271.33
15	31264.20	51.58	20.71	Trace	214.14	256.00
16	36935.40	61.25	186.04	Trace	227.47	268.66
17	38953.00	67.78	126.01	19.67	241.28	285.99
18	31278.00	51.74	26.45	0.48	222.34	260.00
19	37756.60	56.37	118.28	0.48	231.57	308.64
20	36403.00	84.75	204.43	0.05	247.98	271.33
21	39591.20	70.20	177.11	13.88	268.49	287.32
22	35449.80	59.63	83.07	Trace	221.31	267.33
Range	31264 - 40269	51.5 - 84.7	20.7 - 307.5	Trace - 19.6	214.1- 270.5	214.0 - 308.6
Mean	37153.69	60.56	108.05	2.23	238.63	254.05
SD	2347	8.26	71.64	5.29	15.92	23.41

The status of Pb in soils ranged from 214.0 to 308.6 μg g^{-1}, having an average value of 254.10 μg g^{-1} (Table 3). The concentration of Pb in soil samples collected from the study area was 4-5 times higher than the maximum acceptable concentration of Pb (50 μg g^{-1}) for crop production[24], which indicates anthropogenic pollution load of Pb. This finding is supported with other reports published earlier for soils of Bangladesh. Bibi *et al.*[27] reported that Pb concentration in soils of different depths ranged from 19-24 μg g^{-1} while Jahiruddin *et al.*[26] stated that the range of Pb content in 20 calcareous soils was 17.8-26.8 μg g^{-1} with a mean value of 22.8 μg g^{-1}. On the other hand, the total concentration of Cr in soils of Chittagong city ranged from 214.10 to 270.50 μg g^{-1} with an average value of 238.60 μg g^{-1} (Table 3). This result is almost twice than those of the earlier study of Domingo and Kyuma[25], they reported that Bangladesh soils had Cr content of 89 to 196 μg g^{-1} with a mean of 133 μg g^{-1}. Similarly Jahiruddin *et al.*[26] reported that the mean value of Cr in Gangetic alluvium and Brahmaputra alluvium soils were 89.50 and 106.32 μg g^{-1}, respectively. Present study results revealed that the average Pb and Cr content in top soils of Chittagong city were higher compared with several other industrial areas in Bangladesh and the world as well as geochemical background value of continental crust (Table 4).

Table 4: A comparison of different metal concentration (μg g^{-1}) in soils of Chittagong city, Bangladesh and some other industrial areas in home and abroad.

Metals	SP[A]	FCC[B]	SICZI[C]	UPI[D]	DCA[E]	ISG[F]	ISB[G]	GBCC[H]	Present Study (average)
Cu	26.85	40.77	29.87	42.90	75.04	36.18	131.87	55.00	60.56
Zn	94.20	159.85	49.90	159.90	103.34	176.66	28.46	70.00	108.50
Pb	121.40	40.59	15.72	38.30	3.84	27.94	9.60	75.00	254.05
Fe	17991.62	nm	nm	nm	nm	nm	nm	56000.00	37153.69
Cr	155.00	nm	nm	2652.30	32.07	nm	4.05	100.00	238.63
Ni	1782.38	21.92	4.71	nm	nm	nm	7.56	75.00	2.23

SP = Sialkot, Pakistan; FCC = Fuyang County China; SICZI = Shiraz industrial complex zone, Iran; UPI = Uttar Pradesh, India; DCA =Dhaka city area; ISG = Industrial sites of Gazipur; ISB = Industrial sites of Bogra; GBCC = Geochemical background (continental crust) and nm = not measured.

[A] Malik *et al.*[34]; [B] Zhang *et al.*[35]; [C] Shakeri *et al.*[36]; [D] Gowd *et al.*[37]; [E] Zakir *et al.*[7]; [F] Zakir *et al.*[6]; [G] Kohinoor *et al.*[10]; [H] Taylor[17]

Total concentration of Fe in soils of Chittagong city ranged from 21264 to 40269 μg g^{-1} (2.12% to 4.02%), having an average value of 37153.69 μg g^{-1} (Table 3). According to Hossain *et al.*[28], total Fe content in some benchmark soil pedons of the Ganges river floodplain of Bangladesh ranged from 3.06 to 9.09% and no definite sequence in the distribution of Fe with depth was noticeable probably due to young nature of these alluvial soils. However, the average Fe concentration in soils was smaller compared with geochemical background value of continental crust (Table 4). On the other hand, total concentration of Ni in soils of the study area ranged from Trace to 19.60 μg g^{-1} having an average value of 2.23 μg g^{-1} (Table 3). This result is very much lower than those of the earlier study of Domingo and Kyuma[25] and Jahiruddin *et al.*[26]. Similarly, the average Ni concentration in soils collected from different areas of Chittagong city was lower compared with several other industrial areas in Bangladesh and the world as well as geochemical background value of continental crust (Table 4).

Correlation Coefficient Analysis: Correlation matrix for analyzed parameters of soils were calculated to see if some of the parameters were interrelated with each other and the results are presented in Table 5. Examination of the matrix also provides clues about the carrier substances and the chemical association of metals in the study area. Among the relationship between parameters, organic carbon (OC) showed significant positive correlation with Zn (r = 0.48*) and Ni (r = 0.72**). Similarly, Fe content in soils collected from different areas of Chittagong city also showed highly significant positive relationship with Ni (r = 0.59**) and Cr (r = 0.58**) while Cu content in soils showed significant positive relationship with Zn (r = 0.66**) and Pb (r = 0.46*). Zn and Ni showed highly significant positive relationship with Cr (r = 0.53**) which indicate that the parameters were interrelated with each other and may be originated from the same source to the study area. Other relationships among the constituents of soil were insignificant.

Table 5: Pearson correlation coefficient matrix for different physicochemical properties and metals of soils collected from different areas of Chittagong city, Bangladesh.

	pH	EC	OC	Fe	Cu	Zn	Ni	Cr
EC(µS cm^{-1})	0.34							
OC (µg g^{-1})	-0.28	0.39						
Fe (µg g^{-1})	-0.06	0.19	0.11					
Cu (µg g^{-1})	-0.16	-0.01	0.30	0.32				
Zn (µg g^{-1})	-0.16	0.27	0.48*	0.37	0.66**			
Ni (µg g^{-1})	0.11	0.76**	0.72**	0.59**	0.05	0.19		
Cr (µg g^{-1})	-0.16	0.11	0.11	0.58**	0.41	0.53**	0.53**	
Pb (µg g^{-1})	-0.20	-0.03	0.21	0.01	0.46*	0.24	0.19	-0.001

Legend: ** = Significant at 1% level and * = Significant at 5% level.
Tabulated values of r with 20 df is 0.537 at 1% level of significance and 0.423 at 5% level of significance.

Assessment of Pollution Level

Index of geoaccumulation (I_{geo}): The geoaccumulation index, I_{geo} introduced by Muller[16] was used to assess metallic pollution level in soils of Chittagong city. The geoaccumuation index includes various degrees of contamination above the background value ranging from unpolluted to extremely polluted soil quality. The highest grade (class six) can be reflected 100-fold enrichment above the background values[29]. The calculated I_{geo} for metals of soils of Chittagong city and their corresponding contamination intensity are illustrated in Fig. 2. While considering the I_{geo} values for Pb, all locations of different areas of the city exhibited positive values and the range was 3.49-4.02 that means I_{geo} class: 4-5, indicating strongly to extremely polluted soil quality. On the other hand, the I_{geo} values for Cr in all locations were also positive (0.51 to 0.85), which exhibited I_{geo} class: 1 indicating uncontaminated/moderately polluted soil quality. Similarly, in case of Zn, 50% locations exhibited positive values and the range was 0.08-1.54 that means I_{geo} class 1-2, indicating uncontaminated to moderately polluted soil quality. Other metals showed negative I_{geo} values, which means unpolluted soil quality.

Enrichment factors (EFc): To evaluate the magnitude of contaminants in the environment, the enrichment factors were computed relative to the abundance of species in source material to that found in the Earth's crust[17, 30]. If the EFc value of an element is greater than unity, this indicates that the metal is more abundant in the sample relative to that found in the Earth's crust. Although EFc values less than 5 may not be considered significant, they are indicative of metal accumulation, because such small enrichments may arise from differences in the composition of local sample material with respect to the reference Earth's crust ratio values used in the EFc calculations[18]. If the EFc values are greater than 5, samples are considered contaminated. Figure 3 represents the EFc values of metals measured in the soil samples of Chittagong city.

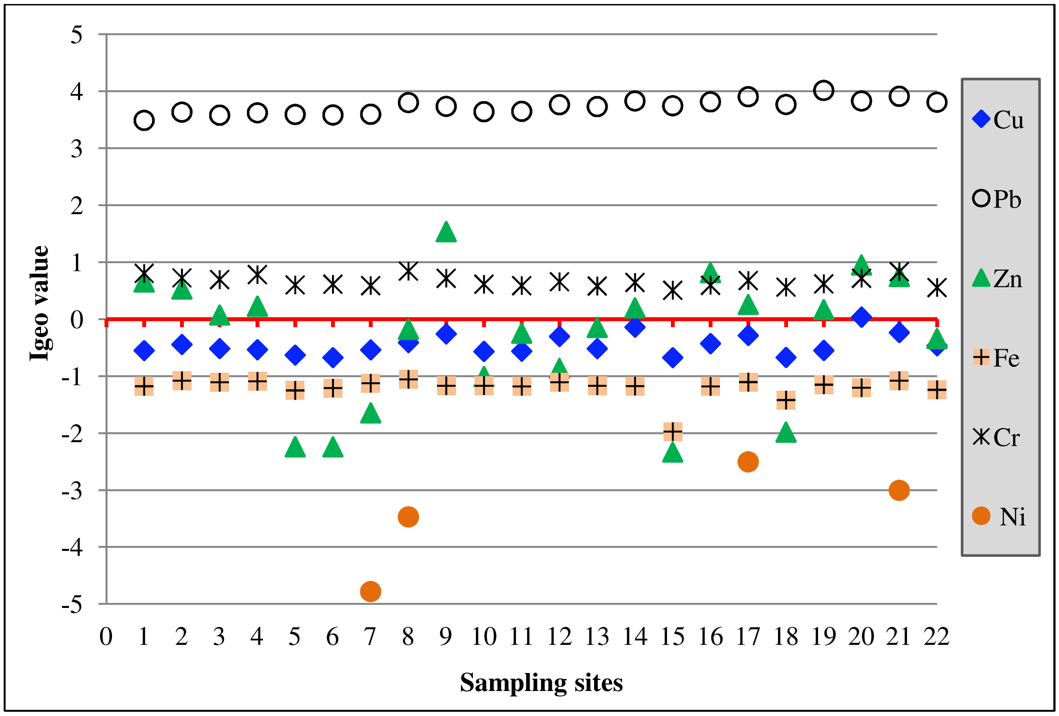

Fig. 2: Geoaccumulation index of metals at different soil sampling sites of Chittagong city, Bangladesh.

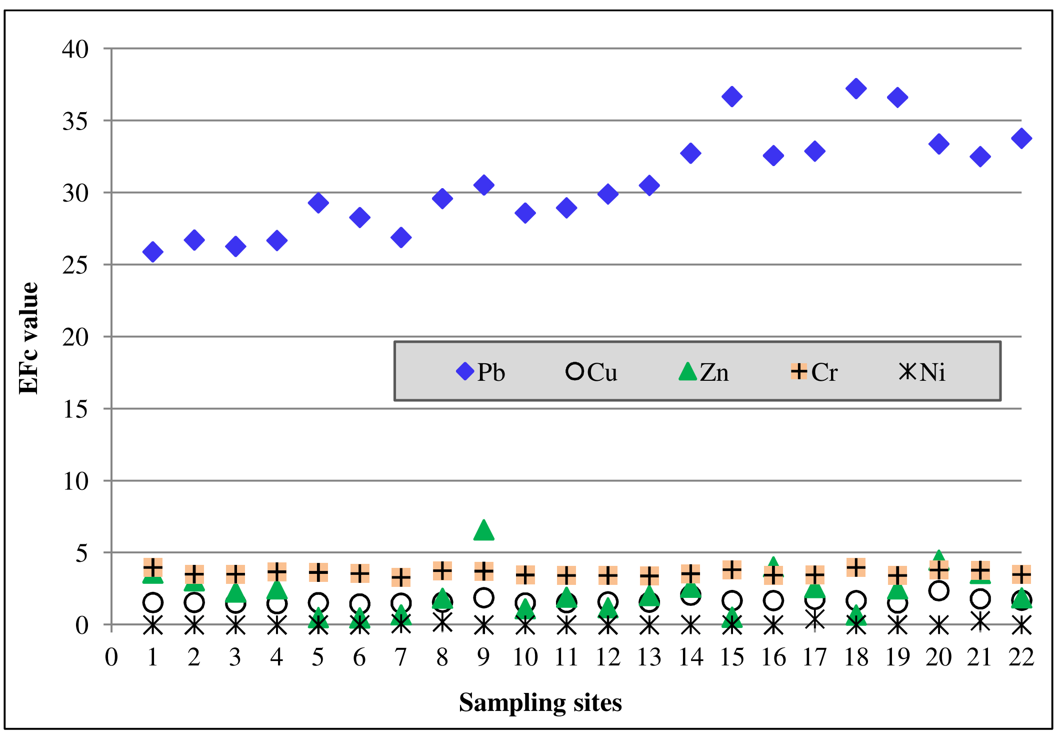

Fig. 3: Enrichment factors of metals at different soil sampling sites of Chittagong city, Bangladesh

It is evident from the Fig. 3 that all locations had EFc values > 5.0 for Pb and the range was 25.90-36.68. On the other hand, only 01 site for Zn had EFc values >5.0 and all locations had EFc values < 5.0 for Cu, Cr and Ni (Fig. 3). It is presumed that high EFc values indicate an anthropogenic source of metals, mainly from activities such as industrialization, urbanization, deposition of industrial wastes and others. Since, the bioavailability and toxicity of any metals in soil depends upon the chemical form and concentration of the metals[31], it can be inferred that metals in soil samples with the highest EFc values have a potential for mobility and bioavailability on the aquatic ecosystems.

Pollution load index (PLI): PLI is a simple and easily understandable index, which describes the quality of a site that can be used to compare the pollution status of different sites. The calculated PLI values for soils of Chittagong city ranged from 1.47-2.84 with a mean value of 2.15 (Fig. 4). Quality of a site is assessed by this index as follows: a value of zero represents perfection, a numerical value = 1.0 indicates only baseline levels of pollutants are present, and values above the baseline i.e. one would indicate progressive deterioration of the site quality[19]. It is evident from Figure 4 that all locations of Chittagong city had PLI value >1.0 indicates pollution load in the respective sites. The PLI is useful to provide some information to the public of the area as well as to the policy and decision makers of the country about the quality of a component of their environment, and it can indicate the trends over time and area.

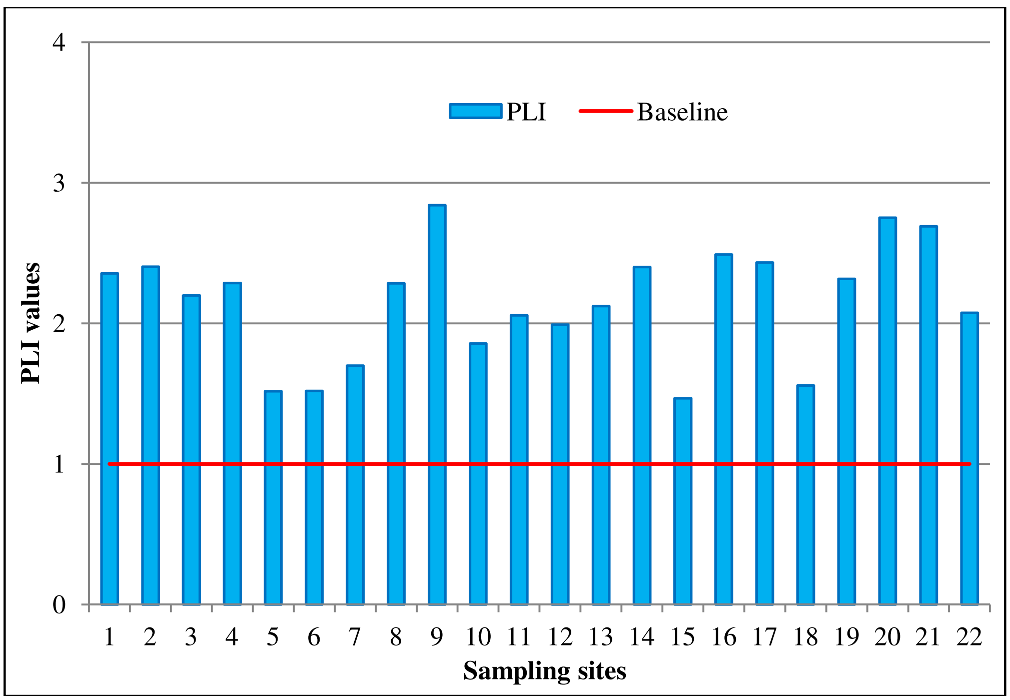

Fig. 4: Pollution load index (PLI) of metals at different soil sampling sites of Chittagong city, Bangladesh

Ecological risk index (RI): Ecological risk index (RI) proposed by Hakanson[20] was measured in this study to evaluate the potential ecological risk of metals. This method comprehensively considers the synergy, toxic level, concentration of the metals and ecological sensitivity of metals[32, 33]. The potential ecological risk index of a single element (E_R^i) and comprehensive potential ecological risk index (RI) were calculated following the method outlined by Hakanson[20], and the results are presented in Table 6. The grading standard of potential ecological risk of metals in soil was adjusted as proposed by Jiang *et*

DOI:10.24214/jcbps.D.7.4.83550.]

al.[33] as follows: $E_R^i < 30$ = Slight pollution; $30 \leq E_R^i < 60$ = Medium pollution; $60 \leq E_R^i < 120$ = Strong pollution; $120 \leq E_R^i < 240$ = Very strong pollution and $E_R^i \geq 240$ = Extremely strong pollution. Incase of RI the grading standard is: RI < 40 = Slight risk (risk level A); 40 ≤ RI < 80 = Medium risk (risk level B); 80 ≤ RI < 160 = Strong risk (risk level C); 160 ≤ RI < 320 = Very strong risk (risk level D) and RI ≥ 320 = extremely strong risk.

The potential ecological risk indices of the four metals are E_R^i(Cu) 4.69-7.70, E_R^i(Zn) 0.30-4.39, E_R^i(Pb) 85.61-123.46 and E_R^i(Cr) 4.28-5.41 (Table 6) and the metals risk was arranged in the order of E_R^i(Pb) > E_R^i(Cu) > E_R^i(Cr) > E_R^i(Zn). It is very much evident from Table 6 that Pb was the key influential metal to raise the potential ecological risk and its mean value of E_R^i was 101.62. Total sampling sites of the city exhibited strong potential ecological risk of Pb, whereas other metals (Cu, Cr and Zn) showed slight potential ecological risk to the environment. The comprehensive potential ecological risk index (RI) ranged from 98.37-134.93 with a mean value of 113.60 (Table 6), demonstrating that the soil potential ecological risk levels around the sampling sites of the city was level C and the corresponding ecological damage degree was strong as categorized by Jiang *et al.*[33].

Table 6: Calculated potential ecological risk index of a single element and comprehensive potential ecological risk index (RI) for soil sampling sites of Chittagong city, Bangladesh

Sampling site	Potential ecological risk index of a single element (E_R^i)				Comprehensive potential ecological risk index (RI)
	Cu	Zn	Pb	Cr	
1	5.11	2.37	85.61	5.27	98.37
2	5.51	2.17	94.67	4.98	107.33
3	5.24	1.58	91.21	4.88	102.91
4	5.17	1.76	93.87	5.19	105.99
5	4.84	0.32	92.01	4.57	101.73
6	4.69	0.31	91.48	4.61	101.09
7	5.16	0.48	92.27	4.53	102.44
8	5.64	1.33	106.40	5.41	118.78
9	6.27	4.39	101.60	4.96	117.22
10	5.07	0.74	95.20	4.61	105.62
11	5.07	1.27	95.60	4.53	106.47
12	5.54	0.82	103.74	4.75	114.85
13	5.24	1.36	101.34	4.51	112.44
14	6.82	1.73	108.53	4.71	121.79
15	4.69	0.30	102.40	4.28	111.67
16	5.57	2.66	107.46	4.55	120.24
17	6.16	1.80	114.40	4.83	127.18
18	4.70	0.38	104.00	4.45	113.53
19	5.12	1.69	123.46	4.63	134.90
20	7.70	2.92	108.53	4.96	124.12
21	6.38	2.53	114.93	5.37	129.21
22	5.42	1.19	106.93	4.43	117.97
Range	4.69-7.70	0.30-4.39	85.61-123.46	4.28-5.41	98.37-134.93
Mean	5.51	1.55	101.62	4.77	113.60
SD	0.75	1.02	9.36	0.32	10.28

CONCLUSION

Chittagong city is highly susceptible to environmental pollution due to over population, rapid industrialization, urbanization and disposal of different types of solid and liquid waste without any treatment. This study was conducted to determine the concentration of different metals in top soils of Chittagong city and to evaluate the status of metallic pollution. Total concentration of Cu, Zn, Cr, Fe and Pb in soil samples were 60.56, 108.05, 238.63, 37153.69 and 254.05 µg g^{-1}, respectively, while the concentrations of Ni in most sampling sites were trace. The study revealed that the average Cu, Zn, Cr and Pb contents in soils were higher compared with several other industrial areas in home and abroad as well as the geochemical background. The calculated I_{geo} values for Pb ranged from 3.49-4.02 that means I_{geo} class: 4-5, indicating strongly to extremely polluted soil quality. The computed I_{geo} values for Cr in all locations were also positive ($0 < I_{geo} < 1$) that means I_{geo} class: 1 indicating uncontaminated/moderately polluted soil quality. But in case of Zn, 50% locations exhibited I_{geo} class 1-2, indicating uncontaminated to moderately polluted soil quality. Similarly, as regards to EFc all sampling sites of the city had EFc values > 5.0 for Pb, which indicates anthropogenic load of the metal to the city. Considering PLI, all locations also showed values >1.0 indicates significant pollution load at the study area. The potential ecological risk was arranged in the order of E_R^i(Pb) > E_R^i(Cu) > E_R^i(Cr) > E_R^i(Zn). Pb was the key influence factor to raise the risk and its mean value of E_R^i was 101.62. All sampling sites of the city exhibited strong potential ecological risk of Pb but other metals present in soils showed slight potential ecological risk. The range of RI was 98.37-134.93, demonstrating that the soil potential ecological damage degree around the city was strong. Finally the study results concluded that the top soil of Chittagong city is strongly polluted with Pb followed by Cr and Zn. The findings of this study will provide practical insights for developing a preventive strategy to minimize environmental pollution in the city area.

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On line publication Date: 20.08.2017

DOI:10.24214/jcbps.D.7.4.83550.]