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Original Article

Assessment of heavy metals concentrations in the soil of Mongla industrial area, Bangladesh

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Abstract

Background: Contamination of soil with heavy metals is an alarming issue around the world. Therefore, this study aimed to assess the contamination status of heavy metals in the soil of Mongla industrial area, Bangladesh.

Methods: Soil samples were randomly collected from 20 sites and digested by wet digestion method. The concentrations of heavy metals (Mn, Fe, Cu, Zn, Cd, and Pb) were determined using atomic absorption spectrophotometer (AAS). The quality of soil was assessed based on the contamination factor (CF), geoaccumulation index (Igeo), enrichment factor (EF), and ecological risk index factor (ERIF) analyses.

Results: The average concentrations of Mn, Fe, Cu, Zn, Cd, and Pb were obtained to be 258.08 ± 51.61, 3736.90 ± 322.17, 19.55 ± 6.49, 66.76 ± 18.32, 0.59 ± 0.13, and 10.40 ± 1.49 mg kg-1, respectively, which were below the permissible limit. The highest value of CF (0.74 ± 0.16), Igeo (0.35 ± 0.34), EF (24.86 ± 6.27), and PERIF (22.11 ± 4.81) was observed for Cd. The pollution of CF, Igeo, EF, and ERIF was classified as very severely polluted, unpolluted to moderately polluted, strongly to extremely polluted, and slightly polluted, respectively, with these heavy metals due to anthropogenic activities. One-way ANOVA indicated a significant difference between Zn and Cd concentrations ($P < 0.05$), whereas Pearson correlation showed a positive correlation between Zn-Pb ($P = 0.01$) and Fe-Zn ($P = 0.05$).

Conclusion: There are different classes of contamination with heavy metals in the study area. Therefore, necessary steps should be taken and people's awareness of the soil pollution should be raised.

Keywords: Soil pollution, Heavy metals, Contamination factor, Geoaccumulation index, Enrichment factor, Ecological risk index factor

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Introduction

Soil is the storehouse of nutrients, minerals, organic and inorganic matters (1,2). But unfortunately, it is being polluted with heavy metals due to natural, as well as anthropogenic activities like smelting procedures, mining, excessive use of wastewater and fertilizers in agricultural fields, and atmospheric deposition from vehicle and industries (3-7). The presence of heavy metals in soil is very dangerous because they are transferred into the food chain (ecosystem) through vegetables and long-term exposure to heavy metals causes different fetal diseases including mental lapse, kidney failure, lung cancer, bone fractures, kidney dysfunction, and hypertension (8-10). At present, soil pollution has become a great global concern. For this reason, the regular monitoring program has been launched to establish a database about the contamination status of heavy metals in soil. Recently, Nessa and Jewel analyzed the concentration of heavy metals in the soil of Dhaka and reported that the concentrations of Cu and Pb were relatively higher than the recommended values (11). In a similar research, Hasnine et al concluded that the level of heavy metals (Mn, Fe, Cu, and Zn) in the soil of Dhaka exceeded the standard regulatory limit (12). Fahmida and Rafizul also reported that the soil of waste disposal site of Khulna was mainly contaminated with Cd and Pb (13). Islam et al showed that the soil of Tangail industrial area was associated with considerable to very high potential ecological risk (14). In another study, Begum et al determined the concentration of heavy metals in the soil of Bogra city and found that the area was strongly contaminated and uncontaminated to moderately contaminated with the elevated levels of Cu and Cd, respectively (15).

Recently, Bibak et al assessed the contamination level of sediments in Bushehr province (Iran) based on the geoaccumulation index (I_{geo}) and enrichment factor

(EF). The higher level of EF was observed for Fe and Pb, indicating that the sediments contamination was mainly due to anthropogenic activities (16). Ediene and Umoetok examined the concentration of heavy metals in the soil of Cross River State (Nigeria) and reported that the level of Zn and Pb in the soil was above the permissible limits, whereas the level of Cu was within the safe limit (17). Moreover, Begum et al analyzed I_{geo} of heavy metals (Fe, Cu, Zn, and Pb) in the soil collected from various localities of Hosur Road, Bangalore (India), and showed that the sampling sites were uncontaminated with Fe and Zn and moderately contaminated with Pb (18). In another study, Saxena and Saxena analyzed the level of heavy metals (Pb, Cd, Mn, Zn, and Cu) in the soil samples collected from Uttar Pradesh (India). They concluded that the level of Pb was higher at three sites, whereas the concentration of Cu in at two sites was higher than the permissible limits (19). Besides, several studies reported the pollution of soil by heavy metals, which is a global concern.

Agricultural products play an important role in Bangladesh economic sector. Although Mongla is an industrial area, the people of this region cultivate different types of agricultural products like vegetables, fishes, crops, and fruits, and supply their products to the local market of Khulna and other parts of Bangladesh. Soil acts as an important resource for the production of these products. If the agricultural products are cultivated in the contaminated soil, the heavy metals may enter the products and consumption of contaminated foods might pose deleterious effects on the human health. Still, there is insufficient information on the contamination status of soil at the southern part of Bangladesh. Due to unrest industrialization in Mongla, different industrial activities, and improper agricultural practices, the soil of this region might be polluted. Therefore, the aim of this study was to determine the concentration of heavy metals in Mongla industrial area and assess the quality of cultivated soil through contamination factor (CF), I_{geo}, EF, and ecological risk index factor (ERIF) analyses, as well as establish a database about the contamination status of heavy metals for future reference.

Materials and Methods

Mongla is a suburban area in Bagerhat district and located at the bank of Pashur river. It lies between 22°33′ and 21°49′ North latitudes and between 89°32′ and 89°44′ East longitudes. It is also surrounded by Rampal Upazila on the north, by Morrelganj and Sarankhola Upazila on the east, by the Bay of Bengal on the south, and by Dacope Upazila on the west (Figure 1).

Mongla is the second largest port in Bangladesh and 19 different industries are located in this region. Due to unrest industrial activities, different types of industrial effluents, solid waste, hazardous materials are generated and most of them are directly disposed into the soil without proper treatment. Generally, the by-products of

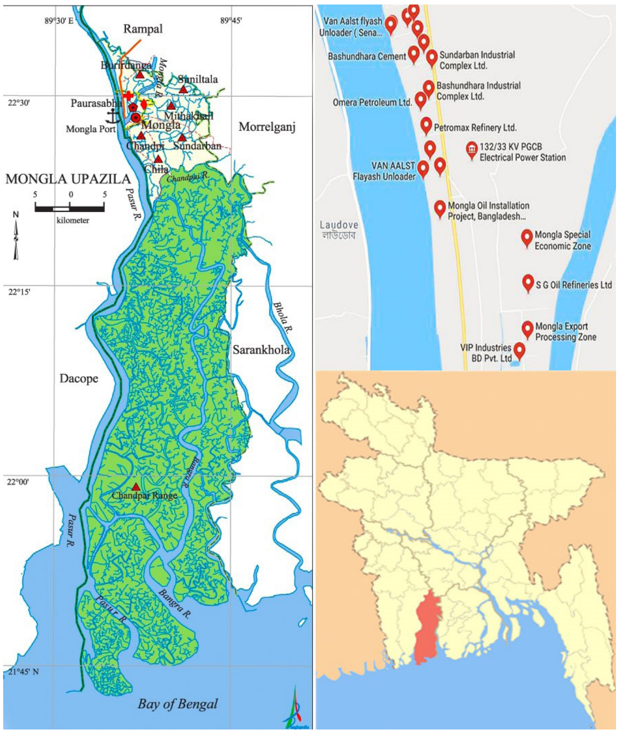

Figure 1. The study area (Mongla, Bangladesh).

cable, petroleum, cement, metallurgy, electroplating, and battery industries contain various heavy metals (Fe, Cu, Zn), (Cu, Zn, Cd, Pb), (Mn, Fe, Cu, Cd), (Cu, Zn, As, Cd, Pb), (Cu, Zn), and (Cu, Zn, Cd, Pb), respectively (20). Therefore, the cultivated soil might be contaminated by the industrial sources. A brief description of the different industries located in Mongla industrial area and sampling stations is shown in Table 1.

Basically, the deposition of heavy metals in soil depends on the soil texture. According to a study by Islam et al, the soil of Mongla industrial area can be categorized as silty clay soil, which is composed of 0%-20% sand, 40%-73% silt, and 27%-40% clay materials (21).

In this study, soil samples (n = 3×20) were randomly collected from 20 relevant sites in Mongla industrial area (Table 1), and the samples were ground into powder form. For each sample analysis, 5:1:1 triacid mixture was prepared by mixing 70% HNO_3 (Merck, Germany), 70% H_2SO_4 (Merck, Germany), and 65% $HClO_4$ (Merck, Germany). In each beaker containing 1 g of dried sample, 15 mL triacid mixture was added. Each mixture was digested at 80°C until a transparent solution was obtained. After cooling, the digested samples were filtered and diluted to 50 mL with deionized water (RCI Labscan Limited) for heavy metal analysis (22). The content of heavy metals (Mn, Fe, Cu, Zn, Pb, and Cd) in the digested solution was quantified using an atomic absorption spectrophotometer (AAS) (Shimadzu AA-7000) (23). Analysis was replicated and the results were compared with the standard permissible limit. To assess the contamination level of soil and identify the possible contamination sources, the CF, I_{geo}, EF, and

Table 1. List of sampling stations and brief description of different industries located in Mongla Upazila, Bagerhat

Sampling Station	Name of Industries	Types of Industries
L-01	Petromax refinery Ltd.	Oil Refinery
L-02	Mongla Oil Installation Project	Oil Refinery
L-03	Shun Shing Edible Oil Ltd.	Oil Refinery
L-04	S G Oil Refineries Ltd.	Oil Refinery
L-05	Omera Petroleum Ltd.	Oil and Gas Refinery
L-06	Bashundhara LP Gas Ltd.	Gas Industry
L-07	Orion LPG Ltd.	Gas Industry
L-08	Sena Kalyan LPG Ltd.	Gas Industry
L-09	KV PGCB Electrical Power Station	Power Station
L-10	Dubai Bangladesh Cement Mills Ltd.	Cement Manufacturer
L-11	Sena Kalyan Cement Factory	Cement Manufacturer
L-12	Bashundhara Cement	Cement Manufacturer
L-13	King Brand Cement	Cement Manufacturer
L-14 and L-15	Holcim Cement Mills Ltd.	Cement Manufacturer
L-16	Sundarban Industrial Complex Ltd.	Industrial Area
L-17	Bashundhara Industrial Complex Ltd.	Industrial Area
L-18	Mongla Export Processing Zone	Industrial Area
L-19	Mongla Special Economic Zone	Industrial Area
L-20	VAN AALST Flyash Unloader	Vacuum Equipment Supplier

ERIF were calculated and compared with those reported by similar studies.

CF is the ratio obtained by dividing the concentration of a specific heavy metal in the soil sample by the background value of that metal. It can be calculated by Eq. (1).

$$CF = \frac{C_m}{C_b} \quad (1)$$

where C_m is the concentration of heavy metal in soil sample and C_b is the background value of the heavy metal. The value of C_b can be measured either in precivilization sediments of the study area or taken from the literature. In this study, the background values were taken from literature and the value of C_b for Mn, Fe, Cu, Zn, Cd, and Pb was considered as 850, 38 000, 36, 140, 0.8, and 85 mg kg^{-1}, respectively (24-26). Moreover, the soil can be categorized into 10 classes in terms of CF. Uncontaminated (CF < 0.1), slightly contaminated (CF = 0.10-0.25), moderately contaminated (CF = 0.26-0.50), severely contaminated (CF = 0.51-0.75), very severely contaminated (CF = 0.76-1.00), slightly polluted (CF = 1.10-2.00), moderately polluted (CF = 2.10-4.00), severely polluted (CF = 4.10-8.00), very severely polluted (CF = 8.10-16.00), and excessively polluted (CF > 16.0) (24,27).

I_{geo} is used to evaluate the contamination level of sediment or soil. Generally, the concentration of heavy metals in the studied soil is compared with the concentration of those in pre-industrial levels. I_{geo} can be calculated by Eq. (2).

$$I_{geo} = \log_2\left(\frac{C_n}{1.5 \times B_n}\right) \quad (2)$$

where C_n is the concentration of heavy metal (n) in soil sample and B_n is the background value for heavy metal (n). Factor 1.5 indicates the variation of background values for heavy metal in the environment (28-30). According to Legorburu et al, 7 classes of soil were identified in terms of I_{geo}. Unpolluted (I_{geo} < 0), unpolluted to moderately polluted (I_{geo} = 0~1), moderately polluted (I_{geo} = 1~2), moderately to strongly polluted (I_{geo} = 2~3), heavily polluted (I_{geo} = 3~4), strongly to extremely polluted (I_{geo} = 4~5), and extremely polluted (I_{geo} > 5) (31).

EF is the measure of anthropogenic and natural sources of heavy metals in soil. In this method, the concentration of heavy metal is compared with that of a reference metal such as Fe or Al, which can be calculated by Eq. (3).

$$EF = \frac{\left(\frac{C_M}{C_{Fe}}\right) \text{Soil}}{\left(\frac{C_M}{C_{Fe}}\right) \text{Background}} \quad (3)$$

where $(C_M/C_{Fe})_{Soil}$ is the ratio of the concentration of heavy metal (C_M) to iron (C_{Fe}) in soil samples and $(C_M/C_{Fe})_{Background}$ is the ratio of the concentration of same metal to iron in the background value (32,33). According to Legorburu et al, soils were categorized into 7 classes based on EF. Unpolluted (EF < 1.5), unpolluted to moderately polluted (EF = 1.5~3), moderately polluted (EF = 3~6), moderately to strongly polluted (EF = 6~12), strongly polluted (EF = 12~24), strongly to extremely polluted (EF = 24~48), and extremely polluted (EF > 48) (31).

ERIF is considered as an effective tool to express the environmental potential risks of heavy metals in the soil and the values are calculated by the following equations:

$$ERIF = \sum PERIF$$

$$PERIF = \frac{T_i C_i}{C_0} = Ti \times CF \quad (4)$$

$$CF = \frac{C_i}{C_0}$$

where C_i is the concentration of heavy metals in soil samples, C_0 is the reference of background value for heavy metals, and T_i is the toxic response factor for the heavy metals, which its value for Mn, Fe, Cu, Zn, Cd, and Pb is 1, 5, 5, 1, 30, and 5, respectively (34-37). Soils were categorized into 5 classes based on the PERIF and ERIF values. Slightly contaminated (PERIF < 30), moderately contaminated (30 ≤ PERIF < 60), strongly contaminated (60 ≤ PERIF < 120), very strongly contaminated (120 ≤ PERIF < 240), and extremely contaminated (PERIF ≥ 240) (38).

Slightly contaminated (ERIF < 40), moderately contaminated (40 ≤ ERIF < 80), strongly contaminated (80 ≤ PERIF < 160), very strongly contaminated (160 ≤ PERIF < 320), and extremely contaminated (PERIF ≥ 320) (38).

Statistical analysis

The concentrations of different heavy metals in the soil were compared using one-way analysis of variance (ANOVA). Moreover, the inter-element relationship of heavy metals in the soil was determined using Pearson correlation. The mean and standard deviations of metal concentrations, CF, I_{geo}, EF, PERIF, and ERIF in the soil were calculated. Data were analyzed using SPSS version 16 software.

Results

The average concentration of heavy metals in the 20 sampling sites is shown in Table 2. As shown in this table, the average concentration of Mn, Fe, Cu, Zn, Cd, and Pb was 258.08 ± 51.61, 3736.90 ± 322.17, 19.55 ± 6.49, 66.76 ± 18.32, 0.59 ± 0.13, and 10.40 ± 1.49 mg kg^{-1}, respectively. The concentration of these metals followed the decreasing order of Fe > Mn > Zn > Cu > Pb > Cd.

CF is used to determine the contamination status of soil with heavy metals. CF values of heavy metals in the soil samples are shown in Table 3. The mean values of CF for heavy metals followed the decreasing order of Fe > Mn > Zn > Pb > Cu > Cd. Generally, I_{geo} measures the contamination level of soil with different heavy metals. The I_{geo} values of the sampling sites are shown in Table 4. The mean values of I_{geo} for heavy metals followed the decreasing order of Cd > Zn > Pb > Cu > Mn > Fe. EF is used to determine the magnitude of heavy metals in soil. In this study, iron was considered as the reference metal to evaluate EF factor. The average EF for these heavy metals is shown in Table 5.

Ecological risk assessment of soil is determined by the PERIF and ERIF. Besides, this model is employed to evaluate the soil quality of an environment as well as to assess the degree of soil contamination with multiple heavy metals. PERIF and ERIF value of the sampling sites are shown in Table 6. The mean values of PERIF for heavy

Table 2. Average concentration (mg kg^{-1}) of heavy metals in sampling sites and their geographical location

Sampling Sites	Longitude	Latitude	Mn	Fe	Cu	Zn	Cd	Pb
L-1	89.596001	22.481231	194.36	3867.71	30.49	50.99	0.59	9.84
L-2	89.598271	22.487010	178.55	3787.38	34.63	53.70	0.61	9.00
L-3	89.598260	22.487063	193.30	3783.07	30.36	53.31	0.55	8.64
L-4	89.596754	22.491637	201.24	3979.86	17.13	54.11	0.66	10.63
L-5	89.596703	22.491142	221.07	3962.69	16.16	76.67	0.83	11.78
L-6	89.595147	22.504722	210.08	3930.31	16.06	89.00	0.50	11.63
L-7	89.590528	22.502399	275.14	3947.15	19.16	62.16	0.70	11.63
L-8	89.591587	22.503849	283.18	3950.74	21.69	100.54	0.51	11.09
L-9	89.590894	22.503177	288.11	3880.86	22.02	72.68	0.40	11.24
L-10	89.594435	22.504664	261.21	3976.04	19.68	62.69	0.54	9.32
L-11	89.588770	22.507420	225.54	3961.38	24.75	72.67	0.32	10.02
L-12	89.589499	22.509362	261.25	3885.82	22.46	72.45	0.42	9.45
L-13	89.589628	22.511206	325.99	3779.31	12.41	53.63	0.56	10.44
L-14	89.589650	22.512712	349.61	3645.77	18.33	88.45	0.74	12.42
L-15	89.587106	22.515993	289.28	3666.52	12.60	93.47	0.73	10.20
L-16	89.593084	22.505880	210.30	3957.61	15.90	89.72	0.67	11.25
L-17	89.591315	22.512612	307.50	3233.49	11.57	45.29	0.69	10.53
L-18	89.591294	22.509004	281.61	3579.31	14.02	39.13	0.49	7.06
L-19	89.593245	22.510450	262.77	2782.61	19.28	41.85	0.58	8.42
L-20	89.574506	22.510867	341.45	3180.39	12.37	62.66	0.70	13.33
Range			178.55-349.61	2782.61-3979.86	11.57-34.63	39.13-100.54	0.32-0.74	7.06-13.33
Mean ± SD			258.08±51.61	3736.90±322.17	19.55±6.49	66.76±18.32	0.59±0.13	10.40±1.49
Safe limit (39)			270	40,000	30	100	1	50

Table 3. Average contamination factor (CF) of heavy metals pollution in the soil of twenty sites

Location	Mn	Fe	Cu	Zn	Cd	Pb
L-01	0.23	0.10	0.85	0.36	0.74	0.12
L-02	0.21	0.10	0.96	0.38	0.76	0.11
L-03	0.23	0.10	0.84	0.38	0.69	0.10
L-04	0.24	0.10	0.48	0.39	0.83	0.13
L-05	0.26	0.10	0.45	0.55	1.04	0.14
L-06	0.25	0.10	0.45	0.64	0.63	0.14
L-07	0.32	0.10	0.53	0.44	0.88	0.14
L-08	0.33	0.10	0.60	0.72	0.64	0.13
L-09	0.34	0.10	0.61	0.52	0.50	0.13
L-10	0.31	0.10	0.55	0.45	0.68	0.11
L-11	0.27	0.10	0.69	0.52	0.40	0.12
L-12	0.31	0.10	0.62	0.52	0.53	0.11
L-13	0.38	0.10	0.34	0.38	0.70	0.12
L-14	0.41	0.10	0.51	0.63	0.93	0.15
L-15	0.34	0.10	0.35	0.67	0.91	0.12
L-16	0.25	0.10	0.44	0.64	0.84	0.13
L-17	0.36	0.09	0.32	0.32	0.86	0.12
L-18	0.33	0.09	0.39	0.28	0.61	0.08
L-19	0.31	0.07	0.54	0.30	0.73	0.10
L-20	0.40	0.08	0.34	0.45	0.88	0.16
Mean ± SD	0.30±0.06	0.10±0.01	0.54±0.18	0.48±0.13	0.74±0.16	0.12±0.02

Table 4. Average geoaccumulation index (I_{geo}) of heavy metals pollution in the soil of twenty sites

Location	Mn	Fe	Cu	Zn	Cd	Pb
L-01	-2.71	-4.19	-1.15	-1.48	0.39	-1.61
L-02	-2.84	-4.22	-0.96	-1.41	0.44	-1.74
L-03	-2.72	-4.23	-1.15	-1.42	0.29	-1.80
L-04	-2.66	-4.15	-1.98	-1.40	0.55	-1.50
L-05	-2.53	-4.16	-2.06	-0.89	0.88	-1.35
L-06	-2.60	-4.17	-2.07	-0.68	0.15	-1.37
L-07	-2.21	-4.16	-1.82	-1.20	0.64	-1.37
L-08	-2.17	-4.16	-1.64	-0.50	0.18	-1.44
L-09	-2.15	-4.19	-1.62	-0.97	-0.17	-1.42
L-10	-2.29	-4.15	-1.78	-1.18	0.26	-1.69
L-11	-2.50	-4.16	-1.45	-0.97	-0.49	-1.58
L-12	-2.29	-4.19	-1.59	-0.98	-0.10	-1.67
L-13	-1.97	-4.23	-2.44	-1.41	0.32	-1.52
L-14	-1.87	-4.28	-1.88	-0.69	0.72	-1.27
L-15	-2.14	-4.27	-2.42	-0.61	0.70	-1.56
L-16	-2.60	-4.16	-2.09	-0.67	0.57	-1.42
L-17	-2.05	-4.45	-2.54	-1.65	0.62	-1.51
L-18	-2.18	-4.31	-2.27	-1.86	0.12	-2.09
L-19	-2.28	-4.67	-1.81	-1.77	0.37	-1.83
L-20	-1.90	-4.48	-2.45	-1.19	0.64	-1.17
Mean ± SD	-2.33±0.29	-4.25±0.14	-1.86±0.46	-1.15±0.40	0.35±0.34	-1.55±0.22

metals followed the decreasing order of Cd > Cu > Pb > Fe > Zn > Mn. The results of Pearson correlation and one-way ANOVA among heavy metals studied are represented in Table 7.

Discussion

Mongla is considered as the second largest seaport of Bangladesh. Due to rapid industrialization and heavy transport systems, the soil might be contaminated with heavy metals. These metals may enter the food chain when different types of agricultural products are cultivated in the polluted soil. Intake of contaminated foods might cause fatal diseases in human. Therefore, regular monitoring of heavy metals in the sediments is necessary to ensure the quality and safety of the foods. This study was designed to estimate the concentration of heavy metals in the soil and also to assess the level of contamination and its possible sources through different pollution indices.

Table 5. Average enrichment factor (EF) of heavy metals pollution in the soil of 20 sites

Location	Mn	Fe	Cu	Zn	Cd	Pb
L-01	2.47	1.00	9.20	6.48	23.75	5.94
L-02	2.32	1.00	10.68	6.97	25.07	5.55
L-03	2.51	1.00	9.37	6.93	22.63	5.33
L-04	2.49	1.00	5.03	6.68	25.82	6.24
L-05	2.74	1.00	4.76	9.51	32.61	6.94
L-06	2.63	1.00	4.77	11.13	19.80	6.91
L-07	3.43	1.00	5.66	7.74	27.61	6.88
L-08	3.52	1.00	6.40	12.51	20.10	6.55
L-09	3.65	1.00	6.62	9.21	16.04	6.76
L-10	3.22	1.00	5.77	7.75	21.14	5.47
L-11	2.79	1.00	7.29	9.02	12.57	5.91
L-12	3.30	1.00	6.74	9.17	16.83	5.68
L-13	4.24	1.00	3.83	6.98	23.07	6.45
L-14	4.71	1.00	5.86	11.93	31.60	7.95
L-15	3.87	1.00	4.01	12.53	30.99	6.50
L-16	2.61	1.00	4.69	11.14	26.35	6.64
L-17	4.67	1.00	4.18	6.89	33.22	7.60
L-18	3.86	1.00	4.57	5.37	21.31	4.61
L-19	4.64	1.00	8.09	7.39	32.45	7.07
L-20	5.27	1.00	4.54	9.69	34.26	9.79
Mean ± SD	3.45±0.90	1.00±0.00	6.10±1.95	8.75±2.17	24.86±6.27	6.54±1.11

Table 6. Average potential ecological risk index factor (PERIF) and ecological risk index factor (ERIF) of heavy metals pollution in the soil samples

Location	Mn	Fe	Cu	Zn	Cd	Pb	ERIF=∑ PERIF
L-01	0.23	0.51	4.23	0.36	22.13	0.58	28.03
L-02	0.21	0.50	4.80	0.38	22.88	0.53	29.30
L-03	0.23	0.50	4.21	0.38	20.63	0.51	26.45
L-04	0.24	0.52	2.37	0.39	24.75	0.63	28.90
L-05	0.26	0.52	2.24	0.55	31.13	0.69	35.39
L-06	0.25	0.52	2.23	0.64	18.75	0.68	23.06
L-07	0.32	0.52	2.66	0.44	26.25	0.68	30.88
L-08	0.33	0.52	3.01	0.72	19.13	0.65	24.35
L-09	0.34	0.51	3.05	0.52	15.00	0.66	20.08
L-10	0.31	0.52	2.73	0.45	20.25	0.55	24.80
L-11	0.27	0.52	3.43	0.52	12.00	0.59	17.33
L-12	0.31	0.51	3.11	0.52	15.75	0.56	20.75
L-13	0.38	0.50	1.72	0.38	21.00	0.61	24.60
L-14	0.41	0.48	2.54	0.63	27.75	0.73	32.54
L-15	0.34	0.48	1.75	0.67	27.38	0.60	31.21
L-16	0.25	0.52	2.20	0.64	25.13	0.66	29.40
L-17	0.36	0.43	1.60	0.32	25.88	0.62	29.21
L-18	0.33	0.47	1.94	0.28	18.38	0.42	21.82
L-19	0.31	0.37	2.67	0.30	21.75	0.50	25.89
L-20	0.40	0.42	1.71	0.45	26.25	0.78	30.02
Mean ± SD	0.30±0.06	0.49±0.04	2.71±0.90	0.48±0.13	22.11±4.81	0.61±0.09	26.70±4.61

Heavy metals are metals whose density is greater than 5 g cm^{-3} (8). These metals are found in the earth crust and can remain in the environment for a long time without any biodegradation (2). Some heavy metals, such as Mn, Fe, Cu, and Zn, are essential micronutrients for biological functions of the human body. On the other hand, Cd and Pb are not essential for a living being, therefore, they are considered as toxic elements in nature.

Among these metals, Mn is considered as the trace nutrient in the human body but exposure to higher concentration of this metal may disrupt the biological functions in the human body. In this study, the average concentration of Mn (258.08 ± 51.00) was lower than the permissible limit (270 mg kg^{-1}) (39). But the average concentrations of Mn in the sampling locations of L-07, 08, 09, 13, 14, 15, 17, 18, and 20 were 275.14, 283.18, 288.11, 325.99, 349.61, 289.28, 307.50, 281.61, and 341.45 mg kg^{-1}, respectively, which were above the safe limit. The elevated levels of Mn in the soil samples might be due to the disposal of industrial wastes from the cement factory, oil refinery,

Table 7. Pearson correlation and ANOVA analysis of heavy metals in the soil samples

	Mn	Fe	Cu	Zn	Cd	Pb
Pearson correlation						
Mn	1					
Fe	-0.435	1				
Cu	-0.624*	0.294	1			
Zn	0.090	0.448**	-0.134	1		
Cd	0.148	-0.203	-0.357	0.061	1	
Pb	0.349	0.127	-0.354	0.563*	0.426	1
ANOVA						
P value	0.622	0.907	0.526	0.015***		0.565
F value	1.233	0.317	1.872	$2.835E^3$		1.570

*Correlation is significant at (*P*=0.01) (2-tailed); **Correlation is significant at (*P*=0.05) (2-tailed). ***Significant value (P<0.05, One-way ANOVA)

liquid petroleum gas (LPG) industry, etc. Islam et al reported that waste materials from cement, petroleum, and metallurgy process contribute to the disposal of Mn in the environment (21). Iron is an essential element for the physiological functions in the human body like hemoglobin formation. The tolerable limit of Mn is beneficial for human but excessive amount of this metal (above 48 mg kg^{-1}) may cause gastrointestinal side effects (40). It was found that Fe had the highest average concentration (3736.90 ± 322.17 mg kg^{-1}) compared to the other heavy metals, though this value was lower than those reported in other similar studies (Table 8). In addition, the mean concentration of Fe was lower than the permissible limits (40000 mg kg^{-1}) in all locations in Bangladesh (39). This study revealed that the average concentration of Cu in all locations was below the safe limit (30 mg kg^{-1}). But the average concentration of Cu in L-01 (30.49 mg kg^{-1}), L-02 (34.63 mg kg^{-1}), and L-03 (30.36 mg kg^{-1}) were slightly higher than the permissible limit. The present study showed that the mean concentration of Zn in these sampling stations was 66.76 ± 18.32 mg kg^{-1}, which was lower than the safe limit (100 mg kg^{-1}) (39). The mean concentration of Zn in all sites except L-08 was below the safe limit. Probably, traffic and other related activities such as liquid petroleum stations, battery packs, oil changes, etc. are responsible for the elevated levels of Cu and Zn in soil (35). The average concentration of Cd in the soil was 0.59 ± 0.13 mg kg^{-1}, which was below the safe limit (1.00 mg kg^{-1}) (39) and also lower than the certified value in Bangladesh (41). Pb and its compounds can easily accumulate in soil due to its low solubility and can remain in the environment for a long time. The mean concentration of Pb was 10.40 ± 1.49 mg kg^{-1}, which was lower than the safe limit (50 mg kg^{-1}) (38) but higher than the certified value in Bangladesh (41). The average value of Pb was higher than that reported in other studies in

Table 8. Comparison of mean heavy metals concentrations (mg kg-1) in the soil samples with other studies

Study Area	Mn	Fe	Cu	Zn	Pb	Cd	Ref.
National							
Bogra	--	--	131.87	28.46	9.60	6.95	(15)
Entire Bangladesh	669.56	37247.15	54.29	202.81	9.4	1.26	(40)
Iswardi	283.50	15684.70	21.43	123.283	68.84	0.538	(43)
Chittagong	160.79	--	32.63	139.30	7.33	2.43	(44)
Mymensingh	182.33	24683.33	49.10	123.19	59.39	--	(45)
Gazipur	--	--	36.18	176.66	75.00	0.20	(46)
Dhaka	--	--	75.04	103.34	3.84	0.52	(47)
Dhaka	--	21216	37.57	--	50.32	0.45	(48)
Dhaka	125.25	455.21	12.09	3.75	2.72	0.03	(49)
Jashore	199.38	3773.29	11.85	49.58	12.61	0.68	(50)
International							
Manila, Philippines	1999.00	--	98.70	440.00	213.60	0.57	(51)
Bangkok, Thailand	340.00	--	41.70	118.00	47.80	0.29	(52)
Palermo, Italy	519.00	--	63.00	138.00	202.00	0.68	(53)
Sialkot, Pakistan	17991.62	--	26.85	94.2	121.4	36.80	(54)
Uttar Pradesh, India	--	--	42.90	159.90	38.30	--	(55)
Fuyang, China	--	--	40.77	159.85	40.59	0.37	(56)

Bangladesh such as Chittagong, Bogra, and Dhaka (Table 8), which might be due to different sources like vehicle exhaust fumes, dry-cell batteries, sewage effluents, run off of wastes and atmospheric depositions, high vehicular traffic, etc (40). Besides, the application of organic and inorganic fertilizers, fungicides, pesticides, manure, and bio-solids in relevant fields may contribute to the increased level of these heavy metals (42).

The CF values for Mn, Fe, Cu, Zn, Cd, and Pb ranged 0.21-0.41, 0.07-0.10, 0.32-0.96, 0.28-0.72, 0.40-1.04, and 0.08-0.16, respectively (Table 3). In this study, about 70% of the total areas were moderately contaminated with Mn (27). In addition, the CF values of Fe in some sites were lower than 0.10, indicating that the sampling sites were slightly contaminated with Fe. Whereas, about 15% of the total area was severely contaminated with Cu, 45% was severely contaminated by Zn, 45% was very severely contaminated with Cd, and 95% of the area was slightly contaminated with Pb (27).

According to Table 4, the mean value of I_{geo} showed the decreasing order of Cd > Zn > Pb > Cu > Mn > Fe. The I_{geo} values were mostly negative in the study area, indicating that the study area was uncontaminated with Mn, Fe, Cu, Zn, and Pb. Sampling sites of L-09, L-11, and L-12 were unpolluted with Cd but other sites were observed unpolluted to moderately polluted (31). The I_{geo} values for Mn, Fe, Cu, Zn, and Pb in all sampling sites were less than zero, indicating that the study sites were unpolluted. The I_{geo} values for Cd showed that 17 sites (with exception of L-09, L-11, and L-12) were moderately polluted. In terms of I_{geo} value, the concentration of Cd was higher due to continuous discharge of industrial (petroleum, cement, etc industries) effluents. On the other hand, discharge of these effluents without any chemical treatment can also increase the value of I_{geo} for Cd.

In this study, the order of average EF for heavy metals in the soil was as Cd > Zn > Pb > Cu > Mn (Table 5). The results revealed that the values of EF for Mn, Cu, Zn, Cd, and Pb were 2.32-5.27, 3.83-10.68, 5.37-12.53, 12.57-34.26, and 4.61-9.79, respectively. If the value of EF is ≤ 2, it is predicted that heavy metals in the soil come from crustal materials or natural weathering processes. If the EF value becomes greater than 2, anthropogenic activities are responsible for the soil pollution (56). In this study, the EF values were greater than 2, indicating that the concentration of heavy metals in the soil might be due to anthropogenic activities in lieu of natural processes. The results of this study indicated that 40% of the total area was unpolluted to moderately polluted with Mn but 60% of the area was moderately polluted with the same metal. Moreover, 40% of the sampling sites was moderately polluted whereas 60% was moderately to strongly polluted with Cu. These sites were also polluted with Zn. Strong pollution was observed in 10% of the sampling sites but 85% of the sampling sites was moderately to strongly polluted with Zn while 5% was moderately polluted with this metal. Besides, pollution index model showed that 50% of the sampling sites was strongly to extremely polluted while the rest of 50% sampling sites was strongly polluted with Cd.

The order of PERIF of specific heavy metals in soil was as Cd > Cu > Pb > Fe > Zn > Mn (Table 6). The potential ecological factor of Mn, Fe, Cu, Zn, Cd, and Pb was 0.21-0.41, 0.37-0.52, 1.60-4.80, 0.28-0.72, 12.00-31.13, and 0.42-0.78, respectively. PERIF values for heavy metals in all sampling sites were less than 30 (PERIF < 30), indicating that these areas were slightly contaminated (< 30) with heavy metals studied (38). ERIF for heavy metal ranged from 17.33 to 35.39 (Table 6). The highest and lowest ERIF values were observed in L-11 and L-05, respectively, and its average value was 26.70 ± 4.61. In this study, ERIF values for all sampling sites were below 40, indicating the low potential ecological risk in these areas (38). Soil pollution indices (CF, I_{geo}, EF, PERIF, and ERIF) obtained in this study were compared with those of other studies and are shown in Table 9.

Similar values of ERIF were found in the sediments of Mediterranean, Egypt (36), while the ERIF values in other studies (37,38) were higher than that obtained in the present study. The results of comparison revealed that the sediments of Turag river (Bangladesh) and the soil of coal gangue dump (China) were ecologically threaten by heavy metals.

According to the results of Pearson correlation analysis, a positive inter-element correlation was observed between Zn-Pb (0.01 level) and Fe-Zn (P = 0.05), while an inverse correlation was found between Mn-Cu (P = 0.01) (Table 7). However, there was no significant positive or negative correlation among other heavy metals in this region. The correlations among these metal pairs (Zn-Pb and Fe-Zn) indicates that these metal pairs might be originated from common sources. In addition, the relationship predicts that these metal pairs might be identically accumulated in silt clay soil (63). According to ANOVA analysis, a significant relationship was observed between Cd and Zn (P<0.05), indicating that the concentration of Cd and Zn depend on the soil samples (64).

Conclusion

According to the results, the level of heavy metals in the soil samples is within the permissible limit. Analysis of various pollution indices (CF, I_{geo}, EF, PERIF, and ERIF) indicated that the study area is associated with different classes of contaminations with heavy metals. Due to anthropogenic activities, the level of heavy metals is gradually increasing in the soil of Mongla industrial area, Bangladesh. As a result, heavy metals are entering the food chain and causing ecological imbalance. Therefore, regular monitoring of heavy metals should be done to control soil pollution in different areas of Bangladesh. In addition, people's awareness of the harmful impacts of heavy metals in the soil should be raised.

Table 9. Comparison of soil pollution indices with other similar studies

Parameters	Mn	Fe	Cu	Zn	Cd	Pb	∑ PERIF	References
CF	--	--	0.2	0.1	5.6	0.2	--	(33)
I_{geo}	0.001	--	0.02	0.01	0.5	0.03	--	
EF	25	--	283	92	8,598	652	--	
PERIF	--	--	0.8	0.1	167	0.8	--	
PERIF	0.44	--	0.91	0.23	21.52	3.01	--	(36)
ERIF	--	--	--	--	--	--	26.11	
CF	--	--	1.58	1.08	1.40	1.64	--	(37)
I_{geo}	--	--	0.06	-0.53	-0.26	0.12	--	
PERIF	--	--	7.88	1.08	42.00	8.20	--	
ERIF	--	--	--	--	--	--	59.16	
PERIF	--	--	5.24	1.27	72.92	5.39		(38)
ERIF	--	--	--	--	--	--	84.82	
CF	--	0.001	--	0.02	--	0.04	--	(40)
Igeo	--	0.001	--	0.005	--	0.003	--	
EF	--	--	--	22.46	--	67.35	--	
CF	0.50	0.57	--	--	--	--	--	(57)
I_{geo}	- 0.48	-0.42	--	--	--	--	--	
Igeo	- 0.24	-0.13	--	-0.15	--	--	--	(58)
EF	0.89	1.11	--	1.10	--	--	--	
CF	--	--	0.22	0.93	7.99	2.34	--	(59)
I_{geo}	--	--	0.02	0.01	1.27	0.02	--	
I_{geo}	--	--	0.76	0.49	1.28	1.05	--	(60)
EF	--	--	0.13	0.30	11.31	10.66	--	
CF	--	2.98	2.33	5.93	--	--	--	(61)
I_{geo}	--	0.30	0.19	0.60	--	--	--	
PERIF	--	--	11.65	5.93	--	--	--	
CF	--	--	0.09	0.03	6.31	0.08	--	(62)
CF	0.30	0.10	0.54	0.48	0.74	0.12	--	Present study
I_{geo}	- 2.33	- 4.25	- 1.86	- 1.15	0.35	- 1.55	--	
EF	3.45	1.00	6.10	8.75	24.86	6.54	--	
PERIF	0.30	0.49	2.71	0.48	22.11	0.61	--	
ERIF	--	--	--	--	--	--	26.70	

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Ethical issues
The authors certify that all data collected during the study are presented in this manuscript, and no data from the study have been or will be published separately.

Competing interests
The authors declare that they have no competing interests.

Authors' Contributions
MHA (Professor) contributed to the conceptualization, study design, fund acquisition, supervision, and revision of the manuscript. PKD (Assistant Professor) assisted in the manuscript preparation and revision. MARK (MSc research student) contributed to the fieldwork, methodology, data collection and analysis, and the manuscript preparation.

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