Spatial Dissemination of Some Heavy Metals in Soil Adjacent to Bhaluka Industrial Area, Mymensingh, Bangladesh

Abdullah Al Zabir¹, M. Wahid U. Zzaman², Md. Zakir Hossen², Md. Nizam Uddin¹, Md. Shariful Islam¹,* and Md. Saiful Islam³

¹Department of Agricultural Chemistry, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh
²Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh, Bangladesh
³Department of Soil Science, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh

Email address:
alzabir361@gmail.com (A. A. Zabir), mzamanacm@gmail.com (M. W. U. Zzaman), zakirhm.ac.bau@gmail.com (Md. Z. Hossen), mnizamacm@yahoo.com (Md. N. Uddin), sharifulpstu@yahoo.com (Md. S. Islam), islam-md.saiful-nj@ynu.jp (Md. S. Islam)

*Corresponding author

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Abstract: Heavy metals released from industries causes severe environmental pollution in developing countries. This study has been conducted to evaluate the intensity of heavy metals pollution in soil at 0, 30 and 60 m distances from waste carrying canal of Bhaluka industrial area of Mymensingh, Bangladesh. Lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) concentrations in soils decreased gradually with the increase of distance from waste canal. Maximum concentration was found at 60 to 0 m distance varied from 67.13–90.93, 52.23–76.73, 32.75–133.85, 61.18–422.10, 26900–36900 and 240–540 µg g⁻¹ for Pb, Cr, Cu, Zn, Fe and Mn, respectively. Geoaccumulation index showing that the soil was moderately polluted for Pb and Zn. Pollution load index values>1.0, explaining pollution load was increased adjacent to industrial area and deteriorate the quality of surface soils day by day. Contamination factor for Pb, Cu and Zn were very high indicating these metals as the major soil pollutants came from anthropogenic sources which was supported by enrichment factor values (>5). The extent of pollution in adjacent to this industrial area implies the condition becoming worse and alarming for biota and inhabitants of that area.

Keywords: Heavy Metal, Soil Pollution, Geoaccumulation, Pollution Load Index, Enrichment Factor

1. Introduction

Soil is a dynamic natural resource for the survival of human life and regarded as the key receiver of the persistent pollutants like heavy metals [1, 2]. Therefore, soil pollution by heavy metals is a global problem due to its significant deleterious consequences on plants, animal and human health. There are numerous human activities which results in the releases of toxic materials to the soil. Bhaluka is a newly industrial growing site of Mymensingh, Bangladesh, which is highly susceptible to environmental pollution over last decade. Almost all industrial units are discharging their untreated wastes in the surface drains and spread over agricultural fields. The national pollution profile of DOE [3] showed that Bangladesh had over 30,000 industrial units of which 24,000 were small and cottage, the remaining 6,000 were large and medium industries. About 300 industries including textile, dyeing, plastics, metal fabrications, diesel plant, leather, tanning discharge wastes and effluent containing As, Zn, Cr, Cd, Pb, Sr, Ni, Li, Ag, Hg, Co and Se [2, 4]. Tanneries of Hazaribagh produce 7.7 million liters of liquid waste and 88 million tons of solid waste every day.
and about 50% is hazardous due to high heavy metal contents [5]. The industrial hot-spots of Bangladesh are located near the urban and suburban areas and most cases surrounded by agricultural fields. The irrigation of industrial, municipal, sewage-sludge effluent and dumping of solid wastes on crop fields due to its high organic matter and nutrient content is a common scenario [6]. As a result the untreated effluents get dispersed throughout the crop field and plants are exposed to a pool of toxic metals. Moreover, flooding causes inundation of the cultivated fields with industrial effluents. In rainy season, surface runoff and seepage contribute to the transport of heavy metals over distance along with waste disposals. The residence time of heavy metals in soil is of the order of thousands of years. The persistence of these metals in soils, uptake by crops results an accumulative effects in animal and human. This is because unlike organic pollutants, metals are not degraded biologically but transformed from one state to another [2, 7]. The transport and accumulation of toxic heavy metals increases the concentration in soil and vegetation. Heavy metals dispersion increases due to sewage water irrigation in soils by 2 to 80% and in crops by 14 to 209% [8]. Certain plants can accumulate heavy metals in their tissues and uptake increases generally in plants that are grown in areas with increased soil contamination with heavy metals and therefore, many people are at risk of adverse health effects from consuming common garden vegetables cultivated in contaminated soil [6]. Concern over the environmental pollutants particularly the toxic heavy metals has increased immensely in Bangladesh during the last few decades due to population explosion, unplanned industrialization and urbanization [9]. The untreated wastes and effluents from the industries are discharged randomly to soils, canals and in the vicinity of the industrial areas. Moreover, the polluted water is irrigated to paddy and vegetable fields. The study area also suffers from flooding during rainy season. In order to delineate the scope of the environmental contamination by heavy metals an ecological risk was assessed. To best of our knowledge, no systematic investigation has been conducted so far, and metal toxicity data is severely insufficient to assess the ecological risk of heavy metals in soil near the industrial area in Bangladesh. Therefore, the objectives of the present study were to investigate the spatial distribution of heavy metals in soil and to assess the level of heavy metals pollution at different distances from waste carrying canals of Bhaluka Upazila.

Table 1. Information regarding soil sampling sites at Bhaluka, Mymensingh, Bangladesh.

| Sampling sites | Location  | Sample ID | Distance from canal | Possible sources of contamination          |
|---------------|-----------|-----------|---------------------|-------------------------------------------|
| Site-1        | Hawailie  | 1a        | 0 m                 | Glass, metallurgical, textile, composite, garments industry. |
|               |           | 1b        | 30 m                |                                          |
|               |           | 1c        | 60 m                |                                          |
| Site-2        | Hawailie  | 2a        | 0 m                 | Metallurgical,                             |
|               |           |           |                     |                                          |

2. Materials and Methods

2.1. Sampling Procedure, Preparation and Preservation

Surface (0–15 cm) soil samples were collected from ten (10) sites (Table 1) near the industrial waste carrying canals to provide satisfactory representation of the entire study area of Bhaluka Upazila (Fig. 1) during February to March, 2014. Samples were collected with the help of a hand auger (a stainless steel crew) at 0, 30 and 60 m distances from the waste discharging canals at each site (Table 1) and were kept in a clean polyethylene bags with proper labeling to avoid contamination. Then the soils were carried to the laboratory for processing and chemical analysis. Samples were placed on brown paper and air dried for two weeks and all clods were disintegrated; crumbs, stones, grabbles, plant parts, inert materials, etc. were removed and mixed uniformly. Soils were sieved through a 2-mm sieve to remove coarse particles. The final samples were kept in labeled polypropylene containers and preserved in desiccators at room temperature for chemical analysis [10, 11].
2.2. Chemical Analysis

Exactly 1.0 g soil from each sample was taken separately in 250 mL digestion tubes, then 10 mL concentrated HNO₃ was added to it. The content was kept for 16 hours at room temperature for pre-digestion and then heated at 140°C for 150 minutes [12]. Heavy metals like Pb, Cr, Cd, Cu, Zn, Fe and Mn in soil sample was determined by using an atomic absorption spectrophotometer (AAS) (Model: SHIMADZU AA-7000) following method described by Sparks [13] and Singh et al. [14]. All chemicals used here were of analytical grade.

2.3. Geoaccumulation Index (Igeo)

A geoaccumulation indexing (Igeo) approach was used to quantify the degree of anthropogenic contamination, and to compare the different metals in soils [15]. This quantitative check of metal pollution in soils was proposed in the form of an equation defined as the index of geoaccumulation as follows:

$$I_{geo} = \log \left[ \frac{C_n}{1.5B_n} \right]$$

Where, $C_n$ is measured concentration of trace metal in the soil, and $B_n$ is the geochemical background for the same element which is either directly measured in pre-civilization sediments of the area or taken from the literature (average shale value as described by Turekian and Wedepohl [16]). The factor 1.5 is introduced to include possible variations of the background values that are due to lithologic variations.

2.4. Pollution Load Index (PLI)

Pollution load index (PLI) is a multi-metal approach, which has been introduced by Tomlinson et al. [17] for an overall assessment of soil and sediment quality with respect to trace metal concentrations. According to Tomlinson et al. [17], PLI describes the quality of a site or an estuary in terms of easily understood by the non-specialist and which can be used to compare the pollution status of different sites and estuaries. The PLI for a single site is the $n^{th}$ root of $n$ number of multiplied together contamination factor (CF) values. The CF and PLI for a single site can be obtained as follows:

$$CF = \frac{C_{Metal}}{C_{Background}}$$

$$PLI = \left( CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n \right)^{1/n}$$

While computing the contamination factor (CF) for pollution load index (PLI) of soils of the studied region, average shale value for each heavy metal as described by Turekian and Wedepohl [16] were considered as background concentration values. The concept of a baseline is a fundamental issue to the formation of a PLI [17, 18].

2.5. Enrichment Factor (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 [19, 20, 21]. The following equation was used to calculate the EFc-

$$EFc = \left( \frac{C_M/C_{Fe}}{C_{Metal}/C_{Fe}} \right)_{sample}/\left( C_{Metal}/C_{Fe} \right)_{Earth's crust}$$

Where, $(C_M/C_{Fe})_{sample}$ is the ratio of concentration of metal $(C_M)$ to that of Fe $(C_{Fe})$ in the soil sample, and $(C_{Metal}/C_{Fe})_{Earth's crust}$ is the same reference ratio in the Earth’s crust. The average abundance of metals in the reference Earth’s crust was taken...
from Huheey [19] and Fe was selected as the reference element, due to its crustal dominance and its high immobility.

2.6. Statistical Analysis

The statistical analyses of the analytical results obtained from the chemical analysis of different soil samples were performed using Excel Statistics version 4.0 and mean differences were made by multiple t-test.

3. Results and Discussion

3.1. Sequence of Heavy Metals in Soils

Sequence of toxic elements in soil samples was shown in order to know the distribution of the metals in the study area. Soil heavy metals were found in the following order: Fe > Mn > Zn > Cu > Pb > Cd at 0 m and Fe > Mn > Zn > Pb > Cr > Cu > Cd at 30 and 60 m away from the waste canal (Fig. 2). For every metal, the highest concentration occurred in soils at the edge of waste canal. Moreover, the concentration of all heavy metals decreased with the increasing of sampling distance from waste canal. The present result agrees with the investigation made by Sultana et al. [22] who investigated the heavy metal contamination in the river sediments near industrial area of Dhaka. She found that heavy metals among all the samples were distributed in a decreasing sequence of Fe > Mn > Zn > Ni > Cu > As > Cr > Pb > Cd.

3.1.1. Lead, Chromium and Cadmium Concentration in Soil

The status of Pb in soil samples collected at 0 m distance from the canal ranged between 50.72 to 90.93 µg g⁻¹ (Fig. 2a), having an average value of 66.31 µg g⁻¹ (Table 2). At 30 and 60 m distances from waste canal the concentration (range value) was 46.62–80.26 and 40.06–67.13 µg g⁻¹, respectively. Maximum content of Pb was found at Jamirdia which might be attributed due to the effects from textile, composite industry and battery acid disposal at this site [2, 6]. All of the 10 samples at 0 m, 7 at 30 m and 5 at 60 m distance from waste canal were contained Pb higher than maximum acceptable concentration (50 µg g⁻¹) for crop production [23] which may result in reduced crop production and food chain contamination by exceeding concentration of Pb. The present study results were almost thrice than other reports published earlier for soils of Bangladesh. Naser et al. [24] observed that mean concentrations of Pb were 20.8, 18.6 and 16.7 µg g⁻¹ at 0, 50 and 100m distances, respectively from the highway of Gazipur, Bangladesh. Again, Bhuluka soils contained much lower Pb than Dashkasan gold mine soils (2710 µg g⁻¹) of Iran [25]. Ahmed et al. [26] reported that Pb concentration of the soil of Bhuluka Upazila ranged from 12.00–34.00 µg g⁻¹. This means Pb content in Bhuluka soil has been increased significantly during last decade. The total concentration of Cr in soil samples collected at 0 m distance from waste canal ranged between 35.69 to 76.73 µg g⁻¹ (Fig. 2b), having an average value of 57.48 µg g⁻¹ (Table 2). At 30 and 60 m distances from waste canal the concentration of Cr ranged between 26.47 to 60.51 and 25.52 to 52.23 µg g⁻¹, respectively. About 50% sites at both 0 and 60 m and 80% at 30 m distance showed values greater than the mean. It is certain that, soils of Bhuluka may exceed reference values of Cr as proposed in [16] within a short period, if present situation continues. Addo et al. [27] observed that the mean Pb, Cr, Cu, Mn and Zn concentrations in the soils decreased as distance increased from the Diamond Cement Factory, Aflao, Ghana. This indicated that the factory which is the only industrial source in the area is the major cause of the pollutants contamination in its vicinity. The study conducted by Ahmed et al. [28] at two Municipal Solid Wastes (MSW) dumpsites at Alexandria in Egypt also showed the similar trend of heavy metal contamination in soils. All the soil samples collected from Bhuluka Upazilla contained trace amount of Cd (<0.0001 µg g⁻¹). This indicates that industrial effluents of this area did not contain considerable amount of Cd and this area is not yet susceptible to Cd pollution.

3.1.2. Copper, Zinc, Iron and Manganese Concentration in Soil

Total concentration of Cu in soils at 0, 30 and 60 m distances from industrial waste flowing canal ranged between 26.45 to 133.85, 19.77 to 127.17 and 13.57 to 32.75 µg g⁻¹ (Fig. 2c, 2d, 2e, 2f) having an average value of 77.85, 45.24 and 24.23 µg g⁻¹, respectively (Table 2). Out of 10 sites, 6 at 0 m, 2 at 30 m and 5 at 60 m away from canal had values more than the mean. The highest concentration was observed at Jamirdia (site-4). Electric industries used huge amount of Cu which might have given rise to greater Cu concentration at Jamirdia. The amount of Cu was quite greater than that (3.8 µg g⁻¹) observed by Al-Oud et al. [29] who studied the heavy metal content of soil around a cement factory in Riyadh city, Central Saudi Arabia. An elevated level of Cu was also observed by Islam et al. [6], where Cu concentration in soils of vegetables field around Dhaka City, Bangladesh was 311 µg g⁻¹ (mean value). The mean concentration of Cu in most of the soil samples at the closest point to the waste canal was almost thrice of the toxicity reference value as reported in [30]. Total amount of Zn in soils at 0 m distance from waste canal of Bhuluka ranged between 81.75 to 422.10 (Fig. 2d), having an average value of 245.12 µg g⁻¹ (Table 2). The concentration at 30 and 60 m distances ranged between 40.53 to 132.60 and 33.06 to 61.18 µg g⁻¹ with an average value of 74.16 and 50.32 µg g⁻¹, respectively. Zn concentration was observed maximum at Kharuali (site-7). The pharmaceuticals are presumed to raise Zn content at Kharuali. Four samples at 0 m, 2 at 30 m and 5 at 60 m distance had values greater than the mean. The mean concentration of Zn (245.12 µg g⁻¹) at 0 m distance from waste canal was much greater than both the normal range (35.0–129.0 µg g⁻¹) at Bhuluka Upazila [26] and average shale value (95 µg g⁻¹) [16]. Total Fe content in soils at the edge of waste canal ranged from 23900 to 36900 (Fig. 2e) having a mean value of 27980 µg g⁻¹ (Table 2). The range of Fe at 30 m distance from waste canal was 18000 to 33000 µg g⁻¹ and the mean value was 24230 µg g⁻¹. At 60 m, Fe occurred in the range of 17400 to 26900 with a mean value of 21840 µg g⁻¹. 50, 60 and 70% sites at 0, 30 and 60 m distances, respectively
showed values greater than the mean. The study revealed similar results with that of Sakawi et al. [31] who found Fe as the most dominant per specific distances and depths and exceeded the DOE minimum standard (301 µg g⁻¹) around the Vicinity of open landfill of Malaysia. The highest level of Fe was observed at site-2 (Hawaile) while lowest was seen at site-8 (Kharuali) and site-9 (Bagrapara). Effluents from metallurgical industry at Hawaile might contain higher amount of Fe to increase soil Fe concentration. According to Allaway [32], typical uncontaminated soil contains 7000–55000 µg g⁻¹ Fe. Total Mn in soils at 0, 30 and 60 m distances from industrial waste flowing canal ranged between 160 to 540, 90 to 250 and 80 to 240 µg g⁻¹ (Fig. 2f) having an average value of 264, 158 and 125 µg g⁻¹, respectively (Table 2). Out of 10 samples, 4 at 0 m, 2 at 30 m and 3 at 60 m distance had values greater than the mean. Maximum and minimum content of Mn was seen at Hawaile (site-1) and Kharuali (site-8), respectively. The concentration of Mn was higher compared to the industrial area of west Algeria where the concentration of Mn in soil of 3 regions was 244.94, 92.00 and 79.03 µg g⁻¹ [33]. The heavy metal pollution indicates that leachate produced by uncontrolled and unscientific disposal of industrial untreated wastes contaminates soil samples of the industrial area [34].

Table 2. Mean Pb, Cr, Cu, Zn, Fe and Mn concentration in µg g⁻¹ (± standard deviation) of soils at 0, 30 and 60 m away from waste canal.

| Distance from waste canal | Pb (µg g⁻¹) | Cr (µg g⁻¹) | Cu (µg g⁻¹) | Zn (µg g⁻¹) | Fe (µg g⁻¹) | Mn (µg g⁻¹) |
|-------------------------|------------|------------|------------|------------|------------|------------|
| 0 m                     | 66.31±14.32a | 57.48±13.09b | 77.84±40.68b | 245.11±135.20b | 27980±3738.92b | 264±112.96b |
| 30 m                    | 59.26±12.73a | 48.35±10.53b | 45.24±42.08b | 74.16±31.49a | 24230±4415.89ab | 158±43.66a |
| 60 m                    | 52.61±9.75a  | 40.82±9.13a  | 24.23±5.84a  | 50.32±8.61a  | 21840±3275.23a | 125±53.18a |

Note: Values within the same column with a common letter do not differ significantly (P <0.01).
3.2. Assessment of Pollution Level

3.2.1. Geoaccumulation Index ($I_{geo}$)

$I_{geo}$ introduced by Muller [15] was used to assess heavy metal pollution in soils at seven grades (Table 3) at different distances from waste canals of Bhaluka Upazila. The calculated $I_{geo}$ for heavy metals of soils at 0, 30 and 60 m distances from waste canals of Bhaluka Upazila, and their corresponding contamination intensity are illustrated in Fig. 3a, 3b and 3c. Out of 10 sampling sites, 5 sites within 0 m distance from waste canal exhibited $I_{geo}$ class 2, indicating moderately contaminated soil quality for Pb. Other samples exhibited $I_{geo}$ class 1 for Pb, indicating uncontaminated to moderately polluted soil quality. The $I_{geo}$ values for Cr, Fe and Mn indicated unpolluted soil quality. However, 6 different samples for Cu and Zn exhibited uncontaminated to moderately polluted soil quality and other samples had negative values for these elements. Four samples at 0 m and 3 samples at 60 m distance for Pb were exhibited moderately polluted soil quality. Soils at 5-1000 m distances from the both roadsides of Xi’an-Baoji Highway, China also revealed unpolluted to moderately polluted soil quality for Pb, Cu and Zn [35].

Table 3. Measure of pollution in soil by using Geoaccumulation index ($I_{geo}$) (Muller, 1969).

| Geoaccumulation Index | $I_{geo}$ Class | Designation of soil or sediment quality       |
|-----------------------|-----------------|-----------------------------------------------|
| 10 – 5                | 6               | Extremely polluted                             |
| 4 – 5                 | 5               | Strongly/ extremely polluted                  |
| 3 – 4                 | 4               | Strongly polluted                              |
| 2 – 3                 | 3               | Moderately/ strongly polluted                 |
| 1 – 2                 | 2               | Moderately polluted                            |
| 0 – 1                 | 1               | Uncontaminated/ moderately polluted           |
| 0                     | 0               | Unpolluted                                    |

Fig. 2. Patterns of Pb (a), Cr (b), Cu (c), Zn (d), Fe (e) and Mn (f) concentration in soil at 0, 30 and 60 m away from waste canal.

Fig. 3. Geoaccumulation index ($I_{geo}$) of heavy metals in soil samples at 0 (a), 30 (b) and 60 m (c) distance from waste discharging canal at Bhaluka Upazila.
3.2.2. Pollution Load Index (PLI)

The highest PLI (2.61) was observed at Site-6 (Amtoli) indicates heavily contaminated site among others and ranges from 0.93 to 2.61 for all sites (Fig. 4) with a mean value of 1.50 for soil samples at 0 m distance from waste canal. At 30 m distance, the PLI values varied from 0.7 to 1.2 with a mean value of 0.8 which was 0.2 for the 3rd distance having PLI ranging from 0.1 to 0.3. The result showed gradual decreases of PLI values with the increased of sampling distance from the waste canal. Out of 10 sampling sites, 8 sites at 0 m and only 1 site at 30 m distance from waste canal had PLI values >1.0, indicates contaminated. Fan [35] also observed moderate pollution level of soils at 5-1000 m distances from the both roadsides of Xi’an-Baoji Highway, China, as per PLI values. The PLI can provide some understanding to the public of the area about the quality of soils of their environment and it can indicate the trends over time and area. In addition, it also provides valuable information and advice for the policy and decision makers about the pollution level of the area [36].

![Fig. 4. Pollution Load Index (PLI) of soil samples at 0, 30 and 60 m distances from waste canal. Vertical bars denote the standard error.](image)

3.2.3. Contamination Factor (CF)

The contamination factor and degree of contamination are used to determine the contamination status of soils or sediments of an area. In this study, CF was calculated according to Tomlinson et al. [17]. CF in soil samples varied from 2.0 to 4.6, 0.3 to 0.9, 0.3 to 3.0, 0.4 to 4.4, 0.4 to 0.8 and 0.1 to 0.6 for Pb, Cr, Cu, Zn, Fe and Mn, respectively (Table 4). It is evident from Table 4 that the contamination factor for Pb, Cu and Zn was higher, which indicates that Pb, Cu and Zn were the major pollutants in these soils giving rise to PLI values for the study area.

| Table 4. The contamination factor (CF) for heavy metals at different sampling sites of Bhaluka Upazila. |
|---------------------------------------------------------------|
| **Concentration factor (CF)**                                  |
| **Pb** | **Cr** | **Cu** | **Zn** | **Fe** | **Mn** | **Mean** |
| Sites   | 0 m    | 30 m   | 60 m   | 0 m    | 30 m   | 60 m   | 0 m    | 30 m   | 60 m   | 0 m    | 30 m   | 60 m   | 0 m    | 30 m   | 60 m   |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Site-1  | 3.6    | 3.6    | 3.4    | 0.6    | 0.4    | 4      | 0.4    | 0.3    | 1.4    | 0.4    | 0.7    | 0.6    | 0.6    | 0.3    |
| Site-2  | 3.3    | 3.1    | 3.1    | 0.6    | 0.5    | 0.4    | 0.6    | 0.5    | 0.4    | 0.9    | 0.8    | 0.6    | 0.8    | 0.7    | 0.3    |
| Site-3  | 4.6    | 4      | 3.2    | 0.4    | 0.3    | 0.3    | 3.2    | 2.7    | 0.7    | 2      | 1.3    | 0.6    | 0.5    | 0.5    | 0.2    |
| Site-4  | 4.6    | 3.8    | 2.9    | 0.5    | 0.4    | 0.3    | 3      | 0.5    | 0.7    | 2.2    | 1.4    | 0.7    | 0.5    | 0.5    | 0.2    |
| Site-5  | 3      | 2.7    | 2.5    | 0.6    | 0.6    | 0.5    | 0.6    | 0.6    | 0.5    | 1.3    | 0.7    | 0.6    | 0.5    | 0.5    | 0.2    |
| Site-6  | 2.5    | 2.5    | 2.4    | 0.7    | 0.6    | 0.6    | 0.9    | 0.6    | 0.6    | 1.5    | 0.7    | 0.6    | 0.5    | 0.5    | 0.2    |
| Site-7  | 2.8    | 3.8    | 2.5    | 0.7    | 0.6    | 0.5    | 1.8    | 0.6    | 0.5    | 4.4    | 0.7    | 0.5    | 0.6    | 0.4    | 0.3    |
| Site-8  | 2.9    | 2.3    | 2      | 0.8    | 0.6    | 0.4    | 2.2    | 0.5    | 0.5    | 3.7    | 0.4    | 0.6    | 0.4    | 0.4    | 0.3    |
| Site-9  | 3.1    | 2.4    | 2.2    | 0.9    | 0.6    | 0.6    | 2.2    | 0.6    | 0.6    | 4.2    | 0.6    | 0.5    | 0.5    | 0.5    | 0.4    |
| Site-10 | 3      | 2.5    | 2.1    | 0.8    | 0.7    | 0.6    | 2.2    | 0.7    | 0.6    | 4.3    | 0.7    | 0.5    | 0.6    | 0.5    | 0.4    |
| Max     | 4.6    | 4      | 3.4    | 0.9    | 0.7    | 0.6    | 3      | 2.7    | 0.7    | 4.4    | 1.4    | 0.7    | 0.8    | 0.7    | 0.6    |
| Min     | 2.5    | 2.3    | 2      | 0.4    | 0.3    | 0.3    | 0.6    | 0.4    | 0.3    | 0.9    | 0.4    | 0.4    | 0.4    | 0.5    | 0.2    |
| Mean    | 3.3    | 3.1    | 2.6    | 0.6    | 0.5    | 0.5    | 1.7    | 0.8    | 0.5    | 2.6    | 0.8    | 0.5    | 0.6    | 0.5    | 0.3    |

3.2.4. Enrichment Factor (EFc)

Sutherland [37] has distinguished five classes of enrichment factors: EFc<2 shows deficiency to low enrichment, 2< EFc <5 shows moderate enrichment, 5< EFc <20 shows significant enrichment, 20< EFc <40 shows very high enrichment, and FFc >40 shows extremely high enrichment. Based on this classification, the sampling sites were moderate to significant enrichment for Pb, Cu, and Zn and low enrichment for Mn and Cr at 0–60 m distances (Fig. 5a, 5b and 5c). The highest EFc value (14.63) was observed at Bagrapara (Site-9) for Zn. Rafiei et al. [25] also reported an elevated level of enrichment factor for heavy metals in Dashkasan gold mine soils of Iran. Measuring enrichment
factor (EFc) is an essential part of geochemical studies and is generally used to differentiate between the metals originating from anthropogenic (non-crustal) and geogenic (crustal) sources, and to assess the degree of metal contamination [38, 39, 40]. 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 metal in soils and sediments depends upon the chemical form and concentration of the metal [41], it can be inferred that metals in soil and sediment samples with the high EFc values like Pb, Cu and Zn have a potential for mobility and bioavailability in the ecosystems and associated health risk.

![EFc values of metals in soil samples at 0 m distance.](image)

**Fig. 5.** EFc values of metals in soil samples at 0 (a), 30 (b) and 60 m (c) distances from waste canals at Bhaluka Upazila.

### 4. Conclusions

This study showed that the intensive uncontrolled operation of various industries has resulted in the release of heavy metals in the local environment and causes elevated concentrations in the surrounding soil. The levels of heavy metals in soils were found to decrease with the increase of distance from waste discharging canal. Pb levels at 0, 30 and 60 m, Cu and Zn at 0 m distance crossed the average shale value indicating heavy metal pollution. The study area was contaminated with Pb, Cu and Zn (upto 90.93, 133.85 and 422.10 µg g⁻¹, respectively) as per different ecological indicators calculation like Igeo, PLI and EFc. Higher Igeo, PLI and EFc values indicates that industrial effluents were the main causes of heavy metal pollution in soil of Bhaluka Upazila. It can be concluded that, soil quality heavily deteriorates continuously with time and spacing, and this may have adverse effects on human health through food chain contamination and ecosystem.
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