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Evaluation of Heavy Metal Contamination in Soil Samples around Rampal, Bangladesh

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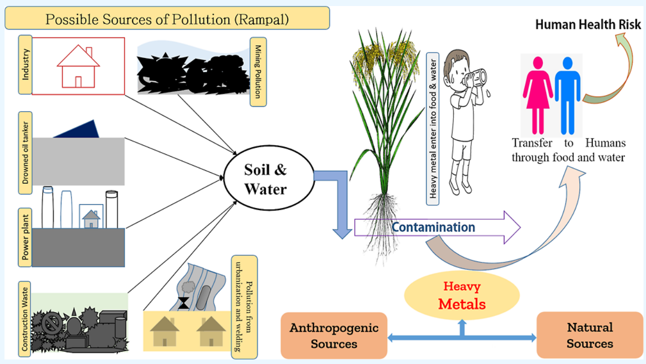
Cite This: ACS Omega 2023, 8, 15990−15999

ABSTRACT: Rising soil pollution has recently emerged as a significant global issue as a result of increased industrialization, urbanization, and inadequate waste management. In Rampal Upazila, soil contamination with heavy metals resulted in a significant deterioration of quality of life and life expectancy, so the study's goal is to appraise the level of heavy metal contamination in soil samples. Inductively coupled plasma−optical emission spectrometry was used to identify 13 heavy metals (Al, Na, Cr, Co, Cu, Fe, Mg, Mn, Ni, Pb, Ca, Zn, and K) from 17 soil samples that were collected at random from Rampal. Enrichment factor (EF), geo-accumulation index (I_{geo}), contamination factor (CF), pollution load index, elemental fractionation, and potential ecological risk analysis were used to evaluate the level of pollution and sources of metal. The average concentration of heavy metals implies that they are below in the permissible limit except for Pb. Environmental indices also showed the same result for Pb. The ecological risk index (RI) for six elements—Mn, Zn, Cr, Fe, Cu, and Pb—is 26.575. For investigating the behavior and origin of elements, multivariate statistical analysis was also applied. From the EF, Na, Cr, Fe, and Mg are in the anthropogenic region, and Al, Co, Cu, Mn, Ni, Ca, K, and Zn are minorly polluted, but Pb is highly contaminated in the Rampal area. The geo-accumulation index exhibits that Pb is slightly contaminated but others are not, while CF shows no contamination in this region. From the ecological RI, the value which is below 150 is called uncontaminated, which indicates that our studied area is ecologically free. There are various classifications of heavy metal contamination in the study area. Therefore, regular monitoring of soil pollution is required, and the public awareness needs to be raised to ensure a safe environment.



■ INTRODUCTION

Bangladesh is a developing nation in the third world. In the past two to four decades, industrialization and urbanization have become widespread in Bangladesh.[1−4] However, environmental protection plans and the application of environmental laws are still being developed.[5] Because of this, a lot of untreated or ineffectively treated industrial effluents, sewage from cities, and agricultural runoff are contaminating soil, water, air, and sediments.[6−8] In numerous ways, such as through mining, excessive wastewater and fertilizer use in agricultural fields, and atmospheric deposition from automobiles and factories, they are being polluted with heavy metals and trace elements.[9−11]

Trace elements affect people, plants, and other animals in both beneficial and bad ways.[12−14] But if ingested in large quantities over an extended period of time, all trace elements are deadly. Due to their non-biodegradability and lengthy biological half-lives, trace elements are extremely toxic.[15] The overall amount and eco-toxicity of trace elements remain in soils for a very long time after introduction because they cannot be broken down in the soil by microbial or chemical deterioration.[16−18]

Due to their occurrence in the environmental matrix in trace (10 mg kg^{-1}) or ultra-trace (1 g/kg) amounts, heavy metals are also known as trace elements.[19] There are both organic and artificial sources of heavy metal pollution.[20−22] One of the biggest ecological issues both globally and in Bangladesh is heavy metal poisoning of the soil, air, and water. The main source of heavy metal exposure for both humans and animals is food chain contamination.[15,23] Even though several heavy metals, like iron (hemoglobin, myoglobin), cobalt (co-enzyme), zinc (in enzymes), and others, perform important physiological roles at minute concentrations, having too much of these can be harmful to your health. The central neurological system (Co, Cu, Cr, Ni), the kidneys, the liver (Pb, Cd, Cu), the skin, the

Received: December 12, 2022
Accepted: February 28, 2023
Published: April 27, 2023

https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

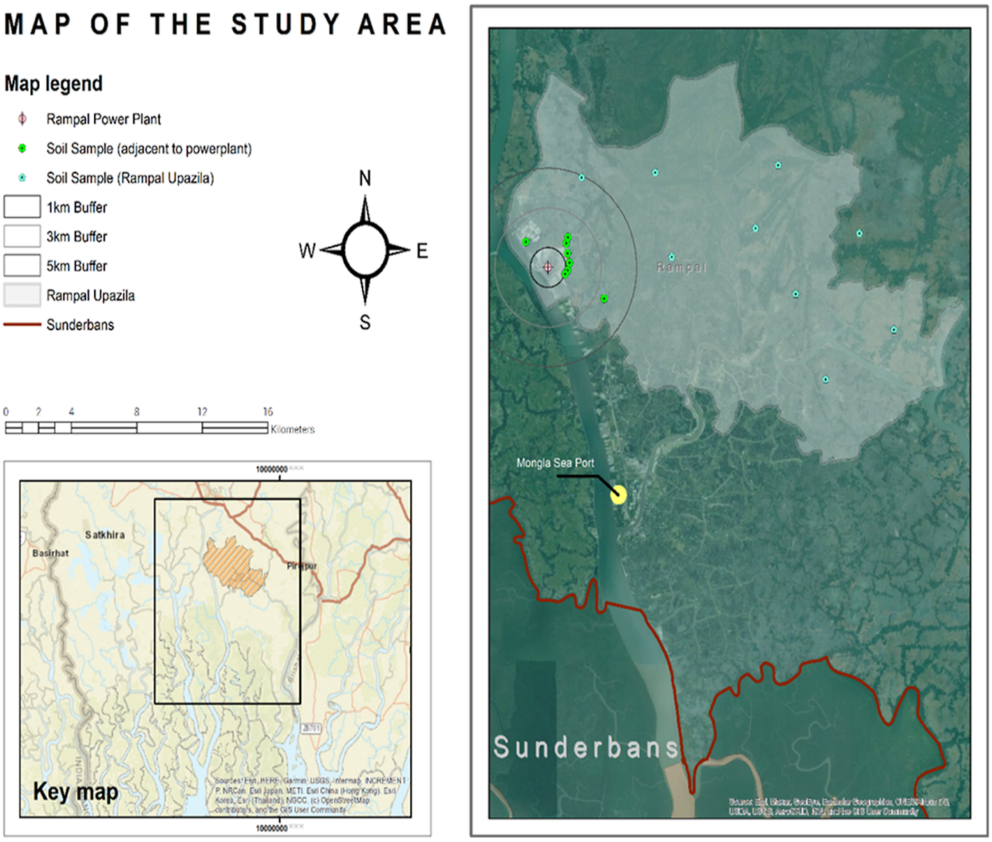


Figure 1. Location of Rampal Upazila (Bangladesh, left) and distribution of soil sampling points (right).

bones, the teeth (Ni, Cd, Cu, Cr), and so forth are all affected by heavy metals in addition to their carcinogenic and toxic effects.[24−31]

The value of the heavy metal can be determined using a variety of techniques, including atomic absorption spectroscopy (AAS), flame AAS, electrothermal AAS, X-ray fluorescence spectrometry, inductively coupled plasma atomic emission spectrometry (ICP−AES), and ICP mass spectrometry (ICP−OES). Because of its quick, multi-element analysis, broad linear dynamic range (up to 5 or 6 orders of magnitude), and high precision value, ICP−OES is the most efficient among all (0.5−5%). The capacity to examine more elements simultaneously with lower detection limits for the trace elements under study is this method's key benefit.

Solids, liquids, and gases can all be analyzed with ICP−OES.[32−34] Numerous studies have been conducted utilizing the ICP−OES method to identify the chemical elements in soil, water, river sediments, vegetables, dried fruits, and so forth.[35] A group of scientists used ICP−OES to measure the number of trace elements (Ba, Pb, Cd, Mn, Cr, Co, Ni, Cu, Zn, Sr, and Fe) in various dried fruit samples, while some other measure the levels of Al, Ni, Co, Mn, Cr, Pb, As, and Cd in agricultural soil and well water samples.[12,36] ICP−OES was used by Durkan to analyze the trace element concentrations of diverse wild edible mushroom species from the Buyuk Menders River Basin of Turkey.[37]

Bangladesh is undergoing rapid industrialization with gradually evolving environmental legislation, just like other emerging nations throughout the world. The greatest mangrove forest is in Rampal, a southern region of Bangladesh, where a coal-fired power plant has been planned to be developed.[38,39] The environment surrounding the power plant location includes soil as a key element. For the evaluation of upcoming pollution problems, a substantial number of industrial establishments are expected to be built at Rampal in addition to the coal-based power station. The majority of earlier research has focused on the river bed sediments in and around Rampal.[6,40−43]

Various studies have been conducted around Rampal and Sundarban regions. Most of the studies show that the regions are in aquatic mobilization of heavy metals (As, Rb, Sb, Cs, and W) and some naturally occurring radionuclides.[6,38] Elemental abundances, anionic concentrations, and physicochemical parameters show that almost all of the elements (heavy metal, trace element, and REE) are below the permissible limit of WHO that shows that these regions are free from pollution.[6,40,42] But recent activates like ship/cargo accident, building coal-based power plant, and recent urbanization will add heavy metals to the environmental constituents like soil and water. General people, children, and pregnant women can be affected by heavy metals through water, soil, and air easily.

The major goals of this research are to (1) evaluate the concentration of heavy metals in the Rampal area; (2) assess the quality of cultivated soil using the contamination factor (CF), I_{geo}, enrichment factor (EF), and correlation; as well as (3) establish a database concerning the level of heavy metal contamination for future use.[9]

MATERIALS AND METHODS

Study Area. Rampal is an Upazila in the Bagerhat district of Bangladesh. It is only 14 km far from the world's largest mangrove forest, the Sundarbans.[38] Rampal Upazila (Bagerhat district) is 291.22 square km in size, located between 22°30′ and 22°41′ north latitudes and 89°32′ and 89°48′ east longitudes.

Bagerhat Sadar and Fakirhat Upazilas border it on the north, Mongla and Morrelganj on the south, Morrelganj and Bagerhat Sadar on the east, and Batiaghata and Dacope on the west. Pasur, Rupsha, Mongla, Daudkhali, and Ghasiakhali rivers run through this Upazila. After passing through the Sundarbans, these rivers flow into the Bay of Bengal.[6]

Rampal has a population of 178,503 people. Agriculture accounts for 52.41% of the income, followed by non-agricultural workers with 7.71%, industry with 0.79%, commerce with 20.71%, transport and communication with 3.64%, services with 5.26%, construction with 1.33%, religious services with 0.24%, rent and remittances with 0.16%, and others with 7.75%.

SAMPLE COLLECTION

Metals first enter the environment through the surface soils, where they tend to build up over time.[44] Most of the time, these pollutants contaminate the top 0−40 cm of the soil.[45] This means that if these pollutants were measured at this depth, there could be a lot of them.[46]

Seventeen composite samples of topsoil were taken from the land around the Rampal Power Station (Figure 1). The sampling points were selected randomly based on agriculture and the residence of general people and around a newly located coal-based power plant. Most of the sites were selected around the power plant to identify the present situation of environment and predict the future. The second most selected sites were the ones where agricultural land predominated because food is the principle way for the heavy metal to enter into the body. Rest of the sites were based on habitation and educational institution playground. The soil samples were selected because mostly heavy metal pollution occurs through soil. First, we put on hand gloves to avoid contamination. Then, we dug the soil up with a medium-sized knife and picked them up with a stainless steel shovel. Then, we put them in a plastic bag with a zipper. The samples were each given a unique identification number that was carefully chosen based on their positions.[38] Each sample weighed between 0.5 and 1 kg.

SAMPLE PROCESSING AND DIGESTION

After the sample was collected, it was processed further into a powder form by being ground. A 5:1:1 triacid mixture was created for each of the sample analysis by first mixing together 70% HNO_3 (Merck, Germany), 70% H_2SO_4 (Merck, Germany), and 65% $HClO_4$ (Merck, Germany). A triacid mixture of 15 mL was added to each beaker, which already contained 1 g of the dried material. At a temperature of 80 °C, each combination was allowed to digest until a clear solution was formed. In order to conduct an analysis of heavy metals, the digested samples were first allowed to cool, then filtered, and then diluted to a volume of 50 mL using deionized water (RCI Labscan Limited).[22] An inductively coupled plasma-optical emission spectrometer was used in order to determine the concentrations of several heavy metals (including Mn, Fe, Cu, Zn, Pb, and Cd) that were present in the digested solution.[9,34,47,48]

ENVIRONMENTAL INDICES

Soil samples from the area of Rampal Power Station were analyzed for heavy metals and trace elements. Analytical techniques such as ICP−OES were used to determine the presence of elements such as Al and Ca as well as Fe and Mg. Cultivation challenges and ecological imbalance are increased by environmental factors. When heavy metals are present in the soil, they pass via the plants and eventually reach the human body. Plant and animal metabolisms are eventually affected. Base-line data is important for figuring out how much of each element is present in soil samples in terms of environmental indices like the geo-accumulation index, EF, CF, and pollution load index (PLI).[49,50] As background data for our study, we looked at the elemental abundances of the upper continental crust (UCC: Rudnick and Gao 2014[51]).

ENRICHMENT FACTOR

As recommended by Sinex and Helz,[52] EF was used to determine the level of contamination and to comprehend the dispersion of the elements of anthropogenic origin from the locations as determined by the individual elements in soil samples. In order to compute EF, the following equation may be used

$$E = \frac{\left(\frac{C_n}{C_{\text{Ref}}}\right)_{\text{Sample}}}{\left(\frac{C_n}{C_{\text{Ref}}}\right)_{\text{Background}}} \tag{1}$$

where C_n is the concentration of any element or metal and C_{Ref} is the concentration of a reference element or metal in the examined environment. There are various elements (Al, Ca, Sc, Ti, Mn, Fe, Sr, and Zr) that can be used as the reference materials for calculating the EF.[40,50,87−89] In our research, iron (Fe) was chosen as the reference element for its geochemical normalization and for following reasons:

- Its geochemistry is comparable to that of numerous trace metals;
- It is associated with fine solid surfaces;
- Its natural concentration is typically uniform.[53]

The EF values close to unity indicate crusted origin (comparable to those of UCC) of the metals, those less than 1.0 suggest a possible mobilization or depletion of metals, whereas EF > 1 indicates that the element is of anthropogenic origin.[54] Therefore, EF values of 1−2 are considered slightly contaminated; on the contrary, 2−5 is moderately contaminated, 5−20 is severely contaminated, and 20−40 is highly contaminated.[55]

GEO-ACCUMULATION INDEX (I_{GEO})

Hakanson suggested that I_{geo} could be used to measure the amount of heavy metal pollution in both land and water environments.[56] The following equation can be used to describe the geo-accumulation index (I_{geo})[57]

$$I_{geo} = \text{Log}_2\left(\frac{c_n}{1.5 \times B_n}\right) \tag{2}$$

where C_n represents the measured concentration of metal n and B_n represents the geochemical background concentration of metal n. Due to lithospheric influences, the background matrix correction factor is 1.5. The geo-accumulation index has seven classes or grades as follows: I_{geo} = 0: class 0 (practically uncontaminated); $I_{geo} \leq 0$: class 1 (uncontaminated to moderately contaminated); $0 < I_{geo} < 1$: class 2 (moderately contaminated); $1 < I_{geo} < 2$: class 3 (moderately to heavily contaminated); $2 < I_{geo} < 3$: class 4 (heavily contaminated); $3 < I_{geo} < 4$: class 5 (heavily to extremely contaminated); $4 < I_{geo} < 5$: class 6 (extremely contaminated); $5 < I_{geo}$: class 6 is an open

https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

Table 1. Explicatory Statistics of Elemental Abundances (mg kg^{-1}, Otherwise Specified) in Soil Samples from the Sampling Site along with UCC, Adjacent River Sediments, Previous Studies, Shale, and World Soil Median

		this study							adjacent study				
		mean (n = 17)	SD (n = 17)	RSD (%)	median	min	max	UCC[51]	Poshur[42] river (mean) (n = 7)	Sela[40] river (Mean) (n = 15)	Rampal-Mongla[6] (n = 9)	shale[67]	world[67] soil median
Al	(%)	8.55	1.05	12.29	8.36	7.05	10.23	8.15	7.77	7.36	9.55	8.8	7.10
Na	(%)	1.13	0.35	31.30	1.15	0.82	1.55	2.43	1.11		0.92	0.6	5.00
Cr		27.63	9.06	32.80	26.65	12.80	40.90	92.0	72.5	67.0	93.0	90.0	70.0
Co		11.73	1.92	16.35	11.25	7.70	15.20	17.3	14.9	13.9	18.1	19.0	8.00
Cu		23.75	6.07	25.57	22.43	12.15	35.75	28.0		22.3	15.2	39.0	30.0
Fe	(%)	4.25	0.38	8.97	4.11	3.80	5.26	3.92	4.16	3.81	4.68	4.80	4.00
Mg	(%)	2.29	0.55	23.94	2.38	1.12	2.92	46.7					
Mn		426.36	74.63	17.50	421.25	319.85	650.25	775	649	634	676	850	1000
Ni		26.91	5.11	19.00	26.10	18.40	37.05	47.0		28.6		68.0	50.0
Pb		51.11	16.56	32.40	46.85	27.00	99.45	17.0		15.8	25.3	23.0	35.0
Ca	(%)	1.26	0.85	67.11	1.20	0.30	2.80	2.57	1.95		1.31	1.60	1.50
Zn		48.58	13.71	28.22	48.30	6.70	74.60	67.0	69.8	67.7	104	120	90.0
K	(%)	1.67	0.40	24.06	1.72	1.03	2.22	2.32	2.52		3.10	2.50	1.40

class and comprises all values of the index higher than that of class 5. The elemental concentrations in class 6 may be 100-fold greater than the geochemical background value.[53,58]

POLLUTION LOAD INDEX

This empirical index offers a quick, straightforward method for determining the degree of heavy metal contamination. The CFs of the particular heavy metals at a sample site are used to construct the PLI, which is defined as follows[56]

$$\mathrm{CF} = \frac{(\text{Samle concentration})_{\text{Sample}}}{(\text{Sample concentration})_{\text{Background}}} = \frac{(C_n)_{\text{Sample}}}{(C_n)_{\text{Background}}} \quad (3)$$

According to Zhao et al.,[59] environmental pollution may be classified as low (CF < 1), moderate (CF: 1−3), considerable (CF: 3−6), or high (CF > 6). Using Tomlinson et al.[60] and Shomar et al.,[61] PLI can be written as follows

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times ... \times \mathrm{CF}_n) \quad (4)$$

where CF = contamination factors, n = total number of CFs, C_{metal} = metal concentration in polluted elements, and $C_{\text{backgroundvalue}}$ = background value of that metal.

For geological samples, a PLI value over 1 implies ongoing degradation, whereas a PLI value below 1 suggests just baseline levels of pollutants.[62]

POTENTIAL ECOLOGICAL RISK INDEX

Potential ecological risk index (RI) is used to figure out how much the soil sample is polluted.[63] Hakanson[56] came up with the following equations to figure out the RI

$$\mathrm{RI} = \sum \mathrm{Er} = \sum (\mathrm{Tr} \cdot \mathrm{CF}) \quad (5)$$

where Er is the potential ecological risk factor for heavy metals, Tr is the biological toxic metal response factor, and CF is the single element CF. We can classify the potential ecological risk factor as low risk (Er < 40), considerable risk (80 < Er < 160), high risk (160 < Er < 320), and very high risk (Er > 320),[6,64] while the potential ecological RI can be categorized as low risk (RI < 150), moderate risk (150 < RI < 300), considerable risk (300 < RI < 600), and very high risk (RI > 600).[65]

RESULTS AND DISCUSSION

Explicatory statistics (mean, SD, RSD, median, max., min.) of 13 elements (Al, Na, Cr, Co, Cu, Fe, Mg, Mn, Ni, Pb, Ca, Zn, and K) from 17 sampling sites determined by ICP−OES are listed in Table 1.[6,9,66]

The literature data for some parts of the studied area (Rampal Mongla: Khan et al.[6]), nearby river sediments (Poshur river: Hossain et al.[42]), relatively far-off river sediments (Sela river: Islam et al.[40]), as well as the elemental abundances of the upper continental crust (UCC: Rudnick and Gao[51]), world soil median (Bowen[67]), and shale (Bowen[67]) are included along with the descriptive statistics of elemental abundances of this study. Depictions of Rampal soil samples do no indicate a wide spatial variation with those of the Rampal-Mongla part, Poshur river, and Sela river except Pb. With the exception of Al, Fe, and Zn, mean concentrations in soils are systematically lower than those of UCC. The concentrations of almost all elements are lower than those found in shale; however, Na is an exception. It has been seen that Pb concentrations are higher among all of the specimen. However, Al, K, Fe, and Co concentrations are higher than all of them in the case of the world soil median.

Heavy metals have densities, atomic weights, or atomic numbers that are higher than 5 gm/cm^{-3}.[68] These metals are not very common in the Earth's crust, but they are used in a lot of everyday things. Heavy metal pollution is a result of human activity, which is the main cause of pollution. It is mostly caused by mining metal, smelting, foundries, and other metal-based industries as well as the leaching of metals from places like landfills, waste dumps, excrement, and animal and chicken manure.[69] Some heavy metals are very important to how the body works. Hemoglobin in red blood cells cannot work without iron. Copper, manganese, zinc, cobalt, and chromium are all needed as cofactors or prosthetic groups for enzymes. If a person does not get enough of these metals in their diet, they can get sick. On the other hand, Pb is not needed for life, so it is considered to be a harmful element in nature.

Elemental Contamination Level. For assessing the contamination level, different environmental indices, for example, EF, geo-accumulation index (I_{geo}), CF, and PLI are introduced. Among all indices, the first three are element and sampling point specific while PLI is the geometric mean of elemental CFs and illustrates immense contamination scenar-

https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

Table 2. Mean Value of EF, Geo-Accumulation Index (I_{geo}), and CF of the Collected Soil Samples from Rampal

	Al	Na	Cr	Co	Cu	Fe	Mg	Mn	Ni	Pb	Ca	Zn	K
EF	0.98	0.43	0.27	0.62	0.78	1.00	0.05	0.51	0.53	2.76	0.46	0.67	0.66
I_{geo}	−0.53	−1.72	−2.40	−1.16	−0.17	−0.47	−4.98	−1.47	−1.41	0.94	−1.99	−1.16	−1.10
CF	1.05	0.47	0.30	0.68	0.85	1.09	0.05	0.55	0.57	3.01	0.49	0.73	0.72

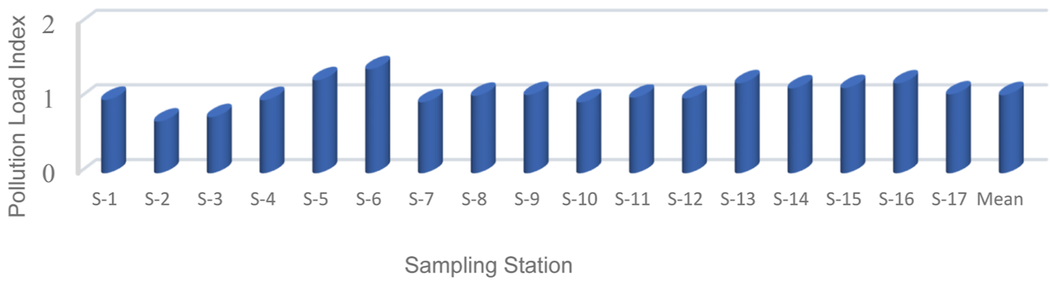


Figure 2. PLI for specific sampling points for specific elements.

Table 3. Pearson Correlation Matrix for Element Data of the Sediment Samples

	Al	Na	Cr	Co	Cu	Fe	Mg	Mn	Ni	Pb	Ca	Zn	K
Al	1.00												
Na	−0.23	1.00											
Cr	−0.07	0.07	1.00										
Co	−0.31	0.13	0.833[b]	1.00									
Cu	−0.28	0.12	0.854[b]	0.920[b]	1.00								
Fe	−0.27	−0.02	0.707[b]	0.747[b]	0.791[b]	1.00							
Mg	0.06	−0.505[a]	−0.04	−0.18	−0.12	−0.14	1.00						
Mn	−0.25	0.07	0.44	0.679[b]	0.626[b]	0.32	0.03	1.00					
Ni	−0.02	0.13	0.703[b]	0.608[b]	0.709[b]	0.28	0.16	0.750[b]	1.00				
Pb	−0.26	0.13	0.625[b]	0.779[b]	0.718[b]	0.37	0.05	0.816[b]	0.761[b]	1.00			
Ca	0.486[a]	−0.18	−0.08	−0.18	−0.30	−0.25	−0.15	−0.41	−0.33	−0.08	1.00		
Zn	0.21	−0.22	0.39	0.47	0.47	0.36	0.41	0.499[a]	0.47	0.609[b]	0.06	1.00	
K	−0.27	0.515[a]	0.598[a]	0.592[a]	0.539[a]	0.507[a]	−0.43	0.48	0.45	0.570[a]	−0.04	0.08	1.00

[a]Correlation is significant at the 0.05 level (2-tailed). [b]Correlation is significant at the 0.01 level (2-tailed).

io.[56,60] Using the EF, one may estimate the concentration of heavy metals in the environment. The EF values for Al, Na, Cr, Co, Cu, Mg, Mn, Ni, Pb, Ca, Zn, and K were in the range 0.657−1.218, 0.309−0.608, 0.144−0.441, 0.459−0.791, 0.448−1.023, 0.018−0.061, 0.366−0.701, 0.376−0.697, 1.638−4.886, 0.109−1.085, 0.094−0.930, and 0.429−0.898, respectively (Table 2). The lowest and highest EF values are for Mg in S-16 and Pb in S-6, respectively. The order of average EF for heavy metals in the soil is Pb > Cu > Al > Zn > K > Co > Ni > Fe > Mn > Ca > Na > Cr > Mg.

If the EF value reaches 2, soil contamination is caused by human activities. In this study, the EF values were greater than 2, indicating that the concentration of heavy metals in the soil may have been caused by human activities rather than by natural processes. Nevertheless, the EF values for most of the elements like Na, Cr, Co, Mg, Mn, Ni, Zn, and K were less than 1, indicating that they were in an anthropogenic region. Conversely, few soil samples exhibited EF values of less than 2 for Al (S-3, S-5, S-7, S-9, S-11 and S-13), Cu (S-6 and S-14), and Ca (S-7 and S-13), which were not a serious contamination concern because they are very close to 1. In contrast, the Rampal area is significantly contaminated with Pb because its EF value is between 2 and 5, and the mean value is 2.763. These results indicated that 86% of the overall area was not polluted, 6% of this area was moderately polluted, and 8% of this area was extremely polluted.

Typically, geo-accumulation index measures the heavy metal contamination status of soil. In our studied area, I_{geo} values range from −5.967 Mg (S-16) to 1.963 Pb (S-6). All elements show negative values except Pb, where all 17 sampling sites show positive values for I_{geo}. 12 sampling sites are polluted by uncontaminated to mildly contaminated materials, while 5 sites (S-4, S-5, S-6, S-13, and S-16) are moderately contaminated by Pb. Table 2 reflects the average I_{geo} values of all elements in sampling sites. I_{geo} values show that the area is unpolluted by measured amounts of all elements but is contaminated by Pb since it naturally occurs in the Earth's crust and as a result of mining, burning fossil fuels, and manufacturing. The I_{geo} mean values for heavy metals followed an ascending order: Pb > Cu > Fe > Al > K > Co > Zn > Ni > Mn > Na > Ca > Cr > Mg.

CF has been used to figure out how much heavy metals are in soil samples. Values range from 0.024 Mg (S-16) to 5.850 Pb (S-6), and most of the elements show contamination less than 1, while some of them (Al, Fe, Cu, and Pb) show more than 1. Based on these results, 80% of the total area is not polluted and 20% is only slightly polluted. Table 2 shows the heavy metal CF values of the soil samples.

To assess the severity of the pollution and its variance across the sites, a different CF PLI was generated from the top six (Pb, Fe, Al, Cu, Zn, and Co) CFs across all sites employed. According to Figure 2, the results vary from 0.735 (S-2) to 1.392 (S-6) and

https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

the mean value of the studied area is 1.047 ± 0.161 (RSD 15.38%).

The overall results exhibit that most of the sites (S-1, S-2, S-3, S-4, S-7, S-10, and S-12) are low contaminated except some sites (S-5, S-6, S-8, S-9, S-11, S-13, S-14, S-15, S-16, and S-17) that are low to moderately contaminated. Rampal is a low to moderately polluted location, as shown by the mean value (PLI = 1.045), and we should be cautious of this in the future.

Elemental Fractionation/Correlation Analysis. In order to account for possible sources of origin of hazardous metals and establish a relationship among elements, multivariate statistical analysis is a congenial technique.[40,53,70−72,86] In our study, Pearson's correlation matrix was employed to interpret the impression of studied variables on the concentration of tress elements (Table 3). The coefficient values (r) and strength of correlation can be categorized as follows: (i) very weak correlation (r = 0.0−0.2), (ii) slightly significant correlation (r = 0.2−0.4), (iii) moderate correlation (r = 0.4−0.6), (iv) strong correlation (r = 0.6−0.8), and (v) very strong correlation (r = 0.8−1.0). The positive correlation among Cr, Co, Cu, Fe, Mn, Ni, Pb, Zn, and K were observed, while no correlation was significant between Al, Na, and Mg. A majority of elements exhibit very poor or negative correlations with Ca because of the presence of carbonates.[73] Table3 shows a very strong correlation among Cr−Co (0.833), Cr−Cu (0.854), Co−Cu (0.920), and Mn−Pb (0.816); strong correlation within Cr−Fe (0.707), Cr−Ni (0.703), Cr−Pb (0.625), Co−Fe (0.747), Co−Mn (0.679), Co−Ni (0.608), Co−Pb (0.779), Cu−Fe (0.791), Cu−Mn (0.626), Cu−Ni(0.709), Cu−Pb (0.718), Mn−Ni (0.750), Ni−Pb (0.761), and Pb−Zn (0.609); and moderate correlation in Al−Ca (0.486), Na−K(0.515), Cr−K (0.598), Co−K (0.592), Cu−K (0.539), Fe−K (0.507), Mg−Zn (0.410), Mn−Zn (0.499), Mn−K (0.480), Ni−Zn (0.470), Ni−K (0.450), and Pb−K (0.570).

A strong correlation among the observed metals indicates that they are from a common source/origin in the investigated region. Table3shows a positive correlation between Cr and Co, Cu, Fe, Ni, Pb, and K, which indicates that they have a similar source and they have serious health hazards when they are injected into the human body by Cr(VI).[74,75] A strong correlation of Co with Cu, Fe, Mn, Ni, K, Pb, and Cr and Cu with Cr, Co, Fe, Mn, Ni, Pb, and K indicates that the K, Pb, Ni, Mn, Fe, and Cr orientations were controlled by identical factors such as cobalt chloride, Cu^{2+}, Mn oxide, clay minerals, anthropogenic activities, industrial pollution, agricultural activities, and so forth.[31,76,77] Mn also possesses a correlation among Ni, Pb, Zn, Co, and Cu because of rocks, fertilizers, pollution, and so forth. A majority of elements exhibit very poor or negative correlation with Mg, Al, Na, Fe, and Ca, which indicates different geochemical behaviors and external input operating.[78,84]

Potential Ecological Risk Analysis. In order to analyze the soil quality of an ecosystem and to determine the extent to which the soil is contaminated with a variety of different heavy metals, an ecological risk assessment of soil is utilized.[79] For proper calculation, the toxic response factors for Mn, Zn, Cr, Ni, Fe, Cu, Co, and Pb are 1, 1, 2, 5, 5, 5, 5, and 5, respectively. The range of Er values for the locations we analyzed is 0.10 (for Zn in S-2) to 29.25, with Pb > Cu > Co > Ni > Fe > Zn > Cr > Mn (for Pb in S-6). To enumerate the potential risk, Table 4 displays the RI values for the sampling location which elicit that the environment of our studied area is pollution free. Also, in the case of the sampling site, the RI is ordered as S-6 > S-13 > S-16 > S-5 > S-14 > S-15 > S-8 > S-4 > S-9 > S-17 > S-12 > S-11 > S-1 > S-10 > S-2 > S-7 > and S-3 that ranges from 52.45 to 20.36, and the mean value is 32.83 ± 7.21 (Table 4). So we can say that due to heavy metals Mn, Zn, Cr, Ni, Fe, Cu, Co, and Pb, our studied area is quite ecologically risk free.

Table 4. Potential Ecological RI and RI of the Studied Heavy Metals

elements	toxic response factor, Tr	contamination factor, CF	Er (n = 17)	SD (n = 17)	RI
Mn	1	0.550	0.550	0.10	32.83
Zn	1	0.725	0.725	0.20	
Cr	2	0.300	0.600	0.20	
Ni	5	0.572	2.862	0.54	
Fe	5	0.566	2.830	0.49	
Cu	5	1.373	6.865	1.08	
Co	5	0.678	3.390	0.55	
Pb	5	3.007	15.035	4.87	

In recent years, there has been a significant emphasis on lead contamination because the metal is harmful to humans and animals. Lead enters the human or animal metabolic system by food or soil dust ingestion.[80] The average daily lead intake for adults in the United Kingdom is estimated to be 1.6 μgm from air, 20 μgm from water, and 28 μgm from food. Pb is considered a trace nutrient in the human body; however, exposure to larger concentrations of this metal may interfere with the body's metabolic activities. Due to their low solubility, lead and its compounds accumulate readily in soil. In this investigation, the average Pb concentration exceeded the allowed limit (50 mg kg^{-1}).[81] The average Pb values at sampling locations S-4, S-5, S-6, S-13, and S-16 were 53.9, 62.2, 99.5, 78.9, and 56.2 mg kg^{-1}, which were above the acceptable limit. The growing amounts of Pb in the soil samples have been attributed to cement factory, oil refinery, and so forth, as well as to leaded gasoline, external lead-based paint, and industrial sources. Pb was discovered to have the greatest average concentration relative to other heavy metals. This investigation demonstrated that the average Cu content at all sites was below the safe limit of 30 mg kg^{-1}.[81] However, the average Cu concentrations at sampling locations S-6, S-14, and S-16 were marginally above the acceptable limit at 34.30, 31.95, and 35.75 mg kg^{-1}, respectively. The present investigation revealed that the mean concentrations of Zn and Fe at these sampling locations were 48.58 mg kg^{-1} and 4.25%, which were below the acceptable limit (100 mg kg^{-1} and 40.0%).[81] Copper is a necessary element for human survival, but excessive exposure can result in anemia, liver and kidney damage, and stomach and intestinal distress. The average concentrations of Co and Cr were below the acceptable limit (47 and 47 mg kg^{-1}) at 11.7 and 27.6 mg kg^{-1}, respectively.[81] The human body requires a small quantity of nickel to manufacture red blood cells, but excessive amounts can be somewhat poisonous. In addition, this investigation revealed that the average Ni concentration was 26.9 mg kg^{-1}, which was below the allowed value (30 mg kg^{-1}), with the exception of sampling sites S-5, S-6, S-13, and S-14, which had concentrations of 32.95, 37.05, 33.05, and 35.85 mg kg^{-1}, respectively. Different soil pollution indices (CF, EF, I_{geo}, RI/PERIF) acquired in this study were compared with other studies conducted in different parts of the world and are displayed in Table 5.

https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

Table 5. Comparison of Soil Pollution Indices with Other Similar Studies

parameters	Al	Na	Cr	Co	Cu	Fe	Mg	Mn	Ni	Pb	Ca	Zn	K	ref
CF						1.73		3.67		4.79	10.3	4.57	3.48	53
I_{geo}						0.34		1.27		1.63	2.60	1.50	1.16	
EF						1.06		2.20		2.85	6.24	2.80	2.09	
CF			0.44		1.57					1.64		1.08		82
I_{geo}			−1.8		0.06					0.12		−0.5		
ER/PERIF			0.89		7.87					8.19		1.08		
CF			4.9		0.2					0.20		0.10		83
I_{geo}			0.50	0.04	0.02			0.001		0.03		0.01		
EF			33	45	35.0			49		57.0		45.0		
ER/PERIF			9.7		0.80					0.80		0.10		
CF	1.17	0.38	1.01	1.05	2.13	1.19		0.87		5.84	0.51	1.55	1.34	6
I_{geo}	−0.4	−2.0	−0.6	−0.5	−1.5	−0.3		−0.8		−0.04	−1.3	0.04	−0.2	
EF	0.97	0.33	0.85	0.88	0.48	1.00		0.74		1.30	0.57	1.30	1.12	
CF					0.54	0.10		0.30		0.12		0.48		9
I_{geo}					−1.9	−4.3		−2.3		−1.6		−1.2		
EF					6.10	1.00		3.45		6.54		8.75		
ER/PERIF					2.71	0.49		0.30		0.61		0.48		
I_{geo}	−0.2	−0.5	−0.3	−0.2		−0.1		−0.2			−0.3	−0.1	−0.1	42
EF		0.48	0.83	0.91		1.12		0.89			0.80	1.10	1.14	
CF	1.05	0.47	0.30	0.68	0.85	1.09	0.05	0.55	0.57	3.01	0.49	0.73	0.72	this study
I_{geo}	−0.5	−1.7	−2.4	−1.2	−0.2	−0.5	−5.0	−1.5	−1.4	0.9	−2.0	−1.2	−1.1	
EF	0.98	0.43	0.27	0.62	0.78	1.00	0.05	0.51	0.53	2.8	0.46	0.67	0.66	
ER/PERIF			0.60	3.39	6.87	2.83		0.55	2.86	15.04		0.72		

CONCLUSIONS

Bangladesh is currently plagued by all forms of pollution, including soil degradation, noise pollution, air pollution, and water pollution. The excessive use of chemical fertilizers, increasing salinity, the use of topsoil in brick kilns, industrial pollution, deforestation, petroleum lead air pollution, and the deposits of electronic and medical waste in the soil are the main causes of the declining soil health. Our research indicates that, with the exception of two or three elements, the level of heavy metals in the soil samples is below allowable levels. The research area is linked to varying degrees of heavy metal contamination, according to the analysis of various pollution indices (EF, CF, PLI, Igeo, and RI). To ascertain the quality that would influence economic, social, and environmental decisions such as land use, agriculture, and ecology, a geochemical analysis of soil samples in Rampal Upazila in the Bagerhat district was conducted.[85] From our experimental data, the present environmental status of the studied area can be summarized as follows:

- Except Al, Co, Fe, and Pb, all the heavy metal concentrations are lower than the world soil median, adjacent river, and UCC. Some sampling locations (S-4, S-5, S-6, S-13, and S-16) suffer Pb pollution, while location S-6 has internecine Pb pollution.
- According to the EF and PLI, 80−86% of the area is pollution free, with the exception of Pb in the case of the geo-accumulation index, where all elements have negative values. All indices show a little bit Pb pollution in the study area.
- In terms of CF, some of the regions of our study area are polluted with Pb, and all other remaining places and elements are not polluted. The following list shows how the mean CF values for heavy metals went up: Mg < Cr < Na < Ca < Mn < Ni < Co < K < Zn < Cu < Al < Fe < Pb.
- Inter-elemental correlation reflects that the orientation of elements is controlled by mining activities, minerals, industrial pollution, agricultural activities, acid rain, vehicle exhaust, vehicle battery acid, and so forth.
- Our study location is ecologically risk-free, and comparisons from many research studies near Rampal show that the majority of values are extremely close. It establishes the reliability of experimental results.

From all of the indices, it is clear that our studied area is potentially polluted with Pb, which may be caused by mining, Pb acid batteries, vehicle exhausts, industries and paints, agricultural activities like farming, and so forth. In this instance, government action is required to stop soil pollution in several Bangladeshi regions. Additionally, it is important to make people aware of this problem. To maintain a safe environment, Bangladesh must also enforce the use of effluent treatment facilities in industrial regions, increasing the awareness among general people.

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https://doi.org/10.1021/acsomega.2c07681
ACS Omega 2023, 8, 15990−15999

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M.S.P. was involved in conceptualization, sample preparation, study design, data analysis, result interpretation, manuscript preparation, writing, reviewing, creating image, and editing. S.N., S.S., and M.S.H. helped in sample preparation, data analysis, manuscript writing, and editing. M.H.R.K., M.A.H., and Z.T.N. helped in reviewing the manuscript. R.K. assisted in experimental work, data analysis, result preparation, and manuscript reviewing. All authors reviewed the final manuscript and approved submission.

Funding

The research was funded by the Research and Innovation Centre of Khulna University, Khulna-9208, Bangladesh

Notes

The authors declare no competing financial interest.
The data sets used in this study are available for sharing on request to the corresponding author.

■ ACKNOWLEDGMENTS

We are grateful to Palash Kumar Dhar for his suggestions of this article and technical help on the project. We are also very grateful to the central laboratory of Khulna University for helping and supporting necessary laboratory facilities. The authors are grateful to Mahmud Uz Zaman for helping to create a site map with the help of Google map (Figure [1]). The images used in the graphical abstract are created by M.S.P., the corresponding author of this article, except the crop image that is a free domain image.

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