



Assessment of soil heavy metal pollution by environmental indices at surroundings of Ishwardi Export Processing Zone (IEPZ), Ishwardi, Pabna, Bangladesh

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Received: 29 March 2021 / Accepted: 19 May 2022 / Published online: 27 May 2022
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Abstract

Heavy metals discharged from the industries contaminating soil and water in and around the Export Processing Zone (EPZ) area are the greatest environmental concern worldwide. The soils were analyzed to assess the heavy metal pollution surrounding the Ishwardi Export Processing Zone (IEPZ). Soil contamination indices like the enrichment factor, the geo-accumulation index, and the pollution contamination index were used. Seven soil samples were collected from the surface layer near IEPZ and analyzed by the XRF (X-ray fluorescence spectrometer) method. The heavy metals studied in these samples are $Pb > Cr > Cu > Ni > Zn > Fe$. The degree of enrichment factor values ranges from 70.76 to 0.82, which showed most samples were contaminated extremely to severely by heavy metals. The geo-accumulation index (I_{geo}) values ranged from 0 to 6, representing uncontaminated to extremely contaminated by the heavy metals in the soil. The heavy metals of Pb, Cu, Cr, and Ni, both for the enrichment factor value and the geo-accumulation value, are rich in maximum stations of soil samples near the IEPZ area. Potential contamination index values range from 73.26 to 1.083, indicating most of the area is contaminated by heavy metals like Pb, Cr, and Ni in the study area. Industrial waste is discharged through the drain. This dumping area recorded high contamination by heavy metals. Methods for different index values are not the same. Hence, heavy metals are correlated with each other. So, it represents an additional source of these heavy metals. These indices assess the combined effect of the heavy metals. These methods are sufficient as well. From all the above, the outcomes of soil analyses are extremely polluted by industrial effluent. The average concentration of iron, copper, and zinc is lower in the IEPZ than in the ship breaking industry.

Keywords IEPZ · Enrichment factor · Geo-accumulation index · Correlation · Potential contamination index

Introduction

All industries, including agriculture, mining, energy, transportation, construction, and consumers, generate waste. In different industrial processes, some industrial wastes are produced and released into the quantity of harmful discharge from industrial actions. There are many industries in the Ishwardi Export Processing Zone (IEPZ) producing

chemicals, garment accessories, metals, plastic goods, lead-acid batteries, etc. Industrial effluent is discharged into the land, surface, and groundwater bodies either directly or indirectly due to inadequate treatment. They can increase the absorption of pollutants such as toxic metals. The heavy metal contamination of soil is a significant issue because of its ability to accumulate in the surroundings of the Ishwardi EPZ area (Rahman et al. 2012). The pollution level should be monitored for socio-environmental and human health safety claims and be claimed for maintainable development for administrative procedures (Azom et al. 2012). The heavy metal contamination of soil in this study was assessed near the Ishwardi Export Processing Zone (IEPZ) area using different parameters such as the enrichment factor (Taylor 1964) and the geo-accumulation index (Abraham and Parker 2008), and the potential contamination index. Lack of proper waste management, lack of facilities for treating

Responsible Editor: Amjad Kallel

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industrial effluent, and environmental problems are increasing daily. So, it is a problem for the environment and the country's social welfare. This study focused on the present scenario arising from such activities and proposed several subsidence measures. This was done by analyzing the effects of various toxic metals on the environment of the studied area. Because of the health implications, an assessment technique investigation of heavy metal pollution in the soil is required. Ishwardi is the westernmost Upazila of Pabna District in Rajshahi Division, Bangladesh. Ishwardi Upazila has an area of 246.90 km² and is located between 24°03' and 24°15' north latitudes and 89°00' and 89°11' east longitudes (Fig. 1). The aims of this work are: (i) to determine the present scenario of the content of heavy metals in soil, (ii) to identify the source of the studied heavy elements, and (iii) to determine the pollution level by some indices for monitoring soil quality in the surrounding IEPZ area.

Materials and methods

Collection and preparation of samples

The soil samples were collected from the surroundings of the IEPZ area (Fig. 2) located at Sara Union of Ishwardi Upazila in February 2019 from the surface layer and were placed in airtight polythene bags and labeled. The heavy metals of Pb, Cu, Cr, Ni, Zn, Fe, and Mn of these soil samples were measured by XRF study in the laboratory of IMMM (Institute of Mining Mineralogy and Metallurgy), BCSIR (Bangladesh Council of Scientific and Industrial Research), Joypurhat. The collected soil samples were dried up in an electronic oven at 100 °C for 1 h to dry (Hasan et al. 2013). Noticeable roots and remains were removed. The dry samples have been crinkled gently by the pestle and are in powder form. Then, these powder samples were pulverized in a pulverizing machine (Rigaku by Japan). The finely ground powder (75 mm) was then placed in a porcelain crucible and dried in an oven overnight at 1000 °C to remove moisture. The powder samples were mixed up in a ring with a binder at the ratio of stearic acid to sample of 1:10 and pulverized

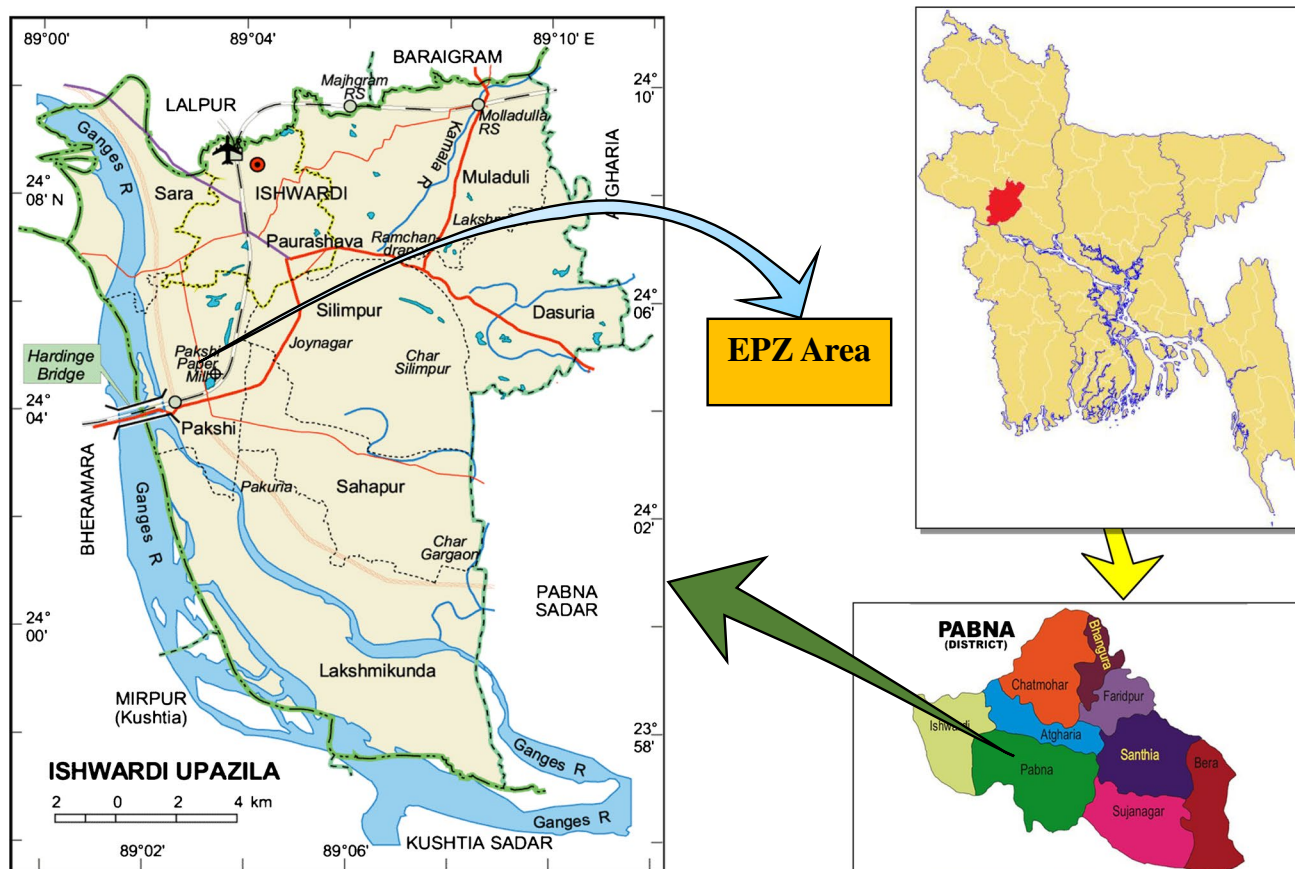


Fig. 1 Location map of the study area

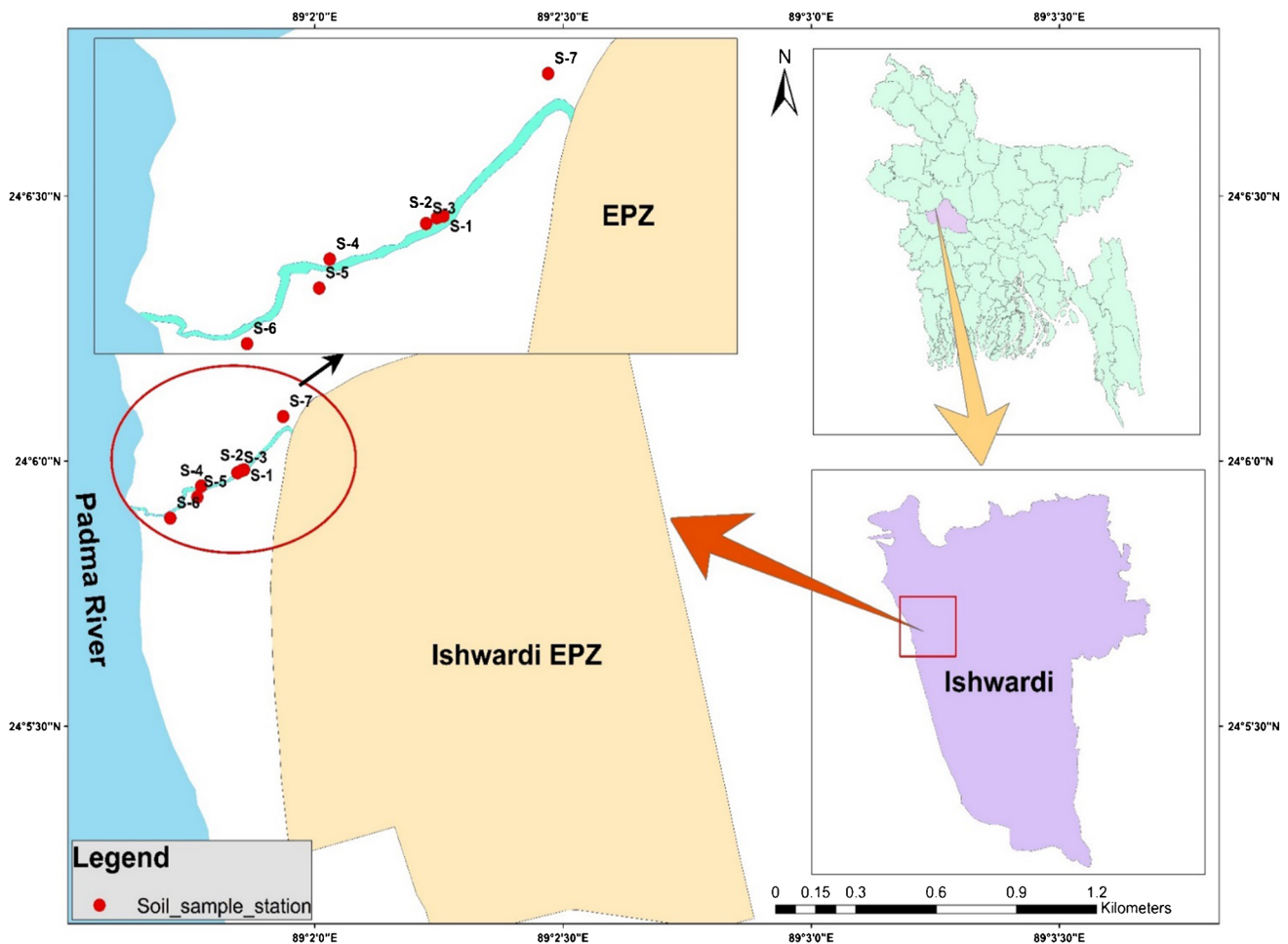


Fig. 2 Soil sampling location

for a few minutes. The acquired mixing powder has been spooned up an aluminum cap (30 mm). The cap was sandwiched between two tungsten carbide pellets using a manual hydraulic press at 10 tons/square inch for 2 min, and finally, the pressure was released slowly. The pellet was then ready for X-ray analysis (Hasan et al. 2020).

Obtained value of the enrichment factor (EF)

The degree of enrichment factor was assessed by comparing the amount of metal pollution in the circumstantial area of the Ishwardi Export Processing Zone (Selvaraj et al. 2004). Metal contamination has been standardized to the relative abundance of a chemical element to the reference point values' comparison with a convenient measure of geochemical trends in the enrichment factor (Aprile and Bouvy 2008; Salomons and Froster 1984). The enrichment factor (EF) values for metals contamination in soil have been measured by the equation followed by Aprile and Bouvy (2008):

$$EF = [(Ms)/(Fes)/(Mr)/(Fer)]$$

where Ms and Fes are the concentrations of heavy elements for soil samples, whereas Mr and Fer are the concentrations in reference values; the reference concentration is Fe because this chemical element has a significant sorbent phase for trace elements and is a conservative tracer (Hasan et al. 2013). The amount of heavy metals is generally influenced by anthropogenic activity, and certain amounts might have been released from geogenic sources under aerobic conditions (Zhang et al. 2014). Iron also absorbs Mn and As from the soil. EF values for the crustal extensive quantity data have been used (Krauskopf and Bird 1995).

Obtained value of geo-accumulation index (I_{geo})

The degree of the geo-accumulation index (I_{geo}) values for seven samples were calculated based on the content of heavy metal concentrations according to Muller (1979), Subramanian and Mohanachandran (1990), Angelidis and Aloupi

(1995), Rubio et al. (2000); Muller (1979), and Abraham and Parker (2008). The equation is as follows:

$$I_{geo} = \log_2\left(\frac{[Ms]}{1.5*[Rs]}\right)$$

where Ms is the soil value, and Rs is the reference value; seven studied heavy metals of Pb, Cu, Cr, Ni, Fe, Mn, and Zn were investigated. To reduce the consequence of potential differences in the corresponding values, a factor of 1.5 has been used, which might be recognized as lithological distinctions in the soil (Al-haidarey et al. 2010). The mentioned crustal abundance data of the reference samples were Mn: 950, Cr: 100, Pb: 13, Cu: 55, Zn: 70, Ni: 75, and Fe: 50,000 mg/kg followed by Krauskopf and Bird (1995).

Obtained value of potential contamination index (C_p)

The degree of potential contamination Index (C_p) in soil was detected in the rate of heavy elements by the equation followed by Davaulter and Rognerud (2001) and Aprile and Bouvy (2008):

$$C_p = \left[\frac{M_m}{M_B} \right]$$

where M_m is the highest heavy metal concentration in the soil and M_B is the expected value of the similar metal at a background level. The background data taken by Krauskopf and Bird (1995) is known as crustal abundance data.

Results and discussion

1Assessment of studied soil data with standard data

The heavy metal concentration in the soil of the surroundings of the IEPZ area has been related to the standard values

of uncontaminated soil. Table 1 shows the obtained minimum, maximum, and mean values of trace metal concentration. The difference between the obtained values of heavy metals and the values of heavy metals mentioned in the unpolluted soils is shown in Table 2. Table 3 represents the difference between heavy metal concentrations in the soil of the studied area and the standard value according to IAEA (1990) and GESAMP (1982). The heavy metal of Pb concentration is at a higher level in 4 stations in the study area than the value of 22.8 µg/g (GESAMP 1982; IAEA, 1990), which is due to the runoff from industrial effluent polluting the soil. The toxic metals of Pb range from 142.037 to 952.48 µg/g indicating pollution by comparing with standard data, which is unusually similar to Baker and Harris (1991), and the average value is 233.412 µg/g of Pb. Cr of heavy metals near the IEPZ area is significantly higher in all the stations. The amount of maximum contamination of heavy elements could be due to waste materials discharged from industrial processes. The Cr concentration in studied samples varies from 1882.9 to 7056.78 µg/g, 47 times greater than the

Table 2 Comparison between obtained values of heavy metals with recommended standard values of uncontaminated soils (values in µg/g)

Heavy metal	Studied value (µg/g)	Recommended value
Cu	110.476	33.00 (GESAMP, 1982)
Zn	236.081	95.00 (Salomons and Froster 1984)
Fe	65,273.53	41,000.0 (GESAMP, 1982; Salomons and Froster 1984)
Mn	1396.466	770.00 (Salomons and Froster 1984)
Cr	3692.391	77.20 (IAEA, 1990)
Pb	233.412	19.00 (Salomons and Froster 1984)

Table 1 Obtained heavy metal concentrations in sediments collected from the Sara Union, Export Processing Zone Area, Ishwardi, Pabna

Station no	Cr (µg/g)	Ni (µg/g)	Pb (µg/g)	Zn (µg/g)	Cu (µg/g)	Mn (µg/g)	S (µg/g)	P (µg/g)	Fe (µg/g)
Station 1	2160	168.16	952.48	433.83	139.81	2335	7910.52	3355.56	51,772.2
Station 2	2873.6	1477.29	142.04	138.99	95.07	1137.18	5683.26	866.71	62,453.6
Station 3	3033	163.44	200.52	211.29	112.64	1237.45	6946.04	780.3	79,208.4
Station 4	4441.1	165	BDL	143.81	89.48	1076.55	3646.7	844.89	55,870
Station 5	4399.36	179.16	BDL	180.76	89.48	1135.63	871.38	1211.04	71,410.1
Station 6	7056.78	194.09	BDL	306.89	134.21	1525.05	3658.08	1482.05	63,981.1
Station 7	1882.9	132.01	338.85	237	112.64	1328.4	7896.5	1747.83	72,219.3
Max	7056.78	1477.29	952.48	433.83	139.81	2335	7910.52	3355.56	79,208.4
Min	1882.9	132.01	142.04	138.99	89.48	1076.55	871.38	780.3	51,772.2
Median	3033	168.16	269.685	211.29	112.64	1237.45	5683.26	1211.04	63,981.1
Mean	3692.39	354.16	408.47	236.08	110.48	1396.47	5230.35	1469.77	65,273.53

BDL below detection limit

Table 3 Comparison between heavy metal concentrations of soil samples and standard value according to IAEA (1990), GESAMP (1982)

Value of the affected site	Stations (Ishwardi Upazila, Sara Union)	Heavy metal concentrations						
		Pb (µg/g)	Cr (µg/g)	Zn (µg/g)	Fe (µg/g)	Mn (µg/g)	Cu (µg/g)	Ni (µg/g)
	SS-1	952.48	2160	433.83	51,772.2	2335	139.81	168.15
	SS-2	142.037	2873.6	138.98	62,453.6	1137.18	95.071	1477.2
	SS-3	200.523	3033	211.29	79,208.4	1237.45	112.64	163.44
	SS-4	BDL	4441.1	143.8	55,870	1076.55	89.479	165
	SS-5	BDL	4399.3	180.76	71,410.1	1135.63	89.479	179.16
	SS-6	BDL	7056.7	306.89	63,981.1	1525.05	134.21	194.09
	SS-7	338.847	1882.9	237	72,219.3	1328.4	112.64	132.01
Standard value		22.8	77.2	95	27,000	1.17	33.0	56.1
		<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>

BDL below detectable limit

Legend: *a*=IAEA (1990), *b*=GESAMP (1982)

standard value (77.20 µg/g) of unpolluted soils (GESAMP 1982; Salomons and Froster 1984; IAEA 1989). The mean value is 3692.391 µg/g, whereas the recommended value of Cr is 77.20 µg/g (IAEA, 1990). The Cu of heavy metals is at the maximum level in all stations. The pattern of distribution of Cu of the heavy element is not regular. The metal of Ni ranges from 132.012 to 1477.287 µg/g. The metal of Ni recorded as 354.164 µg/g is more than the standard value of 56.1 µg/g (IAEA, 1990). A comparison between the affected site value and the standard value of heavy metal pollution in the selected area is shown in Fig. 3. So, it is observed that the soil samples are vastly affected by heavy metals around the IEPZ area owing to the significant effluents discharged by various industries in the IEPZ.

Correlation matrix between heavy elements

The correlation matrix observes the correlation among the heavy metals. It represents the possible source of toxic metals (Kaur et al. 2019; Chandrasekaran et al. 2015). The resulting correlation matrix of samples in the study area is shown in Table 4. A significant correlation was measured by $p < 0.05$ (Hasan et al. 2013). Elements of the study area correlated with the metals of Pb are Cr ($q=0.754$), Ni ($q=0.683$), Zn ($q=0.908$), Cu ($q=0.868$), Mn ($q=0.900$), and Fe ($q=0.827$). Lead is considerably correlated with Zn ($q=0.908$), and Cr is considerably correlated with Cu ($q=0.976$) and Fe ($q=0.976$). The metal of Ni is also correlated with Cu ($q=0.837$) and Fe ($q=0.847$). Manganese was

Fig. 3 Shows the comparison among the affected and standard value of trace elements in soil

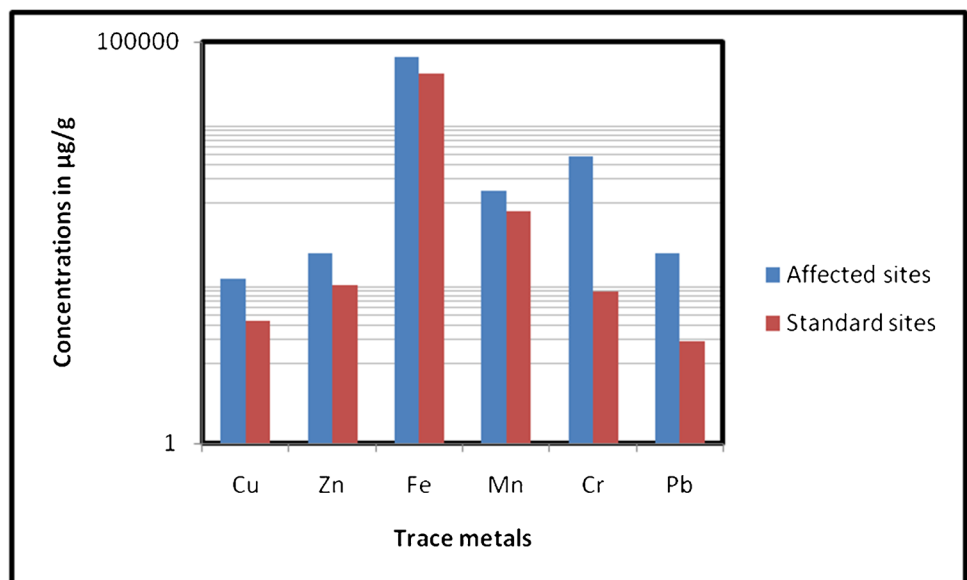


Table 4 Correlation matrix results of heavy metals of soil samples

	Pb	Cr	Ni	Zn	Cu	Mn	Fe
Pb	1.000						
Cr	.754	1.000					
Ni	.683	.817	1.000				
Zn	.908	.958	.798	1.000			
Cu	.868	.976	.837	.993	1.000		
Mn	.900	.963	.827	.998	.997	1.000	
Fe	.827	.976	.847	.975	.993	.984	1.000

Table 5 The degree of heavy metal pollution is based on enrichment factor value, according to Taylor (1964)

EF value	Designation of sediment quality
50	Extremely severe enrichment
25–<50	Very severe enrichment
10–<25	Severe enrichment
5–<10	Moderately severe enrichment
3–<5	Moderate enrichment
1–<3	Minor enrichment
<1	No enrichment

also correlated with Fe ($r=0.984$), and Cu was correlated with Mn ($r=0.997$). Zn is correlated with Mn ($r=0.997$). The value of the correlation matrix shows that almost all the metals are highly correlated with each other. So, these values indicate the possible sources of toxic metals are almost the same in the IEPZ area, which is discharged from different industries (Hasan et al. 2020). Anthropogenic activities contaminate the natural environment, as the use of Fe compounds increases the Fe content.

Degree of the enrichment factor value

The classification of the enrichment factor values is given by Taylor (1964) (Table 5). The computed value of EF value (Table 6) shows that the soil samples were moderately to extremely enriched by Pb through industrial activity owing to industrial effluent. These samples are severely enriched by

Cr, moderately enriched by Cu, Zn, and mildly to severely enriched by Ni and Mn. The collected samples are relatively unhealthy because of the concentration of lead metal, which is extremely enriched. The blank line in the data table indicates the average value of each studied metal. An EF value greater than 1.5 should be classified as polluted (Abraham and Parker 2008). In the study area, the outcomes of the EF value of heavy elements have followed the hierarchy: $Pb > Cr > Cu > Zn > Ni > Mn$. From the above results, soils are mostly contaminated by heavy metals lead, which may cause negative effects on the environment in the surroundings of the IEPZ area.

Degree of the geo-accumulation index value

The classification of geo-accumulation index (Igeo) values is given in (Table 7) by Abraham and Parker (2008) and Muller (1979). The Igeo value is more similar to the EF value. The Igeo value of the studied metals of Pb is highly concentrated. The samples are extremely polluted by the metal Pb in station 1 (952.48 mg/kg), station 7 (338.85 mg/kg), and station 3 (200.52 mg/kg). The maximum contamination of Cr was observed at station 6 (5555.97 mg/kg). There is also high contamination of Cr all over the stations. The maximum concentration of Ni was observed in station 2 (3714.95 mg/kg). According to Abraham and Parker (2008), the computed value of Igeo classes is shown in Table 8 and Fig. 4. The observed Igeo values have followed the hierarchy: $Pb > Cr > Zn > Ni > Cu > Mn > Fe$. The Igeo values of metals like Pb, Cr, and Zn range between 6 and 3, which means they are

Table 6 The obtained value of the enrichment factor of heavy metals in the studied area

Station no	Cr	Ni	Pb	Zn	Cu	Mn
Station 1	20.86	2.165	70.76	5.99	2.45	2.37
Station 2	23.005	15.77	8.75	1.59	35.22	0.95
Station 3	19.15	1.38	9.74	1.9	1.29	0.82
Station 4	39.75	1.96	BDL	1.84	1.46	1.014
Station 5	30.8	1.672	BDL	1.8	1.13	0.836
Station 6	55.14	2.022	BDL	3.42	1.9	1.25
Station 7	13.03	1.218	18.04	2.34	1.42	0.968

BDL below detection limit

Table 7 The degree of heavy metal pollution is based on geo-accumulation value, according to Abraham and Parker (2008)

I_{geo} value	I_{geo} class	Designation of sediment quality
> 5	6	Extremely contaminated
4–5	5	Strongly to extremely contaminated
3–4	4	Strongly contaminated
1–2	2	Moderately to strongly contaminated
2–3	3	Moderately contaminated
0–1	1	Uncontaminated to moderately contaminated
0 <	0	Uncontaminated

extremely to moderately contaminated. Almost all stations are unpolluted with Mn and Fe metals.

The degree of the potential contamination index value

The results of the potential contamination index (C_p) for heavy metals in soil are given in Table 9. The C_p values that have measured the metal of Pb at station 1 (73.26) and station 7 (26.065) indicate a very high contamination index. The metals of Cr range from 18.829 to 70.567, Ni ranges from 1.67 to 19.69, Zn ranges from 1.985 to 6.197,

Table 8 The obtained value of metal pollution is based on geo-accumulation values (Abraham and Parker 2008)

Station no	Cr	Ni	Pb	Zn	Cu	Mn	Fe
Station 1	4	1	6	3	1	1	0
Station 2	5	4	3	1	1	0	0
Station 3	5	1	4	2	1	0	1
Station 4	5	1	0	1	1	0	0
Station 5	5	1	0	1	1	0	0
Station 6	6	1	0	2	1	1	0
Station 7	4	1	5	2	1	0	0

Fig. 4 The geo-accumulation index of 7 studied heavy metals of soil in the IEPZ area of Ishwardi Upazila, Pabna

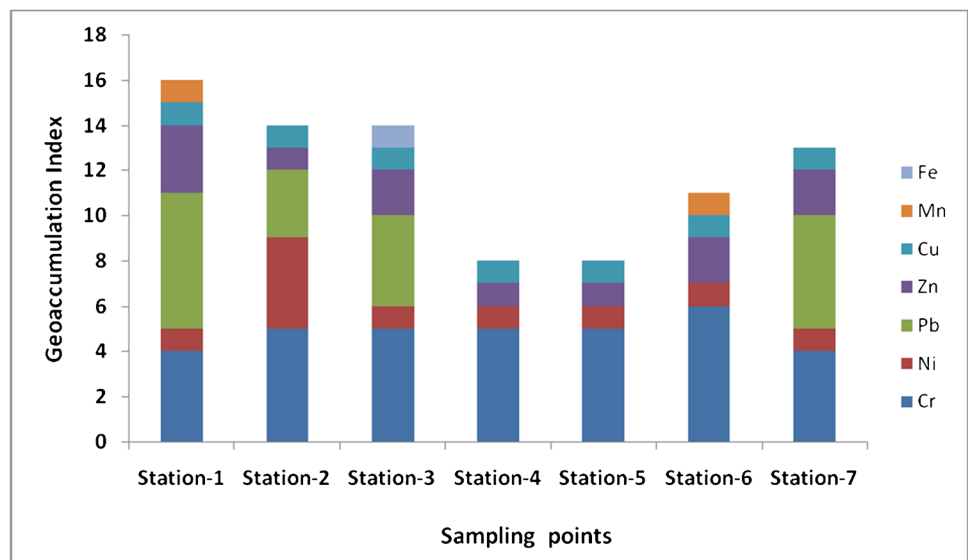
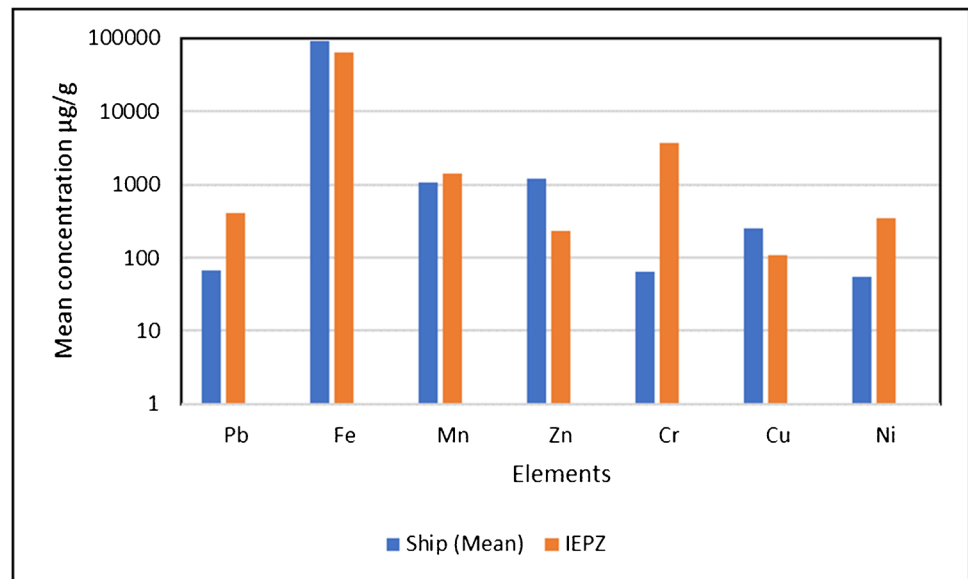


Table 9 The obtained value of the potential contamination index of heavy metals near the IEPZ area of Ishwardi Upazilla, Pabna, according to Aprile and Bouvy (2008)

Station no	Cr	Ni	Pb	Zn	Cu	Mn	Fe
Station 1	21.6	2.242	73.26	6.197	2.54	2.45	1.035
Station 2	28.736	19.69	10.92	1.985	1.728	1.19	1.249
Station 3	30.33	2.179	15.42	3.018	2.048	1.3	1.584
Station 4	44.411	2.2	0	2.054	1.626	1.13	1.117
Station 5	43.993	2.39	0	2.582	1.626	1.19	1.428
Station 6	70.567	2.59	0	4.38	2.44	1.6	1.279
Station 7	18.829	1.67	26.065	3.385	2.048	1.39	1.444

** $C_p > 3$ severe contamination

Fig. 5 Mean concentrations of different heavy metals of ship breaking industry and IEPZ



Cu ranges from 1.62 to 2.54, Mn ranges from 1.13 to 2.45, and Fe ranges from 1.035 to 1.584. The maximum potential contamination index is the Cr in all stations. The ranges of Ni ranged from 1.67 to 19.69, Zn ranged from 1.985 to 6.197, Cu ranged from 1.62 to 2.54, Mn ranged from 1.13 to 2.45, and Fe ranged from 1.035 to 1.584 showing moderate contamination. The metal Mn showed the lowest contamination. The outcomes of potential contamination index values are mostly contaminated with heavy elements caused by an industrial impact on soil near the IEPZ area of Ishwardi Upazila, Pabna.

Comparison of mean concentration of heavy metals in IEPZ and ship breaking industry

An attempt was made to show the comparison of the mean concentration of heavy metals in IEPZ and the ship breaking industry. From Fig. 5, it can be concluded that the mean iron, copper, and zinc concentration is higher in the ship breaking industry (Hasan et al. 2020) than in the IEPZ. The average concentration of Pb, Mn, Cr, and Ni is higher in IEPZ. These results suggest that the IEPZ area is composed of various types of industries in the study area.

Conclusions

The heavy metal concentration of topsoil samples collected from the Ishwardi Export Processing Zone (IEPZ) and its environs was investigated. Due to industrial activity, the IEPZ's environmental impact assessment has been negatively impacted. Therefore, heavy metal (i.e., Zn, Cu, Fe, Pb, Cr, Ni) concentrations in soil samples collected from IEPZ were analyzed by X-ray fluorescence (XRF) spectrometry.

The present research work shows that the soil has higher concentrations of heavy metals, indicating that the investigated soil composition is affected by heavy metal contamination in the surrounding area of IEPZ due to industrial processes. Heavy metal soil contamination can pass these metals into the human food chain through surface water movement. If it rises further, the environment may become adversely polluted. Compared with the standard value of the affected site, it is mainly affected by Cr, Ni, Pb, Zn, and Cu, whereas the mean concentration of iron, copper, and zinc content is lower in the IEPZ than in the ship breaking industry. These metals are highly correlated with each other. The enrichment factor, the geo-accumulation index, and the potential contamination index values reveal that the soils are extremely moderately polluted near the IEPZ area. Due to these pollution indices, soil near the Ishwardi Export Processing Zone is contaminated, which is inappropriate for the environment. It can impact health and also the socio-environment.

Declarations

Conflict of interest The authors declare no competing interests.

References

- Abraham GMS, Parker RJ (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. *Environ Monit Assess* 136:227–238
- Al-haidarey MJS, Hassan FM, Al-kubaisey ARA, Douabul AAZ (2010) The geoaccumulation index of some heavy metals in Al-Hawizeh Marsh, Iraq. *E-J Chem* 7:157–162
- Al-Hamzabi AA, Al-Gharabi MG (2019) Heavy metals concentrations in selected soil samples of Al-Diwaniyah, Southern Iraq. *SN Appl Sci* 1:854. <https://doi.org/10.1007/s42452-019-0892-7>

- Aloupi M, Angelidis MO (2001) Geochemistry of natural and anthropogenic metals in the coastal sediments of the island of Lesvos, Aegean Sea. *Environ Pollut* 113(211):219
- Aprile FM, Bouvy M (2008) (2008) Distribution and enrichment of heavy metals in sediments at the Tapacurá river basin, Northeastern Brazil. *Braz J Aquat Sci Technol* 12(1):1–8
- Azom MR, Mahbub K, Yahya SM, Sontu A, Himon SB (2012) Environmental impact assessment of tanneries: a case study of Hazaribag in Bangladesh. *Int J Env Sci Dev* 3
- Baker EK, Harris PT (1991) Copper, lead and zinc distribution in sediments of the Fly River delta and Torres Straits. *Mar Pollut Bull* 22:614–618
- Chandrasekaran A, Ravisankar R, Harikrishnan N, Satapathy KK, Prasad MVR, Kanagasabapathy KV (2015) Multivariate statistical analysis of heavy metal concentration in soils of Yelagiri Hills, Tamilnadu, India—spectroscopical approach. *Spectrochim Acta Part A Mol Biomol Spectrosc* 137(25):589–600
- Dankoub Z, Ayoubi S, Khademi H, Sheng-Gao LU (2012) Spatial distribution of magnetic properties and selected heavy metals in calcareous soils as affected by land use in the Isfahan region, Central Iran. *Pedosphere* 22(1):33–47
- Davault V, Rognerud S (2001) Heavy metal pollution in sediments of the Pasvik River drainage. *Chemosphere* 42:9–18
- Egashira K, Takenaka J, Shuto S, Moleshuddin AZM (2003) Phosphorus status of some paddy soils in Bangladesh. *Soil Sci Plant Nutr* 49(5):751–755. <https://doi.org/10.1080/00380768.2003.10410335>
- GESAMP (IMO/FAO/IJNESCO/WMO/IAEA/UN/IJNEP) (1982) The health of the oceans. Rep. Stad. GESAMP. 15:108 and UNEP Res. Seas. Rep. Stud., 16:108
- Gong Q, Deng J, Xiang Y, Wang Q, Yang L (2008) Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. *J China Univ Geosci* 19:230–241
- Hasan AB, Kabir S, Reza AHMS, Kabir S et al (2020) Accumulation and distribution of heavy metals in soil and food crops around the ship breaking area in southern Bangladesh and associated health risk assessment. *SN Appl Sci* 2:155. <https://doi.org/10.1007/s42452-019-1933-y>
- Hasan AB, Kabir S, Reza S A.H.M., Zaman MN, Ahsan A, Rashid M (2013) Enrichment factor and geo-accumulation index of trace metals in sediments of the ship breaking area of sitakund Upazilla (bhatiyari-Kumira), Chittagong, Bangladesh. *J Geochem Explor* 125:130–137
- Hoque ME, Nusrat R, Reza AHMS (2021) Iron in groundwater quality evaluation, health risk and spatial distribution in Rangpur City Corporation. *Arab J Geosci* 14(7)
- Hossain G, Howladar MF, Nessa L et al (2010) Hydrochemistry and classification of groundwater resources of Ishwardi Municipal Area, Pabna District, Bangladesh. *Geotech Geol Eng* 28:671–679. <https://doi.org/10.1007/s10706-010-9326-4>
- IAEA (International Atomic Energy Agency) (1989) Reference sheet SD-M-2/TM. Trace elements in marine sediments. Vienna, Austria.
- IAEA (1990) Guidebook on applications of radiotracers in industry. Technical Report Series No. 316.
- Islam MS, Halim MA, Saifullah S, Islam MS, Islam MM (2009) Analysis of organic matter, iron and manganese in soil of arsenic affected Singair Area, Bangladesh. *Res J Environ Toxicol* 3(1):31–35
- Islam ARTM, Sein ZMM, Ongoma V et al (2015) Geomorphological and land use mapping: a case study of Ishwardi Under Pabna District, Bangladesh. *Adv Res* 4(6):378–387
- Jia Z, Li S, Wang L (2018) Assessment of soil heavy metals for eco-environment and human health in a rapidly urbanization area of the upper Yangtze Basin.
- Kaur R, Sharma S, Kaur N (2019) Heavy metals toxicity and the environment, *Journal of Pharmacognosy and Phytochemistry SP1*: 247–249.
- Kodom K, Preko K, Boamah D (2012) X-ray Fluorescence (XRF) Analysis of soil heavy metal pollution from an industrial area in Kumasi, Ghana. *Soil Sediment Contam* 21:1006–1021. <https://doi.org/10.1080/15320383.2012.712073>
- Krauskopf KB and Bird DK (1995) Introduction to geochemistry. 3rd edition, McGraw-Hill, Inc. P-247.
- Muller G (1979) Schwermetalle in den sediments des Rheins-Veränderungen seit 1971. *Umschan* 79:778–783
- Rahman MM, Hossain MM, Arshad MN, Aual MR, Asiri AM (2019) Arsenic sensor development based on modification with (E)-N'-(2-nitrobenzylidene)—benzenesulfonohydrazide: a real sample analysis. *New J Chem* 43:9066. <https://doi.org/10.1039/C9NJ01567A>
- Rahman SH, Khanam D, Adyel MA (2012) Assessment of heavy contamination of agricultural soil around Dhaka Export Processing Zone (DEPZ), Bangladesh: implication of seasonal variation and indices 2:584–601
- Rashed MH, Hoque TS, Jahangir MMR, Hashem MA (2019) Manganese as a micronutrient in agriculture: crop requirement and management. *J Environ Sci Nat Resour* 12(1 & 2):225–242
- Saha S, Reza AHMS, Roy MK (2021) Arsenic geochemistry of the sediments of the shallow aquifer and its correlation with the groundwater, Rangpur, Bangladesh. *Appl Water Sci* 11:166. <https://doi.org/10.1007/s13201-021-01495-1>
- Salomons W, Froster U (1984) Metals in the hydro cycle. Springer, Berlin, p 349
- Sarkar S, Ghosh PB, Sil AK, Saha T (2011) Heavy metal pollution assessment through comparison of different indices in sewage-fed fishes pond sediment at East Kolkata wet land, India. *Environ Earth Sci* 63:915–924
- Schiff KC, Weisberg SB (1999) Iron as a reference element for determining trace metal enrichment in southern California coastal shelf sediments. *Mar Environ Res* 48(161):176
- Selvaraj K, Ram Mohan V, Szefer P (2004) Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: geochemical and statistical approaches. *Mar Pollut Bull* 49(174):185
- Sinex SA, Helz GR (1981) Regional geochemistry of trace elements in Chesapeake Bay sediments. *Environ Geol* 3:315–323
- Subramanian V, Mohanachandran G (1990) Heavy metals distribution and enrichment in sediments of southern east coast of India. *Mar Poll Bull* 21:324–330
- Taylor SR (1964) Abundance of chemical elements in the continental crust: a new table. *Geochim Cosmochim* 28:1273–1285
- Tippie VK (1984) An environmental characterization of Chesapeake Bay and a frame work for action. In: Kennedy, V. (ed.) The estuary as a filter
- Turner A, Millward GE (2000) Particle dynamics and trace metal reactivity in estuarine plumes. *Estuari Coast Shelf Sci* 50(761):774
- Varol M (2011) Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *J Hazard Mater* 195:355–364
- World Health Organization (WHO) (1996) Guidelines for drinking-water quality: 2nd edition, vol. 2, Health criteria and other supporting information. World Health Organization, Geneva, 1996.
- Zhang C, Yu Z, Zeng G et al (2014) Effects of sediment geochemical properties on heavy metal bioavailability. *Environ Int* 73:270–281