



## RESEARCH PAPER

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## Heavy metal pollution in sediments in the vicinity of Barapukuria coal mine, north western Bangladesh

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**Key words:** Barapukuria coal mine, Bangladesh, Heavy metal, Sediment pollution etc.

<http://dx.doi.org/10.12692/ijb/12.1.6-17>

Article published on January 12, 2018

### Abstract

This study reveals that the total concentrations of heavy metals in sediments of Barapukuria coal mine area were determined to assess the degree of pollution. When compared the average concentrations of heavy metals with recommended value of unpolluted sediments it was seen that Ti, Zr, Ni, Cr, Cu, Fe and Zn exceeded these value highly. Enrichment factors (EF), Geo-accumulation index (Igeo) and Potential contamination index were used to quantify sediment pollution. The sediment samples showed severe to extremely severe enrichment with Cr; moderate to moderately severe enrichment with Y; minor to moderately severe enrichment with Zr and Ni; and minor enrichment with Ti, Rb, Ba, Cu and Zn demonstrating input from mining activities. The Igeo values inferred that the sediments were heavily contaminated to extremely contaminated by Cr; moderately to heavily contaminated by Ni and Y; moderately contaminated by Zr and Ti; and uncontaminated to moderately contaminated by Rb, Ba, Cu and Zn. Potential contamination indices of the sediment samples indicated that Cr showed very severe contamination; Ni, Y, Zr and Ti showed extensive contamination; and Cu, Zn, Ba, Rb and Fe showed moderate contamination.

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## Introduction

Barapukuria Coal Mine is the first coal producing mine in Bangladesh. According to Petrobangla this mine has a capacity to produce about 01 (one) Million Metric Tons of coal per year. Although it has the potential of improving the living standards in Bangladesh but Coal mining practices in the Barapukuria are the most hazardous practices in the world (Rahman, 2012), which causes a serious threat to the regional ecology (Rashid *et al.*, 2014). Underground mining has the potential for tunnel collapses and land subsidence (Betournay, 2011). It involves large-scale movements of waste rock and vegetation, similar to open pit mining. Additionally, like most traditional forms of mining, underground mining can release toxic compounds into the air and water. As water takes on harmful concentrations of minerals and heavy metals, it becomes a contaminant and this contaminated water can pollute the region surrounding the mine and beyond (Miranda *et al.*, 1998). Acid mine drainage (AMD) can occur during the exploitation of coal and coal-bearing minerals, and ore bodies containing acid forming metal sulfides such as pyrite (Rashid *et al.*, 2014). Beside these, the coal mine piles consist of a mixture of fragment of shale, sandy shale, mudstone and coal. The shale especially the black variety is known to contain large amounts of heavy metals such as As, Cd, Cr, Cu, Mn, Ni, Se, U, V etc. (Krauskopf and Bird 1995). According to FAO 2014, generally all stages of mining produce environmental impacts, resulting in the destruction of natural soils and the creation of new soils (Pan and Li, 2016). Thus, coal mining area in Barapukuria is facing various environmental problems due to pollution of the air and water, and heavy metal contamination of the soil (Halim *et al.*, 2012; Rashid *et al.*, 2014). Soil, as an important carrier of heavy metals in the terrestrial environment (Nriagu and Pacyna 1988), gives a vital guide for investigating the potential risk to public health and the ecosystem (Hough *et al.* 2004; Pan and Li, 2016). Mining activities are considered to have the potential for causing heavy metal pollution and associated diseases (Lacatusu *et al.*, 2009; Kodom *et al.*, 2010; Ikenaka *et al.*, 2010).

Heavy metals are the most widespread contaminants in the environment (Christoforou *et al.* 2000), and can be transferred to animals and humans through various exposure pathways such as the food chain and direct contact (Alloway, 2013; Pan and Li, 2016). So, due to the toxicity effect of some of these metals on the agricultural soil there is a need to assess the level of heavy metal pollution in the vicinity of Barapukuria coal mine. Many studies from around the world have used the sediments of the wetlands as an indicator for pollution (Syrovetsnik *et al.*, 2007; Hasan *et al.*, 2013). This study examined the spatial distributions of heavy metals in sediments around the Barapukuria coal mine area and analyzed the major factors controlling the variations of heavy metals.

### *Location, extent and accessibility*

The Barapukuria Coalfield is situated within the Barapukuria village of Hamidpur union council under Parbatipur Thana, Dinajpur district, at a distance of about 50 km southeast of Dinajpur town (Fig. 1). Geographically, the study area lies between latitudes 25°31'N to 25°35'N and longitude 88°57'E to 88°59'E, included in the survey of Bangladesh topographic sheet No.78 C/14. The coalfield has a proved area of about 5.25 sq.km. In addition, the field is suggested to have possible extension for 1 to 1.5 sq km area to the south (Wardell, 1991). The coalfield contains coal-bearing seams of 7 groups in 11 seams with total thickness of 74.14 m. Seam-VI is the main mineable bed with thickness ranging from 29.4 to 41.00m and 36.41m on average, belonging to the regular and extra thick coal seam of the coalfield. The nearest railway station, Phulbari, is only 6 km south of Barapukuria and the coalfield lies to the immediate east of the north south running board gauge railway line between Phulbari and Parbatipur. Phulbari has a good communication link with Dhaka and other parts of the country. A fair metalled road is linked Barapukuria with Phulbari, which was construct with the development of Barapukuria coalmine.

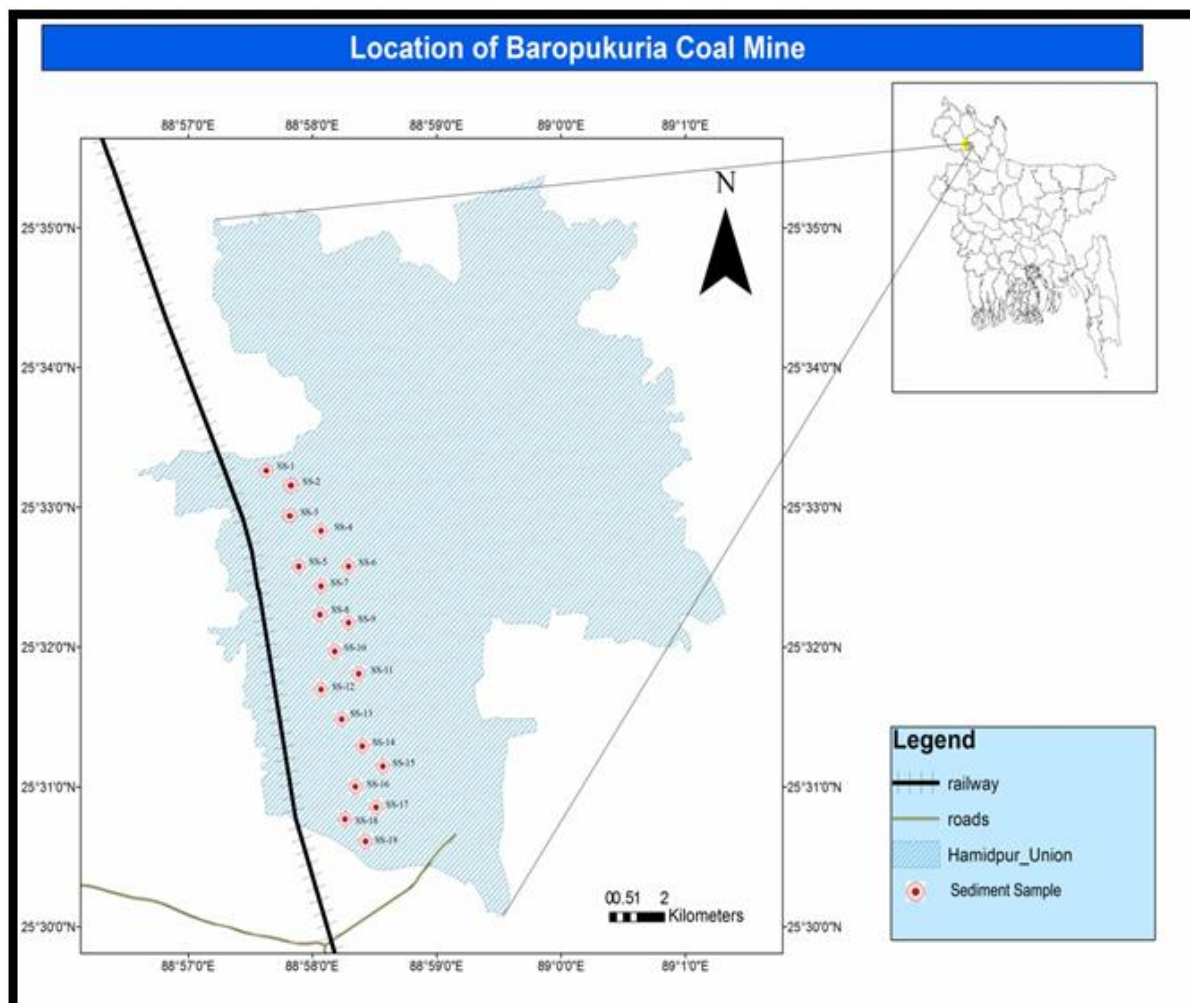
### **Methodology**

#### *Collection of Sediment Samples*

Nineteen sediment samples were collected at the same time by using a hand auger from the Hamidpur union under Parbatipur Thana, Dinajpur district (Fig. 1) in March, 2014.

Sediments samples were then placed in airtight plastic bags with labels. Wet sediment samples were air dried before analysis. Sediment samples were

analyzed in the Institute of Mining Mineralogy and Metallurgy (IMMM), Bangladesh Council of Scientific and Industrial Research (BCSIR), Joypurhat.



**Fig. 1.** Location map of the study area.

#### *Elemental Analysis of Sediment Samples by XRF Method*

The collected samples were dried in a Muffle Furnace at 600°C for 4 hours to make ash form. Then, to make powder form in well mixing conditions the ash samples were crushed for 20 minutes in a planetary ball mill (PM-200, Retsch, Germany). The powder samples were then pulverized in a pulverizer machine. To remove moisture the finely ground powder (<75µm) was then put in a porcelain crucible and dried at 1000°C in an oven overnight. The dried powder samples were mixed with binder (stearic acid:sample at a ratio of 1:10) and pulverized for two minutes. The resulting mixture was spooned into an aluminum cap (30 mm).

The cap was sandwiched between two tungsten carbide pellets using a manual hydraulic press with 10 tons/sq. in. for 2 minutes and finally pressure was released slowly. The pellet was then ready for x-ray fluorescence analysis. The elements were determined by X-ray fluorescence (XRF) in the Institute Mining Mineralogy and Metallurgy, BCSIR, Joypurhat following the standard procedures using Rigaku ZSX Primus equipped with an end window 4.kW Rh-anode X-ray tube. The trace elements were determined using crystal LiF1 at a 40 kV voltage with 60 mA current. The certified reference material used in this work was Japanese Stream Sediments (JSD 1, JSD 2 and JSD 3). The reference materials were firstly analyzed as unknown samples before the analysis of the selected sediments to ensure the standard deviation.

*Quantification of sediment pollution**Determination of Enrichment Factor (EF) of Sediment Samples*

The degree of metal contamination compared to the background area was assessed using the enrichment factor, EF (Woitke *et al.*, 2003; Selvaraj *et al.*, 2004; Hasan *et al.*, 2013). The enrichment factor for each metal is calculated by dividing its ratio to the normalizing element by the same ratio found in the chosen baseline (Taylor 1964) and is computed using the relationship below:

$$EF = \frac{X/Fe \text{ (sediment)}}{X/Fe \text{ (Earth's crust)}}$$

Where X is the metal studied and X/Fe is the ratio of the concentration of element X to iron. Iron (Fe) was used as the reference element for geochemical normalization because Fe is associated with fine solid surfaces, its geochemistry is similar to that of many trace metals and its natural concentration tends to be uniform (Daskalakis and Connor, 1995). Iron was chosen as the element of normalization also because of natural sources (98%) vastly dominates its input (Kamau, 2002). The crustal abundance data of Krauskopf and Bird (1995) were used for all EF values as baseline. The extent of metal pollution is based on seven enrichment factor classes (Taylor, 1964) which are:  $EF < 1$  (No enrichment);  $1 \leq EF < 3$  (Minor enrichment);  $3 \leq EF < 5$  (Moderate enrichment);  $5 \leq EF < 10$  (Moderately severe enrichment),  $10 \leq EF < 25$  (Severe enrichment);  $25 \leq EF < 50$  (Very severe enrichment);  $EF > 50$  (Extremely severe enrichment).

*Determination of Geo-accumulation Index (Igeo) of Sediment Samples*

The geo-accumulation index (Igeo) for the metal concentrations in the Barapukuria coal mine area, Dinajpur were determined using Muller's (1979) expression and is expressed by the following equation:

$$I_{geo} = \log_2 \left( \frac{[\text{sediment}]}{1.5 * [\text{reference sample}]} \right)$$

The factor 1.5 was introduced to minimize the effect of probable deviations in the background values which might be assigned to lithologic variations in the sediments (Al-Haidarey, 2010, Hasan, *et al.*, 2013).

The crustal abundance data of Krauskopf and Bird (1995) were used as the reference value. According to Muller (1981), the geo-accumulation index consists of seven grades or classes. 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);  $5 < I_{geo}$ .

*Determination of Potential Contamination Index (Cp) of Sediment Samples*

According to Davaultier and Rognerud (2001) an estimate of the amount of metallic elements detectable from sediment analysis was acquired by using the potential contamination index (Cp). It is the ratio obtained by dividing the concentration of each metal in the sediment by the background value and can be calculated by the following method (Aprile and Bouvy, 2008).

$$C_p = \frac{[\text{Metal}]_{\text{max}}}{[\text{Metal}]_{\text{Ba}}}$$

Where [Metal]<sub>max</sub> is the maximum concentration of a metal in sediment and [Metal]<sub>Ba</sub> is average value of the same metal in a background level. The crustal abundance data of Krauskopf and Bird (1995) were used as background data.

**Result and discussion***Comparison of analyzed sediment data with controlled data*

The extents of heavy metals in the sediments of the study area had compared with the recommended values of unpolluted sediments. The concentrations of different heavy metals in all the samples were not uniform. The amount of heavy metal concentrations were shown in table 1. Iron concentration in sediments of the affected site varied from 36591 µg/g to 138072 µg/g. The maximum concentration of Fe was observed in sample-1 and the minimum was found in sample-16 of the affected site. The average value of Fe is 60923 which were higher than that of the recommended value of sediment as 41000 µg/g (GESAMP, 1982; Salomons and Froster, 1984).

Manganese concentration in sediment samples varied from 300  $\mu\text{g/g}$  to 3242  $\mu\text{g/g}$  in the affected area. Maximum level of Mn was observed at station-1 and minimum at station-2 in the affected site with an

average 736.4  $\mu\text{g/g}$  which was lower than that of the value (770  $\mu\text{g/g}$ ) recommended by Salomons and Froster (1984).

**Table 1.** Heavy metal concentrations in sediments collected from the Barapukuria Coal Mine area at Hamidpur union under Parbatipur Thana, Dinajpur.

Sample ID	Fe $\mu\text{g/g}$	Mn $\mu\text{g/g}$	Zn $\mu\text{g/g}$	Ni $\mu\text{g/g}$	Cr $\mu\text{g/g}$	Cu $\mu\text{g/g}$	Ti $\mu\text{g/g}$	Rb $\mu\text{g/g}$	Sr $\mu\text{g/g}$	Y $\mu\text{g/g}$	Zr $\mu\text{g/g}$	Ba $\mu\text{g/g}$
ss-1	138072	3242	1110	674	3926	332	25098	210	781	483	790	1621
ss-2	41513	300	60	193	2968	56	9472	160	66	122	629	547
ss-3	107850	1706	162	111	2075	84	15305	58	385	137	250	N.D
ss-4	76311	710	138	270	1842	72	11892	226	109	170	501	867
ss-5	72041	997	129	338	1812	88	10900	190	101	217	595	815
ss-6	50625	481	87	241	2606	67	9638	177	86	187	676	753
ss-7	47791	356	75	130	1513	47	11078	194	82	178	619	692
ss-8	65501	724	72	400	4117	65	9056	182	83	159	580	622
ss-9	36665	362	77	109	3986	49	7996	124	69	158	832	1098
ss-10	37095	350	59	277	3634	63	9011	120	70	112	841	455
ss-11	48321	466	96	130	5013	52	9303	131	79	133	789	590
ss-12	50385	376	64	497	4458	50	8839	112	71	118	652	493
ss-13	38601	440	58	451	4474	72	9356	132	78	153	768	460
ss-14	38605	317	51	127	2643	60	9066	131	76	157	737	430
ss-15	62975	529	57	691	5301	64	8650	127	80	146	768	N.D
ss-16	36591	596	62	223	3117	47	7424	125	65	129	876	719
ss-17	61136	786	91	177	2871	86	9217	195	111	168	439	529
ss-18	76257	416	129	193	2523	103	8749	214	72	189	517	624
ss-19	71210	837	87	613	2869	76	10317	185	73	198	630	701
Mean	60923	736.4	140.21	308	3250	80.7	10546	158	134	174	657	632

The level of Zn in sediments of the affected area varied from 51  $\mu\text{g/g}$  (station-14) to 1110 (station-1)  $\mu\text{g/g}$  with the average value of 140.21  $\mu\text{g/g}$  which was higher compared to that of the recommended value 95.00  $\mu\text{g/g}$  (Salomons and Froster, 1984). The mean concentration of Ni was recorded as 308  $\mu\text{g/g}$  and the range (111  $\mu\text{g/g}$  to 691  $\mu\text{g/g}$ ). In all stations Ni concentrations exceeded the recommended value 65.1  $\mu\text{g/g}$  (IAEA, 1990) of unpolluted sediments. Concentrations of Cr were varied from 1513  $\mu\text{g/g}$  (station-7) to 5301  $\mu\text{g/g}$  (station-15) among the affected sites with the average of 3250  $\mu\text{g/g}$ , whereas the recommended value of Cr was 77.20  $\mu\text{g/g}$  (IAEA, 1990). So, the concentration of Cr near the coal mine area was 42 times higher than the standard value. These higher concentrations could be due to waste disposal of the mine discharged from the coal mining activities.

The value of Cu varied from minimum 47  $\mu\text{g/g}$  (station-7, station-16) to maximum 332  $\mu\text{g/g}$  (station-1). The mean concentration of Cu in the present study was recorded as 80.7  $\mu\text{g/g}$ , which was significantly higher than the standard value 33.00  $\mu\text{g/g}$  (GESAMP, 1982). The concentration of Ti was always higher in all the stations compared to the other metals. Ti concentration in sediment of the affected areas varied from 7424-25098  $\mu\text{g/g}$ . Its mean value was 10546  $\mu\text{g/g}$  which was 28 times higher than the recommended value (374.432  $\mu\text{g/g}$ ) of unpolluted sediments (Akpan and Thompson, 2013).

This high level of Ti in the present study might be due to the runoff from coal mine.

The concentration of Zr was also always higher in all the stations ranging from 250  $\mu\text{g/g}$  (station-3) to 876  $\mu\text{g/g}$  (station-16).



The average value of Zr was 657  $\mu\text{g/g}$ , which was around 5 times higher than the value (134.581 $\mu\text{g/g}$ ) recommended by Akpan and Thompson, 2013.

The value of Rb, Y and Ba varied from 58  $\mu\text{g/g}$  to 226  $\mu\text{g/g}$ , 112  $\mu\text{g/g}$  to 483  $\mu\text{g/g}$ , and 430  $\mu\text{g/g}$  to 1621  $\mu\text{g/g}$ , respectively.

The mean concentration of Rb, Y, Zr and Ba were 158  $\mu\text{g/g}$ , 174  $\mu\text{g/g}$ , 657  $\mu\text{g/g}$  and 632  $\mu\text{g/g}$ , accordingly in the present study which revealed that the high concentrations of heavy metals around the coal mining area were happened may be due to the influence of untreated effluents discharged by various coal mining activities located in the area.

**Table 2.** The results of Enrichment Factor of some heavy metals of sediment samples of the Barapukuria Coal Mine area at Hamidpur union under Parbatipur Thana, Dinajpur.

Sample ID	Mn	Zn	Ni	Cr	Cu	Ti	Rb	Sr	Y	Zr	Ba
ss-1	1.24	5.74	3.25	14.22	2.19	2.07	0.84	0.75	5.30	1.73	1.38
ss-2	0.38	1.03	3.10	35.75	1.23	2.59	2.14	0.21	4.45	4.59	1.55
ss-3	0.83	1.07	0.69	9.62	0.71	1.61	0.30	0.48	1.92	0.70	N.D
ss-4	0.49	1.29	2.36	12.07	0.86	1.77	1.65	0.19	3.38	1.99	1.34
ss-5	0.73	1.28	3.13	12.58	1.11	1.72	1.47	0.19	4.56	2.50	1.33
ss-6	0.50	1.23	3.17	25.74	1.20	2.16	1.94	0.23	5.60	4.05	1.75
ss-7	0.39	1.12	1.81	15.83	0.89	2.63	2.26	0.23	5.64	3.92	1.70
ss-8	0.58	0.79	4.07	31.43	0.90	1.57	1.54	0.17	3.68	2.68	1.12
ss-9	0.52	1.50	1.98	54.36	1.21	2.48	1.88	0.25	6.53	6.88	3.52
ss-10	0.50	1.14	4.98	48.98	1.54	2.76	1.80	0.25	4.57	6.87	1.44
ss-11	0.51	1.42	1.79	51.87	0.98	2.19	1.51	0.22	4.17	4.95	1.44
ss-12	0.39	0.91	6.58	44.24	0.90	1.99	1.23	0.19	3.55	3.92	1.15
ss-13	0.60	1.07	7.79	57.95	1.70	2.75	1.90	0.27	6.01	6.03	1.40
ss-14	0.43	0.94	2.19	34.23	1.41	2.67	1.89	0.26	6.16	5.79	1.31
ss-15	0.44	0.65	7.32	42.09	0.92	1.56	1.12	0.17	3.51	3.70	N.D
ss-16	0.86	1.21	4.06	42.59	1.17	2.31	1.90	0.24	5.34	7.25	2.31
ss-17	0.68	1.06	1.93	23.48	1.28	1.71	1.77	0.24	4.16	2.18	1.02
ss-18	0.29	1.21	1.69	16.54	1.23	1.30	1.56	0.13	3.76	2.05	0.96
ss-19	0.62	0.87	5.74	20.14	0.97	1.65	1.44	0.14	4.21	2.68	1.16

#### Enrichment Factor

The enrichment factor (EF) is a suitable measure of geochemical trends which is used for making comparisons between areas and a value of unity denotes neither enrichment nor depletion relative to the Earth's crust (Sinex and Helz, 1981, Hasan *et al.*, 2013). The enrichment factor (EF) values were explained with support of the classification of Taylor, 1964.

The results of enrichment factor of some heavy metals of sediment samples of the Barapukuria coal mine area were shown in table 2.

According to Taylor (1964) classification, the EF value of Mn (except sample-1) and Sr were <1, indicated that the sediments of the Barapukuria Coal Mine area were not enriched by these metals.

**Table 3.** The Geo-accumulation Index Results of some heavy metals of the Barapukuria Coal Mine area at Hamidpur union under Parbatipur Thana, Dinajpur.

Sample Id	Fe	Mn	Zn	Ni	Cr	Cu	Ti	Rb	Sr	Y	Zr	Ba
ss-1	0.88	1.19	3.40	2.583	4.71	2.01	1.93	0.64	0.47	3.29	1.67	1.35
ss-2	-0.85	-2.25	-0.81	0.779	4.31	-0.56	0.52	0.25	-3.09	1.30	1.35	-0.22
ss-3	0.52	0.26	0.63	-0.019	3.79	0.03	1.21	-1.22	-0.55	1.47	0.01	N.D
ss-4	0.03	-1.01	0.39	1.263	3.62	-0.20	0.85	0.74	-2.37	1.78	1.02	0.44
ss-5	-0.06	-0.52	0.30	1.587	3.59	0.09	0.72	0.49	-2.48	2.13	1.27	0.35
ss-6	-0.57	-1.57	-0.27	1.099	4.12	-0.30	0.55	0.39	-2.71	1.92	1.45	0.24
ss-7	-0.65	-2.00	-0.49	0.209	3.33	-0.81	0.75	0.52	-2.78	1.85	1.32	0.12
ss-8	-0.20	-0.98	-0.54	1.830	4.78	-0.34	0.46	0.43	-2.76	1.68	1.23	-0.04
ss-9	-1.03	-1.98	-0.45	-0.046	4.73	-0.75	0.28	-0.12	-3.03	1.67	1.75	0.78
ss-10	-1.02	-2.03	-0.83	1.300	4.60	-0.39	0.45	-0.17	-3.01	1.18	1.76	-0.49
ss-11	-0.63	-1.61	-0.13	0.209	5.06	-0.67	0.50	-0.04	-2.83	1.43	1.67	-0.11
ss-12	-0.57	-1.92	-0.71	2.143	4.89	-0.72	0.42	-0.27	-2.99	1.25	1.40	-0.37
ss-13	-0.96	-1.70	-0.86	2.003	4.90	-0.20	0.50	-0.03	-2.85	1.63	1.63	-0.47
ss-14	-0.96	-2.17	-1.04	0.175	4.14	-0.46	0.46	-0.04	-2.89	1.67	1.57	-0.57
ss-15	-0.25	-1.43	-0.88	2.619	5.14	-0.37	0.39	-0.09	-2.81	1.56	1.63	N.D
ss-16	-1.04	-1.26	-0.76	0.987	4.38	-0.81	0.17	-0.11	-3.11	1.38	1.82	0.17
ss-17	-0.29	-0.86	-0.21	0.654	4.26	0.06	0.48	0.53	-2.34	1.76	0.83	-0.27
ss-18	0.02	-1.78	0.30	0.779	4.07	0.32	0.41	0.66	-2.97	1.93	1.06	-0.03
ss-19	-0.07	-0.77	-0.27	2.446	4.26	-0.12	0.64	0.45	-2.95	2.00	1.35	0.14

The EF value of all the stations for Ti, Rb (except sample-1 and 3) and Ba (except sample-9 and 18) were in 1-<3 (Minor enrichment). The EF values for Cu in eleven sediment samples were in 1-<3 (minor enrichment), but rest had no enrichment. These EF values for Cu revealed that the sediment samples were not enriched to minor enriched by Cu. Most of the sediment samples were enriched slightly (EF values within 1-<3) by Zn, although there had some evidence of no enrichment and an exception of moderately severe enrichment.

For the Ni metal the EF values varied mostly. The EF value for samples 12, 13, 15 and 19 were in 5-<10 (moderately severe enrichment); samples 1, 2, 5, 6, 8, 10 and 16 were in 3-<5 (moderate enrichment); samples-4, 7, 9, 11, 14, 17 and 18 were in 1-<3 (minor enrichment). So, the sediments of these samples were minor to moderately severe enriched by Ni metal. The Cr metal had also diverse EF values. The EF value of samples 9, 11 and 13 were in >50 (extremely severe enrichment); samples 2, 6, 8, 10, 12, 14, 15 and 16 are in 25-<50 (very severe enrichment); samples 1, 4, 5, 7, 17, 18 and 19 are in 10-<25 (severe enrichment).

These EF values indicated that the sediments of the Barapukuria Coal Mine area were severely to extremely severely enrich by Cr metal. The EF value of Zr metal in samples 9, 10, 13, 14 and 16 are in 5-<10 (moderately severe enrichment); samples 2, 6, 7, 11, 12 and 15 are in 3-<5 (moderate enrichment) and samples 1, 3, 4, 5, 8, 17, 18 and 19 are in 1-<3 (minor enrichment). This result showed that the sediments in these samples are minor to moderately severely enrich by Zr metal. The EF values for Y in most of the samples were in 3-<5 (moderate enrichment), except samples 1, 6, 7, 9, 13, 14 and 16 which were in 5-<10 (moderately severe enrichment). These EF values depict that the sediments samples were moderately enriched to moderately severe enriched by Y.

#### *The Geoaccumulation Index*

The geo-accumulation index (I<sub>geo</sub>) values were explained with support of the classification of Mullars (1981), which consists of seven grades or classes. The geo-accumulation index results and geo-accumulation index classes of some heavy metals of the Barapukuria coal mine area were displayed in table 3 and table 4, respectively.

The Igeo values of Cr in most of the sediment samples fell in class 5, but in some sediment samples these values also fell in class 4 and class 6. These Igeo values inferred that the sediments were heavily contaminated to extremely contaminated by Cr. The Igeo values of Ni varied largely among sediment

samples. The Igeo values for Ni mainly fell in class 3, class 2 and class 1, although in three stations there had an evidence of no contamination, which deduced that Ni uncontaminated or moderately to heavily accumulated in sediments around the coal mining area.

**Table 4.** The results of Geo-accumulation Index classes of some heavy metals of the Barapukuria Coal Mine area at Hamidpur union under Parbatipur Thana, Dinajpur.

Sample Id	Fe	Mn	Zn	Ni	Cr	Cu	Ti	Rb	Sr	Y	Zr	Ba
SS-1	1	2	4	3	5	3	2	1	1	4	2	2
SS-2	0	0	0	1	5	0	1	1	0	2	2	0
SS-3	1	1	1	0	4	1	2	0	0	2	1	N.D
SS-4	1	0	1	2	4	0	1	1	0	2	2	1
SS-5	0	0	1	2	4	1	1	1	0	3	2	1
SS-6	0	0	0	2	5	0	1	1	0	2	2	1
SS-7	0	0	0	1	4	0	1	1	0	2	2	1
SS-8	0	0	0	2	5	0	1	1	0	2	2	0
SS-9	0	0	0	0	5	0	1	0	0	2	2	1
SS-10	0	0	0	2	5	0	1	0	0	2	2	0
SS-11	0	0	0	0	6	0	1	0	0	2	2	0
SS-12	0	0	0	3	5	0	1	0	0	2	2	0
SS-13	0	0	0	3	5	0	1	0	0	2	2	0
SS-14	0	0	0	1	5	0	1	0	0	2	2	0
SS-15	0	0	0	3	6	0	1	0	0	2	2	N.D
SS-16	0	0	0	1	5	0	1	0	0	2	2	1
SS-17	0	0	0	1	5	1	1	1	0	2	1	0
SS-18	1	0	1	1	5	1	1	1	0	2	2	0
SS-19	0	0	0	3	5	0	1	1	0	3	2	1

These variations of Igeo values demonstrated that the source of Ni was not natural; it was anthropogenic, obviously due to mining activities of that area. For the Zr metal Igeo values fell mainly in class 2, but two sediment samples (SS-3 and SS-17) fell in class 1, which revealed that sediment samples were moderately contaminated by the metal Zr. Igeo values for Y fell in class 4 (SS-1), class 3 (SS-5 and SS-19) and rest of the samples fell in class 2, which indicated that Y moderately to heavily contaminated the sediments around Barapukuria coal mining area.

The Igeo values reveal that the values of Ti in all samples fell into class 1 (except SS-1 and SS-3), that

means sediments of the area were uncontaminated to moderately contaminated by the heavy metal Ti. The Igeo values for Zn and Cu in most of the sediment samples fell in class 0, but there were some evidences of moderate to heavy contamination by these metals.

The Igeo values for Fe, Mn, Rb, Sr and Ba fell into class 0 (uncontaminated) in most of the samples, except for Fe in sample 1, 3, 4 and 18 (fell in class 1); for Mn in sample 1 and 2 (fell in class 2 and 1, respectively); for Rb in sample 1, 2, 4, 5, 6, 7, 8, 17, 18 and 19 (fell in class 1); for Sr in sample 1 (fell in class 1); and for Ba in sample 1 (fell in class 2) but 4, 5, 6, 7, 9, 16 and 19 (fell in class 1).



This indicated that the sediments in these samples were uncontaminated to moderately contaminated by these metals.

#### *The potential contamination index*

The results of potential contamination index for heavy metals for sediment sample were listed in the table 5.

**Table 5.** The results of Potential Contamination Index of some heavy metals of the Barapukuria Coal Mine area at Hamidpur union under Parbatipur Thana, Dinajpur.

Sample Id	Fe	Mn	Zn	Ni	Cr	Cu	Ti	Rb	Sr	Y	Zr	Ba
ss-1	2.76	3.41	15.86	8.99	39.26	6.04	5.70	2.33	2.08	14.64	4.79	3.81
ss-2	0.83	0.32	0.86	2.57	29.68	1.02	2.15	1.78	0.18	3.70	3.81	1.29
ss-3	2.16	1.80	2.31	1.48	20.75	1.53	3.48	0.64	1.03	4.15	1.52	N.D
ss-4	1.53	0.75	1.97	3.60	18.42	1.31	2.70	2.51	0.29	5.15	3.04	2.04
ss-5	1.44	1.05	1.84	4.51	18.12	1.60	2.48	2.11	0.27	6.58	3.61	1.92
ss-6	1.01	0.51	1.24	3.21	26.06	1.22	2.19	1.97	0.23	5.67	4.10	1.77
ss-7	0.96	0.37	1.07	1.73	15.13	0.85	2.52	2.16	0.22	5.39	3.75	1.63
ss-8	1.31	0.76	1.03	5.33	41.17	1.18	2.06	2.02	0.22	4.82	3.52	1.46
ss-9	0.73	0.38	1.10	1.45	39.86	0.89	1.82	1.38	0.18	4.79	5.04	2.58
ss-10	0.74	0.37	0.84	3.69	36.34	1.15	2.05	1.33	0.19	3.39	5.10	1.07
ss-11	0.97	0.49	1.37	1.73	50.13	0.95	2.11	1.46	0.21	4.03	4.78	1.39
ss-12	1.01	0.40	0.91	6.63	44.58	0.91	2.01	1.24	0.19	3.58	3.95	1.16
ss-13	0.77	0.46	0.83	6.01	44.74	1.31	2.13	1.47	0.21	4.64	4.65	1.08
ss-14	0.77	0.33	0.73	1.69	26.43	1.09	2.06	1.46	0.20	4.76	4.47	1.01
ss-15	1.26	0.56	0.81	9.21	53.01	1.16	1.97	1.41	0.21	4.42	4.65	N.D
ss-16	0.73	0.63	0.89	2.97	31.17	0.85	1.69	1.39	0.17	3.91	5.31	1.69
ss-17	1.22	0.83	1.30	2.36	28.71	1.56	2.09	2.17	0.30	5.09	2.66	1.24
ss-18	1.53	0.44	1.84	2.57	25.23	1.87	1.99	2.38	0.19	5.73	3.13	1.47
ss-19	1.42	0.88	1.24	8.17	28.69	1.38	2.34	2.06	0.19	6.00	3.82	1.65

The metal that showed the highest contamination in all stations is Cr, which indicated very severe contamination (ranges from 15.13-53.01). The metals that showed the most extensive contamination were Ni (ranges from 1.45-9.21), Y (ranges from 3.39-14.64), Zr (ranges from 1.52-5.31), Ti (ranges from 1.69-5.70).

The heavy metals that showed the moderate contamination were Cu (ranges from 0.85-6.04), Zn (ranges from 0.73-15.86), Ba (ranges from 1.01-3.81), Rb (ranges from 0.64-2.51) and Fe (ranges from 0.73-2.76). The heavy metals that showed lowest contamination were Mn (ranges from 0.32-1.8) and Sr (ranges from 0.17-2.08).

#### **Conclusion**

Barapukuria Coal Mine is the first coal producing mine in Bangladesh but now a day, it has been a prominent source of pollution due to the mine water drainage and heavy metal leaching along the side of the mine area which often contains toxic and objectionable elements.

The levels of trace metals in the sediments of the study area have been compared with the recommended values of unpolluted sediments. Comparing the trace element concentrations of sediment samples with standard values it can be shown that the sediments around the Barapukuria Coal Mining area are polluted by Fe, Zn, Ni, Cr, Cu, Ti and Zr, which may be due to the influence of untreated effluents discharged by coal mine.

According to the enrichment factor values most of the sediment samples were very to extremely severely enriched by Cr, moderately severely enriched by Ni, moderate to moderately severely enrich by Zr, moderately enriched by Y and slightly enriched by Cu and Zn. The EF values of almost all the stations were enriched by Ti, Rb and Ba minorly. No enrichment was occurred by Mn and Sr metals in the sediments of the Barapukuria Coal Mining area, Dinajpur.

The results of the Igeo values for Cr in most of the sediment samples showed moderate to extreme contamination; Ni and Y revealed moderate to heavy contamination; Zr displayed moderate contamination; and Ti exhibited no contamination or moderate contamination in sediments around the Barapukuria Coal mining area, Dinajpur. Although the Igeo values for Zn and Cu in most of the sediment samples showed no contamination, but there were some evidences of moderate to heavy contamination by these metals. From the results of Igeo values it also can be seen that Fe, Mn, Rb, Sr and Ba uncontaminated to moderately contaminated the sediments of that area.

Potential contamination indices of the sediment samples indicated that Cr showed very severe contamination. The metals that showed the most extensive contamination were Ni, Y, Zr and Ti. The heavy metals that showed the moderate contamination were Cu, Zn, Ba, Rb and Fe. The heavy metals that showed the lowest contamination were Mn and Sr.

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