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Environmental Impact of Coal Mining: A Case Study on the Barapukuria Coal Mining Industry, Dinajpur, Bangladesh

[1]Harun-Or-Rashid, [2]Md. Sanower Hossain, [2]Zannat Urbi and [1]Md. Sirajul Islam

[1]Department of Environmental Science and Resource Management, Faculty of Life Science, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh
[2]Department of Biotechnology, Faculty of Science, International Islamic University Malaysia, Kuantan-25200, Pahang, Malaysia

Abstract: The study was performed on the Barapukuria coal mining project in northwestern Bangladesh to evaluate the impacts of coal mining on the surrounding environment specifically on soil and water. Coal potentially contributes to the development of economics of a country but coal mining deteriorates the environment by polluting air, water and soil. Besides this, it also impacts on the surrounding agricultural land that limits the production of crops. The analyses of coal, coal water and soil were carried out using standard methods. The findings of coal analysis indicate that the Barapukuria coal is under bituminous coal and it consists high energy values due to low amount of ash (12.04%) and moisture (2.83%) contents. The pH of coal water was found slightly acidic and available nutrients/heavy metal, organic carbon, exchangeable cations of coal water treated farmland soil suggest that coal mining changes the surrounding water and soil quality. Sulfur (0.64%) and ash content were found in the satisfactory concentration. However, there were no significant differences in trace metal content in sedimentation tank soil, coal water treated farmland soil and normal farmland soil.

Key words: Bangladesh · Environment · Fossil fuel · Heavy metal · Pollution and Trace element

INTRODUCTION

Coal is the most abundant fossil fuel on the earth [1] that comprises about 75% of the total fuel resources [2]. It contributes more than one third (39%) of total electricity production all over the world [3] as well as it is burned to generate heat or liquefied to produce gas and diesel fuel. However, effects of coal mining on the ecosystem cannot be overlooked though it contributes greatly to economic development of a country [4, 5]. The faulty mining operation is a cause of landscape damage, loss of forest, water pollution (both surface and ground) and air pollution that leads to huge deterioration of biological communities [6-9].

There are a total of five coal fields (Table 1) discovered yet in Bangladesh [10]. Out of them, only Barapukuria coal basin (Parbotipur, Dinajpur, Bangladesh) is the running coal mine where both the open pit method and underground mining method are practiced. This field was discovered by U.S. Geological Survey team in 1985 [11]. Structurally, it is a long, narrow and shallow Permo-carboniferous intracratonic rift basin [12]. The production capacity of this mine is one metric ton every year [10, 13]. Quality of the coal from Barapukuria meets the International Environmental Standards, i.e., low ash and extremely low Sulfur (S) [10, 14].

However, the 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 [15]. According to the Petrobangla (Bangladesh Petroliam Corporation), coal mining practices in the Barapukuria are the most hazardous practices in the world [11], which causes a serious threat to the regional ecology. The coal mines strata collapsing leads to land subsidence, destruction of local water resources, soil erosion, air pollution and decreasing biodiversity [16-18]. Heavy metal contamination to the soil due to coal

Corresponding Author: Md. Sanower Hossain, Department of Biotechnology, Faculty of Science, International Islamic University Malaysia, Kuantan-25200, Pahang, Malaysia.

Table 1: Coal reserves in Bangladesh [10].

No.	Place/Field	Discovery	Depth (Km)	Area (Hectare)	Proven Reserve (Million ton)
1	Jamalganj, Jaipurhat	1962	0.9-1.0	1600	1050
2	Barapukuria, Dinajpur	1985	0.118-0.509	668	390
3	Khalashpeer, Rangpur	1995	0.257-0.483	1200	143
4	Dighirpar, Dinajpur	1995	0.327	Yet unknown	200 (Partly proven)
5	Phulbari, Dinajpur	1997	0.15-0.24	3000	572

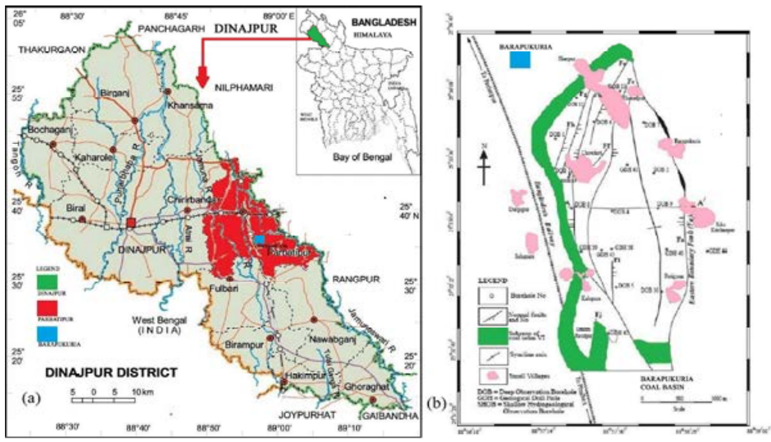

Fig 1: Geographical (a) and Structural patterns (b) of Barapukuria coal basin, Dinajpur, Bangladesh. Modified from Islam (2009) [12]; Kibria *et al*. (2012) [18].

Fig 2: Photographs of sample collections shown on [a] coal, [b] pond water, [c] coal mine drainage water, [d] coal water treated farmland soil and [e] normal farmland soil.

mine drainage as well as mining process is now threatening to the local agricultural economy [19, 20]. Hence, the present study was aimed at finding out the impact of the coal mining practices in Barapukuria on the local environment specifically on soil and water.

MATERIALS AND METHODS

Study Area: The study area is located at Barapukuria in Dinajpur district in Bangladesh. Regionally, it is in the Dinajpur Shield of Bangladesh; surrounded by the Himalayan foredeep to the north, Shillong Shield/Platform to the east and Indian Peninsular Shield to the west. Geographically, the study area lies between latitudes 25°31” N to 25°35” N and longitude 88°57” E to 88°59” E (Fig. 1).

Sample Collection: Coal, water and soil samples were collected from in and around the study area with three replicates for each (Fig. 2). Coal samples (Fig. 2a) were taken from six different coal beds of Barapukuria project. The coal samples were grounded for air dry in laboratory environment and preserved anterior to proximate analysis [21] in air tight polythene bags. Water samples were taken from three sources, pond water (PW) (Fig. 2b), ground water (GW) and coal mine drainage water (CMDW) (Fig. 2c) and were stored in plastic containers prior to analysis. Soil samples were collected from the sedimentation tank soil (STS), coal water treated farmland soil (CWTFS) and normal farmland soil (NFS) in and around the project area. The soil samples were placed on a paper for being air dried at room temperature. Visible roots and plants fragments were discarded. Then the soil samples were passed through a grinder individually and subsequently, a 2 mm stainless steel sieve. Finally, soil samples were kept in clean polythene bags for further analyses.

Laboratory Analyses: All the collected samples were tested for their physical and chemical properties following standard protocols. The laboratory investigations were done in the laboratory of Department of Environmental Science and Resource Management at Mawlana Bhashani Science and Technology University (MBSTU), Tangail and Soil Resource Development Institute (SRDI), Dinajpur, Bangladesh.

Coal samples were tested for percentage of moister, ash, Sulfur and volatile matter and then fixed carbon was estimated according to ASTM (2004) [21] standard procedure. A fixed amount of air dried coal was heated at 105°C for 3 hours in an oven to obtain percentage of moister (weight loss was considered). Same sample was further heated at 700°C for another 2 hours in a muffle furnace (JSMF-45T, South Korea) in order to obtain the percentage of ash. Percentage of ash was calculated from the weight difference before and after heating. Percentage of volatile matter was determined by subtracting the percentage of moister from the percentage of weight loss. For the determination of the sulfur content, gravimetric method had been done by analyzing the washing obtained from the oxygen-bomb calorimeter (IKA 8801800, India). Finally, fixed carbon content was calculated using the following formula:

Fixed carbon (FC) = 100 - (Moister % + Ash % + Volatile matter %)

The water samples were tested for the physical and chemical properties by applying Eaton *et al*. (2005 [22] standard protocols. The physical properties i.e., color; odor and temperature were tested during the sample collecting time. The pH of each samples were determined using pH meter (Corning pH meter 320). Electrical conductivity (EC) and total dissolved solids (TDS) were measured by Electric Conductance Method using TDS meter (TDS-EZ, HM Digital, USA). Dissolve oxygen (DO) level was determined by Winkler method. Then the samples were preserved with $FeCl_2$, $CaCl_2$, $MgSO_4$ and buffer for biochemical oxygen demand (BOD). BOD was analyzed by BOD_5 Bioassay method after five days of DO titration analysis.

Soil samples were analyzed for the chemical properties. The pH was determined by using soil pH and moisture meter (Takemura, DM-15, Japan) followed by Ross (1995) [23] method. Percentage of organic carbon (OC) was determined titrimetrically by Walkley and Black (1934) [24] method. Potassium (K) level was determined by ammonium acetate method [25] using Flame Photometer. The wavelength of emitted radiation was 766-770 nm. Calcium (Ca), Magnesium (Mg), Zinc (Zn), Cupper (Cu), Iron (Fe), Manganese (Mn), Cadmium (Cd) and Led (Pb) were determined by Soil Extraction Method [26] using Atomic Absorption Spectrometer (Analytik Jena AG-novAA300, Germany). Phosphorus (P) availability was estimated calorimetrically by Olsen's Method [27] using $SnCl_2$ as reluctant. Finally, Sulfur (S) was determined by Turbidimetric Method [28] using Spectrophotometer at 420 nm wave length.

RESULTS AND DISCUSSION

Properties of Coal Samples: The results are summarized in Table 2. Moister was found to be 2.83% in these samples and coal ash remains 12.04% after the combustion in specific condition. Coal from most of the countries showed higher moister and ash contents [29], but here the values were lower as compare to them. Typically the ash remainder ranges from 5% to 15%, some studies also reported more than 50% [30]. These two parameters were used to describe the energy value of the coal; the lower the percentages the higher the energy values. The ash remainder has no direct hazardous effect on the environment; however, S content has direct hazardous impact on the environment. For example, acid mine drainage (AMD) occurs in those mines where the S content is found in the range of 1-5% as Sulfur dioxide (SO_2) [29] and Pyrite (FeS_2) [4]. From our study, we have got only 0.64% S in the coal and we can say it is comparatively safe than as described by earlier researchers. In terms of volatile matter, it is the indicator of coking coal and usually varies from 8.8 to 45.5% by mass [31]. Fixed carbon is a measure of the solid combustible material that estimated after removing the volatile matter from coal. Hence, it is also used as an indicator of the yield of coke in the coking process.

Table 2: The properties of coal from Barapukuria coal mine.

Proximate	Amount (%)
Fixed carbon	56.31
Volatile matter	28.82
Ash	12.04
Moisture	2.83
Sulfur	0.64

Table 3: Chemical properties of water samples of Barapukuria study area.

Water source	pH	Temperature (°C)	EC (dS/m)	TDS	DO	BOD
				ppm		
CMDW	6.22	30.92	0.475	199	2.44	1.1
PW	6.73	31.35	0.355	188	4.3	2.14
GW	6.90	29.05	0.162	85	5.8	5

Properties of Water Samples: The results of different properties of water samples are listed in Table 3. The level of pH is the crucial factor in aqueous environment in order to survive aquatic organisms. The pH values of water samples recorded from 6.22 to 6.90, which are slightly acidic. Highly acidic runoff from coal affects pH balance of the surrounding water. This runoff is the ultimate results of rainfall or AMD. In our study, the pH value of CMDW was more acidic than those of GW. The temperature of water samples ranges from 29.05 to 31.35°C; where, the GW temperature was lower than those of the other two sources. The EC of the coal mine area measured and the EC value of CMDW was 1.34 times and 3 times greater than those of PW and GW, respectively. The pH and EC values have growth limiting effects on plants but it varies depending on the plant species [32].

TDS indicates the presence of different materials in water. It comprises of both colloidal and dissolved solids. In the natural water, dissolved solids are composed of mainly Na^+, K^+, Ca^{2+} and Mg^{2+}. The standard value of TDS is 500 ppm and our finding was 199 ppm, 188 ppm and 85 ppm for CMDW, PW and GW, respectively. Water that contains less than 500 ppm of dissolved solid is generally satisfactory for the domestic use and other industrial purposes. Water that contains more than 1000 ppm of dissolved solids usually contains minerals that give it a distinctive taste or make it unsuitable for human consumption [33]. The DO is the indicator of either the water is polluted or it supports aquatic plants and animals. Higher DO value indicates the better quality of water [34]. We found DO value ranges from 2.44 to 5.8 ppm in this study. The value of CMDW indicates the polluted condition of water and PW is more polluted compare to the GW.

The BOD is perhaps even more important than the determination of DO. It is not a specific pollutant, rather a measure of the amount of oxygen required by bacteria and other microorganisms engaged in stabilizing decomposable organic matter. A very low rate of use of oxygen is the indication of clean water. The standard value of BOD in water body is 6 ppm. The findings of BOD level in the study indicate that the CMDW highly impacts negatively on PW. The value of BOD in PW was 1.10 ppm where BOD of the mine drainage water and GW were 2.14 ppm and 5.00 ppm, respectively.

Properties of Soil Samples: The pH is an important indicator of ecological conditions of earthly environment. The STS, CWTFS and NFS were tested to evaluate the changes of physicochemical properties of soil. The results obtained from soil sample analysis are presented in Table 4. These results showed that the pH of soil in the study area varies from 5.8 to 6.78, which was slightly acidic in nature. The pH value of STS (6.78) was higher than that of coal water (6.60), CWTFS (6.26) and NFS (5.8). The relatively high pH of coal water over the coal (6.42) suggests that basic cations of some soils were dissolved in coal mine water keeping the high value of pH. The increasing pH of CWTFS is due to organic matter that modifies the pH of soil. However, coal water release more basic cations like Ca^{2+}, Mg^{2+} into the soil.

The total OC content in the STS, CWTFS and NFS was significantly lower than that of coal (85.95 to 97.22 % less). The NFS OC content was also significantly less than that of STS (78.19% less) and CWTFS (80.18% less). The biological activity and fertility of soil are enhanced by the OC and plant debris, dead root and rhizomes and surface litter or dead leaves that are the main source of

Table 4: Characteristics of soil samples.

Chemical Content	STS	CWTFS	NFS
pH	6.78	6.26	5.8
ppm			
OC	7.10	7.82	1.55
K	32.21	90.06	49.52
Ca	783.12	1560.31	964.55
Mg	103.36	240.73	185.09
P	9.08	11.10	6.16
S	59.97	220.19	30.78
Zn	3.85	12.01	3.89
Cu	1.49	5.67	2.33
Fe	6.39	39.87	15.19
Mn	50.22	160.34	20.79
Cd	0.26	0.12	0.09
Pb	0.78	0.48	0.85

OC of soil [8] OC content of NFS was increased by 80.18% after treating with coal water. Hence, coal may use as the alternative source of OC of soil and in this case coal contributes positive impact on terrestrial environment.

The K content of STS, CWTFS and NFS were 32.21 ppm, 90.06 ppm and 49.52 ppm, respectively. The availability of K of 100 ppm in soil is sufficient for plant growth [8]. The K content in CWTFS was significantly higher than that of the NFS. This indicates that K^+ was exchanged to NFS by coal water. The exchangeable basic cation Ca^{2+} was the highest (1560.31 ppm) in CWTFS whereas it was 964.55 ppm in NFS. However, Ca^{2+} was found significantly low (783.12 ppm) in STS. This Ca^{2+} passed from coal into soil using coal water as a transporter. The concentration of this cation was higher in CWTFS. In addition, soil pH depends on mineral and coal. The pH level of soil was increased by releasing Ca^{2+} and Mg^{2+} into the soil. The results of Mg^{2+} content among the soil samples varied widely. Mg^{2+} content of coal was very negligible whereas it was increased in coal water. After discharging, provisional deposition of coal water in STS increased the Mg content of the STS up to 103.36 ppm. The Mg^{2+} content of soil further increased over the coal, coal water, STS and NFS and it was highest in the CWTFS. The Mg^{2+} content of CWTFS was almost 23.11% higher than that of NFS. The available P content in STS, CWTFS and NFS were 9.08, 11.10 and 6.16 ppm, respectively. P plays an important role in the photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement and several other properties in the living plant [8]. The P content of coal, coal water and STS were 3.51, 0.334 and 9.08 ppm, respectively. This increasing P content in STS was possibly due to gradual deposition of P from coal water. The S content of STS, CWTFS and NFS showed strong variation among them. It has been mentioned in Table 2 that S content of coal was 0.64%. However, in the CWTFS the concentration of S was very high (220.19 ppm). The S content of NFS was also high (30.78 ppm). The S content of CWTFS was almost 7.15 times higher than that of the normal farmers' field soil.

There is no significant differences were noticed about the trace metal in the study site in the STS, CWTFS and NFS. The concentration of total metals such as Zn, Cu, Fe, Cd, Pb and Mn are shown in Table 4. The Mn was the highest concentration (50.22 ppm in STS, 160.34 ppm in CWTFS and 20.79 ppm in NFS). However, the lowest value was for Cd (0.26 ppm in STS, 0.12 ppm in CWTFS and 0.09 ppm in NFS).

CONCLUSIONS

The coal of Barapukuria is a good quality coal but the mining processes deteriorate the surrounding environment including air, water and soil especially agricultural fields. The polluted air of coal mining area can cause of high toxic of acid rain. The acidic pH may limit the growth of plants even death. The chemical properties of surrounding soil of coal mine, such as concentration of Ca, Mg, Pb, Fe, Cu, Zn etc is greatly increased by the mixing of coal water and greatly impacts on the farmer's field soil. These heavy metal contaminated soil may also halt the flora and fauna of the surrounding environment. In addition, the local people have experienced less production of common crops in the study area.

The coal mining processes dramatically alter the landscape and it is one of the most hazardous occupations. It may be the cause of many chronic health diseases including lung cancer, pulmonary tuberculosis and heart failure. Hence, people should be aware of the negative impacts or risks of mining activities on human health and CMDW must be running out after proper treatment of the water. The authority must develop the reusing process of the vast amount of CMDW to reduce the GW depletion or shortage during the dry season. However, exploring coal is a major concern for the policymaker of Bangladesh in relation to the balance pollution and safety of the environment. Further study needed to determine pollution levels of air and effect of coal mining on the health of coal miners and general people of surroundings.

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