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Water Quality of Coal Ash Pond and Its Impact on Adjoining Surface and Groundwater Systems

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Abstract This study was performed to know the quality of coal ash pond water of Barapukuria Thermal Power Plant (BTPP) and its impact on the surrounding surface and ground water systems. Three different types of water samples i.e., directly from coal ash pond, nearby surface water and groundwater system were investigated. Physico-chemical parameters [pH, EC, TDS, Turbidity, DO and BOD] and different heavy metals [Pb, Cr, Fe, Zn and Cu] of water samples were determined. The concentrations of heavy metals were found very high in the investigated area. The contamination level was measured through different water pollution indices such as heavy metal pollution index (HPI), heavy metal evaluation index (HEI), and degree of contamination (C_d). According to water quality standards of Bangladesh standard and International standards it was indicated that this water was highly polluted with regards to Pb, Cr, Fe, Zn and Cu. From this study it can be suggested that if necessary steps should not be taken in near future the heavy metal contamination of coal ash pond will be a serious threat to human and environment. This research will enhance the public awareness about heavy metal contamination.

Keywords: *coal ash pond, water quality standard, heavy metal pollution indices, thermal power plant*

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1. Introduction

Coal ash pond is a vital issue in thermal power plant. Generally, ash pond is an engineered structure for the disposal of bottom ash and fly ash. BTPP produces 300metric ton fly ash per day by burning 2,400 ton of coal to generate 250MW electricity [1]. Ash (bottom ash and fly ash) produced by combustion of coal in thermal power plant are dumped in coal ash pond. This ash is pumped to ash pond in the form of paste under high concentration slurry disposal or mixed with water in a ratio varying from 1: (8 to 20) [2]. As coal ash is the residue left from burning coal it contains contaminants such as lead, chromium, cadmium, zinc, iron, mercury and arsenic that can cause harm to environment. Heavy metals in fly ash fall down to soil and water bodies due to gravity after emission and ultimately uptake by standing plants and leached out to groundwater systems [3]. Coal ash ponds are toxic sources of dangerous pollutants that pose a danger to human and environmental health if the toxins spread to adjacent surface water and ground water. Environmental Protection Agency began overseeing the regulation of all ash ponds in order to establish national fly ash pond standards.

For evaluation of water pollution several methods such as the contamination index (C_d), the heavy metal pollution index (HPI) and the heavy metal evaluation index (HEI) were developed. These indices help assessing the present level of pollution in water resources and combine all the water pollution parameters into some easy approach [4,5,6]. The main objectives of this paper are:

- Characterization and determination of heavy metals concentration of water sample in study area.
- Comparison of water quality with the standards of Bangladesh and International Organization in respect to irrigation and drinking purpose.

2. Methodology

2.1. Study Area

The study area is coal ash pond water of Barapukuria Thermal Power Plant (BTPP) which is situated at the northern part of Bangladesh and adjoining surface and groundwater sources (shown in Figure 1). BTPP started its activity in the year 2006. The area of coal ash pond is 51 acre and its depth is 6.0 meter.

Figure 1. Location map of the study area

2.2. Sample Collection

Sample collection was performed during the time of June, 2016. Three different types of water samples were collected from the plant area, three from ash pond, three from fresh water pond and four samples from nearby tube-well. The GPS coordinates of the sampling site was recorded with the help of a GPS label of each sites are presented in Table 1. The water of coal ash pond (APW-1, APW-2 and APW-3) are reused for cooling purposes inside the plant. Pond (P-1, P-2 and P-3) water samples are used for aquaculture. Ground water (T-1, T-2, T-3) samples were collected from nearby villages and T-4 is 1.5km away from thermal power plant which is considered as background value or control.

Table 1. Sampling location with sample ID

No.	Sampling point	Coordinates	Sample ID
1.	Bottom ash water	25°33'10.78"N and 88°56'56.86"E	BW
2.	Fly ash water	25°33'7.89"N and 88°56'56.39"E	FW
3.	Ash pond water-1	25°33'1.97"N and 88°56'55.49"E	APW-1
4.	Ash pond water-2	25°32'54.14"N and 88°56'50.07"E	APW-2
5.	Ash pond water-3	25°32'58.70"N and 88°56'43.71"E	APW-3
6.	Pond water-1	25°33'5.39"N and 88°56'42.35"E	P-1
7.	Pond water-2	25°33'11.84"N and 88°56'42.20"E	P-2
8.	Pond water-3	25°33'11.97"N and 88°56'32.88"E	P-3
9.	Tube well water-1	25°33'15.02"N and 88°56'28.34"E	T-1
10.	Tube well water-2	25°33'20.09"N and 88°56'42.03"E	T-2
11.	Tube well water-3	25°33'20.54"N and 88°56'26.75"E	T-3
12.	Tube well water-4	25°32'49.65"N and 88°57'14.99"E	T-4

2.3. Chemical Analysis of Samples

The water Samples were collected in plastic bottles which were pre-conditioned with 5% nitric acid and rinsed with distilled water. Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured with portable meter equipped with membrane electrode (Model: HANNA HI 2300) while pH and Dissolved Oxygen (DO) were measured with bench top pH meter (Model: Jenway 3510) and DO meter (Model: HANNA HI 2400) respectively. BOD and Turbidity of water samples were measured with turbidity meter (Model: HANNA HI 93703) and BOD meter (Model: HANNA HI98193) respectively. Heavy metal analysis was performed by Atomic Absorption Spectrophotometer (AAS) (Model: Varian AA240). All the Chemical analysis of water samples were done in the laboratory of the Institute of Mining, Mineralogy and Metallurgy (IMMM), Bangladesh Council of Scientific and Industrial Research (BCSIR), Joypurhat.

2.4. Pollution Evaluation Indices

Pollution indices are estimated for a specific use of the water under consideration. The indices used in this study, namely heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d) are determined for the purpose of evaluating water pollution both drinking and agricultural use, where the formulas deal with the similar characteristics of heavy metals. The HPI and HEI methods provide an overall quality of the water with regard to heavy metals. On the other hand, in the C_d method, quality of water is evaluated by computation of the extent of contamination.

2.4.1. Heavy Metal Pollution Index (HPI)

The HPI method was developed by assigning a rating or weightage (Wi) for each chosen parameter and selecting the pollution parameter on which the index was to be based. The rating is an arbitrary value between zero and one and its selection reflects the relative importance of individual quality considerations. In this study, the concentration limit (i.e., the highest permissible value for drinking water, Si) is taken from the both for international (WHO and FAO) and Bangladesh standards [7,8,9,10]. The uppermost permissive value for drinking water (Si) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The HPI, assigning a rating or weightage (Wi) for each selected parameter, is determined using the expression below [11,12].

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

Where Q_i and W_i are the sub-index and unit weight of the i^{th} parameter, respectively, and n is the number of parameters considered.

$$W_i = \frac{k}{S_i}.$$

The sub-index (Q_i) is calculated by

$$Q_i = \frac{V_i}{S_i} \times 100$$

Where V_i, and S_i are the monitored heavy metal and standard values of the i^{th} parameter, respectively. While Prasad and Bose (2001) considered unit weightage (W_i) as a value inversely proportional to the maximum admissible concentration (MAC) of the corresponding parameter as proposed by Siegel, 2002 [13].

2.4.2. Heavy Metal Evaluation Index (HEI)

HEI, like the HPI, gives an overall quality of the water with respect to heavy metals [14], and is computed as:

$$HEI = \sum_{i=0}^{n} \frac{H_C}{H_{mac}}$$

Where H_c and H_{mac} are the monitored value and maximum admissible concentration (MAC) of the i^{th} parameter, respectively.

2.4.3. Degree of Contamination (C_d)

The contamination index (C_d) summarizes the combined effects of several quality parameters considered harmful to household water [15], and is calculated as follows:

$$C_d = \sum_{i=0}^{n} C_{fi}$$

Where,

$$C_f = \frac{C_{Ai}}{C_{Ni}} - 1$$

C_{fi}, C_{Ai} and C_{Ni} represent contamination factor, analytical value and upper permissible concentration of the i^{th} component, respectively, and N denotes the 'normative value'. Here, C_{Ni} is taken as MAC.

3. Results and Discussion

3.1. General Characteristics of Water

Some physico-chemical properties of water samples for studied area are summarized in Table 2. Lowest pH value was observed for FW which was situated inside the plant area and highest value was found in pond water (surface water) sample. Average pH of APW is 6.96. The pH value of water samples ranged from 4.4 to 8.6 which indicating acidic to slight alkaline nature of water. The highest EC value was found in FW while the EC of ash pond water ranges from 618 to 823µs/cm and in tube-well water was 139 to 231µs/cm. Considering EC values, BW and FW were not suitable for irrigation but rest of the water samples are suitable for irrigation [16].

Most turbid water was found in APW-2 while turbidity is not a problem for pond water & tube-well water. The result of TDS value followed the order: FA>APW-3> BW> APW-1> APW-2> T-1>P-3>P-2> T-3>T-4>T-2. Very low TDS values were found for tube-well water compared to pond water and APW. According to BMAC the entire water samples except tube-well water were highly turbid and too much turbid water is not suitable for aquatic flora and fauna because sunlight cannot pass through the turbid water.

Table 2. Physicochemical parameters of studied water samples

Sample ID	pH	EC (µs/cm)	Turbidity (FTU)	TDS (ppm)	DO (ppm)	BOD (ppm)
BW	7.3	696	499	344	5.3	65
FA	4.4	1062	478	527	5.4	33
APW-1	7.2	618	0.32	310	7.8	14
APW-2	7.3	588	1000	290	7.9	16
APW-3	6.4	823	4.99	407	5.6	20
P-1	7.1	120	12.16	61.9	7.2	9.0
P-2	8.6	196	22.13	104.4	6.2	9.8
P-3	8.6	204	51.0	107.8	4.4	10.0
T-1	6.8	231	1.89	113.5	4.3	6.9
T-2	7.0	139	0.00	70.3	4.2	7.9
T-3	7.1	195	0.00	97.6	6.7	8.3
T-4	7.1	166	0.00	82.5	5.0	8.1

DO and BOD are the most important parameter for aquatic life. DO of water samples ranges from 4.2 to 7.9ppm. It was noticed that ponds (P-1, P-2, & P-3) nearby ash pond were locally used for aquaculture. Based on Do value this water is between the BMAC range and somehow suitable for aquaculture (ECR, 1997) [10] but heavy metal contamination makes problem in fact. BOD values of water samples varied from 6.9 to 65 ppm. Higher BOD values were found in BW and FW. Lowest BOD value was found in T-1 which is used for drinking purpose. Though BOD values of ash pond water (APW) were not so high but after few years this BOD value can be increased because water of APW was reused regularly inside the plant.

3.2 Concentration of Heavy Metals in Water

Heavy metal concentrations of water sample were presented in Table 3. It was found that the concentration of all the investigated metals (Pb, Cr, Fe, Cu and Zn) was very high and water was highly contaminated with heavy metals. Pescod described some limit value of heavy metal when any effluent-contaminated water will be used for irrigation [17]. The results of heavy concentration are also compared with the permissible limit of drinking water by WHO [7]. All the surface water (APW-1,2,3 and P-1,2,3) of studied area were above the permissible limit of irrigation. Groundwater samples (T-1,2,3) were not between the permissible limit. Though T-4 point (1.5km away from BTPP) was taken as control or background, but higher concentration of Cr & Zn was found there. According to water quality standards set by Bangladesh Standard and international organization WHO (2011) [10], FAO (1972) [11], this water was not suitable for drinking and irrigation purposes.

Table 3. Concentration of heavy metal in water samples

Sample ID	Pb (ppm)	Cr (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)
BW	39.5	18.675	2163.5	58.6	517
FA	6	8.025	80.15	1.425	16.755
APW-1	3.5	8.55	74.375	0.625	4.87
APW-2	6	8.2	184.05	0.575	6.825
APW-3	20	14.275	1366.5	26.375	20.695
P-1	8	10.125	161.175	2.5	3.545
P-2	4.5	10.975	161.9	0.6	6.8
P-3	7.5	11.65	415	0.575	5.87
T-1	4.5	12.325	458.25	2.05	4.475
T-2	5.5	13.1	267.6	0.6	4.42
T-3	7	12.6	580.25	2.35	4.095
T-4	5.5	12.1	214.5	0.625	18.915
Irrigation standard (Pescod)	0.5	0.10	----	2.0	2.0
Drinking standard (WHO)	0.1	0.001	----	0.2	1.0

3.3. Pollution Evaluation Indices

The results of Water Pollution Indices are depicted in Table 4. The heavy metal pollution indices were computed using the Bangladesh Standard and international organization standard (WHO & FAO) were represented by HPIa and HPIb, and HPIc respectively. The value of HPIa, HPIb and HPIc for the water samples were varied from 1426.9-23.894, 31608.40-343555.15 and 5306.18-22326.2 respectively. Heavy metal evaluation index (HEI) was computed using Bangladesh standard and WHO standard where HEI values ranged from 394.11-10910.33 and 770.85-11736.8 respectively. The degree of contamination (Cd) [18] was used as a reference of estimating the extent of metal pollution. The values of Cd for water samples were based on WHO standard which ranged from 765.853-11730.8. However highest values of HPI, HEI and Cd were found for bottom ash water (BW) and APW-1 among three ash pond water.

Table 4. Water Pollution Indices

Sample ID	HPIa	HPIb	HPIc	HEIa	HEIb	Cd
BW	23894.2	343555.15	22326.2	10910.33	11736.8	11730.8
FA	1652.74	51626.401	5319.24	559	1033.96	1028.96
APW-1	1426.9	31608.40	5502.88	394.11	770.85	765.853
APW-2	1385.46	52611.47	5306.18	548.3	1380.06	1375.06
APW-3	11383.6	177907.83	13506.3	4758.48	6860.58	6855.59
P-1	2317.65	69134.378	6809.14	785.49	1542.18	1537.18
P-2	1771.39	41226.68	7049.41	554.07	1211.73	1208.13
P-3	1898.58	67869.99	7532.97	875.07	2368.58	2363.58
T-1	2499.15	44313.57	8197.35	1014.67	2226.52	2221.47
T-2	2080.52	50910.58	8408.99	714.33	1705.77	1702.17
T-3	2664.58	65628.13	8448.2	698.9	1148.71	2883.71
T-4	7793.51	50117.70	7793.51	692.4	1514.78	1511.16

HPIa based on Bangladesh standard; HPIb based on WHO standard; HPIc based on FAO standard; HEIa based on Bangladesh standard; HEIb based on WHO standard and Cd based on WHO standard.

Table 5. Categories of Pollution Indices

Index method	Category	Degree of contamination
Surface water		
HPI (International standard)	< 300	Low
	300-600	Medium
	> 600	High
HPI (Indian standard)	< 200	Low
	200-400	Medium
	> 400	High
HEI	< 150	Low
	150-300	Medium
	>300	High
Cd	<150	Low
	150-300	Medium
	>300	High
Ground water		
HPI (International standard)	<60	Low
	60-120	Medium
	>120	High
HPI (Indian standard)	<50	Low
	50-100	Medium
	>120	High
HEI	< 40	Low
	40-80	Medium
	> 80	High
Cd	<40	Low
	40-80	Medium
	>80	High

In this study, the existing contamination levels for HPI, HEI and Cd have also been categorized according to Bhuiyan et al [19] at Table 5. The HPIa, HPIc, HPId and Cd are consistent in showing that the bottom ash water, fly ash water, ash pond water and tubewell water samples fall in the categories of high contamination (Table 5) which suggesting that they are highly polluted.

4. Conclusion

The present study carried out to understand water quality of coal ash pond and its impact on the adjoining surface and groundwater systems.

i). Considering physicochemical parameters it can be said that samples of coal ash pond are not suitable for drinking and irrigation purposes. Apparently the nearby ponds and tube-well water are suitable for irrigation, unfit for drinking purposes; in fact due to heavy metal contamination these water are not usable.

ii). According to heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d) the water is highly contaminated with respect to Pb, Cr, Fe, Cu and Zn. This ground water pollution is directly related to the human health. Due to heavy metal contamination in drinking water negative result must be occurred. As a result there are some cancer like diseases i.e., Minamata, Arsenacosis, Itai-Itai can be outbreak at that locality.

iii). Therefore, proper attention is needed in this sector. If the following steps: Proper maintenance of coal ash pond, checking the overflow during rainy season, leaching can be restricted by concrete bottom floor, side wall should be higher than the surrounding agricultural field, plantation throughout the periphery of coal ash pond, etc. are carefully managed, the contamination in that area will be minimized.

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