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Research Article

Impact of Trans-boundary Coal Mines on Water Quality of Receiving Streams in North-eastern Bangladesh

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ABSTRACT

In the north-eastern part of Bangladesh, direct discharge of Acid Mine Drainage (AMD) from upstream Khashi hill areas of Meghalaya into trans-boundary Rivers causes huge losses of fish and crops. The purpose of this study is to investigate the impact of coal mines on water quality on the basis of physico-chemical parameters, such as temperature, pH, electrical conductivity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total dissolved solids, and heavy metals viz. Fe, Pb, Cr and Cd. For this purpose, a total of 15 samples were collected with 3 replications from 5 different locations of Jadukata River. The mean values of the analyzed parameters for 5 different sampling sites ranged: pH: 6.63-8.47; temperature: 25.77-26.8°C; EC 344.5-383.5 µS cm^{-1}; DO: 7.60-8.30 mg l^{-1}; TDS 337.33-454.33 ppm; BOD: 0.70-1.93 mg l^{-1}; COD: 1.20-2.30 mg l^{-1}; Fe: 0.69-0.86 mg l^{-1}; Pb: 0.05-0.07 mg l^{-1}; Cr: 0.04-0.06 mg l^{-1}. Analyzed results show that, most of the values of the considered parameters were higher at Lakmachara point, which is the nearest site to the Indian border and low at Rajargao, the farthest from the border. Almost all the values of Pb and Cr in different sampling points were higher than their permissible limits for drinking but, the values were within limit for irrigation activities. Other parameters were found within the permissible limit for drinking and irrigation usage. The gradual descending variations of the analyzed parameters from downstream to upstream were mostly due to the effect of AMD, which was mixed with the water of Jadukata River. Leaching of heavy metals near Khashi hill areas of Meghalaya at the upstream of Jadukata River are the major causes of contamination of the Jadukata River.

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Introduction

The Riverine systems of the world sustain the biosphere and strengthen the health and socio-economic well beings of the world's population. Many of these systems are shared by two or more nations. Many of these water bodies are threatened by run-off pollution from coal mining activities. Bangladesh is a Riverine country consisting of 405 Rivers where 57 are trans-boundary. Among them, 54 are common with India and remaining 3 with Myanmar (Joint River Commission, 2012). Jadukata River is a joint River, which starts from India and flows into Bangladesh from the Kalatek border (25°13′ 30.93′′N; 91°66′ 40.77′′E). It is from where a lot of natural coal is collected by the people living nearby the River, which come from coal mining at Meghalaya hills (The Financial Express, 2019). Acid Mine Drainage (AMD) from the coal mining makes the River water acidic and contaminated with heavy metals (Dhir, 2018). It could make vulnerable to the inhabitants living and working around the River who usually depend on the River for a variety of activities such as fishing, irrigation, drinking and washing (Islam et al., 2014a).

How surface water will be regarded in terms of quality is largely depends on its physico-chemical parameters (Ahammad et al., 2017). Presence of inorganic metals like Pb, Cr, Hg, Cu, As, Zn etc. in surface water severely degrade the water quality. Besides, various trace elements may find their way into the River water through coal mining and other industrial processes (Bhuiyan et al., 2011; Tiwary, 2001). Surface water, even with little contamination by trace elements, can have impact on biological integrity and the aquatic ecosystem (Howladar et al., 2017). Heavy metal accumulation can cause deterioration of River ecosystem (Yi et al., 2011) and thereby pose risk to the fishes (Islam et al., 2015) and human health (Islam et al., 2014b; Ahmed et al., 2015). Various consumption

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sectors such as livestock and irrigation are noticeably impacted by the polluted water (Howladar et al., 2014). The River water carrying AMD from coal mining can be toxic to humans, plants, and other aquatic life dealing with the water, directly and indirectly (Yi et al., 2011; Pond, 2010; Tiwary, 2001).

Toxic waste from Indian coal mines in trans-boundary Rivers severely damaged agriculture of Bangladesh in 2017 in the north-eastern districts. In 2015, the report of the Indian Central Pollution Control Board identified water of 38 Rivers of Meghalaya and Assam hazardous (Karar et al., 2017). The Indian scientists and scholars admitted the fact that most of the Rivers and streams from Meghalaya that flow towards south-east into the flood plains of Bangladesh is badly affected by contamination of AMD (da Silva et al., 2006; Lee and Lee, 2001). Even the 2015 report of central pollution control board of the Indian government under the Ministry of Environment, Forest and Climate Change identified that water quality criteria limit for 10 out of 19 Rivers of Meghalaya and 28 Rivers of Assam exceeds the permissible limit. Direct discharge of AMD into the Rivers is a threat to the quality of water for Rivers in Bangladesh that are trans-boundary and flowing from that areas. Indian scientists identified certain stretches of some trans-boundary Rivers that had been devoid of fish due to high toxicity of its water, resulting from direct discharge of AMD into water bodies in coal mining areas. Jadukata River receives coals as a trans-boundary River flowing from that area. The water of Jadukata River is being used for irrigation, fishing and habitat for aquatic life forms. The people living and working in and around the River also use the water for drinking purposes. As a result, rationally it needs to investigate the quality of the River water for recommending suitability of the water for various uses. It will also deliver messages to the policymakers to know the situation and take any necessary measures if needed. Therefore, the study was conducted to find out the impact of coal mines on the water quality of the Jadukata River in north-eastern Bangladesh.

Materials and Methods

Sampling sites

Jadukata River is a blue River at remote side of Sunamganj, Bangladesh. A total of five sampling sites were selected from the Jadukata River in the territory of Sunamganj district. The five sampling points S1, S2, S3, S4 and S5 are referred to as Lakmachara, Niladdri, Barirtila, LaurerGor and Rajargao, respectively (Figure 1). The River is a trans-boundary River and passing through the border between Bangladesh and the Indian state of Meghalaya.

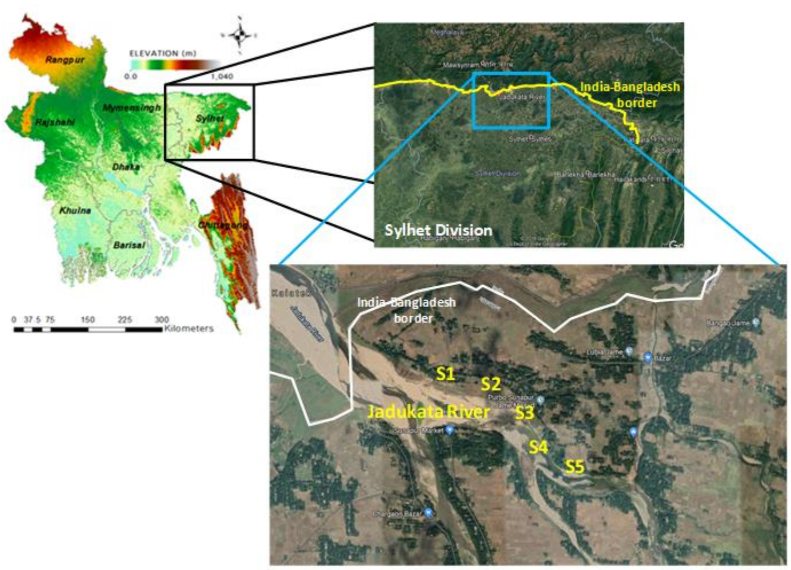

Figure 1. Study site and sampling points (S1 to S5) of Jadukata River

Sample collection and preservation

Water samples were collected in March 2021 with 3 replications from five different sampling points of Jadukata River. A total of 75 samples were collected following the sampling procedures as described by APHA (2012). Samples were collected in 250 ml white and transparent plastic bottles. The bottles were washed with laboratory detergent. 10% dilute nitric acid was used for removing organic matter from the sample bottles. Finally, the sample bottles were rinsed with distilled water prior to sample collection. Samples were collected from three depths viz. 0-30, 30-60 and

60-90 cm. After collection, plastic bottles were labeled by a marker and sealed immediately to avoid direct exposure to air. For heavy metals analysis, HNO_3 was mixed with the samples at the rate of 1 ml per 100 ml of sample to maintain the pH of the samples at about 1 and the sample bottles were kept at 4°C temperature in dark places until chemical analyses (JWA, 1993). In case of sample collection for analyzing BOD, precautions were taken to avoid formation of any bubbles within the sample bottles. The bottles were wrapped with black paper as soon as after collection to avoid sunlight exposure. Then 2 ml of manganous chloride were added followed by mixing 2 ml of sodium iodide-sodium hydroxide solution. Sample bottles were stored in dark places in the laboratory for incubation at 20°C for 5-day incubation period.

Sample analysis

Temperature, pH, EC, DO, TDS were measured on-site immediately after the collection of samples using respective portable meters. Temperature was measured using portable thermometer and the results were noted in notebook. A portable pH meter (Model: pH 10A) was used to measure pH of the samples. To measure EC, DO and TDS a portable multimeter (Model: EC 300A) was used. BOD was measured taking 100 ml sample by Winkler method in which Titration was performed through mixing reagents (sodium thiosulfate, starch solution) and continued until it reaches to the end points i.e. clear and colorless. After 5 days, the same procedures were performed to measure BOD through calculating following formula: BOD (mgL^{-1}) = DO (mgL^{-1}) of first bottle - DO (mgL^{-1}) of second bottle. COD was measured using titration method against 0.10M standard ferrous ammonium sulfate titrant until the solution turned into reddish brown from blue-green color. The determination of heavy metal concentration viz. Iron (Fe), Lead (Pb), Chromium (Cr) and Cadmium (Cd) in water samples was done by using an Atomic Absorption Spectrophotometer (AAS) (Model: Varian AA240). Cathode lamp with wavelengths 228.8, 357.9, 248.3 and 283.3 nm was used for analysis of Cd, Cr, Fe and Pb, respectively. The testing was done in the Bangladesh Council of Scientific and Industrial Research (BCSIR) Laboratory, Dhaka.

Results and Discussion

Temperature

The temperature of Jadukata River water varied with distances. Among the locations, the highest average temperature was found at Lakmachara (26.80°C), which was very close to the average temperature of the samples collected from Niladdri (26.60°C). The lowest temperature value was noted from the sample of Rajargao (25.77°C). The fluctuation in River water temperature usually depends on the season, geographic location, sampling time and temperature of effluents entering the River (Ahipathy and Puttaiah, 2006). Alam et al. (2007) reported that temperature of the Surma River varies from 18-24°C during dry season. Kabir et al. (2020) found temperature ranging from 20.2-28.2°C during winter season in Shitalakhya River. Similar results were reported by Bhuyain et al. (2020) with temperature between 24.1 to 26.3°C with mean 25.21°C during winter periods. The present results comply with the above mentioned results.

pH

The highest average pH was recorded as 8.47 at Rajargao and that of minimum 6.63 at Lakmachara. This results indicate that the pH in the upstream of the River was higher compared to the downstream. Ali et al. (2017) found higher pH in downstream site compared to the coal mine site. In contrast, alkaline pH in Shitalakhya River during winter was found, which might be discharge of industrial wastes containing salts as reported by Kabir et al. (2020). pH was found ranging from 6.5–8.0 and 7.5–8.0, respectively in comparatively less polluted Ramganga and its tributaries (Khan et al., 2016). It reveals that the lower pH of the Jadukata River might be due to the presence of AMD in higher concentration in upstream carrying from the hilly areas of Meghalaya. Standard limit of pH for drinking, fisheries and irrigation is 6.5-8.5, respectively set by the ECR (1997). The pH found in this study was within the standard limit.

Electrical conductivity (EC)

The average EC values ranged from 344.5-383.5 μScm^{-1} where the minimum and maximum value was found at LaurerGor and Niladdri, respectively (Table 1). This indicated that the River water had different quality at different locations. Usually, higher EC value indicates the presence of higher content of dissolved salts in River water (Abdullah and Musta, 1999). Bakali et al. (2014) analyzed the EC of Turag River and found the values within the range between 73-160 μScm^{-1}. On the other hand, according to the River Water Quality Report by the DoE (2016), EC value of the Surma and Kushiyara River varied from 132 to 295 μScm^{-1} and 185 to 221 μScm^{-1} with mean value 213.5 and 203 μScm^{-1}, respectively. In comparison the water of Jadukata River with Surma and Kushiyara River, it was observed that EC value of Jadukata River was much higher than Surma and Kushiyara River. The prescribed standard of EC of fresh water set by the ECR (1997) for irrigation is 2250 μScm^{-1}. Additionally, the standard values of EC of wastewater discharged from industrial units for releasing inland surface water and irrigation purposes are 1200 μScm^{-1}. There is no standard limit for EC found for drinking and fisheries purposes set by ECR (1997). As a consequence, it revealed that all the values of electrical conductivity (EC) were found suitable in terms of irrigation, fisheries and drinking purposes.

Total dissolved solids (TDS)

The mean concentrations for TDS of Jadukata River water were presented in Table 1. Average values of TDS of the water sample varied from 337.33 mgl^{-1} to 454.33 mgl^{-1}. Mean TDS concentrations were found higher in Brirtila, LaurerGor and Rajargao compared to the sampling point Lakmachara and Niladdri. Islam et al. (2012) observed that the TDS contents in the Dhaleshwari River water ranged from 190–224, 69–131, and 95–299 mgl^{-1} in pre-monsoon, monsoon, and post-monsoon season, respectively. Similar result was found by Alam et al. (2007) in Surma River in dry season with TDS concentration 139.3 mgl^{-1}. The present study shows higher concentration compared to the above mentioned Dhaleshwari and Surma River that may be the effect of acid mine drainage effect (Ali et al., 2017). The standard limits of TDS for drinking and irrigation are 1000 (ECR, 1997) and 2000 mgl^{-1} respectively (Ayers and Westcot, 1985). Besides, standard limits of TDS for wastewater from industrial setting for use in irrigation and discharging in inland surface water are 2100 mgl^{-1}. Hence, the reported results of the study demonstrate the suitability of the River water for irrigation and drinking purposes.

Table 1. Mean concentrations of water quality parameters in Jadukata River

Parameters	Unit	Concentration (Mean±SD)	Standards for Drinking (ECR, 1997)	Standards for fisheries (ECR, 1997)	Standards for irrigation		Standard for wastewater after treatment from Industrial units (ECR, 1997)	
					ECR, 1997	FAO[1]	Inland surface water	Irrigation
pH	-	7.3±0.91	6.5-8.5	6.5-8.5	6.5-8.5	6.0-8.5	6.0-9.0	6.0-9.0
Dissolved Oxygen (DO)	mgl^{-1}	7.94±0.29	6.0	5.0 or beyond	5.0 or beyond		4.5	8.0
Biological oxygen Demand (BOD_5)	mgl^{-1}	1.04±0.51	0.2; 2[a]	6.0	10.0		50	100
Chemical Oxygen Demand (COD)	mgl^{-1}	1.53±0.45	4.0				200	400
Electric Conductivity (EC)	μScm^{-1}	361.60±17.2			2250		1200	1200
Total Dissolved Solid (TDS)	mgl^{-1}	402.67±53.03	1000			2000	2100	2100
Chromium (Cr)	mgl^{-1}	0.053±0.03	0.05			0.1	0.5	1.0
Cadmium (Cd)	mgl^{-1}	0.0005±0.0001	0.005			0.01	0.05	0.5
Iron (Fe)	mgl^{-1}	0.41±0.3	0.03-1.0			5.0	2.0	2.0
Lead (Pb)	mgl^{-1}	0.04±0.02	0.05			5.0	0.1	0.1

a= Standards for inland water supplied for drinking purposes after disinfection

1= Ayers and Westcot, 1985

Dissolved oxygen (DO)

The mean dissolved oxygen concentration of Jadukata River water samples varied from 7.6 mgl^{-1} to 8.3 mgl^{-1}. The highest DO content was found at Lakmachara whereas the lowest was at LaurerGor. The mean DO value of Jadukata River water samples in various sampling points have been presented in Table 1. According to River Water Quality Report by DoE (2017), DO contents of the Surma and Kushiyara River varied from 5.03-7.2 and 6.2-6.7 mgl^{-1}, respectively. Analogous result was found by Bhuyain et al. (2020) in Surma River with a mean concentration of DO with 6.85 mgl^{-1} in winter season. In addition, Kabir et al. (2020) found DO within the range between 6.55-6.8 in Sitalakhya River in winter period. In comparison the water of Jadukata River with Surma, Kushiyara and Sitalakhya River, it was found that the DO concentrations of Jadukata River were higher than Surma, Kushiyara and Sitalakhya River. This may because of the agitation of Jadukata River water by the local people during their coal collection from the bottom of the River which came from the upstream mining sites. The standard limit set by ECR (1997) for drinking, irrigation and fisheries are 6.0, 5.0 and 5.0 mgl^{-1}, respectively. The results found from the present study complied with the standard.

Biological oxygen demand (BOD)

Mean values of BOD measured at various sampling points ranged from 0.70 to 1.93 mgl^{-1}. The highest concentration was reported at Lakamchara whereas the lowest was found at Rajargao. DoE (2017) found BOD in Teesta and Brahmaputra River ranged from 1.95 to7.5 and 1.0 to 2.2 mgl^{-1}. Similar result was found by Irin et al. (2017) with range 0.55 to 1.3 mgl^{-1} in Shitalakhya River. Coal contain high organic carbon content (Hasan et al., 2015) which may increase the BOD concentration of the River water. The coal found in Jadukata River is continuously harvested by the local people and because of that there is little chance of decomposition of that coal. As a result, BOD concentrations are more or less similar with other Rivers in spite of presence of coal. The standard limit of BOD set by ECR (1997) for drinking, irrigation and fisheries are 0.2, 6.0 and 10 mgl^{-1}, respectively. The BOD concentration of the Jadukata River was within the prescribed limit for irrigation and fisheries but not for drinking purposes.

Chemical oxygen demand (COD)

Mean values of COD varied from 1.2 to 2.3 mgl^{-1} (Table 1). The maximum value of COD was 2.3 mgl^{-1} observed at Lakmachara. Analyzed results show that, most of the values of COD were higher at sampling points nearest site to Indian border and lower at sampling points farthest from the border. Alam et al. (2007) found COD in Surma River in dry season 1.53 mgl^{-1} which is similar to the present study. The analyzed values for COD were within the standard limit prescribed by the ECR (1997) which are 4.0 mgl^{-1} for drinking purposes and 400 mgl^{-1} for wastewater discharge in irrigation purposes.

Heavy metals in Jadukata River

The mean concentrations of heavy metals like Fe, Pb and Cr were presented in Table 1. The Cd concentration in all the collected water samples were below the maximum permissible limit for drinking and irrigation set by ECR (1997) and Food and Agriculture Organization (FAO) as described by Ayers and Westcot (1985), and therefore, are not shown in this section. Mean concentrations of Fe were observed within the range between 0.69-0.86 mgl^{-1} with the highest concentration at Baritila (0.86 mgl^{-1}) and the lowest at Rajargao (0.69 mgl^{-1}). The average concentration of Pb ranged from 0.05-0.07 mgl^{-1} at different sampling points of the Jadukata River where maximum and minimum values were obtained at Lakmachara (0.07 mgl^{-1}) and Rajargao (0.05 mgl^{-1}), respectively. Islam et al. (2014a) found Pb in Buriganga River with 0.008 mgl^{-1} whereas Alam et al. (2007) reported Pb in Surma River in winter as 0.013 mgl^{-1}. In addition, Ali et al. (2016) found Pb in Karnaphuli River in winter as 0.017 mgl^{-1}. The Pb concentrations in various sampling points in Jadukata River showed higher trends in comparison with above-mentioned Buriganga, Surma and Karnaphuli River and that might be due to the effect of acid mine drainage in upstream of Jadukata River. In case of Cr, mean concentrations in Jadukata River varied between 0.04-0.06 mgl^{-1} with the highest concentration 0.06 mgl^{-1} at Lakmachara and the lowest concentration 0.04 mgl^{-1} at Rajargao. Alam et al. (2007) found Cr in Surma River in winter as 0.039 mgl^{-1}. Islam et al. (2019) also found mean concentration in different sampling points ranged between 0.013 to 0.019 mgl^{-1} in Surma River of Sunamganj district in dry periods. The highest values for all the heavy metal parameters were found at upstream sampling points and lower trends were observed towards the downstream sampling points.

The maximum allowed concentrations of Fe, Pb and Cr for the purposes of drinking set by the ECR (1997) are 0.03-1.0, 0.05 and 0.05 mgl^{-1}, respectively and for the purposes of irrigation set by the FAO as described by Ayers and Westcot (1985) are 5.0, 5.0 and 0.1 mgl^{-1}, respectively. The concentration of Fe of the present study was within the range prescribed by the ECR (1997) for drinking and irrigation purposes. Moreover, values of Cr crossed the standard limit in respect of drinking purposes in first three sampling sites from the upstream of Jadukata River but, in terms of irrigation the concentrations were within the standard. Similarly, the concentrations of Pb exceeded the standard limit for drinking in all the sample sites and were within the limit for irrigation activities.

Conclusion

The present study was conducted to assess the impact of acid mine drainage in upstream coal mines on water quality of Jadukata River. Almost all the analyzed parameters except Pd and Cr were within the standard limit for drinking. In case of irrigation activities, the concentrations of all the studied parameters were found within the permissible limit. The matter of concern that there was found an increasing trends of the water quality parameters towards the upstream of Jadukata River. This might be the fact of effect of acid mine drainage in the upstream areas. The concentration of these parameters could be raise to the concern level if the water of the River continuously exposed to the acid mine wastes. The water ecosystem and associated food chain could be interrupted for that reason. But, to be more confident, more elaborative and explicit study is needed. The study could be extended covering large portion of River areas in consideration for sampling with sediment analysis and other water quality parameters and heavy metals that are not analyzed in this experiment like total suspended solid, hardness, alkalinity, acidity, organic matter content, coliform, arsenic, copper, nickel, boron, manganese etc.

Authors contribution

MAF and MRI were developed the concept, designed the experiments and collected the samples. LA performed the laboratory test and contributed to record the data. MAF evaluated the result, analyzed data statistically and contributed to writing the manuscript. MAF, MRI, LA and MNU contributed to revising manuscript critically for important intellectual content. All authors read the article and approved the final version to be published.

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Competing interests

The authors have declared that no competing interests exist.

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