American Journal of Water Resources, 2017, Vol. 5, No. 5, 146-151
Available online at http://pubs.sciepub.com/ajwr/5/5/2

DOI:10.12691/ajwr-5-5-2

Evaluation of Heavy Metal Pollution Indices in Irrigation and Drinking Water Systems of Barapukuria Coal Mine Area, Bangladesh

Pradip Kumar Biswas[1,*], Nasir Uddin[2], Sha Alam[1], Tamjid-Us-Sakib[1], Sharmin Sultana[1], Tofayal Ahmed[2]

[1]Institute of Mining, Mineralogy and Metallurgy, BCSIR, Joypurhat, Bangladesh
[2]Department of PME, Jessore University of Science and Technology, Bangladesh
*Corresponding author: pradip_immm@yahoo.com

Abstract This paper discusses an integrated approach of pollution indices techniques to assess the intensity of heavy metal pollution in irrigation and drinking water systems discharged from coal mining in Bangladesh. Mn, Fe, Cd and Pb levels in most of the water samples exceed the Bangladesh and international standards. The heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d) schemes indicate that the mine drainage/irrigation waters and the adjoining groundwaters are highly contaminated. The groundwater system in the vicinity of the coal mine site is also heavily polluted by anthropogenic sources. The pollution status of irrigation and drinking water systems in the study area are of great environmental and health concerns.

Keywords: *heavy metal, heavy metal pollution index, heavy metal evaluation index, degree of contamination, Barapukuria coal mine*

Cite This Article: Pradip Kumar Biswas, Nasir Uddin, Sha Alam, Tamjid-Us-Sakib, Sharmin Sultana, and Tofayal Ahmed, "Evaluation of Heavy Metal Pollution Indices in Irrigation and Drinking Water Systems of Barapukuria Coal Mine Area, Bangladesh." *American Journal of Water Resources*, vol. 5, no. 5 (2017): 146-151. doi: 10.12691/ajwr-5-5-2.

1. Introduction

Pollution of water and soil due to discharged water is a major environmental concern worldwide. Barapukuria coal mine is the only one coal mine in Bangladesh. The problems of water quality are more severe in areas where the mining and mineral processes' industries are present. In mining processes, several classes of wastes are produced which may turn into ultimately the sources of water quality and environmental degradation. The discharge mine water through drainage system is generally used for irrigational purpose in the adjoining irrigation area. Coal mine water contains high concentrations of metals and metalloids that can create problem for surface water, ground water and top soils of mine water discharged area [1]. Metals from coal easily dissolve and mobilize into water and residue deposits [2]. The polluted water with metals make bad impact on aquatic life and the surroundings vegetation area of coal mine [3].

Today heavy metals pollution of the groundwater is one of the serious environmental problems. Some of the heavy metals considered as micronutrients can cause adverse effects to human health when their contents exceed the permissible limit in drinking water [4,5]. Thus, heavy metals assessment in groundwater used for drinking purpose is very significance from the human health viewpoint.

Heavy metals as an environmental pollutant, occurrence in waters from natural (such as chemical weathering of minerals and soil leaching) or anthropogenic sources (such as industrial and domestic effluents, urban storm, water runoff, landfill leachate, mining activities, atmospheric sources etc.). For evaluation of water quality 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 [6,7,8].

2. Study Area

The study area is covered the adjoining agricultural land and settlement area of Barapukuria Coal Mine Company Limited (BCMCL) at the northern part of Bangladesh (shown in Figure 1). The area lies between latitudes 25031' N to 25035' N and longitude 88057' E to 88059' respectively.

3. Methodology

3.1 Sample Collection and Analysis

Thirteen water samples, consisting of six from mine drainage and nearby wetlands prefixed drainage water (DW), six groundwater samples from irrigation pumps and hand-dug wells prefixed groundwater (GW) and 1 sample from coal mine subsidence areas (MSW-1) prefixed surface water (SW), during the time of January, 2016. Samples were collected in plastic bottles which were pre-conditioned with 5% nitric acid and rinsed with distilled water. The DW samples were collected from the outlet of mine. 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 type pH meter (Model: Jenway 3510) and DO meter (Model: HANNA HI 2400) respectively. The collected water samples were preserved in a refrigerator at 4°C for further elemental analysis. Heavy metal analysis was performed by Atomic Absorption Spectrophotometer (AAS) (Model: Varian AA240). All the Chemical analysis of water samples were performed in the Laboratory of the Institute of Mining, Mineralogy and Metallurgy (IMMM), Bangladesh Council of Scientific and Industrial Research (BCSIR), Joypurhat.

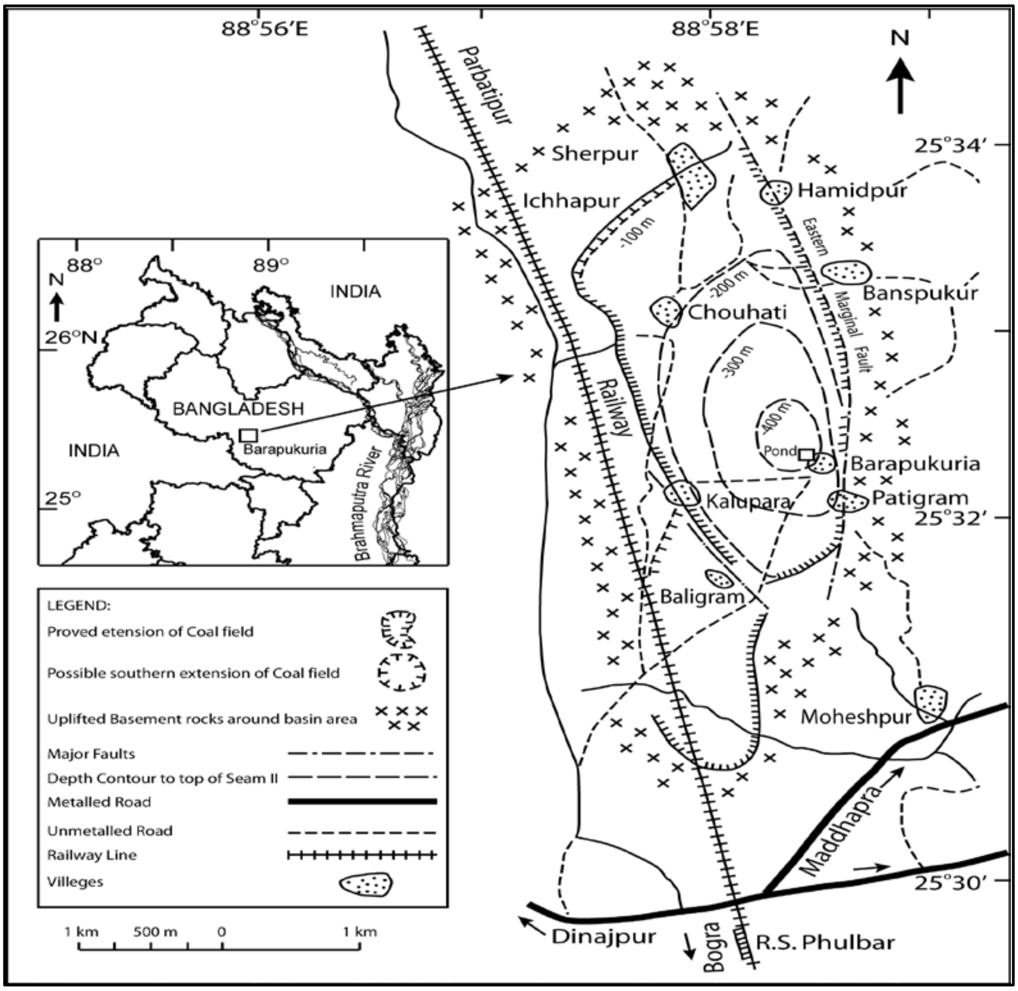

Figure 1. Location map of the study area [9]

3.2. Pollution Evaluation Indices

Usually, 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, the quality of water is evaluated by computation of the extent of contamination.

3.2.1. Heavy Metal Pollution Index

The HPI method was developed by assigning a rating or weightage (W_i) 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, S_i) is taken from the both international (WHO and FAO) and regional (Indian and Bangladesh) standards [10,11,12,13]. The uppermost permissive value for drinking water (S_i) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The HPI, assigning a rating or weightage (W_i) for each selected parameter, is determined using the expression below [14,15]:

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

Where Q_i and W_i are the sub-index and unit weight of the ith parameter, respectively, and n is the number of parameters considered.

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 ith parameter, respectively. While Prasad and Bose [7] considered unit weightage (W_i) as a value inversely proportional to the maximum admissible concentration (MAC) of the corresponding parameter as proposed by Siegel [16].

3.2.2. Heavy metal evaluation index

HEI, like the HPI, gives an overall quality of the water with respect to heavy metals [17], 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 ith parameter, respectively.

3.2.3. Degree of Contamination (C_d)

The contamination index (C_d) summarizes the combined effects of several quality parameters considered harmful to household water [18] 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 ith component, respectively and N denotes the 'normative value'. Here, C_{Ni} is taken as MAC.

4. Results and Discussion

4.1. General Characteristics of Water Quality

General characteristics of groundwater physicochemical parameters for the study area are summarized in Table 1. All the samples (n = 13) showed the pH values ranged from 6.5 and 7.5 with a mean value of 7.3 in drainage water and 6.7 in ground water, indicating acidic to slight alkaline in nature.

The EC was found higher in drainage water (335-339µs/cm) than ground water (149-246µs/cm) samples. Considering the EC values, this water is suitable for irrigation. A similar finding was found in a study of Sultana et al [19]. Total dissolved values of DW at all points cross the BMAC limit (100ppm). In case of ground water (GW-1, GW-4 and GW-6) three points was over BMAC limit.

Turbidity values of DW (116-45.3 FTU) were so high compare to BMAC limit value. According to maximum permissible limit of DO is 6mg/l. In this sense, DO values in both DW and GW were suitable for irrigation. One sample of mine subsidence area (MSW-1) showed similarity (DO, Turbidity) with ground water but have some exception in EC and TDS value.

Table 1. Physicochemical Parameters of Studied Water Samples.

Sample No.	pH	EC µs/cm	TDS ppm	DO mg/L	Turbidity FTU
DW-1	7.4	339	170	9.2	116
DW-2	7.2	336	168	9.8	64
DW-3	7.3	335	168	7.3	55
DW-4	7.1	338	169	7.4	45.3
DW-5	7.5	339	169	5.1	46.62
DW-6	7.5	336	168	9.6	60
Avg	7.3	337.2	168	8.1	64.5
GW-1	6.7	246.2	123	9.5	1.32
GW-2	6.9	149.3	74	2.9	4.52
GW-3	6.8	149.3	74.6	9.8	2.52
GW-4	6.6	211.2	105	9.7	6.1
GW-5	6.5	191.5	95.8	9.4	0
GW-6	6.8	216.6	108	9.8	2.49
Avg	6.7	194.0	97.0	8.5	2.8
MSW-1	7.3	56.3	28.1	9.8	2.81
BMAC	6.5-8.5	700[a]	1000	6	10

[a] FAO standard for irrigation water, BMAC (Bangladesh maximum admissible concentration, 1997).

The mean concentration of heavy metals is followed the descending order: Fe>Pb >Co>Mn>Cd>As. However, the mean value of Fe, Mn, Pb, Cd are higher than the water quality standards set by Bangladesh Standard (1997), Indian standard (2012) and international organization WHO (2011); FAO (1972). It is found that most of the groundwater samples showed the high concentrations of Fe, Pb , Mn, Co and Cd values in the study area.

Table 2. Concentration of heavy metal in water samples

Sample No.	Mn ppb	Fe ppb	Pb ppb	As ppb	Cd ppb	Co ppb
DW-1	192.6	2697	507	0.135	131.5	321
DW-2	191.8	2348	550.3	0.032	120	395
DW-3	181.6	2123	703.3	0	137.7	440
DW-4	225.4	2171	863.7	0.213	157.7	623
DW-5	860.8	2008	948.8	0	197.7	671
DW-6	117.4	1899	1037	0	160.8	778
Avg	294.9	2207	768.3	0.06	150.9	538
GW-1	163.7	1429	956.9	0	204.2	831
GW-2	101	4104	1027	0	175	844
GW-3	192.6	1243	857.5	0	236.1	851
GW-4	250.2	2634	663.3	0	146.5	505
GW-5	381.6	1850	701	0	168.5	480
GW-6	1969	2570	775.9	0	162.2	629
Avg	509.6	2305	830.2	0.00	182.08	690
MSW-1	24.7	101.1	796.2	0	201.2	691
BMAC	100	1000	50	50	10	-

4.2. Pollution Evaluation Indices

The results of pollution evaluation indices are shown in Table 3. The heavy metal pollution indexes was computed using the Indian Standard (2012), Bangladesh Standard, (1997) and international organization FAO (1972) and WHO (2011) standards and were represented by HPI^a and HPI^b, HPI^c and HPI^d respectively. The range and average values of HPI^a for the drainage water and groundwater samples were 987.24–1641.01 and 1262.52, and 1202.85-1876.20 and 1497.47 respectively. The range and average values of HPI^b for the drainage water and groundwater samples were 954.74–1618.95 and 1223.89, and 1164.22-1804.31 and 1461.07 respectively. The range and average values of HPI^c for the drainage water and groundwater samples were 1044.12–1731.92 and 1314.12, and 1448.32-2050.17 and 1589.00 respectively.

Table 3. Water Pollution Indices

S. Id.	HPI^a	HPI^b	HPI^c	HPI^d	C_d	HEI
DW-1	1055.21	1019.74	1143.81	3656.32	51.75	26.63
DW-2	987.24	954.74	1044.12	3498.72	59.52	25.99
DW-3	1152.07	1111.66	1197.27	4146.72	68.60	30.56
DW-4	1335.56	1289.59	1371.56	4856.92	92.01	35.97
DW-5	1641.02	1618.95	1731.92	5839.08	104.73	43.62
DW-6	1404.01	1348.64	1396.06	5241.14	110.99	39.11
Avg	1262.52	1223.89	1314.12	4539.82	81.27	33.65
GW-1	1682.60	1617.59	1773.13	5986.05	118.65	41.53
GW-2	1501.05	1440.40	1518.83	5519.75	120.88	42.48
GW-3	1876.20	1804.31	2050.17	6458.74	121.80	42.64
GW-4	1202.85	1164.22	1275.03	4255.01	75.89	31.38
GW-5	1366.21	1328.09	1468.49	4776.85	76.08	33.99
GW-6	1355.92	1411.81	1448.32	4789.26	97.86	40.87
Avg	1497.47	1461.07	1589.00	5297.61	101.86	38.81
MSW-1	1615.28	1545.07	1744.07	5623.28	99.40	36.23

HPI^a based on Indian standard; HPI^b based on Bangladesh standard; HPI^c based on International standard FAO; HPI^d based on International standard WHO.

In this study, the existing Contamination levels for HPI, HEI and C_d have also been categorized according to Bhuiyan et al [20] at Table 4. The HPI^a, HPI^c, HPI^d and C_d are consistent in showing that the drainage water, mine subsidence water and ground water samples fall in the categories of high contamination (Table 4).

The degree of contamination (C_d) [21] was used as a reference of estimating the extent of metal pollution. The range and mean values of C_d of the drainage water and groundwater samples were respectively 51.75–110.99 and 81.27, and 75.89–121.80 and 101.86, with about 50% of the samples falling below the mean values in both cases. C_d may be classified into three categories [17,18] as follows: low (C_d < 1), medium (C_d = 1–3) and high (C_d > 3). All the drainage water, groundwater and surface water samples have high C_d values (all analyzed samples exceed 3) suggesting that they are highly polluted.

Following the approach of Edet and Offiong [17] the values of HEI in the present study have been classified in terms of pollution levels as low, medium and high. Different HEI criteria values have been developed for surface water and groundwater, guided by their respective mean values, and the different levels of contamination are demarcated by a multiple of the mean values. HEI criteria for the surface and ground water samples using the scheme Bhuiyan et al. [20], surface water (drainage water and mine subsidence water) samples show low contamination, whereas groundwater samples GW-4 and GW-5 shows low and GW-1, 2, 3 and 6 are moderately contaminated.

Table 4. Categories of Pollution Indices Bhuiyan et al (2010)

Index method	Category	Degree of pollution
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
C_d	<150	Low
	150–300	Medium
	>300	High
Groundwater		
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
C_d	<40	Low
	40–80	Medium
	>80	High

4.3. Spatial Distribution Map

Geostatistical modeling for spatial distribution of the groundwater parameters has done by inverse distance weighting interpolation method; using Arc GIS (10.2 versions). The sample locations are shown in Figure 2.

Figure 2. Sample Location of the study area

The spatial map of HPI scores demonstrated a complex distribution pattern (Figure 3). The discrepancies were found along the mine drainage line of the study area. The spatial map of HPI values indicated that high values were observed in both side of the mine drainage water line. Poor quality water could be happened due to leaching of ions, over exploitation of groundwater, direct discharge of effluents from mine drainage and agricultural impact.

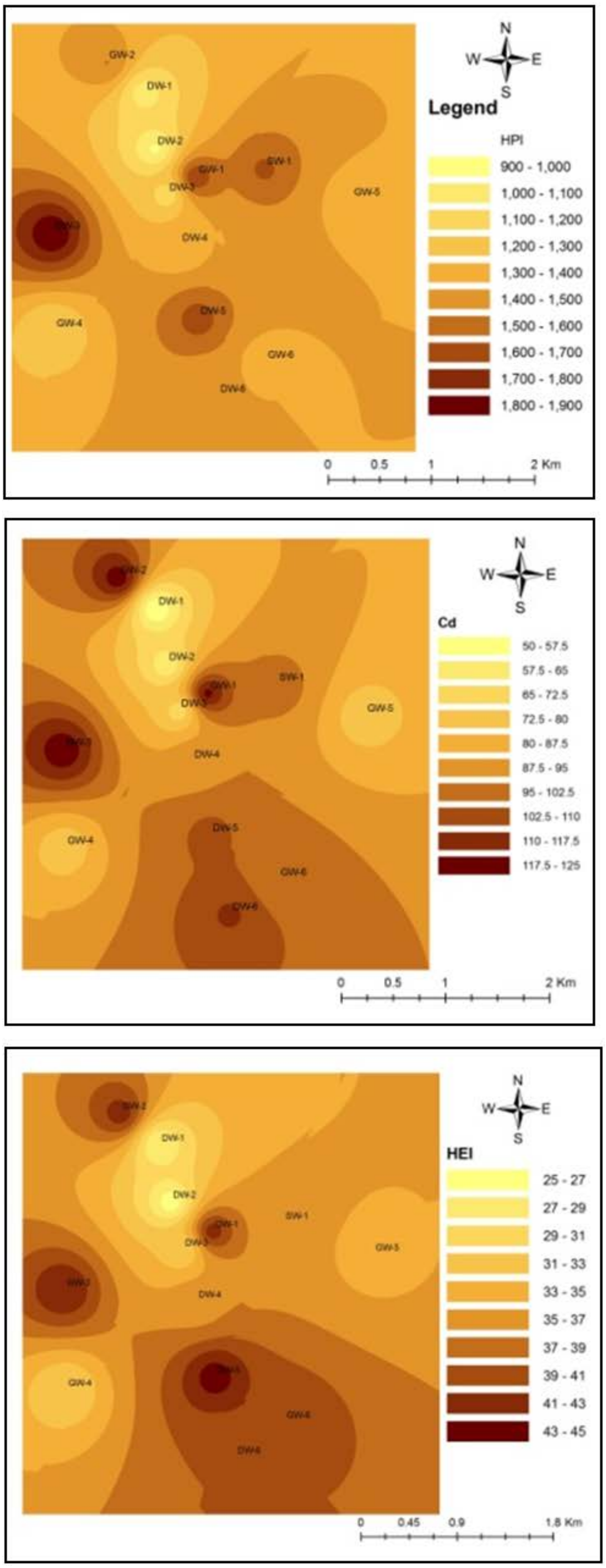

Figure 3. Maps showing the spatial distribution of three indices scores obtained by heavy metal pollution evaluation indices of the water samples: (a) HPI, (b) C_d , (c) HEI

The C_d and HEI exhibit more or less similar distribution patterns with an increasing trend in the southern direction, which suggested the existence of similar point sources. However, it has been suggested that anthropogenic sources are likely to be attributed the high scores of the HEI and C_d in the study area.

5 Conclusions

The study shows that the drainage water and ground water of surrounding areas of Barapukuria Coal Mine area exhibits high concentration of heavy metals like Cd, Pb, Mn and Fe. The contamination index C_d place water quality in high contamination level and heavy metal pollution index HPI on the other hand consider the level of contamination critical. The concentrations of the physicochemical parameters and heavy metals in most DW and GW samples exceed the Bangladesh and international standards. The possible source of these harmful elements (e.g., Mn, Co, Pb, Cd) released from mine effluent have a high potential of contaminating the important water reservoirs within and outside the mining area in the irrigation zone. Due to heavy metal contamination some diseases like Itai-Itai, Arsenicosis, and skin diseases can be occurred in that area. In fact, the contamination of the water systems by heavy metals poses serious threat to human health and ecological habitat in the study area, which therefore require attention.

Acknowledgements

The authors are indebted to the authorities of the Institute of Mining, Mineralogy and metallurgy (IMMM), Bangladesh Council of Science and Industrial Research (BCSIR), Joypurhat.

References

[1] Sultana, S., Biswas, P.K., Rahman, A., Sultana, S. and Zaman, M.N. Risk Factor Assessment of Coal Mine Drainage Water on Surrounding Agricultural Soil: A Case Study at Barapukuria in Bangladesh. *Journal of Geoscience and Environment Protection*, 4, 7-17. 2016.

[2] Akcil, A. and Koldas, S. Acid Mine Drainage (AMD) Causes, Treatment and Case Studies. *Journal of Cleaner Production*, 14, 1139-1145. 2006.

[3] Cherry, D.S., Currie, R.J., Souek, D.J., Latimer, H.A. and Trent, G.C.). An Integrative Assessment of a Watershed Impacted by Abandoned Mined Land Discharges. *Environmental Pollution*, 111, 377-388. 2001.

[4] Prasanna MV, Chitambaram S, Hameed AS, Srinivasamoorthy K. Hydrogeochemical analysis and evaluation of groundwater quality in the Gadilam river basin, Tamil Nadu, *India. J Earth Syst Sci*; 120(1): 85-98. 2011.

[5] Prasad B, Kumari P, Bano S, Kumari S. Ground water quality evaluation near mining area and development of heavy metal pollution index. *Appl Water Sci*; 4:11-7. 2014.

[6] Abdullah EJ. Quality assessment for Shatt Al-Arab River using heavy metal pollution index and metal index. *J Environ Earth Sci*; 3(5): 114-20. 2013.

[7] Prasad B, Bose JM.). Evaluation of the heavy metal pollution index for surface and spring water near a Limeston mining area of the lower Himalayas. *Environ Geol*; 41(1-2): 183-8. 2001.

[8] Maria-Alexandra H, Roman C, Ristoiu D, Popita G, Tanaselia C. Assessing of water quality pollution Indices for hevay metal

contamination. A study case from Medias City groundwaters. *Agric Sci Pract*; 3-4: 25-31. (2013).

[9] Armstrong, W. Techno-Feasibility Study of the Barapukuria Coal Project. Dinajpur, Bangladesh, Vol. 1. 1991.

[10] WHO, Guidelines for Drinking-Water Quality, 4th ed. World Health (WHO) Organization. 2011.

[11] FAO, Overall Study of the Messara Plain. Report on Study of the Water Resources and their Exploitation for Irrigation in Eastern Crete, , FAO Report No. AGL:SF/GRE/31. 1972.

[12] Indian Standard, Bureau of Indian Standards Drinking Water Specifications, BIS 10500:2012, New Delhi, India. 2012.

[13] Bangladesh Standard (DoE), The environment conservation rules 1997. Government of the People's Republic of Bangladesh, Dhaka. 1997.

[14] S.J. Reddy, Encyclopaedia of Environmental Pollution and Control, vol. 1, Environmental Media, Karlia, India, p. 342. 1995.

[15] S.V. Mohan, P. Nithila, S.J. Reddy, Estimation of heavy metal in drinking water and development of heavy metal pollution index, J. *Environ. Sci. Health* A31 283-289. 1996.

[16] Siegel F.R., Environmental geochemistry of potentially toxic metals. *Springer*-Verlag, Berlin. 2002.

[17] A.E. Edet, O.E. Offiong. Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (southeastern Nigeria), *GeoJournal* 57 295-304. 2002.

[18] B. Backman, D. Bodis, P. Lahermo, S. Rapant, T. Tarvainen. Application of a groundwater contamination index in Finland and Slovakia, *Environ. Geol*. 36 55-64. 1997.

[19] Sultana, S., Ahmed, A.N., Sultana, S., Biswas, P.K., Saha, B. and Alam, S. Assessment on Water Quality of Waste Water in Sugar Industry and Its Impact on Environment. *Open Access Library Journal* , 4: e3455. 2017.

[20] M. A. H. Bhuiyana, M.A. Islam, S.B. Dampare, L. Parvez, S. Suzukia, Evaluation of hazardous metal pollution in irrigation and drinking water systems in the vicinity of a coal mine area of northwestern Bangladesh, *Journal of Hazardous Materials* 179 1065-1077. 2010.

[21] M.Y. Al-Ami, S.M. Al-Nakib, N.M. Ritha, A.M. Nouri, A. Al-Assina, Water quality index applied to the classification and zoning of Al-Jaysh canal, Bagdad, Iraq, *J. Environ. Sci. Health* A 22 305-319. 1987.