Evaluation of Heavy Metals Pollution Index of Mine Water in East Bokaro Coalfield Region, Jharkhand, India

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Abstract: *Mine water is the major source of domestic water uses in East Bokaro Coalfield region of Jharkhand State. It is the most reliable source of domestic water supply in the area. Mining by its nature consumes as well as diverts water and in this process it may pollute the water resources of the nearby areas. In the present study, sixteen mine water samples were collected from open cast project (OCP), pit water and pumped out water during pre-monsoon and monsoon seasons. Samples were analyzed by using Inductively Coupled Plasma Mass Spectrometer for 12 heavy metals including Fe, Mn, Cu, Pb, Zn, Ni, As, Se, Cd, B, Al and Cr. The results show that concentrations of metals during both seasons such as Mn, Cu, Pb, Zn, Ni, As, Cd, Al, and Cr were well below the permissible limit for drinking water, simply the concentrations of Fe were above the permissible limit. Fe concentration varies from 118 to 566 µg L^{-1}.The highest concentration was recorded at location MW-7 (Kaveri, OCP pit water), while the lowest concentration was recorded in location MW-13 (Govindpur, OCP pit water) during pre- monsoon season. But during monsoon season, it varied between 129 to 613 µg L^{-1}. The highest concentrations were recorded at location MW-12 (Kathara, OCP Pit water) while the lowest concentration in location MW-6 (Amlo, OCP pit water). The data was used to calculate a heavy metal pollution index (HPI). The HPI value of the mine water was 15.2 and 7.3 during pre monsoon and monsoon season respectively. The HPI of mine water was found to be far below the critical index limit of 100 pointing to the fact that the mine water was not polluted with respect to heavy metals in spite of the prolific growth of mining and allied industrial activities. The HPI approach used here seems to be promising and is proved to be a useful tool in evaluating the overall pollution level of mine water in terms of heavy metals. The study recommends proper planning, treatment and management for better utilization of mine water in the region.*

Key words: Mine Water, Heavy Metal Pollution Index, East Bokaro Coalfield

1. Introduction:

Mine Water is the major source of domestic water uses in East Bokaro Coalfield region of Jharkhand State. It is the most reliable source of domestic water supply in the community. Mine Water has long been utilized as a readily accessible and stable source of water supply for domestic, industrial and agricultural use throughout the world [1]. Mining by its nature consumes as well as diverts water and in this process it may pollute the water resources of the nearby areas. During the mining operation, huge quantities of water were discharged from mine sumps and pits to provide working face and facilitate safe mining. Unscientific mining, improper mine water disposal and unsanitary conditions has threatened ,mine water quality and consequently human health in many parts of the world by naturally occurring pollutants and anthropogenic pollutants. Contamination of mine water with heavy metals (i.e., Iron, Manganese, Copper, Lead, Zinc, Nickel, Cobalt, Arsenic, Selenium, Cadmium, Boron, Aluminum, Strontium and Chromium) could come from several sources, including industrial discharges from coal washeries and mining activities [1]. Some of these metals have been reported to produce severe diseases like cancer, kidney failure, liver damage, and neurological and genetic malfunctions [2, 3, 4, 5]. Mining threatens the quality and quantity of surface and ground water resources in many parts of India [6, 7, 8, 9, 10, 11, 12, 13]. Mining's impacts on the natural water environment may be observed throughout the life cycle of a mine and even long after mine closure [14]. The potential impacts of mining on the water environment are: (a) disruption of hydrological pathways; (b) seepage of contaminated leachate into aquifers; (c) disposal of mine water, and (d) depression of the water table around the dewatered zone. Disposal of mine water is a worldwide problem, at both underground and opencast workings [15].

The quality of the mine water depends on a series of geological, hydrological and mining conditions, which vary significantly from mine to mine [14]. The discharged mine water varies greatly in the concentration of contaminants and in some cases it may even meet the drinking water specifications [12]. Many times, the discharged mine water as such is not usable and may contain unacceptable levels of heavy metals, toxic anions, organic and biological contaminants [7, 8].

Quality indices are a useful and relatively easy way to assess the composite influence of overall pollution. Quality indices make use of a reproducible series of judgments to compile the effects of all of the pollution parameters in to some easy approach. Several methods have been proposed to develop quality indices for evaluation of characteristics of water with water quality parameters. [16, 17, 18, 19, 20]. In recent years much attention has been given towards the evaluation of heavy metal pollution index in ground and surface water with development of heavy metal pollution index. Various researchers have used heavy metal pollution index for assessing the heavy metal pollution worldwide [21, 22, 23, 24, 25]. In the present study evaluates the heavy metals in mine water and development of heavy metal pollution index as a tool for assessing environmental condition of the study area.

2. Study area:

The East Bokaro Coalfield lies between $23^0\,45'$ N to $23^0\,50'$ N latitude and $85^0\,30'$ E to $86^0\,03'$ E longitude, This Coalfield located in the Bokaro district of Jharkhand, State covering an area of 237 sq. km. (Figure 1). The coalfield is serviced by the Barkakana- Gomoh section of the Eastern Railways passing in an East-West direction through the centre of the coalfield. The southern part of the coalfield possesses a gently undulating topography of the plains of the Damodar River and Bokaro River. In the Northern part, the compact and massive sandstone of lower Barakar have given rise to a comparatively rugged terrain. Lugu hill, the most prominent topographical landmark of the coalfield, rise to a height of almost 950 m. The coalfield is drained by three prominent rivers viz. the Bokaro River in the central part, the Konar River in the Eastern and the Damodar River in the Southern. The average temperature during summer season is 30°C while during the winter season is 20°C. During summer season, maximum temperature rises up to 44°C while in winter season, minimum temperature comes down to 2°C. Average rainfall is 1200 mm with the bulk of rainfall occurring around the July to September.

2.1. Geological Setup:

The East Bokaro coalfield contains a number of thick and thin, persistent regional Barakar as well as thin, interlarded regional Raniganj coal seams along with a continuous deposition from Talchir to Supra-Panchet formations. Besides, a few local seams also occur within both the coal measures. Scanty, scattered exposures of Talchir formation unconformably overlie the Basement rocks to the northeastern part of the coalfield around Chapri area and to the west of Gomia, in the north-western portion of the coalfield [26].The eastern part of the basin is occupied by Barakar formation whereas the crescent-shaped outcrops of the Barren Measures are exposed in the central and western portions. Successively overlying Raniganj and Panchet formations also follow the same crescentic pattern further towards west. Supra Panchet formation, occupying the higher elevation in Lugu hill at the western most part of this coalfield shows an angular unconformity with the underlying Panchet formation at the south eastern part of the Lugu hill. To the north and northwest, along the margin of the coalfield, the Barakar strata in the northern limb occurs as narrow, elongated, detached and faulted wedges / slices against the Basement rocks, Barren Measures and Panchet formations.

3. Material and Methods:

3.1. Sampling and Analysis:

For the analysis of metals, the samples were collected in pre-washed TARSONS container (capacity 100 ml), (Table 1) during pre-monsoon (May 2012) and monsoon (August 2012). Samples were filtered with Millipore filtration unit, filter paper (pore size 0.45µm) and preserved by adjusting the pH<2 with 6 N ultrapure nitric acid [27]. Appropriate quality assurance procedures and precautions were carried out to ensure reliability, and samples were carefully handled to avoid contamination. Glassware was properly cleaned and analytical grade reagents were used. Milli Q water was used throughout the study. The concentration of heavy metals in mine water samples was determined by ICP–MS (Make: Perkin Elmer, Model: ELAN DRCe).Reagent blank determinations were used to correct the instrument readings. For the accuracy of the analysis was checked by analysing reference standard of water (NIST 1640a and NIST 1643b). The precision obtained in most cases was better than 5% RSD with comparable accuracy.

3.2. Indexing Approach:

The proposed HPI was developed by assigning a rating or weightage (W_i) for each selected parameter. The rating is a value between zero and one, reflecting the relative importance of individual quality considerations, and can be defined as inversely proportional to the recommended standard (S_i) for each parameter [16, 24, 28]. For this study, the concentration limits [i.e. highest permissive value for drinking water (S_i) and maximum desirable value (Ii) for each parameter] were taken from the Indian drinking water specifications [29, 30]. The highest permissive value for drinking water (S_i) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The desirable maximum value (I_i) indicates the standard limits for the same parameters in drinking water.

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

Where, Q_i is the sub index of the i^{th} parameter, W_i is the unit weightage of i^{th} parameter, and n is the number of parameters considered. The sub index (Q_i) of the parameter is calculated by

$$Q_i = \sum_{i=1}^{n} \frac{[M_i - I_i]}{[S_i - I_i]} \times 100 (2)$$

Where, M_i is the monitored value of heavy metal of i^{th} parameter, I_i is the ideal value of i^{th} parameter, and S_i is the standard value of the i^{th} parameter, in ppb. Generally, the critical pollution index value is 100.

4. Results and discussion:

The level of the detected heavy metal constituents during pre-monsoon season and monsoon season in mine water samples shows that in all the sampling locations of the study area.

The concentration of 12 heavy metals analyzed in 16 mine water samples collected from different mines of East Bokaro coalfield region. With a few exceptions, heavy metal concentrations did not exceed the permissible limits specified by the World Health Organization [30] and Indian Drinking Water Standards [29] during both seasons. However, concentrations of Fe were above the desirable limit of the [30] and Indian Drinking Water Standard [29] at 7 locations (i.e., MW-2-4, 7, 9, 10 &11) during pre-monsoon season while at 6 locations (i.e., MW-2, 7-9, 11 &12) during monsoon season. The amount of Fe ranged from 118.2 to 566.5 and 129 to 613 µg L^{-1}, exceeding the desirable limit of 300 µg L^{-1} in 37.5 % and 43.8% during pre-monsoon and monsoon season respectively. However, it was below the maximum permissible limit of 1,000 µg L^{-1} [29]. Concentration of Mn was varied between 0.9 to 23.6 µg L^{-1} (avg. 4.2 µg L^{-1}) in pre-monsoon season and 0.08 to 26.2 µg L^{-1} (avg. 4.9 µg L^{-1}) in monsoon season, within the permissible limit of 500 µg L^{-1}in all mine water samples. Concentration of Cu ranged from 1.13 to 8.8 µg L^{-1} (avg. 2.5 µg L^{-1}) during pre-monsoon season while during 0.13 to 2.84µg L^{-1} (avg. 1.14 µg L^{-1}). Pb detected ranged from 0.01 to 0.88 µg L^{-1} and 0.05 to 0.37 µg L^{-1} during pre-monsoon and monsoon seasons respectively, well below the Indian permissible limit of 50 µg L^{-1}.The concentration of Zn and Ni is within the limit. The amount of highly toxic metals, such as Cd, As, and Se, was also found to be well within the specified limit of Indian Drinking Water Standards in both seasons [29]. Boron concentrations ranged from 9.1 to 20.6 µg L^{-1} (avg. 16.4 µg L^{-1}), and 8.9 to32.8 µg L^{-1} (avg. 16.9 µg L^{-1}), below the drinking water desirable limit of 300 µg L^{-1}. Concentrations of other measured metals in majority of the mine water samples were found well below the desirable/ permissible levels recommended for the drinking water. The water that contained higher concentrations of Fe would require treatment before domestic and irrigation use. The HPI was determined by taking the mean concentration value of the selected metals, using Equation 1. The detailed calculation of the HPI with unit weightage (W_i) and standard permissible values (S_i) are presented for the mine water of both seasons (Table 2). In the HPI came out to be 15.2 and 7.3 during pre monsoon and monsoon season respectively, which is below the critical value of 100. This indicates that, in general, the mine water is not critically contaminated with respect to heavy metals. This indicates that the mine water of the study area was likely contaminated with metals. The HPI values of each sampling locations was also calculated separately (Figure 2, Table 3). The HPI of all of the mine water was below during both seasons, the critical index value of 100.

5. Conclusions:

The analyses of heavy metals in mine water around various locations of the East Bokaro Coalfield region. It was important for establishing a baseline characterization prior to the start of coal mining, considering present status of metals concentrations in mine pit water and pumped out water. We find that concentrations of metals are generally less than permissible drinking water levels except for Fe, which were above the permissible limits at some locations during both seasons. The elevated level of Fe is a natural occurrence in the area because of mineralization and background rock geochemistry. The HPI used in our study proved to be a very useful tool in evaluating the overall pollution level of mine water in terms of metals. The mean HPI values for mine water of study area were well below the maximum threshold value of 100. In addition, none of the individual locations in any seasons exceeded the maximum threshold value. These observations show that the mine water is not polluted with metals despite natural mineralization, coal mining, and other allied activities in the area.

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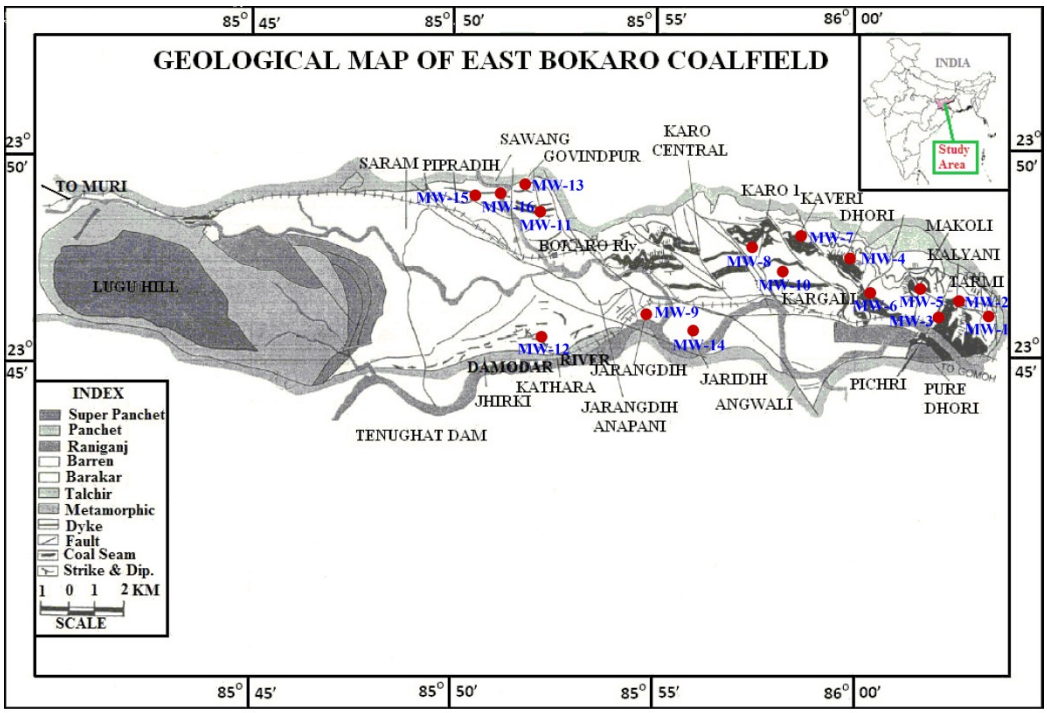


Figure 1: *Location map including sampling sites of the study area*

Figure 2: *Site specific HPI values for mine water in the East Bokaro Coalfield region*

S No.	S Code	Sampling Site	Water Type	Latitude (N)	Longitude (E)
1	MW-1	Tarami Open Cast Project	Pit Water	23º45’42.8’’	86º03’05.9’’
2	MW-2	Kalyani Open Cast Project	Pit Water	23º45’40.8’’	86º02’03.1’’
3	MW-3	Kari Pani Open Cast Project	Pit Water	23º46’34.1’’	86º02’12.2’’
4	MW-4	Dhori Open Cast Project	Pit Water	23º46’13.1’’	86º00’29.8’’
5	MW-5	Makoli Central Open Cast Project	Pit Water	23º46’56.7’’	86º01’13.7’’
6	MW-6	Amlo Open Cast Project	Pit Water	23º46’34.3’’	86º00’08.5’’
7	MW-7	Kaveri Open Cast Project	Pit Water	23º47’28.5’’	85º58’23.5’’
8	MW-8	Khas Mahal Open Cast Project	Pit Water	23º47’00.4’’	85º55’10.3’’
9	MW-9	Jarangdih U/G	Pump water	23º46’00.3’’	85º54’22.5’’
10	MW-10	Kargali Open Cast Project	Pit Water	23º46’22.1’’	85º58’53.5’’
11	MW-11	Govindpur U/G	Pump Water	23º47’21.9’’	85º52’29.4’’
12	MW-12	Kathara Open Cast Project	Pit Water	23º45’46.7’’	85º51’32.6’’
13	MW-13	Govindpur Open Cast Project	Pit Water	23º48’10.0’’	85º51’24.6’’
14	MW-14	Jarangdih Open Cast Project	Pit Water	23º46’13.8’’	85º54’23.0’’
15	MW-15	Swang U/G	Pump Water	23º47’52.5’’	85º50’54.6’’
16	MW-16	Swang Open Cast Project	Pit Water	23º47’59.8’’	85º51’03.0’’

Table 1*: Details of mine water sampling location along with their latitude and longitude*

Heavy metals	Minimum (µg L^{-1})	Maximum (µg L^{-1})	Mean concentration (M_i) (µg L^{-1})	Highest permitted value for drinking water (S_i)	Desirable maximum value (I_i)	Unit weightage (W_i)	Sub-index (Q_i)	$W_i \times Q_i$
Fe	118	566	285	1000	300	0.001	2.181	0.002
Mn	0.92	23.63	4.91	300	100	0.003	47.546	0.158
Cu	1.12	8.81	2.52	1500	50	0.001	3.274	0.002
Pb	0.01	0.88	0.27	50	-	0.020	0.549	0.011
Zn	1.97	84.16	12.57	15000	5000	0.000	49.773	0.003
Ni	2.13	10.41	6.40	70	-	0.014	9.140	0.131
As	0.12	0.43	0.30	50	-	0.020	0.590	0.012
Se	2.43	6.54	3.58	10	-	0.100	35.788	3.579
Cd	0.03	0.71	0.16	10	-	0.100	1.598	0.160
B	9.10	20.61	16.36	5000	1000	0.000	24.598	0.005
Al	3.44	52.64	19.67	200	30	0.005	6.076	0.030
Cr	1.09	12.12	5.47	50	-	0.020	10.949	0.219

Table 2: *HPI calculations for mine water of the study area during pre-monsoon season (May 2012), based on drinking water standards*

$\Sigma W_i = 0.2846$
$\Sigma W_i \times Q_i = 4.312$

HPI Value = 15.2

Table 3: *HPI calculations for Mine water of the study area during monsoon season (August 2012), based on drinking water standards*

Heavy metals	Minimum ($\mu g\ L^{-1}$)	Maximum ($\mu g\ L^{-1}$)	Mean Concentration (M_i) ($\mu g\ L^{-1}$)	Highest permitted value for drinking water (S_i)	Desirable maximum value (I_i)	Unit Weightage (W_i)	Sub index (Q_i)	$W_i \times Q_i$
Fe	129	613	308	1000	300	0.001	0.265	0.000
Mn	0.08	26.15	12.96	300	100	0.003	44.397	0.148
Cu	0.13	2.84	1.14	1500	50	0.001	3.388	0.002
Pb	0.05	0.37	0.16	50	-	0.020	0.311	0.006
Zn	0.92	29.87	6.60	15000	5000	0.000	49.890	0.003
Ni	1.37	28.13	8.10	70	-	0.014	32.554	0.465
As	0.08	0.87	0.26	50	-	0.020	0.519	0.010
Se	0.21	4.61	1.42	10	-	0.100	14.180	1.418
Cd	0.01	0.71	0.20	10	-	0.100	2.022	0.202
B	8.97	32.86	16.91	5000	1000	0.000	24.629	0.005
Al	2.64	44.75	11.82	200	30	0.005	10.694	0.053
Cr	0.53	2.45	0.95	50	-	0.020	1.909	0.038

$\Sigma W_i = 0.2845$
$\Sigma W_i \times Q_i = 2.065$

HPI Value = 7.3