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Evaluation of Surface Water Quality by Using GIS and a Heavy Metal Pollution Index (HPI) Model in a Coal Mining Area, India

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Abstract Twenty eight surface water samples were collected from fourteen sites of the West Bokaro coalfield, India. The concentration of Mn, Cu, Zn, Ni, As, Se, Al, Cr, Ba, and Fe were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) for determination of seasonal fluctuations and a heavy metal pollution index (HPI). The HPI values were below the critical pollution index value of 100. Metal concentrations were higher in the pre-monsoon season as compared to the post-monsoon season. The Zn, Ni, Mn, As, Se, Al, Ba, Cu, and Cr concentrations did not exceed the desirable limits for drinking water in either season. However, at many sites, concentrations of Fe were above the desirable limit of the WHO (2006) and Indian drinking water standard (BIS 2003) in both seasons. The water that contained higher concentrations of Fe would require treatment before domestic use.

Keywords West Bokaro coalfield · Metals · Seasonal fluctuation · *t* test · HPI · GIS

Access to safe drinking water remains an urgent necessity, as 30 % of the urban and 90 % of the rural Indian population still depend completely on untreated surface or groundwater resources (Kumar et al. 2005). Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari and Singh 2014). The presence of heavy metals in both surface and groundwater supplies is a major environmental problem. The occurrence of toxic metals in pond, ditch and river water affect the lives of local people that depend upon these water sources for their daily requirements (Rai et al. 2002). Contamination of surface water may also degrade the groundwater quality, resulting in a very serious issue in many developing countries.

Water quality indices are tools, to determine conditions of water quality and, like any other tool, require knowledge about principles and basic concepts of water and related issues (Nikbakht 2004). Several researchers have used water quality indices methods for the assessing quality of waters (Zhang et al. 2009; Kikuchi et al. 2009; Pandey et al. 2009; Giri et al. 2010; Virha et al. 2011; Srivastava et al. 2011; Kumar et al. 2012; Prasanna et al. 2012; Díaz et al. 2013; Giri and Singh 2014; Mahato et al. 2014; Protano et al. 2014; Tiwari et al. 2014; Varghese and Jaya 2014; Panigrahy et al. 2015). However, in recent years much attention has been given towards the evaluation of heavy metal pollution in ground and surface water with the development of a heavy metal pollution index (HPI) (Reddy 1995; Mohan et al. 1996). The aim of this study was to assess the seasonal variations in heavy metals concentrations in river and pond water using the HPI approach for the determination of the suitability of the water for drinking.

Materials and Methods

The West Bokaro coalfield lies between 23°41′ to 23°52′ N latitude and 85°24′ to 85°41′ E longitude (Fig. 1). The coalfield is drained by the Bokaro River passing through

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the central part of coalfield with easterly flows. Chutua River is the main tributary of the Bokaro River which drains the northern hilly terrain of the coalfield. Chotha River is a tributary of the Bokaro River which drains the southern region of the coalfield. The coalfield area experiences a tropical climate characterized by very hot pre-monsoon and cold post-monsoon season. The average annual rainfall of the district is 1418 mm and more than 85 % of annual rainfall occurs during the four monsoon months (June to September). The coalfield forms a broad syncline trending east to west. The complete sequence of lower Gondwana formation rests unconformably on basement rocks. The Barakar formation covers the major part of the coalfield and is comprised of coarse to fine grained sand stone, pebbly conglomerates, gritty sandstones, grey shales, carbonaceous shales, fire clays and coal seams.

Twenty eight of the surface water samples (fourteen samples in the post-monsoon season, and fourteen samples in the pre-monsoon season) were collected from fourteen sites of the West Bokaro coalfield area and placed into narrow-mouth pre-washed polyethylene bottles (capacity 100 mL) during month of November, 2012 and May, 2013 (Fig. 1). Samples were filtered with Millipore filtration unit, filter paper (pore size 0.45 µm) and preserved by adjusting the $\mathrm{pH} < 2$ with 6 N ultrapure nitric acid (Radojevic and Bashkin 1999). 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. Concentrations of heavy metals were analyzed by ICP-MS (Perkin Elmer model ELAN DRCe, 710 Bridgeport Avenue Shelton, Connecticut 06484-4794, United States). Reagent blank determinations were used to correct the instrument readings. For the accuracy of the analysis, it 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.

Geographic information system (GIS) is widely used for collecting diverse spatial data and for overlay analysis in spatial register domain to represent spatially variable phenomena (Bonham-Carter 1996; Babiker et al. 2004; Gupta and Srivastava 2010). The water quality indices and GIS which synthesize different available water quality data into an easily understood format, provide a way to summarize overall water quality conditions in a manner that can be clearly communicated to policy makers (Singh et al. 2013a). The spatial distribution maps were prepared using ARC GIS- 10.2 software (Environmental Systems

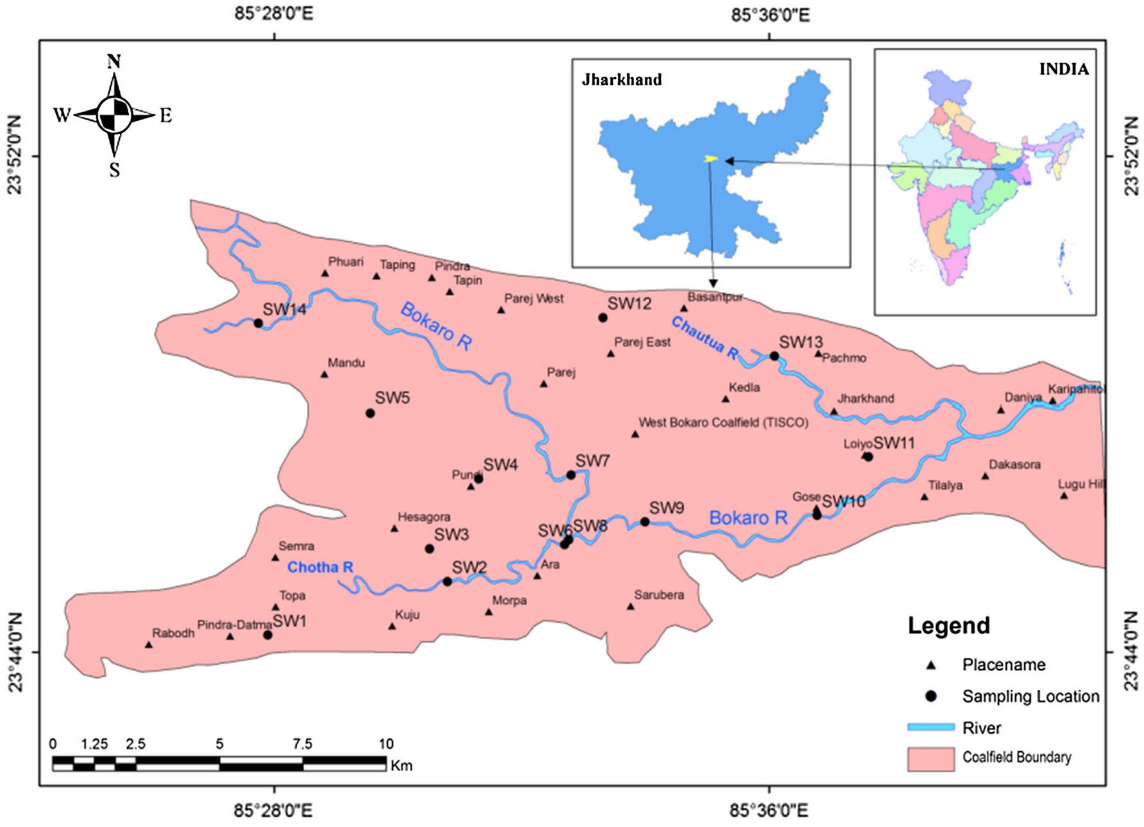

Fig. 1 West Bokaro coalfield map showing sampling locations

Research Institute, Redlands 380 New York Street 92373, California, United States).

The heavy metal pollution index (HPI) is a rating technique that provides the composite influence of individual heavy metal on the overall quality of water. The rating system is an arbitrary value between zero to one and its selection depends upon the importance of individual quality considerations in a comparative way or it can be assessed by making values inversely proportional to the recommended standard for the corresponding parameter (Horton 1965; Mohan et al. 1996). In computing the HPI, Prasad and Bose (2001) considered unit weightage (W_i) as a value inversely proportional to the recommended standard (S_i) of the corresponding parameter as proposed by

Table 1 Summary statistics of the dissolved metals (μg L^{-1}) compared to WHO and Indian Standards (IS: 10500) for domestic purposes

Metals	Post-monsoon (n = 14)			Pre-monsoon (n = 14)			WHO (2006)	BIS 2003 (IS: 10500)	
	Range	Mean	SD	Range	Mean	SD		Max. desirable	Hig. permissible
Mn	2.4–36.4	9.6	11.0	5.6–57	20	16.0	100	100	300
Cu	0.9–1.9	1.3	0.3	1.2–10.0	3.2	2.8	2000	50	1500
Zn	0.5–10	3.6	3.1	0.9–29.6	11.6	9.9	4000	5000	15,000
Ni	1.4–11.2	5.8	3.2	1.6–28.7	10.3	7.1	20	–	–
As	0.1–0.5	0.3	0.1	0.2–0.9	0.5	0.2	10	50	No relaxation
Se	0.05–0.4	0.18	0.11	0.1–2.9	0.7	0.8	10	10	No relaxation
Al	13.7–89.4	36.8	20.7	19.6–198	83	51	100–200	–	–
Cr	0.1–0.4	0.2	0.1	0.2–10	2.3	3.0	50	50	No relaxation
Ba	16.3–103	43.7	22.6	26.2–231	83	54	300	1000	5000
Fe	198.5–905	431	232	267–1621	706	412	300	300	1000

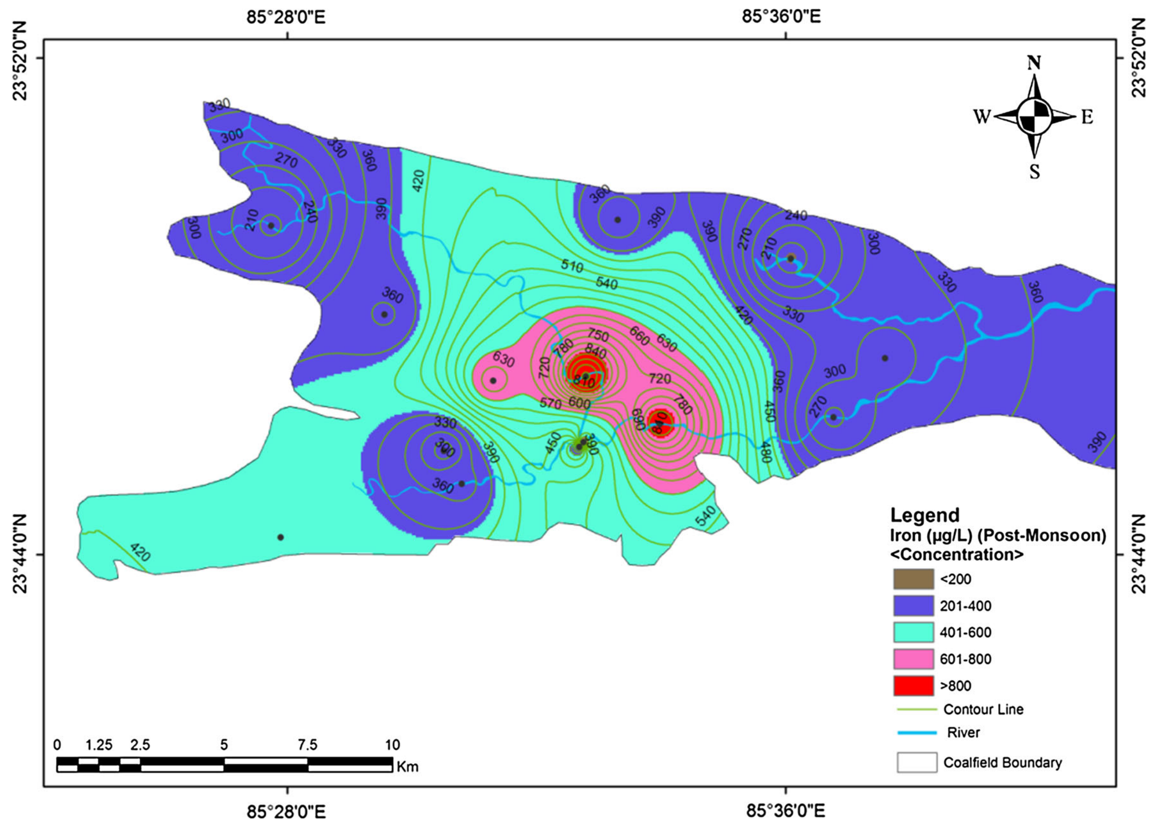

Fig. 2 Concentration contour showing spatial distribution for Fe in surface water throughout the study area in the post-monsoon season

Reddy (1995). The critical pollution index of HPI value for drinking water as given by Prasad and Bose (2001) is 100. However, a modified scale using three classes has been used in the present study after Edet and Offiong (2002). The classes have been demarcated as low, medium and high for HPI values <15, 15–30 and >30, respectively.

For this study, the concentration limits [i.e. highest permissive value for drinking water (S_i) and maximum desirable value (I_i) for each parameter] were taken from the Indian drinking water specifications (BIS 2003). The highest permissive value for drinking water (S_i) refers to the maximum allowable concentration in drinking water in the absence of any alternate water source. The desirable maximum value (I_i) indicates the standard limits for the same parameters in drinking water.

The HPI model (Mohan et al. 1996) is given by Eq. (1)

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

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 Eq. (2)

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \tag{2}$$

where M_i is the monitored value of heavy metal of i^{th} parameter, I_i is the ideal value (maximum desirable value for drinking water) of the i^{th} parameter and S_i is the standard value (highest permissive value for drinking water) of the i^{th} parameter. The sign (−) indicates numerical difference of the two values, ignoring the algebraic sign.

Results and Discussion

The results of the metal analysis for the two seasons viz for the post- and pre-monsoon seasons are provided in Table 1. The Zn, Ni, Mn, As, Se, Al, Ba, Cu, and Cr concentrations did not exceed the desirable limits for drinking water in either season. However, at many sites, concentrations of Fe were above the desirable limit of the WHO (2006) and

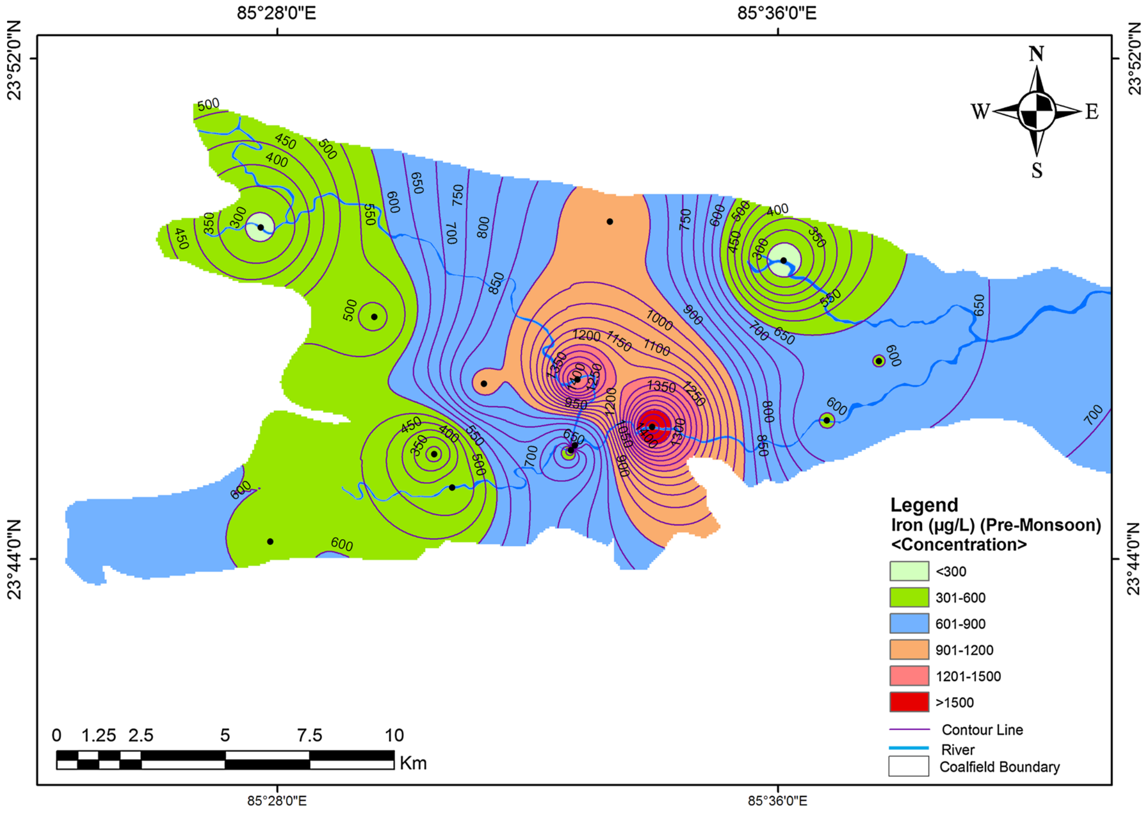

Fig. 3 Concentration contour showing spatial distribution for Fe in surface water throughout the study area in the pre-monsoon season

Table 2 Paired *t* test of the post- versus pre-monsoon seasons surface water samples

	Paired differences					*t*	*df*	Sig. (2-tailed)
	Mean	SD	Std. error mean	95 % confidence interval of the difference				
				Lower	Upper			
Pair 1 Mn PosM–PreM	−10.342	10.040	2.683	−16.139	−4.545	−3.854	13	0.002
Pair 2 Cu PosM–PreM	−1.967	2.701	0.721	−3.527	−.407	−2.725	13	0.017
Pair 3 Zn PosM–PreM	−8.076	9.468	2.530	−13.543	−2.609	−3.191	13	0.007
Pair 4 Ni PosM–PreM	−4.541	5.815	1.554	−7.898	−1.183	−2.922	13	0.012
Pair 5 As PosM–PreM	−0.133	0.135	0.0361	−0.211	−0.055	−3.687	13	0.003
Pair 6 Se PosM–PreM	−0.477	0.715	0.191	−0.890	−0.064	−2.498	13	0.027
Pair 7 Al PosM–PreM	−46.165	34.031	9.095	−65.815	−26.516	−5.076	13	0.000
Pair 8 Cr PosM–PreM	−2.025	2.946	0.787	−3.726	−0.323	−2.571	13	0.023
Pair 9 Ba PosM–PreM	−39.181	33.629	8.987	−58.598	−19.764	−4.359	13	0.001
Pair 10 Fe PosM–PreM	−274.728	223.790	59.810	−403.941	−145.516	−4.593	13	0.001

PosM = post-monsoon season, *PreM* = pre-monsoon season, *SD* = standard deviation, *df* = degrees of freedoms

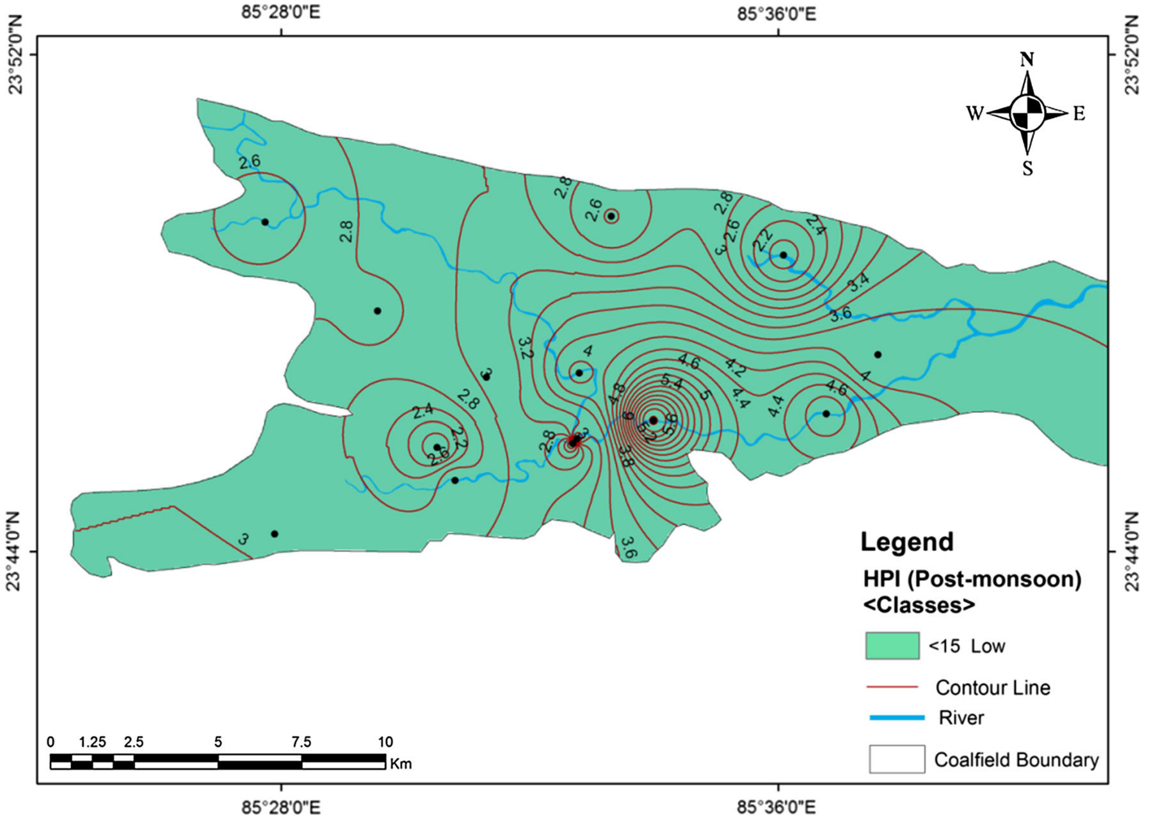

Fig. 4 Heavy pollution index class map of the West Bokaro coalfield area in the post-monsoon season (according to Edet and Offiong 2002)

Indian drinking water standard (BIS 2003) in both seasons. The concentrations of Fe ranged from 198.5 to 905 µg L^{-1} in the post-monsoon and 267 to 1621 µg L^{-1} in the pre-monsoon season, exceeding the desirable limit of 300 µg L^{-1} in 57 % of the surface water samples in the post-monsoon season and 86 % of the surface water samples in the pre-monsoon season, respectively. The spatial variation showed higher Fe values at sites 1, 4, 7, 8, 9 in the post-monsoon season (Fig. 2). However, in the pre-monsoon season the higher Fe values were measured at sites 1, 4, 7, 8, 9, 10, 11 and 12 (Fig. 3). Excess Fe in water is thought to result from industrial effluents. Except for agricultural based activity and coal mining and washing, there are no other major anthropogenic or industrial

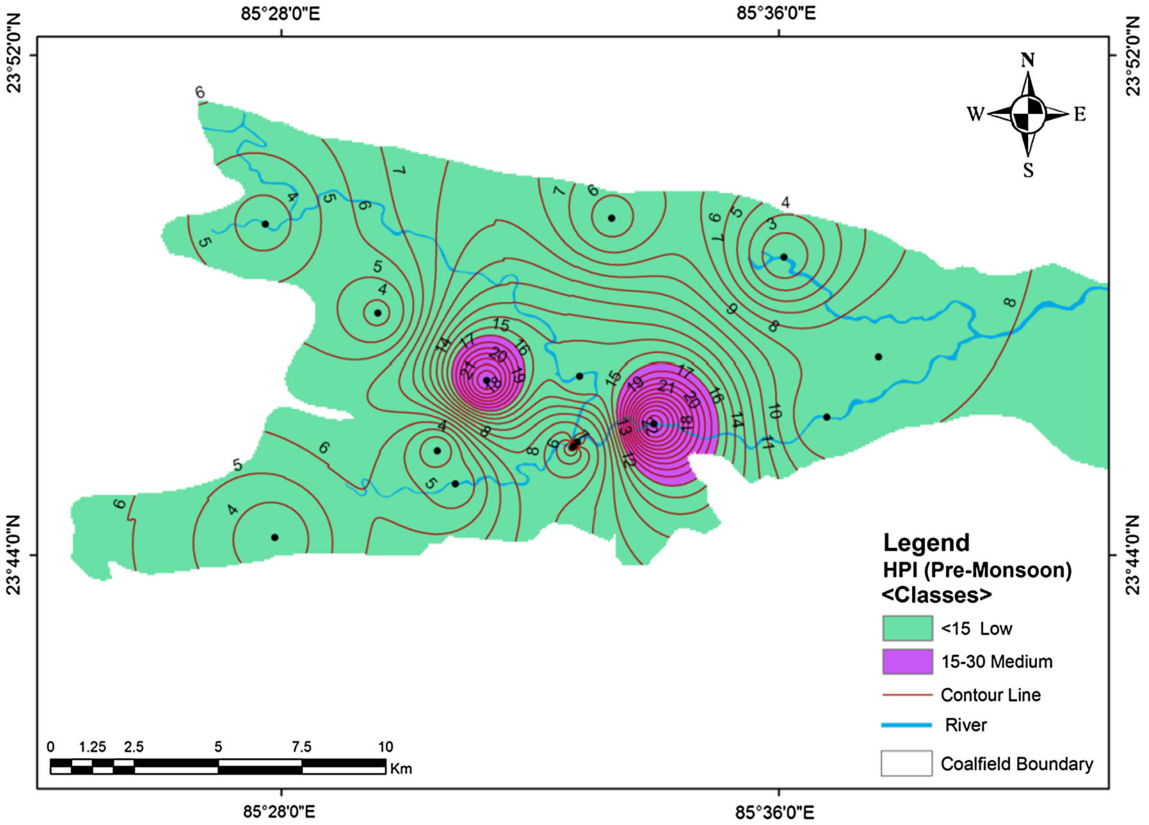

Fig. 5 Heavy pollution index class map of the West Bokaro coalfield area in the pre-monsoon season (according to Edet and Offiong 2002)

activities in this region. Excess Fe is an endemic water quality problem in many part of India (Singh et al. 2013b).

The concentrations of variables displayed great seasonality. The total concentrations of all the studied elements in surface water had an average of 532 and 921 µg L^{-1} in the post- and pre-monsoon seasons, respectively. Metal concentrations were higher in the pre-monsoon season as compared to the post-monsoon season irrespective of the locations. This may be attributed to the high evaporation and intense anthropogenic activities (high degree of mining activities and agriculture) in summer (Vega et al. 1998; Olias et al. 2004). The dilution effect due to heavy rainfall may also results in the consequent reduction in the total concentration of the metals in the post-monsoon season. Eighty-five percent of the annual precipitation falls in the rainy season and subsequently dilutes pollutants in surface waters.

A paired sample *t* test was run on the metals data, comparing the post- versus pre-monsoon seasons, for each of the ten parameters. Table 2 depicts the mean differences of the post- versus pre-monsoon seasons metals data for all the ten variables along with the corresponding *t* values, degrees of freedoms (*df*) and *p* values for two-tailed paired sample *t* tests. Metal concentrations of the pre-monsoon season were statistically higher than the post-monsoon season and shows significant variations in their concentration (Table 2).

Mean concentrations of the analyzed metals were used to calculate the HPI values. These values ranged from 2.1 to 6.4 (mean 3.3 ± 1.3) in the post-monsoon season and from 2.3 to 26 (mean 9 ± 8.0) in the pre-monsoon season. The highest HPI values were calculated in water from sites 4, 7, 8 and 9. The higher values of HPI may be attributed due to the natural and anthropogenic activities. Lower HPI values in the post-monsoon season again indicate a dilution affect. The HPI values of the samples within the study area were less than the critical HPI value of 100 (Prasad and Bose 2001). However, considering the classes of HPI, all the locations for both the seasons fall under the low class (HPI < 15) to medium class (HPI 15–30) (Figs. 4, 5). In the post-monsoon season among all of the surface water samples, the percentage (%) of HPI categories, low class (100 %) were observed. However, in the pre-monsoon season the percentage (%) of HPI categories, low class (86 %) and medium class (14 %) were observed. This indicates the water is not critically polluted with respect to heavy metals.

In conclusion, the HPI values within the study area were below the critical pollution index value of 100. The concentrations of most metals in the surface water in the study area were well below the limits for the desirable/permissible levels recommended for drinking water by the Bureau of Indian Standard (BIS 2003) and World Health Organisation (WHO 2006). The water that contained higher concentrations of Fe would require treatment before domestic use.

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