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TECHNICAL ARTICLE

An Evaluation of Metal Contamination in Surface and Groundwater around a Proposed Uranium Mining Site, Jharkhand, India

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Abstract The East Singhbhum region is a highly mineralised zone, with extensive mining of copper, uranium, and other minerals. The concentrations of certain metals (Fe, Mn, Zn, Pb, Cu, and Ni) were measured in 10 groundwater locations and eight surface water locations for four seasons during 1 year around a proposed uranium mining area. The ranges of Fe, Mn, Zn, Pb, Cu, and Ni in surface water were 0.08–1.21, 0.02–0.32, 0.02–3.48 mg/L, 0.84–14, 1.25–36, and 1.24–15 µg/L, respectively, while in groundwater, the ranges were 0.06–5.3, 0.01–1.3, 0.02–8.2 mg/L, 1.4–28, 0.78–20, and 1.05–20 µg/L, respectively. Only Fe and Mn were found to exceed India's drinking water standards. The data have been used to calculate a metal pollution index (MPI). The MPI of both groundwater (28) and surface water (10) is well below the index limit of 100, which suggest that neither is generally contaminated with respect to these metals.

Keywords Drinking water · Groundwater · Metal pollution index · India · Surface water · Uranium mining

Introduction

Industrial activities, including mining, generate chemical and physical changes in their nearby environment. In the case of uranium mining, radionuclides and other metals can find their way into the water resources in the vicinity of the facilities involved in mining, milling, ore separation, and purification. Leaching of metals, non-metals, and radionuclides from surface impoundments of tailings generated during uranium mining and milling often leads to groundwater contamination. Some of these metals have been reported to produce severe diseases like cancer, kidney failure, liver damage, and neurological and genetic malfunctions (Abbasi et al. 1998; Johnson 1998; Lasheen et al. 2008; Miller et al. 2004). Thus, monitoring of ground and surface water surrounding uranium mines has great significance from a human health perspective.

Water quality indices are useful in evaluating the composite influence of various parameters. Water quality indices incorporate a series of judgements and concentration data into a single parameter that is indicative of the level of pollution. Several methods have been proposed to develop water quality indices to assess water quality (Horton 1965; Joung et al. 1979; Landwehr 1979; Nishidia et al. 1982; Tiwary and Mishra 1985). Specific pollution indices have also been used to evaluate the extent of pollution with respect to certain metals (Prasad and Jaiprakas 1999; Prasad and Bose 2001).

The present study was undertaken to investigate and evaluate the presence of certain metals in ground and surface water around a proposed uranium mining area at Bagjata, Jharkhand (India) using a water quality index based on the concentrations of six metals: Fe, Mn, Zn, Pb, Cu, and Ni. These metals were selected as being most representative of the impacts of mining. Other metals, like Hg, As, and Cd, were found to be below the detection level in the samples.

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Materials and Methods

Description of the Study Area

Bagjata is a proposed uranium mining area situated at latitude 22°26′07″N to 22°28′34″N and longitude 86°25′16″E to 86°31′29″E in the Dalbhum subdivision of East Singhbhum district in Jharkhand State. In the Singhbhum thrust belt, uranium mineralization is associated with a sodic granite intrusive, the source of hydrothermal solutions that found an easy passage through the shear planes. Studies of mineral paragenesis indicate that mineralization along the thrust belt took place over a long period. The first minerals to form were apatite and magnetite, closely followed by uranium mineralization. Metal sulphides, including chalcopyrite, were deposited last. Uranium-copper mineralization coexists in the area; however, depending on economic grades, either Cu or U is mined and processed at individual mines.

The Bagjata mining area is situated in the Bhalki-Kanyaluka deposit (Bhola et al. 1964). The primary uranium minerals are uraninite and pitchblende; the common secondary uranium mineral is autonite. The uranium minerals are associated with a wide variety of sulphides of Cu, Ni, Co, Mo, As, and Bi (Sarangi and Singh 2006).

The climate of the study area is temperate. Annual rainfall is 1,200 to 1,400 mm. The area is subject to the southwest monsoon and receives heavy rain during June to September (the monsoon season). During the summer seasons, maximum temperatures range from 40 to 45°C, whereas in winter, the temperature dips as low as 8°C. The location of the study area is shown in Fig. 1. The ground and surface water sampling locations are shown in Figs. 2 and 3, respectively.

Sampling and Analysis

Sampling and analyses of the water samples were carried out following standard protocols and methodologies. Groundwater samples were collected from wells; surface water samples were collected from streams and rivers following standard procedures (IS 1987). Ten groundwater locations and eight surface water locations were sampled on four occasions: June 2006, September 2006, January 2007, and May 2007 (Figs. 2 and 3). Five samples were collected and composited for each occasion and each location. The 10 groundwater sampling sites were based on proximity to the proposed site. The eight surface water sites were selected based on the expected discharge locations of effluent from the proposed mining site.

Bagjuria is a small streamlet flowing adjacent to the Bagjata mine and will be first recipient of the treated effluent from the mine (Figs. 2 and 3). Two sampling sites were located in this stream, one upstream and the other downstream of the mine site. The Bagjuria meets the Sankhnalla River, which is a prominent SW-NE flowing river about 1 km north of the site (Figs. 2 and 3). Three sampling sites

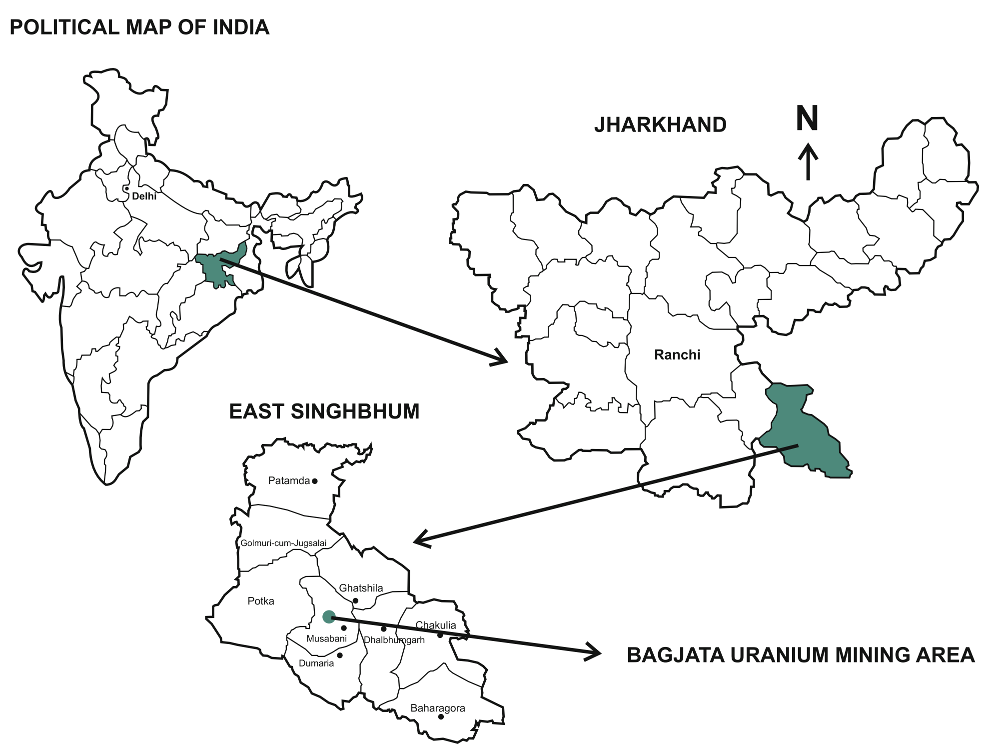

Fig. 1 Location map of the study area

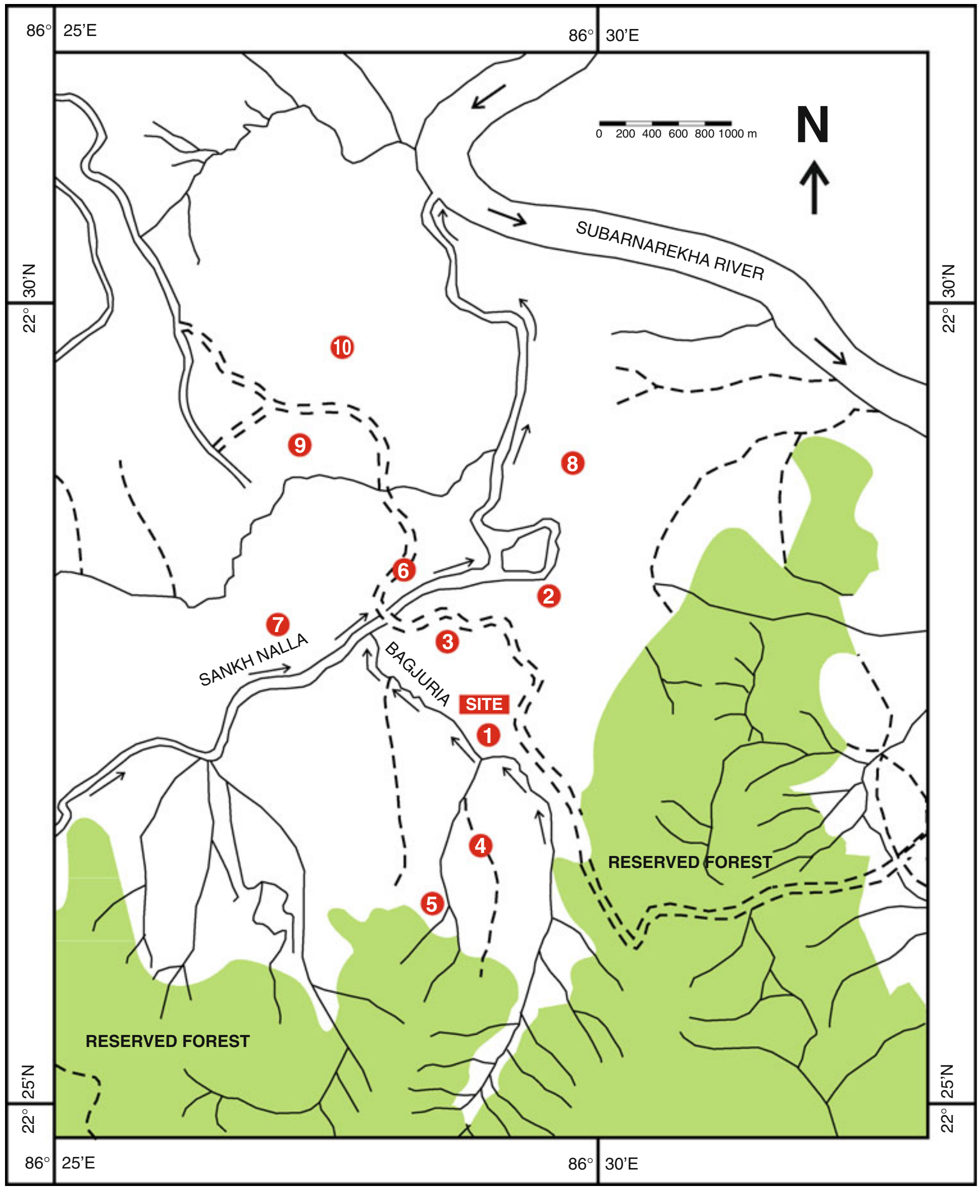

Fig. 2 Groundwater sampling locations in the Bagjata mining area

were located in this river, namely Sankhnalla, upstream with respect to Bagjuria, Sankhnalla (downstream), and at the confluence of Bagjuria and Sankhnalla. The Sankhnalla finally meets the Subernarekha River, a major river of the region. As in Sankhnalla, three sample sites were located in this river; Subernarekha upstream, Subernarekha downstream, and at the confluence of Sankhnalla and Subernarekha.

For the analysis of metals, the samples were collected in pre-conditioned acid-washed PVC containers, filtered with Whatman Filter Paper- (grade-42, diameter-125 mm, pore size-2.5 μm), and preserved by adjusting the 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. Double distilled deionised water was used throughout the study. Reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, a recovery study was carried out by spiking and homogenizing several already analyzed samples with varied amounts of standard solutions of the metals. Metal analyses were done by atomic absorption (AA) (AA model GBC Avanta); standards were run after every 15 samples analyzed. Acetylene gas was used as the fuel and air as support. An oxidising flame was used in all cases. Table 1 shows the different parameters at which the instrument was set for each metal.

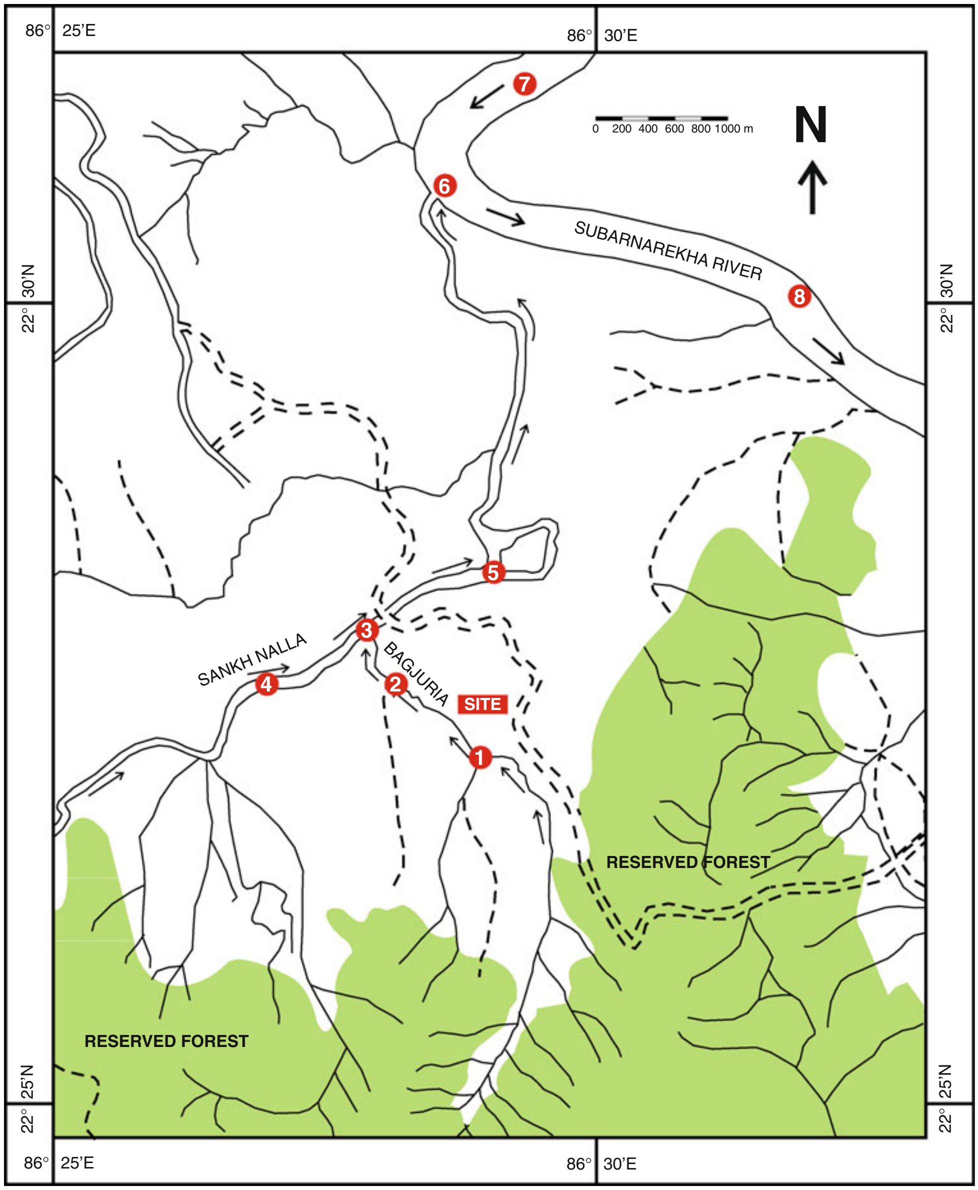

Fig. 3 Surface water sampling locations in the Bagjata mining area

Calculation of Metal Pollution Index

The metal pollution index (MPI) represents the overall quality of water with respect to metals. The MPI is based on the weighted arithmetic mean quality method and is calculated in two steps: a rating scale is established that weights each parameter, and then the pollution parameter(s) are selected on which the index is to be based. The weighting for individual water quality parameters is a value between zero and one, which is defined by the relative importance of the individual quality parameters under consideration, or by making the values inversely proportional to the recommended standard for the corresponding parameter (Horton 1965; Mohan et al. 1996). In the formula used in this study, the weighting factor (W_i) for each parameter was defined as the inverse of the recommended standard (S_i) (Reddy 1995). The drinking water standards for India (IS 1993) were used for the metals for the calculation of W_i, with the exception of Ni, for which IS (1993) does not provide a standard. Instead, the World

Table 1 Wavelength (nm) and detection limits (mg/L) of atomic absorption spectrophotometer (GBC Avanta)

Element	Wavelength	Detection limit
Fe	248.3	0.005
Mn	279.5	0.0015
Zn	213.9	0.0005
Pb	217.0	0.001
Cu	324.7	0.0004
Ni	232.0	0.0009

Table 2 Concentration ranges of metals in groundwater samples

	Location	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Pb (μg/L)	Cu (μg/L)	Ni (μg/L)
1	Bagjata	3.25–5.08	0.13–0.34	0.12–0.98	2.6–10	1.8–6.8	3.6–9.7
2	Bhaduya	0.06–0.15	0.1–0.19	0.4–1.22	3.1–6.3	0.78–2.6	4.2–10
3	Phuljhari	0.12–0.92	0.13–0.63	0.1–0.74	4.11–15	2.4–10	1.05–14
4	Manajhari	0.82–5.3	0.13–0.25	0.02–1.2	6.4–14	1.3–13	5.4–10
5	Balidungri	1.27–3.4	0.61–1.3	0.03–1.35	6.8–15	4.02–12	8.5–20
6	Bakra	0.09–0.37	0.32–0.85	0.67–2.5	3.5–28	5.3–11	2.5–16
7	Katsakra	0.09–0.15	0.36–0.63	0.06–0.1	4.4–12	4.66–20	6.2–14
8	Gohala	0.08–0.35	0.01–0.07	0.06–0.23	4.5–7.8	4.5–9	2.29–8.7
9	Latia	0.29–2.24	0.11–0.92	2.8–6.9	5.7–16	0.92–12	2.1–15
10	Mosabani	0.15–1.12	0.34–0.79	0.12–8.2	1.4–3.4	3.5–6.7	2.9–10
	IS:10500	0.3	0.1	5	50	50	70(WHO)
	IS:10500*	1.0	0.3	15	No relaxation	1,500	

* In absence of alternative source

Table 3 Metal concentrations (mg/L) reported in Indian groundwater samples in other studies

Location	Fe	Mn	Zn	Pb	Cu	Ni	Reference
Chikmagalure	0.2–1.8		0.001–0.2	0.001–0.005	<0.005–0.9	0.001–0.02	Babu et al. 2006
Golaghat	0.28–5.88	<0.01–0.522	<0.001–7.38	<0.001–0.123	0.001–0.272		Chetia et al. 2008
IREL, Orissa	0.08–2.56	0.01–0.33	0.03–0.49	0.05–7*	0.05–4.5*		Sahoo et al. 2005
Jharia	0.13–2.18		0.02–0.04	0.01–0.04			Abhishek et al. 2006
U deposits, Meghalaya	0.23–5.1	<0.01–0.286	<0.001–0.098		<0.005–0.008		Sinha et al. 2005
Bombay			7.5–30.3*	0.6–2.6 *	1.3–16.8*		Tripathi et al. 1997
Bagjata	0.06–5.3	0.01–1.3	0.02–8.2	1.4–28*	0.78–20*	1.05–20*	Present study

* Concentrations in μg/L

Health Organization standard for Ni was used (WHO 2004). Ni is an important metal for the study area as the area is mineralised with respect to U, Cu, and Ni.

Six metals, Fe, Mn, Zn, Pb, Cu, and Ni, were included in the MPI calculation according to the following equation (Mohan et al. 1996):

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} \mathrm{W}_i \mathrm{Q}_i}{\sum_{i=1}^{n} \mathrm{W}_i} \tag{1}$$

In Eq. 1, W_i is the unit weightage of the ith parameter and n is the number of parameters considered. The sub-index (Q_i) is calculated from:

$$\mathrm{Q}_i = \sum_{i=0}^{n} \frac{|\mathrm{M}_i - \mathrm{I}_i|}{(\mathrm{S}_i - \mathrm{I}_i)} \times 100 \tag{2}$$

In Eq. 2, M_i is the monitored value of the metal of ith parameter, I_i is the ideal value of the ith parameter (desirable limit given by IS 1993), and S_i is the standard value of the ith parameter (maximum permissible limit given by IS 1993). There are no desirable limits for Pb defined in IS (1993) and Ni in WHO (2004); hence, their ideal values were set equal to zero.

Generally, pollution indices are based on a specific use; this index was calculated for the purpose of drinking water. The maximum threshold is derived by replacing the monitored value (M_i) by the standard value (S_i), which is the maximum permissible limit in Eq. 2. Since the maximum threshold pollution index value for drinking water would be 100, unacceptable drinking water quality is indicated by an MPI value greater than 100.

Results and Discussion

Groundwater

The concentrations of metals were generally below the prohibited levels, except for the concentrations of Fe and Mn, which were above the limits of 0.3 and 0.1 mg/L, respectively, at most stations (Table 2). The maximum concentration of Zn also exceeded the permissible limit of 5 mg/L at two locations. Table 3 gives the reported concentration range of metals in groundwater by various researchers. It can be seen that the concentrations of metals

Table 4 MPI values for groundwater of the Bagjata Mining Area

Metals	Mean value (M_i) (μg/L)	Permissible value (S_i)(μg/L)	Highest desirable value (I_i) (μg/L)	Unit weighting factor (W_i)	Sub index (Q_i)	$W_i \times Q_i$	MPI
Fe	1205.55	1,000	300	0.001	129.36	0.1294	28
Mn	380.53	300	100	0.0033	140.26	0.4675	
Zn	1346.50	15,000	5,000	0.000067	36.54	0.0024	
Pb	8.66	50	–	0.02	17.32	0.3464	
Cu	6.21	1,500	50	0.000667	3.021	0.00201	
Ni	8.29	70	–	0.01429	11.84	0.16918	
				$\Sigma W_i = 0.039$		$\Sigma W_i Q_i = 1.117$	

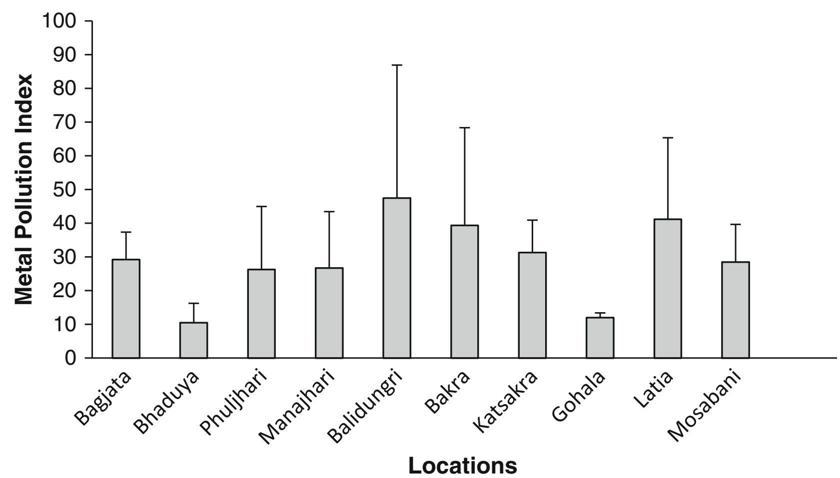

Fig. 4 Site specific HPI values for groundwater in the Bagjata mining area (*error bars* represent the maximum value)

reported in the present investigation are in good agreement with the concentration range reported by other researchers.

To assess the extent of pollution and potability of the water, MPIs were calculated (Table 4). The MPI value for groundwater in the study area, considering all the seasons and locations, was 28, using the mean concentrations from all sample sites. This MPI value is less than 100, indicating that the groundwater is not polluted with respect to metals, despite mineralisation, mining, and industrial activities near the site.

The MPI of the groundwater were also calculated for the different locations (Fig. 4). The maximum MPI is denoted by the vertical error bars. The MPI values ranged from 6.8 to 87. However, considering the average MPI for each location, the lowest MPI was calculated for Bhaduya village (11), while the highest was for Balidungri village (48). The next most polluted location according to the MPI was Latia village (41). The high MPI values in these locations may be attributed to the high concentration of metals in the soil of the locations, which may have leached into the groundwater aquifers. The study area is within the mineralised zone of the Singhbhum Thrust Belt and the soils are naturally enriched in metals (Sarangi and Singh 2006).

To assess the seasonal variation in metal pollution, the MPI was calculated for each sampling period and the results are shown in Fig. 5. During the summer (June 2006 and May 2007), groundwater was found to have the highest metal concentrations and therefore the highest MPI values. The lowest concentrations were generally observed in September, which represents the peak monsoon season. The MPI values for June 2006 and May 2007 were 46 and 37, respectively. However, the MPI values for September 2006 and January 2007 were about 17, substantially lower than in summer.

It has been observed that groundwater chemistry in other mineralised areas with strong wet to dry rainfall patterns demonstrates a marked seasonality, with all solute concentrations decreasing during the rainy season. The fluctuations are due to the seasonality in groundwater flow, with high recharge and discharge during the rains and little to no further groundwater discharge by the middle dry season (Heyden and New 2004). Thus, the recharge of the groundwater during the monsoon leads to dilution of the metals, reducing the MPI.

Surface Water

The surface water becomes enriched with metals due to surface runoff and other anthropogenic activities. The concentration ranges of metals in the surface water of the Bagjata mining area are given in Table 5. Table 6 provides the reported concentration range of metals in surface water by various researchers. It can be seen from the tables that the concentrations of metals reported in the present investigation are consistent with the concentration range reported by other researchers.

The mean MPI of surface water of the area considering all the seasons and locations was determined to be 10 (Table 7). This value is well below the threshold limit of 100. Based on the low MPI values, it is reasonable to conclude that the surface water of the area was not

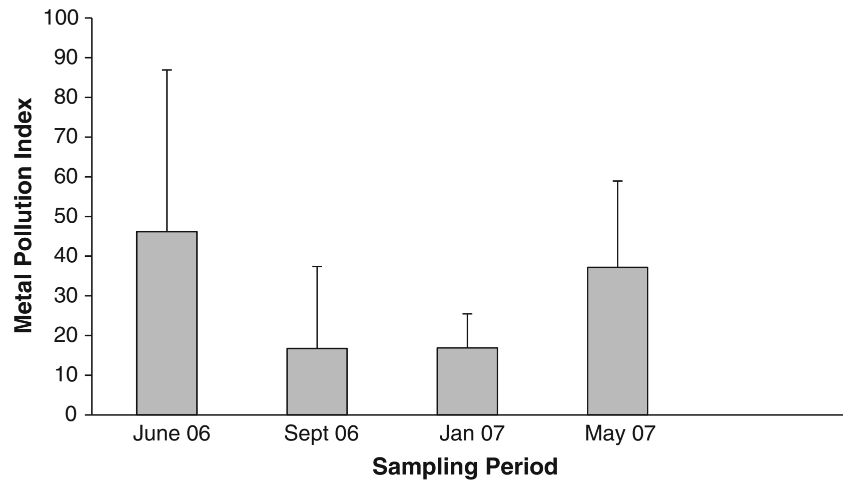

Fig. 5 Seasonal variation in HPI values for groundwater in Bagjata mining area (*error bars* represent the maximum value)

Table 5 Concentrations of metals in surface water samples

	Location	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Pb (µg/L)	Cu (µg/L)	Ni (µg/L)
1	Bagjuria(U/S)	0.34–1.02	0.04–0.32	0.02–0.21	1.2–5.5	3.2–6.5	2.2–3.7
2	Bagjuria(D/S)	0.38–1.21	0.02–0.26	0.02–1.14	0.84–5.2	3.4–14	2.5–4.9
3	Bagjuria and Sankhnalla (Confl.)	0.12–0.71	0.06–0.19	0.03–2.31	1.02–8.2	1.3–9.9	3.1–11
4	Sankhnalla (U/S)	0.12–0.87	0.07–0.19	0.42–2.48	1.44–10	10.5–25	4.1–13
5	Sankhnalla (D/S)	0.1–0.36	0.04–0.13	0.02–0.05	3.2–7.4	4.1–11	3.3–15
6	Sankhnalla and Subernarekha (Confl.)	0.08–0.52	0.02–0.12	0.04–3.48	3.9–12	8.1–36	1.3–12
7	Subernarekha (U/S)	0.15–0.95	0.02–0.08	0.11–2.2	6.2–14	10.3–34	5.5–11
8	Subernarekha (D/S)	0.13–0.61	0.03–0.12	0.03–0.66	1.03–2.4	5.4–8.1	1.2–5.1
	IS:10500	0.3	0.1	5	50	50	70 (WHO)
	IS:10500*	1.0	0.3	15	No relaxation	1,500	

* In absence of an alternative source

Table 6 Concentration ranges of metals in surface water from other studies

	Fe	Mn	Zn	Pb	Cu	Ni	Reference
U deposits Meghalaya, India	<0.01–0.91	<0.01–0.52	<0.002–0.06		<0.007–0.015		Sinha et al. 2005
Ganga, India	0.025–5.49	0.025–2.72	0.012–0.370	0.001–0.250	0.003–0.032	0.012–0.375	Kar et al. 2008
Jharia coalfield, India	0.15–1.91		0.03–0.09	0.01–0.03			Abhishek et al. 2006
Bendimahi, Turkey	0.56	0.05	0.12	0.08	0.09		Özlem et al. 2008
Siahroud, Iran	0.33	0.17	0.09	0.08	<0.01		Charkhabi et al. 2005
Guadiamar, Spain	2.1	0.47	0.35	0.04	0.03		Alonso et al. 2004
Bagjata	0.08–1.21	0.02–0.32	0.02–3.48	0.84–14*	1.25–36*	1.24–15*	Present study

* Concentration in µg/L

Table 7 MPI values for surface water of the Bagjata mining area

Metals	Mean value (M_i) (µg/L)	Permissible value (S_i)(µg/L)	Highest desirable value (I_i) (µg/L)	Unit weighting factor (W_i)	Sub index (Q_i)	$W_i \times Q_i$	MPI
Fe	467.16	1,000	300	0.0010	23.879	0.024	10
Mn	103.84	300	100	0.0033	1.922	0.006	
Zn	779.28	15,000	5,000	0.0001	42.207	0.003	
Pb	5.43	50	–	0.0200	10.868	0.217	
Cu	11.52	1,500	50	0.0007	2.654	0.002	
Ni	6.30	70	–	0.0143	8.996	0.129	
				$\Sigma W_i = 0.039$		$\Sigma W_i Q_i = 0.381$	

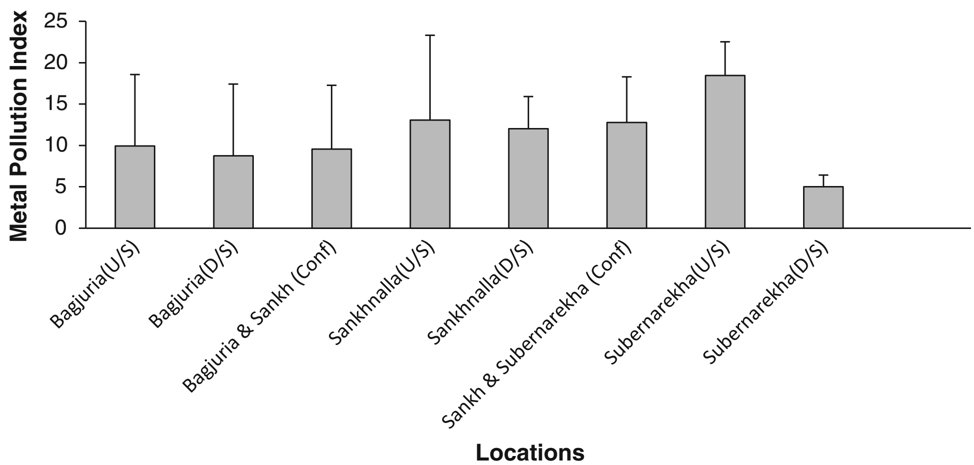

Fig. 6 Site specific HPI values for surface water in Bagjata mining area (*error bars* represent the maximum value)

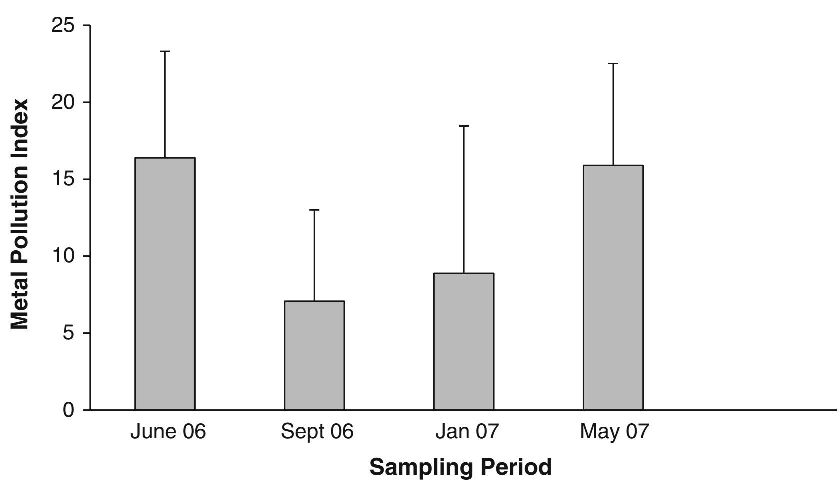

Fig. 7 Seasonal variation in HPI values for surface water in the Bagjata mining area (*error bars* represent the maximum value)

substantially affected by elevated levels of metals. The MPI of the surface water is lower than the MPI of the groundwater due to the comparatively lower metal concentrations. This difference may be due to the longer contact time that groundwater has and the greater rock to water ratios in soils and aquifers.

The MPI values of the surface water were calculated for the different locations and different seasons of the area (Figs. 6 and 7, respectively). The maximum MPI is denoted by vertical error bars. The lowest MPI (5) was found for Subernarekha (D/S), while the highest (18) was for Subernarekha (U/S). This pattern is ascribed to the fact that Subernarekha flows near Cu-processing sites before its confluence with Sankhnalla and is affected by their effluents.

To assess the seasonal variation of metal pollution, the MPI was calculated for each sampling period. Like groundwater, the summer season had the highest MPI values. The MPI for June 2006 and May 2007 (summer season) was found to be 16. In comparison, the MPI for September 2006 and January 2007 was comparatively low: 7.1 and 8.9, respectively. Again, dilution during the monsoon seasons led to the lower MPI.

Conclusions

The analyses of metals in ground and surface water around various locations of the proposed Bagjata mining site was important for establishing a baseline characterization prior to the start of mining, considering that the areas is mineralised and mining has occurred nearby. We find that concentrations of metals are generally less than permissible drinking water levels except for Fe and Mn, which were above the permissible limits at most stations. The elevated levels of Fe and Mn are a natural occurrence in the area because of mineralisation and background rock geochemistry. The MPI used in our study proved to be a very useful tool in evaluating the overall pollution level of ground and surface waters in terms of metals. The mean MPI values for ground and surface waters of the Bagjata uranium mining area were well below the maximum threshold value of 100. In addition, none of the individual locations in any sampling period exceeded the maximum threshold value. These observations show that the ground and surface water are not polluted with metals despite natural mineralisation, mining, and other allied activities in the area.

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