Ground water quality evaluation in the lean period of a mining township

Babli Prasad¹ · Deblina Maiti¹ · Adarsh Kumar¹

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Abstract Groundwater of mining towns is very much affected due to mining activity. During mining of mineral from underground, huge quantity of ground water is pumped out to make mining possible. Groundwater samples have been collected from the 20 sampling sites of Dhanbad, a mining Township, in the lean period (summer) of the years 2011 and 2014. Four samples have been obtained from open well and 16 from hand pumps. Water quality parameters such as pH, total hardness, Ca hardness, Mg Hardness, chloride, sulphate, total dissolved solids, and heavy metals have been evaluated. The values of pH, total hardness, Ca hardness, Mg hardness, chloride, sulphate, and total dissolved solids have increased in 2014 as compared to 2011 which may be due to increase in mineral content in the lean period and decrease in the rate of recharge of aquifers in 2014. The concentration of heavy metals has decreased in 2014 as compared to 2011 which may be due to less leaching of heavy metals from the ground strata. From the overall study, it has been concluded that most of the water quality parameters of all the 20 groundwater samples in the year 2014 are not exceeding the acceptable concentration level, as mentioned in Indian drinking water specifications. Groundwater in the year 2014 has not shown any significant change in its quality as compared to the year 2011. In the incoming years, quality of groundwater will not show any drastic change unless and until any anthropogenic activity other than mining will affect it.

Keywords Groundwater · Water quality parameters · Coal mining · Heavy metals · Heavy metal pollution index

Introduction

Groundwater is becoming a major concern with respect to coal mining (Karroum et al. 2017; Kumari et al. 2014). Dhanbad, the coal capital of India, is famous for coal mining. Groundwater of Dhanbad town is very much affected due to nearby mining activity in Jharia coalfields. During mining, a large amount of groundwater is pumped out to make mining possible (Prasad et al. 2014; Selvakumar et al. 2017; Srinivas et al. 2017). This creates problem to groundwater with respect to its quality as well as quantity (Custodio et al. 2016; Saravanakumar and Kumar 2011). Mining affects the physical and chemical changes in the mine environment resulting in groundwater pollution (Pathak and Banerjee 1992; Singh 1988; Verma et al. 2017). Bukowski et al. (2006) have reported that underground mining operations can be associated with many environmental effects like vulnerability of groundwater to pollution and the effects of mining on useful aquifers. Banks et al. (1997) have reviewed the variety of hydro-chemical characteristics, environmental impacts, and treatment methods pertaining to groundwater discharging from mines. Seeing the importance of groundwater quality in mining area, the investigation has been carried out to understand the changes in groundwater quality of Dhanbad township within 3 years of time duration (May 2011–May 2014). Heavy metal pollution index (HPI) of the groundwater has also been evaluated according to described methodology (Prasad and Jaiprakash 1999; Prasad and Bose 2001; Prasad and Kumari 2008; Prasad and Mandal 2008; Prasad et al. 2011; Chabukdhara et al. 2017). On the basis of

✉ Babli Prasad
drbabliprasadd@yahoo.com

¹ CSIR-Central Institute of Mining and Fuel Research (CSIR-CIMFR), Barwa Road Campus, Dhanbad, India

Fig. 1 Layout of Dhanbad township showing different groundwater sampling points

this, groundwater quality of Dhanbad township has been predicted.

Materials and method

Study area

Dhanbad, one of the biggest coal belts of India, is actively associated with mining activities for more than a century. The oldest geological formations of the Dhanbad district are composed of crystalline metamorphic rocks which belong to Dharwar system in Indian stratigraphy. In these formations, rock types of both sedimentary and igneous origin are found. Course gritty soil is predominant in Dhanbad coal basin (Gautam et al. 2015). This type of soil mixed with big fragment of rocks is formed from the weathering of pegmatite, quartz, and conglomeratic sandstones. About 200 coal mines of Jharia coal fields, which produce prime coking coal, are located around Dhanbad

Township. The large-scale industries such as coal washing and coke making are located nearby. There is drinking water shortage in the township, especially in summer season. The population here is mainly depended on ground water sources. Taking all these into consideration, 20 groundwater sampling points have been selected, which covered almost entire township of Dhanbad (Fig. 1). Study of quality of selected groundwater samples had been carried out in the lean period of the years 2011 and 2014 to know the changes if any due to mining and allied activities.

Sampling and analysis

Out of 20, four samples have been taken from open well and 16 from hand pumps. The depth of open wells has been 25–30 feet and hand pumps 100–120 feet. Sampling has been done for the month of May (Summer) 2011 and May 2014 to get an idea of the change in concentrations of water quality parameters in 3 year time duration. Groundwater

samples have been collected in 2.5 l plastic containers pre-rinsed with groundwater. Analysis of different water quality parameters such as pH, total hardness, Ca hardness, Mg hardness, sulphate, chloride, and TDS has been carried out according to the standard method (IS: 3025 2009). For analysis of heavy metals, samples have been digested, concentrated, and prepared for analysis by Atomic Absorption Spectrophotometer (AAS) Model: M Series Thermo Fisher (Arnold et al. 1992). The digestion and concentration of water sample were carried out by reducing the volume of 1000–50 ml by slow heating on a hot plate with the addition of few milliliters of concentrated nitric acid. Slow heating was done to avoid metal loss due to evaporation. Analysis of metals has been performed by calibrating the instrument with different dilutions of the standard solutions and analysis of Cu, Mn, Pb, Fe, Cd, Zn, and Cr was performed at 324.7, 279.5, 217.0, 248.3, 228.8, 213.9, and 357.9 nm, respectively. Three replicates were run for each sample and the instrument was recalibrated after analysis of ten samples. The detection limit of AAS was well within the range for all elements analyzed. Overall precision expressed as percent relative standard deviation was obtained for all the samples. Because the samples were concentrated during digestion, the result obtained was calculated to get the actual concentration value.

Results and discussion

The results of physico-chemical analysis of 20 groundwater samples of Dhanbad Township, in lean period (summer) are given in Table 1. From Table 1, it has been observed that the highest pH value of 7.68 and the lowest of 5.82 in the year 2011, whereas the highest pH of 7.15 and the lowest of 5.95 in the year 2014 have been obtained. The pH value has not shown any remarkable change during the 3 years of period. In the year 2011, highest total hardness, Ca hardness, Mg hardness, chloride, sulphate, and total dissolved solids have been found 684, 456, 59.3, 260, 379, and 1184 mg/l, respectively. Whereas in the year 2014, these values have been found 860, 504, 86.51, 356, 547, and 1402 mg/l, respectively (Fig. 2). The increased concentrations of the above parameters in 2014 clearly indicate that it may be due to increased mineral content in groundwater in the lean period of 2014 as recharge of aquifers is lesser in 2014 than in 2011. In six groundwater samples in 2011 and 2014, the total hardness value exceeded the desirable limit of 300 mg/l as per drinking water specification (IS: 10500). Increased concentration of sulphate in 2011 and 2014 has been observed in groundwater sampling point 20 (379 mg/l) and 5 (547.36 mg/l), respectively. In rest all groundwater samples, sulphate has been found less than 200 mg/l (desirable limit of drinking

Table 1 Analysis of different parameters of groundwater in lean period of years 2011 and 2014 (in mg/l except pH)

Sampling site	pH		Total hardness		Ca hardness		Mg hardness		Sulphate		Chloride		TDS	
	2011	2014	2011	2014	2011	2014	2011	2014	2011	2014	2011	2014	2011	2014
1	7.17	6.78	120	116	76	92	10.692	5.832	21.442	20.6	40	76	244	223.5
2	5.82	6.15	232	240	120	136	27.216	25.272	92.288	100.528	68	128	579	313
3	7.29	6.93	128	124	92	88	8.748	8.748	70.864	79.516	88	148	322	332.5
4	6.92	6.71	684	496	456	300	55.404	47.628	181.28	94.348	220	356	1184	1105.5
5	7.26	6.87	284	860	156	504	31.104	86.508	56.44	547.36	68	188	446	1401.5
6	6.53	6.17	212	236	120	112	22.356	30.132	119.48	191.58	56	116	392	401.5
7	6.45	6.33	324	268	224	168	24.3	24.3	111.652	20.6	16	208	707	532.5
8	6.2	6.04	316	300	152	128	39.852	41.796	76.632	89.404	140	256	609	680
9	6.51	6.34	396	520	224	252	41.796	65.124	100.52	147.908	104	224	660	1016
10	6.97	6.53	376	348	204	152	41.796	47.628	61.388	82.4	152	192	673	532
11	6.41	6.25	620	228	376	52	59.292	42.768	196.524	93.524	260	132	1158	428.5
12	7.37	7.01	244	212	148	108	23.328	25.272	78.28	69.216	124	168	848	692
13	6.44	6.37	216	372	140	240	18.468	32.076	50.264	117.832	100	312	426	522
14	7.01	6.74	280	268	136	152	34.99	28.188	46.968	44.908	56	76	444	340.5
15	6.51	6.58	268	332	124	200	34.992	32.076	65.92	66.33	76	160	499	601
16	5.96	6.28	104	160	68	100	8.748	14.58	13.18	21.012	28	32	220	246
17	6.10	6.07	200	160	88	116	27.216	10.692	66.33	47.38	72	300	455	353.5
18	6.75	6.92	176	168	92	104	20.412	15.552	28.84	16.48	36	40	288	287.5
19	6.19	5.95	220	240	124	180	23.328	14.58	53.56	65.096	76	168	475	546.5
20	7.68	7.15	180	224	92	152	21.384	17.496	379.04	63.86	48	140	315	419

Fig. 2 Variation in concentration of different water quality parameters in groundwater of Dhanbad township, **a** pH, **b** Ca hardness, **c** total hardness, **d** Mg hardness, **e** sulphate, **f** chloride, and **g** TDS

Table 2 Analysis of heavy metals concentration (ppm) in ground water (in mg/l)

Sampling site	Analysis of Cu		Analysis of Mn		Analysis of Fe		Analysis of Pb		Analysis of Cd		Analysis of Zn		Analysis of Cr	
1	0.003	0.001	0.004	0.066	0.067	0.242	0.005	BDL	BDL	BDL	0.015	0.022	BDL	BDL
2	0.004	0.002	0.250	0.009	0.024	0.056	0.003	BDL	BDL	BDL	0.096	0.071	BDL	BDL
3	0.004	0.002	0.036	0.016	0.093	0.052	0.049	0.009	BDL	BDL	BDL	0.141	BDL	BDL
4	0.033	0.002	0.011	0.436	0.418	0.133	BDL	BDL	BDL	BDL	0.224	0.148	0.004	0.004
5	0.005	0.004	0.035	0.073	1.399	0.063	0.003	0.002	BDL	BDL	0.172	0.195	BDL	BDL
6	0.002	0.001	0.374	0.441	0.438	0.081	BDL	BDL	BDL	BDL	0.011	0.022	BDL	BDL
7	0.011	0.005	0.111	0.152	0.385	0.208	0.001	0.001	BDL	BDL	0.026	0.033	BDL	BDL
8	0.009	0.005	0.008	0.018	1.667	0.511	BDL	BDL	BDL	BDL	0.281	0.052	0.002	0.002
9	0.014	0.003	0.196	0.039	1.986	0.094	BDL	BDL	BDL	BDL	0.019	0.009	BDL	BDL
10	0.001	0.003	0.006	0.005	BDL*	0.063	BDL	BDL	BDL	BDL	0.038	0.027	BDL	BDL
11	0.031	0.002	1.246	0.495	0.079	0.081	0.002	0.009	BDL	BDL	0.097	0.058	0.006	0.005
12	0.002	0.005	0.001	0.109	BDL*	0.124	BDL	0.011	BDL	BDL	BDL	BDL	0.001	0.001
13	0.006	0.003	0.029	0.019	0.165	0.057	BDL	0.001	0.004	BDL	0.031	0.030	0.003	0.002
14	0.003	0.001	0.092	0.015	0.001	0.040	0.001	0.001	BDL	BDL	0.032	0.032	0.004	0.003
15	0.008	0.001	0.004	0.073	0.550	0.063	0.001	0.002	0.004	BDL	0.078	0.019	0.002	BDL
16	0.006	0.002	0.009	0.349	0.689	0.276	0.001	0.005	BDL	BDL	0.177	0.146	0.002	0.002
17	0.014	0.001	0.015	0.017	2.450	0.147	0.002	0.001	BDL	BDL	0.023	0.028	0.003	0.002
18	0.002	0.001	0.168	0.047	0.378	0.248	BDL	BDL	BDL	BDL	0.069	0.022	0.001	0.001
19	0.008	0.003	0.101	0.036	0.810	0.064	BDL	BDL	BDL	BDL	0.469	0.091	0.002	0.002
20	0.004	0.008	0.008	0.002	0.123	0.031	0.001	0.001	BDL	BDL	0.079	0.048	0.003	BDL

* Below detection limit

water specification, IS: 10500). Chloride concentration in one sampling point 11 (260 mg/l) in 2011 and four sampling point 4, 8, 13, and 17 (356, 256, 312, and 300 mg/l) in 2014 are higher than the desirable limit (250 mg/l) of Indian drinking water specification. This observation favours decrease in recharge of aquifers and increased mineral content in groundwater in 2014. Eight groundwater samples in 2011 and ten in 2014 have exceeded the desirable limit of 500 mg/l with respect to TDS value (Table 1). During the investigation period, the highest TDS of 1184 mg/l in 2011 and 1401 mg/l in 2014 has been obtained which indicate high dissolved mineral content in groundwater of Dhanbad Township.

The evaluation of concentration of seven heavy metals such as Cu, Mn, Fe, Pb, Cd, Zn, and Cr in the years 2011 and 2014 in groundwater of Dhanbad town is listed in Table 2. The highest concentration of Cu, Mn, Fe, Pb, Cd, Zn, and Cr in groundwater in the years 2011 and 2014 has been found 0.033, 1.246, 2.451, 0.049, 0.004, 0.469, 0.006 and 0.008, 0.495, 0.511, 0.009, BDL, 0.195, 0.045, respectively (Fig. 3). From the results, it has been observed that concentrations of Cu, Pb, Cd, Zn, and Cr were well below the permissible limit of Indian drinking water specification (IS: 10500). The concentration of Mn and Fe has been found more than the permissible limit at many places in both the years, but the concentrations have shown a declination trend from 2011 to 2014. In 2011, at seven

sampling site (2, 6, 7, 9, 11, 18, and 19), Mn concentration has been more than the permissible limit of 0.1 mg/l, but in 2014, six sampling sites (4, 6, 7, 11, 12, and 16) have concentration above the permissible limit. Similarly, in 2011 at 11 sampling points (4, 5, 6, 7, 8, 9, 15, 16, 17, 18, and 19), Fe concentration has been more than the permissible limit of 0.3 mg/l, and in 2014, only one sampling site 8 has shown higher concentration of Fe (0.511 mg/l). The decrease in metal concentration in 2014 as compared to 2011 indicates that less leaching of these metals from ground strata to groundwater has been taken place.

The Heavy Metal Pollution Index (HPI) model (Eqs. 1 and 2) proposed given by (Mohan et al. 1996) has been used for knowing the total quality of groundwater with respect to heavy metals in the years 2011 and 2014:

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

where Q_i is the sub-index of the i th parameter. W_i is the unit weightage of the i th parameter and n is the number of parameters considered.

The sub-index (Q_i) of the parameter is calculated by

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

where M_i is the monitored value of heavy metal of the i th parameter, I_i is the ideal value of the i th parameter, and S_i

Fig. 3 Variation in concentration of different heavy metals in groundwater of Dhanbad Township, **a** Fe, **b** Mn, **c** Cu, **d** Zn, **e** Pb, **f** Cr, and **g** Cd

is the standard value of the i th parameter. The sign (–) indicates the numerical difference of the two values, ignoring the algebraic sign.

Since the unit weightage (W_i) of Fe and Mn is very less in HPI calculation of groundwater, these metals contribute very less on HPI value. Heavy metals such as Pb, Cd, and Cr have no relaxation in drinking water standard and they have high unit weightage (W_i) value in HPI calculation. Hence, even their very low concentration present in water makes it of poor quality and gives high values in HPI evaluation. The HPI calculation of groundwater quality of Dhanbad Township in the years 2011 and 2014 in the lean period is given in Tables 3 and 4. The value of HPI calculation in the year 2011 is 4.7640 and its value decreased to 1.4735 in the year 2014 supports the fact that less leaching of these metals from ground strata to groundwater is taking place. Overall, the groundwater of Dhanbad town with respect to heavy metal contamination is not a serious issue and groundwater contamination of the township is not taking place due to severe coal mining activity near the township, though the concentration of few water quality parameters such as total hardness, Ca hardness, Mg hardness, chloride, sulphate, and total dissolved solids has

increased in 2014 as compared to 2011, which may be due to increased mineral content in groundwater in lean period and decrease in recharge rate of aquifers in 2014. From overall study, it has been seen that different water quality parameters in the year 2014 have not shown any significant change with respect to the year 2011 and there is no significant degradation in the quality of groundwater. In the incoming years, quality of groundwater of Dhanbad Township will not show any drastic change in its quality unless and until any anthropogenic activity will affect it.

Conclusion

The concentration of various water quality parameters such as total hardness, Ca hardness, Mg hardness, chloride, sulphate, and total dissolved solids has been increased in 2014 as compared to 2011 which might be due to increase in mineral content in the lean period and decrease in the recharge of aquifers in 2014. The value of HPI calculation in the year 2011 was 4.7640 and its value decreased to 1.4735 in the year 2014 supports the fact that less leaching of heavy metals from ground strata to groundwater had

Table 3 HPI calculation for groundwater of Dhanbad Town in 2011

Heavy metal	Mean value (ppb) M_i	Standard permissible value (ppb) S_i	Highest desirable value (ppb) I_i	Unit weightage (W_i)	Sub-index (Q_i)	$W_i \times Q_i$
Cu	8.5	1500	50	0.0006	2.8620	0.0017
Mn	135.2	300	100	0.0033	17.6	0.0580
Zn	96.85	15000	5000	0.00006	49.03	0.0029
Pb	3.45	50	–	0.02	6.9	0.138
Fe	131.7	1000	300	0.001	24.042	0.0240
Cd	0.4	10	–	0.1	4	0.4
Cr	1.65	50	–	0.02	3.3	0.066
				$\sum W_i = 0.14496$		$\sum W_i \times Q_i = 0.6906$

HPI = 4.7640

Table 4 HPI calculation for groundwater of Dhanbad Town in 2014

Heavy metal	Mean value (ppb) M_i	Standard permissible value (ppb) S_i	Highest desirable value (ppb) I_i	Unit weightage (W_i)	Sub-index (Q_i)	$W_i \times Q_i$
Cu	2.75	1500	50	0.0006	3.258	0.0019
Mn	120.85	300	100	0.0033	10.425	0.034
Zn	59.70	15000	5000	0.00006	49.403	0.0029
Pb	2.15	50	–	0.02	4.3	0.0286
Fe	586.1	1000	300	0.001	40.857	0.0408
Cd	0.0	10	–	0.1	0.0	0.0
Cr	1.2	50	–	0.02	2.4	0.048
				$\sum W_i = 0.14496$		$\sum W_i \times Q_i = 0.2136$

HPI = 1.4735

taken place. Overall, the contamination of groundwater of Dhanbad town was not a serious issue and groundwater contamination of the township was not taking place due to severe coal mining activity near the township. Different water quality parameters in the year 2014 did not show any significant change with respect to the year 2011 and there was no significant degradation in the quality of groundwater. On the basis of the study, it was predicted that in the coming years, quality of ground water will not show any drastic change in its quality unless and until any anthropogenic activity will affect it.

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