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Heavy Metal Pollution Index of Ground Water of an Abandoned Open Cast Mine Filled with Fly Ash: a Case Study

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Abstract Ground water samples were collected from the periphery of a fly ash filled open cast mine, from within the mine property, and from a half kilometre away from the site. Concentrations of metals such as Cu, Zn, Cd, Pb, and Cr were consistently below the permissible limit for drinking water, but concentrations of Fe and Mn were above the permissible limit. The data were used to calculate a heavy metal pollution index (HPI). The HPI of the ground water of the ash filled mine was 36.67, which was below the critical index limit of 100. The HPI of Dhanbad Township ground water, from very near to the mining area, was 11.25. The results indicate that leachate from the fly ash filled mine has apparently contaminated the ground water to a limited extent.

Keywords Fly ash · Ground water · Heavy metal pollution index · Mine filling

Introduction

In a previous paper (Prasad and Mondal 2008), we reported on the effects of filling an abandoned open cast mine with fly ash from the Chandrapura Thermal Power Plant. We analysed physico-chemical parameters and heavy metals in ground water obtained from the ash-filled mine, from the periphery of the mined area, and from a site a half kilometre away from the ash-filled zone, and concluded that ground water concentrations of Fe and Mn were significantly greater in the ash-filled area than in the uncontaminated area. Other parameters were found to be affected but not at problematic levels.

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 judgements to compile the effects of all of the pollution parameters. Several methods have been proposed (Horton 1965; Tiwary and Mishra 1985; Joung et al. 1979; Landwehr 1979; Nishidia et al. 1982). The authors (Prasad and Jaiprakas 1999) and several others have previously used a heavy metal pollution index (HPI) based on work by Mohan et al. (1996). In the present paper, we used the weighted arithmetic average mean of the concentrations of seven metals, iron, manganese, lead, copper, cadmium, chromium and zinc, as the basis of an HPI. The critical pollution index value, above which the overall pollution level should be considered unacceptable, is 100. In the present study, we use the previously reported data (Prasad and Mondal 2008) to illustrate how this approach may be used to evaluate ground water pollution near any mining area.

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 (Horton 1965; Mohan et al. 1996; Reddy 1995). 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 (Indian

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Table 1 HPI calculations for ground water of the fly ash filled mine, based on Indian drinking water standards (Indian Standard 1991, 10500)

Heavy metals (ppb)	Mean concentration (M_i)	Highest permitted value for drinking water (S_i)	Desirable maximum value (I_i)	Unit weightage, W_1	Sub-index (Q_i)	$W_i \times Q_i$
Fe	115.6	1,000	100	0.001	1.73	0.0017
Mn	1,706.2	300	100	0.0033	803.1	2.6502
Pb	5.2	50	–	0.020	10.4	0.2040
Cu	7.5	1,000	50	0.001	4.47	0.0045
Cd	1.5	10	–	0.100	15.0	1.5
Cr	3.9	10	–	0.100	39.0	3.900
Zn	316.0	15,000	5,000	0.00006	46.84	0.0028

$\Sigma\, W_i = 0.22536$, $\Sigma\, W_iQ_i = 8.26$, HPI = 36.67

Standard 1991, 10500). 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.

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

where Q_i is the sub index of the ith parameter. W_i is the unit weightage of ith 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 ith parameter, I_i is the ideal value of ith parameter, and S_i is the standard value of the ith parameter, in ppb. Generally, the critical pollution index value is 100.

Results and Discussion

The sampling and analytical methodology was reported in Prasad and Mondal (2008). The HPI was determined by taking the mean concentration value of the selected metals over 8 months (Prasad and Mondal 2008), using Eq. 1. In Table 1 detailed calculation of the HPI with unit weightage (W_i) and standard permissible values (S_i) are presented for the ground water under study. The HPI came out to be 36.67, which is below the critical value of 100. This indicates that, in general, the ground water is not critically contaminated with respect to heavy metals. In an earlier study (Prasad and Jaiprakas 1999), the HPI of ground water from very near the mining area was found to be 11.25. This indicates that the ground water of the fly ash filled mine was likely contaminated with metals leached from the fly ash. The HPI of each sampling point was also calculated separately (Table 2).

Table 2 HPI of ground water at each sampling point

Sampling point	HPI	Mean deviation	% Deviation
1	15.53	−21.14	−57.65
2	16.69	−19.98	−54.49
3	75.10	+38.44	+104.83
4	55.77	+19.11	+52.11
5	50.41	+13.74	+37.50
6	7.62	−29.05	−79.23

Mean HPI = 36.67

This enabled us to compare the quality of water at each ground water sampling point with respect to the selected metals. The HPI of all of the ground water was below the critical index value of 100, though the HPI value of sampling points 3, 4, and 5 were much higher than at the other sampling points.

Conclusion

The HPI calculated for the ground water of the ash-filled mine, based on the mean concentrations of all of the selected metals for all sampling points for 8 months was 36.67, which is below the critical index value of 100. The HPI of ground water from very near the mining area was previously found to be 11.25 (Prasad and Jaiprakas 1999). The HPI proved to be a very useful tool in evaluating overall pollution of the ground water. It indicated that although the ground water at the study site was likely affected by leaching of heavy metals from the fly ash, it was not critically contaminated with respect to heavy metals. This approach may be useful elsewhere.

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