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Technical Communication

Performance of a Natural Wetland Treating Acid Mine Drainage in Arid Conditions

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Abstract. A wetland naturally formed in the discharge from a copper mine tailing impoundment in Rajasthan, India. The wetland is abundantly vegetated. This study investigated changes that occurred in the seepage as it travelled 180 and 380 m (P_1 and P_2) through the wetland. The pH increased from 6.17 to 7.10 at P_1 and 7.34 at P_2 in the pre-monsoon season, 6.53 to 7.36 at P_1 and 7.77 at P_2 in the post-monsoon season, and from 6.20 to 6.63 at P_1 and 6.89 at P_2 in the winter. Contaminant removal at P_2 ranged from 40 to 95%.

Key words: Acid mine drainage; natural wetland; pollutant removal; tailings impoundment

Introduction

Acid mine drainage (AMD) typically requires long-term collection and treatment. Conventional treatment systems require the addition of chemicals like hydrated lime and caustic soda, which are expensive and generate voluminous low-density (solids ≈ 5%) sludge (Fiset et al. 2003; Stark et al. 1994). The disposal of this sludge is again an environmental problem. Natural processes require minimal on-going maintenance and represent a better long-term solution to AMD treatment (Kleinmann 1990; Ye et al. 2001). There has been growing interest in the use of wetlands and other passive treatment systems to remediate a variety of wastewaters, including AMD (Allen et al. 1996; Cole 1998; Eger et al. 1994; Fyson et al. 1994; Groudev et al. 2001).

Quiescent water conditions in a wetland are conducive to the sedimentation of AMD solids. The adsorption/ filtration potential of aquatic plants roots and stems and the ion exchange/ adsorption capacity of wetland sediments also facilitate wastewater treatment (Matagi et al. 1998) Although direct uptake of trace elements into plant tissues appears to account for only a small portion of the total removal (Mitsch and Wise 1998), plants provide suitable habitat and energy sources (organic carbon) to maintain and stimulate a diverse microbial population in the sediment (Skousen 2001). Agglomeration processes, carried out by metabolites secreted by microorganisms, aid in the precipitation of fine suspended particulates. These microbes drive the immobilization of pollutants in the sediments through oxidative and reductive processes, and precipitation of metal oxides and hydroxides (Stark et al. 1994; Ye et al. 2001).

This paper presents the results of field experiments conducted on-site at one of the largest copper projects in India. We studied the effectiveness of a wetland that had naturally developed down-gradient of a tailings dam.

Experimental Site

The Khetri Copper Project (KCP) (located at latitude 75° 48' in northeastern Rajasthan, Figure 1) is India's largest mining cum metallurgical copper project, and is a major component of Hindustan Copper Ltd. The project includes both an open pit and an underground mine and is a permanent source of AMD. At present, the project produces 4000-5000 t of copper ore (chalcopyrite, also containing pyrite) daily. About 90% of the processed ore is rejected as tailings and is pumped as a slurry (55% solids), at a rate of about 1.7 x 10^6 t per annum (Jha et al. 1996), to a tailings impoundment, which is 1.6 km from the plant. When the tailings dam was first constructed in 1978, it was 12 m high with capacity of 1.75 x 10^6 m^3. During the next two years, it was raised to 22 m and then 25 m, with a capacity of 9.0 million and 12.0 million m^3, respectively (Jha et al. 1996).

While all of the solids in the tailings slurry are retained within the impoundment, water seeps from the dam and flows downstream. The continuous seepage of water has created a natural wetland. The main plant species in this wetland are *Typha angustata* (patera, pata), *Desmostachya bipinnata* (bor, grass), *Saccharum bengalense* (munja), and *Oscillatoria* (blue green algae).

This Khetri project is in an arid area and was facing an acute shortage of water in 1992 when it was decided to reclaim the seepage water. About 1000 m^3/day of this water is currently collected at four locations down-gradient of the wetland and pumped back to the processing plant.

Collection of Samples

We examined how water quality changed during passage through the wetland. Seepage quality varies depending on rainfall, i.e., pre-monsoon and post-

Figure 1. Geographical location of field study

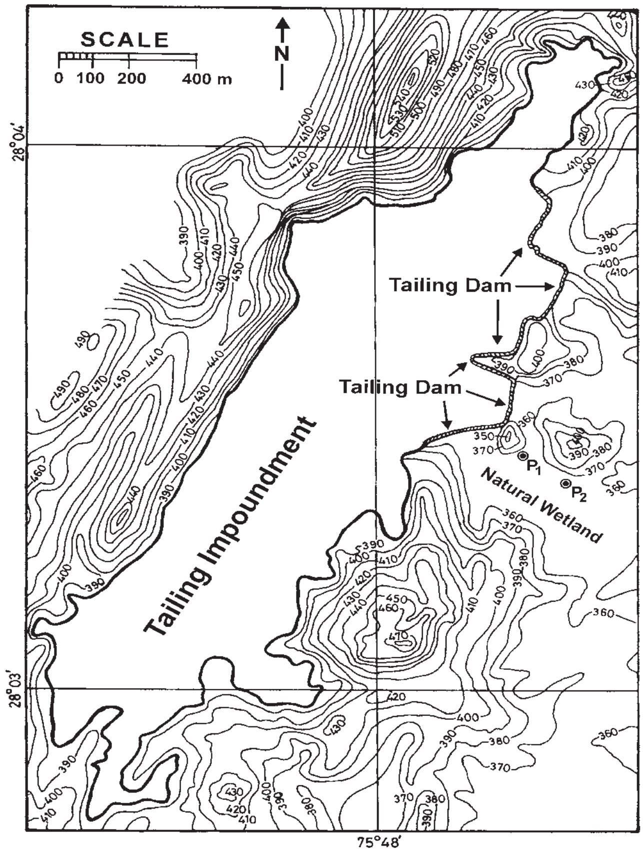

Figure 2. Plan showing field experiment site

monsoon. Samples were collected at 8 sites between the dam and the wetland and at two other locations where the AMD has travelled a distance of 180 m (P_1), and 380 m (P_2), as shown in Figure 2. P_1 and P_2 are two sumps excavated by the mine management to collect the seepage water so that it can be pumped to the processing plant. The natural wetland falls between the tailing dam and these collecting pits. The area that this seepage water travels in the wetland before reaching P_1 is 8000 m^2; the area covered by the seepage water before reaching P_2 is about 17500 m^2.

In an attempt to obtain representative samples, eight 1 L samples were collected at each site in the pre-monsoon (25 – 26 May 2002), post-monsoon (22 Aug. 2002), and winter (25 Feb. 2003) seasons; the values for the 8 samples were then averaged. Pre-wetland samples were consistently collected at 8 sites downstream of the tailings dam, 50-100 m apart; at P_1 and P_2, samples were collected at 1 hour intervals. Although samples were collected along the tailings dam, the flow rate could not be measured because the rate of seepage was very low. Thus, it was not possible to measure the total amount of water entering the wetland.

We measured: pH, electrical conductivity (EC), turbidity, total hardness, acidity, alkalinity, and concentrations of sulphate, and various metal ions. Metal concentrations were determined for filtered water samples that had been preserved with nitric acid using an atomic absorption spectrophotometer (G.B.C. Australia, AVANTA). All parameters were determined using standard methods (APHA 1992).

Results

The average water quality of AMD samples collected up-gradient of the wetland for the pre-monsoon, post-monsoon, and winter seasons are given in Table 1. Tables 2 and 3 list the equivalent values for P_1 and P_2, respectively. For all three sites, there was very little variability in the observed water quality relative to sampling site (Table 1) or time of day.

EC was decreased by 15.28%, 12.13%, and 7.4% at P_1; at P_2, EC was decreased by 29.61%, 24.39%, and 14.53%, respectively in pre-monsoon (May, 2002), post-monsoon (Aug., 2002) and winter (Feb., 2003).

Turbidity was decreased by 38.55%, 26.76%, and 19.69% at P_1; at P_2, it was decreased by 56.59%, 53.22%, and 38.94%, respectively.

Sulphate was decreased by 21.27%, 20.66%, and 12.74% at P_1; at P_2, it was decreased by 35.59%, 36.41%, and 22.70%, respectively.

Table 1. Seasonal water quality variation (averaged for 8 samples for each site at each date) at the entrance of the wetland at the Khetri Copper Project

Parameters	Pre-monsoon	Post-monsoon	Winter
pH	6.17	6.53	6.20
EC, µs/cm	8152.88	7240.38	8211.88
Turbidity, JTU	26	39	26
Sulphate, mg/L	2806	2671	2811
Acidity, mg/L as $CaCO_3$	40.37	27.34	39.07
Alk., mg/L (as $CaCO_3$)	7.81	13.48	7.10
Hardness, mg/L	2671.8	2566.6	2669.2
Fe, mg/L	7.251	5.321	7.196
Cu, mg/L	2.244	2.110	2.224
Zn, mg/L	1.671	1.408	1.679
Pb, mg/L	1.143	1.065	1.175
Co, mg/L	0.758	0.615	0.770
Ni, mg/L	1.824	1.602	1.784
Mn, mg/L	0.908	0.742	0.880

Table 2. Seasonal water quality variation (averaged for 8 samples for each site and date) at the first water collecting pit (P_1) at the Khetri Copper Project

Parameters	Pre-monsoon	Post-monsoon	Winter
pH	7.10	7.36	6.63
EC, µs/cm	6906.4	6362.1	7604.9
Turbidity, JTU	16	28	21
Sulphate, mg/L	2209	2118	24531
Acidity, mg/L as $CaCO_3$	19.5	14.3	27.3
Alk., mg/L as $CaCO_3$	100.7	117.8	88.0
Hardness, mg/L	2311.9	2176.8	2392.1
Fe, mg/L	3.202	3.032	3.978
Cu, mg/L	1.289	1.112	1.726
Zn, mg/L	0.450	0.358	0.813
Pb, mg/L	0.567	0.334	0.806
Co, mg/L	0.295	0.209	0.347
Ni, mg/L	0.892	0.655	1.145
Mn, mg/L	0.287	0.214	0.397

The percentage of acidity neutralized was 51.62%, 47.62%, and 30.02% at P_1; at P_2, it was 87.12%, 85.73%, and 61.86 % respectively.

Hardness was decreased by 13.47%, 15.19%, and 10.38% at P_1; at P_2, it was decreased by 28.72%, 30.28%, and 20.49%, respectively.

The percentage of copper removed was 42.56%, 47.30%, and 22.39% at P_1; at P_2, it was 82.26%, 94.74%, and 50.27% respectively.

The percentage of iron removed was 55.84% 43.01%, and 44.72% at P_1; at P_2, it was 83.13%, 79.93%, and 70.99%, respectively.

Table 3. Seasonal water quality variation (averaged for 8 samples for each site and date) at the second water collecting pit (P_2) at the Khetri Copper Project

Parameters	Pre-monsoon	Post-monsoon	Winter
pH	7.34	7.77	6.89
EC, µs/cm	5738.3	5474.4	7081.5
Turbidity, JTU	11	18	16
Sulphate, mg/L	1808	1698	2173
Acidity, mg/L as $CaCO_3$	5.2	3.9	14.97
Alkalinity, mg/L	166.0	184.4	113.5
Hardness, mg/L	1904.5	1789.4	2122.3
Fe, mg/L	1.223	1.068	2.087
Cu, mg/L	0.398	0.111	1.059
Zn, mg/L	0.143	0.104	0.318
Pb, mg/L	0.441	0.286	0.611
Co, mg/L	0.171	0.145	0.239
Ni, mg/L	0.641	0.421	0.810
Mn, mg/L	0.094	0.041	0.252

The percentage of cobalt removed was 61.08%, 66.02%, and 54.94% at P_1; at P_2, it was 77.44%, 76.42%, and 68.96%, respectively.

The percentage of zinc removed was 73.07%, 74.57%, and 51.58% at P_1; at P_2, it was 91.44%, 92.61%, and 81.06%, respectively.

The percentage of lead removed was 50.39%, 68.64%, and 31.40% at P_1; at P_2, it was 61.42%, 73.15%, and 48.00%, respectively.

The percentage of nickel removed was 51.10%, 59.11%, and 35.82% at P_1; at P_2 it was 64.86%, 73.72%, and 54.60%, respectively.

The percentage of manganese removed was 68.39%, 71.16%, and 54.89% at P_1; at P_2, it was 89.65%, 94.61%, and 71.36%, respectively.

Efficiency/Performance of the Wetland

Out of 1000 m^3/day of water reclaimed from the seepage of the tailing dam, 400 m^3 is reclaimed at P_1 and 500 m^3 is reclaimed at P_2. The remaining water is reclaimed at two other locations, which were not monitored. Based on the area and the outflow of the wetland, the efficiency of the wetland was estimated. It is likely an underestimation because evaporation and transpiration have not been considered, and although the underlying stratum beneath the wetland is an impermeable quartzite, some percolation undoubtedly occurs.

Dietz et al. (1994) reported unit area removal rates at three surface flow wetlands ranging from 0.22 to 6.47 $g/m^2/d$ for Fe, from 0 to 0.26 $g/m^2/d$ for Mn, and from

1.95 g/m^2/d to 17.7 g/m^2/d for acidity. Eger et al. (1994) reported removal rates of 0.04 g/m^2/d Ni, 0.005 to 0.002 g/m^2/d for Cu, 0.009 to 0.0001 g/m^2/d for Co, and 0.04 to 0.006 g/m^2/d for Zn in wetlands receiving acid mine water. Our unit area removal rates for each parameter are given in Tables 4 and 5.

Discussion and Conclusions

Natural forces tend to ameliorate the adversities to nature created by man. The Khetri management was unaware of the beneficial functions of the natural wetland because the importance of passive treatment is not well known in India. Management's main aim was to recover the maximum amount of water downstream of the tailing dam. To do this, they made some small channels/trenches from the tailings dam to the collecting points, passing through the wetland. This undoubtedly reduced the efficiency of the wetland. In addition, this wetland has received no maintenance since it naturally developed 25 years ago, and there is no control over flow rate or water depth.

Our goal was to assess the performance of a wetland that had developed naturally and had not been optimised. There is no control on substrate, AMD loading, and plant type or density in natural wetlands (Eger 1994; Eger and Lapakko 1988; Eger et al. 1994; Frostman 1996). Our findings are consistent with other reported work (Dietz et al. 1994; Eger et al.1994). The seepage water flowing through the dense vegetation was naturally treated; considering the lack of maintenance, our study revealed a promisingly efficient removal of heavy metals, sulphate, and hardness.

The wetland plants tolerated the water quality well and showed no negative effects. This is important since wetland vegetation disperses flow and enriches the substrate by continuously adding decaying biomass and nutrients for sulphate reducing bacteria, which help treat the AMD. The root system and plants provide surface area for the adhesion of microorganisms, and the roots facilitate the diffusion of oxygen, creating conditions for both aerobic and anaerobic microenvironments (Komnitsas et al. 2001).

Despite maximum temperatures above 40° C for eight months of the year and the fact that the annual rainfall hardly exceeds 200 mm per year, the wetland was sustained by the continuous flow from the tailings dam. The efficiency of the water treatment was apparently affected by ambient temperature. However, good results were achieved even in the cooler winter months, due presumably to the continued contribution of dead plant biomass and clays (Groudev et al. 2001 a, b). The drop-off in efficiency in the winter could also have been because

Table 4. Wetland efficiency in terms of pollutant removal in g/m^2/day at P_1

Parameters	Pre-monsoon	Post-monsoon	Winter
Sulphate	29.84	27.63	17.91
Acidity	1.042	0.651	0.587
Alkalinity	-4.646	-5.214	-4.043
Hardness	17.993	19.491	13.855
Iron	0.202	0.114	0.161
Copper	0.048	0.050	0.025
Zinc	0.061	0.053	0.043
Lead	0.029	0.037	0.018
Cobalt	0.023	0.020	0.021
Nickel	0.047	0.047	0.032
Manganese	0.047	0.026	0.024

Table 5. Wetland efficiency in terms of pollutants removal in g/ m^2/day at P_2

Parameters	Pre-monsoon	Post-monsoon	Winter
Sulphate	28.54	27.79	18.24
Acidity	1.005	0.670	0.689
Alkalinity	-4.520	-4.885	-3.040
Hardness	21.921	22.204	15.625
Iron	0.172	0.122	0.146
Copper	0.053	0.057	0.033
Zinc	0.044	0.037	0.039
Lead	0.020	0.022	0.016
Cobalt	0.017	0.013	0.015
Nickel	0.034	0.034	0.028
Manganese	0.023	0.020	0.018

the wetland plants are harvested then by the local people for making furniture (*S.bengalense*), thatched roofs (*D.bipinnata*), and ropes (*T. angustata*).

In the samples collected in the post-monsoon season, the possibility of dilution should not be ignored**.** However, sulphate levels only decreased by about 10%, so dilution did not appear to be too significant.

The contribution of the studied wetland is evident, indicating that wetlands should be an attractive option in developing countries facing similar water problems. Natural wetlands can provide long term treatment of mine water as long as the discharges do not overwhelm their capacity, though periodic maintenance is recommended. However, more research is needed on how to sustain and increase the treatment life of such wetlands.

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