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Environmental Quality of the Boula-Nuasahi Chromite Mine Area in India

Biswaranjan Dhal · Nigama Nanda Das · Banshi Dhar Pandey · Hrudaya Nath Thatoi

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Abstract Chromite mining can create hostile conditions for organisms in the surrounding environment. Overburden soil and mine water samples were collected and analyzed for their microbial diversity, nutrient content, and water quality at the Boula-Nuasahi Mine. Most of the water parameters that were measured exceed national/international standards. The microbial population was low (soil: $45 \pm 0.06 \times 10^5$ bacteria, $20 \pm 0.03 \times 10^5$ fungus) and the overburden soils have a low nutrient (N, P, K) content. The metal ions were found to have leached to nearby agriculture lands, making them less fertile for crop production. Overburden dumps and seepage water were found to be the main sources of chromium pollution.

Keywords Chromium · Mine water · Orissa · Overburden soil · Pollution · Toxicity

B. Dhal · B. D. Pandey (✉)
National Metallurgical Laboratory, CSIR,
Jamshedpur 831007, India
e-mail: bdpnml@gmail.com

N. N. Das
Department of Chemistry, North Orissa University,
Baripada 757003, Orissa, India

H. N. Thatoi
Department of Biotechnology, College of Engineering &
Technology, Bhubaneswar 751014, Orissa, India

Present Address:
B. D. Pandey
Mineral Resources Research Division, Korea Institute
of Geoscience and Mineral Resources (KIGAM),
92, Gwahang-no, Yuseong-gu, Daejeon 305-350, Korea

Introduction

The mineral deposits of Orissa account for 95% of India's chromite, 92% of its nickel ore, 69% of its cobalt ore, 55% of its bauxite, 51% of its titaniferous magnetite, 40% of its limestone, 36% of its pyrophyllite, 33% of its iron ore (hematite), 26% of its sillimanite, 25% of its fireclay and garnet, 24% of its coal and zircon, and 20% of its vanadium ore resources (Ministry of Mines 2010). Chromite, the only economic ore of chromium, is considered to be one of Orissa's most important resources, with approximately 183 million tons of deposits located in the region's Sukinda and Baula-Nuasahi mining belts. Chromite is mostly found near Jajpur (16 mining leases; 4,320.93 ha mining area), and Keonjhar (5 mining leases; 2,013.123 ha mining area), the Dhenkanal districts (3 mining leases; 960.8 ha). The Bangur chromite mine lease of OMC Ltd. (Boula-Nuasahi) occupies an area of 145.85 ha (360.5 acres) in the Keonjhar district. Chrome and chrome concentrate is generally exported to China, Russia, Japan, and the Netherlands, totalling about 32.8 lakh (hundred thousand) tons of chromite ore in 2007–08 (Govt of Orissa 2009).

Chromite belongs to the spinel group and has the basic formula $R^{++} R_2^{+++} O_4$, where $R^{++} = $ Mg, Fe with traces of Mn and Ni and $R^{+++} = $ Cr, AI and Fe with traces of Ti and V. It has five major components, viz. MgO, FeO, Cr_2O_3, Al_2O_3, and Fe_2O_3. Pure chromite contains 67.9% chromic oxide (Cr_2O_3) by weight or 46.5% chromium by weight (Sahoo 1998).

Most of the chromite is extracted through open cast mining. In this study, we studied the environmental parameters of the Boula-Nuasahi chromite mine area, Orissa, India to assess the possibility of subsequent restoration and management of the mine site. Different parameters, such as nutrient content, water quality, and microbial diversity of the overburden dumps and mine drainage water were analyzed, and details are presented.

Materials and Methods

Study Area

The Bangur mining lease of OMC (Orissa Mining Corp.) Ltd is located to the north of the village of Bangur in the Anandpur sub-division of Keonjhar District, Orissa. This area lies between longitude 20° 15′38″—21° 16′55″ north latitude and 86° 19′14″—86° 20′10″ east longitude (Fig. 1).

A tropical environmental and humid temperate climate prevails over this region. The area shows a sub-dendritic pattern with a low drainage density. River Salandi forms the principal drainage channel in the area, collecting the surface run off from its tributaries and seasonal streamlets. The area is rocky and before mining, there are small herbs and shrubs present. The shrubs are large (1–3 m or larger) and joined to each other with branching. At the time of open cast mining, the top soil and waste rocks were deposited in dumps. Groundwater seepage and mine water are pumped by means of electrical pumps to the land surface, where it is used to irrigate approximately 10 km^2 of agricultural land, and finally mixes with the irrigation canal of the Salandi River. This watercourse is used for agriculture, for bathing and washing by nearby residents, and is consumed by animals.

Sample Collection

Altogether, six soil samples and three water samples were collected from different locations from the mining area. Soil samples collected from the mining site overburden dumps varied from fresh low grade ore to 15–16 year old dumps. Chromite overburden soil (COS-1) was collected from a 3 year old overburden dump, COS-2 (fresh low grade ore with soil), COS-3 (8–9 year old overburden dump), COS-4 (7 year old overburden dump), COS-5 (15–16 year old overburden dump), and COS-6 (agricultural land adjacent to a 15–16 year old overburden dump). The water samples that were collected from the mine site were designated as chromite mine water: CMW-1 from the underground seepage, CMW-2 (100 m deep quarry water), and CMW-3 (stored pond water). All the samples were collected and stored in sterile polythene bags and bottles at 4°C.

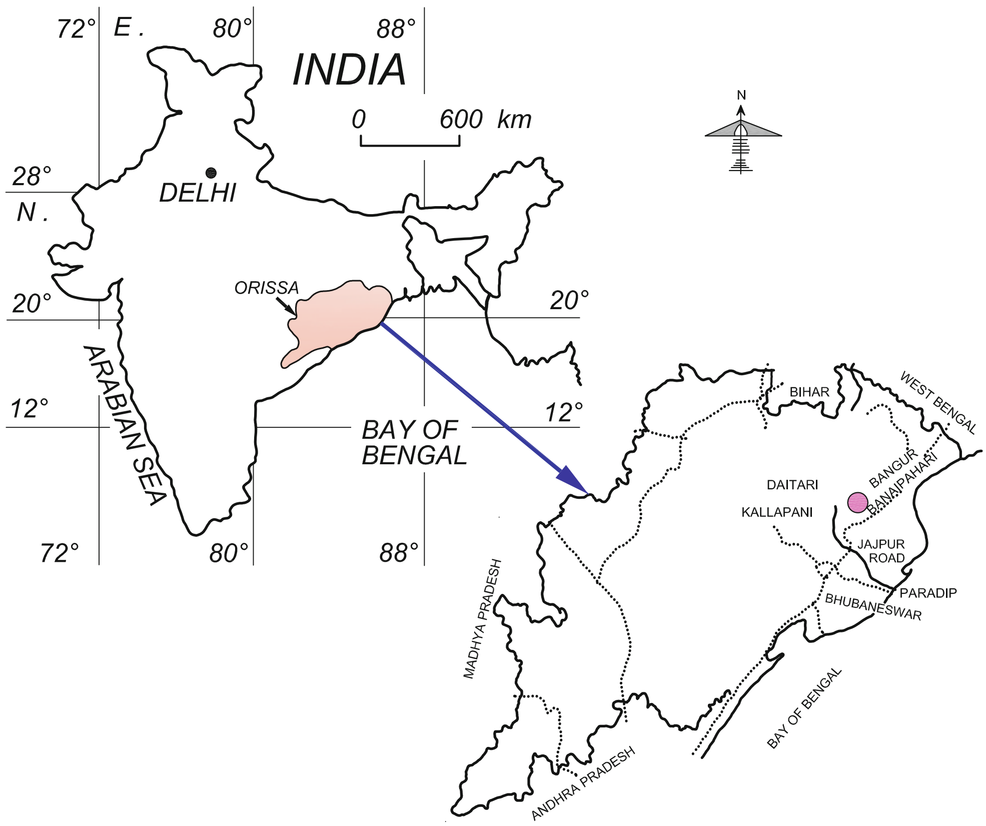

Fig. 1 *Filled circle* Location of the Baula-Nuasahi (Bangur) chromite mine of Orissa

Microbial Diversity in Overburden and Water Samples

Microorganisms were isolated using the dilution spread plate technique (Dhal and Thatoi 2007). In this process, 1 g of each soil was mixed with 100 mL of sterile distilled water, and then serially diluted using sterile water up to 10^{-5} dilution. Each one mL of 10^{-5} diluted sample was spread over three replicate nutrient and potato dextrose agar plates. Water samples (1 mL each) were also directly spread on the nutrient and potato dextrose plates, without any dilution. The plates were incubated for 48 h at 37°C in a BOD incubator. After the incubation period, different bacterial and fungal colonies grew on the nutrient and potato dextrose agar plates. The bacterial and fungal colonies were counted in the three replica plates and the average number was taken from the total number of microbes multiplied by the dilution factor for each sample.

Physico-Chemical Analysis of Soil and Water Samples

The chemical compositions of the soil samples were analyzed using X-ray fluorescence spectrometry (XRF) (Philips, Germany). The nutrient contents of the soil samples were also analyzed using chemical methods. Physical parameters of the water samples, i.e. pH and conductivity (EC), were determined using a digital pH meter and a conductivity meter (Systonics PVT^{TM}). Total alkalinity (TA) was measured using a phenolphthalein indicator, total dissolved solids (TDS) concentration was determined using the evaporation method, and dissolved oxygen (DO) was determined by titration against sodium thiosulphate, as described in APHA (1989). Total suspended solid (TSS) was determined by filtering a known volume of water sample using fibre filter paper. Biological oxygen demand (BOD) was evaluated at an interval of 5 days at 20°C whereas chemical oxygen demand (COD) was determined by titrating the sample against a standard ferrous ammonium sulphate solution. Total hardness (TH) and magnesium of the mine water samples were analyzed by titration using a standard EDTA solution, with Eriochrome Black T as an indicator. Calcium content was evaluated by titration with EDTA using murexide as an indicator. Chloride (Cl^-) content was measured using potassium chromate as an indicator relative to silver nitrate. Sulphate (SO_4^{2-}) and phosphate (PO_4^{3-}) were determined using the turbidimetric method, comparing the results with the standard graphs and using barium chloride and stannous chloride as reagents, respectively. Total dissolved metals were determined by filtering the water samples using Whatman 42 filter paper, evaporating the aliquot to almost dryness, followed by digestion in concentrated HCl and analyzing the clear solution by atomic absorption spectrometer (AAS).

Results and Discussion

Soil Samples

The overburden soils were dry, rocky in nature, and low in nutrients (N, P, K and organic carbon). The colours of the soil were mainly light brown, black, light yellow, light black, and brown (Table 1). The texture ranged from clay, to city sand, and sandy. Soil pH was found to range from 6.2 to 8.4, with the pH of COS-4 being the lowest (6.2); all of the other samples had near-neutral to alkaline pH (6.8 to 8.4). The nutrient content as N (nitrogen) was found to range from 63 to 93 kg/ha. The nearby agricultural land soil has low N content (95 kg/ha). Phosphorous (P) was found to range from 2.4 to 3.6 kg/ha, and potassium (K) ranged from 67 to 205 kg/ha. The soils also contained a low percentage of organic carbon, ranging from 0.08 to 1.15%, reflecting the low microbial activity of the soil. Organic carbon content was also influenced by the age of the dumps.

Soil samples were analyzed for the composition of metal oxides by XRF, as summarized in Table 2. The principal metal, chromium, was in the form of chromium oxide (Cr_2O_3) and was found to be highest in COS-3. Other metal oxides (Al_2O_3, MgO, SiO_2, TiO_2, NiO, Fe_2O_3, and MnO) were present in all of the soil samples in minute to high amounts. COS-4 had a relatively high content of Si, Al, Fe, Ca, Mg, and Ni metal oxides. These metals could be leached using oxidizing agents for metal recovery. The alternative, allowing the metals to continue to leach out and contaminate nearby agricultural lands, as evident from the chemical analysis of COS-6, is clearly less desirable. The chemical analysis of COS-6 showed chromium (0.272 wt% Cr_2O_3, ≈ 1,860 mg Cr kg^{-1} soil), along with Fe (3.85), Mg (1.95), Ca (0.88), Na (0.534), and K (1.48) wt% as major contaminants, and Ti (0.041), V (0.016), Mn (0.044), Cu (0.006), Ni (0.0133), and Zn (0.006) wt% as minor constituents.

Microbial diversity depends on the nutrient and moisture/water holding capacity of the soil to reproduce/degrade the constituents and increase the fertility of the soil. It has also been found that microbial populations decrease due to low nutrient contents and adverse environmental conditions (Table 3). The 13 year old overburden dump (COS-6) soil contained the highest microbial population ($34 \pm 0.03 \times 10^5$ bacteria and $15 \pm 0.04 \times 10^5$ fungal populations/g of soil) due to natural leaching of metals. The microbial population was lower in sample COS-4 ($9 \pm 0.02 \times 10^5$ of bacteria and $4 \pm 0.14 \times 10^5$ fungal populations/g of soil). As one would expect, the nearby agricultural land soil contained higher numbers of microorganisms ($45 \pm 0.06 \times 10^5$ of bacteria and $20 \pm 0.03 \times 10^5$ of fungal populations/g of soil). These populations are still very low compared to natural agricultural land soil (cells $\times$ 10^{10-15}/g).

Table 1 Nutrient content and characteristics of overburden samples

Characteristics of sample	Sample					
	COS-1	COS-2	COS-3	COS-4	COS-5	COS-6
Color	Light brown	Black	Light yellow	Light black	Brown	Light brown
Texture	Clay	City sand	City sand	Clay	City sand	Sandy
pH	7.4	8.1	6.8	6.2	7.8	8.4
N (kg/ha)	81	93	69	63	87	95
P (kg/ha)	3	3.6	2.4	2.8	2.6	3
K (kg/ha)	92	79	206	82	67	215
Organic carbon (%)	0.08%	1.15%	0.86%	1.15%	0.22%	0.51

COS Chromite Overburden soil, *ha* Hectare

Table 2 Chemical composition of the soil samples

Chemical composition	Weight (%)					
	COS-1	COS-2	COS-3	COS-4	COS-5	COS-6
Al_2O_3	10.1565	12.3125	11.408	8.358	16.8144	17.6595
Na_2O	0.4119	0.4576	0.5727	0.3202	0.1012	0.7204
MgO	13.4505	22.1625	20.4352	28.457	8.3258	2.6055
SiO_2	50.9472	54.2144	34.4224	40.8945	53.3812	65.8902
K_2O	0.2424	0.2048	0.3164	0.2268	0.2811	1.7949
CaO	2.6535	2.886	3.8192	2.7362	1.0848	1.2352
TiO_2	0.4254	0.128	0.3452	0.3144	0.357	0.7324
V_2O_5	0.0525	0.0128	0.0813	0.0616	0.0334	0.0299
Cr_2O_3	2.3149	0.2639	19.3241	10.0495	1.0486	0.2721
MnO	0.1828	0.13	0.1458	0.098	0.1482	0.0569
Fe_2O_3	10.5408	5.7139	8.2435	7.8654	8.7462	5.5005
CaO	0.0109	0.006	0.0099	0.0095	0.0062	0.0044
NiO	0.0908	0.0384	0.0644	0.0983	0.069	0.0173
CuO	0.0089	0.0058	0.0073	0.0577	0.01175	0.0082
ZnO	0.0091	0.0046	0.0158	0.0149	0.0056	0.0069
Moisture content	8.6	1.5	0.8	0.5	9.6	3.5

Table 3 Microbial diversity of different overburden soil samples

Average no. of colonies $\times 10^5$/g				
Sl. no.	Sample name	Bacteria	Fungus	*Actinomycetes*
1	COS-1	17 ± 0.04	11 ± 0.05	3 ± 0.12
2	COS-2	13 ± 0.14	5 ± 0.26	–
3	COS-3	20 ± 0.05	7 ± 0.07	–
4	COS-4	9 ± 0.02	4 ± 0.14	–
5	COS-5	34 ± 0.03	15 ± 0.04	6 ± 0.22
6	COS-6	45 ± 0.06	20 ± 0.03	8 ± 0.13

Results represent mean ± standard error of triplicate sets

Water Samples

Water samples were found to have a slightly lower pH (Table 4), in the range 5.94–6.32, than the Indian standards (pH: 6.5–8.5) for freshwater (river and streams). EC (electrical conductivity) is a measure of the dissolved constituents in water, which affects taste and is important in deciding its potability (Pradeep 1998). The EC of three samples varied from moderate to high (750–1,110 ms/cm). However, the EC and pH of the water samples were within the permissible limits (EC: 2 ms/cm, pH: 5.5–9.0) of industrial waste water being used for land irrigation (WHO 1984). The TDS values (534–946 mg/L) crossed the WHO desirable limit (500 mg/L).

The concentration of total suspended solids (TSS), which plays an important role in waste water chemistry, ranged from 12 to 64 mg/L, whereas the permissible limit of TSS in inland surface water is only 100 mg/L. Differences in total alkalinity (132–210 mg/L) of the water samples represent the total carbonate and bicarbonate level, whereas the total hardness values (as $CaCO_3$) in the three samples ranged from 258 to 305 mg/L, and were mostly within the prescribed limits (300 mg/L, IS: 2490 1981).

Table 4 Water quality of chromite mine water samples

Sl. no.	Parameters	CMW-1	CMW-2	CMW-3	Standards
1	pH value	5.94	6.28	6.32	6.5–8.5[d]
2	Temperature (°C)	26	29	28	30[d]
3	Conductivity(μ Siemens/cm)	0.844	0.75	1.11	–
4	Total alkalinity, TA (mg/L)	210.0	165.0	132.0	300[d]
5	Total solids, TS (mg/L)	1043.0	630.0	935.0	600[c]
6	Total suspended solids, TSS (mg/L)	12	52	64	100[g]
7	Total dissolved solids, TDS (mg/L)	946.0	534.0	848.0	500[e]
8	Dissolved oxygen, DO (mg/L)	2.4	3.2	4.2	5.0[f]
9	Biological oxygen demand, BOD (mg/L)	12.3	13.6	14.2	3.0[g]
10	Chemical oxygen demand, COD (mg/L)	24.00	22.40	26.23	0[b]
11	Total hardness, TH (mg/L)	305	292	258	300[d]
12	Calcium (mg/L)	24	36	48	–
13	Magnesium (mg/L)	224.46	155.2	186.77	30[d]
14	Chloride (mg/L)	369.2	255.6	210.1	1,000[a]
15	Sulphate (mg/L)	175	210	230	1,000[d]
16	Phosphate (mg/L)	0.42	0.73	0.64	–
17	Free CO_2 (mg/L)	36	27	29	–
18	Iron(mg/L)	1.63	0.96	1.09	–
19	Total chromium (mg/L)	0.9	1.25	0.76	2.0[g]

[a] IS:2490 (1974), [b] IS:3307 (1974), [c] IS:3306 (1974), [d] IS:2490 (1981), [e] WHO (1984), [f] ISI-ICMR (1989), [g] MoEF (2000)

The hardness increases the boiling point of water and depends on anions such as carbonate, bicarbonate, sulphate, and chloride and major cations, such as calcium and magnesium (Trivedy and Goel 1984) which are all within the permissible limits.

Sulphate was also found to be within the permissible limit (1,000 mg/L, IS: 2490 1981) in all samples. Chloride content of the three water samples ranged from 210 to 370 mg/L and was also within the maximum permissible limits of India (1,000 mg/L, IS: 2490 1974). Phosphate, which is a critical nutrient for the growth of algae in water (Trivedy and Goel 1984) and can cause eutophication, was very low.

In the three chromite mine water samples, the DO values ranged from 1.65 to 2.4 mg/L, and therefore did not meet the wastewater and bathing water criteria (5.0 mg/L or more, ISI-ICMR 1989). A low DO content can cause serious environmental problems. BOD was found to range from 12 to 14 mg/L, which exceeds the bathing water standards (3 mg/L or less, MoEF 2000), due to the nutrient and metal contamination in the water. COD ranged from 22 to 26 mg/L, which are high values for surface discharge water (IS: 3307 IS 1974).

The microbial diversity of the mine water samples was also studied using dilution plating and colony counting (Table 5). The colony forming units ranged from 96 $\pm$ 0.26 to 209 $\pm$ 0.35 colonies/mL of sample. Among the three samples, CMW-1 had the lowest number of colonies (96 and 51 colonies of bacteria and fungus, respectively). The CMW-3 water sample contained the highest number of microbial colonies (bacteria: 209 $\pm$ 0.35, fungus: 167 $\pm$ 0.04). The relatively low microbial diversity of the water samples may be due to the metal ion contamination and unfavourable water parameters.

Table 5 Microbial diversity of the water samples

Sl. no.	Sample name	Average nos. of colonies/1 mL		
		Bacteria	Fungus	*Actinomycetes*
1	CMW-1	96 $\pm$ 0.26	51 $\pm$ 0.02	–
2	CMW-2	183 $\pm$ 0.14	105 $\pm$ 0.12	–
3	CMW-3	209 $\pm$ 0.35	167 $\pm$ 0.04	–

Results represent mean $\pm$ standard error of triplicate sets

Other Aspects

Another important problem sometimes associated with mining is the formation of wastelands. Open cast mining and the creation of overburden dumps can do more than reduce forest yields; overburden dumps are often hostile to plant growth due to the existence of various stress conditions like low nutrient content, pH imbalance coupled with toxic and heavy metal ion accumulation, and poor water holding capacity (Misra et al. 1994).

Metals like iron, boron, copper, manganese, zinc are required in low concentrations for normal growth of plants, but an excessive amount is toxic to plants (Williamson et al. 1982). In aqueous system, chromium exists primarily in two oxidation states: haxavalent chromium [Cr(VI)] and trivalent chromium [Cr(III)]. Changes in the oxidation state of chromium have a profound effect on toxicity and bioavailability. While Cr(VI) is toxic, Cr(III) is not only less toxic but is an essential nutrient (Mertz 1979). Mertz (1969) also reports that chromium is an important component of electron transport chains. Cr(VI) was found to be almost negligible in the water samples collected in this study, but the mining organizations in this area need to monitor this aspect carefully, considering that the adjoining water bodies are the only source of water for the local population.

Conclusions

Mining can impact water and soil quality, depending on the chemical composition of the ores and waste dump materials, and factors such as slope, erosion potential, nearness to river, and natural drainage system also affect the extent of contamination. The magnitude of water pollution depends on the kind of treatment and mitigation measures adopted by the mining company. Of particular concern, in the case of chromite mining, is the chance for pollution by highly toxic hexavalent chromium. However, the Boula-Nuashahi chromite mines currently appear to have no sign of hexavalent chromium pollution. Several other water parameters are within permissible limits, while some exceed water quality standards. The overburden dumps contain various metals that may cause problem to the surrounding environments because of natural leaching of such metals over time. The adjacent agricultural land has been contaminated with such metals, which harms the productivity of the crops. The microbial diversity is also affected. So, the mining companies need to pay attention to the restoration and management of overburden dumps and mine drainage to reduce metal contamination of the adjoining area-soil and water bodies.

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