Mine water quality and its management in Indian metalliferrous mines

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Abstract: Surface mine development and underground mine working below piezometric level invariably change the hydraulic gradient, thus affecting ground and surface water flow and water quality. The presence of water in mining sites creates a range of operational and stability problems and requires a drainage plan to avoid slope stability problem, oxidation of metallic sulfides and corrosion of mining machinery and equipment. The quality of the drainage water depends on a series of geological, hydrological and mining factors which vary significantly from mine to mine. Water quality impacts are primarily due to the alteration of equilibrium in the underground water regime and the formation of acid mine water due to occurrence of pyritic ore impurities with parent metallic ores.

In India there are approximately 9906 mining leases spread over an area of 7453 sq. kilometres covering 55 minerals other than fuel. 35% of the valid lease area are covered by iron and limestone. Major states having metal mining activities are Rajasthan (25%), Karnataka (15%), Orissa (14%) and Bihar (11%), covering 65% of the lease area. Predominantly copper, iron, lead zinc, chromite and manganese are extracted in India.

The extraction of the metals is done by both opencast and underground mining methods. Large volumes of mine water are discharged in underground operations while minor volumes are discharged in hill mining. Some mine water, in the case of lead zinc, copper, manganese and chromite is slightly acidic and contains toxic heavy metals. In some cases, mine water is treated with lime to reduce acidity and finally discharged to the tailing dam for further settlement of suspended solids.

Environmental legislation have been framed to control the discharge quality and appropriate guidelines have also been suggested for their treatment to avoid contamination of surrounding land and water resources. The paper discusses the detail study of mine water quality in metalliferrous mines of copper, lead zinc, manganese, iron and chromite and their treatment and disposal system for water quality management.

1 INTRODUCTION

In the process of development, mining is one of the core industries contributing, knowingly or unknowingly, towards the deterioration of the environment in terms of air pollution, water pollution and land degradation. To achieve sustainable development, an environmental protection element should be introduced at the planning stage of the mining project itself.

India is endowed with a wide range of mineral reservoirs. In the country there are approximately 9906 mining leases spread over an area of 7453 square kilometres covering 55 minerals other than fuel. 35% of valid lease area are covered by Iron and Limestone. These minerals are extracted from over 3200 operating mines out of which 30 minerals are produced exclusively through medium small scale mining. Major states having metal mining activities are Rajasthan (25%), Karnataka (15%), Orissa (14%) and Bihar (11%) covering 65% of the lease area (IBM Publication, 1997). Among the important minerals produced in India at present are Bauxite, Chromite, Copper Ore, Iron Ore Lead Zinc, Gold and Manganese Ore. A large majority of these mines are opencast and the rest are underground mines. Substantial increase in the level of production of these minerals is envisaged by the turn of this country.

Land damage is a major impact of an opencast mine which is degraded by excavation / pits, waste disposal sites and other allied operations. Disposal of solid waste generated by mining operations including overburden / waste rock, sub-grade ore and mineralized reject could result in environmental pollution and cause disturbance of water level and surface and ground water quality (Dhar, 1993).

Mine water can frequently have quality problems, primarily due to the alteration of equilibrium in underground water and the formation of Acid Rock Drainage (ARD). This in turn creates a problem of dissolving heavy metals and carrying suspended particles of lithological materials existing in the affected area. Acid Rock Drainage has been recognized as one of the largest environmental problem facing the metal mining sector. Acid Rock Drainage and associated heavy metal contamination is caused by natural oxidation taking place when minerals are exposed to air and water. Sulphide oxidizing bacteria also play an important role (Kleinmann et al, 1985). While waste rock and tailings are the most significant sources of acid drainage, other mine components such as open pit surfaces, underground workings, stock piles and concentrate stage and loading areas are also potential sources.

Water pollution may be caused by direct discharge of mine water to the water streams and also by runoff from waste dumps. Sometimes water may be acidic and contaminated with dissolved chemicals, toxic substances or suspended particles. Metal mining especially Pb-Zn mine severely contaminate ground water quality (Gajowiec and Witkowski, 1993).

Metal mining poses problems to the water environment by discharging mine water from underground and open pit mines. Leachate water and runoff water from overburden / waste rock dumps also contaminate nearby water streams (Tiwary, et al 1995). Tailing dams seepage as well as effluent discharged from concentration and screening plants also plays an important role in water pollution.

The quality of the mine water depends upon the numerous factors including physical characteristics of the ore, net acid generating potential, ground water characteristics, back fill practice, mining practice and age of mine etc.

2 METAL MINING SCENARIO IN INDIA

Mineral production in the country continues to maintain a growing trend. India continues to rank third in the world chromite production and fifth in iron ore production. It also holds a significant position in copper and lead -zinc ore production. The production (1996-97) figure and number of mines are presented in Table 1.

2.1 Copper Mine

The recoverable reserves of copper are at 416.01 Mt equivalent to about 4.374 Mt of metal content. These recoverable reserves are mostly distributed in Bihar (108.69 Mt with 1.086 Mt of metal content), Madhaya Pradesh (1.77.438 Mt of ores with 1.983 Mt of metal content), Rajasthan (104.975 Mt of ores with 1.009 Mt of metal content) and the rest from other states.

Table 1 Metal Production in India

S.N.	Mineral	Number of Mines	1996-97
1.	Copper Ore	12	3.89 million tons
2.	Lead Zinc	8	60271 tons
3.	Iron Ore	264	68.17 million tons
4.	Manganese Ore	171	1.87 million tons
5.	Chromite	23	1.45 million tons

Hindustan Copper Limited is the sole producer of primary copper in India whose operations are spread over the states Bihar, Madhaya Pradesh and Rajasthan. The company produced 4.70 Mt copper ore during 1994-95. The Malanjkhand Copper Project produced 1.92 Mt followed by Khetri Copper Complex (1.65 Mt) and Indian Copper Complex (1.13 Mt). The average grade of copper ore mined in India was 1.11% Cu.

2.2 Lead Zinc Mine

In the country there are eight lead-zinc mining leases accounting for 9,334 ha. Of these, Rajasthan has 85.34% (7966.20 ha) of the total lease hold with five leases. Andhra Pradesh with one mining lease occupies 9.18% of lease hold, Orissa with one mining lease (5.35%) and M.P. has 0.12% of the total lease hold (11ha). Hindustan Zinc Limited, a Public Sector undertaking, is the main producer.

Hindustan Zinc Limited possess three groups of mines namely Zawar, Rajpur Dariba and Rampur Agucha Mines. Two mine group are extracting Pb-Zn ore by under ground mining operation, whereas in Rampur Agucha it is extracted by opencast mine operations. Annually 9.0, 3.5 and 13.5 lakh metric tones of ore are produced in the respective mines.

The ore constituents are Zn, Pb, Ca and Mg in which 11 to 13% of Zn ,and 1.8 to 2.0% of Pb are found in Rampur Agucha mine which is an opencast mine. In the other mines Zn percentage varies from 2.5 to 5.5% and Pb varies from 1.5 to 2.0%.

2.3 Iron Ore Mines

There were 276 reporting mines in 1994-95 compared with against 260 in 1993-94. Of this, 36 mines were in the public sector and 240 in the private sector. The contribution of public sector mines to the total production was 58% and the remaining 42% of the total production in 1994-95 was reported from private sector mines. India possesses vast resources of iron ore of which about 75% are hematite and the remaining 25% magnetite deposits. The hematite deposits comprise mainly hematite with minor amount of hydrated iron oxide (limonite, geothite etc.) and in some cases are intimately associated with gangue minerals like quartz, clay, feldspar, mica, gibbsite, chlosile etc. The magnetite ores are of low grade (30-40% Fe) containing quartz as the main gangue mineral and occur mainly in Karnataka, Andhra Pradesh, Goa, Kerala and Tamilnadu. In Bihar and Orissa, high grade hematite is found (containing 58-66 % Fe). Deposits of Madhaya Pradesh. Dalhi Rajhera & Bailadiha deposits are of high grade (56-60% Fe and 64-65% Fe respectively) ore.

In Goa state, iron ore reserves are estimated to be 74.1 mt out of which 59.7 mt is recoverable. In Bicholim mine, Goa approximately 1.7mt overburden dump is produced.

2.4 Manganese Mines

462 lease hold areas of manganese have been ore granted in nine states of the country. As of 1.1.94 the total lease hold area is 53,229 ha. Orissa continued to be leading state with 44 active leases covering an area of 13,757 ha producing 6,44,394 tonnes for the year 1993-94. Prominent among the manganese ore producers are. Orissa Mining Corporation Ltd. (OMC) (18.8% country production), Orissa Mining Development Corporation Ltd. (OMDC) (7.2 to 9% in 1993-94 and 94-95) Bharat Process & Mechanical Engineering's Ltd. (6.7%). The maximum contribution in manganese production was made by Manganese Ore India Ltd. (MOIL) in the order of 33.0% which has increased in subsequent year to 40.58% in 1994-95.

MOIL, a Government of India undertaking having mines in Maharastra and Madhaya Pradesh, is producing about 0.6 million tones of Mn ore per annum. Mines are both underground and opencast in nature and the total lease area under MOIL is 2145.89 ha.

2.5 Chromite Mines

Total recoverable reserves of chromite in India were assessed at 88.35 million tonnes as of 1.4.1990. 34% is of metallurgical and 29% of charge grade chrome.

The largest share in the total recoverable reserves is accounted for by Orissa (8%) state.

The nature of the ore in Orissa state is Friable ore (Chromite, Cr_2O_3 - 38-58%), containing Fe (9.5-24.5%), SiO_2 (0.88-9.08%) and gangue (contains Geothites, Limonite, serpentanite Talc etc.) whereas Lumpy Ore (Cr_2O_3 = 23.42-47.94%), contains Fe 10.29-11%.

3 MINE WATER QUALITY

3.1 Copper Mine

3.1.1 Tailing Disposal

Effluent from the Malnjkhand (Hindustan Copper Limited) concentrator plant is discharged to the tailing pond at the rate of 17,267 m^3/day. Tailing water accumulated in the tailing pond is generally recirculated to the concentrator plant for reuse. In the rainy season, however there may be some overflow from the tailing pond through an emergency spillway. The copper concentration of the tailing pond overflow is much below the permissible limit of 3 mg/l.

3.1.2 Mine Water

The seepage water is ultimately accumulated in the sump and is being pumped out at the rate of 560 m^3/day. At present the accumulated pit bottom water is being discharged to an outside surface drain by pumping.. The results of analysis were compared with IS-2490 Part-I for quality of effluents discharged into inland surface water and is presented in the Table 2. The level of pollution in the mine water are found within the permissible limits with the exception of suspended solids. The concentration of suspended solids was found 135 mg/l in winter and 195 mg/l in summer as compared to the 100 mg/l its permissible limit.
The level of trace metals in the mine water were found within the limit except the concentration of iron and copper. Copper in mine water is found higher (i.e. 3.03 mg/l) as compared to permissible limit of 3.0 mg/l and varies between 1.28 to 3.03 mg/l whereas the level of iron varies between 0.56 and 9.52 mg/l.

3.1.3 Waste Dump Seepage and Waste Dump Ditch Water

As precipitation occurs over the waste dump, leachates are produced and flow as waste dump seepage at the average rate of 526 m^3/day. This flow varies in quantity as well as quality. This flow accumulates in the ditch, where open pit bottom water is also being discharged by pumping. Both these waters after mixing, overflow the ditch and flow into the natural water course.

Waste dump seepage water quality shows that the level of Copper, Iron and Manganese vary from 2.02 to 4.24 mg/l, 1.44 to 15.2 mg/l and 40.9 to 89.0 mg/l. The pH level of seepage water is found in the range of 6.3 to 7.8 which is nearly neutral.

Table 2 Open Pit Pond Mine Water Quality

Parameter	Post Monsoon	Winter	Summer	Monsoon	IS:2490 Part - I 1981
TSS	108	135	13	22	100
TDS	400	460	300	385	2100
pH	6.9	7.9	8.1	6.71	5.5-9.0
Sulphate (as SO_4)	180	176.44	170	185	1000
Fluoride (as F)	0.88	0.6	0.78	0.69	2
Cadmium (as Cd)	<2	<2	<2	<2	2
Selenium (as Se)	<0.05	<0.05	<0.05	<0.05	0.05
Zinc (as Zn)	0.04	0.05	0.02	0.035	15
Mercury (as Hg)	<0.01	<0.01	<0.01	<0.01	3
Arsenic (as As)	<0.02	<0.02	<0.02	<0.02	0.2
Lead (as Pb)	<0.1	<0.1	<0.1	<0.1	0.1
Copper (as Cu)	2.08	3.03	2.40	1.28	3
Nickel (as Ni)	<0.1	<0.1	<0.1	<0.1	0.3
Iron (as Fe)	3.28	9.52	0.56	0.61	-
Manganese (as Mn)	<0.1	<0.1	<0.1	<0.1	-

Concentration in mg/l except pH.
IS:2490 - Standards for industrial discharge.

3.2 Lead Zinc Mine

The quantity of mine water discharged from Pb-Zn mines generally found in the range of 120-150 m^3/day in Zawar mine, 1200-1500 m^3/day in Rajpur Dariba and 500-600 m^3/day in Rampur Agucha. In Rampur Agucha, mine water is discharged into the tailing dam, whereas in the other two mines it is being used for internal purposes like drilling and beneficiation plant. Mine water quality is presented in the Table 3. The pH level varies from 3.0 to 8.5. Acid Rock Drainage problem has been observed in only Rampur Agucha mine. The level of Zn and Pb are found higher than the prescribed limit of 5.0 and 0.1 mg/l. To reduce acidity, lime treatment is in practice for this mine.

3.3 Iron Ore Mine

Mine water quality of iron ore mines generally do not contain any objectionable pollutants except high TSS during monsoon periods (Table 4). However, the pH level goes up to 5.4 and Iron is found in the range of 2.19 -2.63 mg/l.

Table 3 Water Quality in Pb-Zn Mine of HZL

S.N.	Parameters	Zawar Mines	Rajpur Dariba	Rampur Agucha
1.	pH	8 to 8.5	6 to 6.5.	3.0-4.5
2.	Zn	0.2 to 0.5	10 to 6 15	60-80
3.	Pb	0.004 - 0.007	0.06	0.5-0.7
4.	Fe	0.01	0. 15	0.3-0.4
5.	Cl	80-120	450	150-250
6.	SO_4	150-250	750	400-500

Concentration expressed in mg/l except pH

Table 4 Mine Water Quality

S. N.	Parameters	Station Code					
		Cu Mine	Mn Mine	Iron Ore Mine	Chromite Mine	Pb-Zn Mine	IS:2490
1	pH	6.7-8.1	7.6-7.8	5.4-6.5	6.0-6.6	3.0-8.5	5.5-9.0
2	Total Suspended Solids	13-135	20-50	72-85	79-88	75-90	100
3	Total Dissolved Solids	300-460	251-325	248-565	640-850	525-775	2100
4	Sulphates (as SO_4^{--})	170-185	120-175	5-10.2	36-56	150-750	1000
5	Fluorides as (F^-)	0.6-0.9	0.5-0.8	0.2-0.5	-	0.5-1.3	0.6-1.2
6	Cadmium (as Cd)	<2.0	<2.0	<2.0	<2.0	<2.0	2.0
7	Selenium (as Se)	<0.05	<0.05	<0.05	<0.05	<0.05	0.001
8	Zinc (as Zn)	0.02-0.05	0.04-0.03	0.07-0.3	0.04-0.08	0.2-6.15	5.0
9	Lead (as Pb)	<0.01	<0.01	<0.01	<0.01	0.004-0.7	0.01
10	Copper (as Cu)	0.15-0.20	0.01-0.06	0.009-0.034	0.01-0.02	0.02-0.07	3.0
11	Iron (as Fe)	0.61-9.52	0.03-0.7	2.19-2.63	0.31-0.42	0.01-0.4	-
12	Manganese (as Mn)	<0.1	1.0-1.3	<0.1	<0.1	<0.1	-
13	Chromium (as Cr^{+6})	<0.01	<0.01	<0.01	0.58-0.64	<0.01	0.01
14	Total Chromium	<2.0	<2.0	<2.0	2.4-2.6	<2.0	2.0

All parameters are expressed in mg/l except pH.
IS:2490- Standards for industrial discharge.

3.4 Manganese Mine

Mine water quality data of manganese mines shows that the concentration of manganese lies in the range of 1.0-1.3 mg/l in such water which is not very high.

The level of TSS and TDS are found below the prescribed limit of 100 and 2100 mg/l for liquid effluents (Table 4).

3.5 Chromite Mine

Mine water discharged from one of the chromite mine is estimated to be 7000 m^3 / day during the rainy season. In winter month mine water is discharged at low level i.e. 100 m^3 / day whereas in summer month it goes up to nil. Mine water quality is presented in the Table 4.

3.6 Comparative Study of Mine Water Quality

Mine water quality of the different ores are expressed in Table 4. It has been observed that low levels of pH are found only in iron and lead - zinc mines. Acid rock drainage problems are only found in lead - zinc mines. Hexavalent chromium is found in substantial concentration in chromite mines and may be toxic to the surrounding water regime and are discharged with the proper treatment. In case of copper mine the level of copper and iron content are found alarmingly high, whereas in manganese mines, the level of Mn varies from 1.0 to 1.3 mg/l.

4 MINE WATER MANAGEMENT

The present opencast copper mining and the existing concentrator plant utilizes water for a number of activities. Part of this water is being recirculated to the plant and part is being discharged into surface drains after use. In addition, there is seepage water at the pit bottom which is also disposed.

Mining and beneficiation are physical processes and generally do not involve any chemical transformations. The ore is being extracted and concentrated in the beneficiation plant by flotation process, and the tailing generated is discharged into a tailing dam.

In most of the mines liquid effluent are being recirculated and being used for internal purpose and rest are discharged to tailing dam. In case of iron ore mine, most of the mines have made settling tanks to restore suspended particles matters. But in hill top mining i.e. 300-400 m above the adjacent flat level runoff water takes its own course after passing through several check dams.

In case of Pb-Zn mine, open pit water is found to be acidic and being treated with lime and again transferred to the tailing pond for further treatment. In case of chromite mine treatment procedures includes the introduction of ferrous sulphate at the delivery end of the pumping site using chemical solution doser for the reduction of Cr^{+6} to Cr^{+3} and removal of Cr(III) hydroxide and Fe (III) hydroxide precipitates are done in the horizontal Roughing Filter. Filtrate are disposed of into a nullah through open surface drain. The process considerably decreases the level of hexavalent chromium in the final effluent and is able to reduce from 0.64 to 0.04 mg/l.

5 PRESENT GUIDELINES AND LEGISLATION TO CONTROL WATER POLLUTION

5.1 Guidelines made by Central Pollution Control Board, Government of India in respect of mine water management are summarized below:

- Efforts should be made to process or reduce the discharge of toxic and objectionable effluents into surface water bodies, ground water aquifers or usable lands to a minimum. Wherever possible, reuse of waste water should be practiced.
- Effluents should be treated to confirm to the standard laid down by the Central & State Boards for Prevention and Control of Water Pollution before discharge.
- While adopting environmental quality standards of liquid effluents, due consideration to local conditions should be given with a view to possible reuse.
- The Central Board for the Prevention and Control of Water Pollution should prepare guidelines for treatment of liquid effluents for different mineral industries on the basis of problems specific to the particular industry characteristics of effluents, ambient soil and water quality and other relevant factors.
- Wherever practicable, mine water should be utilized for irrigation of plantations raised to stabilize the mine waste dumps.
- Legislation related to mine water are as follow:

    a) Water (Prevention and Control of Pollution) Act, 1974
    b) Water (Prevention and Control of Pollution) Act, 1977
    c) Environment (Protection) Act, 1986

5.2 Techniques to Control AMD

- To prevent the formation of acid mine drainage at source, the techniques include modified mining methods; sealing of mine or part after closure; surface reclamation; water diversion; and control of ground water flow system by well fields or other methods to prevent the exposure with gels.
- The control techniques also include deep well injection, making subsurface dams and grout curtains.
- To dilution of rock drainage to an acceptable effluent quality.

* Employ standard waste water treatment method for neutralization and removal of dissolved solids. The techniques include lime or limestone treatment accompanied by aeration or oxidation process to convert ferrous iron to ferric iron; neutralization with soda ash, caustic soda and anhydrous ammonia reverse osmosis, ion exchange; electro-dialysis evaporation; ozone oxidation; desulfating, sulfide iron removal; microbiological control; and permanent iron removal.

6 CONCLUSION AND RECOMMENDATION

The study revealed that metal mining in India is going to increase in coming future to meet it's economic requirement and thus mine water problem will remain as such if the present guidelines will not be restructured and modified. New technology which is economically and technically viable should be implemented for mine water treatment and management. Some of the recommendation are suggested as follow:

* Zero discharge concept should be applied by recirculation of water for washing, dust suppression and ore concentration purposes.
* Specific methodology should be adopted to reduce the concentrations of individual metal to a permissible limit led by Central Pollution Control Board such as Pb and Zn in Lead-Zinc mines, Mn in Manganese mine, Cr in Chromite mine, and level of Fe^{++} in Iron ore mining.
* Acid rock drainage should be treated properly to reduce high concentrations of sulphate, iron and total dissolved solids using most economically viable and effective technology.
* in addition to suggested method for controlling ARD the following methods should also be considered.
    - ◊ Wetland engineering (Kleinmann, 1985, Nortan, 1992)
    - ◊ Water inundation of tailing dam or pyritic rock (Amyot and Vizina, 1997)
    - ◊ Compaction of the overburden materials to reduce seepage and thereby leachate.
    - ◊ In situ alkaline injection method in underground mines.
    - ◊ Microbiological methods.
    - ◊ Use of bactericides to reduce the rate of acid formation.
    - ◊ Use of overburden materials as neutralizing agent (Jamal and Tiwary, 1999)

* Reclamation of abandoned and old mines should be practiced in view of the water management.

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Jakość wód kopalnianych i zarządzanie zasobami wodnymi w kopalniach metali w Indiach

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Streszczenie: Eksploatacja w kopalniach odkrywkowych jak i podziemnych poniżej poziomu zwierciadła wód podziemnych wpływa na przepływ i jakość wód powierzchniowych i podziemnych. Obecność wody w eksploatowanym górotworze wymaga planowanego drenażu, aby uniknąć niekorzystnych zjawisk geomechanicznych, hydrochemicznych jak również korozji maszyn górniczych i urządzeń. Jakość drenowanej wody zależy od czynników geologicznych, hydrologicznych i eksploatacyjnych, które różnią się znacznie w zależności od kopalni. Zagrożenia dla jakości wody są związane przede wszystkim ze zmianą równowagi reżimu wód podziemnych i tworzeniu się kwaśnych wód kopalnianych w związku z występowaniem pirytu w rudach metali. W Indiach znajduje się około 9906 koncesjonowanych obszarów górniczych, na obszarze 7453 km^2, wydobywających 55 minerałów innych niż surowiec opałowy. 35% z nich wydobywa żelazo i wapień. Stany o największej koncentracji przemysłu wydobywczego to Rajasthan (25%), Karnataka (15%), Orissa (14%) i Bihar (11%), stanowiące 65% całego terenu wydobywczego. W Indiach wydobywa się głównie: miedź, żelazo, ołów, cynk, chrom i mangan. Metale te wydobywa się metodą odkrywkową lub podziemną. Większe ilości wody kopalnianej są

odprowadzane w wyniku eksploatacji podziemnej, a mniejsze – w wyniku eksploatacji powierzchniowej. Niektóre wody kopalniane, w przypadku eksploatacji rud cynkowo-ołowiowych, miedzi, manganu i chromu, są lekko kwaśne i zawierają toksyczne metale ciężkie. W niektórych przypadkach do wód dodaje się wapno dla zmniejszenia kwasowości, a następnie odprowadza się je do osadników dla dalszej sedymentacji zawieszonych cząstek. Określono środowiskowe przepisy prawne dla kontroli jakości odprowadzanych wód i przedstawiono odpowiednie wytyczne odnośnie ich uzdatniania dla uniknięcia zanieczyszczenia otaczających terenów i zasobów wodnych. W artykule omówiono szczegółowo badania jakości wód kopalnianych w kopalniach metali: miedzi, cynku-ołowiu, manganu, żelaza i chromu, oraz ich oczyszczanie i system odprowadzania.