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RESEARCH ARTICLE

Environmental Modeling Studies on Impacts of Tailing Ponds on Groundwater Quality at Iron Ore Mines, India

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ABSTRACT

The impacts on water environment are inherent part of any major developmental projects in two ways: one is stress on water resources (continuous withdrawal of large quantities of water) and the other is pollution impacts through discharge of effluents. These impacts may be on either or both surface and groundwater resources in the project area depending on the specific situation.

In the present study, an environmental aspect of tailings ponds of Bolani iron ore mines Orissa, India was studied. The quantity and characteristics of tailings are among the most important determinants of water quality at mine sites. The slime from the tailing pond showed 59% of material of inferior grade (50% Fe content) and 41% of material with higher grade Fe content (above 56% Fe). The tailing pond water was slightly alkaline with negligible nutrient content and the metals like Cu, Cr, Mn & Fe at trace concentration. The potential hazard of ground water pollution due to seepage from tailings pond was studied by Variably Saturated 2-D Flow and Transport Model (VS2DT) and it was found that the pond seepage of iron from tailings pond to groundwater would be negligible even after 3 years. Therefore groundwater would not be adversely affected.

KEYWORDS

Tailings pond, impacts, ground water, heavy metals, VS2DT

INTRODUCTION

Processing, extraction and beneficiation of ore is important technique for value addition to the ore before its entry in steel industry because of high content of alumina and silica in trace (Sengupta and Prasad, 1990). A major feature of these processes is that result in the production of an extremely high volume of unwanted material called as tailings. The disposal treatment of which constitute one of the most serious environmental challenges to the industry. These wastes vary from approximately 30% of the mass of ore in case if iron, gypsum and other non-metals. The earliest metallic mineral deposits exploited were of sufficiently high grade to be smelted directly or need beneficiation (Gray, 1998).

Beneficiation is the dressing of an ore in preparation for subsequent stages of processing such as smelting, leaching and refining. It serves to remove unwanted ore constituents. Thus increasing the concentration of the desired mineral and improving the grade of ore &/or to alter the physical properties of the ore such as particle size and moisture content. Beneficiation usually consists of three steps:

Preparation, in which the ore is comminuted by crushing &/or grinding; concentration, to separate the desired ore mineral from other ore material or gangue which is discarded as waste. Tailings are composed of small and uniform particles mainly in the sand and silt categories which quantity of slurry of tailings is disposed off in manmade ponds. Scientific way of disposal of tailings has yet to be done in India.

The impacts of tailings dam depend on physico-chemical property of the tailings, particle size and pH. The tailings contain concentration of some heavy metals which may leach out and pollute rivers and surface water bodies as well as ground water due to seepage. After filling-up of tailing dam, the tailings are scrapped and utilized for land filling purpose which is then restored by developing vegetation cover through plantation of suitable plant species (Soldner et al., 2004). Mining of basic metal sulphides (Cu, Pb, Zn, Fe) is considered among industrial activities generating serious problems of water resources (Marques et al., 2001).

The objective of this study is to characterize groundwater conditions at the tailings pond and to perform groundwater modeling to estimate groundwater seepage rates from the tailings pond through the shallow geologic units into the surrounding groundwater systems. Groundwater modeling is performed by VS2DT model to understand the groundwater flow and potential seepage pathways from the tailings pond to the surrounding groundwater regime.

MATERIALS AND METHODS

Tailing pond of Bolani Iron ore mines was selected for study. In beneficiation plant, the ore is crushed and grinded and then washed with water. The slime water produced flows to thickner. Overflow from thickner is carried to recirculating pump house. Slime water is discharged to tailing pond by gravity as underflow of thickner through slurry pipeline. Two lines of 350 mm diameter slurry pipeline have been laid down to discharge the slime water into the tailing pond. Tailing pond has got three numbers of dams existing top of water level is at 471.89 mRL & top of the dam is at 477.465 mRL. The catchment areas of pond at different mRLs are as follows:

- 470 mRL - 171075 Sq.m
- 471.30 mRL - 231895 Sq.m
- 475 mRL - 405000 Sq.m

The annual rainfall in the area is 200 cm.

With the height of dam 477mRL and maximum allowable level of settled slime 471mRL, the slime holding capacity of the pond is 1.56 million cubic meters so for about 0.34 million cubic meter of slime was deposited in the pond and can cater for 8 days at the existing slime generating rate.

The tailing pond was visited and samples were collected. Soil samples were also collected around tailings pond area for Physico-chemical analysis. The analysis of water and soil were carried out using standard methods (APHA, AWWA, WPCF, 2003).

Modeling Scenario

In the present study, Variably Saturated 2-D Flow and Transport Model (VS2DT) is used for predicting the impact of tailing pond on groundwater. VS2DT is a comprehensive unsaturated zone model based on the solution of Richards's equation. This model can simulate the transport of different types of contaminants (conservative and non-conservative) in unsaturated zone along with its transformation in the soil water phase in one and two dimension depending on the physical problem. In the present case assumption of one dimensional flow and transport is appropriate due to the large surface area of the tailing pond to arrive at the worst impacts on ground water. Moreover it reduces computational burden as well as reduces the uncertainty associated with the prediction due to variability of soil and transport properties (heterogeneity) in the other direction.

The following aspects are studied:

- Simulation is carried out to understand the movement of water below Tailing Pond.
- Leaching of Iron (Fe) from the Slime to Groundwater.

RESULTS AND DISCUSSIONS

The tailing pond area is a shallow through like natural depression surrounded by natural ridges. At present the pond has been constructed by means of two numbers of earthen dams joining the hillocks. The earthen dam will be constructed after getting forestry clearance from MoEF. At the dam site, natural soil has been stripped off upto 300 m beneath the ground level. The dams have been built from that base in stages, layer by layer. The inside slope of the dam has been secured firm by a 100 mm coarse sand level, followed by 100 mm thick crush stone layer and finally by 250 mm thick Rip-Rap. The lower half has turning on 300 mm thick layer of humus earth. At the bottom there is a rock toe on 200 mm thick graded filter of crush stone and sand.

The entire water requirement for the ore washing plant is made through the Karo River. The flow diagram of the ore washing plant indicating material flow and water uses is given in **Figure 1.**

The ore washing plant consists of four lines each having capacity of 600 T/hr. Out of these two lines are used for wet processing of beneficiable ore and the other two are used for dry processing of desired ore. In dry circuit the ore is screened by double deck vibratory screen and separate lumps and fines and sent to respective loading points. However in the wet circuit, the beneficiable ore is washed through drum scrubber followed by screening to separate lumps and fines. Total water requirement in the wet circuit is about 1.5 m^3/tonne of ore. The water balance diagram for the ore washing plant is given in **Figure 2.**

Total water requirement at each wet circuit is about 900 m^3 / hr, of which 270 m^3 /hr of water is reclimed through thickner and rest 630 m^3/hr is drawn from the make –up water tank. The distributions of 900 m3/hr water in each wet circuit are as followed:

- 650 m^3/hr to drum scrubber
- 150 m^3/hr to double deck screen
- 150 m^3 /hr to classifier
- 50 m^3/hr to de-watering screen

The fines along with water from the Double deck screen i.e. slimes is sent to rake classifier where all the coarser particles are removed and the ore flow goes to thickners. About 35% of water from the thickner is being recycled to the system and the underflow of thickner slurry is discharged to tailings pond.

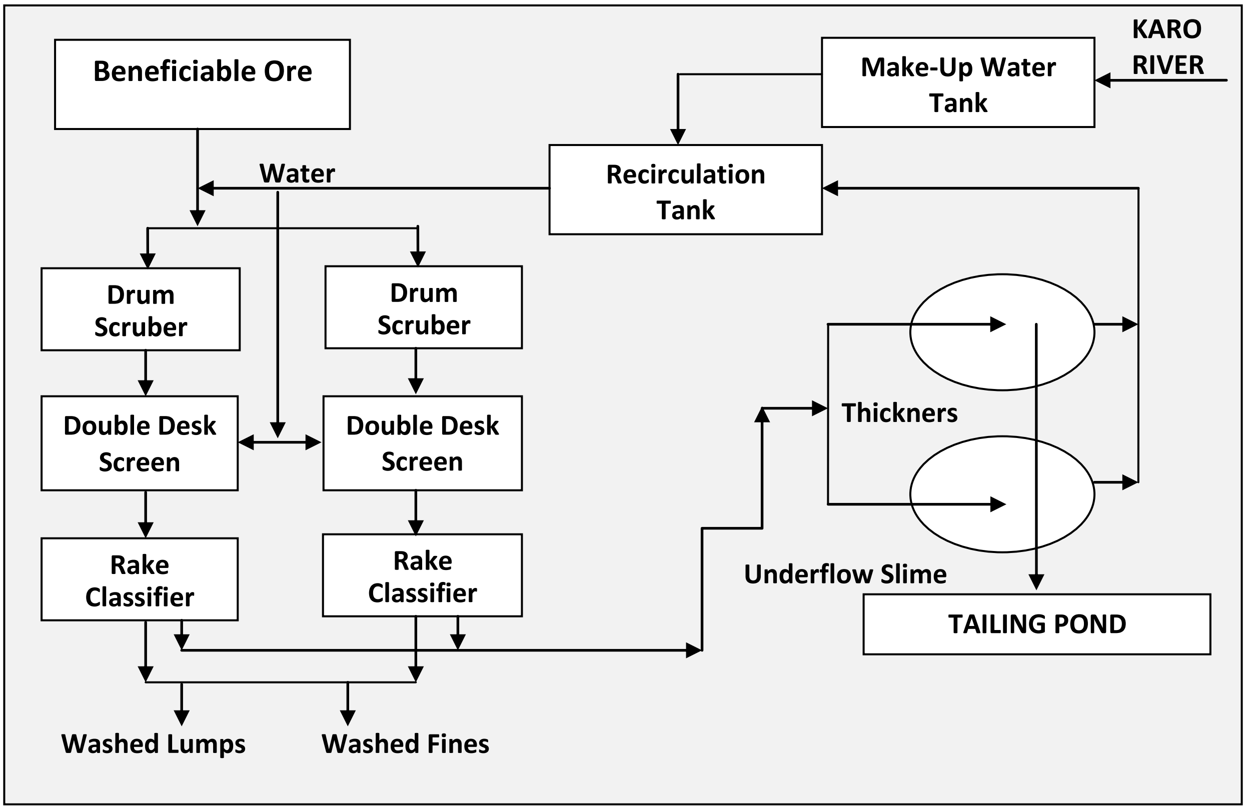

Figure 1: Flow Diagram of Ore Washing Plant.

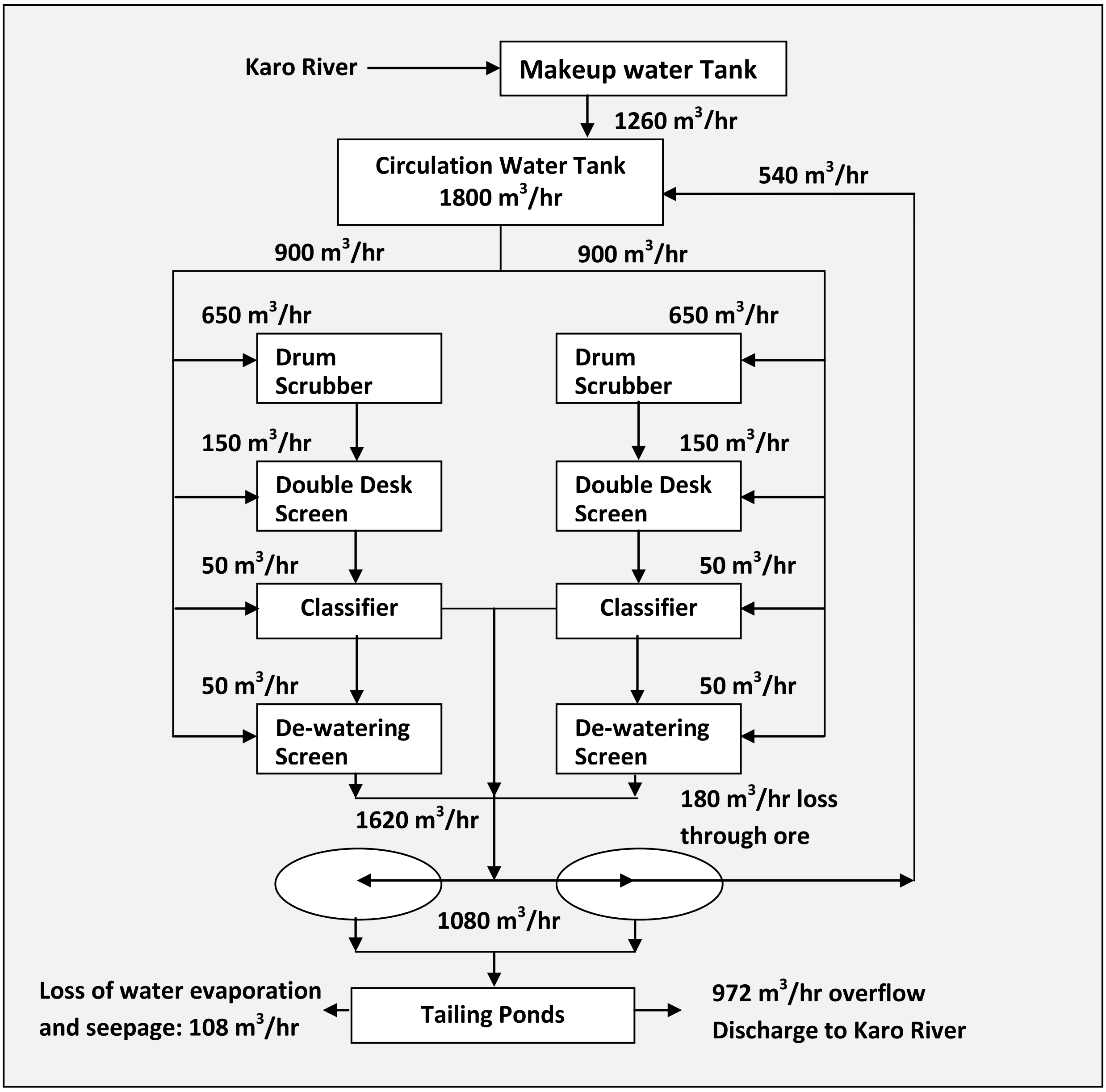

Figure 2: Water Balance of Ore Washing Plant

Slime Characterisation

Iron slime samples collected from the Bolani Ore Washing pond were characterised by Granulometry and chemical quality (SAIL, 2004). The assay analysis of slime showed that it contains 53.71 % Fe, 5.24% SiO_2, 6.25% of Al_2O_3. The granulometry analysis showed about 59% of material is below 0.038 mm and is of inferior grade having iron content only 50%. The fraction above 0.038 mm constitutes 41% of material with higher iron content above 56% (**Table 1**). The mineralogical study by microscopy and XRD technique had shown the presence of iron minerals namely hematite, marmite and goethite and gangue minerals namely gibbsite, Chlorite and Caolite.

Table 1: Characteristics of Iron Ore Slimes of Bolani Mines

Size, mm	% Yield	Fe	SiO_2	Al_2O_3
0.20	3.2	56.69	3.54	4.46
0.15	5.6	57.91	3.61	4.16
0.075	10.8	57.91	3.20	4.61
0.044	10.6	59.58	2.98	4.00
0.038	10.8	87.75	3.69	4.53
0.038	59.0	50.19	5.96	6.73
Composite	100.00	53.71	5.24	6.25

Quality of Tailings Pond Overflow

The quality of tailings pond overflow from Kamarpada tailings pond, Rang-Ring tailings pond and new tailings pond seepage is shown in **Table 2**. Tailings pond water was observed to be slightly acidic to alkaline in nature, pH ranging from 6.7 to 7.3. The conductivity was observed to be varying from 58.4 to 68.5 /cm. Total dissolved solids varied from 28.3 to 37.5 mg/lit showing less amount of dissolved salts. The total hardness was low and ranged from 8 to 38 mg/lit which was also very low. However some trace elements like Ca, Mg, Cu, Mn and Fe were observed to be present in the water. The ammoniacal nitrogen (0.058-0.223 mg/lit) and phosphates (0.01 – 0.43 mg/lit) indicate lower amount of nutrient level in the tailing pond water. Chromium was also recorded in the pond water consisting negligible amount of or absence of hexavalent Chromium.

The above discussion indicates that the tailing pond overflow or seepage water is slightly acidic to slightly alkaline having a number of trace metals or heavy metals and Iron and Manganese. Organic content is negligible with Sulfide and Fluoride at low concentration.

Soil Characteristics

The soils of the Bolani Ore Mines area have characteristic reddish tinge and predominant soil type may be broadly classified as red earth and red loam. The dominant colours found in field conditions are dusky red, reddish brown, dark reddish brown, red dark red etc. The texture of the soil varies from sandy clay to loamy in the areas of tailings pond and tailings pond discharge area. This type of soil coupled with gravel, poulder etc. allows free drainage of water, down in the profile causing intense leaching. The water retention capacity of the soil in tailings pong areas is high. Most of the soil is found to be slightly acidic in nature and this may be to be due to weathering and bacterial action on available sulphur. The heavy metals like Pb, Cd, Cr, Cu and Ni present in the soil are found to be below the toxicity level.

The soil quantity is of significance as seepage and groundwater pollution hazards from tailing pond depend on treatment and physico-chemical characteristics of soil. Soil also acts as filter from various pollutants thus protecting ground water. Therefore soil quality parameters are included in modeling exercise to predict seepage and groundwater pollution.

Table 2: Quality of Tailings Pond Overflow at Bolani Iron Ore Mines

Sr. No.	Parameters	Unit	Kamarpada	Rang-Ring	New Tailings pond	Norm as per E (P) Act, 1986
1.	Temperature	°C	29.7	27.9	23.7	-
2.	Colour	Pt-Co Scale	34	13	29.1	-
3.	pH		7.3	6.7	7.1	5.5-9.0
4.	Conductivity	μ S/cm	58.4	68.5	59.2	-
5.	TDS (mg/lit)	mg/lit	28.3	37.5	29.8	-
6.	TSS (mg/lit)	mg/lit	34	5	7.6	100
7.	Total Hardness	$CaCO_3$ (mg/lit)	10	29.3	22	-
8.	Calcium	as Ca mg/lit	3.5	8.2	6.3	-
9.	Magnesium	as Mg mg/lit	0.73	2.13	1.5	0.31
10.	Chloride	as Cl mg/lit	6.5	5	28.7	-
11.	Sulfate	as SO_4 mg/lit	1	1.5	6	-
12.	Phosphate	as P mg/lit	0.01	0.11	0.43	5.0
13.	Nitrate	as N mg/lit	0.058	2.5	0.24	50
14.	Copper	as Cu mg/lit	0.013	0.035	1.3	3.0
15.	Ammonical Nitrogen	as N mg/lit	0.058	0.223	0.013	50
16.	Total Chlorine	as Cl mg/lit	0.013	0.083	0.28	3.0
17.	Hexavalent Chromium	as Cr^{+6} mg/lit	0.003	0	0.031	0.1
18.	Total Chromium	as Cr mg/lit	0.003	0	0	2.0
19.	Manganese	as Mn mg/lit	0.29	0.4	0.006	2.0
20.	Total Iron	as Fe mg/lit	0.29	0.28	0.711	3.0
21.	COD	mg/lit	1.8	6	0.424	250
22.	Sulfide	as S mg/lit	0.007	0.013	0.008	2.0
23.	Fluoride	as F mg/lit	0.01	0.098	0.104	2.0

Table 3: Soil and Transport Parameters Used in the Simulation Along with Initial and Boundary Conditions

Input Parameter	Range
Soil Texture	Silty Clay Loam
Elevation: Top (m)	0
Elevation: Bottom (m)	300
Saturated Hydraulic Conductivity (cm/hr)	15
Porosity (cc/cc)	0.47
Q_r (vol/vol)	0.120
Alpha L (m)	0.7500
D_m (Cm^2/day)	0.20
Bulk Density (g/cc).	1.40
Decay Constant	0.00
Kd .(l/g)	0.45
Maximum Simulation Time (year)	1.3
Alpha (Van Genuchten) (m)	- 2.7
Beta (Van Genuchten)	2.0
Transport Simulation	Linear adsorption
Initial Condition: Water	Uniform pressure head
Initial Condition: Chemical	Uniform Concentration
Inflow Concentration (ppm)	0.29
Specific Storage (1`/cm)	0.000000010

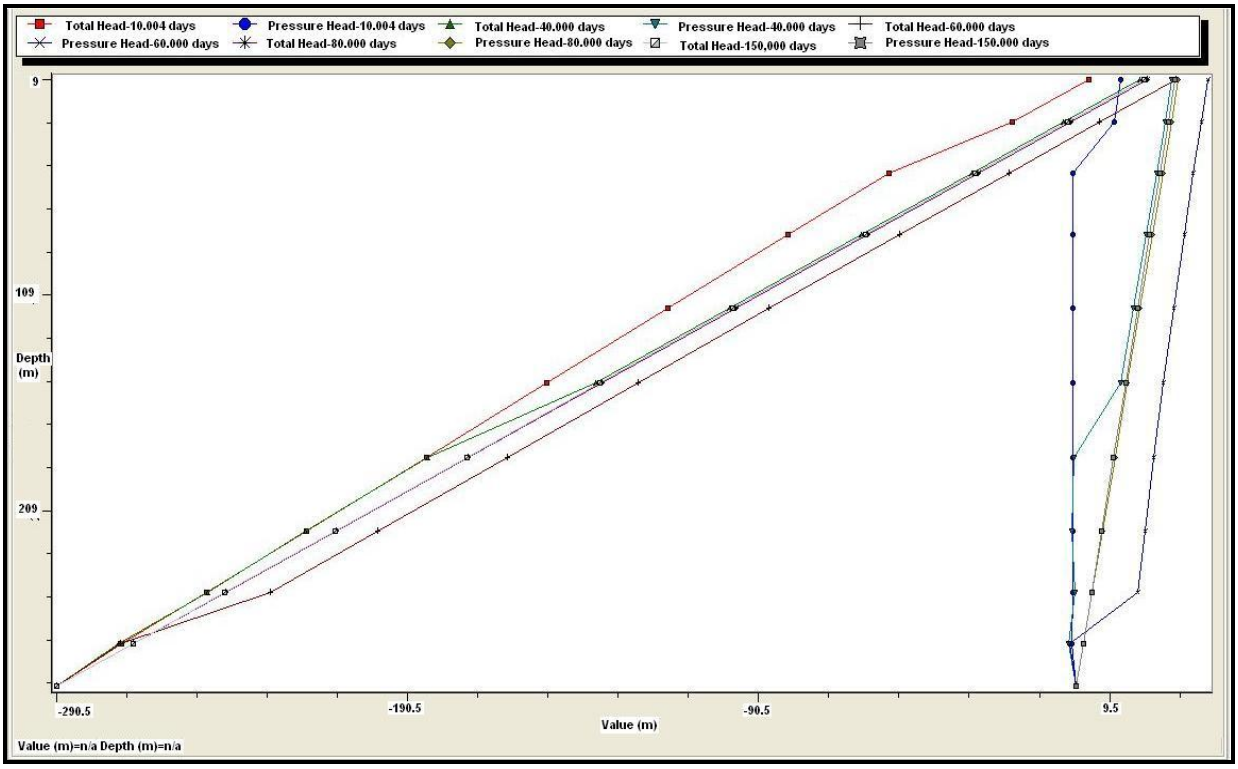

Figure 3: Total Head and Pressure Head Variation below the Pond

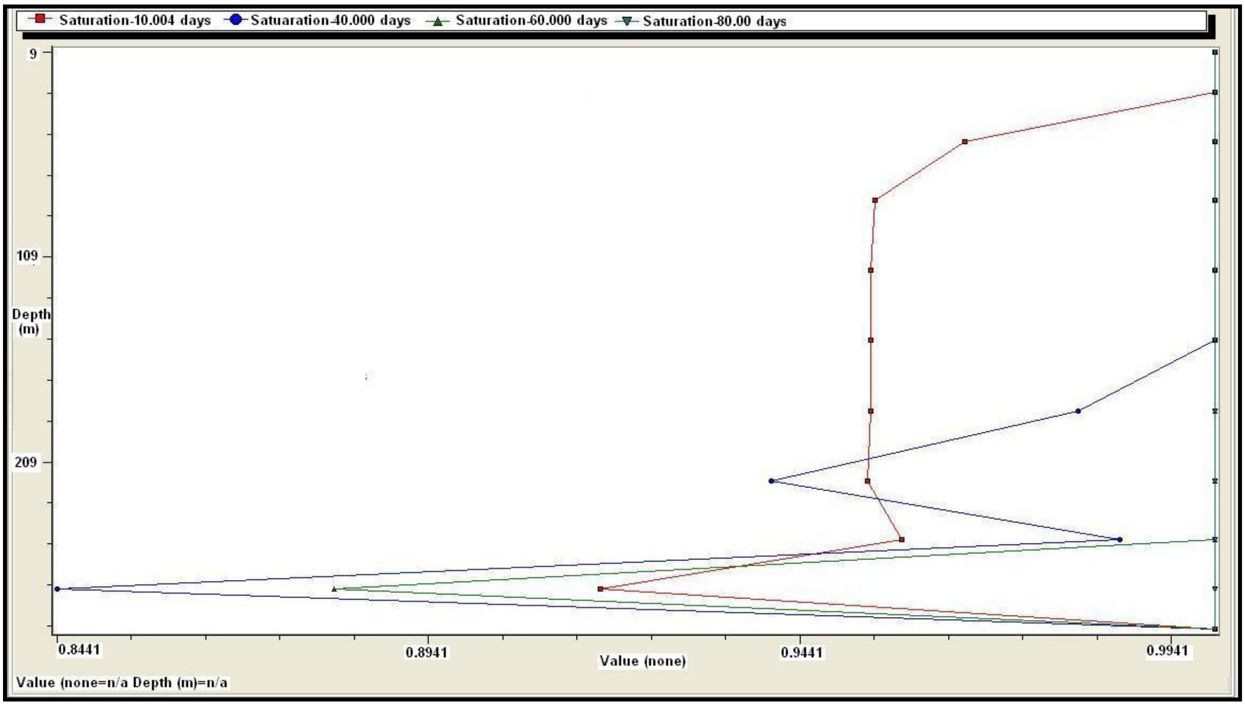

Figure 4: Saturation levels in the Soil Column

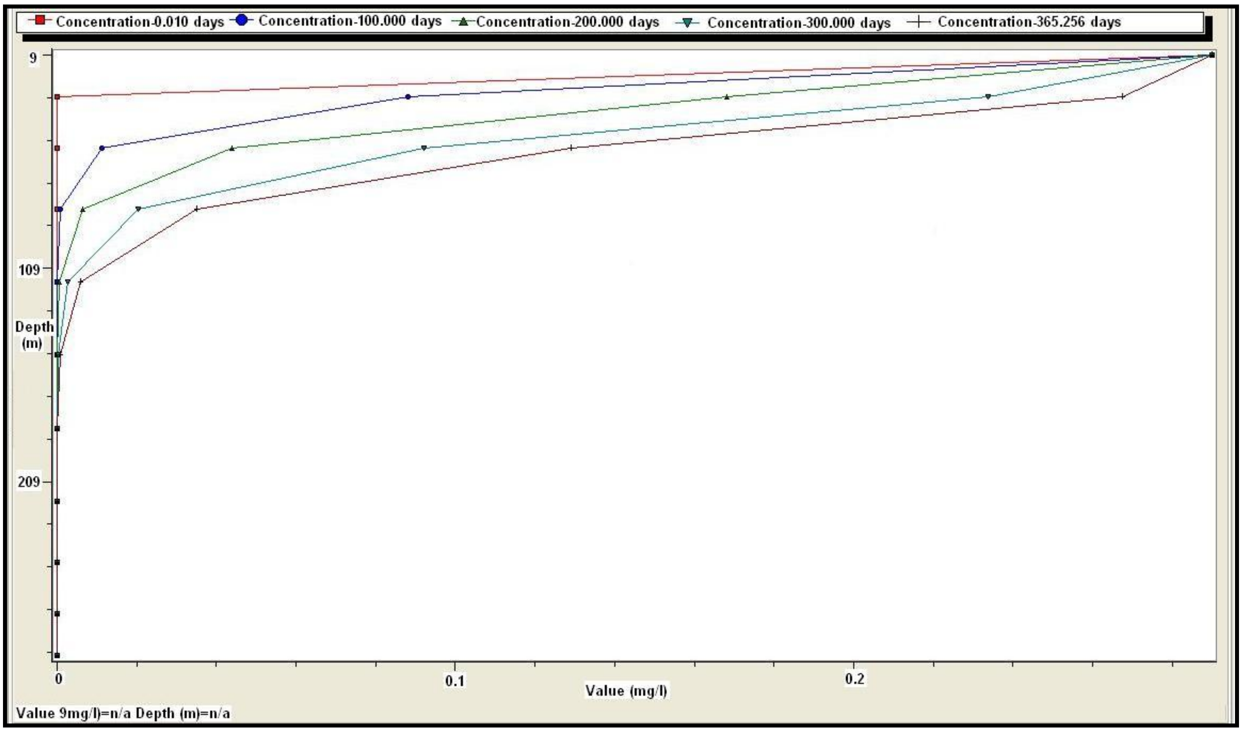

Figure 5: Variation of Iron Concentration with Time

Prediction of Impact on groundwater due to Iron ore tailings pond

Prediction of impacts is an important component in environmental impact assessment studies. Storage of wastewater in the tailing pond containing dissolve metals is a routine practice in the mining activity. Such storage leads to the hazard of polluting ground water through percolation of metal containing wastewater. It is therefore necessary to assess the extent of possible contamination of groundwater using mathematical modeling technique.

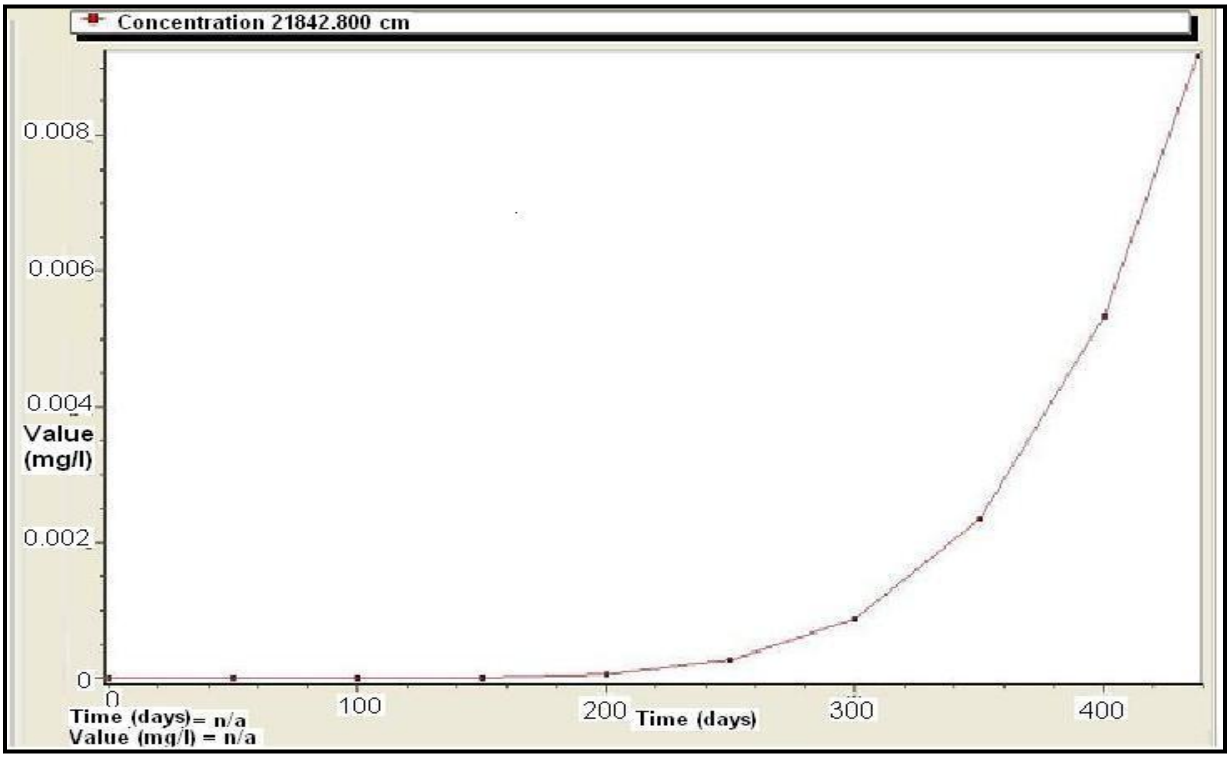

Fig 6: Variation of Iron Concentration with Time at Depth (21842 cm) from Ground Surface

The Tailing Pond

Slime water from ore washing plant flows to thickener. Slime water is discharged to tailing pond by gravity due to underflow of thickener through slurry pipelines. Estimated slime discharge from thickener is around 0.25 million m^3 per year depending on operation of wet circuit of Ore washing and screening plant. To take care of this slime, Kamarpada tailing pond, Rang-Ring tailing pond and a new tailing pond are constructed in the mining area approximately 2-3 Km from the ore washing and screening plant. The thickened slime is allowed to settle in the pond.

The Tailing pond area is a shallow natural depression surrounded by natural ridges. At present it is constructed by means of 2 nos. of earthen dams joining hillocks and natural soil will be stripped off up to 300 m beneath the ground level. The slime holding capacity of the pond will be 1.56 million cubic meters. It is expected that the pond will cater for minimum eight years at the existing slime generation rate taking into consideration annual rainfall of 22 cm (average), evaporation and groundwater recharge. Two lines of 350 mm diameter slurry pipeline will be laid to discharge the slime water into the tailing pond.

Analysis of earlier work indicates that beneficiation of iron ore tailings is not difficult, but the beneficiation techniques to be used must be matched to the quality of the ore and must be suitable for the range of products. Prasad et al., (1988) studied the beneficiation of iron ore slime produced from washing plants and tailing ponds of Kiriburu mines by using wet high intensity magnetic separators followed by classification in hydrocyclone. They showed that a concentrate containing 63% Fe and 3.3% alumina could be produced with an overall iron recovery of 56%. Pradip (1994) showed that the multi gravity separation is the most promising technique for treating the iron-ore tailings and it is particularly effective for reducing alumina. Other avenues of treating the iron-ore tailingss have also been considered to establish significant beneficiation potentials that cover a wide range of iron ores in India (Rakshit 1997; Bhattacharya et al.,1997; Bhagat and Dey, 1997; Srivastava et al.,1997).

Impact assessment by VS2DT Modeling

Table 1 show the anticipated chemical properties of slime, which will be generated due to mining activities in Chiria. **Table 3** shows the soil and transport parameters used in the simulation along with initial and boundary conditions. The depth of water table is 300 m near the tailing pond. A constant flux (Neumann) boundary is applied at the top boundary, which is calculated based on the hydraulic conductivity of the slime and water depth in the pond, which is a function of time. The lower boundary is taken to be a constant pressure head boundary equal to zero (water table). The heavy metal in the soil is generally governed by linear isothermal adsorption and is proportional to the soil water concentration. The model was executed by taking the above parameters for one year. **Figure 3** shows total head and pressure head variation below the pond after 10, 40, 60, 80, 150 days. A steady state (saturation) is attained in 80 days after which the total and pressure head remains constant in the soil column. **Figure 4** shows the saturation levels in the soil column after 10, 40, 60 and 80 days. It is evident in the figure that the soil below the pond is completely saturated in 80 days. **Figure 5** shows the Iron concentration profile with time. Even after a year of simulation the Iron concentration reaching the groundwater is zero due to adsorption of metal in the soil. If the simulation is carried out for 500 days (1.3 years) the Iron concentration reaching the groundwater is negligible as seen in **Figure 6**. The maximum concentration reaching the groundwater is estimated to be 0.29 mg / lit after a period of 3 years which is still below the permissible limit (3 mg/lit) as prescribed by Environment Protection Act (EPA, 1986).

CONCLUSION

Decantation ponds are used in mines for the disposal and storage of tailings from ore beneficiation plant. The chemical and microbiological transformations in the tailings pond are responsible for the quality of overlying water in the pond. The tailing pond water can contaminate the environment through seepage to ground water or spill over and run off. Therefore the present observation is made on tailings pond of Bolani ore mines in Orissa with special reference to tailings pond water quality, biological growth in the pond as indicator of environmental quality to study the seepage potential leading to degradation of ground water.

The assay analysis of iron ore slime from tailings pond showed the presence of 53% Fe, 5.24% SiO_2, 6.25% Al_2O_3. The particle size analysis indicated that tailings are extremely fine i.e. 59% of material below 0.038 mm which is of inferior grade (50% iron content) and 41% of material above 0.038 mm with higher grade iron content i.e. above 56% Fe. The soil around Bolani ore mine varies from sandy day to loamy and slightly acidic in nature. The water retention capacity of the soil was high. The quality of tailing pond was observed to be slightly alkaline with almost negligible phosphate content and presence of metals like Cu, Cr, Mn and Fe at trace levels.

The potential hazard of tailings pond polluting ground water through seepage was studied by variably saturated 2-D flow and transport model (VS2DT). The results showed that a steady site (saturation) is attained in 80 days and even after a year of simulation the iron concentration reaching the ground water is zero due to adsorption of metal in the soil. The maximum concentration of iron reaching the ground water after a period of three years is estimated to be 0.29 mg/lit which is still below the permissible limit (3 mg/lit) as prescribed by Environmental Protection Act, (EPA, 1986).

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