Environmental scenario of chromite ore mining at Sukinda valley beyond 2030

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ABSTRACT

Sukinda valley in Jajpur and Dhenkanal district of Odisha contains about 98% of the chromite reserve and it is being exploited by Opencast Mining since 1950. Out of six chromite ore bands occurring within weathered ultrabasics, Band-I is thickest (75mtr wide) and proved to continue beyond 300 mtr below ground level. Discharge of mine seepage by pumping facilitates mine operation at deeper level. Most of the promising working quarries in this region shall be discontinued beyond 2030 due to non-viability of working by open cast mining and want of adequate information on feasibility of underground development. Due to occurrence of nickel in the limonitic overburden and continuance of chromite ore beyond ultimate pit bottom, it is not permitted by IBM for reclamation by backfilling. Ground water in the valley is encountered at a shallow depth in semi-confined aquifer. Therefore all the opencast quarries will be left as large water reservoirs. Leaching of overburden and weathered ultrabasics in mine seepage water shall add hexavalent chromium (Cr\textsuperscript{6+}) in to the water reservoir. Cr\textsuperscript{6+} is carcinogenic beyond permissible limit (0.05mg/l). Therefore there is a threat of contamination of Cr\textsuperscript{6+} to the groundwater regime of the valley. Author felt that all the Stakeholders, Regulatory authorities and Environmental Scientists should come out with a time bound action plan to minimize the adverse effect of Cr\textsuperscript{6+} on groundwater environment in the valley and conserve and utilize the mineral in the ambit of sustainable development.

Keywords: Cr\textsuperscript{6+}; Nickelliferous limonite; Platinum group of elements; Ultimate pit limit; Reclamation; Water reservoir.

Abbreviations: PGE - Platinum group of elements; IBM - Indian Bureau of Mines; OB - Over burden; mg/l - Milligram per litre; AMSL - Above Mean Sea Level; GSI - Geological Survey of India; DGMS - Director General of Mines Safety; SZ - Safety Zone; UPL - Ultimate Pit Limit; OC - Open Cast; Cr\textsuperscript{6+} - Hexavalent Chromium; Sol - Survey of India; IOSG - Iron Ore Super Group; GPS - Geographical Positioning System; CMRS - Central Mining and Research Station.

1. INTRODUCTION

Chromium, out of the most commonly occurring elements in the Earth's crust occupies 21st position in order of abundance. Over 95% of economically viable chromium deposits are situated in South Africa. The other important World chromium ore producing countries are India, Kazakhstan, Brazil, Turkey and Russia. Major production of world chromium ore is from stratified deposits (Mineral Year Book-2010 by IBM). Chromium in India is considered as a strategic mineral due to its limited reserve potential. It is indispensable for aerospace, Iron and Steel industry. Manufacture of superior military armaments for defense depend largely on this mineral.

In India Chromite deposit was discovered in 1950 in Sukinda valley (21° 0' 00"—21° 04' 07" N; 83° 43' 16"—85° 52' 30" E), confined to Survey of India Topo Sheet Nos.73 G/16 SE & SW and 73 G/12 SE, in 1:25000 scale spread in Jajpur district, Odisha. The valley runs in NE-SW direction closing towards east and fanning out towards west. It is situated 50 km NE of Jajpur-Keonjhar Road Railway station. It is flanked by Tomka-Dairali Hill ranges to North and Mahagiri Hill ranges to the East. Damsal Nala flowing southwesterly drains the entire valley and is perennial in nature. The maximum 220 AMSL is at Kalarangi in the valley. Dendritic drainage pattern of 1st to 3rd order streams from eastern and western slopes of Mahagiri and Dairali Hills respectively drain to Damsal Nala, being a 6th order rivulet.

Ultrabasics hosts the chromite deposits that intrude as a transgressive sill in to the pre-cambrian iron ore Super group (Acharya, 1983). This was subsequently co-folded to asymmetric synclinal structures plunging steeply to southwest. Both laterally and vertically, chromite occurs as persistent layers, lenses or pockets in the serpentinitized and silicified dunite-peridotite. Sukinda Valley chromitites of Odisha are predominantly strati form in nature (Chakraborty et al., 1984). The width of the chromite bands vary from 3.0 mtr to 50.0 mtr and separated each other by limonite and pyroxenite (Source: GSI). The ore bands to the east dip westerly at 400 to sub-vertical. Except Band-V, all other chromite bands occur within chert limonite, proved to be continuing beyond 300 mtr below ground level. This weathered limonite is nickelliferous (Pattanaik, 1990). The limonite on hanging wall side show more nickel values (Pattanaik, 1989). During extraction of chromite ore the limonite is excavated as overburden and stored as dump for future use.

Opencast Mining for chromium in Sukinda valley commenced since 1950. Total 17 mining leases have been granted for chromite ore mining in Jajpur and Dhenkanal district, Odisha. Out of which 12 are operating (two are underground) and 5 are not in operation due to want of statutory clearances (www.orissaminerals.gov.in). The list of mining leases predominantly with incompetent host rock is given in Table 1.

Chromitites of Band-I are confined to weathered limonite. Band-I is the most promising chromite

Ultrabasics: It is a metamorphic rock with less than 8% SiO\textsubscript{2} and is a host rock for chromite mineralization of pre-cambrian age

Mine seepage: Ground water percolation through permeable rocks strata in to the excavated pit developed due to mining

CHROMITE ORE

Chromite is found in peridotite from the Earth’s mantle. It also occurs in layered ultramafic intrusive rocks. In addition, it is found in metamorphic rocks such as some serpentinites. Ore deposits of chromite form as early magmatic differentiate. It is commonly associated with olivine, magnetite, serpentinite, and corundum. The vast Bushveld igneous complex of South Africa is a large layered mafic to ultramafic igneous body with some layers consisting of 90% chromite making the rare rock type, chromitite. The Stillwater igneous complex in Montana also contains significant chromite. The only ores of chromium are the minerals chromite and magnesiochromite. Most of the time, economic geology names chromite the whole chromite-magnesiochromite series: FeCrO₄, (Fe,Mg)Cr₂O₄, (Mg,Fe)Cr₂O₄ and MgCr₂O₄. The two main products of chromite refining are ferrochromium and metallic chromium; for those products the ore smelter process differs considerably. For the production of ferrochromium the chromite ore (FeCr₂O₄) is reduced with either aluminium or silicon in an aluminothermic reaction and for the production of pure chromium the iron has to be separated from the chromium in a two step roasting and leaching process. Chromite is also used as a refractory material, because it has high heat stability.

Figure 1
Plan showing water reservoirs at the conceptual stage in Sukinda valley

Limonite:
It is an weathered and altered ultra-basic raw associated with Nickel it is not permeable and usually traversed by secondary chert veins

2. MATERIALS AND METHODS
The list of all the mining leases along with the boundaries was plotted on the Geological map of Sukinda valley in 1:25000 scales (Source: OPCB). The exposure of the chromite ore body picked up from individual mining leases maps were plotted (Source: GSI). The existing quarry boundaries and the ultimate pit configuration were demarcated on it. The detail mine wise information is compiled to determine the life of the mine, ultimate pit limit and the dump area. It is ascertained from the Geological map and report that the mining leases listed from 1 to 12 as per the Map at Fig.No.1 is mostly confined to weathered chromitite. The excavation area estimated is 850.0 ha and that of the area to be occupied by overburden dump will be 400.0 ha (Pattanaik, 2012). The DGMS circular and guidelines by IBM are collected to ascertain the bench slope and reclamation procedure and restriction of backfilling the quarried voids by nickelliferous limonitic overburden. All these information lead the author to think about this conceptual paper regarding possible environmental hazard and its projected mitigation measures after mine closure.

Figure 2
Production of chromite in 2011
Table 1. Details of the mining leases where underground mining is under feasibility study

<table>
<thead>
<tr>
<th>Index No. as in Fig.1</th>
<th>Name of the lease</th>
<th>Name of the lessee</th>
<th>ML area (ha.)</th>
<th>Mineral Reserve in million tons</th>
<th>Approved production per annum in million tons</th>
<th>Life of the opencast mine</th>
<th>Land use at conceptual stage in ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kaliapani Chromite Mines</td>
<td>O.M.C Ltd</td>
<td>971.245</td>
<td>1.79</td>
<td>0.065</td>
<td>27</td>
<td>104.19</td>
</tr>
<tr>
<td>2</td>
<td>Sukinda Chromite Mines</td>
<td>TISCO</td>
<td>406.00</td>
<td>1.95</td>
<td>0.55</td>
<td>25</td>
<td>9.03</td>
</tr>
<tr>
<td>3</td>
<td>Sukinda chromite Mines</td>
<td>IMFA Ltd</td>
<td>26.82</td>
<td>0.528</td>
<td>0.011</td>
<td>48</td>
<td>22.02</td>
</tr>
<tr>
<td>4</td>
<td>Kaliapani Chromite Mines</td>
<td>Jindal Steel Ltd</td>
<td>89.00</td>
<td>2.91</td>
<td>0.211</td>
<td>14</td>
<td>43.09</td>
</tr>
<tr>
<td>5</td>
<td>Kaliapani Chromite Mines</td>
<td>Balasore Alloys Ltd</td>
<td>64.463</td>
<td>6.72</td>
<td>0.42</td>
<td>16</td>
<td>7.41</td>
</tr>
<tr>
<td>6</td>
<td>Mahagiri Chromite Mines (UG)</td>
<td>ICC Ltd</td>
<td>73.777</td>
<td>1.458</td>
<td>0.078</td>
<td>18</td>
<td>11.67</td>
</tr>
<tr>
<td>7</td>
<td>Not allotted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>South Kaliapani Chromite Mines</td>
<td>O.M.C. Ltd</td>
<td>552.457</td>
<td>31.843</td>
<td>0.13</td>
<td>40</td>
<td>73.10</td>
</tr>
<tr>
<td>9</td>
<td>Sukurangi chromite Mines</td>
<td>O.M.C. Ltd</td>
<td>382.709</td>
<td>5.283</td>
<td>0.13</td>
<td>40</td>
<td>73.10</td>
</tr>
<tr>
<td>10</td>
<td>Saruabli Chromite Mines</td>
<td>Misrilal Mines Pvt. Ltd</td>
<td>246.858</td>
<td>3.793</td>
<td>0.07</td>
<td>54</td>
<td>63.50</td>
</tr>
<tr>
<td>11</td>
<td>Kamarda Chromite Mines</td>
<td>B.C Mohanty &amp; Sons Pvt. Ltd</td>
<td>107.241</td>
<td>1.440</td>
<td>0.088</td>
<td>16</td>
<td>29.42</td>
</tr>
<tr>
<td>12</td>
<td>Saruabli Chromite Mines</td>
<td>IMFA Ltd</td>
<td>116.76</td>
<td>5.433</td>
<td>0.351</td>
<td>15</td>
<td>41.50</td>
</tr>
</tbody>
</table>

Table 2 Hexavalent chromium content in surface water

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description</th>
<th>Location</th>
<th>Co-ordinates by GPS</th>
<th>Hexavalent Chromium content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitude</td>
<td>Latitude</td>
<td>Permissible Limit (mg/l)</td>
</tr>
<tr>
<td>1</td>
<td>Entry point of Damsal Nala (Sukurangi ML)</td>
<td>85° 48' 23.6&quot;</td>
<td>21° 03' 32.8&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>2</td>
<td>Kania on Damsal Nala</td>
<td>85° 52' 13.0&quot;</td>
<td>21° 03' 54.2&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>D’Quarry water on Band-I Chromite lode</td>
<td>85° 46' 44.9&quot;</td>
<td>21° 02' 39.9&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>P’Quarry water on Band-IV Chromite lode</td>
<td>85° 47' 59.1&quot;</td>
<td>21° 02' 27.0&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>5</td>
<td>AC Quayry water on Band-IV chromite lode</td>
<td>85° 48' 36.2&quot;</td>
<td>21° 02' 41.5&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>6</td>
<td>Down stream of F’Quarry on Damsal Nala</td>
<td>85° 46' 55.4&quot;</td>
<td>21° 08' 12.1&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>7</td>
<td>D’Quarry Eastern wall at bottom</td>
<td>85° 47' 14.4&quot;</td>
<td>21° 02' 56.8&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>8</td>
<td>D’Quarry Western wall at bottom</td>
<td>85° 47' 10.3&quot;</td>
<td>21° 02' 53.2&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>9</td>
<td>Down stream of D’Quarry on Damsal Nala</td>
<td>85° 46' 04.2&quot;</td>
<td>21° 02' 57.6&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>10</td>
<td>Pump House on Damsal Nala</td>
<td>85° 45' 04.6&quot;</td>
<td>21° 02' 18.2&quot;</td>
<td>0.10</td>
</tr>
<tr>
<td>11</td>
<td>Down stream TISCO near Kalarangi</td>
<td>85° 45' 30.5&quot;</td>
<td>21° 01' 14.3&quot;</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Date of sampling: Dt 26.02.2012

Table 3 Reserve of chromite ore as on 01.04.2012

<table>
<thead>
<tr>
<th></th>
<th>INDIA (in million tons)</th>
<th>ODISHA (in million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proved</td>
<td>Remaining resources</td>
<td>Reserve</td>
</tr>
<tr>
<td>54.00</td>
<td>149.00</td>
<td>203.00</td>
</tr>
</tbody>
</table>

Table 4 Production of chromite ore from Odisha (www.orissamanerals.gov.in).

<table>
<thead>
<tr>
<th>Year</th>
<th>Chromite ore in million ton</th>
<th>Year</th>
<th>Chromite ore in million ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2001</td>
<td>1.75</td>
<td>2008-2009</td>
<td>3.28</td>
</tr>
<tr>
<td>2001-2002</td>
<td>1.93</td>
<td>2009-2010</td>
<td>2.79</td>
</tr>
<tr>
<td>2002-2003</td>
<td>1.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Higher concentration of Cr$^{6+}$ in Sukinda was noticed in the 1990’s and many studies have been done on this issue since then.

1. Chromium occurs in several oxidation states, ranging from Cr$^{2+}$ to Cr$^{6+}$ (Dubey et al., 2001). Approximately 35% chromium released from anthropogenic activity is hexavalent chromium out of which mining is considered as one of the major anthropogenic activities. Hexavalent chromium is highly mobile and can readily move through soil and ground water. It originates out of leaching of overburden and weathered serpentinite causing threat of pollution to the groundwater regime of the valley (Godkul et al., 1994; Dutta, 2012). Hexavalent chromium is considered to be carcinogenic in nature beyond certain limit.

2. At the approved rate of chromite production the life of the individual mine will commence closing by 2030

Leaching:
Transportation of element in ionic form by the moment of ground water through permeable rock strata

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8. Ground water is affected by mining due to depletion of ground water table and by pollution of aquifers (Kar, 1993). Recharge of Ground water is not in practice.

9. The major issue in Sukinda is the pollution of Damsal Nala (Pattanaik et al., 2008). Discharge of mine effluent in to Damsal Nala without proper treatment increases Cr\(^{+6}\) at some stretches of the Nala.

10. The surface water is highly affected by pollution as the runoff and erosion potential of soil is high.

11. The ground water movement being south-westerly the movement of the contaminated water in the reservoirs shall be in the same direction to pollute the ground water regime (Pattanaik et al., 2011).

12. The mining lease boundaries are separated by a safety zone barrier of 7.5 mtr on either side which gradually increases at depth. Percolation of accumulated water under pressure may cause piping which may threaten failure of the barrier and flash flood downstream.

13. The standing water shall exert a static load which is adverse to any underground mining operation, if at all found feasible in future.

14. Even after closure of the mine if beneficiation of low grade chromite is continued by utilizing water from the reservoir the tailing and the concentrate shall cause a threat of addition of Cr\(^{+6}\) by leaching to the ground water.

15. Due to sub-vertical nature of ore body underground method of working is technically ideal to avoid high stripping ratio. But incompetent host rock as well as the ore body cannot withstand rock pressure for underground development. It is still under feasibility study. Large area of excavation is therefore required to win ore from deeper level.

4. CONCLUSION

- Each and every anthropogenic activity that contributes hexavalent chromium to the environment should be regulated in such a manner so that the adverse impacts are containable within reasonable limits. Regular online monitoring is highly essential.

- Regulatory authorities and environmental scientists should formulate an acceptable and economically viable proposal so that at the beginning of the activities the possible adverse impacts are regulated. Their needs a provision of legal frame work to address the issue. This should be preferably concurrent with the mining activity.

- Nickel ore is not produced in India. R & D efforts should be made to use limonite for extraction of nickel. This will sort out the problem of accumulation of overburden dump. The existing dumps may be stabilized properly.

- Once these dumps are reclaimed there should be a provision to reutilize the said area if nickel extraction is economically viable.

- More R & D efforts may be taken up for bio-remediation of Cr\(^{+6}\).

- Sincere effort is required for fixing of hexavalent chromium by bacteria as laboratory tests by some of the researchers are found to be encouraging (Dey Satpura et al., 2010).

- Post mine closure monitoring of ground as well as surface water is desired.

- Suitability of use of water from the reservoirs for agricultural purpose need to be confirmed as some of the literature available are in favor of accumulation of Cr\(^{+6}\) in paddy crop (IBM-BRGM Report, 2001).

- Check dams, gulley plugging, garland drains, etc. may be provided at selected locations to arrest soil erosion and reduce suspended particulate matter in the runoff.

- All the major mines in Sukinda valley will close with open cast mining due to want of adequate R & D effort on feasibility of underground mining where the host rock is weathered limonite (Mishra, 2000).

- Agricultural practice may be encouraged to utilize the stretch of land available to the west of Damsal Nala. This will facilitate engagement of the local workers even after mine is closed.

- Water from these reservoirs can be utilized for beneficiation of low grade chrome ore after closure of mine but the tailing pond should be properly lined to prevent leaching.

- The regulatory authorities through legal procedure should see that the ground water is not contaminated even after closure of all the mining operation.

- Surface run off from the catchment area of individual mines needs to be treated before it goes out of individual mining lease area.

SUMMARY OF RESEARCH

- The ground water in the valley occur at a depth of 8mtr to 11mtr and when comes in contact with atmospheric air and chrome ore during open cast mining is contaminated with hexavalent chromium (Cr\(^{+6}\)) beyond permissible limit.

- The associated overburden contains Nickel and need to be preserved.

- Chromite ore bands continue more than 300mtr below the ground level.

- Surface run off through overburden gets Cr\(^{+6}\) contaminated and pollute Damsal Nala.

- Suitability of underground mining is required.

- Bio-remediation of Hexavalent chromium is a possible technique to be examined after closure of the mines.

- Treatment of surface run off and post mine closure monitoring of groundwater quality.

FUTURE ISSUES

The present requirement of the chrome ore in the alloys industries has augmented the production without considering the environmental hazards it will invite in future. Therefore it is the need of the hour to concentrate on post mine closure scenario in the light of contamination of ground water by Cr\(^{+6}\). The financial assurance approved by Indian Bureau of Mines under Mining Plan/Scheme is not just sufficient to counterbalance the after effect of mine closure. The reclamation of the quarried voids are not permitted as chrome ore is not exhausted and due to nickel content in the overburden the material cannot be used as backfilling material. Surface run off and ground water is contaminated by Hexavalent chromium and is treated by ferrous sulphate dosing to bring the pollutant to permissible limit. The significance of the topic is that:

1. Underground mining is not feasible due to incompetent host rock.

2. Chromite being a strategic mineral mining cannot be stopped at this moment.

3. Mining pits cannot be reclaimed by back filling once it reaches the Ultimate Pit Limit (UPL) due to presence of chrome ore at the bottom and contents of nickel in the back filling material and

4. The most vital aspect of the topic is water to be accumulated after mine closure shall be contaminated with Hexavalent chromium and with the flow the ground water of the entire valley shall be severely contaminated. Therefore the future planners are required to attend the above issue through a possible bio-remediation process.

DISCLOSURE STATEMENT

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5. Mineral Year Book-2010 by IBM
7. Pattanaik LN, Rout DK. Report on environmental issues of chromite mining in Sukinda valley

RELATED RESOURCE

7. Samantaray S, Rout GS, Das P. Studies on Up-take of heavy metals by various plant species on chromite mine spoils in subtropical regions of India. Environ.Monit. & Assessment. 1999, 55, 389-399
Soil samples from chromite mining site and its adjacent overburden dumps and fallow land of Sukinda, Odisha, were analysed for their physico-chemical, microbial and metal contents. Chromite mine soils were heterogeneous mixture of clay, mud, minerals and rocks. The pH of the soils ranges between 5.87 and 7.36.