Hydrogeological Studies - A Tool for Monitoring Water Contamination due to Mining

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Abstract

Mining operations has been considered as one of the most important activities in polluting the environment through enhancement of dust particles in air, wash-offs in surface drainage systems and large scale land degradation. When the mine operations cut the water table, large quantities of ground water flow into the mine pit, thereby getting contaminated and causing subsequent contamination, if being pumped out without treatment. Hence, hydrogeological studies become an important tool to monitor ground water contamination and undertake mine planning in an environment friendly manner.

Mining of various kinds of ores have different levels of hazards associated with them. Chromium mining is under discussion because despite being an essential element for various life forms, when chromium comes into its unstable hexavalent state, its mobility increases along with its potency to induce mutagenic and toxic effects. Therefore, careful observation, regular monitoring and appropriate treatment for hexavalent chromium are a must.

The phenomenon of contamination by seepage water in mine sumps has been studied in the Sukinda Chromite Belt in Dist. Jajpur of Orissa. The ore in the Sukinda Belt is of friable nature and leaches chromium ions in both trivalent and hexavalent forms into the mine sump water. Water sampling was done during the study period as well as the records and observations available with the mine sump owners were collected which reveal that the concentration of hexavalent chromium exceeds the permissible limits for drinking water. The water quality in the wells surrounding the Sukinda belt, within a 10 km radius, have also been studied and it is found that the concentration of hexavalent chromium ions decreases with increase in distance from the ore body. A case study of the environmental management measures undertaken to manage hexavalent chromium during mining operations has been discussed along with a study on its efficacy.

1.0 Introduction

Majority of the naturally occurring chromium is in the trivalent state (Cr^{3+}), which is a stable form and an essential human nutrient. However, chromium is not essential for plant nutrition but can benefit plant growth by limited substitution for Molybdenum. It is more frequently observed that hexavalent chromium (Cr^{6+}) has been detected in the environment, especially in ground water under waste disposal

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bins and land fills. Whereas Cr^{3+} is a nutritionally useful form, Cr^{6+} form is toxic and mutagenic. The biotoxicity of chromate is largely a function of its ability to cross biological membranes and its powerful oxidising capabilities. Human beings can absorb Cr^{6+} compounds through inhalation, dermal contact and ingestion. Adverse effects due to excessive Cr exposure include ulceration and perforation of nasal septum, respiratory cancer, skin ulceration and in the event of ingestion, kidney damage and damage to various proteins and nucleic acids leading to mutation and carcinogenesis.[1] Experiments on rats demonstrated that oral intake of Cr^{6+} results in adverse effects on fertility and development of the offspring. Phytotoxicity and Cr^{6+} accumulation in plant root systems has also been documented.[2] Such accumulation at lower steps of the food chain can biomagnify and can prove fatal to organisms higher up in the food chain. Hence, the presence of unmonitored Cr^{6+} in high concentrations in any natural eco-system poses a great threat to the growth, development and progenitive capabilities of any terrestrial or aquatic species residing therein with higher risks to the last links in food chains due to bio-magnification.

1.1 Study Area Description

Sukinda Valley covers part of survey of India toposheet no. G/12, 16 and is bounded by N latitudes 21°00' and 21°05' and E longitude 85°40' and 85°53' in the eastern state of Orissa in District Jajpur (Fig 1 : Location Map). It is roughly east-west trending narrow intermontane valley lying between the Daitari and Mahagiri hill ranges. The altitude of the valley floor varies between 80 to 230 m above mean sea level with the master slope towards west. In this Sukinda valley falls the Sukinda Utramafic Complex, a famous chromite bearing belt of India. This chromite belt is being mined for the last 60 years and has enough reserves to continue being mined for a comparable period. There are more than 20 mines spread over an area of 70 sq. km. as shown in Fig 2. The recovery of chromite ore has been taking place through open cast mines which have reached depths of over 70 m from the ground levels and have intersected the ground water table at about 10 m below ground level. Hence, inundation and water logging from ground water are common problems for miners.

1.2 Climate and Rainfall in Study Area

The climate of this region is mainly tropical type and is influenced to some extent by the conditions in the Bay of Bengal. Month wise and year wise meteorological data for the period of 1990-1999 has been studied. South west monsoon season starts from June and extends upto October with total average annual rainfall of 1591.0 mm out of which about 83% of the rainfall can be observed in the monsoon season only. The summer is severe during May-June. The highest temperature recorded is 50°C in the month of May of year 1995 and the lowest temperature recorded during January, 1992 is 11.6°C. A pleasant winter prevails from December to January. The relative humidity varies from 48.92% (January) to 85.57% (August). The highest reading is recorded in Setember, 1991 as 90.17% and the lowest is 45.39% during January, 1991.

Normal Monsoon rainfall (mm) (IMD Bhubaneshwar 1951-1980, June-Sep)	878.60

Average Moonsoon rainfall (mm) 1197.70
(1992-1999, Ostapal Station, FACOR , June –Sep)

1.3 Geology of Study Area

The Sukinda ultramafics belong to the metamorphosed rocks of Pre-Cambrian age. The rocks of the area are associated with six sedimentary sequences separated by unconformaties. The Sukinda ultramafics belong to the second sequence of the succession from a major intrusive into the older rocks and occur as intrusive. The stratigraphic succession of the region is given in Table 1.

Table 1 : Stratigraphic Succession Of The Region

	Granite
Sixth Sequence	Intrusive Contact
	Shales Carbonatites
	Shale lava and tuffs, conglomerates
----------------------------- Unconformity -------------------------	
Fifth Sequence	Gabbros, Ultrabasics and dyke
	Swarms Quartzites
	Conglomerates
----------------------------- Unconformity -------------------------	
Fourth Sequence	Basal Granite
	Intrusive Contact
	Managanese bearing Shales
"Iron Ore stage of Dunn" Banded Hematite Jasper Shale	
----------------------------- Unconformity -------------------------	
Third Sequence	Gabbro and Ultrabasics (intrusive)
	Lavas and interbedded grits
	Conglomerates grits, Sandstone
----------------------------- Unconformity -------------------------	
Second Sequence	Granite and granite gneiss (intrusive) Granophyre (intrusive) Gabbro and Ultrabasic with chroimite lodes (intrusive) Branded Hematite quartzite Banded Hematite Jasper Conglomerate, ferruginous shale and phyllites
----------------------------- Unconformity -------------------------	
First sequence	Metavolcanics chlorite schist Quartzites, BHQ, Banded ferruginous Quartzite, Mica Schists, Fuchsite

The ultramafics are distributed with two different types of metamorphic facies :

(a) Green Schist facies Quartzite or Blotite homblende-Granite in the northern part.

(b) Granulite facies Assemblages in the Southern part of the region

The ultramafics suite of rocks of Sukinda area is a layered complex of alternate bands of Chromite, Dunite , Peridotite and Orthophyroxinite. The dunite peridoties are completely serpentinised. The presence of numerous Chert bands in association with Chromite bands is the characteristics feature of the aera.

The lower sequence of Iron Ore Super Group of the region has been folded into syncline with gentle plunge to the WSW direction. The ultramafics are intrusive into older sequence and subsequently co-folded. The area has been faulted along the northern margins of ultramafic body.

The chrome ore mineralisation is mainly restricted to the ultramafics and occurs at six different stratigraphic levels. Band-I is the most important chromite bearing unit/member of the region. It extends for a longer distance and is the thickest among all the bands.

1.4 Surface and sub-surface Water Regime of the Study Area

1.4.1 Sub-surface water regime

Hydrogeological studies were taken up for the entire water shed of Damsal nala (Sukinda Valley). The study area covers 20 revenue villages (16 in Sukinda tehsil of Jajpur district and 4 in Kamakhya Nagar tehsil of Dhenkanal district). The study area of bore wells of the area showed that no bore wells are used for irrigation purposes.

Rainfall is the principal source of ground water, which percolates down to the water table through the top soil. The weathered lateritised – limonitised mantle as well as the underlying semi weathered and fractured country rocks form the repository of ground water in the area. The nature, extension and yield potentials of the ground water reservoir are controlled by wide lithological variations, structural set up and weathering characteristics of the rock formations. The intermittent limonite – chert form potential aquifers in the area. The ground water generally occurs under phreatic conditions and occasionally under semiconfined to confined conditions in deeper horizons. The occurrence of aquifers are briefly described as follows :

Broadly the following major hydrogeological units occur in the area

A. Laterite – Limonite chert
B. Laterite – Weathered and fractured ultramafics associated with limonite and chert
C. Alluvial and channel fill deposits.
D. Other hydrogeological units including Orthopyroxenites.

Laterised Ultramafics : Laterised ultramafics are on the southern side of the alluvial region and the Sukinda Mines (Chromite) area lies in this formation. The pre monsoon water levels were recorded as 6 m and 8 m respectively. It was reported by the local users that the water level in monsoon period is 2.64 m and 5.44 m respectively.

Alluvial Region: Alluvial formations are noted on both sides of Damsal nala. Villages Tailangi, Ostia, Chingudipal, Benagadia, Kendubani lie in alluvial belt. The depth of water table in pre-monsoon was found to be between 5.01 m and 10.01 m.

The bore well at Chingudipal lies within the zone. The post monsoon levels, as per information gathered from the local users, varied between 0.0 m and 2.79 m.

1.4.2 Surface Water Regime

Besides some water bodies and ponds within the study area, the valley is drained by Damsal nala which sustains perennial flow and generally follow a westerly course and finally joins with the river Brahamani. The nala and its tributaries exhibit a dendritic drainage pattern. The annual average flow of Damsal nala is about 1.457 m^3/sec. Surface water is not utilised for the mining activity. Mine water will be disposed into the Damsal nala after treatment.

1.4.3 Problem of Hexavalent Chromium in the Study Area

Chromite ore leaches out both Cr^{3+} and Cr^{6+} when it comes in contact with water. Since Cr^{3+} is less mobile than Cr^{6+} in most soil or water systems due to the relative insolubility of Cr^{3+} at relevant pH (pH>5) values, the observed Cr^{6+} concentrations in the mine sumps of Sukinda belts are way beyond those permitted for drinking water or disposal without pretreatment.

Hence, Cr^{6+} contamination is a burning environmental issue in that area. There are two facets to the Cr^{6+} contamination of water:

(i) Firstly, the contamination of the ground water due to percolation of Cr^{6+} contaminated mine sump water
(ii) Secondly, the contamination of surface water in the regional drainage network due to discharge of mine sump water

During studies it was observed that Cr^{6+} is more (0.43 mg/l) in sump than in shallow wells, hence, the possibility of movement of Cr^{6+} to some other sink cannot be ruled out. Secondly, the contaminated mine sump water is pumped out into a natural drain, Damsal Nala (refer Fig. 2) passing through the Sukinda Ultramafic Belt predominantly without treatment since most mines do not have effluent treatment facilities (ETP). Therefore, released Cr^{6+} from all mines cumulatively exceeds concentrations to the tune of 5-10mg/l in the regional drainage network[3].

2.0 Objective

The objective is to identify the concentrations of hexavalent chromium in sub surface and surface water in the areas surroubnding the ore bodies as well as the mine sumps.

3.0 Methodology

The total study area is 416.15 sq. km out of which about 40% of the area is occupied by Mahagiri and Daitary Protected Forest which does not have any ground wells/dug wells and no habitation. The remaining area is about 250 sq. km. Hence, 27 dug wells/bore wells have been inventoried in this area which give an average coverage of about 9 sq km/bore well.

The well/ bore well inventory was undertaken between 11th and 21st April 2003. The survey was undertaken with the help from employees/experts of Indian Metal and Ferro Alloys (IMFA) who had knowledge of local language, terrain and location of wells.

The location of dug well/bore wells that were inventoried is given in Fig 3 and the details are compiled in Table 2. The location (latitude, longitude) was established by using automatic Global Positioning System (GPS). Thereafter, the mapping of the borewells was done on the map (Fig 3). Hydro-geological map of Sukinda Valley is given in Fig 4.

Table 2 : Water Level Inventory Of Dug Wells /Bore Wells In Study Area

Well No.	**Location**	**Water level below ground (m)**	**Fluctuation* (m)**
		Pre monsoon (measured)	
1	Kusumundia	5.95	
2	Kankariapal	2.46	
3	Kuhika-Bambil	4.60	
4	Kuhika	6.71	
5	Pimpudia	7.93	
6	Kustampur	1.65	0.43
7	Odisa	8.41	
8	Odisa	8.54	
9	Kansa	4.57	1.27
10	Kamarada	18.29	1.65
11	Saruabil	9.15	1.73
12	Sukurangi	6.38	2.03
13	Kansa	5.41	1.93
14	Maidarpur	7.37	2.59
15	Chirugunia	8.92	5.69
16	Chadaragadra	6.99	3.96
17	Bandaria	8.28	
18	Kaliapani	6.00	3.35
19	Chinguripal	10.01	2.79
20	Kaliapani	8.00	2.57
21	Kaliapani	7.01	2.82
22	Benagadia	8.54	7.98
23	Benagadia	8.54	7.01
24	Benagadia	8.54	7.01
25	Kedubani	5.01	3.86
26	Sitalbasa	7.75	
27	Maidarpur	9.96	
	Average	**7.44**	**3.45**

** Information collected from villagers. Since most of the structures under investigation were bore wells, it was difficult for villagers to estimate the fluctuation. Hence, at some places, information was not available.*

4.0 Result

4.1 Water Quality

The water requirement of inhabitants around the mine belt is met from ground water source. Ground water is being exploited for domestic purposes only through bore wells and dug-cum-bore wells.

With a view to assess the water quality aspects and likely impacts on ground water regime due to mining activities, the quality of ground and surface water collected from within the study area were examined. In all seven locations were selected and monitored for four seasons during the months of October, January, May and July. 32 parameters as per the drinking water standards were analysed. Surface water samples were monitored in Tailangi Nala (upstream of Damsal Nala) and Damsal Nala while ground water was monitored in Dugwell at Tailangi Village, Bore well at Chingudipal, Bore well at Garamian village, Bore well at IMFA's ML area and one m,ine seepage water sample from Mine Pit Water of IMFA Ltd.

The pH values of water samples collected from different sources ranges between 7.43 and 8.42, which is within the desirable limits for drinking water purposes except in Sitalbasa village where it is 5.83. Total dissolved solids in water samples collected from all sources are higher than the desirable limits (500 mg/l). The values of chemical parameters like iron, chloride, calcium, magnesium and sulphate are within the desirable limits for drinking water requirements. In general ground water quality is good for drinking water purpose. Considering the heavy metal analysis, they are found to be within the desirable limits in all samples (ground and surface water) except that Cr^{+6} is found higher than limits in sump water of Chingudipal Mine (0.132 against permissible 0.05 mg/l).

The study indicates that there may not be any deterioration in the quality of ground water due to mining operations of the past. However, to ensure that the environment remains unpolluted special treatment plants should be installed for treating sump water before its release to the environment.

4.2 Hexavalent Chromium Concentration

The hexavalent chromum concentration in another set of ground water and surface water samples is given in Table 3.

Table 3 : Hexavalent Chromium (Cr^{6+}) contents in Surface Water and Ground Water Samples of Sukinda Valley[4]

S.No.	Location	Sample Source	Cr^{6+} content (mg/l)
1.	Damsal Nala Near Sukinda	Stream	0.30
2.	Damsal nala near Kaliapani Intake Area	Stream	0.10
3.	Kamardah near M/S B.C. Mohanty Mines	Tube well	0.110
4.	Kamardah near GSI Camp	Dug well	0.030
5.	Kalarangi near Guest House	Dug well	0.035

S.No.	Location	Sample Source	Cr^{6+} content (mg/l)
6.	Saruabil (Nuasahi) adjacent to Road	Dug well	0.080
7.	Chinguripal (inside the compound of Haribandhu Mohan)	Dug well	0.050
8.	Kamardah Mines (B.C. Mohanty)	Quarry Seepage	0.060
9.	Ostapal Mines	Quarry Seepage	0.520
10.	Damsal Nala, near Kaliapani	Stream	0.055
11.	South Kaliapani, F-Quarry	Quarry Seepage	0.120
12.	TISCO OBX Quarry	Quarry Seepage	0.740
13.	TISCO OBX Quarry	Quarry Seepage	0.930
14.	TISCO OBX Quarry	Seepage water (near ore body)	1.220
15.	Kaliapani no. 3 Quarry	Quarry Seepage	0.340
16.	TISCO OBX Quarry	Quarry Seepage	0.210
17.	Kathpal A Quarry	Quarry Seepage	0.050
18.	Kathpal B Quarry	Quarry Seepage	0.050
19.	Tungeisuni	Tube well	0.050
20.	Kansa forest beat office	Dug well	0.80
21.	Kansa Village	Tube well	0.060
22.	South Kaliapani, F-Quarry office	Tube well	0.070
23.	Kaliapani Mines Office near D Quarry	Tube well	0.530
24.	TISCO near admin office and labourers shed	Tube well	0.700
25.	Kaliapani township nearR.M. office	Tube well	0.200

The concentration of Cr^{6+} exceeding permissible limits (0.050 mg/l) is detected from few samples of ground water, surface water and mine water as well as mine seepage. It is seen that the hexavalent chromium content is high near the ore bodies and reduces with distances. In the ground water samples it varies from 0.03 to 0.8 mg/l in dug wells and 0.05 to 0.7 mg/l in the tube wells. The concentration of Cr^{6+} was found in the range of 0.05 to 1.22 mg/l in quarry seepage, which is much higher. In Damsal Nala it is found in the range of 0.03 to 0.104 mg/l and found more in the downstream, which reflects the impact of mine water discharge and leaching process from quarry seepage in the nala.

Cr^{6+} content varies from 0.11 ppm to 0.04 ppm in openwell and borewells. The water samples from tubewells/ borewells narthe quarries show very high hexavalent chromium ranging from 0.11 ppm inside M/S B.C.Mohanty residence premises to 0.70 ppm near TISCO D.M. Office. The seepage water from various quarries also show very high hexavalent chromium content varying from 0.06 ppm (M/S B.C. Mohanty mines quarry) to 1.22 ppm (TISCO OB 10 Quarry). The water samples collected from the Damsal Nala showed the content of Cr^{6+} ranging from 0.01 to 0.055 ppm, which may be due to discharge of mine seepage water into the Damsal Nala. Also the mine owners often resort to surface spreading of the seepage water of mines over the cultivated lands for irrigation which seeps underground to pollute the groundwater.

5.0 Discussion

The treatment of hexavalent chromium before discharge water from the mine water sump is of primary importance in the study area. One of the mine operators M/S IMFA has started such a treatment plant and the discussion on the same has been done below.

The mine water discharge is stagnated in a settling pond at surface after passing through oil-grease separator/trap. As the sump water contains Cr^{6+} of higher concentration than permitted under law, the stagnated mine water at surface is passed through a treatment plant before the water is discharged to the surface water channels. Treatment is being done by neutralising hexavalent chromium to trivalent chromium by reduction process.

Hexavalent chromium is a strong oxidising agent and can readily be reduced to trivalent chromium by means of adding reducing agent i.e. Ferrous Sulphate ($FeSO_4$). After proper mixing with Ferrous Sulphate the Hexavalent Chromium (Cr^{6+}) is reduced to trivalent chromium (Cr^{3+}) while Ferrous ion (Fe^{2+}) will be oxidised to Ferric iron (Fe^{3+}). In the next stage, by adding alkaline reagent i.e. Sodium Hydroxide (NaOH), the Ferric iron will be precipitated as Ferric Hydroxide ($Fe(OH)_3$) and the trivalent chromium will be precipitated as Chromium Hydroxide ($Cr(OH)_3$). Both the precipates will be coagulated alongwith other suspended solids and ultimately settle down in a settling tank.

The treatment units essentially consist of an Intake tank cum primary setting tank, Chemical Dozing and Mixing Tank, Final Setting Tank, Drain for carrying supernatant water to main discharge nala amd bypass discharge drain to remove the sludge from the bottom of the setting tank to sludge pond from where it is cleaned time to time. The pictures of the treatment plant functioning at IMFA's mine are given in Fig 5. Table 4 gives the results of water treatment by the Effluent Treatment Plant

Table 4 : Characteristics of mine sump water before and water treatment with specific reference to Hexavalent Chromium (Trial Run for Optimisation)[5]

	Before treatment	After Treatment	Before treatment	After Treatment
Date	03.01.2004	03.01.2004	03.01.2004	03.01.2004
Time	12.00	13.00	13.00	14.00
PH	7.2	7.3	7.3	7.4
Cr^{6+} (ppm)	0.37	0.012	0.41	0.009
Total Cr (ppm)	1.57	0.069	1.39	0.056
TSS (ppm)	40.0	26.0	34.0	24.0

Table 4 contd. : Characteristics of mine sump water before and water treatment with specific reference to Hexavalent Chromium (Trial Run for Optimisation)[5]

	Before treatment	After Treatment	Before treatment	After Treatment
Date	03.01.2004	03.01.2004	04.01.2003	04.01.2003
Time	12.30	13.00	12.00	12.30
PH	7.49	7.51	7.47	7.64
Cr^{+6} (mg/l)	0.35	BDL (<0.008)	0.38	0.048

Acknowledgment

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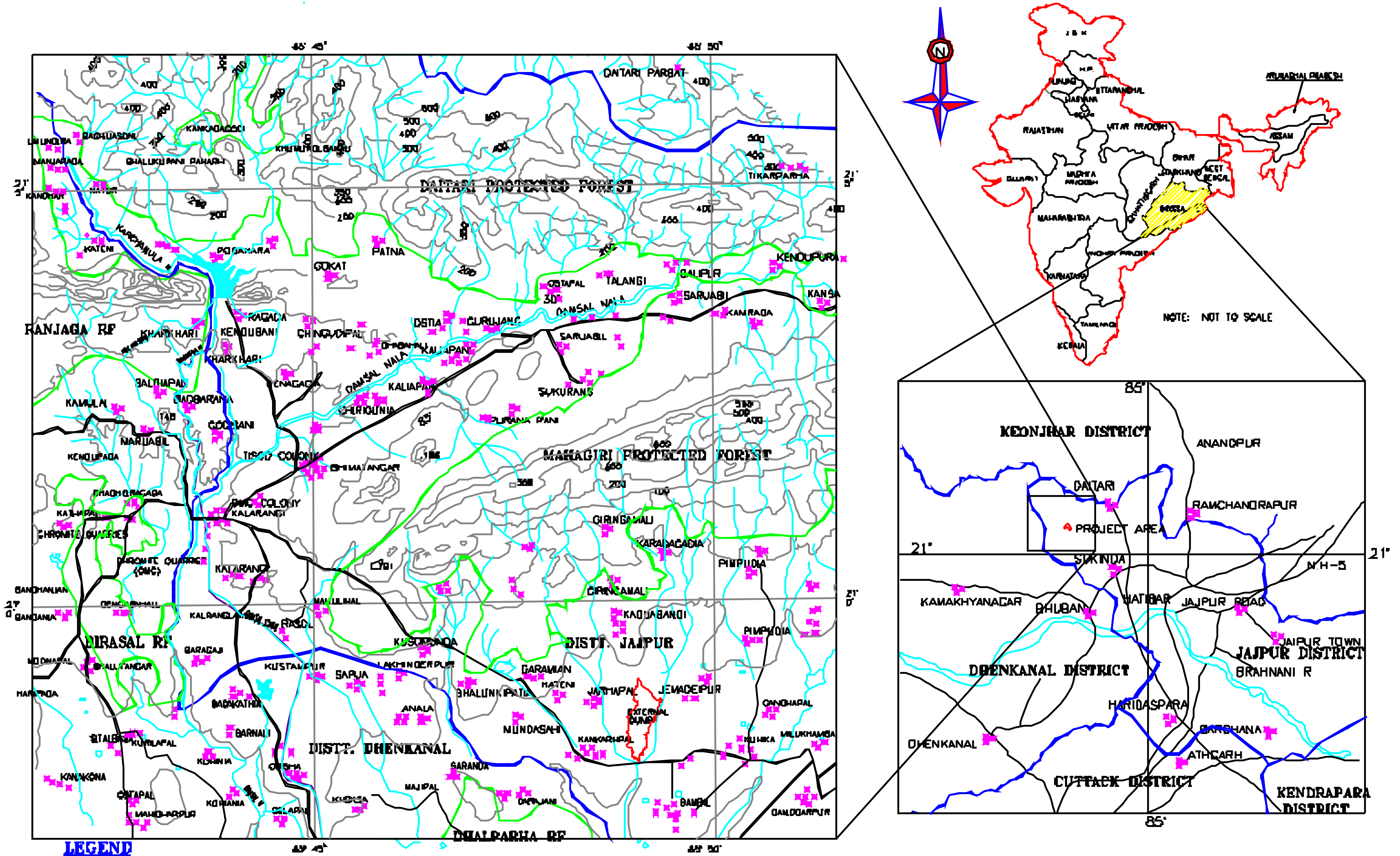
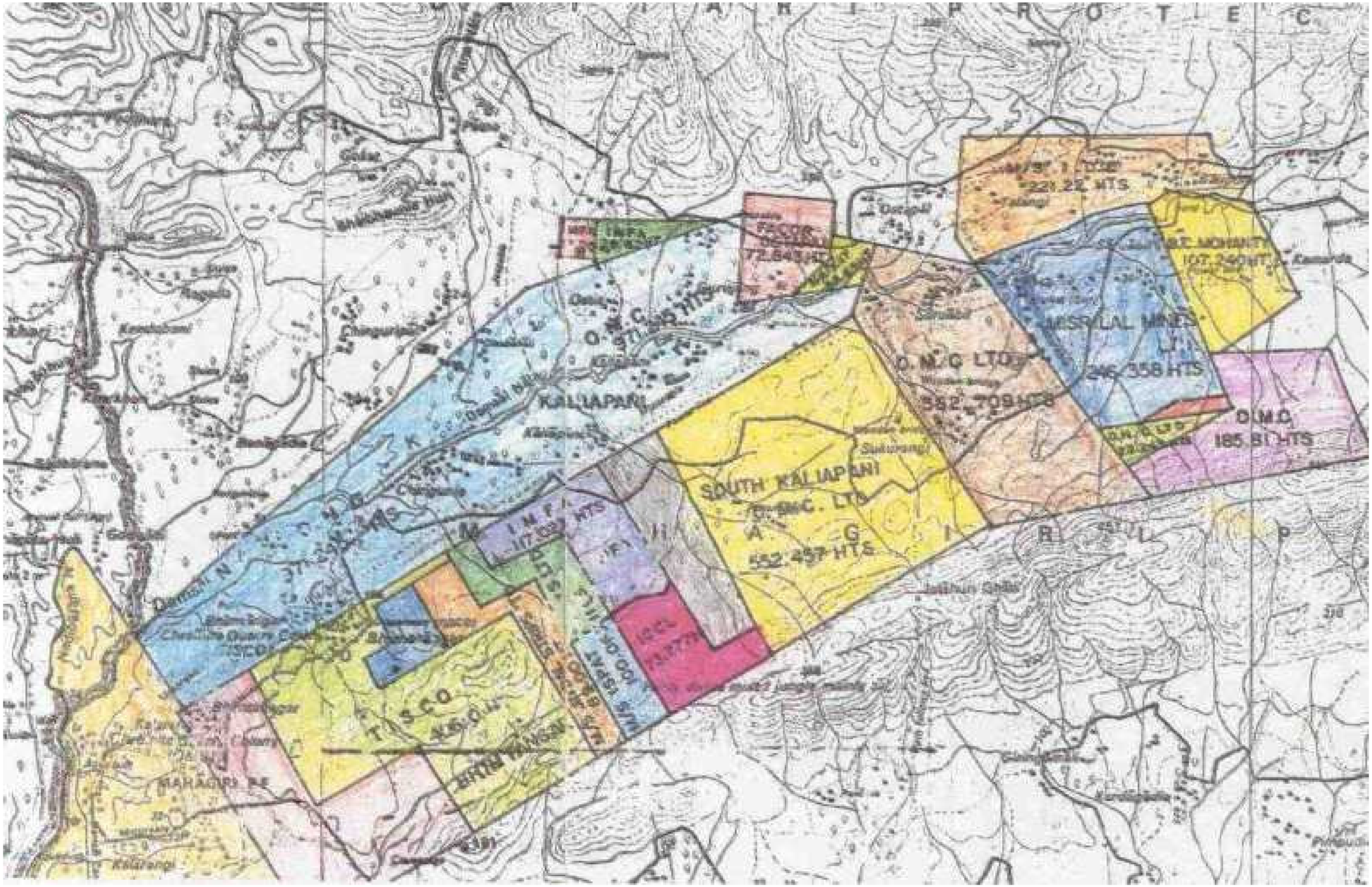


FIG 1 : LOCATION PLAN SHOWING SUKINDA VALLEY

FIG 2 : MAP SHOWING THE MINES IN THE SUKINDA VALLEY



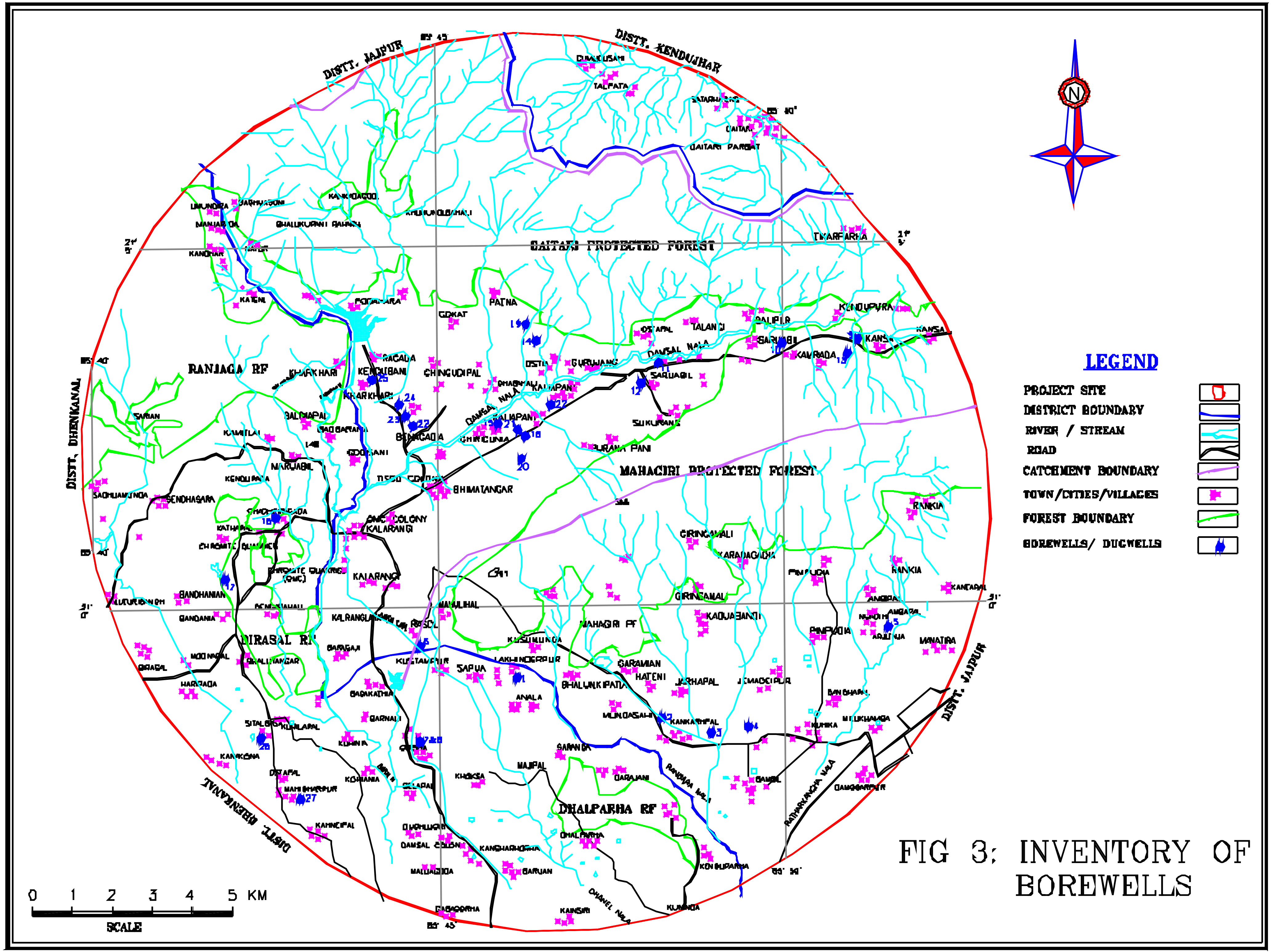
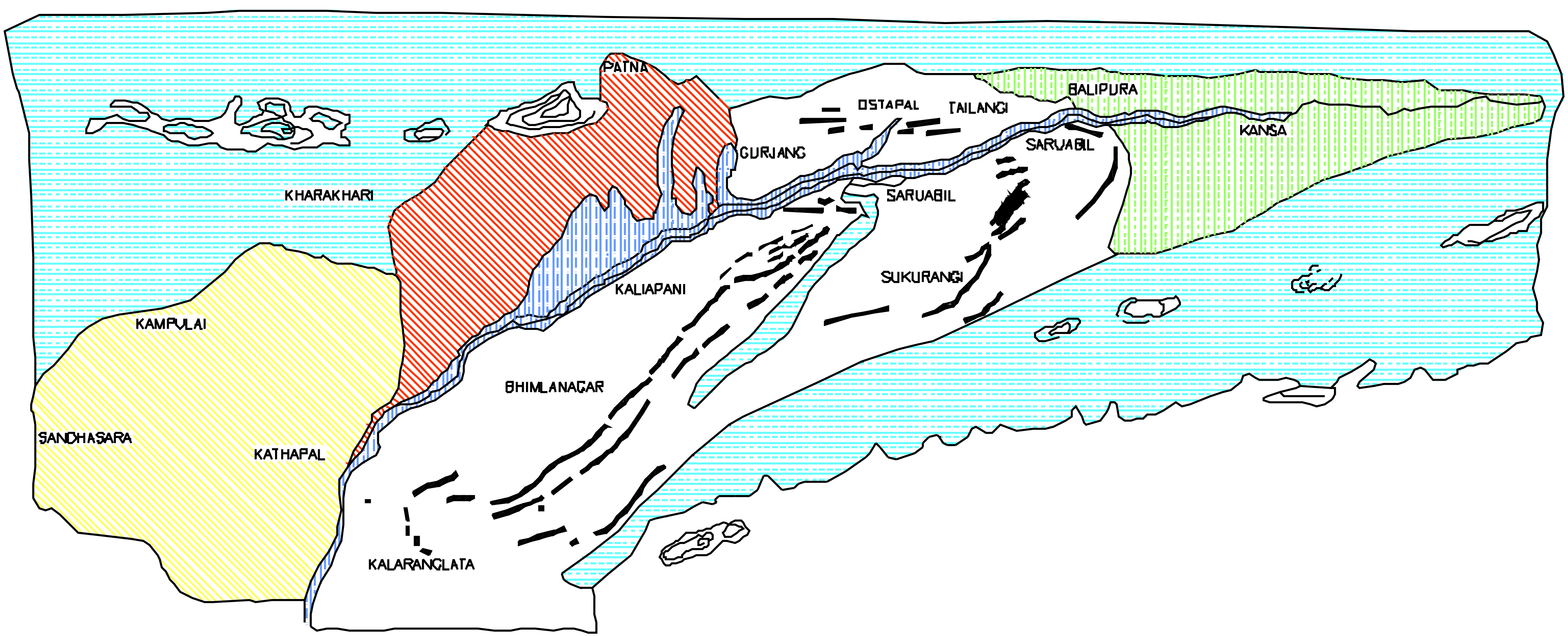


FIG 3: INVENTORY OF BOREWELLS



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- LATERITES-LIMENITE-CHERT-- HIGH POTENTIAL, HIGHLY WEATHERED & PERMEABLE YIELD < 12 L.P.S. TRANSMISSIVITY : 2 TO 74 m2/day IN DEEPER AQUIFERS
- WEATHERED & FRACTURED ULTRAMAFICS WITH LATERITE CAPPING & INTERMITTENT LIMONITE- CHERT/CHROMITE BANDS. MODERATE TO LIMITED POTENTIALS. YIELD < 4 L.P.S. TRANSMISSIVITY : 1 TO 92m2/day IN DEEPER AQUIFERS
- ORTHOPYROXENITE
- METABASALTS
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(ORTHOPYROXENITE, METABASALTS, ULTRAMAFICS ASSOCIATED WITH GRANULES & DYKES:) WEATHERING LESS PRONOUNCED, INCIPIENTLY FRACTURED, YIELD < 3 LPS TRANSMISSIVITY : 1-5 m2/day IN DEEPER AQUIFERS

- QUARTZITES OCCUPIED BY HILLS AND FORESTS

SCALE

500 0 500 1500 2500 3500

SOURCE: KAR, CGWB

FIG 4 : HYDROGEOLGICAL MAP OF SUKINDA CHROMITE VALLEY

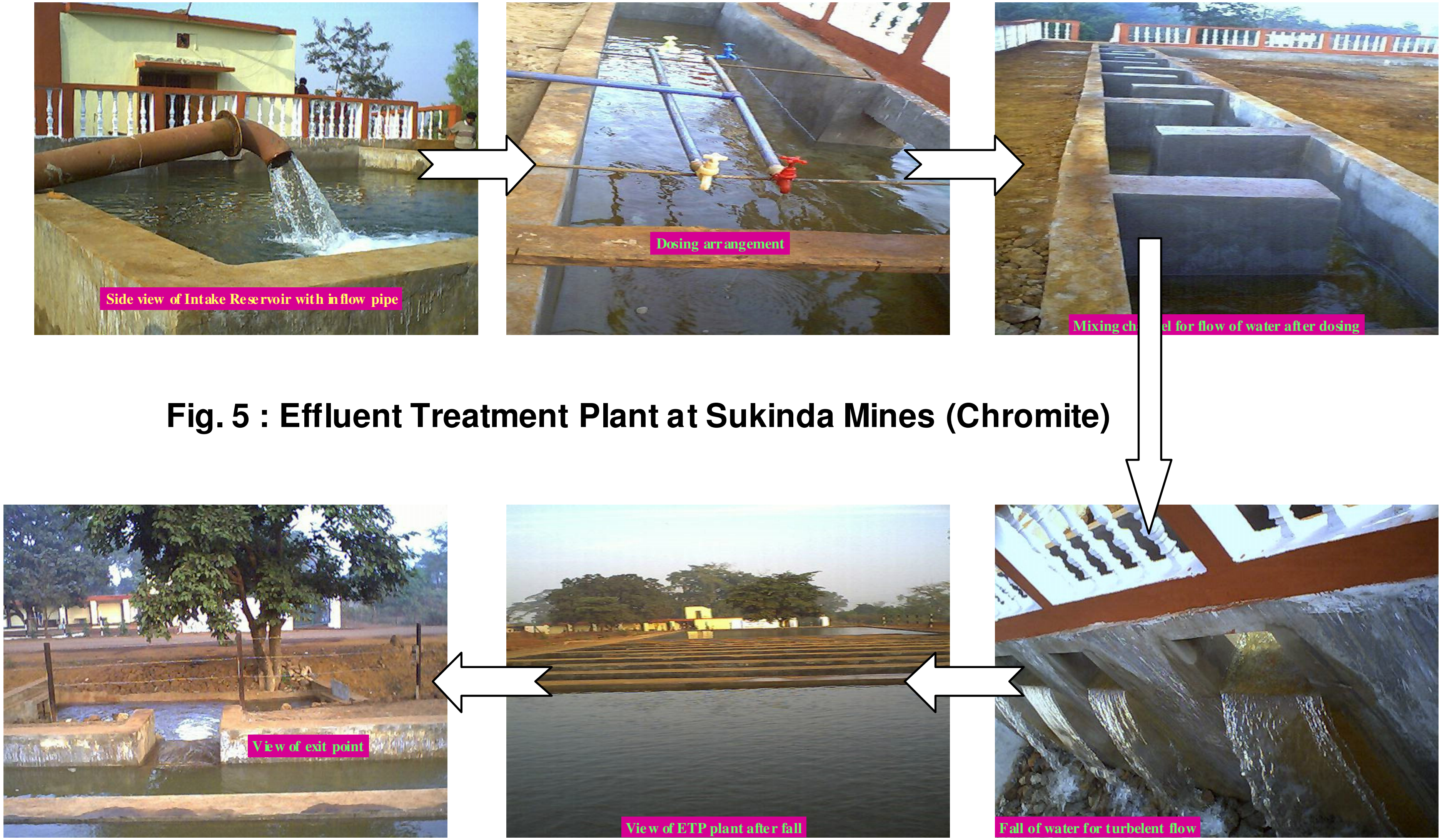

Fig. 5 : Effluent Treatment Plant at Sukinda Mines (Chromite)