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Geo-hydrological study for quantitative estimation and dewatering planning in an opencast iron ore mine of India

Rajhara iron ore mine is working for the last fifty years and with deepening of mine, slopes have been enlarged and the excavation levels have approached very close to the groundwater table and intercepted causing water accumulation problem in the pit. The mine water accumulation obviously hampers the normal production particularly in wet months and during post-monsoon season when all aquifers are fully charged with water. Based on the pumping test conducted at mine site, quantitative estimation of water, aquifer parameters and pumping requirement during different period of year had been worked out and presented in this paper. Mine dewatering scheme is accordingly designed to keep the quarry bottom dry and thereby achieving the targeted production. It is concluded that scientifically planned geo-hydrological study, proper drainage system, water conservation and judicious water management is the best solution to reduce the mine-water related impacts for the Rajhara mine and mine area nearby. The mine dewatering and its planning, designed in 2006 and field implementation results derived in 2016, were helpful to remove lacunae and practical difficulties of current practices.

Keywords: Mine water, iron ore mine, geo-hydrological study, quantitative estimation of water, mine pumping and mine dewatering

1.0 Introduction

Iron ore is the main and essential raw material for steel manufacturing. For all practical purpose (s), iron ore is a major non-metallic mineral of industrial category. In India, it is extracted from surface mines only. Bhilai Steel Plant of Steel Authority of India Limited (SAIL) owns its five captive mines near Dalli Rajhara in the state of Chhattisgarh, which are excavating iron ore by mechanized, semi mechanized as well as manual means (Fig. 1). In 'Rajhara mechanized mine (RMM)' groundwater is intercepted and the deepening of mine continued for extraction of iron ore. The mine management took decision to plan and tackle the mine water interception (drawdown) scientifically and based on the hydro-geological investigation. Thus, the ensuing case study encompasses mine planning angle taking into consideration the site-specific hydrological and geological parameters. A practically applicable mine dewatering scheme have been designed and developed, to keep the mine bottom dry during maximum period in a year and especially in wet months. Suitable steps for its implementation are taken by the mine authorities.

This research paper (case study) is an important case study from follow up point of view for the readers. It is important to note that field work for design/development of dewatering planning was done in 2006 and after ten years of its observation in actual field (2006-2016) the results are summed up and portrayed in this work depicting current practices. This assessment has been done by CIMFR in association with mine management (second author of paper) to remove some lacunae that has occurred as result of practical difficulties.

2.0 Study area and its details

SAIL's Rajhara mechanized mine (RMM) is a captive opencast mechanized iron ore mine of Bhilai Steel Plant (BSP). It is the second largest mine from among five captive mines supplying raw material feed to BSP. The study area lies between latitudes 20°30'N to 20°40'N and longitudes 81°00'E to 81°10'E and covered under Survey of India topographic sheet No.64 H/2. The mine is located in the Dalli Rajhara taluka of Balod district, Chhattisgarh and its location map is shown in Fig. 2. The ore deposit at Rajhara lease comprises two distinct blocks, Rajhara main and Kokan (West). Dalli-Rajhara range can be distinctly separated into two groups of hills namely Rajhara Pahar and Dalli Pahar with a valley in between ('Pahar'- a Hindi word meaning a hill). The RMM lease covers land area of 220.42 ha.

The area comprises plains as well as hills and has an undulating topography. It has denudational slope on granite and metamorphic rocks with adjacent pediment or pediplains. The average ground elevation is 450m. There lies a fault/ unconformity between Dalli and Rajhara Pahar and as such they are separated geologically.

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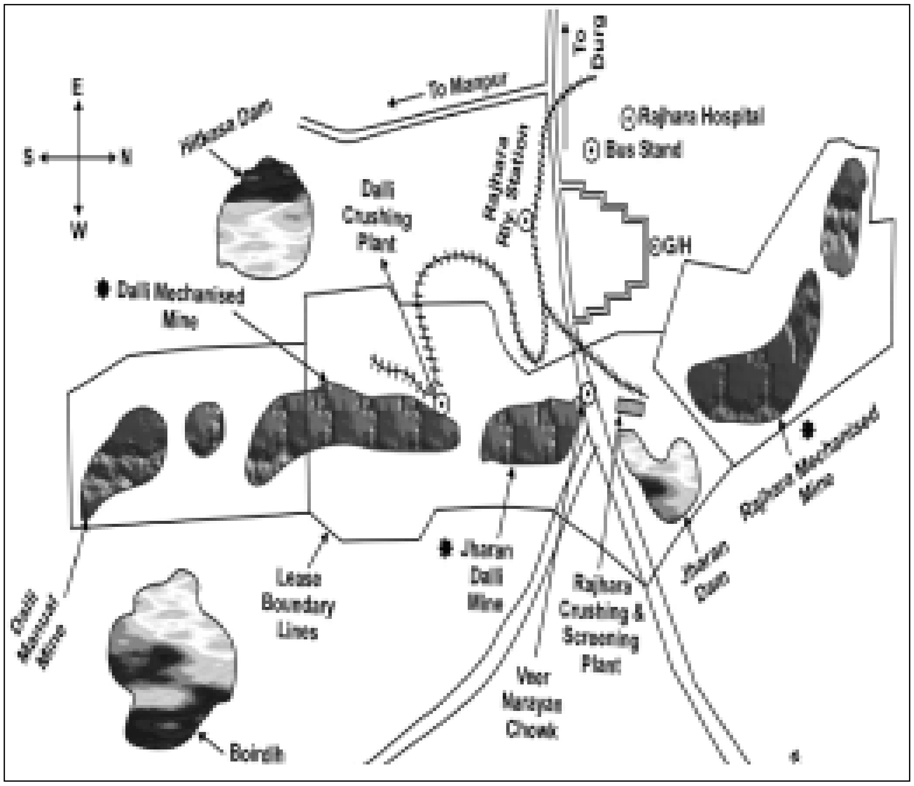

Fig.1 Iron ore mines of Dalli-Rajhara group

The soil in the study area is rich in iron content (Anon, 1990-1991). However, the dominant soil type in the study region is red lateritic (alfisols) and yellow soil. The study region has major types of land uses namely forest land, agricultural land and mining land.

2.1 Geology

The lithological assemblages of Rajhara mine areas are dominantly of the metamorphic formation. These rocks consist of quartz and mica-schist, phyllites and banded hematite quartzite (BHQ). The iron ore deposits are associated with the banded ferruginous formations belonging to the Chilpi formations of Pre-Cambrian age. The BHQ outcrops at the surface in the S-W and to some an extent in the N-W parts of the study area forming a chain of hills for a considerable length. The dip angle is 40º-60ºN. The outcrop of trap rocks of Dharwar age can be seen in a large area in the northwest part of the region. In the south and southwest areas, granite shows a very rich development and includes rather thick quartzite veins. The BHQ and ferruginous shale in the middle ferruginous unit of the stratigraphic succession form the footwall in which iron ore occurs (Fig.3).

Geologically, Rajhara deposit has following types of iron ores –

- Massive hematite ore (Fe content = 65-67%)
- Compact laminated ore
- Soft laminated ore
- Lateritic ore

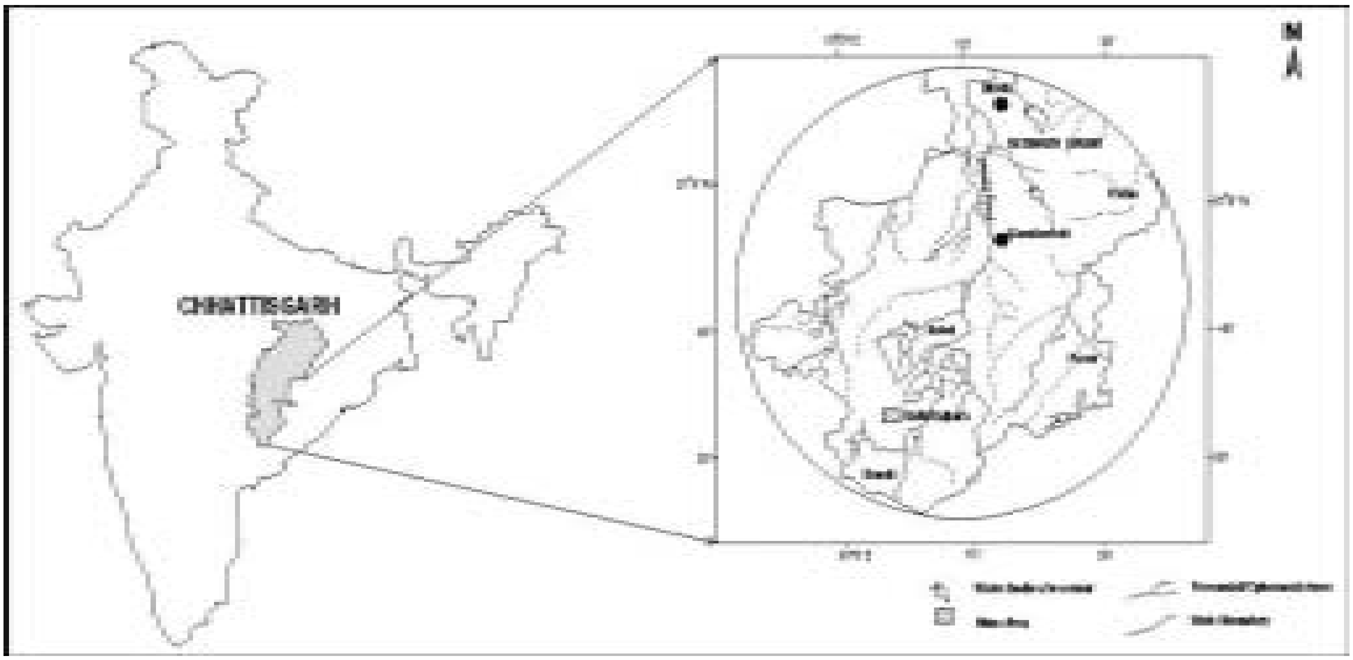

Fig.2 Location map of the study area

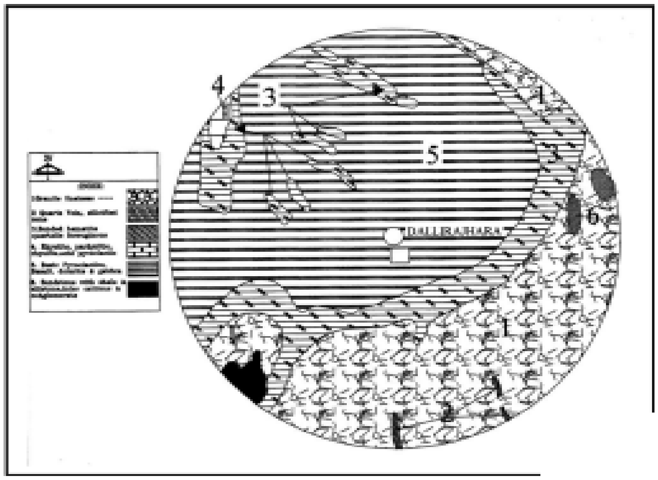

Fig.3 Geological map of the study area

2.2 Rainfall (regional and local)

The study area receives maximum rainfall from S-W monsoon. The average regional rainfall over the past forty four years, i.e. for the period from 1960 to 2004, is worked out as 1252 mm (Fig. 4) and rainfall recorded locally near RMM is shown in Table I. Both, the regional and local rainfall pattern are nearly equal and matching (Table I column 4).

2.3 Drainage

The drainage pattern is dendritic. A drainage map of the study area is shown in Fig.5. From this figure it is evident that there are no major rivers in the study area. Two small seasonal nallahs namely Jharan Nallah and Kusum Nallah (flowing through Rajhara town) are important from the hydrological angle because they contribute marginally to the drainage of the study area. The study area has one relatively large man made water bodies namely Boirdih reservoir at a distance of 6 km from mine.

Table I: Rainfall statistics of Rajhara mechanized mine (local)

Year	Rainfall (in mm)	Difference from regional
1. 2003	1409.15	(+) 39.81 mm
2. 2004	1483.15	(+) 153.65 mm
3. 2005	1434.16	N A
4. 2006*	1343.45	NA

Source: MVT Centre, RMM, Dalli-Rajhara

3.0 Geo-hydrological investigation

To know the hydro-geological set up of study area it is necessary to know the water resource scenario. As per the hydro-metrology and watershed in which the study area falls,

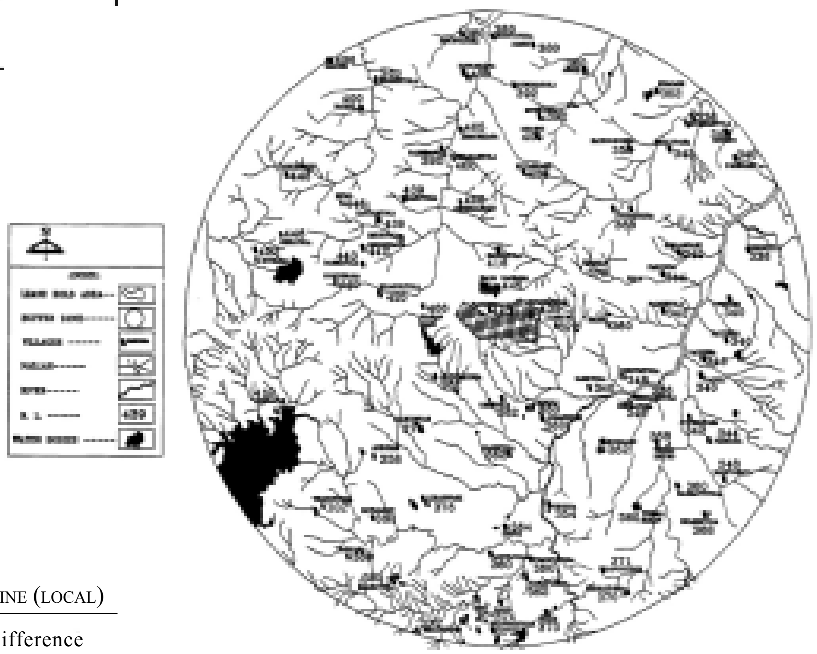

Fig.5 Drainage map of the study area

planning for water resources can be done. To reveal the hydro-geological set up of the area a pumping test (also called as ‘aquifer test’) has been carried out which has revealed important facts about the groundwater and aquifer present, whose details were not clearly known earlier.

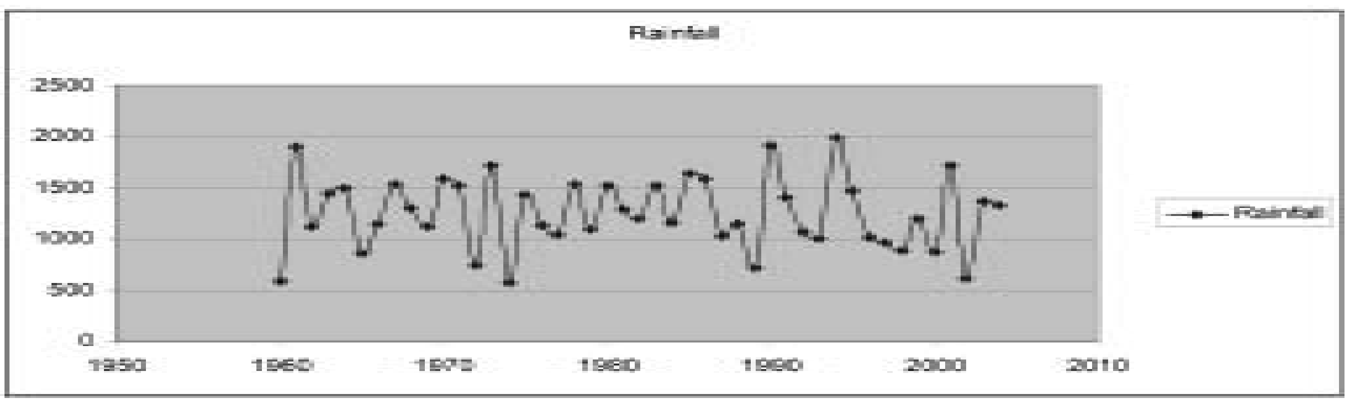

Fig.4 Trend of regional rainfall (yearly, in mm)
Source: Meteorology Department, Chhattisgarh Government

TABLE II : AQUIFER PARAMETERS FOR CONCERNED GROUNDWATER PROVINCES OF STUDY REGION

Groundwater province	Parameter	Potential of groundwater based on aquifer parameters	Reference
Basement crystalline province (52730 sq. km.; 38% approx.)	Transmissivity = 0.15 to 100 m^2/day Specific capacity (hard rocks) = $1.37*10^{-2}$ to $7.86*10^{-3}$ m^3/min/m Specific capacity index (shallow aquifers) = $0.577*10^{-3}$ to $1.997*10^{-3}$ m^3/min/m for unit cross section Less 'storativity'	Poor in groundwater potential	65% wells have drill time yield of 1 lps (86 m^3/day) 32% wells have drill time yield of 1 to 5 lps (86 m^3/day to 432 m^3/day)
Plutonic-volcanic and meta-sedimentary province (29310 sq. km.; 20% approx.)	Transmissivity = 0.5 to 250 m^2/day Specific capacity = $8.92*10^{-2}$ to $5.72*10^{-3}$ m^3/min/m Specific capacity index = $0.623*10^{-3}$ to $1.82*10^{-3}$ m^3/min/m for unit cross section Poor 'storativity'	Better groundwater potential compared to basement crystalline	70% wells have drill time yield of >1 lps (86 m^3/day) 35% wells have drill time yield of more than 5 lps (432 m^3/day) 30% wells have drill time yield of <1 lps (86 m^3/day) which is very poor

Source: CGWB, 2006

The aquifer present in the area (local) is gneisses which contain groundwater in the cracks and fractures. The aquifer parameters for concerned groundwater provinces of study area (i.e. Transmissivity-T, Specific Yield-Sy, Permeability-K and Porosity) and region are worked out and cross verified from the authentic secondary source i.e. Central Ground Water Board (CGWB). These values are as shown in quantitative estimation sub-section and Table-II respectively.

3.1 Surface water resources

Major surface water reservoir present on the periphery of the study region is Tandula reservoir, which is located at a road distance of 25 km from mine. Large number of small seasonal nalas and tributaries meets the Tandula reservoir forming part of Mahanadi basin and Godavari basin. Particularly, in hard rock terrain (granitic) high value of average drainage density and drainage frequency (>1.5) is indicative of low permeable surface. The Jharan dam (also termed as Rajhara dam) and Boirdih reservoir Hitkasa tailing dam/pond, built by SAIL for its industrial requirement are the water body noticed from hydro-geological investigation angle. Two small seasonal nalas namely Jharan Nallah and Kusum Nallah are noticed in the area.

3.2 Groundwater resources

On the basis of 'basin study' and review of district water resources in which the mine area is situated i.e. Balod district, Chhattisgarh (GSI, 2003) the availability of groundwater and its potential in the area can be said as average and satisfactorily. But in summer, water shortage in dug wells may be observed because of local seasonal effect only.

The study region (Chhattisgarh state) consists of both fractured and porous media in which groundwater is contained. It is mostly covered with hard rocks only. In such rock areas the availability of groundwater is the direct response to the intensity of monsoon and hard rock aquifers shows a quick response. In the lease area, groundwater potential and availability is medium hence water management is not very difficult.

3.3 Watershed and hydro-meteorology

The RMM and areas adjacent to it, broadly falls under the 'Mili Watershed' having a total area of 2000 hectares (4G3D3I and 4G3D2Z5) and consist of five micro-watersheds of Mahanadi basin. Potential evapo-transpiration of the region and regional water balance diagram (for rainy season and for other periods of the year) has been studied to know the hydro-meteorology of the study area (NBSS and LUP, 1992). The study region water need and natural regional availability has been assessed accordingly. Thus, regional data were found helpful in calculating the site-specific water estimation.

Based on various evaluated parameters of 'pumping test', conducted at site in 2006 an analysis has been done and results are as given below –

- Aquifer system present in the area has less to moderate water yielding potential.
- Pre-monsoon water levels in the dug wells of study region are mostly around 10m below ground level (bgl) and during post-monsoon period within 5m bgl. Water level fluctuations (WLF) remain between 2m to 5m. Higher WLF are restricted where groundwater development is comparatively higher.
- Groundwater development is moderate, ranging from 20% to 65%.The stage of groundwater development has increased from nearly 3% to 21% (CMRI, 2007).

4.0 Quantitative estimation

Important surface water source is 'rainfall' and groundwater source is the aquifer encountered during mining. It should be noted that groundwater availability in the mine area will be throughout the year but will be highest during post-monsoon season of October and November, whereas surface water will be maximum (and copious) during the monsoon period of 92 days in a year and gradually decline with time. There is no important river or flowing water body in the area. However, Jharan dam (Rajhara Dam), Boirdih reservoir and Hitkasa tailing dam which are the stagnant water bodies will contribute to the groundwater seepage in the Rajhara lease area. This type of groundwater seepage i.e. seepage as base flow has been considered based on hydro-geological parameters derived through pumping test.

An estimate of groundwater availability within Rajhara mechanized mine lease area is calculated by infiltration method and specific yield method. To work out aquifer parameters and estimate water quantity, "pumping test" is performed at the site. Particular attention has been given to the 'core zone' (5 km radius area) and 'buffer zone' (10 km radius area) of study area as well as local rainfall, presence of water source, geological details and drainage of pit mine working levels and elevations etc. Followings are the details (CMRI, 2007) –

- Surface water availability = 15427.32 m^3/day
- Seepage from surface water bodies into the mine = Negligible.
- Groundwater in the mine lease area
    - Groundwater availability = 7426 m^3/day
    - Total groundwater recharge in the area = 4281.26 ha-m
    - Total groundwater withdrawal in the area = 1221.38 ha-m
    - Water balance in the study area = (+) 2729.24 ha -m
    - Groundwater recharge is available as base flow in the mine lease area.

The study result and observation showed that at RMM single aquifer is encountered which is unconfined and the rock type is gneisses. The groundwater potential and availability in the lease area is of medium category. Research work indicated that geological unconformities present in RMM area are restricting the seepage into the adjoining formations. The water balance of the study region indicates that recharge is taking place and observed water impact (due to drawdown by pumping) is local and repairable through replenishment of water during monsoon (Soni and Khond, 2013).

Estimated average value of aquifer parameters for the RMM aquifer are – Transmissivity (T) = 68.608m^3/day/m; specific yield (Sy) = 0.1564 %; permeability (K) = 46.06m/day and porosity = 6.788 (CMRI, 2007). Therefore, all pumping/ dewatering arrangements shall be done keeping in view the water quantity and its availability in the RMM leasehold area. For mine planning and design purpose groundwater recharge should also be considered appropriately. This will aptly deal with the mine water problem in Rajhara open pit mine.

5.0 Mine planning and dewatering planning in RMM

Water accumulation in open pit mines is a common phenomenon. In the present case study, the presence of water in the RMM pit has two causative side effects namely

(a) Reduction in the stability of slopes or hanging wall slopes of pit.

(b) Water accumulation on the dip side of pit (may be due to direct rainfall or surface runoff from adjacent areas or due to groundwater seepage by groundwater table interception at lower benches)

Therefore the dewatering becomes extremely important. To keep the quarry bottom dry and to achieve the desired production a scientific mine planning and water estimation/ prediction is needed and accordingly worked out as described below briefly.

Geological features are indicative that the area, consist of hard rock formations. Seepage through strata (hanging wall seepages) is not present at RMM and mine area has undulating topography. Hard rock formations in and around the Rajhara mining area, restricts the groundwater seepage but surface runoff from adjacent hilly areas (Kokan) is evident due to topographical features. In this mine study it is observed that the groundwater movement in mining area aquifer occurs through weathered and fractured gneisses (phyllite) rocks. During rainy season and post-monsoon period of Oct -Nov month it is significant.

With deepening of the mine, the groundwater table is intercepted and the present quarry bottom has reached at 383m RL. By the year 2025 mine is targeted to reach at 303 m RL approximately. When the mine reaches at bottom most level of 303 m MRL and ore is fully exposed for production, it is predicted that the working pit levels will be 3-4 m below the water.

The predictive study done by authors is indicative of the fact that water accumulation, as a result of direct rainfall and during monsoon and post-monsoon period, will be unavoidable and required to be managed through adequate pumping arrangements. Mine water in the pit can be dewatered and managed easily and dewatering is the most practical as well as economical way to keep the mine faces or work places dry and thereby increasing the operational efficiency of mine.

Water quantity at mine pit is highest during monsoon season from July to September and continues to remain copious during post-monsoon season because the aquifers are saturated and fully charged. It is observed that this quantity reduces by about 20% of the peak quantity during December month and nearly 30% during January-February month. Obviously, the water quantity will remain minimum during the months of March to June as these are the dry months of summer. On dip side of the mine workings the water accumulation will take place as these levels are lowest. Compared to the rise side, the dip-side workings of pit is filled fast.

To design the mine dewatering system scientifically, water quantity estimation (as shown in a separate section above) is helpful. Whenever excessive pumping of mine water is done, drawdown is inevitable which may be local. This means that in the next monsoon season the refilling of water table will take place and permanent damage due to over withdrawal of water will be compensated. Due to increase in mine depth the water handling and management severity may increase. Hence, appropriate pumping arrangements and adequate drainage pattern in the mine area must be done to overcome water trouble of the mine, particularly during monsoon season. Impact of water on slopes stability of mine or on HW faces of pit is not very problematic because of the existing hard strata formations that exist at the RMM mine.

The sump and its details for the RMM mine has been planned with due consideration of peak water quantity and rate of inflow of water into the mine (at certain period of time). It is equally important that sump location be proper as it reduces the overall cost of pumping.

Water head

The top most RL of eastern end of mine is taken into consideration because the location of sump is on the eastern periphery of RMM. It is estimated that an altitude difference (above mean sea level) of 75-85 m do exist for pumping which will increase further by 10m to 20m as the mine is deepened further. For water head of the order of 62 m approximately a single stage pumping system is being practiced at this mine and is as per the scientific planning and design.

Pumps and pumping system

For dewatering planning basically there are two ways in which pumps are used to manage water in mines - (a) As station duty pumps and (b) As dewatering pumps. In contrary, dewatering system is much more complex than a station duty system or its application because water head in the later case is kept on changing with mine deepening. Later system is applied in the present case study of RMM.

As written above, to cope up with the calculated water quantity ‘centrifugal pumps’ with single (or multi) stage pumping are best available options for Rajhara mine because they are reliable, popular and easy to use. Their spare parts are cheaper and commercially available in case of requirement. Assuming that the pumping rate always exceeds the inflow rate the pump must operate over a wide and varying range of static head. It should be noted that during pumping an inflow could keep recharging the standing water capacity to some degree.

The groundwater level (static) in and around the mine lease area varies from 3m to 14m (average) approximately during different period in a year. Considering average rainfall of 1200 mm per annum and with four operational pumps at proper locations and with an operational efficiency of 80-85%, the pumping requirement of RMM is easily manageable, this scientific analysis concludes. Two standby pumps of medium capacity should be kept as reserve for breakdown during monsoon and post-monsoon period. This size of pumping infrastructure will cope up the water filled area of approximately 5-6 hectare. With practical observations at mine the CIMFR recommended pumping systems at RMM has been modified and Pontoon pumps has been replaced by Centrifugal pumps of 750 M3/hour rated discharge. Water discharged from RMM by pumping in recent years is shown in Table III.

Table III: Water discharged from RMM by pumping

Year	Water pumped (m^3)		
Month	2014	2015	2016
January	-	32400	62100
February	-	54600	63600
March	-	45750	57900
April	33150	64950	47250
May	13500	66150	-
June	29250	48900	-
July	133350	167100	-
August	320400	168150	-
September	450450	266850	-
October	166200	122550	-
November	40350	70350	-
December	18750	59700	-

Source : Rajhara Mine, SAIL, BSP

However, it is felt that pumps mounted on floating platforms (commonly referred as pontoon pumps) are the preferred alternate to meet out the dewatering requirement. Combination of pontoon pumps and centrifugal pumps in the mine for dewatering is adjudged as the right choice due to the fact that pontoon pumps can avoid loss of pumps, due to submergence in the water, which may occur due to power failure over a long period of time during peak water season; accidental inflow of water into the mine; excessive accumulation of mine water due to breakdown of pumping machine or due to the heavy rain (downpour) of longer duration.

6.0 Current scenario of mine water at Rajhara

This geo-hydrological study was carried out in 2006 but RMM natural geological setting and the basics of aquifer/ mine site etc. have remained same. One recent mine picture is shown below in Fig.6. To judge the current scenario in respect of mine water at RMM, the rainfall trend is observed from 2007 onward (Table IV) and water level fluctuation (WLF)

Fig.6 A recent view of Rajhara mine and its pit bottom

TABLE IV: YEARLY TREND OF RAINFALL (AFTER 2007)

	Year	Rainfall (in mm)
1	2007	1273.96
2	2008	776.06
3	2009	1057.16
4	2010	1474.93
5	2011	1234.58
6	2012	1062.92
7	2013	1537.17
8	2014	1787.77
9	2015	1136.21

Source: MVT Centre, RMM, Dalli-Rajhara

trend is assessed. The average WLF ranges from 3.0 m locally to 4.2 m regionally and is nearly same as that of 2006.

From this trend, it is clear that the availability of rain water for groundwater recharge is more than that of previous years i.e. before 2006. It is obvious that less rainfall means less groundwater recharge and this causes less water availability for the human consumption. With time since the mine is further deepened (up to 303m MRL) the water problem will also increase progressively. Looking at this and the accelerating demand of iron ore (production has increased from 1067900 tonnes in 2006 to 1993231 tonne in 2015) management solutions have to be in place so that mine operation remains smooth.

As on 01.04.2016 the total balance iron ore reserves of Dalli-Rajhara iron ore complex is 82.05 million tonnes (Mt) and for RMM it is only 28.38 Mt. The iron ore deposit is going to be exhausted by 2030 in another next 15 years with present targeted production. Presently, Mineral Exploration Corporation Limited (MECL) is carrying out exploratory drilling at this site for assessment of reserves at further depth. In view of the expansion and modernization plans of Bhilai Steel Plant, iron ore requirement is certainly going to rise. Looking into this scenario, SAIL has started planning for Raoghat deposit (90 km from Rajhara) to feed the BSP. A new small mine, ‘Dulki’ of the Dalli-Rajhara group of mines, with 8.62 Mt reserve is being added shortly in the iron ore production schedule. Considering all these finer points of mine planning, the water management can be done scientifically.

7.0 Surface water and groundwater management

Surface water and groundwater management is an essential component of any geo-hydrological studies. At the same time the industrial operation (i.e. ‘mining’) should not cause negative impacts on the hydrological regime as well as groundwater and surface water characteristics.

Some measures, particularly for open pit mines, are necessary either fully or partially while deepening of mine workings. These measures are implemented as well as adopted in routine practices at RMM. They are –

- Avoid runoff water from entering into mine by providing garland drains.

- Dump slopes be maintained and kept always away from the mine.
- Breakdowns of pumps and pumping system are inevitable and hence alternative arrangements are necessarily required (Abbi and Jain, 2006).
- Recharging aquifers is difficult whereas its discharge is very easy. Therefore attempt should be made for less discharge and adopt the water recharge. Various methods of aquifer recharge those are in general use are: Percolation tanks, check dams, cement plugs, recharge shafts, existing dug wells, injection well techniques, nala bunding, contour trenching, gabions structures etc. Construction of these structures around the mine area is thus helpful to improve the groundwater scenario and problems of nearby villages, where water deficit during summer occurs, can be managed. According to the site conditions, these measures have been adopted into practice at RMM.
- Water conservation practices are essentially required for judicious water management for both surface water as well as groundwater. This is being done at RMM for effective water management.

Implementing, the plans and measures as described and analyzed above, water accumulation at the working sections of Rajhara iron ore mine during peak rainy days of monsoon can be managed easily and flooding of mine can be avoided. In this way, targeted production is achievable and problem of ore blockage at deeper levels is handled scientifically.

8.0 Conclusions

Geological features and its analysis indicates that the entire mine area consist of hard rock formations and the aquifer encountered is gneisses which is unconfined. Yield potential of aquifer is moderate and recharge is more than withdraw therefore water management is not difficult.

It is concluded that geological features (unconformities) present in RMM area are restricting the seepage into and from the adjoining formations. The availability of groundwater at RMM, in a particular year, is the direct response to the monsoon intensity. The water shortage around the mine area (i.e. in dug wells nearby mine) may be observed because of local seasonal effect only. The dewatering should be taken to deal with the water problem in RMM mine and to keep the mine bottom dry. Mine planning as per the surface drainage pattern of the mine is helpful and needed. Single stage (or multistage) pumping are best suited for Rajhara mine considering altitude difference of 70 to 85 m above mean sea level (water head: 85 m ± 20 m).

Based on the geo-hydrological investigation and the pump test observations, it is arrived that adequate attention should be given to the -

a. Proper selection of pumps, ancillary equipment and crew.
b. Pumps and its maintenance including standby arrangements (The planned maintenance schedule is essential for wet monsoon season to overcome water trouble in the mine).
c. Proper location of sump (nearer to the NE corner of the mine).
d. Gradient of mine floor and sump floor.
e. Drainage pattern of the mine and adjoining areas.
f. Provision of garland drains to avoid runoff water from entering into mine.

In the mine area, water conservation is desired and construction of groundwater recharge structures is suggestive for better and efficient aquifer recharge.

9.0 Acknowledgments

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