HYDROGEOLOGICAL STUDIES FOR DEWATERING OF JHAMARKOTRA MINES, UDAIPUR, RAJASTHAN

Interim Report - II

Submitted

to

RSMML, Udaipur

By

NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE – 247 667

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STUDY GROUP

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I am thankful to ***Er. RD Singh, Director, National Institute of Hydrology, Roorkee*** for providing administrative support during the project period.

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1.0 INTRODUCTION

1.1 ABOUT THE PROJECT

Jhamarkotra rock phosphate mine, located about 26 Km from Udaipur city in the Udaipur District of Rajasthan, is the largest open cast mine in India and practically the only commercially exploitable deposit of rock phosphate in India. It has the greatest potential of the rock phosphate than any other mine in the India. Rajasthan State Mines and Minerals Limited (RSMML) is mining rock phosphate from this mine since 1968. Also it is one of the major activities of Rajasthan State Mines and Mineral Limited in Jhamarkotra area. The mine has a total estimated reserve of 80 million tons of the rock phosphate however the deposit is highly disturbed by the folding and faulting of the beds during early Proterozoic Orozen called the Aravali-Delhi Orogen. Nevertheless, growing techniques of excavation are making it possible to continue the mining at present and also in future.

Rock phosphate occurs in cavernous dolomitic limestone and it is present as a thin bed dipping at an angle of 45o to 55o to the horizontal. The top surface level is about 600 m above MSL and mine working has gone to a depth of 190 m i.e. upto 410m above MSL. Further, RSMML plans to excavate the deposit upto 330 m above MSL. Ground water level contours indicate that present water level in the mining area is about 414 in D block and 419 m in E block and the ground water flow direction is from NW to SE. As the water level is very near to the bottom of the mining pit, it is not possible to excavate to further depth unless the water table is lowered. Fractures and solution cavities provide paths for movements of ground water in the rock phosphate bearing dolomitic limestone and under the present condition of water level the mine is facing the threat of closure. Therefore, it is the need of the hour to lower the water table in the mine area in order to facilitate safe mining.

The major problem is that mining activity is facing from time to time is the ingress of groundwater in the mining pit mainly in the 'D' and 'E' block. The geometry of the ore body (i.e. thin and steeply dipping) had resulted in long and narrow pits with great depth extension, which involves very high stripping ratio with high lead and lift for waste and mineral. It is estimated that the aquifer in the mining area has a potential of 35 million cubic meter static water. So in order to keep working levels dry tube wells are installed around the periphery of the pit.

The top surface level in the mine area was about 600 m above mean sea level (MSL) and mine working has gone to a depth of up to 410 m and 420 m above MSL in D & E block respectively. Further, RSMM Ltd. plans to excavate the deposit up to 330 m above MSL.

National Institute of Hydrology, Roorkee has carried out Hydrogeological studies of Jhamarkotra Mines during June 2010 to December 2012. The successful implementation of recommendations resulted in achieving the required drawdown in the Block D and Block E for mining to continue.

1.2 OBJECTIVES

Keeping the above in mind, RSMML, Udaipur has approached National Institute of Hydrology, Roorkee to take up a study with the following objective:

- To identify the source of groundwater in Jhamarkotra mines through isotopic techniques
- To suggest future dewatering requirement to achieve 10-12 meters of drawdown for smooth functioning of Jhamarkotra mines.
- To periodically review the ongoing monsoon water dewatering operations from the mining pit.
- To suggest measures for protection of groundwater quality in nearby wells
- To critically review the ongoing mine dewatering activities at Jhamarkotra Mines on annual basis.

1.3 SCOPE OF THE STUDY

- Collection and compilation of all required data from RSMML
- Establishment of raingauge station
- Groundwater level monitoring in and around Mine
- Pump Tests to determine Sp. yield and Hyd. Cond. (by RSMML)
- Estimation of groundwater draft through installattion of flow meters
- Collection and analysis of SW and GW samples for water quality
- Collection and analysis of SW and GW samples for isotopic analysis(δD and $\delta^{18}O$)
- Collection of samples for groundwater dating
- Estimation of Natural Recharge to groundwater
- Feasibility of dewatering of monsoon water from the pit in shortest possible time
- Identification of the source of groundwater in blocks D & E of Jhamarkotra mines
- Measures for protection of groundwater quality in nearby wells
- Assessment of availability of groundwater for supply to Udaipur city

1.4 DATA REQUIREMENT

Following data is required to decipher the groundwater regime and to study the impact of dewatering (of the proposed mine) on the groundwater regime near the mine:

Physiographic Data / Maps

1. Topographical map of the study area (1:5,000 scale)

2. Location map showing mining area, natural drains, and locations of rain gauges, G & D sites, and climatological station, if any
3. Maps showing location of villages and indicating land-use pattern,
4. Cross-sections and Longitudinal section of the river, and
5. Map showing reservoirs, lakes and other water bodies.

Geological Data

1. Geological map of the area (1:10,000 Scale)
2. Structural map of the area along with details of fractures, joints etc.

Surface Water Data

1. Monthly rainfall data (for past 10 years),
2. Monthly evaporation records, (past 10 years)
3. Gauge and discharge data (at least at two locations) of the river and/or canals flowing nearby the mining area, if any.

Groundwater data

1. Monthly water level data at different observation wells for unconfined aquifers,
2. Water level fluctuation in different piezometers for deeper aquifers,
3. Lithologs / geological information in the mining area and the surrounding area,
4. Existing groundwater practices such as; withdrawal and uses,
5. Pumping data - groundwater withdrawal through pumping which should include existing tube wells, bore wells, large diameter wells, screen depth, duration of pumping and capacity of the wells, etc.
6. Aquifer parameters such as; hydraulic conductivity and storage coefficient of each layer and thickness of each layer,
7. Chemical constituents of soil and water of the mining area.

2.0 STUDY AREA

2.1 LOCATION

The present area is bound by north latitudes of 24°27'30" and 24°29'30" N and east longitudes of 73°49' and 73°52' E and is covered by Survey of India Toposheet No. 45H/15. It is located 26 km southeast of Udaipur city and falls in the Girwa block of Udaipur district (***Figure 2.1***).

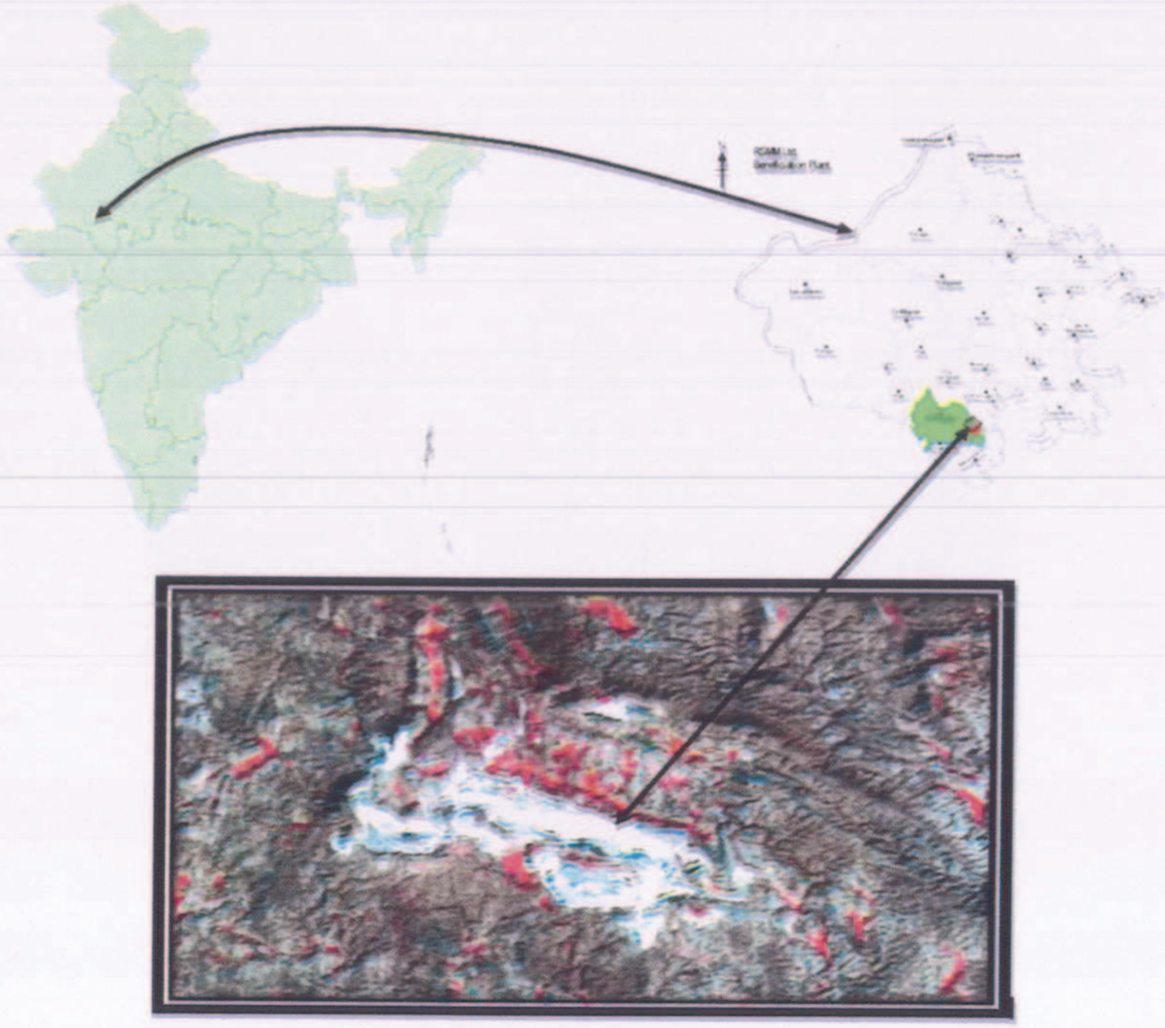


Figure 2.1: Location of the Area

The mine, covering a total area of about 18.44 km^2, is divided into 12 blocks, namely A, A-extension, B, C, D, E, F, G, H, I, J and K (Ground Water Department Report, 1991). Topographically the area is comprised of highly undulating Aravali hills. Structurally, the area forms antiformal and synformal basins having rock phosphate deposits which have attained the heights of 480 to 600 m above MSL.

2.2 PHYSIOGRAPHY

Jhamarkotra area depicts an undulating topography in general, formed by the tectonic hills of Aravallis. The highest elevation is about 680 m above MSL. A synform basin surrounded by ridges is formed and comprises of rock phosphate deposits. These deposits attain a height of 480 m to 600 m above MSL. Towards the south of the deposits, there is a shallow valley composed of Banded Gneisses. Lithological characters plays remarkable role in physiography of the area. Quartzite being hardest rock occupies high hills, whereas, dolomitic limestone occupy gently sloping terrains. Because of their brittle nature and susceptibility to erosion, phyllites and schists form lower horizons. As in most parts of Rajasthan, the area has very little soil cover.

2.3 DRAINAGE

The area is drained by two major tributaries of Jhamari river which are ephemeral in nature (***Figure 2.2***). The rivers flow from NW to SE. The area can be divided into three sub basins developing to the extent of 4^{th} order streams. The stream frequency of the three sub basins is 10.712. Mean length of streams ranges from 0.30 to 6.45 km for 1^{st} to 4^{th} order of stream. Average drainage density for all the sub basins is 4.33 km^{-1}.

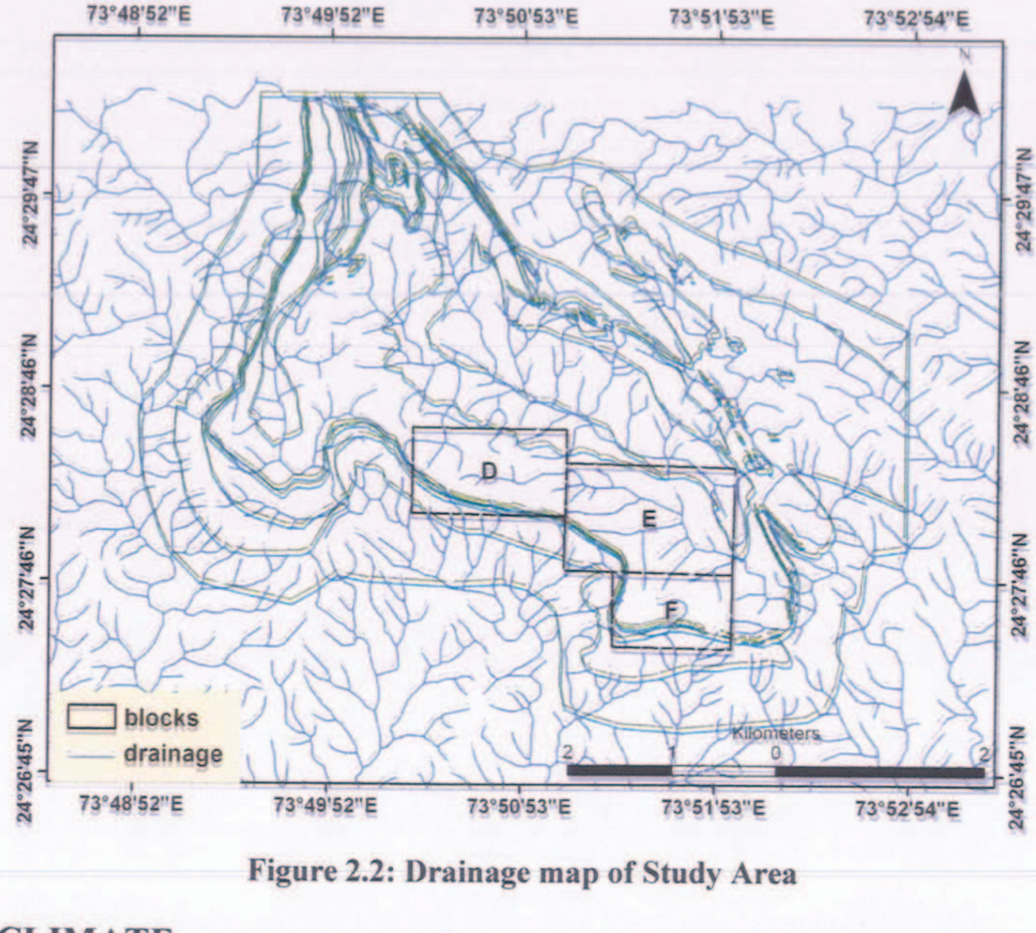


Figure 2.2: Drainage map of Study Area

2.4 CLIMATE

The area has a semi-arid type of climate with mean annual temperature of 25°C however the annual temperature varies from 15°C in January to 35°C in May. The temperature may rise upto 44°C in summer while in winter, it may drop to a minimum of 0.5°C. The normal monsoon rainfall for last 30 years is 569.3 mm (1983-2012) and the average monsoon rainfall for last 15 years (2000-2014) is 667.9 mm. The non monsoon rainfall is about 32.2 mm. Monsoon and

Non monsoon rainfall for the 15 years period (2000 – 2014) is given in ***Table 2.1 and shown in Figure 2.3***.

Table 2.1: Yearly Rainfall (in mm) for the period 2000 to 2014 at Jhamarkota Mines

S.No.	Year	Monsoon Rainfall (mm)	Non monsoon Rainfall (mm)	Total Rainfall (mm)
1	2000	308.5	23.0	331.5
2	2001	400.2	0.0	400.2
3	2002	461.1	0.0	461.1
4	2003	563.9	0.0	563.9
5	2004	653.0	0.0	653.0
6	2005	910.1	29.0	939.1
7	2006	1185.4	16.2	1201.6
8	2007	566.2	109.0	675.2
9	2008	363.4	21.7	385.1
10	2009	603.1	5.0	608.1
11	2010	355.8	88.0	443.8
12	2011	1095.2	0.0	1095.2
13	2012	774.9	9.7	784.6
14	2013	797.6	122.6	920.2
15	2014	979.6	58.6	938.2

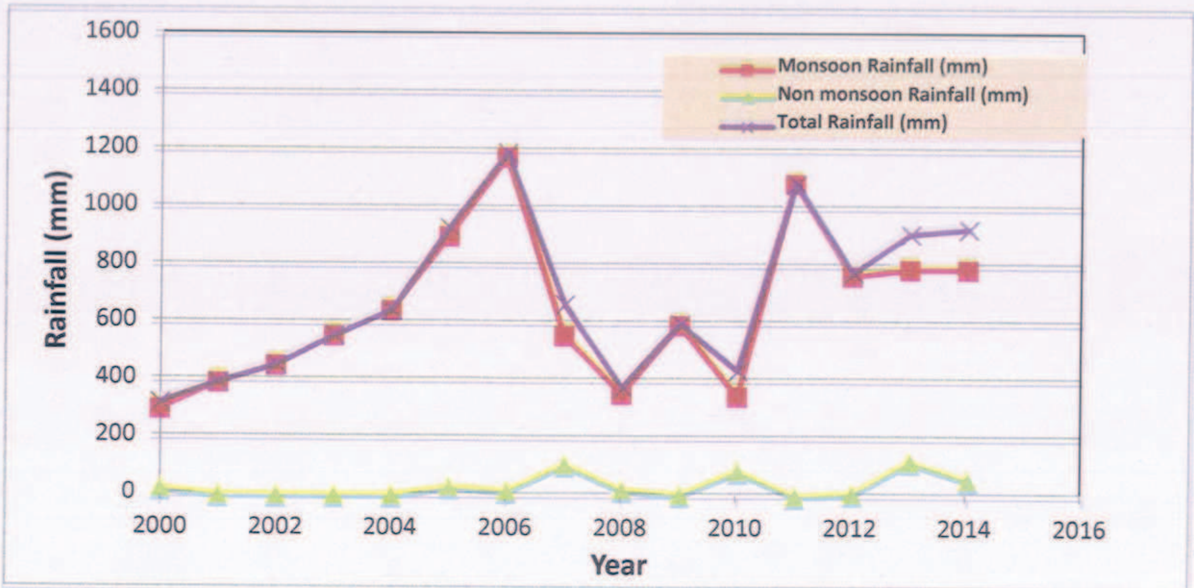


Figure 2.3: Yearly rainfall in Jhamarkotra Mines area 2000-2015

2.5 GEOLOGY

In the area around Jhamarkotra mines, metasedimentary rocks belonging to the Aravalli Group lie unconformably over a basement of gneisses and granites (Banded Gneissic Complex of Heron, 1953). The rock phosphate horizon outcrops near the base of the Aravalli rocks. The banded gneisses are the oldest rock unit in the area. The general geological succession of the rocks at Jhamarkotra is given in ***Table 2.2*** (Ground Water Department, 1991).

Table 2.2: Lithological succession of Jhamarkotra Mines

Stratigraphic Unit	*Lithology*
Delhi Supergroup	Phyllite, schists, quartzite --------------------Unconformity-----------------
Debari Formation	Buff to reddish brown orthoquartzites with intercalated phyllite and chlorite schists. Meta-conglomerate, feldspathic quartzite, arkose.
Aravalli Group	Greywacke and phyllite Phyllite and schists (garnetiferous) Carbon phyllite, brecciated quartzite, dolomitic limestone, chert and silicified limestone Biohermal phosphorite Basal gritty quartzite ------------------Unconformity------------------
Banded Gneissic Complex	Gneisses, banded gneisses, granites, mica schists, amphibolites, marble etc

Geological map of the Jhamarkotra mines is given in ***Figure 2.4***.

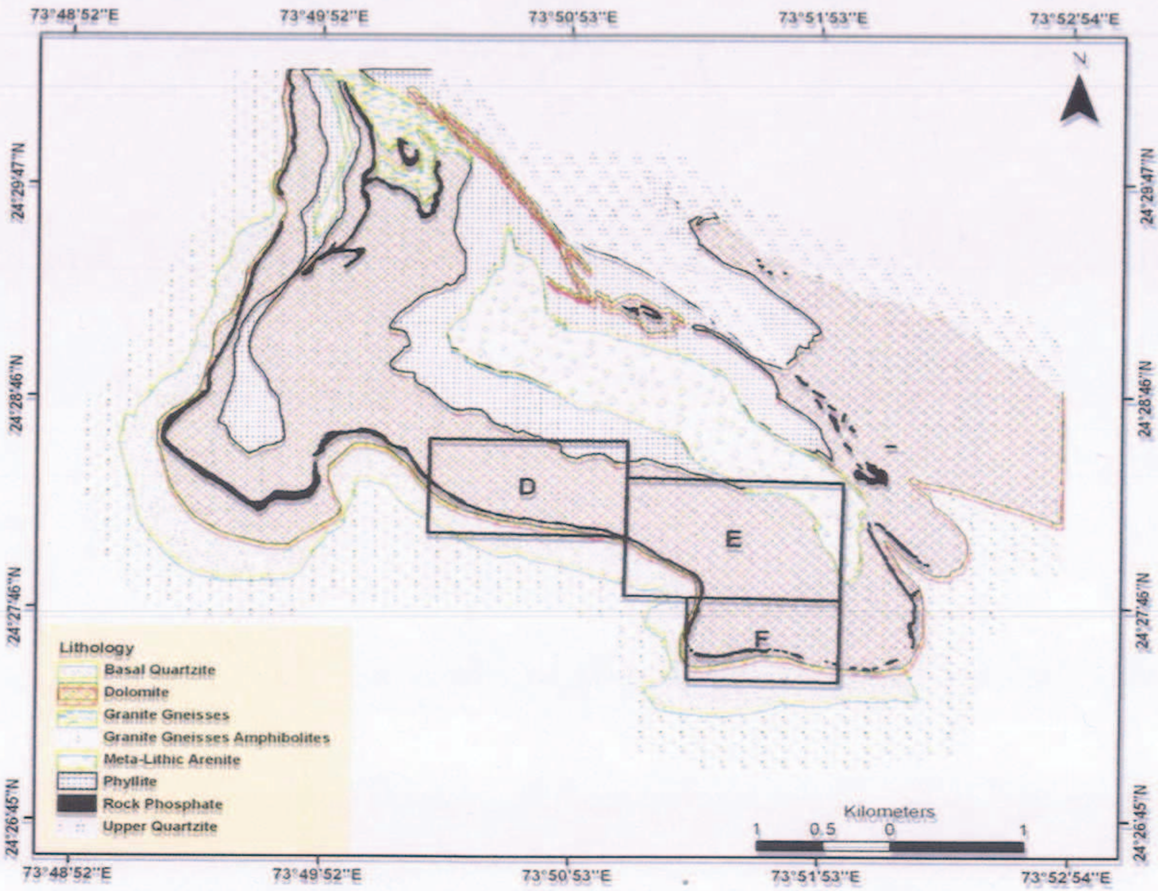


Figure 2.4: Geological map of Jhamarkotra Mines

The stromatolitic phosphorite in the area is hosted by the dolomitic limestone which in places has become cherty and silicified towards the top. The Phosphorite ore extends for about 16 km with an average width of 15 meters and exposed in blocks A to K. The stromatolitic phosphorite occurs as columnar, brecciated, stratiform, lenticular, and in minor quantities as secondary colloidal deposit. The high-grade ore Jhamarkotra phosphorite contain P_2O_5 content between 30 to 35% are directly usable, however, low-grade ores are needed to be beneficiated before use.

2.5.1 LITHOLOGY

The description of the various litho units found in the area is given below:

Banded Gneissic Complex:

It is exposed in the vast low lying planes towards the southern, eastern and western parts of the area as seen in blocks A,B,C,D,E,F,G,J,K and extends further east of Debar quartzite beyond Bagdara village. The foliation planes show high angle of dip (75° to 85°) to the bedding planes of overlying Basal quartzite and are intricately folded. These rocks lie directly in contact with limestone and also with phosphorite in some parts of J and K blocks. There is a notable difference in the state of metamorphism in the basement rocks and the Basal quartzite.

Basal Quartzite

Basal quartzite is exposed at the footwall of the phosphorite in blocks A, A-Extension to F. The quartzite is hard, compact, massive and white to pink in colour. Grain size varies from medium to coarse passing into gritty nature in some parts which is indicative of shoreline deposition. Thickness of the strata is also variable, exhibiting maximum width in parts of block B and D and thinning out in southern part of block J. The rocks show E-W strike in general dipping northerly at 45° to 55° but the strike changes to N-S in blocks A-extension and J with a north-easterly dip.

At some places, these rocks are massive and vitreous in nature. The irregular thickness of the quartzite, occasional gritty nature is typical of basal formations which accumulate on the eroded basement rocks i.e. Banded Gneissic Complex.

Dolomitic Limestone

Dolomitic limestone is the major rock unit in the area and hosts the rock phosphate. The passage from basal quartzite to limestone is often gradational in nature. Dolomitic limestone shows lithofacies changes to ferruginous, manganiferous, carboniferous and phyllitic dolomite and orthoquartzites.

Silicification of limestone leads to formation of cherts as seen in blocks B, D and at places, even definite crystals of calcite are formed in blocks D and H. The rocks show an E-W strike with northerly to north-easterly dip. Colour of the rocks is generally grey to reddish brown and also greyish black.

Rock Phosphate (Biohermal Phosphorite)

The phosphorite deposit extends over 16 km in Jhamarkotra area. Thickness of the deposit varies from 1 m to 30 m. It has an average thickness of 15 m along a continuous stretch of 5 km strike length which accounts for the 80% of the reserve. At places, it shows wedge shaped appearance. It is dominantly a biostromal type of deposit hosted by the dolomitic limestone. It is bluish grey to dark grey in colour.

Quartz Breccia

Quartz breccia is a compact rock, composed of angular fragments of quartz. It is white to dark red in colour. It occurs as patches in parts of block A, A-extension and D, while in block J it is seen at the top of the hills. The quartz fragments ranging in size from 1 cm to 10 cm are set in a siliceous matrix. Angular shape of the fragments suggests that no transportation has taken place. Therefore, the breccia may be of tectonic origin.

Phyllites, Carbonaceous phyllites and Schists

These rocks are exposed in the valley portion of the present area. These are whitish grey to brownish in colour, soft and friable in nature showing sericitized appearance. Carbonaceous material is present as small patches in some parts. At Jhameshwarji temple, presence of garnet is noticed in phyllites.

Towards the north of the area, intercalation of limestone and phyllite beds is noticed.

Greywacke (Metalithic Arenite)

These rocks are exposed near Jhamehwarji and the Base Camp. These are grey to black rocks composed of detrital grains of quartz, fragments of feldspar, phyllites and schists embedded in a matrix of the same material. The rock is massive and at places shows graded bedding. Polyphase metamorphism has led the rocks to exhibit compositional variation from compact amphibolite (as seen near Jhameshwarji) to greywacke (as seen near base camp). These rocks are better known as metalithic arenite.

Debari Formation

Debari formation is represented by quartzite, metaconglomarate, arkosic and feldspathic quartzites, phyllites and chlorite schists occurring in the north-eastern part of the Jhamarkotra area. Quartzites are exposed in blocks H, I and K and occupy the hilly area. They are white to reddish in colour. Phyllites and chlorite schists are exposed in low lying areas. Quartzite partly overlaps the rocks of the Aravalli Group and it can be inferred that it occupies a higher position in the stratigraphic column. Therefore, it has been designated as `Upper Quartzite' to differentiate it from basal quartzites.

2.5.2 STRUCTURE AND TECTONICS

Jhamarkotra area is a part of the Aravalli synclinorium, which experienced several phases of folding. Banded Gneissic Complex forms an asymmetrical synformal structure trending

NW-SE. The meta-sedimentary beds trend E-W in central and southern regions but changes to north on both sides of the deposit. The dip of the beds varies from 20° to sub-vertical. A brief description of the structures of the area is as follows:

Folds

Four phases of folding can be detected in the area. These are designated as F_1, F_2, F_3 and F_4. These folding phases are associated with the development of schistosity S_1, S_2, S_3 and S_4 respectively. The early formed folds (F_1) have been refolded by three successive phases of folding (F_2, F_3, and F_4). Though it is difficult to determine the original orientation of F_1 folds because of superimposition of later folds it appears that these folds are recumbent folds with axial planes trending E-W to ESE-WNW.

The second generation of folds (F_2) are either upright or have steeply dipping axial planes. These folds are open to tight having variable interlimb angle and even isoclinal at places. Domes and basin structures (eyed folds) resulting from the interference of F_1 and F_2 folds are very common.

Sporadic occurrence of F_3 folds is noticed which develops as puckers on steeply inclined planes (S_0, S_1, S_2). These folds do not have significant effect on the outcrop pattern.

F_4 folds are formed by the refolding of F_1 and F_2 folds. These folds exhibit moderate to steeply inclined axial planes having E-W trend. They are generally open folds and appear as gentle warps.

The outcrop pattern of the rocks indicates presence of two N-S trending regional folds in the western part of the area. The westernmost fold is a synform (F_2), showing plunge variation in N-S direction. From north of Dhamdhar till Sameta the synform runs as an isoclinal fold with overturned eastern limb. Towards east, it passes to an F_2 antiform. Plunge direction varies from northerly to southerly through horizontal, where it interferes with a large F_4 synform trending easterly. In the central part of the area, the rocks trend in WNW-ESE direction. From the orientation of the bedding planes, it is apparent that a series of antiforms and synforms probably F_1 folds are present crossed occasionally by smaller folds of later generations. South-eastern part of the area shows an antiform with a corresponding synform of F_4 generation. The antiform bends the main F_1 fold east of Jhameshwar temple. A series of F_2 antiforms and synforms develop in the eastern part of the area. To the north of Jhamarkotra, dolomitic limestone beds exhibit plunge culmination and depression along the axial trace of F_2 folds, probably because of interference of F_2 folds with F_4 folds.

3.0 METHODOLOGY

To achieve the objectives of the study, a multi disciplinary approach is being adopted. Major approaches adopted for the study are given below:

- Geological approach
- Geophysical approach
- Remote Sensing and GIS approach
- Isotopic Approach

The geological, hydrogeological and climatic data provided by RSMML have been thoroughly evaluated. The mining area has been studied and extracted using Remote Sensing and GIS approach.

Isotopic characteristics of the water (surface and groundwater) were determined to understand the recharge characteristics in the area.

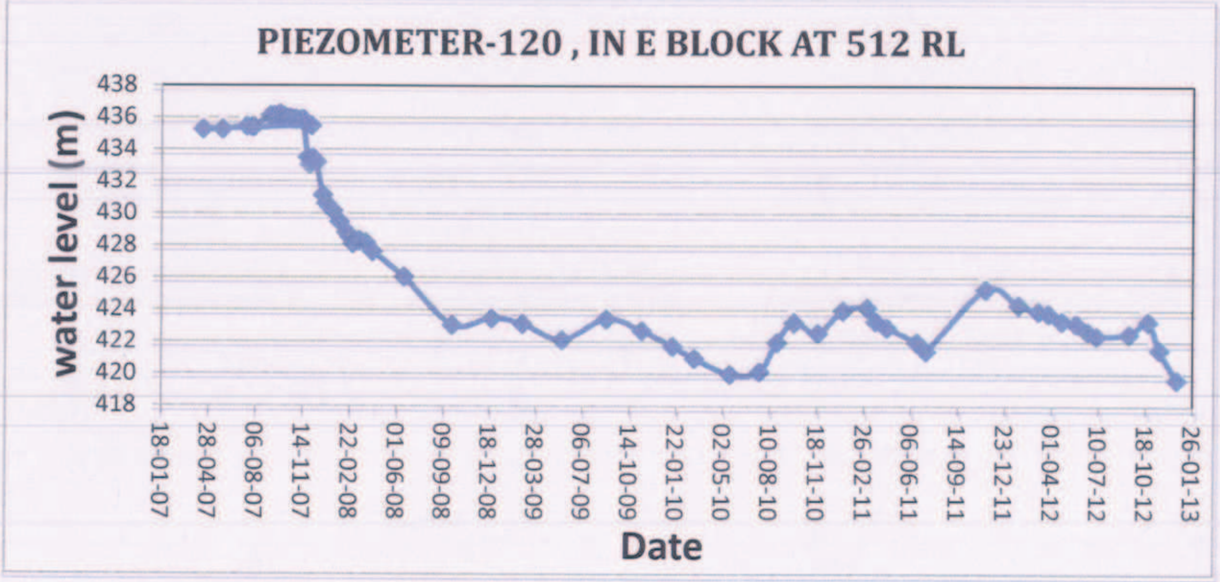
Methodology adopted for each task is given in relevant sections. The tasks and methodology being adopted for the study are summarised below in ***Table-3.1***:

Table 3.1: Methodology adopted

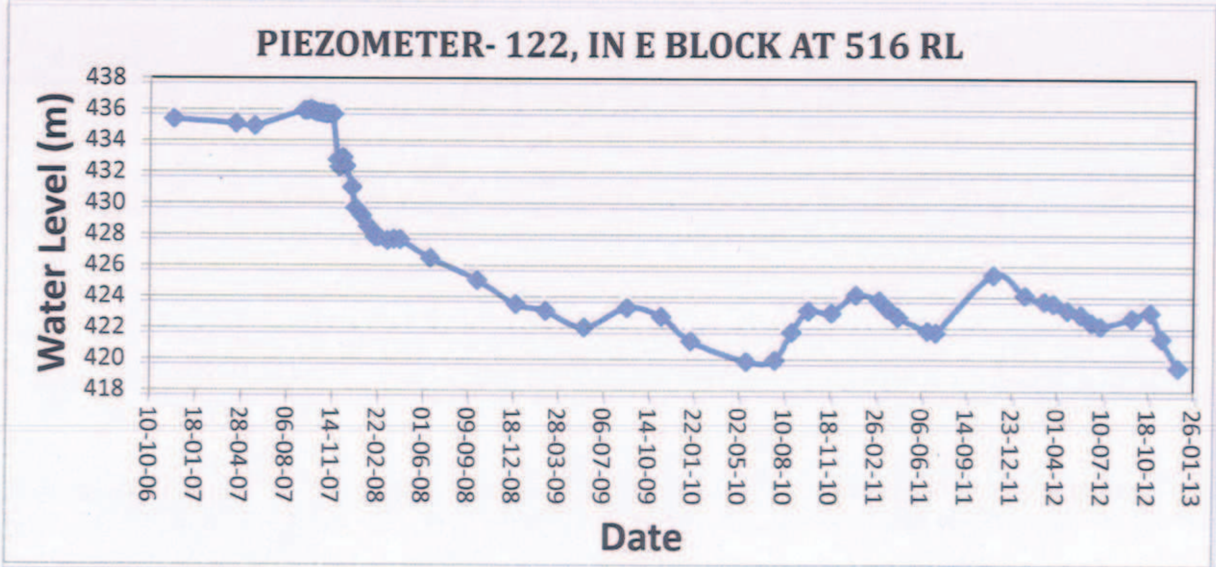
S. No.	Task envisaged	Methodology
1.	To identify the source of groundwater in Jhamarkotra mines through isotopic techniques	Isotopic approach, by determining the stable isotope composition of surface water bodies and groundwater in and around mine
2.	To suggest future dewatering requirement to achieve 10-12 meters of drawdown for smooth functioning of Jhamarkotra mines.	Groundwater Contours, and Resistivity Survey
3.	To periodically review the ongoing monsoon water dewatering operations from the mining pit.	Total volume of water entering into the pit due to rainfall and lateral flow entering into the pit area has been computed using Darcy'e equation.
4.	To suggest measures for protection of groundwater quality in nearby wells	By determining the water quality parameters of water of nearby wells determined.
5.	To critically review the ongoing mine dewatering activities at Jhamarkotra Mines on annual basis.	Pre and post monsoon visits to the mine to evaluate the dewatering scheme being implemented

4.0 HYDROGEOLOGY

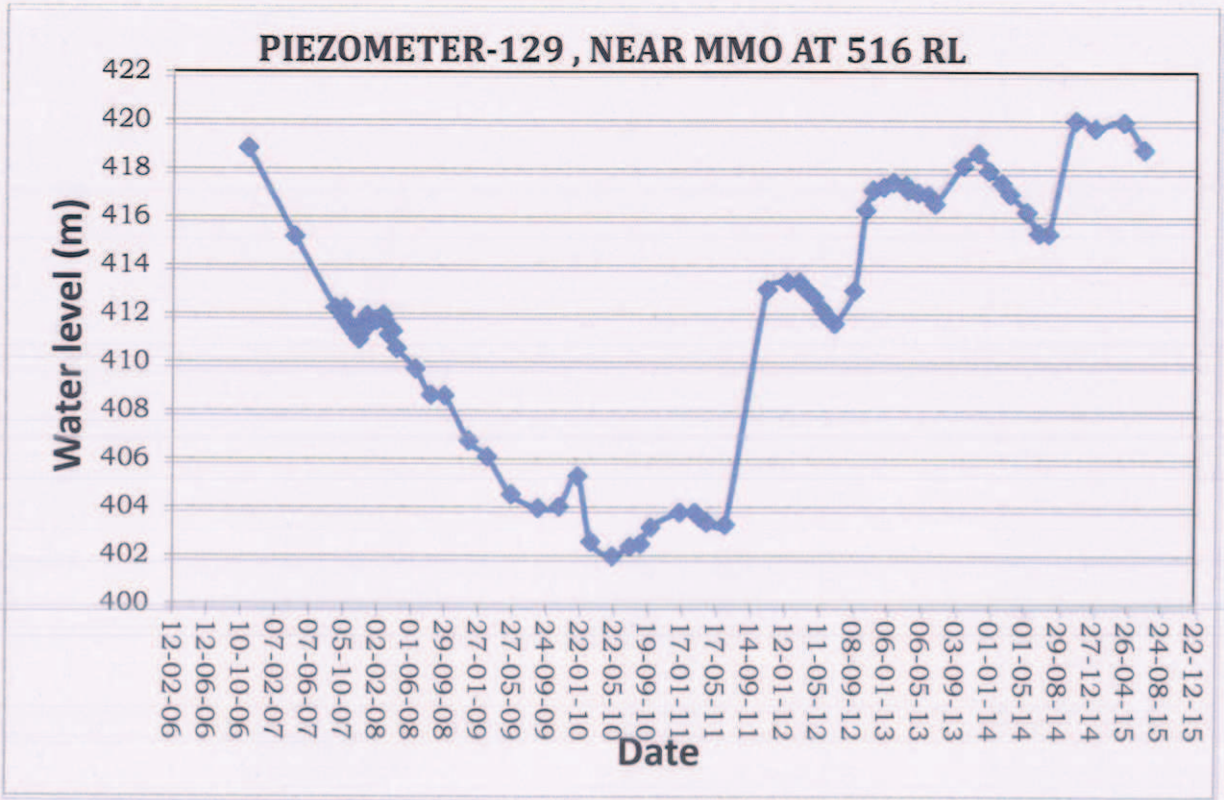
In Jhamarkotra area, groundwater occurs under confined to semi confined conditions in dolomitic limestone, the main aquifer that is characterized by the presence of solution cavities of varying dimensions at various depths and is fresh in quality. Groundwater movement in the mines was observed to be from North-West to South-East during 90's. The water level in the D-block used to be higher than the E-block. But now the water level in the E-block is observed to be higher than in the D-block. The hydrographs of some of the observation wells are given in ***Figure 4.1 (a to f).***



(a)

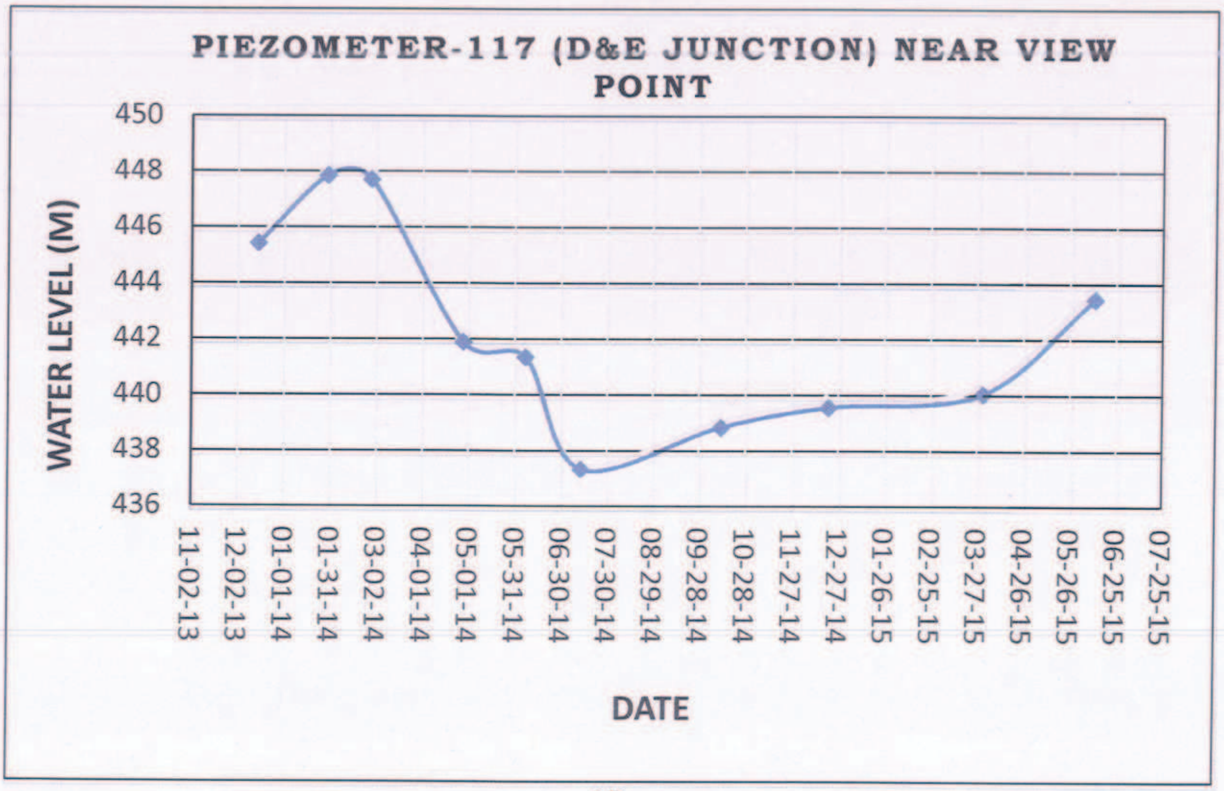


(b)



PIEZOMETER-129 , NEAR MMO AT 516 RL
Water level (m)
422
420
418
416
414
412
410
408
406
404
402
400
12-02-06
12-06-06
10-10-06
07-02-07
07-06-07
05-10-07
02-02-08
01-06-08
29-09-08
27-01-09
27-05-09
24-09-09
22-01-10
22-05-10
19-09-10
17-01-11
17-05-11
14-09-11
12-01-12
11-05-12
08-09-12
06-01-13
06-05-13
03-09-13
01-01-14
01-05-14
29-08-14
27-12-14
26-04-15
24-08-15
22-12-15
Date

(c)



PIEZOMETER-117 (D&E JUNCTION) NEAR VIEW POINT
WATER LEVEL (M)
450
448
446
444
442
440
438
436
11-02-13
12-02-13
01-01-14
01-31-14
03-02-14
04-01-14
05-01-14
05-31-14
06-30-14
07-30-14
08-29-14
09-28-14
10-28-14
11-27-14
12-27-14
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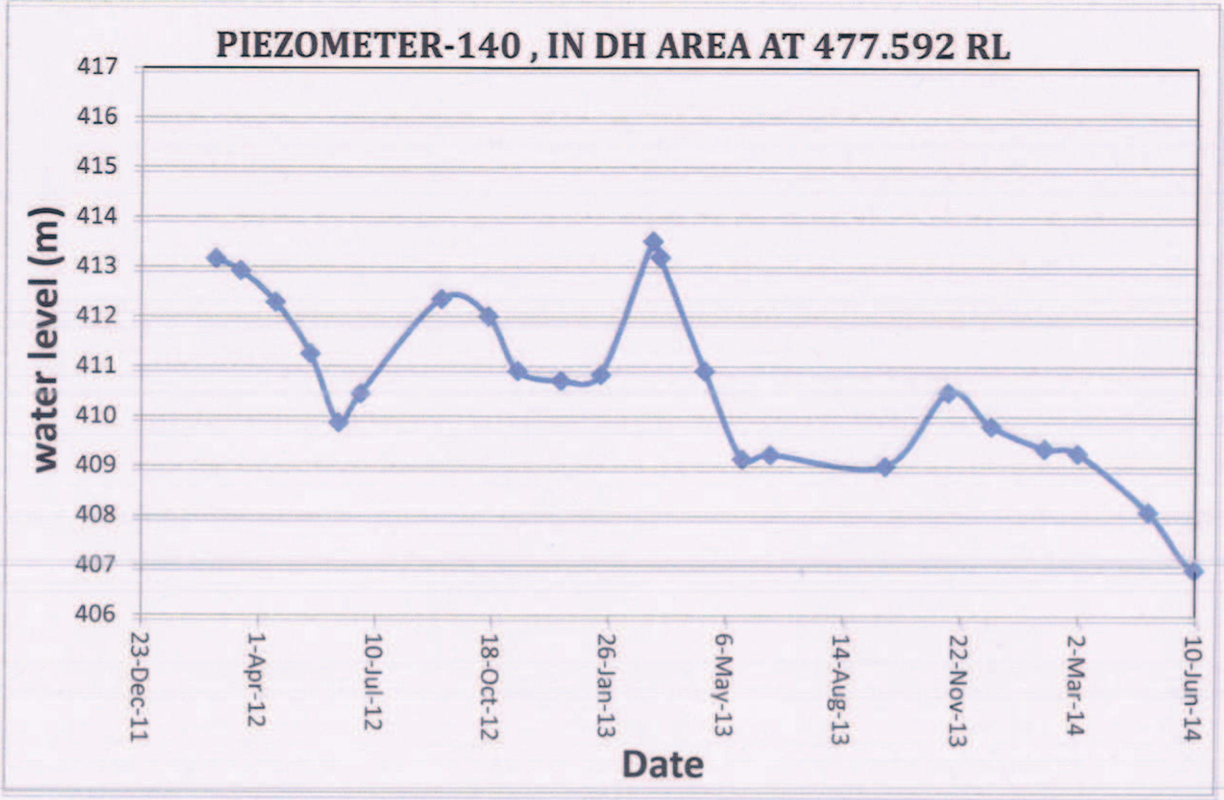
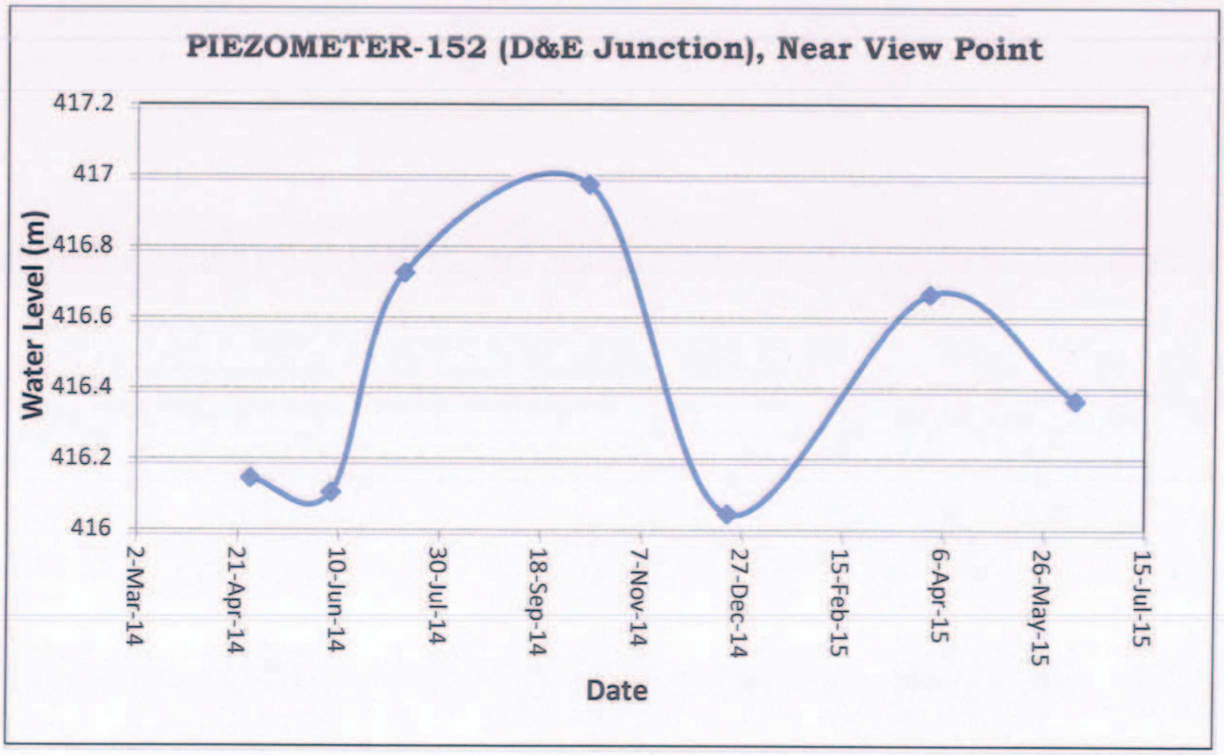
06-25-15
07-25-15
DATE

(d)



(e)



(f)

Figure 4.1: Water table trends in Jhamarkotra mines.

The figure clearly indicates that the water table in E block is higher than that in the D block now.

Further due to slow / disrupted pumping from sump has resulted in rise of water table in the wells in D and E blocks during 2014-15.

5.0 SOURCE OF WATER

The source of groundwater in the mine has been determined by analyzing the stable isotope of oxygen and hydrogen in the waters of the area.

Groundwater in any area can be due to recharge from rainfall or any surface water body or it may be the paleowater which might have been recharged in the past. The source of groundwater can be ascertained using properties of the atoms and their isotopes that constitute the molecule of water, i.e., oxygen and hydrogen. A brief background of isotopes is given below:

The isotopes are defined as atoms with same atomic number (z) but different atomic weight (A). The radioactive isotopes decay with time while the stable isotopes do not.

For example, Hydrogen has three isotopes: $^{1}_{1}\mathbf{H}_0$ (1p), $^{2}_{1}\mathbf{H}_1$ (known as deuterium D) - (1p+1n); $^{3}_{1}\mathbf{H}_2$ (known as Tritium)- (1p+2 n). First two isotopes are stable and only $^{3}_{1}\mathbf{H}_2$ is radioactive.

Similarly, Oxygen has 11 isotopes, out of these ^{16}O, ^{17}O and ^{18}O being stable in nature, are found useful in the hydrological studies and are relatively more abundant compared to the remaining isotopes. In hydrological studies, among all the stable isotopes, the isotopes of oxygen and hydrogen are considered to be the most important. Within the hydrogen and oxygen isotopes the combination that form the water molecule as $^{1}H^{1}H\,^{16}O$, $^{1}HD^{16}O$, $^{1}HD^{18}O$, $^{1}H^{1}H^{17}O$ and $^{1}HD^{17}O$ are the most important among all. The natural occurrence of few very important types of water molecules is given below;

$H_2{}^{16}O$: 997640 ppm (99.7640%);

$H_2{}^{18}O$: 2040 ppm (0.204%)

$HD^{16}O$: 320ppm (0.032%)

The stable isotopes and their abundance in sample are measured on stable isotope ratio mass spectrometer. The measurement of absolute abundance of isotope of an element requires dedicated mass spectrometer. To avoid this problem, generally, rather than measuring the absolute values relative abundance of rare isotope with respect to the most abundant isotope of the same element is measured. The ratio is termed as isotope ratio. Further, to have uniformity in measurements globally, these ratios are measured with respect to the reference standard. The ratio is expressed in 'delta' (δ).

Unlike most geochemical tracers, ^{2}H and ^{18}O are conservative in nature. Therefore, stable isotope can serve to quantify groundwater mixing at the local to watershed scale. The interpretation of stable isotope data utilizes an interplot between isotopic data for oxygen and hydrogen or cross plot between isotope data and chemical data. The type of inter-plots or cross-plots exclusively depends on the type of study area and the problem to be analyzed.

In the case of precipitation, $\delta^{18}O$ vs. δD (D is same as ^2H) follows a straight line with its approximate equation (also called Global Meteoric water Line):

$\delta D = 8x\delta^{18}O + 10$ ----- Craig (1961)

Isotopes are useful in tracing the groundwater flow paths and in analyzing the mixing ratio qualitatively for multiple recharging sources forming the groundwater. Isotope ratio provides information on the rate of chemical reaction, evaporation effects, condensation process, diffusive processes etc. Similar to DNA fingerprinting, isotope provides fingerprint indexing to the recharge sources. Some of these applications can be simply verified by the isotopic plot shown in the ***Figure 5.1***:

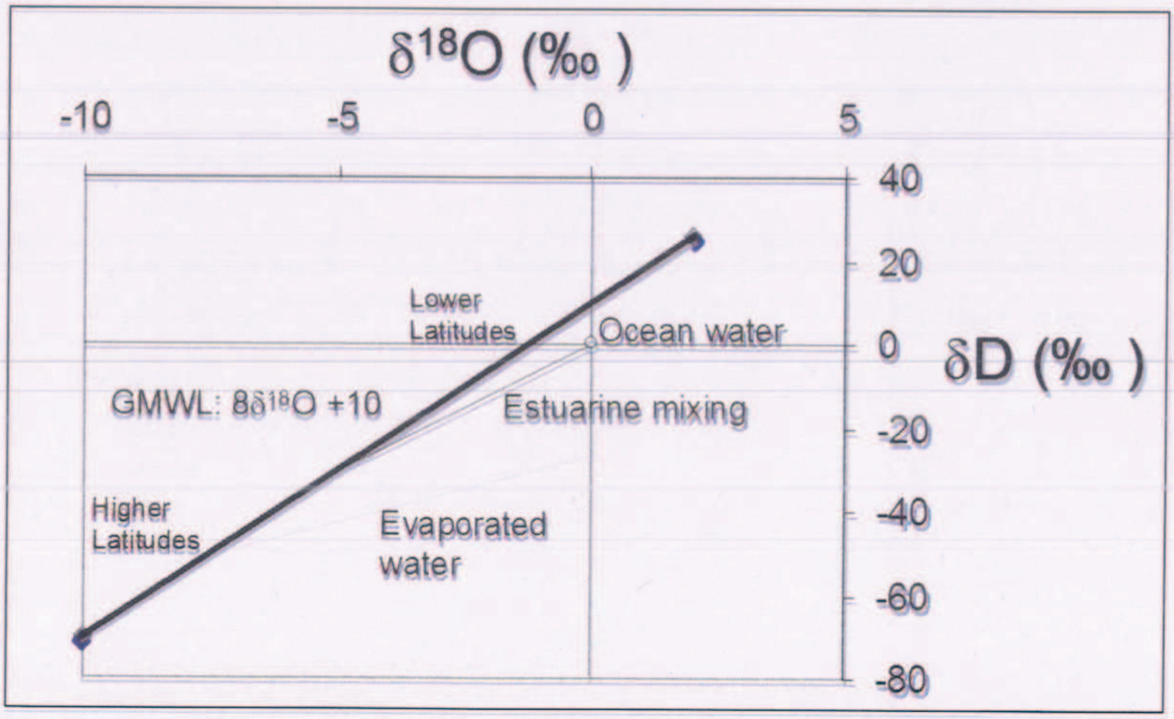


Figure 5.1: Relation between natural variation of $\delta^{18}O$ and δD Water.

(Ocean water (represented by filled circle at origin), Global Meteoric Water (denoted by GMWL and represented by the equation $8\ \delta^{18}O+10$), Estuarine mixing water (line representing mixing of meteoric water with ocean water) and the evaporated water represented by line with lower slope than GMWL.)

Isotopic character of groundwater provides unique information about the recharge source and flow paths systematic. Groundwater forms from the integration of precipitation water, surface water sources like canal water, pond water over a time depending upon its traverse in the area of recharge. Therefore, δD and $\delta^{18}O$ of groundwater provides information about the recharging sources. Since, δD and $\delta^{18}O$ are hydrologically conservative tracers; the resultant groundwater formed from various recharging sources can be expressed as the sum of the isotopic mass of the water recharged from each of these sources.

Groundwater samples were collected from the mine and the surrounding areas during the months of October 2013 and March 2014. The precipitation samples were also collected from the study area during the period.

The samples were analysed for δD and $\delta^{18}O$, and plot of δD v/s $\delta^{18}O$ is shown below in ***Figure 5.2***:

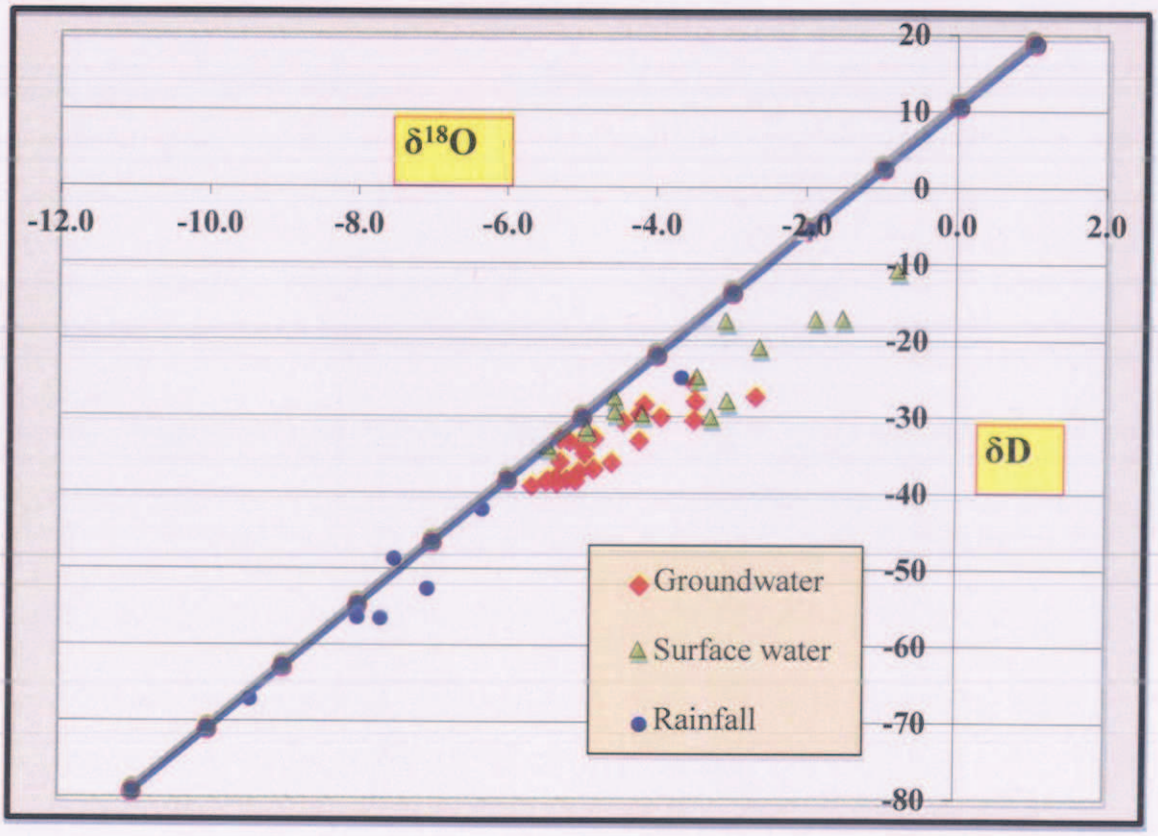


Figure 5.2: δD v/s $\delta^{18}O$ of groundwater Jhamarkotra Mines

To find the source of groundwater in the pumped water from the mines, the isotopic signatures of precipitation, surface water bodies and groundwater were plotted. The precipitation water samples were collected from the nearby area during 2009-10 under some other study. The isotopic signatures of the precipitation almost follow the Global Meteoric Water Line (GMWL). The groundwater samples also lie very close to GMWL, indicating its origin from the precipitation. The surface water samples lie away from the line indicating evaporation effect. Some groundwater samples also show evaporation effect.

Isotopic signatures of precipitation, groundwater, and surface water indicate that the source of groundwater is the direct precipitation and there is no contribution from the surface water bodies (lakes) located around the mining area.

6.0 MINE DEWATERING

Effective water management is critical in both open-pit and sub-surface mining operations. Mine dewatering is an essential part of resource extraction, as it lowers the water table around the mine or quarry. Effectively managed dewatering processes typically employ continuous water level monitoring. Mine dewatering is usually undertaken for several reasons:

- Ensure stability of mine walls during and after excavation - In open-pit mines, a water table that is too high can destabilize mine walls, haulage roads, and slopes. Water pressure reduces the stability of mine walls and can lead to sliding and collapse of materials in the slope. In underground mines, the inflow of water must be controlled to prevent flooding; however, a balance must be maintained so that groundwater levels are not needlessly depleted.

- Optimize mine production and reduce operational costs - Effective dewatering operations create dry conditions so that low-strength aquifer sequence materials (sands, gravel, and clays) can be safely excavated, reducing drilling and blasting costs. Additionally, wear and corrosion on equipment is minimized, and the possibility of pump burn out is reduced by accurately monitoring drawdown. Haulage costs for unsaturated excavated material is significantly less than for saturated materials, further reducing operational cost.

Mine dewatering can be achieved by pumping continuously from a series of dewatering wells around the mine and by installing pumps in special sumps on the mine floor to remove surface water. Mine dewatering operations must optimize the locations and pumping rates of these dewatering wells, as well as control regional drawdown - this cannot be achieved without accurately monitoring groundwater levels around the mine and surrounding areas.

6.1 DYNAMIC GROUNDWATER RESOURCES

The Jhamarkotra area has a semi-arid climate with an annual temperature of 25°C. Though the area receives only average 667.9 mm of rainfall (2000-2014), still the dewatering of mines is a big problem. As per the yearly data provided by RSMML, total rain water received by the area within the last nine years is computed to be 13.797 MCM (***Table 6.1***).. This water is mainly from monsoon rainfall (>95%) and is of the order of 12.9539 MCM.

From the ***Table 6.1,*** it is found that though the average rain water received within the pit during last nine years is 1.53 MCM but it varies from 0.7 MCM (in year 2010) to 2.32 MCM (in year 2006) during monsoon. This large variation is due to the erratic rainfall received in the area. Out of the total rainfall falling into the pit area, about 20% is expected to evaporate during raining season itself, leaving 80% of rainfall to either recharge or collect into the sump. Thus, the water accumulation in sump or in the aquifers shall be about 1.224 MCM for average rainfall, 0.56 MCM for low rainfall and 1.86 for high rainfall.

Table 6.1: Water received by the mining pit during water year 2005-2014

Year	Area of Mining pit	Annual Rainfall		Monsoon rainfall		Total Water received in the pit	
						Annual	Monsoon
	(m^2)	(mm)	(m)	(mm)	(m)	(MCM)	(MCM)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2006	1956446	1201.6	1.2016	1185.4	1.1854	2.3509	2.3192
2007	1956446	675.2	0.6752	566.2	0.5662	1.321	1.1077
2008	1956446	385.1	0.3851	363.4	0.3634	0.7534	0.711
2009	1956446	608.1	0.6081	603.1	0.6031	1.1897	1.1799
2010	1956446	443.8	0.4438	355.8	0.3558	0.868	0.6961
2011	1956446	1095.2	1.0952	1095.2	1.0952	2.143	2.1427
2012	1956446	784.6	0.7846	774.9	0.7749	1.535	1.5160
2013	1956446	920.2	0.9202	797.6	0.7976	1.800	1.5604
2014	1956446	938.2	0.9802	879.6	0.8796	1.836	1.7209
Total						13.797	12.9539

Apart from this, water enters into pit though recharge from the dumping sites and lateral groundwater flow. The average recharge in to the pit from the dumping sites has been takes as 20% of the direct rainfall into the pit, i.e., 0.28 MCM. The lateral inflow of groundwater due to the gradient created due to pumping is also added to the rainfall recharge.

As per Darcy's equation water entering in to the pit from all the directions (radial flow) can be written as:

$$Q = KIA$$

Where Q is the discharge in m^3/day, K is the hydraulic conductivity in m/d, I is the hydraulic gradient, and A is the area cross sectional area perpendicular to the direction of flow in m^2. In terms of Transmissivity the equation can be written as:

$$Q = TIL$$

Where, T is the Transmissivity in m^2/d, and L is the width of aquifer in m.

Average transmissivity in the Jhamarkotra, as determined by pump tests, is 2230 m^2/d (see Chapter 3). Considering the saturated thickness of 100 m, hydraulic conductivity of the aquifer comes to be about 22 m/d. Hydraulic gradient has been computed considering the water level in the pit (average 410 m) and just outside the pit (490 m) on the northern side. Average diameter of the pit boundary is taken as 500 m. Thus the hydraulic gradient comes to be 80/500 = 0.16. Considering the pit bottom area to be 0.3 km^2 (Length 1.5 km and av. width 200 m), the perimeter of the pit bottom comes to be 3400 m.

Substituting the values of K, I and A in the equation for Q.

$$Q\ (m^3/d) = 22\ (m/d)\ *\ 0.16 *\ 3400\ (m)$$

= 119680 m^3/day

But the porosity (n) of the formation is 0.1 (same as specific yield, GWD, 1991)

Therefore total flow coming to the pit is estimated due to be Q*n = 119680*0.1 = 11968 m^3/d. Therefore, lateral groundwater inflow in to the mine in a year shall be =5984*365 m^3 = 4.368 MCM. This lateral flow will take place, if the lateral flow is from all the sides. But in the present case, lateral flow from BGC side is not expected as these rocks have very low groundwater potential. Thus for calculation of total lateral flow, only 50% area should be considered, contributing only 2.184 MCM water.

Total dynamic recharge water coming to the pit shall be equal to sum of direct rainfall recharge plus the recharge entering through dumping areas and lateral flow of groundwater (***Table 6.2***).

Table 6.2: Dynamic recharge to the Mining pit area

Scenario	Rainfall recharge (MCM)	Recharge from dump areas (MCM)	Lateral flow (MCM)	Total inflow (MCM)
Case –I (Low rainfall)	0.56	0.14	2.184	2.884
Case-II (High rainfall)	1.86	0.464	2.184	4.508
Case-III (Av. rainfall)	1.224	0.276	2.184	3.684

6.2 STATIC GROUNDWATER RESOURCES

Static groundwater reserves have been calculated for the area of the pit, because our interest is to lower the water level with in the pit area only.

Draw down required per annul = 10 m
Pit bottom area of block D & E = 100 ha = 1,000,000 m^2
Specific Yield = 0.1 (GWD, 1991)
Water to be removed from static reserves = drawdown * area* specific yield
= 10*1000000*0.1 = 1.0 MCM

Thus to lower the water table by 10 m annually, 1.0 MCM water is to be removed from the static reserves.

7.0 GROUNDWATER QUALITY

7.1 GENERAL

Ground water occurs in a variety of ways, depending upon depth below land surface, rock type, and topography. Three important aspects of ground water related to the "hydrologic balance" are the storage capacity of rocks for ground water, the rate of movement of ground water and chemical quality. Ground-water pollution can occur both directly and indirectly as a result of surface mining. Direct degradation can occur to ground water situated downhill or down gradient from a surface mine, by flow of contaminated drainage from the mine. This mine drainage can come from pits, ponds, or from rainfall infiltration and ground-water flow during mining and after reclamation. Indirect degradation of ground water could result from blasting, which causes a temporary shaking of the rock and results in new rock fractures near working areas of the mine.

Pollutants are also added to the groundwater system through human activities and natural processes. Solid waste from industrial units is being dumped near the factories, and is subjected to reaction with percolating rainwater and reaches the groundwater level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the groundwater. The problem of groundwater pollution in several parts of the country has become so acute that unless urgent steps for abatement are taken, groundwater resources may be damaged.

The quality of groundwater depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportions of dissolved constituents are found in groundwater than in surface water because of greater interaction of ground water with various materials in geologic strata. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health.

7.2 WATER ANALYSIS AND SAMPLE COLLECTION

It is neither feasible nor advisable or necessary to measure the concentration of all constituents that conceivably might occur in water. A routine analysis involves measuring the concentration of a standard set of the most abundant constituents. Such a test forms the basis for assessing the suitability of water for human consumption or various industrial and agricultural uses. The routine analysis typically includes the major constituents with the exception of silicon and carbonic acid, and the minor constituents with the exception of boron and strontium. Laboratory results are reported as concentrations in mg/kg or mg/L. The reported concentration for metals (for example, Ca, Mg) is the total concentration of metals regardless of whether this mass is actually present as the free metal or metal complexes. The routine analysis also includes measurements such as, pH, total dissolved solids reported in mg/L, and specific conductance, reported in μS/cm. The TDS content is the total quantity of solids when a water sample is evaporated to dryness. Specific conductance is a measure of the sample's ability to conduct electricity, and it provides a proxy measure of the total quantity of ions in solution.

Total 8 samples were collected for analysis of water quality from in and around Jhamarkotra mine (7 groundwater and 1 surface water) (***Figure 7.1***). The results for different water quality parameters were presented in ***Table 7.1***.

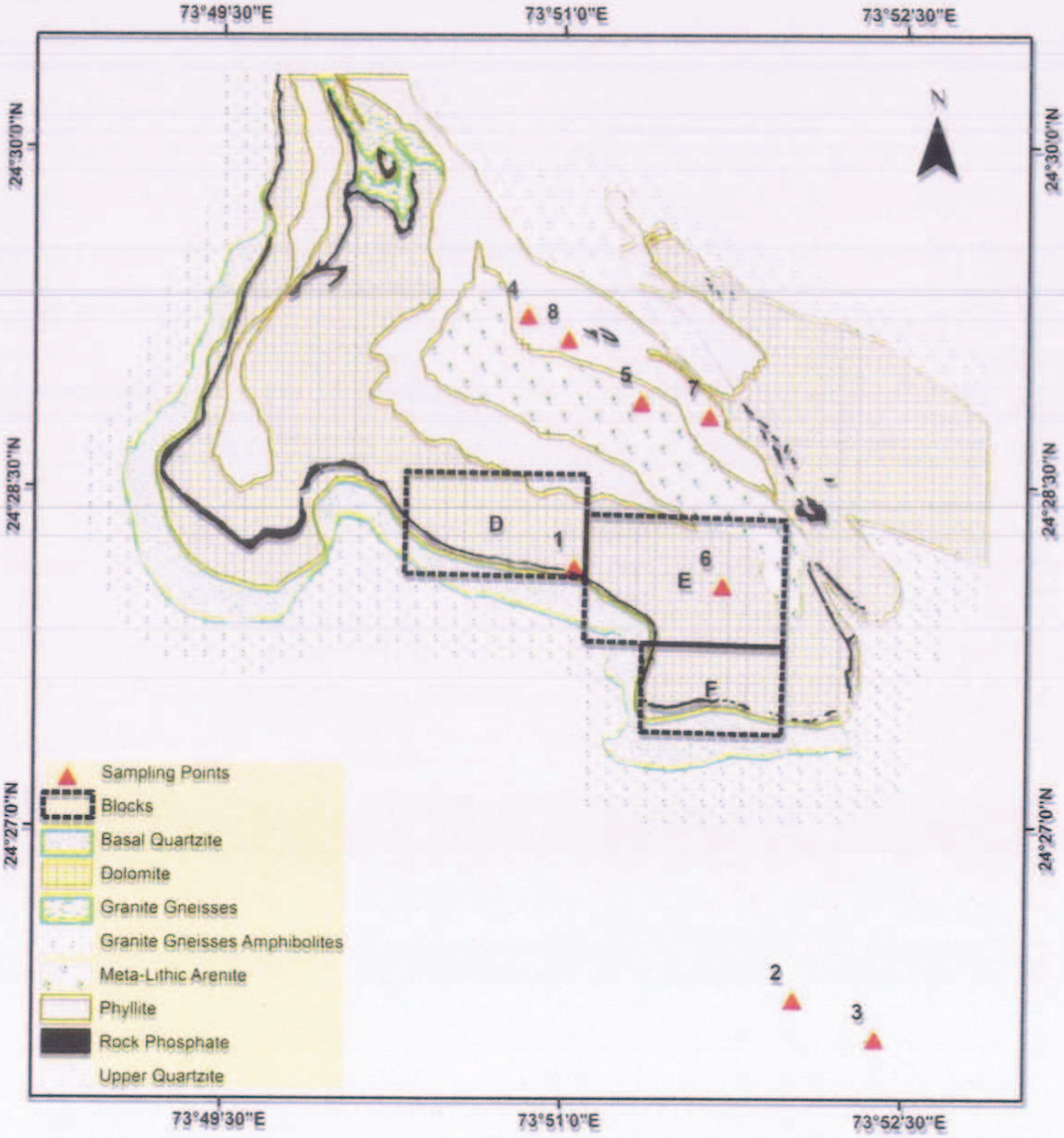


Figure 7.1: Location of Sampling Sites for Water Quality

Table 7.1: Values of different water quality parameters

No.	pH	EC	TDS	Alk	Hard	Na	K	Ca	Mg	HCO_3	Cl	SO_4	NO_3
		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1.	6.9	702	449	202	514	14	1.6	69	83	246	22	75	41
2.	7.0	1398	895	464	429	39	12	60	68	566	104	90	54
3.	7.1	1388	888	378	552	41	10	106	70	461	136	85	91
4.	6.8	991	634	328	485	45	3.3	102	56	400	68	53	12
5.	6.70	1190	762	286	537	37	26	133	50	349	84	81	157
6.	6.8	788	504	332	498	16	1	94	64	405	64	39	12
7.	6.6	1125	720	264	539	24	5.6	160	34	322	54	31	219
8.	6.8	830	531	332	581	38	10.3	134	60	405	45	72	143

7.3 SUITABILITY OF GROUNDWATER

The water quality should satisfy the requirements or standards set for the specific use namely domestic, livestock, agricultural and industrial purposes. Certain chemical quality standards have been established for evaluating the suitability of water for different uses.

Domestic Use:

Water to be used for drinking requirements must meet high standards of physical, chemical and biological purity. It should be free from colour, odour, turbidity and microorganisms. Chemically, the water should preferably be soft, low in dissolved solids and free from poisonous constituents. Bureau of Indian standard (1991) have specified standards for drinking water and are given in ***Table 7.2***.

Table 7.2: Drinking Water Specifications (IS: 10500:1991)

S. No.	Substance or Characteristic	Requirement (Desirable Limit)	Permissible Limit in the absence of Alternate source
1.	pH Value	6.5 to 8.5	No Relaxation
2.	Total Hardness (as $CaCO_3$) mg/l, Max	300	600
3.	Chlorides (as Cl) mg/l, Max.	250	1000
4.	Dissolved solids mg/l, Max	500	2000
5.	Calcium (as Ca) mg/l, Max	75	200
6.	Sulfate (as SO_4) mg/l, Max	200	400
7.	Nitrate (as NO_3) mg/l, Max	45	100
8.	Alkalinity mg/l, Max	200	600

In general the chemical quality of ground water of the wells is found to be good in and around the mine area. The pH values of ground water vary from 6.6 to 7.1 indicating slightly acidic to neutral nature of ground water. TDS values obtained in the study area are within the desirable limits, making the water suitable for various domestic activities. The concentration of chloride in major part of the district is ranging within 22-136 mg/l. Total dissolved solids (TDS) in the study area vary in the range 449-895 mg/l. The concentration of calcium in the study area ranges from 66-160 mg/l. The major source of magnesium in the groundwater is due to ion exchange of minerals in rocks and soils by water, and the samples of the study area vary in the range of 34-83 mg/l. The concentration of potassium varies from 1 mg/l to 26 mg/l.

Bicarbonate is the dominant anion, followed by chloride and sulfate. Bicarbonate in the study area ranges from 246-566 mg/l. The concentration of chloride ranges from 22-136 mg/l whereas of sulphate ranges from 31 to 90 mg/l. Nitrate concentration in the study area varies in the range of 12-219 mg/l, including 4 samples fall below the desirable limits and 3 samples above the limits. Higher concentration of nitrates may be due to infiltration of sewage from the septic tanks or from the organic fertilizers used in agricultural activities. Very high nitrate concentration in sample No 6 (in E block) may be due to use of ammonium nitrate in blasting.

Except nitrate, the overall groundwater quality of the study area is suitable for drinking purposes.

8.0 OBSERVATIONS AND RECOMMENDATIONS

Based on the analysis of the available data and the field surveys carried out, the following observations and recommendations are made:

Major Observations:

1. Flow meters procured during 2012-13 were installed during 2014-15, but most of them are not working.
2. Booster pump has not been installed in the sump in D-Block as suggested previously.
3. The pumps installed in the sump are not working, resulting in accumulation of large volume of water in D-Block. No standby pump has been provided in the sump.
4. Only 5 piezometers are in place in the mines.
5. Only 2 tube wells in Block E and 9 tube wells in Block D are working
6. Automatic raingauge installed by NIH was found to be chocked. Needs regular cleaning of the catch funnel, at least before the monsoon.

Recommendations

1. Six large tube wells may be constructed along the periphery of the mine pit to have proper dewatering as per requirement.
2. To ascertain the performance of the tubewells (discharge), the flow meters should be got repaired / replaced immediately.
3. Presently the position of water table is measured at five locations only that too non uniformly distributed in the Jhamarkotra mines. Therefore, it is suggested that position of water level be monitored at 12 – 15 locations uniformly distributed in the mines with one to two piezometer in smaller blocks (A, A-extension, B, C, F and G) and three to four each larger blocks (D and E).
4. Atlease one piezometer in each block should be equiped with automatic groundwater level recorders.
5. The water collected in the sump must be removed immediately. It is recommended that at least 200 m^3/hr be removed from the sump.
6. For implementation of all recommendations regarding effective dewatering of the mines, it is suggested to constitute a mine dewatering cell with members from mining, planning, geology, civil, and electical departments.
7.

All the recommendations made in the interim report may be implemented immediately to get the desired results in shortest possible time.

Annexure-1

Water Level Data of Jhamarkotra Mines

PIEZOMETER-117 , At D&E Junction, Near View Point	
DATE	WATER LEVEL (in M)
17-Sep-13	446.9
9-Nov-13	
15-Dec-13	445.6
29-Jan-14	448.03
26-Feb-14	447.9
27-Apr-14	442.08
6-Jun-14	441.54
12-Jul-14	437.52
11-Oct-14	439.04
19-Dec-14	439.75
29-Mar-15	440.25
9-Jun-15	443.65

PIEZOMETER-120 , IN E BLOCK AT 512 RL	
DATE	WATER LEVEL (in M)
30-11-2007	435.83
15-04-2007	435.61
26-05-2007	435.61
17-07-2007	435.79
28-07-2007	435.75
01-08-2007	435.78
05-09-2007	436.47
11-09-2007	436.46
18-09-2007	436.46
25-09-2007	436.56
03-10-2007	436.43
09-10-2007	436.31
16-10-2007	436.3
23-10-2007	436.24
30-10-2007	436.23
08-11-2007	436.22
13-11-2007	436.21
23-11-2007	433.87
27-11-2007	433.41
04-12-2007	433.83
11-12-2007	433.57
25-12-2007	431.48
01-01-2008	430.97
15-01-2008	430.49
29-01-2008	429.82
13-02-2008	429.14
20-02-2008	428.84
26-02-2008	428.47
11-03-2008	428.66
25-03-2008	428.5
08-04-2008	427.97
14-06-2008	426.38
26-09-2008	423.39
20-12-2008	423.81

24-02-2009	423.47
20-05-2009	422.47
22-08-2009	423.77
05-11-2009	423.05
09-01-2010	422.05
25-02-2010	421.31
12-05-2010	420.32
14-07-2010	420.48
20-08-2010	422.32
25-09-2010	423.57
14-11-2010	422.9
06-01-2011	424.32
26-02-2011	424.49
16-03-2011	423.65
09-04-2011	423.25
12-06-2011	422.32
01-07-2011	421.77
04-11-2011	425.65
13-01-2012	424.68
24-02-2012	424.29
16-03-2012	424.15
15-04-2012	423.67
15-05-2012	423.51
08-06-2012	423.02
27-06-2012	422.75
04-09-2012	422.87
14-10-2012	423.65
08-11-2012	421.87
15-12-2012	420.01
18-01-2013	418.87

PIEZOMETER- 122, IN E BLOCK AT 516 RL	
DATE	**WATER LEVEL (in M)**
30-11-2006	435.71
15-04-2007	435.43
26-05-2007	435.29
11-09-2007	436.28
18-09-2007	436.28
25-09-2007	436.35
03-10-2007	436.23
09-10-2007	436.14
16-10-2007	436.12
23-10-2007	436.08
30-10-2007	436.05
08-11-2007	436.03
13-11-2007	436.03
23-11-2007	433.12
27-11-2007	432.64
04-12-2007	433.26
11-12-2007	432.71
25-12-2007	431.35
01-01-2008	430.03
15-01-2008	429.52
29-01-2008	428.85
13-02-2008	428.19
20-02-2008	428.18
11-03-2008	427.95

25-03-2008	428.04
08-04-2008	428.03
14-06-2008	426.82
26-09-2008	425.41
20-12-2008	423.87
24-02-2009	423.44
20-05-2009	422.39
22-08-2009	423.65
05-11-2009	423.09
09-01-2010	421.53
12-05-2010	420.22
14-07-2010	420.3
20-08-2010	422.1
25-09-2010	423.48
14-11-2010	423.35
06-01-2011	424.49
26-02-2011	424.15
16-03-2011	423.63
09-04-2011	423.07
12-06-2011	422.18
01-07-2011	422.08
04-11-2011	425.8
13-01-2012	424.47
24-02-2012	424.11
16-03-2012	423.95
15-04-2012	423.53
15-05-2012	423.26
08-06-2012	422.75
27-06-2012	422.52
04-09-2012	423.03
14-10-2012	423.4
08-11-2012	421.74
15-12-2012	419.85
18-01-2013	418.65

PIEZOMETER-123 , At D&E Junction, Near View Point	
DATE	**WATER LEVEL (in M)**
17-Sep-13	412.7
9-Nov-13	415.72
15-Dec-13	415.6
29-Jan-14	damaged

PIEZOMETER-127, At D&E Junction, Near View Point	
DATE	**WATER LEVEL (in M)**
30-11-2006	416.93
15-04-2007	415.51
27-05-2007	412.27
17-07-2007	412.10
28-07-2007	412.07
01-08-2007	412.04
05-09-2007	415.59
11-09-2007	412.47
18-09-2007	412.17
25-09-2007	411.93
03-10-2007	411.67

PIEZOMETER-127, At D&E Junction, Near View Point	
DATE	WATER LEVEL (in M)
09-10-2007	411.52
16-10-2007	411.35
23-10-2007	411.22
30-10-2007	410.98
08-11-2007	410.82
13-11-2007	410.65
04-12-2007	410.42
11-12-2007	410.49
26-12-2007	410.89
01-01-2008	411.05
15-01-2008	410.9
22-01-2008	411.02
29-01-2008	411.17
13-02-2008	411.37
20-02-2008	411.31
26-02-2008	410.97
11-03-2008	410.67
25-03-2008	410.32
08-04-2008	407.8
14-06-2008	407.72
08-08-2008	407.08
25-09-2008	407.25
20-12-2008	405.67
24-02-2009	405.01
20-05-2009	403.56
22-08-2009	403.44
05-11-2009	402.71
08-01-2010	402.27
25-02-2010	401.67
12-05-2010	401.37
14-07-2010	401.82
20-08-2010	402.16

PIEZOMETER-129 , NEAR MMO AT 516 RL	
DATE	WATER LEVEL (in M)
03-11-2006	419.07
15-04-2007	415.42
05-09-2007	412.46
11-09-2007	412.39
18-09-2007	412.33
25-09-2007	412.24
03-10-2007	412.06
09-10-2007	412.45
16-10-2007	411.82
23-10-2007	411.75
30-10-2007	411.62
08-11-2007	411.5
13-11-2007	411.4
27-11-2007	411.16
04-12-2007	411.41
11-12-2007	411.54
18-12-2007	411.96
26-12-2007	412.13
01-01-2008	411.74

15-01-2008	411.9
22-01-2008	411.94
29-01-2008	411.94
13-02-2008	412.06
20-02-2008	412.16
26-02-2008	411.91
11-03-2008	411.34
25-03-2008	411.49
08-04-2008	410.78
14-06-2008	409.94
08-08-2008	408.84
25-09-2008	408.83
20-12-2008	406.96
24-02-2009	406.31
20-05-2009	404.75
22-08-2009	404.18
05-11-2009	404.25
10-01-2010	405.51
25-02-2010	402.8
12-05-2010	402.2
14-07-2010	402.6
20-08-2010	402.7
25-09-2010	403.4
05-01-2011	404
26-02-2011	404
16-03-2011	403.8
09-04-2011	403.6
12-06-2011	403.5
04-11-2011	413.24
13-01-2012	413.54
24-02-2012	413.54
16-03-2012	413.26
15-04-2012	412.91
15-05-2012	412.41
08-06-2012	412.04
27-06-2012	411.82
04-09-2012	413.2
14-10-2012	416.52
08-11-2012	417.34
15-12-2012	417.48
18-01-2013	417.68
02-03-2013	417.54
09-03-2013	417.34
13-04-2013	417.24
18-05-2013	417.14
11-06-2013	416.78
17-09-2013	418.37
09-11-2013	418.89
15-12-2013	418.16
29-01-2014	417.64
26-02-2014	417.19
27-04-2014	416.45
06-06-2014	415.57
12-07-2014	415.55
11-10-2014	420.24
19-12-2014	419.92
29-03-2015	420.17
09-06-2015	419.04

PIEZOMETER-130 , SAMETA AT 519.53 RL	
DATE	WATER LEVEL (in M)
30-11-2006	421.99
15-04-2007	418.79
05-09-2007	418.69
11-09-2007	415.95
18-09-2007	415.21
25-09-2007	415.08
03-10-2007	414.86
09-10-2007	414.61
16-10-2007	414.43
25-09-2008	411.66
20-12-2008	410.20
24-02-2009	409.08
20-05-2009	407.68
22-08-2009	408.53
05-11-2009	406.45
12-05-2010	405.89
14-07-2010	405.83
20-08-2010	408.36
25-09-2010	407.75
14-11-2010	408.27
06-01-2011	408.78
26-02-2011	408.27
09-04-2011	407.77
12-06-2011	407.71
10-09-2011	
25-09-2011	433.87
12-10-2011	431.07
04-11-2011	420.42
13-01-2012	428.03
24-02-2012	416.05
16-03-2012	415.62
15-04-2012	415.08
15-05-2012	414.66
12-06-2012	414.18
27-06-2012	414.10
04-09-2012	
14-10-2012	413.65
08-11-2012	425.53
15-12-2012	420.95
18-01-2013	421.13
03-03-2013	420.18
16-03-2013	418.31
18-05-2013	408.42
04-06-2013	407.32
15-12-2013	407.30
29-01-2014	407.00
26-02-2014	407.10
27-04-2014	Damaged

PIEZOMETER-140 , NEAR DH AREA AT 477.592 RL	
DATE	WATER LEVEL (in M)
24-02-2012	413.27
16-03-2012	413.03

15-04-2012	412.40
15-05-2012	411.37
08-06-2012	409.98
27-06-2012	410.57
04-09-2012	412.46
14-10-2012	412.12
08-11-2012	411.03
15-12-2012	410.83
18-01-2013	410.95
03-03-2013	413.63
09-03-2013	413.31
16-04-2013	411.03
18-05-2013	409.26
11-06-2013	409.35
17-09-2013	409.12
09-11-2013	410.60
15-12-2013	409.93
29-01-2014	409.48
26-02-2014	409.39
27-04-2014	408.21
06-06-2014	407.05
12-07-2014	407.62
11-10-2014	409.98
19-12-2014	409.26
29-03-2015	415.13
09-06-2015	415.89

PIEZOMETER-141 , NEAR DH AREA AT 480.30 RL	
DATE	**WATER LEVEL (in M)**
03-03-2013	413.88
16-04-2013	415.60
18-05-2013	410.42
11-06-2013	411.33
17-09-2013	409.00
09-11-2013	410.61
15-12-2013	409.90
29-01-2014	410.00
26-02-2014	409.90
27-04-2014	409.45
06-06-2014	407.70
12-07-2014	407.53
11-10-2014	413.25
19-12-2014	412.05
29-03-2015	414.35
09-06-2015	414.32

PIEZOMETER-152 , AT D&E JUNCTION, NEAR VIEW POINT	
DATE	**WATER LEVEL (in M)**
27-04-2014	416.16
06-06-2014	416.12
12-07-2014	416.74
11-10-2014	416.99
19-12-2014	416.06
29-03-2015	416.68
09-06-2015	416.38