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Technical Communication

Evaluation of Hydrogeological Parameters Associated with Limestone Mining: A Case Study from Chandrapur, India

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Abstract. Hydrogeological study of the Manikgarh and Naokari limestone mining areas, located in the Chandrapur region of central India, indicate that the mining operations should not cause environmental problems. Conversion of hill mining to pit mining at the Manikgarh Limestone Mine should be feasible and safe. At the Naokari Limestone Mine, a partial diversion of a seasonal stream, the Bop Nala, has been proposed to simplify mining and maximize production; this can be done without significantly altering the natural drainage pattern of the area and is not expected to have any adverse effects on the hydrological regime of area.

Key words: Limestone mining; Chandrapur (India); hydrogeological parameters; impact evaluation

Introduction

The impact that surface mining might have on the hydrology of an area in central India has been the subject of intensive study (CMPDIL 1993; CMRI 2000, 2006; Soni 2006). This paper summarizes the surface and ground water scenario at the Naokari and Manikgarh cement limestone mines, located in this industrial region, as analyzed by the Central Mining Research Institute (CMRI) over the last six to seven years. Unlike most mine impact studies, the nature of the strata meant that water quality issues had to be considered but were not the principal concern. Ideally, this study can serve as an example on factors to consider when assessing potential water-related problems of limestone mining.

Study Area / Region

The Chandrapur district (latitude N 19°30' - 20°45'; longitude E 78°46' - 80°00') encompasses a 10,489 sq km area in central India, and occupies the eastern part of the state of Maharashtra. It is surrounded by the Gadchiroli district in the east, the Wardha and Nagpur districts in the north, the Yavatmal district in the west, and the state of Andhra Pradesh in the south (Figure 1). The city of Chandrapur is the district headquarters as well as the industrial hub of the district, with a population of about two million people (Anon 2001). The region as a whole is endowed with rich forests and mineral wealth, particularly coal and limestone. It has a mixed economy and good infrastructure facilities and is an important district from an industrial angle. The studied mines serve the Awarpur (M/s Ultratech Cement Co. Ltd.) and Manikgarh (Century Textiles and Industries Ltd.) cement plants and produce 5MT and 2MT of limestone per annum, respectively.

Parameters that Influence the Hydrogeology

The Chandrapur region in general and the study area in particular are described in brief in the following paragraphs. Various parameters for the studied mines have also been tabulated (Table 1).

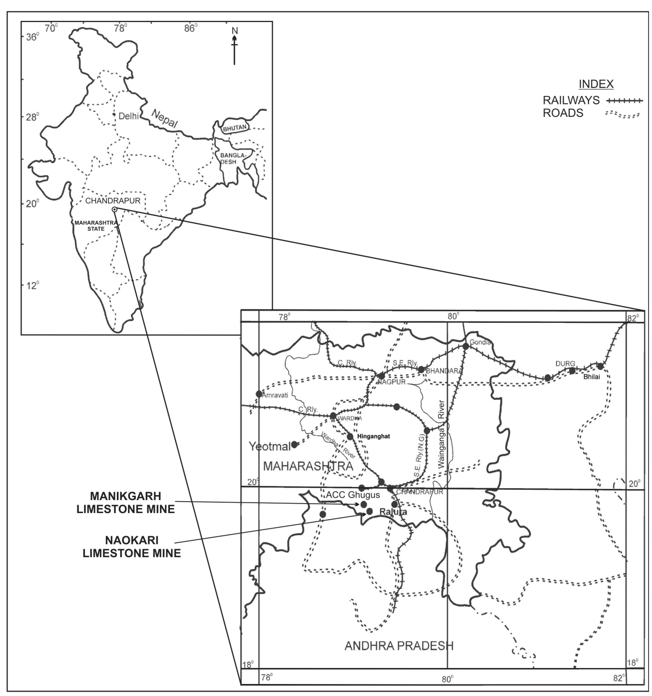

Figure 1. Location map of study area

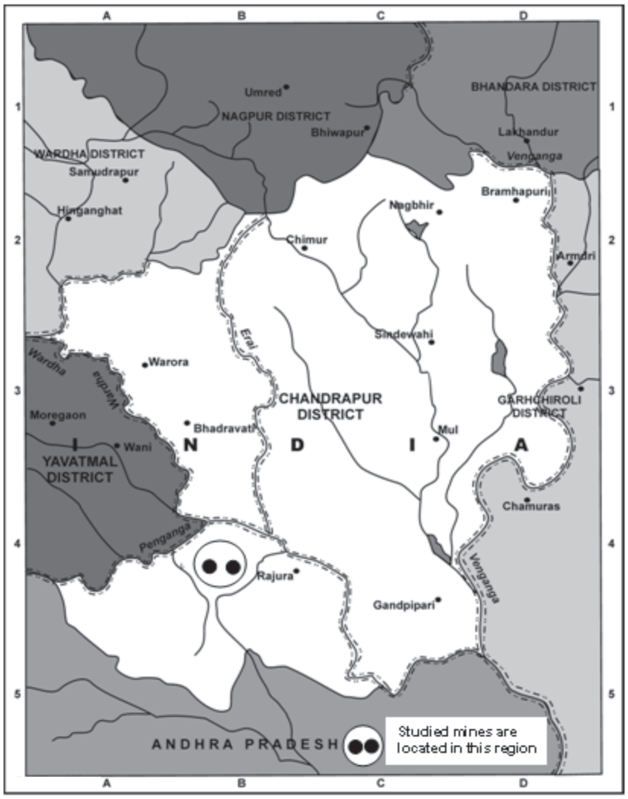

Figure 2a. Drainage map of Chandrapur district

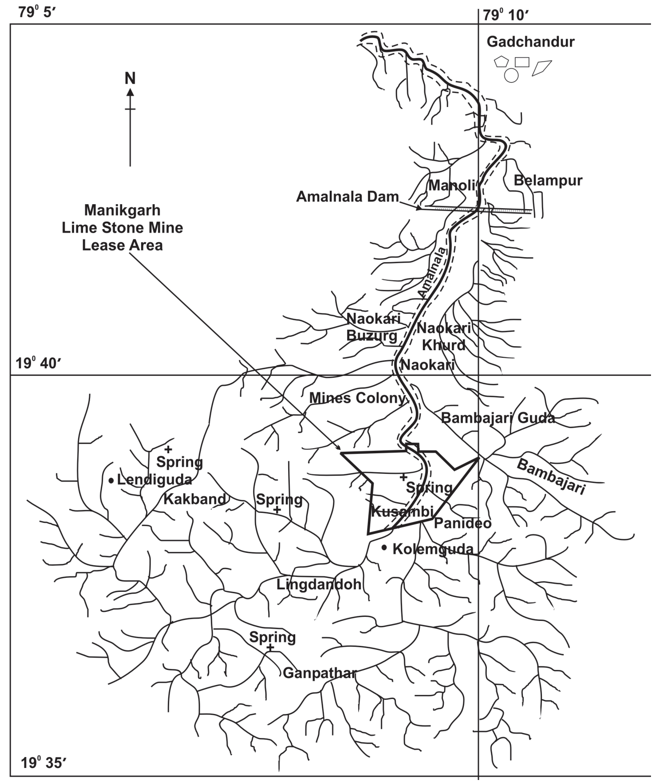

Figure 2c. Drainage map of Naokari Limestone Mine.

Physiography / Topography

The Chandrapur district has fertile plains and upland hills. The flat terrain occurs mostly along the Wardha River. The flat terrain of the Chandrapur district on the whole lies generally at 250 m above mean seal level (MSL). The upland hilly region lies between the Wardha and the Wainganga Rivers. It has sandy soil. The hills in Wardha, Brahmapuri and Chandrapur areas are low lying hills, with an average elevation of 300 m above MSL. In the southwestern parts of the district, the hills are known as Gadchandur and Manikgarh hills, in general, rise to 500 m above MSL.

Meteorology

Average yearly rainfall is generally 1200 to 1450 mm (Anon 2005). The climate of the district is characterized by a hot summer and general dryness, except for well-distributed rainfall during the southwest monsoon (June to September).

Drainage

The entire area of the district falls in the Godavari basin (Survey of India toposheet No. 56 M/1 and 56 M/2). The major tributaries of the Godavari River, the Wardha, the Wainganga, and the Penganga Rivers, drain the area (Figure 2a to 2c). The Penganga, flowing along part of the western boundary, meets the Wardha River near Ghughus. It further flows in a NW-SE direction, finally merging into the Wainganga River at the southeastern corner of the district. After this confluence, the river is known as the Pranhita River.

Aquifer Parameters

Aquifer parameters, based on pumping test data and basin studies carried out periodically for regional planning by the Central Ground Water Board (CGWB) (1995, 2000), are provided in Table 1. Secondary data of the Ground Water Survey and Development Agency (GSDA) (1998, 2005) and CMRI (2000, 2006) have also been included for evaluation. Details are given in analysis and discussions below.

Geology and Geomorphology

The limestone formations in the study area are karstic and serve as aquifers, with a high permeability and porosity. The Chandrapur district presents a variety of stratigraphic units from Pre Cambrian to recent alluvium and laterites (Table 2). The Manikgarh limestone (the Naokari – Kusumbi deposit), belongs to the Penganga Series, which are equivalent to Vindhyans and are of Pre Cambrian age. The limestone is platy, fractured, and fissured. The Naokari limestone (the Awarpur – Bakardi deposit) also belongs to the Penganga or Vindhyan systems. Broad irregular Deccan traps overlie the outcrop of the Naokari

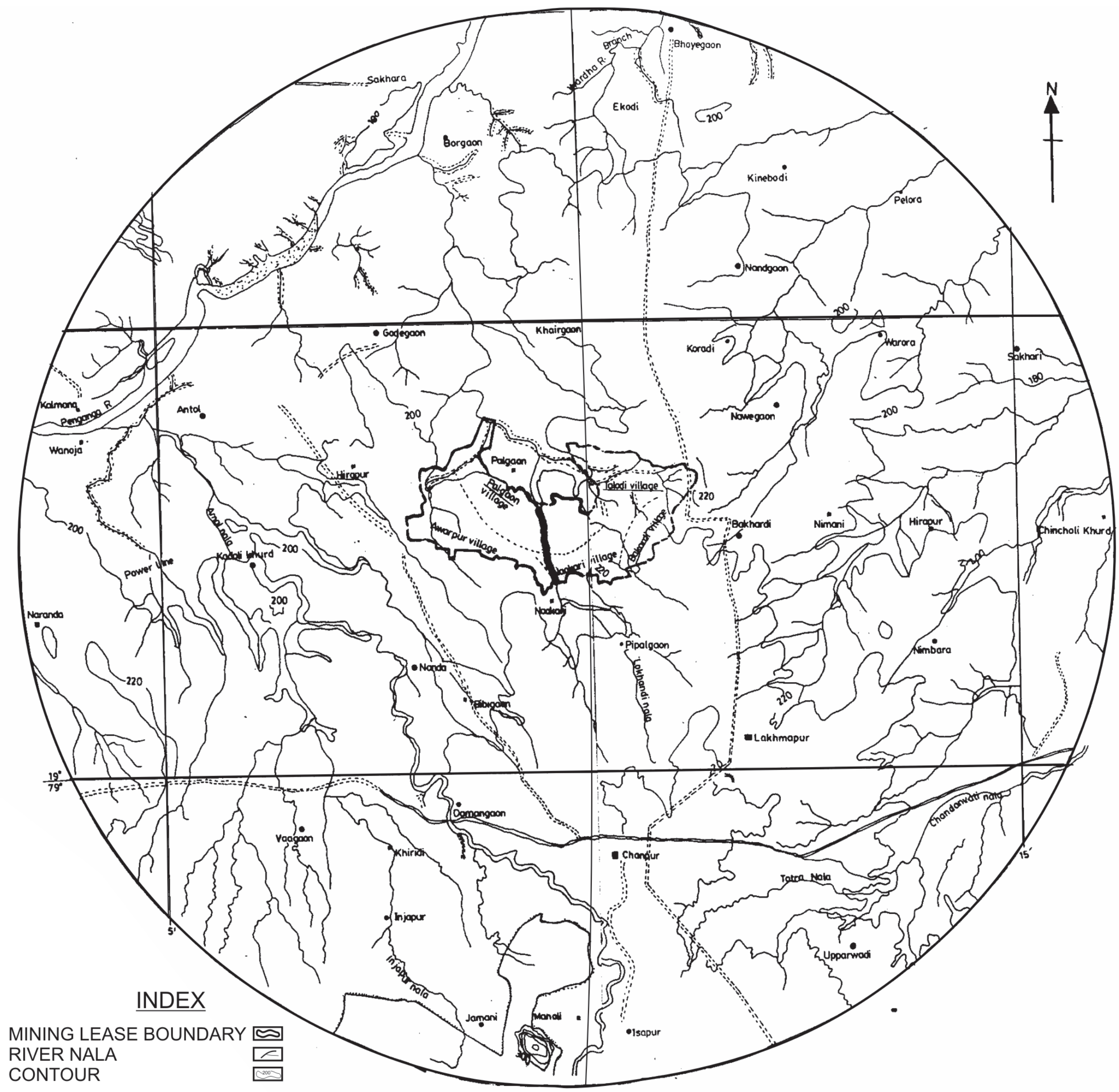

Figure 2b. Drainage map of Manikgarh Limestone Mine.

limestone. The Penganga shales and limestone are, in most places, found directly above the gneisses.

Land Use and Soil

Knowledge of land use and soil of an area are important for hydrogeological studies and helps in planning artificial recharge structures for ground water improvement. The statistical details of land use (Anon 1998) for the region is given in Table 3. The area under investigation is in an agricultural belt with 1,092,000 ha of total land area. Traditionally, the agriculture had been based on a Spring harvest, through the benefits of irrigation. Seasonal crops and vegetables are grown only in areas with perennial irrigation or where ground water based irrigation sources are available. About 34% of the Chandrapur district is forested. The soil type of Chandrapur district is largely 'black cotton soil,' which is medium coarse with clayey and loamy texture. The average depth of soil is 20 cm or more (NBSS and LUP 1990).

Mining Operation Vis-à-vis Hydrological Impacts

The environmental impacts of mining have been described by Canter (1996), Curtis (1997), Saxena et al. (2002), Soni (1994, 2006), and Singh (2006), but it is mining's hydrologic effects that has drawn recent

Table 1. Mining and hydrogeological parameters

Parameter	Case 1: Manikgarh Mine	Case 2: Naokari Mine	Remarks
		Mining Parameters	
Mine working depths (as of March 2006)	Six designated limestone blocks from block 'A' to block 'F' exist. Mining in block 'A', 'B' and 'F' only; block 'B' = 5 m	Block 'A' = 25 to 50 m; block 'B' = less than 10 m	Expected depth of working: case 1 = 50 m; case 2 = 55 m
Geological parameters (formation types)	Archaean to recent alluvium and laterites	Limestone of lower Vindhyan system (Pre-Cambrian)	Important aquifers
		Hydrological Parameters	
Surface water features: the Chandrapur district is part of the Godavari Basin; the Wainganga, Wardha, and Penganga Rivers form the major watersheds.	The Manikgarh Mine lies in the micro-watershed of Amal Nala of the Penganga sub-basin of the Wardha basin.	The Naokari mine lies in the micro-watershed of BOP Nallah	The drainage of the area dendritic.
Ground water resources	Dug wells and hand pumps	Dug wells and hand pumps	Ground water development is poor and flows to the NW
Aquifer type	Unconfined	Unconfined	Weathered / fractured limestone acts as a water-bearing aquifer.
Static water level*	2 – 7 m (average)	0.20 – 13.76 m	See footnote below
Specific yield / effective porosity	9%	9%	
Transmissivity	207.7 m^2/day	207.7 m^2/day	
Specific capacity / storativity	272 L/unit/m of draw down	272 L/unit/m of draw down	
Hydraulic gradient	1:250	1:250	

Note: * = Case 1: from CGWB records, 1987 to 1999 (average value shown); Case 2: from May 1973 to March 2005 covering 94 records and also the static water level data from the piezometer at Gadchandur from Feb. 1999 to April 2005 covering 58 records (Source: Central Ground Water Board (CGWB), Ground Water Survey and Development Agency (GSDA), and the Central Mining Research Institute (CMRI).

attention in the Chandrapur district. The following points should be considered.

a) Excessive dewatering of a mine area may cause a disruption of ground water systems, including its flow pattern. Ground water levels may be permanently or temporarily lowered, shallow aquifers may be drained or physically removed, and existing wells or small surface streams may become ephemeral or completely dry. Such impacts could extend kilometers away from the mine site (Curtis 1971).

b) Extensive removal of water from aquifers can result in irreversible ground subsidence (Saxena et al. 2002).

c) Surface mining can cause the deterioration of water quality, both surface and underground. Mining spoils may generate toxic leachates due to water thereby polluting surface as well as ground water. Quality deterioration is recorded in terms of decreased pH, increased hardness, and elevated concentrations of sulphate, Ca, F, As, Fe, etc. (Singh 2006).

d) It is well established that the removal of protective vegetation and disruption of the soil surface in a mining area can have adverse effects, such as increased runoff, erosion, sedimentation, etc.

Table 2. Regional geology

Age	Formation	Rock Types
Recent to sub-recent	Alluvium, soils laterites	Sand, clay, silt, soils & laterites
Lower Eocene to Upper Cretaceous	Deccan Traps	Basalts, weathered, vesicular & massive basalts
Triassic	Upper Gondwanas group malaris	Clay, shales, sandstones
Lower Triassic to Upper Carboniferous	Lower Gondwanas Group	
	Kamthis	Reddish brown sandstone, shale, clay
	Barakars	Light grey to white feldspathic sandstones, carbonaceous shales, coal seams & clay
	Talchirs	Greenish to dark olive green colored shales & coarse-grained sandstones.
Precambrian	Vindhyans	Shales, sandstones, flaggy and massive limestone and sandstones of variegated colours
Archaeans	Crystallines & older metamorphics	Gneisses, quartzites, schists with acid and basic intrusives

Table 3. Land use statistics of the Chandrapur District

Type of Land	Area	% Share
Agricultural land	5,80,000 ha	53.11
Forest Land	3,71,280 ha	34.01
Fallow land	58,600 ha	5.36
Wasteland	82,120 ha	7.52
Total Land Area	1,092000 ha	

Source: Anon 1998

e) Changes in topography may result in storage of water in surface depressions, impoundments, or mine sumps. Unplanned detention in such areas can reduce mine productivity and encourage infiltration of polluted water into the ground water.

It is important to note that not all hydrologic effects of mining are negative. For example, excavated surface depressions and impoundments can serve as a beneficial water resource to an area and aid in ground water recharge. In some situations, the backfill material of a mining area can also act as an aquifer recharge zone (Wood 1981). The mining pits in Case-1 (Manikgarh) and Case-2 (Naokari) will not be backfilled and will be left open to act as water recharge zones (Holtech 1999; MCG 1992).

Analysis and Discussion

The limestone deposits of the Chandrapur region belong to the Penganga series. Each of these deposits shows distinct color, chemical composition, and physical characteristics, though the geological interrelationship of these deposits is not fully understood. The Naokari-Kusumbi (Case-1) and Awarpur-Bakardi deposits (Case-2), where this study was done, are not as geologically complex as other deposits, but have undergone some folding and faulting. The limestone deposits and rock units adjacent to the studied regions are permeable and the aquifers are unconfined and anisotropic in nature; they have good potential for ground water storage. Considering regional climatic conditions, rainfall statistics (1200 to 1450 mm) and potential evapo-transpiration, the area has good ground water availability and high yield potential in general (NBSS and LUP 1990). Aquifer recharge takes place during the monsoon and post-monsoon season. This has been verified using old depth to water table data (CMRI 2000, 2006). However, the region does experience seasonal drinking water shortages, particularly during summer.

Based on the CGWB (1995) evaluation and CMRI (2000) assessment, the overall ground water development was 2.74% in 1995. It had increased nearly five-fold by 2000, reaching a figure of 13 to 14% (CGWB 2000), but is still relatively low (it can be regarded as high if it is more than 50%). This slow increase in ground water development is basically attributed to the non-implementation of agricultural-based irrigation. During 1995-2005, very few or no irrigation facilities were commissioned by the state authorities. However, coal and limestone mines and cement factories have been developed in the area.

To evaluate the potential impacts of the limestone mining on the hydrological regime of the study area, secondary data (Anon 1980; Holtech 1999; MCG 1992) were studied and the environmental conditions

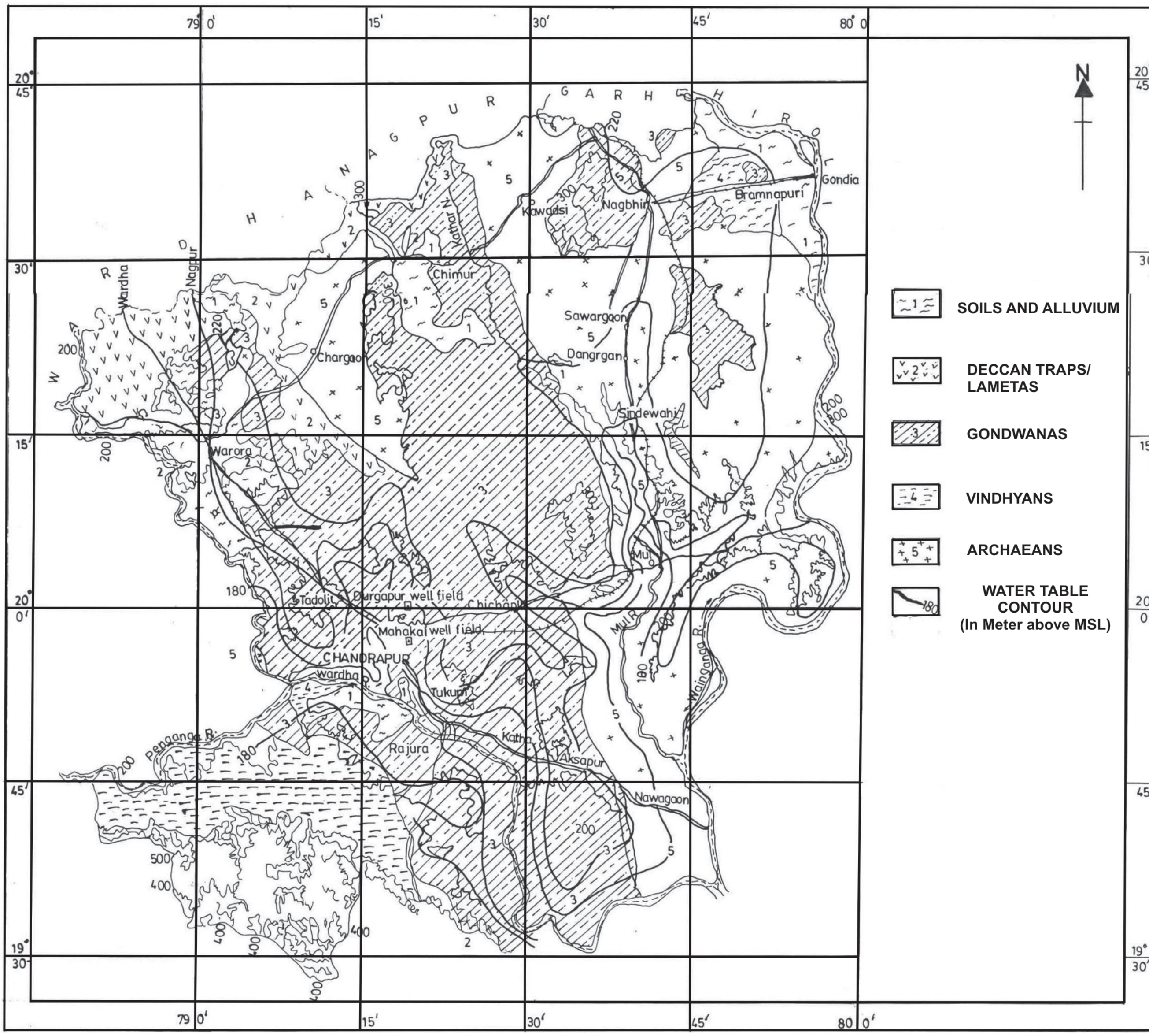

Figure 3. Hydrogeological map of Chandrapur District ,India.

at each mine were assessed (Table 1). Based on the overall facts, a hydrogeological map of the region was prepared (Figure 3) and aquifer parameters were evaluated, as detailed in the paragraphs below.

The specific capacity or storativity (*C*) of the unconfined aquifer is an indication of its water-yielding property. The average value of *C* was calculated as 272.0 L per unit per m of drawdown for both sites. The transmissivity (*T*) was determined to be 207.72 m^2/day (Table 1), which indicates that the strata are good aquifers. The transmissivity and storativity values define the hydraulic characteristic of water-bearing formations and indicate how much water can be removed by pumping or draining these aquifers. Field investigations also indicated the presence of limestone cavities at certain locations, which is congruent with the relatively high value of *C*.

Based on the survey of India toposheet (No. 56 M/1 and 56 M/2), the hydraulic gradient was estimated as 1:250 for both mine sites and the permeability (K) of the studied aquifers indicates that the medium is capable of transmitting water. The vertical hydraulic conductivity values (25.64 m /day and 47.20 m/day for the Manikgarh and Naokari deposits, respectively) reflect the different saturated thickness values for the aquifers.

Specific yield values (*S*) were determined by field pumping tests conducted near the studied sites (CGWB 1995). Generally, *S* value lies in the range of 5% to

40%. In the present case study, the S value was 9%, which means that the aquifers are non-homogenous in nature with interconnected voids.

The above mentioned analysis defines as well as evaluates the hydraulic characteristics of the ground water at the studied areas. Amal Nala in Manikgarh and Bop Nala in Naokari lease area are the only important surface water bodies in the respective study areas. Having analyzed the ground water and surface water scenarios, each mine site was analyzed from an engineering perspective. From Table 4, it is clear that water quality pollution is not a cause of concern for the studied mine sites. It should be noted that there is no discharge of mine water in to the natural drainage system or nala. Thus, no effects of mining have been observed or are anticipated on the water quality of the aquifer system.

The Manikgarh Limestone Mine is an excellent example of conversion of hill mining into pit mining. The entire hill where mining was done was composed

Table 4. Ground water quality in and around the Manikgarh and Naokari Mine lease areas (physico-chemical parameters)

Item	In and around the Manikgarh mine lease area	In and around the Naokari mine lease area	BIS Standards (IS: 10500 -1983)	Remarks
Period	1 year (1999 – 2000)	1 year (2005 –2006)	Requirement/ Desirable Limit	Covers winter, summer and rainy seasons
Type of water source	• Dug wells • Hand pumps	• Dug wells • Hand pumps		–
# of locations	2	10		–
		Water Quality Parameters		
pH	7.34	7.54	6.5 –8.5 (Neutral)	Quality assessment based on average values at locations in and around the two sites
TDS	434.83	778.56	500	
DO	6.86	6.40	--	
BOD	0.633	3.9	--	
Chloride (Cl^-)	14.73	33.98	250	
Sulphate	14.69	41.486	150	
Nitrate	9.75	ND	45	
Iron (Fe)	0.34	0.11	0.3	
Fluoride	0.17	0.696	0.6 –1.2	
Copper	0.014	0.0163	0.05	
Pb	BDL	0.0018	0.1	
Zinc	0.11	0.02	0.5	
Ca	ND	51.96	75	
Mg	ND	19.65	30	
As	BDL	BDL	0.05	
Cd	BDL	BDL	0.01	
Pesticides	Absent	Absent	Absent	
Coliform	Absent	Absent	Absent	
Total hardness	241.87	473.3	300	

Source: CMRI 2000 and CMRI 2006; Note: (1) In India, Bureau of Indian Standards (BIS) Standards for Drinking Water Quality (IS: 10500-1983) are followed for quality assessment; (2) BDL: below detectable limit; ND: not detected; (3) All values are expressed in mg/L except for pH.

of limestone, with only 10 – 15 cm of overburden cover. Mining operations have now reached ground level, and are being deepened further. Yet, mining has, and should have, an insignificant impact on the hydrologic regime because the water table has not been and will not be intercepted (Soni 2006).

Similarly, analysis of Naokari Limestone Mine data indicates that the seasonal stream, BOP Nala, which passes through the middle of the lease area and divides the limestone into two Blocks - 'A' & 'B', could be partially diverted out of the lease area to increase the limestone reserves available for exploitation. The geo-hydrological studies have prima facie indicated that the diversion will allow more effective and more efficient extraction of the limestone without affecting the hydrologic regime of the area (CMRI 2006), due to the following:

1. The BOP Nala only flows during the monsoon season, when it carries water to the main river of the region, the Penganga River. It has no permanent or perennial input source and other than during the rainy season, it remains virtually dry. Its catchment area for ground water recharge is only periodic and not very significant.

2. Based on a survey of various villages surrounding the mine site, water development and utilization in this study area is low (≈ 10-11%). Thus, a significant potential for ground water development exists (CMRI 2006). Water scarcity, when it occurs, is only a localized seasonal effect (CGWB 2000).

3. The proposed diversion, though permanent, is only a partial one, and only affects a portion of the lease area. It will not affect the confluence point of the nala with the Penganga River. It will have virtually no effect on the surrounding villages and drainage pattern of the area because only one village, Palgaon, with a population of 700 – 800, lies on the route of the proposed diversion. The BOP Nala water is not used for drinking or for irrigation.

4. The diversion has a positive cost-benefit ratio. It will allow the limestone in the stream bed to be extracted, and will streamline the planning and mining process. The present mine design is rather lengthy and cumbersome due to the demarcated blocks and partition barrier. In addition, the absence of a water body from the lease area will simplify the procedure for administrative and statuary clearances, and will decrease the transportation cost, thereby reducing the overall cost of limestone production.

Correlating the drainage pattern, physiography of the region, and hydrogeological data (including aquifer parameters) of the studied sites, an impact assessment has been made (CMRI 2000, 2006). It was concluded that the ongoing industrial activity (mining) has not caused and is not likely to cause any adverse impact on the hydrological regime of the area. Thus, mining and development can proceed together sustainably. Based on this determination, decisions were made to permit the proposed future mining and rerouting of the nala (diversion).

Conclusions

1. The limestone mines and their operation should not have a significant impact on the hydrological regime of the Chandrapur region.

2. Ground water development and ground water draft is relatively low in the area and the potential exists for future development; mining will not adversely affect that condition.

3. Geological formations in the study area have a high potential for ground water development.

4. Water quality will not be adversely affected by the industrial operation, i.e. mining.

5. The ensuing hydrogeological study and detailed analysis of each mine site indicates that the sub-surface excavation of the Manikgarh Limestone Mine and the partial diversion of a seasonal stream (BOP Nala) at the Naokari Mine can be done safely and conveniently and will increase limestone production at both sites, without adversely affecting the local population or the environment.

Acknowledgements

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