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Mining of Minerals and Groundwater in India

Abhay Kumar Soni

Abstract

Mining of minerals is essential for our day-to-day life so is the groundwater. Mother Earth is the custodian of these two essential commodities, and both are part and parcel of sustainable living for human beings. This chapter of book focuses on the need, quantity, quality, and management of groundwater encountered in mines, from where extraction of minerals takes place. By understanding interrelationship between groundwater hydrology and mining, the basic objective of sustainability, that is, conserving for future generations with particular reference to the mines, has been addressed. Such scientific approach makes the mine planning easier, ensures better water management, and solves water scarcity as well as security problems in the vicinity of mining areas.

Keywords: surface mining, underground mining, impact of mining on groundwater, quantitative estimation in a pit, statutory compliance, groundwater in hard rocks

1. Introduction

Minerals and their exploitation had been carried out since centuries by two major methods, namely, surface mining methods and underground mining methods. In both these methods, groundwater role is important as well as advocated because mining has influence on hydrology. While permitting mining, the disturbance to the hydrological regime should be minimum or as less as possible.

It is beyond doubt that for food security, human health, energy, and ecosystem, groundwater is absolutely important for the entire world [1].

This groundwater is continually being put under increasing stress because of the industrialization, growing needs of the population, and its improper use as a resource. Its mismanagement has led to uncalled water scarcity in present time and also threatened us with water pollution problems. Groundwater science and its accurate estimation for the mining areas are a bit cumbersome because the dynamics of groundwater keep on changing as excavation size is changed. Therefore, the role of groundwater in mining of minerals assumes special emphasis which is analyzed and discussed as a separate chapter in this book. This knowledge, though very exhaustive, will be certainly helpful for the mining areas and mega-sized mining/mineral sector in improving the quality of human life.

While dealing with water problems of mines, three keywords must always be remembered as they are extremely important, namely, mine water (MW), groundwater (GW), and surface water (SW). Our focus in this chapter has been kept on

mine water and its analysis with respect to the two principal methods of mining, that is, opencast mine and underground mine only. Besides these principal methods, other methods are not covered, though other novel methods and technologies of mining do exist, for example, solution method, mechanical method, aqueous extraction methods (hydraulic mining), etc.

The MW analysis automatically covers SW and GW, as mine water is either/or a combination of both for all mineral types (categorized as fuel minerals, that is, coal and lignite; metallic minerals, that is, iron ore, bauxite, etc.; nonmetallic minerals, that is, limestone, dolomite, etc.; and minor minerals, that is, sand, building materials, etc.) and their extraction from earth called “mining of minerals.”

In this introductory paragraph, it is apt to highlight some basic points of groundwater to deal mining of minerals, scientifically. “Groundwater” in surface mines is found below the water table and covered by a layer of soil and/or rock. Groundwater is always present at below ground level and indirectly available at the mine pit as “base flow.” It gets intercepted while excavating mineral(s) in open mines. Availability of groundwater in open-pit mines and underground mine workings has number of differing dimensions of basic hydrology influenced by site-specific geology. Thus, it requires basic knowledge of water flow and water movement (Darcy’s law). Groundwater of mining area occurs in aquifers which are of different categories, namely, unconfined aquifers, semi-confined aquifers, and confined aquifers. The groundwater is contained either in the rock pore spaces or rock fractures/cracks depending on the rock types. Compared to the surface water, it is generally considered to be less easily contaminated, but this does not infer that groundwater is safe from pollution perspective. The groundwater can become contaminated where polluted runoff seeps through the ground to the water table or flows down through fractures or cracks in bedrock (seepages). Wherever surface water bodies are fed from groundwater sources, water contamination may be present in both, though isolated by ground cover. In addition, groundwater often contains dissolved minerals as a result of prolonged contact with rocks containing minerals of different types and varieties which can alter its quality, for example, the presence of arsenic, nitrates, and fluoride [2–6] in aquifers has been reported, and this is an indication for this. The depth of the groundwater at which it is present in and around the mine area is a one major point of observation as well as concern for mine water-related issues.

To understand groundwater-related problems of mine, hydrological and geological setup of the area is first studied. With reference to any mine or the mining area, hydrogeological setup encompasses aquifer characteristics, that is, nature, type, parameters, etc.; all local and regional geological details; and plans for mining and total picture of hydrology, drainage, discharge, etc. The approach for scientific investigation, to search solution, usually includes field monitoring (pre-monsoon and post-monsoon monitoring), instrumental survey (e.g., Resistivity Image Profiling Survey and GPR Survey, etc.), groundwater modeling, and mine planning, that is, drainage, dewatering, etc. Mine being a production enterprise (unit) requires its assessment from industrial perspective; hence, this chapter makes no pretense of neither mining engineering nor of hydrology but explains to the reader the interrelation of mining process with water in general and groundwater in particular.

Here, it is equally important to describe briefly what *new insights* the work has added in terms of knowledge on top of the existing knowledge. In general, mining of minerals and groundwater pertains to the open-pit mining of minerals. Technical literature is also vogue in terms of analysis and with particular reference to the surface mines only. Very little had been dealt about different aspects of underground versus groundwater in mining science. But in this book chapter, both “underground mining” and “open-pit mining” knowledge have been dealt together

forming a consolidated base and considering that groundwater is equally important for operative underground mines. Such attempt will provide total and at-a-place look to the reader. Not only this, but it will also enhance further scope of knowledge development, to be done by other researchers, in underground mines/mining and other excavations, which are less researched. Site-specific and typical field conditions will certainly add further to the existing groundwater knowledge base and make underground excavations further safe as well as productive.

2. Water in mines: pollution, discharge, control, and treatment

Water in mines, that is, “mine water,” usually refers to the water contained in the mined-out open area or dug-out area generated as a result of mining of mineral. This excavated area is in open-pit form and contains surface water as well as groundwater. In the case of underground mine, the water encountered is principally groundwater. To address technical issues, it is always better to consider them as two entities, that is, surface water and groundwater (**Figure 1**), though difficult, to categorize in the case of surface mine.

The principal source of mine water is the “rainfall,” and other possible sources could be enumerated as:

1. Intersection of water table during mining
2. Seepage water
 - a. Nearby major water bodies in and around the mining area
 - b. Nearby mine workings, may be surface or underground
3. Incessant rainfall/heavy downpour

Mine water, a valuable commodity, is also a form of industrial wastewater (effluent) which can be a disaster in mining areas or a boon to ease the water scarcity problem locally. Both SW and GW are considered at all stages of the mining operation starting from planning to extraction to restoration stage. Different aspects

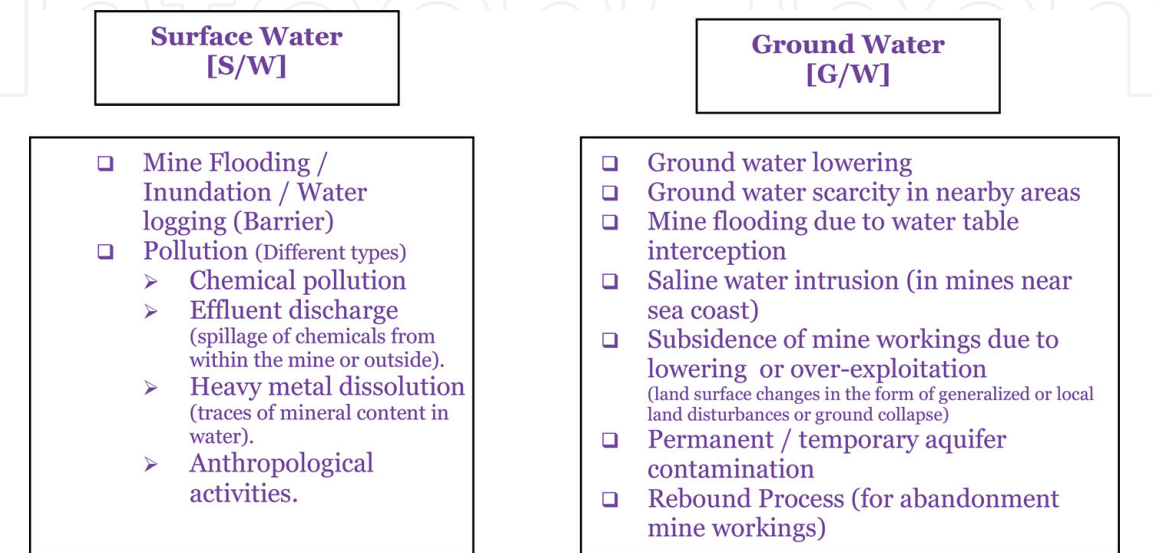


Figure 1.
Problem and issues of water in mines.

of water covered include collection and handling of hydrological data, control of runoff, magnitude of water, diversion of water channels in mines, (if any), erosion and sediment control, dewatering, different water pollution forms as observed in mines, and water management. As said above that the interrelationship of water and mine is complex and far reaching, the solution should be practical to ensure the efficient running of mining operation while adequately protecting the environment.

2.1 Pollution

It has been observed that water pollution in mines is common and well described but their scientific importance is often ignored while managing the mine production. The reasons for this are enumerable. It is desirable that every mine's water, if present, is turned into a useful asset. In some situations water management at mine is neither environmentally friendly nor comparatively easier to manage, for example, acid mine/rock drainage (AMD/ARD), and its management is a costly affair compared to higher TDS water in a limestone quarry. Therefore, sincere attempts have to be made to ensure that AMD pollution and high TDS hard water are treated properly. Similarly, elemental concentration must be checked within permissible limit.

When water comes in contact with exposed mineral at the mine (either at pit or in underground), the potential for water contamination increases manifold. In order to reduce and minimize the water pollution requiring treatment, various control techniques are available. On case-to-case basis and looking at the type of mineral mined, the mine water pollution are dealt for different solutions, for example, heavy metal contamination into water, thereby raising pollution levels are quite frequent in the case of metallic mines.

Mine water control techniques and their selection strategies are cost based and site-specific. It should be carefully selected to prevent the release of contaminated water into the environment. From area to area, one or combination of more than one method may be applied for the pollution control. With high rates of precipitation in an area, significant emphasis must be placed on drainage and its combinations in varying topographies, whereas the mine environment in arid regions with little water availability must choose *water recycling* as the technique of mine water containment for pollution abatement. If pollution has to be controlled and contained in the mining areas alone, the mine water discharge must be routed effectively. This will make the water pollution management more cost-effective. Judicious utilization of water for the appropriate purpose and water conservation for the future need should be implemented into practice as per the law of land. In India, for prevention of pollution due to mine water, the principal act is Water (Prevention and Control of Pollution) Act, 1974 (amended in 1988 and 2003). This act, despite the prevention and control of water pollution, also guides for the maintaining or restoring of wholesomeness of water.

The topic of pollution is so vast and varied that its description in limited pages is beyond the scope of this chapter. Therefore, readers are advised to consult specific literature related with the problem.

2.2 Discharge

Water discharge from a mine is often controlled by effective drainage around. In India, water discharged from mines are governed by general discharge standards/limits framed by the Ministry of Environment, Forest and Climate Change (MOEFCC) Govt. of India [7]. These effluent discharge standards of India containing about 33 pollutant parameters are framed under the Environment (Protection) Rule, 1986 (under Schedule VI).

Discharge of mine water into natural drainage system without any treatment is also an issue to be reckoned in mining geohydrology. In order to avoid the degradation of downstream water channels by excessive suspended sediments from mine, all runoff leaving the mining area should be routed through “sedimentation pond” where the suspended solid can be reduced to acceptable limits. Factors to be considered during design and construction of sedimentation pond include hydrology, its location in mine, construction material and its cost, maintenance/cleanout operations, and applicable legislative requirement [8].

In mining areas, either dendritic pattern or parallel drainage pattern is often present (Figure 2).

Intercepting and diverting surface water (rainwater, runoff water, stream water, snowmelt water, etc.) from entering the mine site are the first step to tackle water accumulation in a pit. Since surface mining causes land disturbance including the removal of vegetation, increased runoff, erosion, and sediment, every attempt should be made to control the mine water discharge. Proper relief and gradient together with adequate slope design are helpful in capturing drainage water which can control runoff and erosion of soil as well as sediments. Topography and watershed details of the project area are equally important from drainage and discharge angle. For the mine water discharge, the knowledge of flow direction together with reduced level (RL/MRL) detail helps in planning. Small seasonal nallahs/streams with first-, second-, and third-order drainage pattern are observed in the mining region. Drainage map of the studied mine area is generally drawn covering core zone or CZ (5 km radius) and buffer zone (BZ) of the mine lease (10 km radius). Together with drainage and the watershed area details, an assessment about the seepage from the pit, mine dumps and tailing dams, etc. in nearby area can be made. Such analysis provides the basis for delineating control measures of seepage flow and water management.

In mine-related studies, generally the term *watershed* [classified as first-, second-, third-, or higher order watershed or else they could also be delineated as micro (3000–5000 ha area), macro (>5000 ha area), or mini watershed (<3000 ha area)

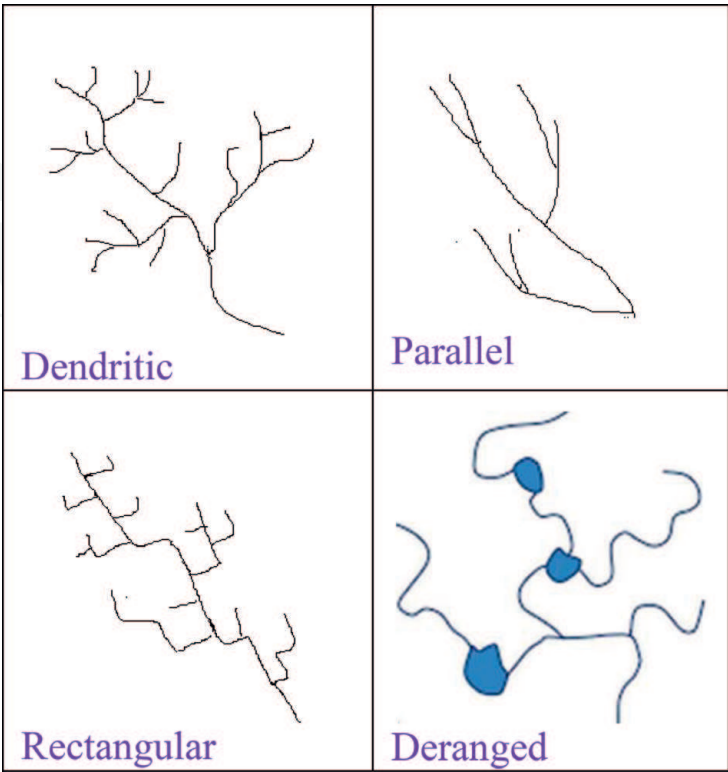


Figure 2.
Drainage patterns commonly encountered at mining sites.

according to their size] has been used for planning and management [9]. This term “watershed” is taken synonymously with catchment or drainage basin, an area of land which drains to a common outlet, and is said to be related with water only. But watershed and its management are not only related with water; it essentially relates to resource conservation which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water, proper management of water for drainage, sediment reduction, and increasing productivity from all land uses. According to the multilevel planning policy at national, state, district, and lower area levels, natural resource data management, which includes groundwater as well, is done on watershed basis considering each watershed as a constituent unit for planning. Thus, to facilitate area-specific microlevel planning for management of water resources (groundwater/surface water), it is convenient to apply “integrated strategy” on watershed basis. This integrated approach has close relation with watershed and management related therewith because it defines the optimum conservation of water with due regard to other resources. Watershed approach provides the mineral production which is resource-centered and environmentally friendly and helps in promoting sustainable development and pollution abatement.

2.3 Control and treatment

Several techniques of “control and treatment” are available to manage groundwater, for example, zero-level discharge. As a basic rule of thumb, if one has to control and treat water in a mining area, the approach should be to keep pollution contained in the mine itself. Their control beyond the mine boundaries is neither economical nor manageable. Depending on the problem encountered, groundwater infiltration or discharge should be handled and aquifer contamination be avoided, for example, oxidation and leaching of mine drainage produce high iron and sulfate concentrations and low pH in groundwater.

For the sustainable development of mining areas, the main source of pollution should be traced, and by applying chemical and bacteriological methods of treatment, water pollution shall be dealt or treatment methodology applied. The cost of treatment and risk involved must be checked for viability of adopted measures deployed to control pollution. To control mine water discharge and treat it for pollution abatement, *Intelligent Mine Water Management (IMwM)*, a solution for mine water management, is extremely scientific in approach (**Figure 3**), which can be enforced by the mining industry, regulators, and stakeholders world over.

As depicted in **Figure 3**, *IMwM* when expanded fully (see points below) will explain past, present, and future of control and treatment thereby helpful in maintaining an acceptable standard of living—now and in the future for benefits to the mining industry. All technical interest related to water in mines, including the burning and current topics, are covered under the following:

- Mine water hydrogeology
- Mine water geochemistry
- Qualitative analysis of mine water
- Quantitative estimation of mine water
- Water-related mine design (tailing pond, etc.) and dewatering planning

infiltration, cone of depression, water table lowering, mine drainage, consequences of dewatering and management, etc. are all covered in it.

Recycling concept rationally articulated for comprehensive short-term as well as long-term planning is very useful for water control, treatment, and management provided their effective implementation is done in field.

3. Impact of mining on groundwater (mining and its consequences)

Mining of minerals often leads to various environmental impacts [10] including water [11, 12]. The analysis of impact(s) can be done by comparing present scenario with past or pre-mining scenario [13] and evaluated as either positive or negative or the combination of both. These are analyzed with respect to the core zone, 5 km radius area (or alternatively consisting of the active mining area alone), and buffer zone, consisting of 10 km radius area. The likely impacts of open-pit mining could be in terms of:

- a. Drawdown, that is, lowering of water table
- b. Water quality deterioration, that is, water pollution

3.1 Groundwater lowering due to water table interception

When water is discharged from the pit mine which has intercepted water table, firstly the “collected water” is discharged, and then water from phreatic surface (water table) is sucked, and a “cone of depression” is formed with its axis at the lowest point at the sump bottom having lowest RL. If discharging is done for more time period, this cone of depression continues to enlarge, and pronounced effect is noticed. In technical terminology this is what is referred as “drawdown.” **Figure 4** explains this drawdown principle in general for a discharge through pit or dug well as well as applies in hydraulics. If more than one point of water discharge or drawdown exists in a pit mine and kept overlapped, the lowering of water level takes place rapidly, and quarry bottom can be dried with faster speed (**Figure 5**).

In respect of drawdown, two different kinds of situations come across in an open-pit mine: firstly, when the mine is working above the water table and, secondly, when the mine is working below the water table. Water (or drawdown) does not pose any problem in the former case, whereas in the latter case, lowering of water table may be the impact of mining. As a general principle, drawdown is usually in excess of 65% of

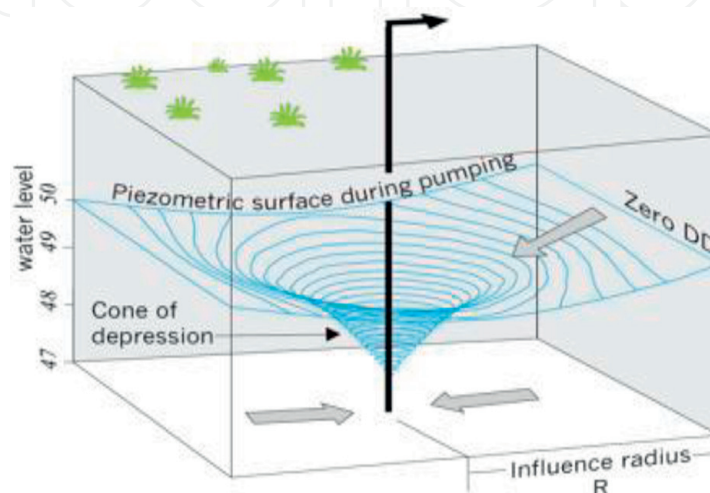


Figure 4.
Cone of depression and radius of influence (courtesy: Dr. Yohannes Yihdego, Australia).

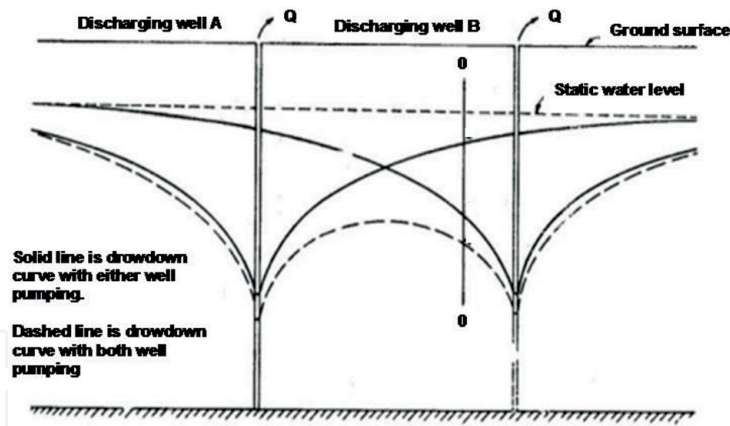


Figure 5.
Interference between discharging wells (courtesy: D.K. Todd).

unconfined aquifer thickness [14]. Such drawdown varies from rock type to rock type. Therefore, this statement cannot be taken as a thumb rule.

While analyzing the impact of mining on nearby villages, that is, adjacent to pit, the water-level records or fluctuations (in open dug well/borewell or piezometer) in pre-monsoon and post-monsoon season are taken into account. Because India has monsoonal climate and maximum rainfall occurs during June to September months, pre and post monsoon philosophy is considered best. On the basis of field observations, that is, rock, formations, and aquifer conditions, the impact is assessed of that study area, for example, GW in hard rocks will be present in the fractures/cracks/ and fissures in small quantity while compact soft sandstone rocks contain significant groundwater quantity in rock pores and interstices. The continuity of cracks in aquifer determines the water availability even though stratum has impervious characteristics. Therefore, in such situations drawdown by pumping will be observed as local impact only. Another impact of mining that could be natural also is defined in terms of “radius of influence.”

It is often asked how to estimate or quantify the impact of mining on groundwater regime? This question can be scientifically and effectively answered by estimating the influence radius or radius of influence (Ro/Re). The importance of Ro/Re with respect to a mine is that it demarcates a visually assessable picture of impact in terms of a measurable distance and should be kept constant/or minimum as far as possible.

Radius of influence (Ro) in technical terminology is the impact area, spread around the mine due to groundwater extraction or use. It is calculated using Eqs. (1) and (2) given in the below figure.

RADIUS OF INFLUENCE (Re / Ro)

$$Ro = 3000(H - h) \sqrt{K} \dots\dots (1)$$

Where, Ro = Radius of influence for unconfined aquifers (in meters)
H = the total head of the water table aquifer (in m, saturated thickness)
K = hydraulic conductivity (in meters per second i.e. m/s)
h = the total head of the dewatered aquifer (in m), and

Equivalent Radius of Influence (Re)

$$Re = \sqrt{A / \pi} \dots\dots\dots (2)$$

Where, A= a x b = length x width

(a & b are two dimensions of mine considering it as rectangular area as shown in side figure and r_c is the radius of mine from centre)

Radius of Influence
(Area measured in sq. m / sq. Km)

Ro is directly proportional to “draft magnitude” and “average rainfall” that occurs in an area. Here, the GW extraction is limited to mines only and as an industrial unit which otherwise could be for irrigational, agricultural, or domestic purpose also. For a “single pit” in an open mine, an equivalent radius of influence (Re) is calculated, whereas “Ro” is determined for multiple/concentric pits.

The operative staff, for all practical purposes, can judge the cone of depression, drawdown conditions, and radius of influence in the mine based on their field experience.

3.2 Water quality implications

Besides groundwater lowering, water quality implications (in the form of pollution) are a major impact issue of mining on environment globally. The pollutants (or traces of heavy metals) are released into the groundwater by geogenic sources through weathering of the geologic formations [15] and anthropogenic sources. Contamination in groundwater because of anthropogenic sources, for example, agricultural fields and use of fertilizer/pesticides, sewages and solid wastes, return flow due to irrigation, etc., is most often noticed and is far-far larger than the water-level lowering impact mentioned above. The water quality implications and environmental impacts are described/covered in appropriate section of this chapter in a scattered manner. It is so because number of cross-connecting factors of land and water has to be looked into for quality evaluation (Sections 2 and 5.2).

4. Groundwater and planning for mining below ground level

When mine becomes deep or excessive watery conditions are encountered in underground mines or when mine is located in the vicinity of a major water body and intensive seepage through strata (more than normal) occurs, then scientific mining and planning for groundwater management becomes essential. At varying locations, different mining and differing groundwater conditions are observed, for example, when mine is located adjacent to sea/in coastal areas, when aquifer encountered is confined and water table is under pressure, etc. In all these situations, mine planning for mineral extraction below the water table has to be carried out differently taking into account the water hydrology. World over, the depth denomination differs from country to country for an open surface mine, operating in pit form (**Box 1**). But in general and in practical sense, all mines below water table are likely to encounter water or watery condition whether it is an open-pit mine or an underground mine.

Planning for mining below ground level has to consider the effect of deepening of pit. Therefore, an interdisciplinary approach intermingling both planning and engineering aspects is needed. Considering the constraints posed by the dynamics

Box 1. When mine is deep?

Deep mine or deep mining is simply mining underground, in which the miner and/or machinery work beneath a cover of soil or rock. There is no fixed norm for mine to become “deep” or “shallow.” As a rule of thumb, exploitation of fuel minerals (coal/lignite/brown coal) at depths exceeding 300 m depth can be considered as deep mine, whereas for metallic or nonmetallic mineral deposits of modest mineral value, this norm may be taken as 350 m approximately.

When open-pit mine is deepened beyond a certain depth, “economic stripping ratio” comes into picture and the underground mining originates in which gaining access to the mineral deposit is by means of vertical shafts, inclined shafts, drift mining, or by other means. The value of mineral exploited, that is, cost of mineral production from mine (ROM cost), govern its excavation depth. For a higher value mineral and lower value mineral, such norms are staggering differently.

of groundwater, that is, spatial variability, hydrogeological data and its availability, socio-economic conditions, demographic profile of the area, etc., its quantitative estimation is done. In Indian condition, Groundwater Estimation Committee (GEC-1997) methodology seems practical for calculating water quantity. On this basis, planning of mining below ground level and water management through engineering approach yields desired output. To plan a mine for industrial purpose, obtaining groundwater abstraction permission is necessary. Such statutory compliance, particularly groundwater permission in mining, makes the water management easier [16]. In India and until now, it was mandatory for all new industries to apply for groundwater extraction clearance, but now it is mandatory to obtain these clearance for old as well as new industry (http://timesofindia.indiatimes.com/articleshow/49832855.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst). This has initiated the need and emphasized for estimation of groundwater quantity and its management.

To do the planning as per the approved mining plan, excavation depth (RL/MRL) and the lowest MRL up to which mining will reach in the future have to be designed scientifically. Depth-wise RL, pit dimensions, and water quantity (Q) are then needed for assessment. It may be noted that the excavated area dimensions keep on changing as per the *ultimate pit plan*. As per the dug-out area, the water availability in the mine area varies during different periods of a year. Accordingly, water quantity (Q) is first estimated for that particular mining pit. Related to Q or water quantity, three areas are important, namely, “mine lease area,” “catchment area,” and “pit area” (excavated area/water-filled area).

Geohydrological evaluation of the mine area is extremely helpful for the groundwater assessment and futuristic planning of the mine area. In addition to the GW and SW, seepage water is also accounted for in mine’s planning. Seepage water appears through mine walls in open pits, and field observations for seepage flow are generally recorded during post-monsoon season. To get the total water quantity of mine pit, it is simply added to the SW and GW quantity.

By groundwater modeling and simulation methodology, groundwater-level decline (maps, etc.) and the groundwater quantity can be estimated [17]. To understand the groundwater resource position in a mining area, water table depth below ground level and aquifer types are extremely important. If these are known and utilized correctly, the planning for mining will be easier. A general trend indicating rate of groundwater discharge/rate of outflow with time is illustrated below (**Figure 6**). The help of graph can be taken to know the availability of water during different months in a year, which varies from 200% (100% for surface water and 100% for groundwater) to as low as 55%.

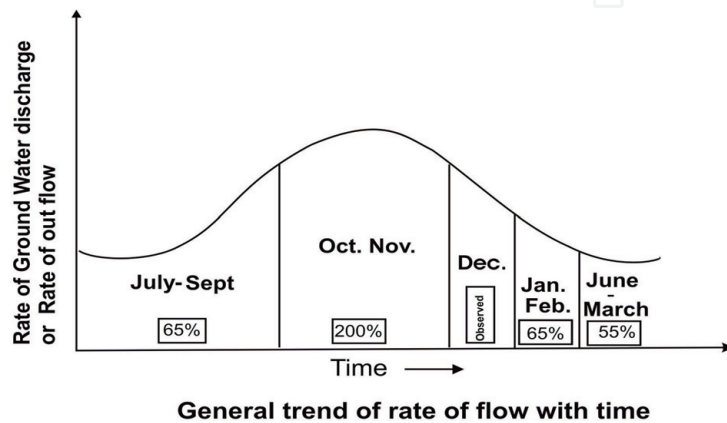


Figure 6.
Rate of groundwater discharge (or rate of outflow) with time

As a part of mine planning, operation, and execution, following methodology is helpful for mining *below ground level*:

1. Based on topo sheet of the area, a *drainage map* is prepared. These days using GIS and satellite imageries also, such maps are prepared.
2. Observe the flow pattern of surface water in and around the mine area.
3. Determine the groundwater flow and its direction using hydrogeological map of the area. Such maps are also available with state/federal groundwater authorities.
4. Calculate total water quantity which includes SW + GW+ seepage water.
5. Find out the “area of influence” in measurable parameters, and assess the real field conditions.
6. Execute planning of mine, keeping in mind the drainage, flow direction, water quantities, influenced area, and ground elevations of various nodal points of mine lease area.
7. Make “dewatering plans and scheme” in totality and not patch-wise. Sump design with “desilting arrangements” and suitable “pumps and pumping system” are a part of dewatering plan and scheme [18]. Their design should be based on engineering considerations and technical intricacies.
8. Decide the network of drains and drainages, its location, elevation, etc. for proper water outflow of water based on drainage pattern of the area. Make use of surveying for finalization.
9. Keep check on:
 - a. Runoff inside the pit
 - b. Slope erosion and control (including stabilization by natural vegetation, etc.)
 - c. Sediment/silt load accumulation in sump/sedimentation pond, etc.
 - d. Water quality and its deterioration at mine level
 - e. Periodical maintenance/observation
10. Prepare a “master plan” and implement it in practice.

5. Quantitative estimation and qualitative analysis of groundwater

Mine water in the mining areas comes across two broad issues, namely, water quantity and water quality. In most of the mines and in different parts of the world, both quality and quantity of groundwater resources are required for management, for statutory compliance, and for planned extraction of minerals from the mine [19–23].

The groundwater resources have both static and dynamic dimension. But essentially it is a dynamic resource which is replenishable (annually or periodically) through precipitation. It is static in “saturated zone” and dynamic in the upper

unsaturated zone (upper part of the water table) where water-level fluctuation is recorded. Near accurate estimation of groundwater resources is possible by adopting a set of the steps and formula framed for the purpose. A brief about Indian methodology for groundwater estimation is given in this chapter below for reader's knowledge and understanding. This may be noted that from country to country, such estimation procedure or methodology may differ.

To estimate groundwater extraction in an open mining pit, two broader approaches are possible. First is "planned depletion approach" (sustainable yield method), and second is "safe yield approach." "Safe yield approach of assessment" is based on groundwater recharge that takes place in an area or region, and recharge is calculated using *water balance method*, discrete numerical modeling, or tracer technique. In the "sustainable yield method," assessment can be made using "discrete numerical modeling" only. In India, later one safe yield approach is adopted and found more appropriate for groundwater estimation. Based on this approach, groundwater estimation methodology (GEC)-1997 has been formulated by Central Groundwater Board (CGWB), Govt. of India, and the same is applied in Indian mining sector for groundwater assessment.

5.1 Estimation of groundwater quantity (Q)

Groundwater Estimation Committee methodology, abbreviated as GEC '97 methodology, is an interactive methodology designed by the expert committee [24]. India has adopted it for estimation nationally, and since then mining water quantity is also estimated by this methodology. For groundwater estimation in India, methodologies for alluvium/soft-rocks and for hard-rock areas both have been formulated by the expert committee. This is significant to note that nearly 80% of the mine areas lie in hard-rock terrain.

India with its vast areal extent, long coastline, and large deltaic tracts forming a linear strip around peninsula is characterized by diversified geological, climatological, and topographic setup. Discontinuous aquifers of varying yield potentials occupy 2/3 area of the country, and as said above most of the mine area lies in hard-rock terrain. Thus, GEC '97 methodology and its norms for hard-rock areas [24] remain applicable for evaluation and assessment of groundwater. By understanding the behavior and characteristics of rocks, the water quantity as well quality in the mining area can be estimated. Steps and formulas of GEC '97 methodology and the calculation for open-pit mine (surface mine only) are shown below.

(A) Groundwater calculation

GW quantity available is that quantity which is likely to be experienced in the form of pit water either as punctured water table (groundwater) or in the form of seepage water from the footwall (FW)/hang wall (HW) sides of mine pit walls (see point C of this section below).

• Groundwater Quantity (W1)

(for mine lease area and maximum rainfall/maximum water-level fluctuation occurred for worst-case scenario)

Method 1: infiltration method

Maximum feasible groundwater quantity

$$A \text{ (m}^3\text{)} = \text{lease area/pit area} \times \text{rainfall (max.)} \times \text{RIF}$$

(refer Table 1 for rainfall infiltration factor (RIF) values)

Method 2: specific yield method

Maximum feasible groundwater quantity

$$B \text{ (m}^3\text{)} = \text{lease area} \times \text{max.fluctuation} \times \text{specific yield}$$

Average groundwater quantity within lease hold area in a year

$$C = (A + B)/2 \text{ (in m}^3\text{/TCM/MCM)}$$

Considering, 365 days in a year, quantity in a day can be worked out

$$\text{Thus, available groundwater quantity in m}^3\text{/day} = W_1/365$$

Note: Groundwater, as base flow, is present in the mine area during whole year, and seepage is governed by the geological and topographical features of the area. Thus, groundwater availability can be taken as 365 days in a year.

- Groundwater development/groundwater utilization for mine area

Groundwater development can be assessed and estimated by the established procedure of GEC '97. An assessment about the stage of groundwater development is helpful in knowing the overall groundwater scenario of the study area.

The stage of groundwater development in a given sub-unit is defined as the current annual gross groundwater draft for all uses (C) in that sub-unit expressed as a percentage of the net annual groundwater availability (B) in that sub-unit (GEC '97). Thus, if stage of groundwater development is "A," this can be calculated as follows:

$$A = (\text{gross availability/net availability}) \times 100 = (C/B) \times 100\%$$

Similarly, for a mine area GW utilization = output/input (in percentage) = total discharge through mine/net groundwater availability

Category	Stage of GW development	Water table trend/level
Safe	$\leq 70\%$	No water table falling trend
Semi-critical	$> 70\% \leq 90\%$	Falling water table trend
Critical	90–100%	Falling water table trend
Overexploited	$> 100\%$	Falling water table trend

The sub-unit for the purpose of assessment can be a lease area of mine or a command/non-command area. Having known the GW development/utilization in the mining area, the same can be compared with the standard regional norms. Based on this, the very purpose of evaluation and assessment of groundwater analysis can be categorized as "safe" or "critical."

According to the availability, the current stage of development, and water table fluctuation trend, its allocation for various uses in future, that includes domestic and industrial uses, can be made.

- Groundwater recharge or total annual replenishable recharge (TARR)
(unit— $\text{m}^3\text{/TCM/MCM}$)

This is the maximum feasible recharge per annum (R_c or R_c'), and usually referred as total annual replenishable recharge (TARR) is calculated by two methods as per the formula given below.

Method 1: rainfall infiltration method

$$Rc = \text{catchment area} \times \text{rainfall (average)} \times \text{rainfall infiltration factor}^*$$

or Rc in million m³ (MCM)

Method 2: specific yield method

$$Rc' = \text{catchment area} \times \text{water table fluctuation (average)} \times \text{specific yield}$$

or Rc' in million m³ (MCM)

Note:

- i. Here * = rainfall infiltration factor (RIF) = values as per GEC '97 (**Table 1**).
- ii. For TARR calculation catchment area or alternatively the active mining area can be taken.
- iii. Normalization of rainfall recharge: the water table fluctuation in an aquifer corresponds to the rainfall of the year of observation. The rainfall recharge estimated should be corrected to the long-term normal rainfall for the area. For calculating the annual recharge during monsoon, the formula indicated below is adopted as per GEC '97 methodology.

(A) For alluvial terrain of India				
S.no.	Geographical location/formations	RIF as a fraction		
		Recommended value	Minimum value	Maximum value
1.	Indo-Gangetic plains and inland areas	0.22	0.20	0.25
2.	East coast	0.16	0.14	0.18
3.	West coast	0.10	0.08	0.12
(B) For hard-rock terrain of India				
S.no.	Rock types	RIF as a fraction		
		Recommended value	Minimum value	Maximum value
1.	Weathered granite, gneiss, and schist with low clay content	0.11	0.10	0.12
2.	Weathered granite, gneiss, and schist with significant clay content	0.08	0.05	0.09
3.	Granulite facies like charnockite, etc.	0.05	0.04	0.06
4.	Vesicular and jointed basalt	0.13	0.12	0.14
5.	Weathered basalt	0.07	0.06	0.08
6.	Laterite	0.07	0.06	0.08
7.	Semi-consolidated sandstone	0.12	0.10	0.14
8.	Consolidated sandstone, quartzite, limestone (except cavernous limestone)	0.06	0.05	0.07
9.	Phyllites, shale	0.04	0.03	0.05
10.	Massive poorly fractured rock	0.01	0.01	0.03

Table 1.
Rainfall infiltration factor (RIF) as per GEC '97 and terrain conditions.

Monsoon recharge = area (km²) × water – level fluctuation (m) × specific yield.

Groundwater recharge may also take place through other point/line sources namely tanks, ponds and river/nala. Thus, recharge through different sources includes:

- a. Recharge through irrigation
- b. Recharge through stagnant water bodies namely ponds and tanks etc.
- c. Recharge through water-filled small-sized pits or spread of water
- d. Recharge through return flow

This can be estimated for the catchment area and command/non-command area as the case may be using GEC '97 methodology. Its descriptive details can be referred from [25]. With increasing focus on sustainable development of groundwater resources, augmentation of water conservation structures, with the aim of increasing groundwater recharge, can be implemented in the field. The water conservation structures include percolation tank, check dam, nalla-bund, etc. Recharge through such planned/proposed recharge structure can then be calculated by knowing average water spread area, seepage factor, and water containment days.

- Draft calculation/estimation (unit—m³/TCM/MCM per year)

“Draft” means consumption. In mining case study, which is an industrial setup, three types of drafts are considered prominent in estimation/calculation, namely, “domestic draft,” “draft through mine discharge,” that is, pumped out water quantity from pit, and “industrial water draft” for mineral processing (consumption). To estimate domestic draft, total population of the study area and sources of groundwater abstraction must be known. For such calculation all villages and human settlements in the core zone (CZ) and buffer zone (BZ) area are considered which covers 10 km radius area around the pit center. Thus, domestic draft/year (considering groundwater as the only sources).

$$= \text{Population/no of persons (total)} \times \text{water consumption per head} \\ (\text{liter/person/day}) \times \text{days in a year}$$

(B) Surface water calculation

In general, surface water (SW) quantity, that is, W₂, is calculated on per day basis because surface water quantity differs from season to season. This quantity is dependent on rainfall/precipitation (during wet season of monsoon). For estimation purpose, maximum rainfall occurred (i.e., worst-case scenario) or average rainfall for 10 years or more can be considered. Separate estimation should be done/shown for peak rainfall period indicating number of days and either the lease area or catchment area as the case may be is considered for calculation.

Surface water quantity (W₂)

$$\text{Surface water quantity/day} = W_2 = \{X - (Y_1 + Y_2)\} / \text{no.of rainy days}$$

$$\text{where } X = [(M_1 + M_2) \times \text{rainfall}] / 2$$

where $M1$ = lease area/catchment area; $M2$ = water filled area; $Y1$ = evaporation losses (30% of the rainfall); $Y2$ = infiltration losses (10% of the rainfall).

$Y1 + Y2$ are the “water losses,” which are taken into account for the estimation/calculation. Nearly 40% of the rainfall goes as waste in the form of “total runoff” for the hard-rock areas.

In India, where monsoonal climatic condition exists, the maximum surface water quantity in a mining pit will be available for a period of 92 days (3 months approximately) in a year, that is, during monsoon and post-monsoon period of July to September end only. In summer season, quantity of water present in pit as well as in lease area will be minimum and always less than the quantity during monsoon period (**Table 2**).

(C) Seepage water calculation

Normally, seepage water in mine pits occurs as a result of interconnection of pit wall with water body located either in vicinity or at a distance. Capillary action with aquifer also leads to the seepage on pit walls even at upper elevation. If less seepage is observed, the same can be ignored, and seepage water quantity can be taken as “nil.” For more seepages, the calculations are based on the general principle of water outflow from the seeped surface area in a recorded time. It is simply added to the SW and GW quantity to obtain total water quantity. Thus, seepage water quantity (Q_{seepw}) of mine pit is equal to flow rate in a given time of that surface area from where seepage is occurring.

(D) Water balance

When GW, SW, and seepage water quantity is known, the water balance of the assessment area is calculated as follows:

S.no.	Period/ month	Total number of days	Availability of water quantity		Remarks
			Surface water	Ground water	
1.	January to February	59 days	Less than moderate	Present as base flow	1. Surface water, groundwater, seepage water, and water through recharge constitute the total water quantity present in the area
2.	March to June	122 days	Minimum	Present as base flow	
3.	July to September	92 days	Maximum	Maximum	2. Maximum means peak season quantity; moderate means 75% of peak quantity; less than moderate means 30% less than peak quantity. Minimum means 50% less than peak quantity
4.	October to November	61 days	Less than maximum (but ample)	Maximum	
5.	December	31 days	Moderate	Present as base flow	

Important notes:

1. Since, surface water quantity varies widely over the time period of one complete year, total yearly calculation should not be indicated/shown.
2. Groundwater and surface water quantity and availability shown above are applicable for Indian mines/geo-mining condition and elsewhere the situation may change according to the pattern and period of precipitation.
3. Groundwater availability (W_1) and surface water quantity (W_2) in m^3/day should be shown separately indicating the area and period considered. Summation of groundwater quantity and surface water quantity of the study area should not be done because groundwater and surface water quantity and availability fluctuate throughout the year.

Table 2.
Quantity-wise surface water availability over different periods in a year

Water balance = input – output = net GW availability – discharge through mine
 = (+) or (–) can be expressed in TCM or MCM/year

Case records: To know the field scenario, four open-pit mines of India are studied, and they are (i) Partipura limestone mine, Banswada district, Rajasthan [26]; (ii) Rajhara iron ore mine, Balod district, Chhattisgarh [27]; (iii) Malanjkhand copper ore mine, Balaghat district, Madhya Pradesh [28]; and (iv) Lanjiberna limestone and dolomite mine, Sundergarh district, Odisha [29, 30]. In all these mines, different minerals are excavated, and varying geo-mining conditions exist. At *Partipura limestone mine*, mining conditions are that of a normal open-pit mine, whereas twin mining, that is, surface mining and underground mining, both exist in close vicinity at *Malanjkhand copper ore mine* and *Rajhara mechanized mine* of Chhattisgarh state, the excavated iron ore is very hard, and ore reserves are getting exhausted, that is, mine has reached at its last stage of life. “Lanjiberna mine” of Odisha is a typical surface mine in which three pairs of pits (i.e., total six dug-out areas) are excavated for obtaining limestone and dolomite, which is filled with water. All these working pits have different depths (**Table 3**), and water table is intercepted as a result of mining. At all these mines, comprehensive geohydrological studies had been carried out, and groundwater quantity using GEC '97 is assessed (**Table 3**). It is observed that all the four mines are having hard-rock formations with unconfined aquifers (GW occurs under water table condition). Average rainfall and maximum rainfall (for the worst-case scenario) in all these mines differ widely, and average water-level fluctuations (WLF) are less than 10 m below ground level. In different seasons the water quantities fluctuate widely for which number of reasons and factors are responsible. When water quantity Q is checked (verification by ground truth), it was found correct by the concerned statutory agencies with ± 10 –20% variations from actual. Based on this, necessary permission for continuance of mining operation was granted for these mines.

5.1.1 How to estimate Q for an underground mine ($Q_{u/g}$)

Having discussed the groundwater quantity for an open-pit mine, an obvious question arises. Whether groundwater calculation for underground mine ($Q_{u/g}$) is also estimated in the same way? Its answer is no. The approach for estimating groundwater quantity with respect to an underground mine is sharply different. Q for an u/g mine is full of uncertainties and based on the actual field conditions encountered. Such field conditions are many, either created or naturally encountered, for example, extent of underground mine development affects the creation of void's underground, this in turn has a close connection with groundwater movement in encountered aquifers.

Secondly, depth of underground workings from surface has linkages with groundwater recharge occurring in that particular area, which in turn is related with local rainfall. Obviously, rock types, its porosity, and hydrological characteristics have key role in groundwater movement. Similarly, geological features such as faults, folds, unconformities, lineaments, etc. reflect their own dominance in groundwater quantity as well as movement. Thus, both rock type (different formations) and geology, for either open-pit mine or an underground mine, have tremendous importance. Its detailed study and engineering judgment can help one to estimate the groundwater quantity approximately, if not exactly. Thus, approach for estimating $Q_{u/g}$ must incorporate study of borehole litho-logs of the mine/area and other related parameters, namely, rainfall, recharge, aquifer and its characteristics, extent of underground mine development, and working depth. Based on





(i) Partipura limestone mine [26]	(ii) Rajhara iron ore mine [27]
	
Annual GW quantity at 70 m pit depth = 0.1616 MCM	Annual GW quantity at 250 m pit depth = 1.713 MCM
(iii) Malanjkhanda copper ore mine [28]	(iv) Lanjiberna limestone mine [29, 30]
	
Annual GW quantity at 240 m pit depth = 4.735 MCM Note: MCM = Million cubic meter; GW = Groundwater	Annual GW quantity for pit depth from 39 m to 56 m = 0.268 MCM to 1.4 MCM [pit depths: pit 1 and pit 3 = 41 m; pit 2 and pit 6 = 56 m and pit 4 and pit 5 = 39 m]

Table 3.
Estimated GW quantity for different case studies using GEC ‘97

groundwater movement principles (Darcy’s law), runoff and recharge relationship of surface water and general estimation formulas as applied in GEC ‘97 methodology $Q_{u/g}$ for quantitative can be estimated. Further, this may be noted that the “underground mine water quantity” is proportionally related with the actual excavation area exposed in underground workings (size and area of panel/stope) as well as surface area above the extraction/depillaring panel.

Here, it is important to reaffirm that in the paragraph above, author has clearly showed how the groundwater quantity can be calculated and how it is related with several factors. This water quantity calculation is helpful at the planning stage and operational stage of the project for “dewatering planning and related aspects.” One can also know the *water availability* and how to use it whether within mine pit or outside. Similar excavations being operated below ground, for example, caverns, tunnels, etc., are the other beneficiaries for such knowledge. Since the estimated quantity(ies) are based on aquifer parameters and scientifically proven, it is true and near actual. Its immense benefits can be encashed, in terms of cost savings and cost overrun of project(s).

5.2 Qualitative analysis of groundwater in mines

The qualitative assessment of groundwater samples (or surface water samples) from the mining area and surrounding areas is required to infer water quality (WQ)

and thereby knowing its suitability for various uses. The mine water vary greatly in terms of concentrations of various chemical constituents, as water quality is likely to be affected with mine site parameters which are specific in nature.

Various studies on interrelationship between water quality, geology, and mining activities have been carried out in Indian mines [11, 15, 21, 31–33]. Similar studies and attempts are in vogue with reference to the different mines around the world, and their list is exhaustive.

Water quality assessment can be done either by field method(s) or by laboratory method(s). Their related aspects, that is, quality parameters and its selection for analysis, characterization, field sampling, water storage before and after lab analysis, periodical monitoring of quality for drawing inference, etc., require in-depth description parameter-wise [34]. For this, standard operating procedure (SOP) can be applied [35], and available literature on the specific subject can be referred for the details. Their elaborate description (field and laboratory method) has not been described in this chapter because ample of literature is available on the water quality and its assessment, even some of it is described by other authors in this book itself.

As regards water quality in mines, the following comes into the reader's mind— (i) the water quality of surface channels flowing in the mining area; (ii) the mine pit water quality; (iii) dump/spoil bank water quality; and (iv) tailing ponds/ impoundments water quality. Depending on the type of mineral excavated, the quality issues are to be recognized and assessed, for example, acid mine drainage problems are a severe water quality issue in the case of coal mines. The elemental analysis (pH, TDS, total hardness, etc.) is needed for limestone and dolomite mine, whereas lead-zinc, copper, iron ore, and bauxite mines (mines of metallic minerals/ ore) require attention toward heavy metal constituent's analysis.

Inseparable surface water and groundwater and its pollution can be assessed or evaluated qualitatively. Some important water quality parameters and major possible water contaminants and pollution indicators for mining and allied industry are shown in **Tables 4** and **5**. Having determined the value of each parameters, may be either low/high or within permissible limit/outside permissible limit, the scientific explanation of pollution status can be given. For each of the studied case, the pollution parameters that accounts are different and as according to the water usages. It is also recognized that the mine water quality, which is present in the mine or in the surrounding areas around the mine sites; in shallow aquifers and deep aquifers of mine sites, though not comparable with one another but governed by the same scientific principles/groundwater chemistry. Chosen WQ parameters are hence critical for valuation.

By knowing the water quality, one can easily trace back the source(s) of pollution, and management measures can be taken accordingly. Further, it is helpful and suggestive to know the background history also for proper assessment of WQ. Advances in instrumentation, modern computational technology, and improved management techniques are able to reduce many negative impacts arising out of water quality pollution.

It is found that the pH of the mine water fluctuates both ways from the normal range of 7 and the total hardness (TDS) parameter also varies considerably depending on the prevailing hydrological regime and the variation in lithology. These parameters mainly decide the mine water suitability for domestic, irrigation, and other miscellaneous uses. The anion and the cation chemistry (dominated by $\text{HCO}_3^-/\text{SO}_4^-$ concentration and Ca^{2+} and Na^{2+} ions, respectively) and hydro-chemical facies (Mg-Ca- HCO_3 and Mg-Ca- HCO_3 -Cl, etc.) knowledge can put forward the water chemistry mechanism for its various uses [36]. By knowing parametric values of various chemical parameters, sodium absorption ratio and residual sodium carbonate and acidity/salinity of mine water can be determined or assessed.

Physical	Chemical	Biological	Radiological
Color	pH	Virus	Uranium
Odor	Acidity/alkalinity	Bacteria (<i>Coliform</i>)	
Temperature	Hardness	Algae	
Turbidity	Ammonia (free)	Other nuisance organisms	
Foam and froth	Nitrates		
	BOD/COD	Human-related inorganic constituents	
	Calcium	Arsenic	Lead
	Magnesium	Asbestos	Zinc
	Chlorides	Barium	Nickel
	Sulfates	Cadmium	Nitrate
	Phosphates	Chromium	Selenium
	Sodium	Cyanide	Silver
	Potassium	Fluoride	Sodium
	Redox potential	Iron	Mercury
	Conductivity	Hardness	

Table 4.
Some important water quality parameters

TDS	Sulfates (SO_4^{2-})	Fluoride
COD	Arsenic	Phosphates (PO_4^{2-})
BOD	Bicarbonates	Zinc
Carbon (organically linked)	Iron	Copper
Hydrogen (organically linked)	Manganese	Lead
Nitrogen	Sodium	Mercury
Detergents	Potassium	Temperature
Oxygen	Calcium	pH
Nitrates (NO_3^-)	Magnesium	Conductivity
Nitrites (NO_2^-)	Total hardness	Redox potential
Ammonia (NH_4^+)	Chlorides	
H_2S (in dissolved form)		

Table 5.
Main possible groundwater contaminants and pollution indicators in mining and allied industry

Thus, in brief, it is learnt that assessment of water quantity and quality is a pre-requisite for planning and development of mine. Mining of minerals at shallow depth can be done without adversely affecting the groundwater; however, when mine/mining goes deep, that is, below water table, the need to check its quantity, availability, and scientific management arises. Both quality and quantity assessment parameters are since field-based; a minor departure in filed values is possible. Nearly (\pm) 20% departure from actual scenario is generally observed and admissible. By overcoming field measurement difficulties and adopting standard operating procedure (SOP), near accurate evaluation of groundwater can be done.

6. Policy framework for mines

For the mining industry as a whole, clear and transparent “corporate policy” provides a direction for the implementation of plan and programs in respect of water. This effectively controls the cost component as well and expresses the desire of the organization to achieve the aims fixed toward the improvement of water management. If any organization policy recommends for better water utilization and sound water management, then it is also essential that companies must have ingenuity for its effective implementation. Commonly, policies do exist in developing countries, but the desire for their implementation is often lacking. This is particularly the case in small- and medium-sized companies in “unorganized sectors” having lacks of financial resources. One of the difficulties, mining companies or the mine management focuses in regard to policy formulation are also the lack of proper equipment, machinery, expert knowledge, or financial resources for executing the policy. Adequate funds are essential for the implementation of plans and ideas. Furthermore, the organization policy and the national water policy should be in tune with each other [37].

It should be emphasized here that water policy usually focuses on water in general and not in particular on mine water. This becomes especially complicated when the water policies and the mineral resources policies are managed by different departments or regulatory bodies in developed and developing countries. Deficiencies in certain aspects of groundwater-related policies particularly on the management aspects and its core issues can be addressed as well as enforced by the industry, regulators, and stakeholders through policy perspective.

7. Extracting value from mine water

Before I discuss extraction of value from the mine water, let me clarify that it is beyond doubt that water is everybody’s concern; it is apparent that water in general or water from mine (s) should not be wasted and has to be properly utilized as well as conserved. Different aspects of water utilization and conservation are commonly dealt in books, but how to earn or extract value from water is dealt very sparingly.

This idea is purported in my mind from the International Mine Water Association (IMWA) annual conference held in Leipzig, Germany, in 2016 wherein special attention is given on the topic of “extracting value from mine water” and lectures were invited from world over. It is understood that it will be a rare situation in which extracted values can pay for all of the costs of water treatment; however, it would be good to extract value from the mine water and this can partially defray the costs of water treatment and both short-term and long-term gain can be made.

Nearly all mines whether surface or underground are situated in far-flung *plain areas* or *hilly areas* with single-layer and multiple-layer aquifers. These, surface mine pits, operational or mined-out pit, from where minerals are extracted, contain huge quantity of mine water (**Table 6** column 4). The extraction of value from the water of mine can be done by the following uses:

- a. Coal quality improvement by coal washing at the pithead washery or in an installation closer to the mine
- b. For ore cleaning and in metallurgical process
- c. For construction-related civil works in mines/plants

- d. For haul road wetting to suppress dust
- e. Irrigation/agricultural uses of mine water after quality analysis
- f. For miscellaneous uses by mine/plant colonies, gardening, etc.

The value addition from the mine water can be easily and effectively implemented into practice through corporate social responsibility (CSR) scheme of the mining company concerned. In the mines and mining industry, corporate social responsibility assumes a highlighted importance. Some noted examples of value addition are:

1. Putki-Ballihari colliery of Bharat Coking Coal Limited (BCCL) in India has 400 L of mine water treatment pilot plant for miscellaneous uses by villagers which help in extracting value from mine water and water conservation both.
2. In the course of coal mining, Western Coalfields Limited (WCL) mines tap a huge quantity of underground mine water (basically groundwater) out of which a small portion is utilized for its day-to-day functions, namely, coal washing, dust suppression in transport routes, domestic uses, etc. (**Table 6**). A major quantum of water went unutilized. Now these practices are being changed slowly, and water is being utilized for various developmental activities in nearby areas, for example, recharging canals, wells, and rivers, providing water for irrigation, and providing potable water to local people. WCL is using water from mines to help people combat water scarcity in and around mining areas. In many mining regions, thus converting mine water into potable water is one useful value addition by which number of mines can be benefited. Such initiative also helps mining company to develop strong societal bond between mine management and local population.

A packaged drinking water plant (RO plant of Coal Neer) at Patansaongi mine is yet another example of extracting values from the mine water (see facing figure) by the coal mining company WCL.



3. In one of the cement plant that uses coal for firing cement kiln, a thought to pre-wash coal using mine water was attempted to get the benefit of less coal consumption and low ash generation at source. The operational efficiency of kiln/plant can thus be enhanced considerably with less coal consumption and more energy use. Various captive mines of cement plant, owned by private companies, can get commercial benefits from this idea by making effective use of mine water within their industrial areas and for a selected specific purpose.

Some other ways to extract values from water available in mine are:

- i. Both treated/non-treated mine water can be supplied/sold by company at a cost for the miscellaneous uses to local users. In an arid region, for example, Rajasthan, India, this may bring great value.

S. no	Name of coal mine	Purpose	Details	Remarks
(1)	(2)	(3)	(4)	(5)
1.	Saoner Underground Mine	Recharge of water channels/ rivulet and improvement in water level	Not available	For miscellaneous uses. Boregaon village is the beneficiary
2.	Bhatadi Mine	Recharging of water table	5.66 million LPD	Reuse of mine water in Chandrapur district
3.	Padmapur Mine	Recharging of water table and reuse of mine water	2.46 million LPD	Chandrapur district
4.	Kamptee O/C Mine	To provide potable water to Kanhan township from the mine water discharge. Also for irrigation uses	Discharge of mine water; 47 lakhs; 3.5 km pipeline from mine to filter plant	“K2K”: Kamptee to Kanhan Project, Oct 2015 Water filtration plant in Kanhan Municipal area; 800 people benefitted
5.	AB Incline, Pipla and Silewara Mine	For irrigation uses by pipelines	Mine water discharge	Recharging of canal system for agriculture (2 km long); 350 farmer families benefitted
6.	Adasa Underground Mine	Mine water for irrigation	—	Angewada and patkakhedi villages; recharge of water table
7.	Bhanegaon Opencast Mine	For recharge of wells and river recharging	Uses in irrigation and agriculture for cultivation	Bina and Bhanegaon villages
8.	Murpar Underground Mine	Pumped out for supply to village pond	3500 GPM water; 50 ha land irrigated	Around 2000 population benefitted
9.	Wani North	Recharge of water table through groundwater augmentation, that is, desilting and deepening of water bodies and villages ponds, etc.	48 lakhs; under CSR activities of company	Jalyukt Abhiyan of the Maharashtra Government for Nagpur and Chandrapur district in India

Source: WCL, Nagpur

Table 6.
Mine water uses at WCL coal mines: extracting value

- ii. In captive mines of nearly all companies/cement plants, etc., “water charges” are paid to the government by the industrial organizations to make use of fresh groundwater for their industrial operations, for example, cooling, colony supply and other miscellaneous uses, etc. The fresh water use can be replaced with mine water, and a considerable value addition from mine water is possible.
- iii. Immense value can be extracted, had underground mine water is made as potable. If treated using cost-effective techniques, conferring to the drinking water quality standards [38, 39], the potable mine water can also help in removing water crisis of the area too.

In brief, to extract the value from the mine water, a number of novel and innovative ideas are available, but practical methods as per local requirement are extremely useful. The abovementioned examples are simply a curtain raiser and not to be seen as the ultimate for value extraction from the mine water.

8. Groundwater and mine water management

Groundwater is a resource first. Its management at mine level and as mine water is a major challenge. To preserve and protect groundwater in mining areas from overexploitation and to manage it properly, the approach should be site-specific and engineering-oriented. Mining industry worldwide manages it through dewatering/pumping economically and properly. Both quality and quantity of groundwater and the intricate relationships between physical, chemical, and biological processes within mine deposits are a key to the development of effective strategies for water management. Application of “preventive approach” along with artificial recharge techniques and water conservation measures can remove the water management bottlenecks to a large extent. Hence, an approach to deal groundwater effectively works out better at different levels of management. The entire water management chain should be understood by all levels of management, that is, at corporate, at site, and at operations management level, and it has to be a “bottom-up approach rather than a top-down approach.”

Looking at operational stage of surface mines (pit mine) which are working below the water table, the puncturing of water table results into the accumulation of water on dip side of the open mines. Due to heavy precipitation in limited period (downpour), such water accumulation problems lead to the hampering of normal mine production. Similarly watery underground mines have multistage pumping needs. Sustainable water management at mine sites has close linkages with production; hence to improve water management in the mining environment, the following areas need attention:

1. Corporate policy with respect to water management
2. Planning and machinery used, that is, pumps and pumping
3. Mine drainage
4. Water quantity
5. Water quality and pollution
6. Ore processing, tailings, and waste disposal

Clear and transparent policy and sound water management give a direction to the implementation plan and programs economically and as per the desire of the organization. Improvement in water management practices periodically and practically is imperative for GW management.

Planning and machinery used involve the site conditions and stage of operations, in the chain of water management. It requires innovative thinking so that planning is practical in implementation and percentage utilization of machinery is maximum. Routine condition monitoring (RCM) for routine maintenance of equipment and machinery should be cost-effective for proper water management in general.

Mine drainage can pose a serious threat to water quality and mine productivity. The importance of this issue becomes more critical as demand for resources grow. When complex metallic ore deposits are mined, the geochemical evaluation of mine drainage water becomes important in pollution evaluation as well as deciding

prevention strategies. Their economical remediation is possible to an extent through proper mine drainage system.

Undoubtedly, in ore processing, tailings, and waste disposal, methods and procedures are key areas of focus in the pollution abatement strategies. Therefore, to deal with it, attention toward the “best practices in water management” is needed. Practically, for improving water management in the mining environments, approaches should be:

- i. Long-term and short-term costs of water treatment: Mine water management involves its treatment too. The mine water and its treatment involve a sizable long-term and short-term costs of water treatment. If the cost economics are understood correctly, it can be applied in curbing the overall cost of mineral production. Mine water is valuable in terms of its quantity and ease in extracting it for bulk reuse, if available in open-pit mine. The “pit water” may or may not confer to the prescribed quality standards, either for irrigational or miscellaneous uses, but certainly able to meet out the water scarcity in an area. Therefore, its treatment is sought after, though considered as not economical. In the case of underground mines, how the mine water increases overall cost of mineral production (**Box 2**) needs to be understood?
- ii. Local solutions are always cost-effective in mining activity because most of the time it requires crude solutions (and not very precise) on site-specific basis.

Box 2. How mine water increases cost of production?

Mine water presence in excess requires pre-draining that adds to the cost of pumping; more expensive construction prevents the use of preferred methods and equipments. Overall it puts additional burden on cost of mineral production. If underground mine is watery, it requires use of more expensive explosive. “Timber support,” if used in underground mines, are not good if mine has wet conditions. Alternate wetting and drying of timber cause timber decay and endanger mine safety. The mine water washes weak ground from underground openings, for example, sand, silt, gravel, clay, etc. are washed easily causing reduced safety for wall, roof, etc.

In the case of underground mine water, if one knows the effect of water on surrounding underground environment, its value can be assessed both directly and indirectly, for example, water is hazardous in mine shaft because wetness corrodes hoist ropes, steel girders, ladders, planks, shaft timber, etc.; mine water and wetness add to the maintenance of underground equipments, reduce effectiveness of lubricant, increase corrosion, cause scaling in pipes, lead to rusting in wet exposed metallic surfaces, etc.; mine water may add to miner’s discomfort due to continuous wetness of protective clothes and bring illness (a form of indirect cost). Increased electrical hazards are the anticipated effect of mine water on mine safety underground.

- iii. Preventive water management (PWM): impact of mining on groundwater and its imprints should be kept controlled. Through this approach and in the mine catchment area, this can be done by preventive water management. Plans for PWM should be such so that attention is paid to both quality and quantity aspects as they are to be managed with the ultimate goal of achieving an ecological balance. Some key points as regards with this approach are:
 - Preventive approach has the ability to remove or add the nutrients from soil/land (through surface water) because land, soil, and water are an integrated part of natural water system. By this approach soil/land quality can be made sustainable, for example, (a) nitrogen compounds are broken down and phosphate is fixed for agricultural land use in plain profile land areas with adequate water. (b) By allocating proper land use

profiles with the land use activities for each catchment area, an improvement in overall land quality is achievable. (c) Designing of suitable land use pattern within the mine lease area or catchment areas is a step forward toward mitigation and preventive care.

- Adequate drainage pattern of mine/project area commensurate with the natural drainage.
- Effective local runoff arrangement of rainwater for GW infiltration into the soil and in hard-rock areas.
- Widening of watercourses, cleaning of silt from pond/tank beds or open ditches and raising the drainage level of water channels thereby increasing groundwater recharge and the water storage capacity.

The description given above explains that how management of water can be done economically and effectively with practically implementable water management practices. Since underground mine water management is sharply different from open-pit water management, technical knowledge of mining engineering can be an added advantage. However, it would be good to extract value from the mine water, as doing so can partially recover the water treatment costs and both short-term and long-term gain can be made. It is also understood that proper water treatment and management with respect to mines can bring a stage/situation in which groundwater will turn into a useful commodity for that particular mine which is scientifically managed and evaluated.

8.1 Solutions for water problem in mines

In mining sector, which is prospective, very large, and capital intensive too, scientific approach toward groundwater management should be applied to curb and restrict groundwater overexploitation and maintain basic groundwater equation, that is, more recharge, less draft. To tackle water problem in both mine types, the following solutions are noteworthy:

- Best management practice (BMP): Number of solutions for open-pit as well as underground mines can be solved through case study experiences available internationally. Some *best management practice* (BMP) for water in mining and mine environment area are important from this view point [40, 41]. Guidance manual and case study experiences in various parts of the industry worldwide, provide solutions together with lessons (to be learnt) for better understanding.

Sometimes BMP is also referred as “best practice mining” or “best mining practice.” In brief, BMP does not refer to any designed/formulated method but implies to “the continuous improvement of mining and management practices to maintain maximum performance for achieving an acceptable level of environmental protection.” In doing so, it is necessary to incorporate and integrate economic, environmental, and social considerations into the mining operations in a practical way.

Mining involves mostly excavation, loading, and transportation operations. The most environment-unfriendly among these is the “transportation” and “dust generation by transportation.” By adopting BMP the stress on environment is reduced because BMP emphasizes curtailing unscientific practices and avoiding shortcuts. Effective surface water utilization is the best management practice (BMP) for optimum use of rain-fed water resources. Similarly, pollution control measure

as applicable to large-sized public sector mines, that is, preventive approach, control at source, and zero liquid discharge (ZLD), is a solution through BMP.

- **Integrated water resource management (IWRM):** This becomes relevant when addressing water availability, water security, and water access for all users. IWRM involves the coordination of stakeholders in the water use of a site, an area or region to ensure economic and social development together with maintaining the ecosystem balance. Based on IWRM and stakeholders' experiences, water policy can be made sound, and balanced decisions in response to specific water challenges, being faced by the industrial company, can be taken. It is always desirable that cooperation between community, authorities, and organizations be maintained and public participation in water management be encouraged.

Thus, IWRM is an interdisciplinary approach to devise and implement efficient, equitable, and sustainable solutions to water and development problems. This approach is open and flexible and brings together decision-makers across the various sectors that impact water resources. IWRM principle ensures that water is sufficient for industrial operation and all users too. These days companies are concerned about continued water access in light of increasing scarcity. Their response is to maximize their efficiencies and limit their inputs. IWRM also involves "standardized water reporting," which is a low priority issue for the operating mines or industry. The issue with water reporting is that of hiding impacts of mine water-related issues with communities and regulatory authorities. Money/financial obligations are the principle cause for this hiding. Beyond this there exists a need to comply national environmental laws/regulations, which should be complied and put into practice. Some of the barriers to IWRM in the past were the lack of hydrological data and models which have been overcome these days by the scientific studies. IWRM together with BMP (best mining and management practices) is capable to yield desired water resource management results as expected.

- **Sustainable groundwater exploitation policy:** Area/states which are mineral-rich and having number of operative mines should formulate and frame a sustainable groundwater exploitation policy for mines separately in line with the "National Water Policy." For groundwater protection, practically applicable regulatory framework [42] should be in place and enforced strictly for solving water problems.
- **Reliable mine water technology:** Open-pit mine water management contains number of lacunas, and these can be reduced by bridging the gaps in water use and reuse, for example, surface mining operations in water-stressed and water-critical areas. Since maximum mineral production is achieved from surface mines, industrial attempt should be such so that reduced water consumption philosophy be adopted for excavation and ancillary industrial operations. This also makes mine water sufficient. Reliable mine water technology [43] is yet another option for tackling mine water problem.
- **Recycling, conservation, and recharge:** Promotion and encouragement for mine water recycling/reuse, water conservation, and groundwater recharge can remove water crisis in and around the mining site. In this regard, sub-categorization of water as "surface water" and "groundwater" will provide better solution. By addressing the impressive technical solutions related to water pollution, positive results can be achieved.

To curb the overexploitation (excessive withdrawal of groundwater from aquifer) for industrial purpose, imposition of tax or *cess* and pricing of the groundwater use is a way out. To conserve groundwater and rationalize the groundwater use by the mines, limited withdrawal permission is helpful in the excessive groundwater exploitation.

Rainwater harvesting (RWH), the most popular method of groundwater recharge, is the best solution to reduce dependence on groundwater. Implementation of these techniques and optimization of innovative alternates of RWH need to be encouraged according to the mine needs and requirements to provide solution locally.

- U/G versus surface mine: Underground (U/G) mines and surface mine's water-related problems are different. Therefore, solution to tackle water problem in underground mines are also typically different. Some encountered conditions of underground mines are:

Condition (i): sudden inrush of water or heavy water seepage from surface water body to underground mine workings in proximity, leading to inundation

Condition (ii): underground mining near "perched water table" (an accumulated/stored water underground)

Condition (iii): unprecedented or accidental connection of underground mine workings with aquifer containing infinite amount of water or water under pressurized conditions

Underground mines either operative or abandoned when filled with water pose a problem of "mine inundation." Many times such inundated waterlogged areas lead to mine disasters and also hamper normal mineral production in underground mines. The worst ever disaster caused by mine inundation in India was at "Chasnala Colliery" in the state of Bihar, India, in the year 1975 wherein 372 persons were drowned underground. Underground galleries approached the waterlogged old workings of an abandoned mine and faulty prediction of mine development had caused this accident to happen. The safest procedure to deal with inundation in mines is never to take the position of old working "for granted" until they have actually been proved by proper survey. No mine working which has approached within a distance of 60 m of any disused or abandoned working, whether in the same mine or in an adjoining mine, shall be extended further to endanger safety.

In underground mining, the mining operation near water bodies [44] assumes significant importance from research point of view. This is principally due to the uncertainty involved. Behavior of the surface water bodies (water head), intervening strata over the mine workings, its location (in the buffer zone/core zone of the mine lease area), and in between distances, plays considerable role and hence assumes significant importance. Therefore, geological, mining, and hydrological parameters must be looked while evaluating the real field situation, for example, topographical features such as hills/valley(ies) or ravines land, etc. should be considered. For solutions one must observe, examine, and check the proximity of old underground mine workings, whether the area is dry/damp or seeping in (heavy/low). It is possible that the workings of adjacent mine may not be filled with water but the barrier pillar and its thickness are important and must be maintained as per the statutory requirement or the existing guidelines framed for the purpose.

To search solutions for water problem of underground mines, due consideration should be given for water impoundments (stagnant water bodies) on surface as well. Seasonal or perennial streams, standing water bodies, and sea vicinity to the

mine are important for pressure head created by the surface water or impoundments. Similarly, underground mining should not come closer to active oil and gas well (150 ft. minimum).

9. Conclusions

Groundwater during mining of minerals causes problems related to environmental impact, most commonly *depletion of water tables* in and around mining areas, which in turn leads to social/industrial unrest. Hence, ground water quantity pumped out of the mine should not be more and known as well, for proper use. Every necessary effort shall be made to restore original level of water table below ground, whether it is open-pit mining operation or underground mining or any other similar excavation. In brief, and summarily, it is inferred that mining industry should guide their efforts toward proper use of groundwater encountered in mines and avoid wastages because water quantity handled in mines is very large.


Mine, being an important mineral production enterprise and groundwater as a valuable resource being continually under stress, has to be assessed scientifically from industrial perspective. The water management measures shall be identified beforehand and remedial measures be kept in place. To augment water level, artificial recharge of groundwater by rainwater harvesting, creation of pit lakes/water lagoons, and recharge through abandoned tube wells are some easy and economical measures. Needless to say the basic principle of sustainability, that is, conserving for future generation, must be adhered.

Author details

Abhay Kumar Soni
CSIR—Central Institute of Mining and Fuel Research (CSIR—CIMFR), Nagpur,
Maharashtra, India

*Address all correspondence to: abhayksoni@gmail.com

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References

- [1] Gleeson T, Befus KM, Jasechko S, Luijendijk E, Cardenas MB. The global volume and distribution of modern groundwater. *Nature Geo-science*. 2016; **9**:161-170. DOI: 10.1038/NGEO2590. Available from: www.nature.com/naturegeoscience [published online on 16 Nov. 2015]
- [2] UNICEF [Internet]. Water in India—Situation and, United Nation's India Children Education Fund (UNICEF). New Delhi; 2013. p. 93. Available from: <http://www.indiaenvironmentportal.org.in/files/file/water%20in%20india.pdf> [Accessed: 05-2014, 2017 & 2018]
- [3] Ayoob S, Gupta AK. Fluoride in drinking water: A review on the status and stress effects. *Critical Reviews in Environmental Science and Technology*. 2006; **36**(6):433-487
- [4] Jacks G, Bhattacharya P, Chuodhary V, Singh KP. Control on genesis on some high-fluoride groundwater in India. *Applied Geochemistry*. 2005; **20**:221-228
- [5] Dharashivkar AP, Khond MV, Murkute YA. Preliminary report of fluoride contamination in groundwater from PG-2 watershed of Penganga River Basin, Korpana Taluka, Chandrapur District, Maharashtra. *Gondwana Geological Magazine*. 2014; **14**:161-166
- [6] Waghmare SS, Tanvir A. Fluoride removal from water by various techniques: A review. *International Journal of Innovative Science Engineering and Technology (IJISSET)*. 2015; **2**:9. ISSN: s2348-7968. Available from: www.ijiset.com
- [7] Available from CPCB web page: <http://cpcb.nic.in/industry-effluent-standards/>
- [8] Wood Peter A. Hydrological problems of surface mining, Report No. ICTIS/TR17. London: IEA Coal Research; 1981. p. 102
- [9] Maitra MK. Watershed Management—Project Planning, Development and Implementation. New Delhi: Omega Scientific Publisher; 2001. p. 216. ISBN: 8185399549
- [10] Lamare RE, Singh OP. Limestone mining and its environmental implications in Meghalaya, India. *ENVIS Bulletin Himalayan Ecology*. 2016; **24**:87-100
- [11] Lamare RE, Singh OP. Degradation in water quality due to limestone mining in East Jaintia Hills, Meghalaya, India. *International Research Journal of Environmental Science*. 2014; **3**(05): 13-20
- [12] Lamare RE, Singh OP. Localized effect of artisanal and small scale mining of limestone mining on water quality in Meghalaya, India. *Pollution Research*. 2015; **34**(02):321-329
- [13] Canter LW. Environmental Impact Assessment. Vol. 660. Singapore: McGraw Hill International Editions; 1996
- [14] USDOI: Groundwater Manual—A Water Resources Technical Publication, US Department of the Interior (USDOI), Indian Reprint. Jodhpur: Scientific Publisher; 1985. 480 p
- [15] Tarnekar PS. Study of environmental implications of water quality with special reference to geology and mining activities in parts of Nagpur and Bhandara districts of Maharashtra [Ph.D. thesis, unpublished]. Nagpur: Rashtrasant Tukadoji Maharaj Nagpur University (RTMNU); 1993
- [16] Soni AK. Groundwater abstraction in mining for industrial applications:

Obtaining permission for statutory compliance. Mining Engineering Journal. 2018;12:22-26

Central Groundwater Board (CGWB), Government of India; 1997. Available from: <http://cgwb.gov.in/>

[17] Chunhu Z, Jin D, Geng J. Numerical simulation of the groundwater system for mining shallow buried coal seams in the ecologically fragile areas of Western China. *Mine Water Environment*. 2019; 38(1):158-165. DOI: 10.1007/s10230-018-0551-z. (Now published ; First online in 2018)

[25] NABARD. Review of Methodologies for Estimation of Groundwater Resources in India. New Delhi: National Bank for Agriculture and Rural Development (NABARD); 2006. 179 p

[18] Abbi YP, Jain S. Handbook on Engineering Audit and Environmental Management. New Delhi: The Energy Research Institute (TERI) Press; 2006. pp. 148-164

[26] CSIR-CIMFR. Geo-hydrological Study for Mining at Deeper Levels in Limestone Mine of M/s Trinetra Cement, District— Banswara, Rajasthan, India (No.: CNP/N/3259/2012-13). Dhanbad: Central Institute of Mining and Fuel Research (CIMFR); 2013. 73 p

[19] Choubey VD. Hydrological and environmental impact of coal mining, Jharia Coalfield, India. *Environmental Geology*. 1991;17:185-194

[27] CSIR-CMRI. Comprehensive Geo-hydrological Studies for Rajhara Mechanized Mine of Bhilai Steel Plant (BSP), Dalli Rajhara, District—Durg (Chhattisgarh), No. : GC/MT/N/22/2005-2006. Dhanbad: Central Mining Research Institute (CMRI); 2007. 168 p

[20] Allen SK, Allen JM, Lucas S. Concentration of containments in surface water samples collected in west-central impacted by acid mine drainage. *Environmental Geology*. 1996;27:34-37

[28] CSIR-CMRI. Hydro-geological Study of Malanjkhanda Copper Project, Hindustan Copper Limited, District Balaghat (M.P.), No. SSP/N/235/2017-18. Dhanbad: Central Mining Research Institute (CMRI); 2018. 114 p

[21] Tiwary RK. Environmental impact of coal mining on water regime and its management. *Water, Air and Soil Pollution*. 2001;132(1-2):185-199

[29] CSIR-CIMFR. Geo-hydrological Studies for Quantitative Estimation of Water and its Management at the Lanjiberna Limestone and Dolomite Mine of M/S OCL Limited, District-Sundergarh, Odisha (No.: CNP/N/2344/2009-2010). Dhanbad: Central Institute of Mining and Fuel Research (CIMFR); 2011. 98 p

[22] Khan R, Israili SH, Ahmad H, Mohan A. Heavy metal pollution assessment in surface water bodies and its suitability for irrigation around the Neyveli lignite mines and associated industrial complex, Tamil Nadu, India. *Mine Water and the Environment*. 2005;24:155-161

[23] Soni AK. Evaluation of hydro-geological parameters associated with limestone mining: A case study from Chandrapur India. *Mine Water Environment*. 2007;26:110-118

[30] Soni AK, Sahoo LK, Ghosh UK. Quantitative estimation of water in an opencast limestone mine of India. *The Indian Mineral Industry Journals*. 2016; 21-29(11) (also published in Geomintech Symposium on New Equipment, New Technology, Management and Safety in Mines and

[24] CGWB. Groundwater Estimation Methodology (GEC). New Delhi:

Mineral Based Industries (ENTMS);
11-12 May; Bhubaneshwar)

[31] Rawat NS, Viswanathan S.
Assessment of water quality
deterioration in some coal mines of
Northeastern Coalfields and Jharia
Coalfields. *Journal of Mines, Metals &
Fuel*. 1990;**01**:15-21

[32] Mohabey NK, Taranekar PS,
Thergaonkar VP. Impact of mining
activity on water quality of Umrer
Coalfield. *Journal of Gondwana
Geological Society. Golden Jubilee
Special Volume*. 1996:303-315

[33] Singh AK, Mahato MK, Neogi B,
Singh KK. Quality assessment of mine
water in the Raniganj Coalfield Area,
India. *Mine Water Environment*. 2010;
29:248-262

[34] Handa BK. Water Sampling and
Analysis, Chapter 4, New Delhi: Govt.
of India; 1974. pp. 51-72. Available from:
[http://www.who.int/water-sanitation-
health/dwg/2ed/vol3d.pdf](http://www.who.int/water-sanitation-health/dwg/2ed/vol3d.pdf)

[35] APHA. Standard Methods for the
Examination of Water and Waste
Water. 14th ed. Washington, DC:
American Public Health Association
(APHA); 1998. pp. 6-187

[36] Khond MV. Hydro-geochemical
characterization of groundwater around
Naokari and Manikgarh Limestone
mines, Chandrapur District,
Maharashtra [Ph.D. thesis unpublished].
Nagpur: Rashtrasant Tukadoji Maharaj
Nagpur University (RTMNU); 2014

[37] Soni AK, Wolkersdorfer C. Mine
water: Policy perspective for improving
water management in the mining
environment with respect to developing
economies. *International Journal of
Mining, Reclamation and Environment*.
2015;**30**(2):115-127. DOI: 10.1080/
17480930.2015.1011372

[38] BIS, Indian Standard. Specification
for Drinking Water (IS:10500). New
Delhi: Bureau of Indian Standard (BIS);
2003. pp. 1-5

[39] WHO. Guideline for Drinking Water
Quality Recommendation. World Health
Organization (WHO). 2004;**1**:1-4

[40] EPA. Overview of Best Practice
Environmental Management in Mining,
Australia. Environmental Protection
Agency (EPA); 2002

[41] USEPA. Coal Re-mining Best
Management Practices Guidance
Manual. Washington, DC, USA: U.S.
Environmental Protection Agency; 2001

[42] CGWA. Draft Guidelines for
Issuance of No Objection Certificate
(NOC) for Groundwater Withdrawal.
Central Groundwater Authority
(CGWA), Government of India; 2017.
Available from: [http://www.cgwa-noc.g
ov.in/Sub/CheckEligibility/CheckEligib
ility.aspx](http://www.cgwa-noc.gov.in/Sub/CheckEligibility/CheckEligibility.aspx)

[43] Brown A. Reliable mine water
technology. *Journal of Mine Water and
the Environment*. 2010;**29**(2):85-91

[44] Lele MG. Water Problems in Mines.
1st ed. Institute of Technology—BHU
Varanasi. India: Nishkam Press; 1980.
399 p