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TECHNICAL COMMUNICATION

Estimation of Mine Water Quantity: Development of Guidelines for Indian Mines

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Abstract
There are no available guidelines in India for estimating the quantity of mine water in an operational mining pit. Based on multiple case studies, procedures to determine water quantities have been developed for Indian geo-mining conditions, which varies with season and pit depth, India's monsoonal rainfall pattern, aquifer conditions (local and regional), and groundwater flow directions have been considered. These guidelines can be used for scientific assessments in surface pit mines, and for planning dewatering. Groundwater movement in underground mines is predominantly lateral, coinciding with the water table, and recharged by leakage from overlying aquifers, so water estimation can be based on volume and the size of voids/openings created underground. These guidelines should be useful for planning mine production and water management.

Keywords Mining · Pit water · Surface water · Groundwater

Introduction and Background

Surface mines in India are characterized by diverse geological, climatological, and topographic conditions. Some of them operate above the water table and some below it. The mine water in the pit, which might be a mixture of surface water and groundwater (GW), or rainwater alone, typically fluctuates. Water handling/management is necessary for planning dewatering as well as optimum and safe reuse. This necessitates water quantity estimation. The government of India has formulated a GW estimation methodology for general use and various industrial sectors, which is commonly referred to as the groundwater estimation committee (GEC)'97 methodology. The GEC'97 methodology was formulated by a committee of multidisciplinary experts of different relevant fields (CGWB—http://cgwb.gov.in) for use in alluvium and hard rock areas. However, when mine pit water estimation is required, the frequently changing scenario of pits and mine faces (actual working area), fast varying topography, and fractures due to blasting operations (rock conditions) come into the picture. These dynamics makes the general GEC'97 methodology erroneous for a mine site. Thus, there are no available guidelines in India for estimating the quantity of mine water in an operational mining pit.

In contrast, in Australia, which is a leading mineral-producing country, methodology and guidelines are available for industry use (GOWA 2013). Hence, we have developed practical and easy-to-use procedures, based on multiple case studies, for the Indian mining industry and its geo-mining conditions, to help one determine water quantities, season-wise and depth-wise, for an opencast mine area. To develop these guidelines, site-related hydrological parameters (i.e. aquifer condition, rainfall, GW flow direction), topographical features (plain/hill/coast), and special mine features have been considered.

Developing guidelines for calculating mine-water quantity for various geo-mining conditions has practical utility. Since mining is a site-specific business, such guidance are important for all operational mines where mine water quantities fluctuate. They also enhance the coherence and relevance of dewatering planning.

This research communication is intended to guide the mining community on how to estimate water quantities and apply corrections as the mine deepens. When the water quantity is known, mine water management and mine planning can proceed accordingly. In addition, mine water quantity estimation is important for scientific assessments and

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evaluations. However, these particular guidelines, though applicable for India, cannot simply be applied elsewhere.

Cases Studied for Development of these Guidelines

To develop these guidelines, water quantities have been determined at various mine sites over a time span of 18 years, starting in the year 2000 (Table 1). In addition, studies were also carried out in underground mines, to draw inferences that relate to water estimation. For example, the Kandri underground mine of MOIL Ltd., Nagpur, India, was studied to assess and compare water quantities in underground and surface mines under actual field conditions. The CSIR-CIMFR (2013c) study was directed towards environmental evaluation, based on geo-hydrological investigations for stopes of actual manganese mine workings.

Similarly, a virgin coal block, named the Keranadari coal block of the Hazaribagh district in Jharkhand state was studied in 2013 during planning to convert a mined out open pit to a pit lake at decommissioning (CSIR-CIMFR 2013a). This mine block was allocated to the Jharkhand Integrated Power Company Ltd. (JIPCL), Mumbai. Hence, the development of these guidelines required the consideration of different conditions.

Groundwater modelling was the key tool used in these case studies (CMRI 2007; CSIR-CIMFR 2009, 2013d, 2017). It was applied at the Lafarge Cement Nongtrai mine, Singareni Collieries' Medapalli coal mine, and UltraTech Cement's limestone mines for different purposes, one of which was calculating water quantity. Various in-depth details can be found in the technical reports of these case studies. Complete descriptions of the varying mining and geological conditions are provided in these documents. (See reference list; please contact the corresponding author with specific queries).

Sources of Mine Pit Water

The principal source of water in the Indian peninsula is the monsoonal rain. This type of rainfall occurs in all of India's regions and generally occurs during two seasons of the year: the SW monsoon (June–September) and the NE monsoon (October–December). The SW monsoon contributes maximum rainfall in the western and northern parts of India, whereas the NE monsoon contributes its maximum rainfall to the eastern areas. Average annual normal rainfall of India ranges from ≈ 200–300 mm to 2500 mm (NCERT 2018). The difference between the highest and lowest recorded rainfall in India is ≈ 1178 cm (https://byjus.com/free-ias-prep/rainfall-distribution-in-india).India as a whole receives enormous amounts of fresh water through rainfall but most of it is simply wasted as runoff and does not recharge aquifers. Furthermore, many of the big river basins (Ganges, Brahmaputra, Mahanadi, Krishna, Godavari, Cauvery, etc.) discharge water into the sea (through 100 odd rivers) without recharging GW or being effectively utilized, thus causing water scarcity problems too. There are two principal sources of mine pit water: direct precipitation at the mine site and GW at sites where mineral excavation intersects the water table.

How these Guidelines were Developed

Past precedents and research carried out at various mines (Table 1) have revealed that water quantity in a mine pit is related to the size/dimension of the excavated pit area. Pit depth (i.e. elevation differences) is equally important for mine water estimation. The quantity of water was found to differ widely during the year, meaning that it is highest in rainy and post-monsoon months (≈ 60% of total water quantity) and lowest in pre-monsoon and summer months (6% of total). Normal monsoonal rains contribute to the total

Table 1 Cases studied and its salient details

Name of mine and mineral mined	Study years	Location	References
Manikgarh Cement open pit mine; limestone	2000	Maharashtra	CMRI (2000) and Khond (2014)
Kovaya open pit mine; marl/limestone	2005–2006	Gujarat	CMRI (2007a)
Naokari open pit mine; limestone	2005	Maharashtra	CMRI (2006) and Khond (2014)
Rajhara mechanized mine; iron ore	2006–2007	Chhattisgarh	CMRI (2007b)
Nongtrai open pit mine; limestone	2009	Meghalaya	CSIR-CIMFR (2009)
Lanjiberna open cast mine; limestone/dolomite	2010–2011	Odisha	CSIR-CIMFR (2011)
Medapalli opencast mine; coal	2011–2012	Andhra Pradesh	CSIR-CIMFR (2013d)
Partipura limestone mine; limestone	2012–2013	Rajasthan	CSIR-CIMFR (2013b)
Pandridalli and Rajhara Pahar; iron ore	2017	Chhattisgarh	CSIR-CIMFR (2018a)
Malanjkhand copper mine; copper ore	2018	Madhya Pradesh	CSIR-CIMFR (2018b)

surface water quantity accumulating in the mining pit and, adding to it, is runoff from adjoining areas. The run-off water accumulating in pits is associated with the natural drainage pattern of the area. In open mines working below the water table, the water is a mixture of GW and surface water (SW), while in mines operating above the water table, only SW is present. This variation (60–6%) of water quantity/availability has to be accommodated for. It was found by comparing predicted and actual water quantities at all 11 of the studied mines (Table 1) that the predicted water quantity deviated from actual water quantities by 0–10%. This quantity factor of ± 10% accounts for variations in rainfall and water flow direction within and adjacent to the mine area and the erratic pattern of seasonal rainfall events.

Similarly, in an operational mine, the quantity of pumped out water is known from the mines office records and can be used to assess/evaluate with an adjustment factor of ± 2% (tolerance limit). This adjustment factor is derived on the basis of field studies carried out at each of the mine sites. The method of back analysis has been used to compare the pumped water quantity with the calculated water quantity, i.e. $Q_{pumping}$: $Q_{predicted}$, because it is quick, practical, and easy to use.

Together, these two factors account for seasonal variations of water quantity, depth-wise variations, and differing availability of pit water. If any mine has special characteristics, due to the particular nature of the mine or geographical set up of that area, such parameters should also be considered, e.g. steep hydraulic gradient, drainage density, and water density of salt/fresh water in case of a mine located near the coast.

Changes in monsoonal patterns and an increased number of dry days have been observed in recent monsoon seasons. This climatic change has affected the hydrological regime by concentrating the precipitation; this has been observed at various mines (Table 1). Therefore, in calculating mine pit water, consideration has been given to total water quantity and average availability of water per season. Since GW availability and recharge are affected by the fluctuating monsoon pattern, it is important to consider how changes in the monsoonal pattern due to climate change will disturb the mining area as well as to the hydrological regime of that area. Varying field conditions, such as the type of ore being mined and the porosity of the ore and host rocks, also play a pivotal role in GW movement, which in turn affects water quantities and thus guideline development. Separate sections on realignment of GW forces, effects of climate change, and applying the guidelines to underground mine workings have been incorporated to consider water estimation in totality and all field aspects.

The three parameters that matter most relative to water quantity and availability at a particular mine are: rock type, rainfall, and aquifer characteristics (local/regional), though the drainage and topography/physiography of the area are also important in SW assessment. The rate of GW discharge or rate of outflow vs. time and rainfall/pumping quantity (Q) vs. time period (seasonal variation) have been appropriately considered and incorporated in the guidelines (Fig. 1).

Experience gained through various case studies can be applied to estimate area-wise and depth-wise water quantities as long as the 10% quantity factor and ± 2% adjustment factor are incorporated. This is all illustrated in the example

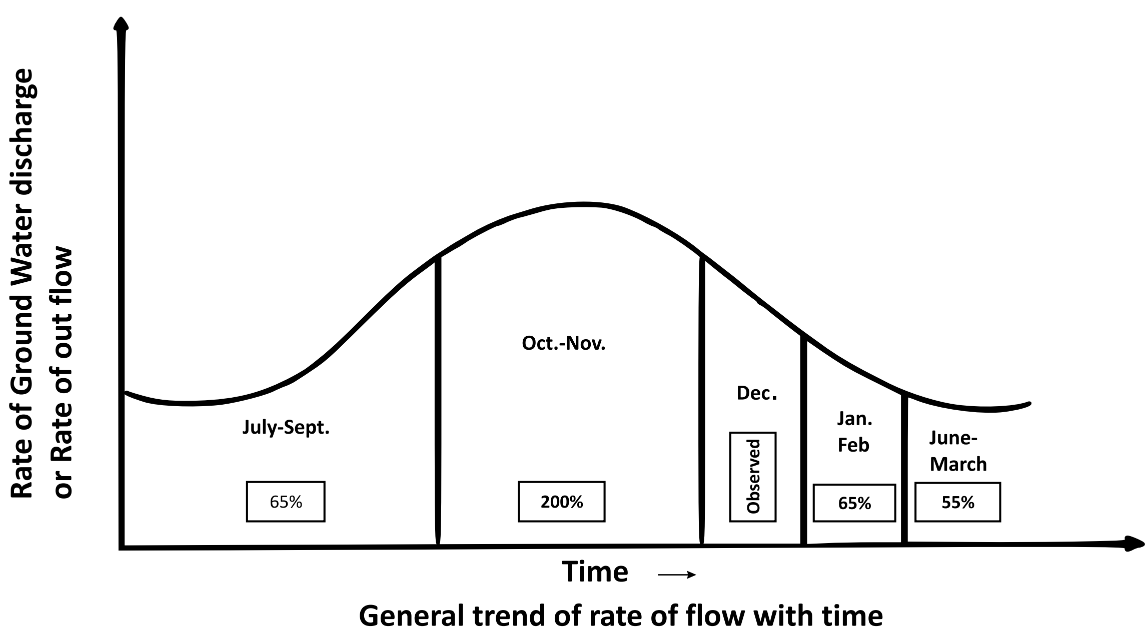

Fig. 1 Rate of groundwater discharge (or rate of outflow) with time (Source: Soni 2019)

provided in the "Appendix" section, which follows the References. In brief, when we consider all water-related mining conditions (CMRI 2000, 2006, 2007a, b; CSIR-CIMFR 2009, 2011, 2013a, b, c, d, 2017, 2018a, b) and apply the quantity and adjustment factors as per the guidelines, water quantity only departs 2–5% from actual values. GW and SW do not always get mixed in the open pit, since good SW management limits its accumulation in the pit. This allows the calculation of just the GW seepage component, which is vital in understanding the hydrogeology of the particular mine system.

Planning for Mining below the Ground Level

The GEC'97 methodology of GW estimation for any general area has been reoriented to formulate these guidelines, which can be referred to as the estimation procedure for a mine/mining area. As already mentioned, some additional factors have been incorporated to address the requirement of mines/mining areas. In particular, since a mines excavation area changes frequently, the area is extremely important for water quantity estimation. It could be either a lease area, a pit area, or a catchment area. Water quantity calculations are based on the worst case scenario, considering maximum rainfall and maximum likely water level fluctuations in that particular area. These procedures are applicable for hard rock mining areas, which in India constitute 80% of the mines [Ed. note: in India, hard rock simply excludes softer rock: coal, talc, marl, and clay]. In areas where alluvium rock conditions are encountered, the general GEC'97 methodology can be followed for the mine site (CGWB 1997; http://cgwb.gov.in).

The developed guidelines described here provide a good base for planning below the ground level and water estimation in a pit meant to extract mineral(s). Since SW and GW gets mixed in a mining pit, both calculations have to be done separately, as shown below.

SW and GW Calculations

The applicable formula to be used for SW calculation (Q_{SW}) is:

- Q_{SW} (m^3/year) = Catchment area (or lease area) × Max rainfall (m) × runoff

  The applicable formulae to be used for GW calculation (Q_{gw}) are:
- Method 1: Infiltration Method

  GW (A in m^3) = max. feasible GW quantity = lease area × rainfall (Max.) × rainfall infiltration factor (RIF)

  where the RIF can be determined per GEC'97 norms; Table 2.
- Method 2: Specific Yield Method

  GW (B in m^3) = lease area × max. fluctuation × specific yield

Table 2 Rainfall infiltration factor (RIF) Source: http://cgwb.gov.in

Geographical location	RIF as a fraction		
	Recommended value	Minimum value	Maximum value
(a) For alluvial terrain/areas			
Indo-gangetic plains and inland areas	0.22	0.20	0.25
East coast	0.16	0.14	0.18
West coast	0.10	0.08	0.12
(b) For hard rock terrain/areas			
Weathered granite, gneiss, and schist with low clay content	0.11	0.10	0.12
Weathered granite, gneiss, and schist with significant clay content	0.08	0.05	0.09
Granulite facies like charnockite, etc.	0.05	0.04	0.06
Vesicular and jointed basalt	0.13	0.12	0.14
Weathered basalt	0.07	0.06	0.08
Laterite	0.07	0.06	0.08
Semi consolidated sandstone	0.12	0.10	0.14
Consolidated sandstone, quartzite, limestone (except karstic)	0.06	0.05	0.07
Phyllites, shales	0.04	0.03	0.05
Massive poorly fractured rock	0.01	0.01	0.03

Surface water, ground water, seepage water, and water from recharge constitutes the total water quantity present in the area. Maximum means peak season quantity or the highest recorded average rainfall of previous years for worst case scenario; moderate means 75% of peak quantity; less than moderate means 30% less than peak quantity. Minimum means 50% less than the peak quantity

A and B are then averaged to produce the maximum feasible GW quantity of the mine catchment area/mine lease hold area in m^3/year, as the case may be. Then, the SW and GW quantities are added to produce an estimate of the total water quantity in m^3/year; average daily water quantities can then be calculated in m^3/day i.e. $Q_{predicted}$. Thus, $Q_{predicted}$ is the maximum total predicted (or anticipated) annual/daily water quantity for that open pit mine. However, field conditions are important and these must be observed through periodic field inspections. The following points are thus concluded:

Based on the quantity factor of 10% (which includes SW as well as GW in that particular year), the actual available water quantity in a mining pit (total and at least) = Q_{actual} = 1/10th of $Q_{predicted}$……..m^3/year.

In addition, the annual pumping records of the mine at different RLs (reduced level relative to a datum) can be used to calculate $Q_{pumping}$: $Q_{pumping}$ = annual pumped quantity (actual from field) ± (5–10%)…….m^3

As per the developed guideline, the $Q_{pumping}$ values should nearly match the $Q_{predicted}$ values for an operational mining pit. Total predicted quantity ($Q_{predicted}$ in m^3/year) is then distributed over the year since water quantity varies from season to season.

Seasonal and Depth Aspects of Groundwater Quantity and Flow Direction

Groundwater quantity and flow direction can be determined with the help of Figs. 1 and 2 for an open pit mine in India. In Fig. 1, the percentage shows the GW base flow in the mining area or the pit area during that period. The curve of Fig. 1 (i.e. the trend shown) is indicative of how total water quantity varies. This graph is meant to assess GW discharge or rate of outflow required for water estimation. Similarly, in Fig. 2, the percentage (%) shown is meant for the SW that remains in the mining area with respect to the total water quantity, Q. The trend and percentage figures shown in Figs. 1 and 2 are based on the studied cases (Table 1), considering the total water quantity pumped out of the mine, the rate of outflow from the mine, and the rainfall of the studied area.

Hydrogeological maps of the area are extremely useful for assessment of SW and GW flow direction in a mine pit area (seasonal and depth aspects). Groundwater flow direction can be ascertained from features such as drainage of the area, RLs, and water level contours on the region's GW maps.

Seasonal Distribution

Open pit mine workings can be above and below the water table. Table 3 can be used to accommodate seasonal variations for hard rock mines working below the water table. Nearly 65% of the rainfall occur during monsoon months

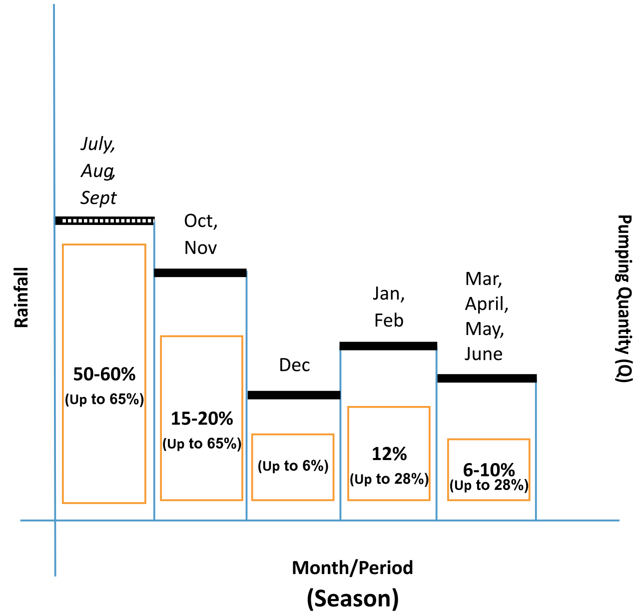

Fig. 2 Norms for hard rocks/open pit (Based on different mining case studies)

and nearly 28% of the rainfall occurs in other months i.e. from Jan to April. The period between pre-and post-monsoon is an observation period, allowing for adjustments that may contribute about 6% (Fig. 2 and Table 3). Thus, the formula for seasonal distribution of total water quantity % for the entire year is:

- Total quantity % = Period 1 + Period 2 + Period 3 + Period 4 + Period 5 + (± 1%)….. (I)
  where the period refers to different months of the year, as indicated in Fig. 2. (Period 1 = July–Sept; Period 2 = Oct–Nov; Period 3 = Dec; Period 4 = Jan–Feb; and Period 5 = Mar–June). As an example, the Hindustan Copper Ltd. (HCL) case record is provided in the supplement section:
- Total water quantity % (seasonal distribution) = 65% + ..0.. + 06 + ..0.. + 28% ± 01% = 100%

Open mines in northeast India and coastal regions experience rainfall beyond the normal rainy season. Similarly, mines in southern India, i.e. Tamil Nadu, experience rainfall from the retreating monsoon. Winter rains, intense rainfall events, and rainfall prior to June occurring in Kerala state and the Andaman and Nicobar islands have been covered in the guidelines by using a range of 65–80% of total rainfall. This means that if the total % quantity of July–Sept (period 1) is say 70%, the remaining 30% ± 1% will be distributed over the remaining periods. A range of rainfall and tolerance of ± 1% is maintained to accommodate widely varying rainfall across India from north to south and from east to west.

Table 3 Seasonal water quantity in an open pit

Month/period	Days	Range of total annual rainfall		Pit water quantity (Q) per developed norms (m^3)	Remarks
(A) Jul–Sept	92	50–60%	65%	Q = 60% of total Q (max.)	A and B total ≤ 65% of total SW: Max.; GW: Ample/maximum
(B) Oct–Nov	61	15–20%		Q = 20% of total Q (max.)	
(C) Dec	31	06% (Observed)		Q = 06% of total Q	This period lies between pre- and post-monsoon; hence is considered an observation period for Q adjustment SW: Moderate; GW: Base flow
(D) Jan–Feb	59	12%	28%	Q = 12% of total Q	SW: < moderate; GW: Base flow
(E) Mar–Jun	122	6 and 10%		Q = 10% of total Q (max.)	In dry season, it is assumed that pit has no input from SW and only intercepted GW is present in the mine pit SW: Minimum; GW: Base flow
Tolerance limit of ± 1–2% in total rainfall/water quantity is permissible for both SW and GW					

Surface water, ground water, seepage water, and water from recharge constitutes the total water quantity present in the area. Maximum means peak season quantity or the highest recorded average rainfall of previous years for worst case scenario; moderate means 75% of peak quantity; less than moderate means 30% less than peak quantity. Minimum means 50% less than the peak quantity

Thus, in the developed guidelines, geographical variations of rainfall has been incorporated.

If site-specific hydrogeological maps are developed or made available, it is better to use them for more precise water assessments, though regional maps can be used for scientific evaluation. Regional maps are easily available from government GW authorities. Local dynamic conditions, e.g. size of mine, mine production, and other important topographical surface features must also be considered at the time of assessment.

Depth-Wise Distribution

As there is no fixed guideline for depth-wise quantity variations, again a rule of thumb based on experience have been developed. A conventionally excavated open pit mine has benches that are 10–12 m high and, as mining goes deeper and deeper, incremental water quantity variations occur, due to the transmissivity of local and regional aquifers.

In hard rock formations (most of the surface mines in India lies in these rock types), an increase in water quantity of ≈ 10–12% in monsoon and post-monsoon season and about 5–6% in dry summer season can be assigned for depth-wise water distribution in mine workings below the water table, i.e. the water table has been passed and the pit is receiving GW. Using the studied case records, it was found that applying these increments increased the calculated water quantity to close to actual levels as long as the mines lie in plain areas, i.e. mainland, not island nor hill areas, nor near the sea coast.

In hilly areas and coastal areas, unusual and special field conditions are encountered (Box-I). Due consideration should be given to actual field conditions while doing water estimation and calculations.

BOX - I

Mines in hilly areas

The water table in hilly areas resembles the topography. The water table fluctuations depend on the actual water sources that connect to the hill being excavated; the most common water sources in hill deposits are springs. The GW availability in the mining pit is assessed depending on the connectivity of different springs. Comparative rainfall magnitude and resulting run-off is also a contributory factor for GW base flow in hills. Thus, the height of hills and interconnectivity of hill springs assume significant importance. In general, the observed field conditions vary widely and frequently in hilly mines.

Mines in coastal areas

Groundwater conditions in coastal area mines are usually governed by the distance of mines from the sea and the height of working areas above mean sea level. High tides can change the GW scenario abruptly and frequently. Mine areas located close or along the coast lines are inflicted with natural sea water intrusion (or salt water intrusion) and the distance of the mining /excavation area from the sea has to be considered. For example, some mines in India are located only 500 m from the sea shore. In such cases, sea water intrusion naturally occurs and the distance matters a lot.

For the above-mentioned two mine type areas, seasonal water quantities and depth-wise water quantities should be estimated on a case-to-case basis using hydrological principles of GW movement.

In addition, abnormal field conditions can occur at open surface mines due to, e.g. intense storms, inundation due to storm crests in coastal areas, and other natural events beyond human control. Under these conditions, the quantity and adjustment factors will not be sufficient for water quantity estimation.

Realignment of Groundwater Forces

Both groundwater and mining operations are dynamic in nature. Prevailing geological features (faults, slip planes, shear zones, etc.), mining methodology, and rock conditions, i.e. natural and induced porosity and water stresses, can cause groundwater realignment. Such realignment can increase or decrease GW flow in working areas. Examples include multiple operating pits in the same mine, two or more pits in the same immediate vicinity, and the presence of two mining systems, i.e. open pit and underground, in tandem or in the same immediate vicinity. Such conditions help build a complex dynamic system and in such cases, it is almost certain that realignment of GW forces will take place. The "Radius of Influence Criteria for Impact Assessment" remains helpful for understanding this mechanism (Soni et al. 2015).

However, the site-specific aspects of GW realignment mechanism means that each mining site requires individual consideration of the sites peculiarities and complexities, which means that they cannot be well understood without detailed examination. Inferences drawn in one case may not match with those at another, so all conclusions need to be verified and cross-checked.

Underground Mine Workings and Water Estimation

Data evaluation of pumping tests carried out at underground mine sites, some of them by the author (Soni et al. 2013), has resulted in estimates of aquifer properties of the mining areas, e.g. Kandri mine of MOIL (Sewa 2012). The estimated aquifer properties were used for dewatering planning, water quantity estimation, and engineering design of the mine (CSIR-CIMFR 2013c). Experience gained at the Kandri mine indicated that high infiltration zones are sometimes encountered in underground workings, and that during high intensity rainfall events, excessive water can flow through strata into the mine. Although GW movement in the deeper aquifer system of underground mines is predominantly lateral, the deeper aquifer system is recharged by leakage from overlying unconfined and semi-confined aquifers. The degree of hydraulic connectivity depends on the permeability of the intervening strata. Cyclic and synchronous fluctuation of water levels in deeper aquifers and the shallow water table aquifer shows the extent of their hydraulic connection.

Study of water estimation in underground mine areas are largely based on the volume of void space created underground. Although there is no standardization or uniformity in calculation procedures, the rock material (e.g. the primary porosity of inter-granular void spaces and secondary porosity formed by solution channels, joints, fractures, and karstic features), the type of aquifer system (confined/unconfined/semi-confined), and geological features in the mine area (fault zones, shear zones, etc.) can all act as conduits and potential water sources in underground areas. Therefore, for underground workings, the volume of void space and the inflow potential should be known for water quantity estimation. In underground mines with active working areas, the water inflow generally consists of groundwater exclusively and the negligible amount contributed by SW may be accounted for as GW. Using these basic scientific principles, water quantity calculations can be done for underground mines.

A case study example of water quantity estimation using these guidelines at the Malanjkhand Copper Project of Hindustan Copper Ltd. is provided as an illustration. Since this is a real, very recent, field study, one can assess and understand the reality of this estimation. At this mine site, twin mining conditions were encountered (CSIR-CIMFR 2018b), leading to realignment of groundwater forces.

Effect of Climate Change

Climate change has clearly impacted India's rainfall and distribution pattern. Hence, it is obvious that the availability of water in a mining pit is also going to be impacted. This effect has been observed in mining areas as increased seasonality, with more sudden and heavy rainfall events, and less rainfall than usual during dry seasons. It is well known that climate change is not yet fully established and more detailed research is still needed to determine how the various changing climatic factors, e.g. geographical domain and the effect of warmer temperatures on monsoonal rains and rain distribution patterns, should be accounted for in water quantity assessments. Perhaps this can be addressed in the future using another corrective factor, inserted at appropriate places in the calculation procedure mentioned above. This will strengthen the developed guideline further. At the time of framing these guidelines though, there is insufficient data.

Conclusions

The thriving Indian mining industry lacks practical guidance on how to calculate the quantity of water in an operational mine, be it an open mining pit or underground workings. This requirement have been fulfilled by this paper for Indian geo-mining conditions. In these developed guidelines, the quantity factor and adjustment factor, which one may think like a safety factor, have been applied for the water quantity estimation. Using rules of thumb and back analysis methods, workable numerical values have been determined under practical conditions.

When field conditions of Indian mines were studied, it was concluded that in an operational mine, a near-actual quantity of mine water suffices for mine planning; however, a systematic, scientific calculation procedure is needed for mine water quantity estimation. To make the calculated water quantity comparable with the near-actual water quantity, the adjustment factors with a tolerance limit works pretty well. Hence, they have been included in this guideline, and the estimation procedure described. Since the developed guidelines were derived from Indian case studies, they are most applicable for Indian geo-mining conditions. More refinement and improvement is possible through inclusion of more case studies and experiences. Further suggestions are welcomed by the author to improve the mine water environment conditions hitherto.

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Appendix

HCL/MCP CASE STUDY (CSIR-CIMFR 2018b)

The Malanjkhand copper project (MCP) is a large operative open pit mechanized mine with 3 million ton per annum planned production. MCP is located between the 21° 56 to 22° 05 N (latitude) and 80° 39 to 80° 46 E (longitude) and can be traced on Survey of India Topo sheet 64 B /12,64B/16, 64C/9, and 64C/13. MCP falls within the catchment boundaries of the Banjar River. The study area includes four watersheds (5D5D3, 5D5D4, 4E8I2, and 4E8I5). Currently, this open pit mine has reached its last stage and is being converted into an underground mine for Cu ore extraction (chalcopyrite) because the ore at shallow depths is exhausted. The water requirement for this mine project is fulfilled by surface water from the Banjar River, not groundwater. The pumped out pit water is distributed at various process points as well as recycled for industrial applications.

The water quantity for various seasons and for different depth has been predicted for MCP using the developed guidelines (Tables 4, 5). The input data is given below, the calculation details follow:

Table 4 Predicted water quantity at MCP

Month/period	Rainfall range as per norms		MCP pit water quantity (m^3)	HCL case study	Remarks
(1)	(2)		(3)	(4)	(5)
(A) Jul–Sep	50–60%	65%	6,923,840	64%	A and B total should ≤ 65% of total A + B = (48 + 16 = 64–65%)
(B) Oct–Nov	15–20%		2,406,575		
(C) Dec.	06%* (observed)		9,172,59	06%	Observation period (from field investigation and rule of thumb adjustment)
(D) Jan–Feb	12%	28%	1,745,751	12%	–
(E) Mar–Jun	6 and 10%		2,406,575	≈ 16%	The MCP pit has no input from SW, only GW from water table during this period
	Total (SW + GW)		14,40,0000	± 1–2%	–

Table 5 Approximate water quantity (Q) at MCP during different period and at different depths (in m^3)

Pit depth (m)	Quantity of water (m^3/day/year)										
	July–Sept (92 days)		Oct–Nov (61 days)		Dec. (31 days)		Jan–Feb (59 days)		March–June (122 days)		Annual total
	m^3/day	Total (A)	m^3/day	Total (B)	m^3/day	Total (C)	m^3/day	Total (D)	m^3/day	Total (E)	m^3/year
340–328	75,289	6,923,840	39,452	2,406,575	29,589	91,7259	29,589	1,745,751	19,726	2,406,575	14,400,000

340 and 300 m RL were the mine working RLs in the year 2018. Between these RLs, 40 m barrier pillar will be left. Hence, water quantity (Q) between 340 RL to 300 m/296 m RL should be the same as indicated in table above, i.e. 14,400,000 m^3/year

Input data:

- Lease area = 479.9 ha
- Maximum rainfall = 1484 mm
- Catchment area = 1413.5 ha
- Water level fluctuation (WLF) = 6.9 m (from field observations)
- Specific yield = 0.20
- Pit bottom RL = 340 m
- Bench height = 12 m
- Annual pumped quantity in the year 2018 = 1,360,000 m^3
- Aquifer encountered = Gneisses (unconfined)
- Pit depth = 240 m (bgl); water table has been intercepted.
- Other field conditions: the presence of two mining system i.e. open pit and underground in tandem; the open pit will be closed in 2020 and there will be no more ore produced from open pit; underground operations will commence in the immediate vicinity of the open pit in 2020; per the mine plan, the same water quantity will be pumped out of the mine pit in 2019 and 2020 as in 2018; the total quantity available for pumping will diminish with time.
- GW Calculation

  Method 1: Infiltration Method

  The maximum feasible groundwater quantity = Lease area × Rainfall (max.) × RIF = 4,799,000 × 1.484 × 0.40

  A = 2,848,686.4 m^3

  Method 2: Specific Yield Method

  The maximum feasible groundwater quantity = Lease Area × Ma × fluctuation × specific yield = 4,799,000 × 6.9 × 0.20

  B = 6,622,620 m^3

  The average groundwater quantity within the lease hold area (C = (A + B)/2):

  C = (2,848,686.4 + 6622620)/2 = 4,735,653.2 m^3/year
- SW Calculation

  Catchment area × Ma × rainfall (m) × runoff = 1413.5 ha or 14,135,000 m^2 × 1.454 m × 0.46

  SW = 9,649,116.40 m^3/year.

Therefore, SW + GW = 4,735,653.2 + 9,649,116.4 0 = 14,384,769.6 m^3/year or ≈ 14,400,000 m^3/year. For the purpose of estimation in surface mines, total water quantity in pit is 10% of the anticipated /predicted water quantity i.e. 10% of (SW + GW). Therefore, the total water quantity ($Q_{predicted}$) available in the pit totals at least 14,400,000/10 = 1,440,000 m^3/year.

Water quantity field study for pumping/year (at 340–328 m RL) is calculated as follows:

$Q_{pumping}$ = Annual pumped quantity (actual from field per MCP office record) ± 6% = 1,360,000 + 6% of 1,360,000 = 1,360,000 + 81,600 = 1,441,600 m^3/year ≈ 1,440,000 m^3/year

Inference drawn from study: $Q_{pumping} = Q_{predicted}$. The two water quantities nearly match; hence, the predicted quantity is correct.

Accordingly, when per year water quantity (14,400,000 m^3/year) is calculated, estimation of the quantity at one RL of the mine pit, preferably the lowest, is possible (Table 5). The incremental increase for depth variations can be applied thereafter @ 10% per the developed guidelines. In this case study, water quantity was only estimated at 340–328 m RL because this pit mine has reached its final RL.The distribution range, from 65 to 6% of the total water quantity, has been applied and this varies as per the long-term average annual rainfall. The shown water quantity in Table 4, column 3 is the annual water quantity (calculated/estimated).

These guidelines have been applied at this operating MCP mine site. Mine management uses engineering judgment to modify water management measures based on periodic observations of actual field conditions.

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