HYDROGEOLOGICAL EVALUATION OF A WATERSHED WITH MINING ACTIVITIES: CASE STUDY OF SALAULIM RESERVOIR, GOA, INDIA

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Abstract

Open-cast mining is an important economic sector in Goa, India. It often requires large quantities of groundwater to be pumped out. This can lead to water stress conditions if the quantity of groundwater extracted surpasses the total recharge. To examine this, hydrogeological investigations were carried out in the catchment of Salaulim reservoir which had mining activities. The watershed was delineated into three sub-watersheds (Guleli, Kumbhari and Curpem) covering a total area of 180 km² and a reservoir area of 29 km². During the study period (2011-12), 4 working, 22 non-working mines and 5 laterite quarries were recorded. The groundwater level data was collected for 3 seasons. The average water level fluctuation (between pre- and post-monsoon) was found to be 1.06, 0.97 and 1.14 m for the wells in the above-mentioned watersheds respectively. Flow net maps were prepared to study the flow path of the groundwater and understand the potential pathway of contaminant. Field experiments were conducted to estimate aquifer parameters and monitor water quality. The sectoral groundwater demand, draft and recharge were calculated and used to estimate total groundwater availability which was 192 hectare meter per annum. The stage of groundwater development was 38.8% which is classified as 'Safe' as per the norms. This stage is based on the draft from only 4 active mines and would definitely aggravate if more mines are allowed in the vicinity of the reservoir. Well hydrographs based on 5 five years secondary data indicate that there was no decrease in groundwater levels in the study area. However, a decreasing trend was observed in a well which lies close to the watershed. Taking this as an indication, judicious withdrawal of groundwater in future is warranted.

Keywords : *Mining, hydrogeology, groundwater quality, flow-net, aquifer parameters*

Introduction

Water stress conditions arise whenever the quantity of groundwater extracted within a given watershed surpasses the total recharge. This is likely to happen in areas where open-cast mining of minerals is carried out below the groundwater level. In Goa, India, mining was a major economic activity until recently. There are studies such as (TERI 2005; NEERI 2009; Somasundaram2009) that looked at the impact of mining on the groundwater especially, in North Goa. There was a need to undertake a hydrogeological study in South Goa which witnessed a rapid growth in mining-related activities in the recent past. Based on the stakeholder discussions, it was found that mines were in operation in the catchment area of Salaulim dam which is a prime source of water supply for 55% of the population in the State[2]. It was felt that, this may have negative impacts on the reservoir and hence, detailed investigations were warranted to assess the impacts and formulate necessary prevention or remedial action in time. Hence, the watersheds contributing to the reservoir and having mining activity were selected for hydrogeological study to estimate groundwater balance in the contributing watersheds of Salaulim reservoir and evaluate the status of groundwater quality. This study was carried out in 2011-12.

Materials and Method

Groundwater balance was computed using water table fluctuation and rainfall infiltration factor methods. This methodology conforms to the guidelines suggested by Ministry of Water Resources, Government of India (2009). The step-wise approach that was used is as follows:

- Survey of India (SoI) toposheet (1:25,000 scale) was procured. The drainage pattern & contour/ground elevation was studied and the

watershed boundaries and areas contributing to the reservoir were demarcated.
- Base maps (drainage) were prepared by scanning and then digitizing the maps. Digitization was done using DIDGER 3 software. Field visits were carried out for ground check. Main watersheds and sub-watersheds were identified. Watershed areas and drainage density were estimated. Topographical map for the study area was prepared and ground level gradient distribution was analysed to assess the aerial distribution of the rainfall infiltration potential in the watershed. Land–use and soil pattern were used to assess the areas of potential groundwater recharge.
- Sixty six groundwater monitoring wells were established. Existing wells were used. Pre-monsoon, monsoon and Post-monsoon water levels were measured. Other parameters that were measured included GPS coordinates of the wells, diameter of the wells, depth, static water level, geological information in terms of soil/rock strata, height of each monitoring station above mean sea level (msl), and measuring point height above ground.
- These monitoring well stations were transferred to the digitized base maps after assigning identification numbers to each of them.
- Rainfall data was collected from WRD for water balance computation. Other data like unit draft per groundwater abstraction structure, was collected from CGWB. Domestic per capita use and water used by cattle was estimated based on field survey and literature review.
- The number of operating mines in the region, their area and draft were collected from the Department of Mines & Geology and from the respective mining companies.
- Pumping tests were carried out to estimate specific yield of the aquifer. Specific yield, water level fluctuation and watershed area are the basic inputs in the water balance equation. The watershed was classified into

different categories depicting feasibility of rainfall recharge as per 1997 guidelines of Groundwater Estimation Committee, Government of India.

- Flow-net analysis was carried out for pre- and post- monsoon seasons using contour plotting software called SURFER.
- Interpretation was done on groundwater recharge and discharge areas, groundwater level gradients and hydraulic conductivity variation. Based on the groundwater balance calculations, the watershed was categorized into classes of groundwater development. (Groundwater classes are: Safe, partially exploited, over-exploited)
- In order to overcome the complexities of representing the field situations in the hydrogeology component, some assumptions were made which are (a) the topography is fairly uniform (b) the aquifer in the study area is homogeneous and all the monitoring open wells tap the same aquifer.

Results & Discussion

Characterization of the watersheds

Location and drainage

The catchment of the Salaulim reservoir was demarcated using Survey of India toposheets (1:25,000) bearing nos. 48I/4 and 48I/8. The drainage pattern and contours were studied and the watershed boundaries and areas contributing to the reservoir were demarcated. The contributing watersheds have been sub-divided as Guleli watershed (77 km^2) located in the southeast of the reservoir, Kumbhari Nala watershed (73 km^2) located in the east and south east of the reservoir and Curpem watershed (32 km^2) located in the west along the periphery of the reservoir (Figure 1). The water spread area covers around 29 km^2. Topographically the major part of the watershed area is represented by high peaks of the Western Ghats with elevation ranging between 150-500 meters above mean sea level (WGEEP 2011). The highest topographical elevation is found in the eastern part of the watershed.

The drainage pattern in the study area was found to be mainly dendritic to sub-dendritic in nature and sparse drainage network is seen in Curpem watershed. The drainage density is fairly high in the Guleli and KumbhariNala watersheds indicating hard grounds and steep slopes of the ground. The drainage is mainly influenced by the property of the rock rather than structural features. The drainage pattern of the study area is shown in Figure 2.

Figure 1:Three-dimensional view of the entire study area

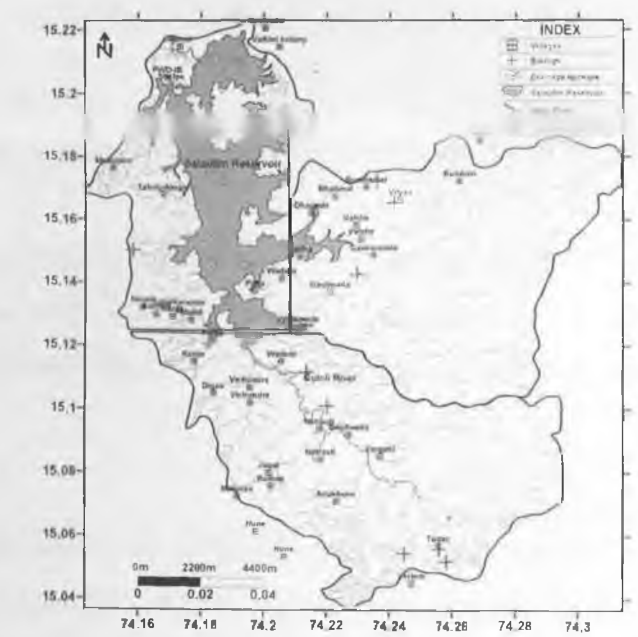

Figure 2: Drainage pattern of catchment of Salaulim reservoir

Soil, geology and land-use

The top soil of varying thickness was observed almost throughout the study area except on steep slopes and hill-crests, where the land is rocky with exposed laterite. Loamy and sandy soils are generally found in the low lying agricultural fields. Soils of Torse/Netraveli and Darbandora/Gavane type were mainly seen in the southern and eastern parts of the study area. Whereas, Metavade/Velguem and Bandoli/Arukot type of soils were exposed in the south central and western parts of the Salaulim study area. Further, this area mainly consists of quartz-chlorite-biotite-schist with layers of chert, iron oxides, metabasalts, metagabbro. Laterites form the top layer in many parts of area followed by Greywacke with conglomerate, metagabbro, metaanorthositic gabbro, and banded iron formations. The major geological structures include plunging anticlines and synclines. Based on the SOI topographic map and satellite images, the Salaulim catchment displays different land uses comprising forests (68.5%), agriculture (10%), plantations (8.3%), and other land uses that include mining (laterite, iron, and manganese), mining dumps, and water spread areas (13.2%).

Climatic condition in the region

The minimum and maximum temperature is in the range of 20^{0}C to 36^{0}C. The relative humidity varies from a minimum of 80 to 85% in April/May to a maximum of 90 to 95% in the month of July/August. The overall climate in the region falls in the category of humid tropical. The catchment area receives heavy precipitation during monsoon period between June and September.

Mining activities in the region

The Salaulim catchment falls in a geologically potential iron and manganese ore zone. Mining activities in the catchment area primarily include extraction of iron and/or manganese ore and laterite quarrying. During this study, a detailed analysis of the number and distribution of all the lease concessions

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were carried out using the data collected from Directorate of Mines & Geology. Extensive search and mapping of mining activities using satellite images was done. Field inspections were undertaken to ground check the active, abandoned and very old mine pits in the watershed area. The location of all the sanctioned mine concessions by erstwhile Portuguese are shown in Figure 3. The location of the laterite quarries, active mines and abandoned mines is shown in the Figures 4 and 5 respectively.

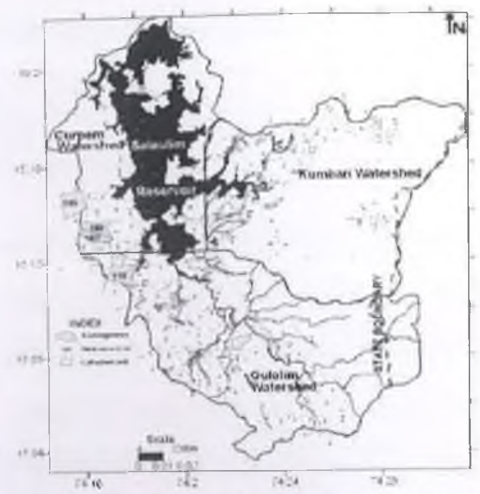


Figure 3: Location of mining concessions (working and non-working) in the Salaulim watershed

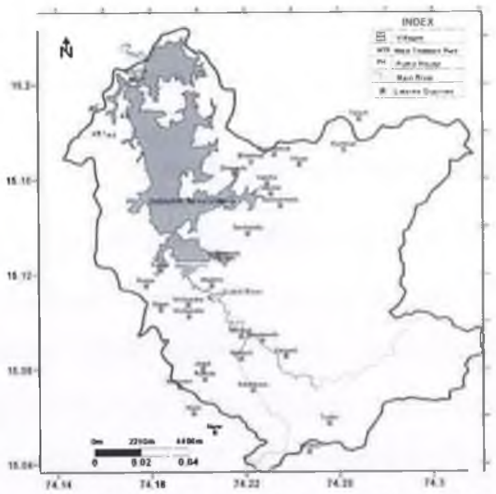


Figure 4: Location of laterite quarries in the catchment

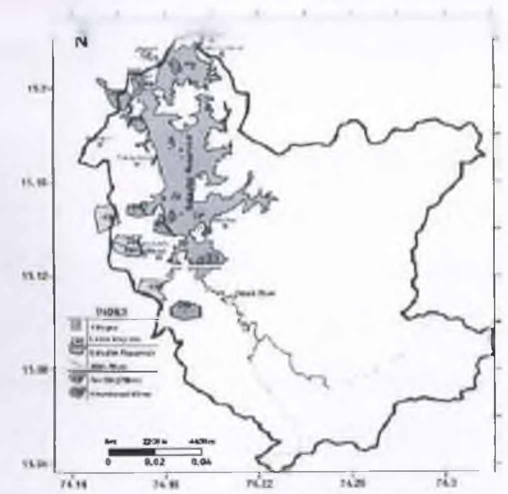


Figure 5: Location of working, abandoned and old mines in the catchment

Of all the above concessions or leases, very few mines were in operation during the study period. There were four active mines and seven abandoned mines. There were seventeen very old non-working mines that were identified from the satellite image. As shown in the figures above, all the working and abandoned mines were in the Curpem watershed in western part of the Salaulim reservoir. The old non-working mines were located in Guleli and Curpem watersheds and two were in Kumbhari watershed. Two old and abandoned mines were seen located within the reservoir in the northern part now an island after the dam was built.

Hydrogeological Investigations

Groundwater Monitoring Stations

For hydrogeological investigations, monitoring of the groundwater levels at different locations in the watershed at different times is essential for various calculations. Existing open wells tapping shallow groundwater were used for water level monitoring. Care was taken to represent the maximum possible area. However, in the dense forest areas and non-populated areas open wells were not available. Sixty six groundwater monitoring wells were established out of which 19 were in Kumbhari, 39 were in Guleli and 8 were in Curpem watershed. The water levels were measured during monsoon, post monsoon and pre monsoon seasons at all these wells. These sampling locations are shown in Figure 6. In order to analyse the past trend in groundwater level, secondary data from Central Ground Water Board (CGWB), Government of India was collected for the stations lying within and close to the present study area. The location of these CGWB water level monitoring wells is shown in Figure 7. As shown in the figure, only two CGWB wells fall in the watershed.

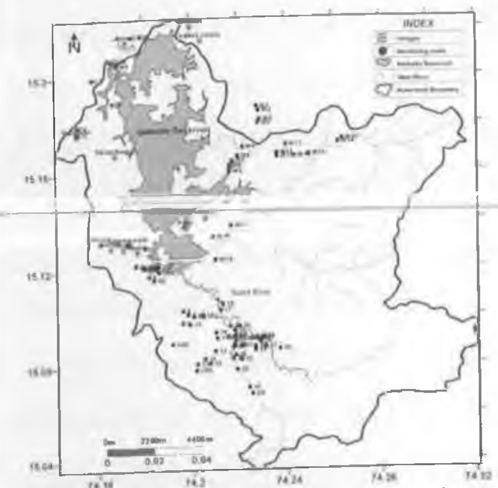


Figure 6: Map showing the location of groundwater monitoring wells

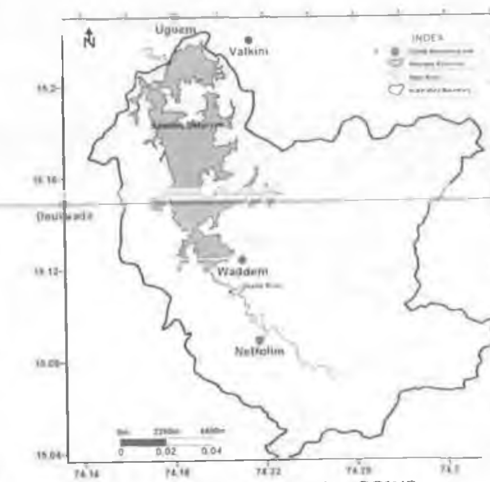


Figure 7: Location map showing CGWB monitoring stations in the watershed

Groundwater Data Collection

The computed difference in the water levels in wells measured during May and November of a given hydrological year is termed as water table fluctuation. The magnitude of groundwater level fluctuation is an indicator of quantum of groundwater recharge from rainfall. Lower magnitude fluctuations are indicative of low groundwater recharge and vice versa. In the present study, the water table fluctuations have been calculated for all the three watersheds. The average water level fluctuation (between pre- and post-monsoon) was found to be 1.06, 0.97 and 1.14 m respectively for Guleli, Kumbhari and Curpem watersheds. In Curpem watershed, the fluctuations were quite large at one location between Malcopona and Shelpem. This may be due to active mining activities in the area. In rest of the area the water table fluctuations were low to moderate

Groundwater flow net construction and analysis

A flow net is a sketched representation of the flow paths taken by water molecules through the subsurface. The "grid" of a flow-net is comprised flow-lines (idealized paths followed by water molecules in moving from position of high hydraulic gradient to those of low head represented by smooth curves at right angles to equipotential lines) and equipotential lines

(lines along which the hydraulic head is equal). Flow-net is a very powerful analytical tool for studying the groundwater behaviour. In the present study computer assisted flow-net sketching was adopted using SURFER 7.0. The input to the program included X and Y co-ordinates of the observation wells and the Z coordinate representing water level data above msl, depth to water level below ground and water level fluctuation. Kriging technique was used for plotting various equipotential contours as it was found that, it is the best-fit method for plotting of smooth contours. In order to understand the dynamics of groundwater occurrence and movement, it is necessary to construct flow nets for different seasons. In the present study, the groundwater flow nets were constructed for three seasons of pre-monsoon, monsoon and post-monsoon for each of the watersheds. As the groundwater basin generally coincides with the surface water basin, particularly in hard rock areas the flow net construction and other related maps were prepared separately for each sub-basin. The flow nets for the study area during pre-monsoon season for Guleli, Kumbhari and Curpem watersheds are given in Figures 8, 9 and 10 respectively. These groundwater flow nets are approximate representations of the actual field condition.

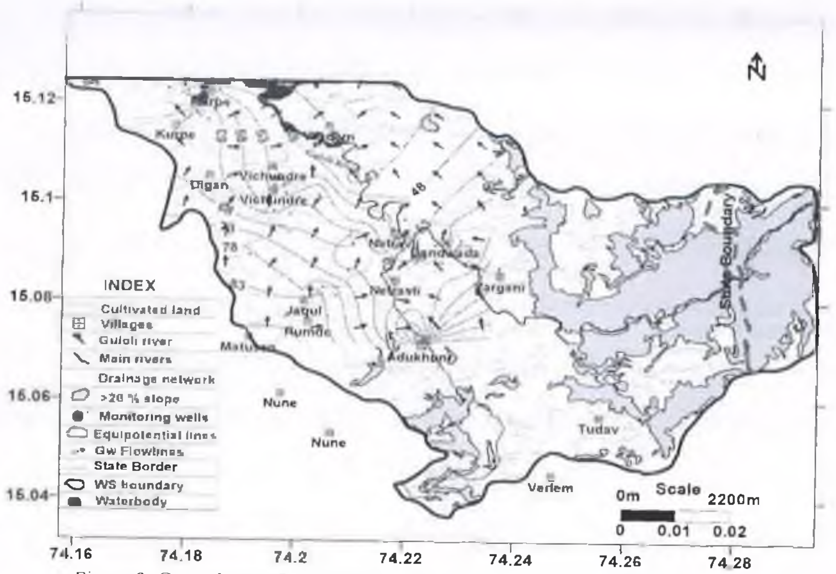


Figure 8: Groundwater flow net during pre-monsoon season in Guleli watershed

Groundwater seepage into a stream or a river is called *baseflow*. A river is called as 'effluent' when it receives groundwater and 'influent' when the river water is discharged into groundwater. As seen from the Figure 8, the groundwater mostly follows the ground topography. Flow of groundwater is generally northwest and in north east directions. Guleli river receives groundwater in the western side making it effluent in nature even during pre-monsoon season. Downstream in northeast the river behaves as influent in nature. The groundwater level gradients were moderate and so was the hydraulic conductivity of the saturated zone. Many of agricultural lands receive groundwater flow from the base of the hills for summer cultivation of crops. The hilly areas act as main groundwater recharge zones as seen from the flow lines. At Adkune, south of Netravli a small groundwater trough has developed. Otherwise there are no major troughs and groundwater mounds in the area.

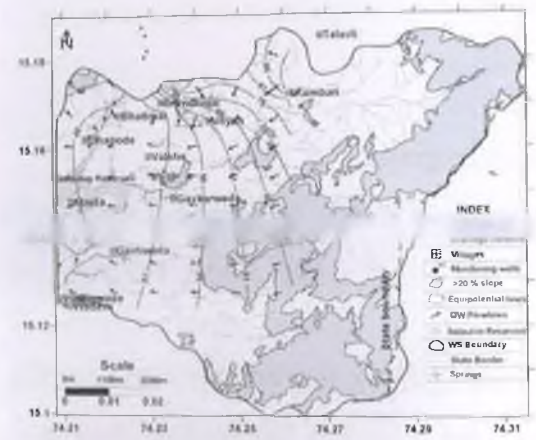


Figure 9: Groundwater flow net for pre-monsoon season in Kumbhari watershed

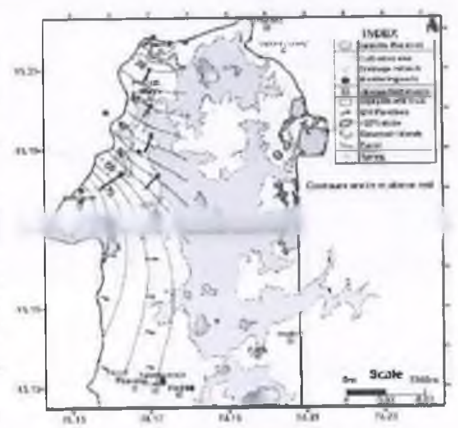


Figure 10: Groundwater flow net for pre-monsoon season in Curpem watershed

The groundwater mostly follows the ground topography in Kumbhari watershed (Figure 9) with the flow towards west. Salaulim reservoir receives groundwater from the eastern side making it effluent in nature even during pre-monsoon season. The groundwater level gradients are low to moderate and so is the hydraulic conductivity of the saturated zone. In the north central part, steep hydraulic gradients were seen. Many of agricultural lands receive groundwater flow from the base of the hills for summer cultivation of crops especially around Waddem and Gavliwada villages. The hilly areas act as main groundwater recharge zones as seen from the flow lines. There were no major troughs and groundwater mounds in the area.

In case of the Curpem watershed (Figure 10), the groundwater flow mostly follows the ground topography and is in the east direction towards Salaulim Reservoir. Salaulim reservoir receives groundwater in the western side making it effluent in nature even during pre-monsoon season. The groundwater level gradients were low to moderate along with the hydraulic conductivity of the saturated zone. The hilly areas act as main groundwater recharge zones as seen from the flow lines. There are no groundwater troughs and mounds in the area. The groundwater flow net pattern remains almost identical during monsoon and post-monsoon seasons with minor changes for all the watersheds and therefore these flow net maps have not been included here for sake of brevity.

Trend analysis of groundwater level hydrograph

Long term and regular records of groundwater levels at a point provide temporal variations in the groundwater levels. The cause of temporal groundwater level variations can be due to natural, anthropogenic or combination of both the causes. For trend analysis, five water level recording points of CGWB were identified and water level data for last five years was collected from CGWB. The five sites were Waddem, Netrolim, Uguem, Valkini, and Deulwada. The location of these monitoring wells is shownin Figure 11. Only the first two sites were within the study area. Consistent data was not available for Waddem. The well hydrographs were plotted along with the corresponding rainfall data. The well hydrographs for open wells located at Netrolim and Deulwada are shown in Figures12 and 13 respectively. Based on the figures, it was seen that Netrolim well (that lies

within the study area) hydrograph did not show any decreasing trend whereas the well hydrograph at Deulwada located outside the study area in the western part did show a decreasing ground water level trend. The analysis of the bore well hydrographs located at three other sites did not show any decreasing trends.

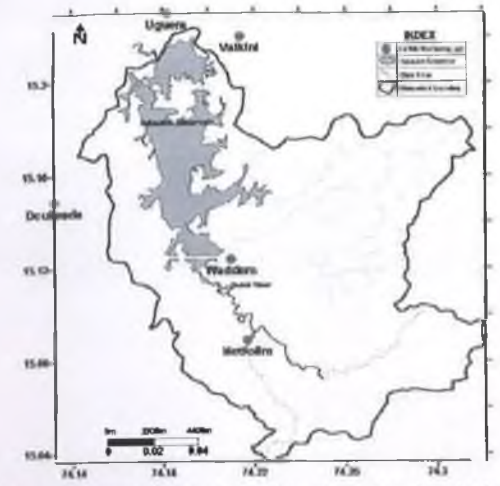


Figure 11: Location map showing CGWB monitoring stations in the watershed

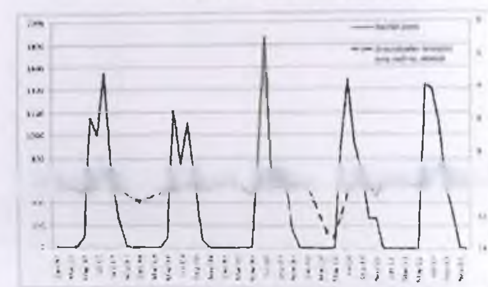


Figure 12: Well hydrograph at Netrolim site

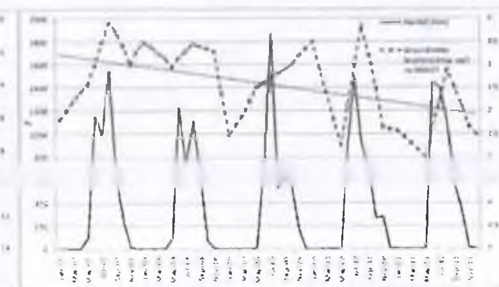


Figure 13: Well hydrograph at Deulwada site

Groundwater Quality

Groundwater quality examination was carried out for three seasons. The samples were collected for pre-monsoon, monsoon and post-monsoon seasons and analysed in the laboratory for the physico-chemical parameters such as pH conductivity, total dissolved solids, total suspended solids (TSS), chloride, hardness, alkalinity, potassium, sodium, nitrate, iron, manganese, BOD, COD and DO using the standard methods (APHA 2005). The details of seven sampling locations are given in Table 1 and shown in Figure 14. All the physico-chemical parameters were found to be within the stipulated limits. The iron, manganese, and total suspended solid (TSS) concentrations were used as indicators to assess impact of mining. The variation in TSS, iron and manganese during various seasons is graphically depicted in Figures 15, 16, and 17 respectively. The TSS values at locations such as Bhatimal, Neturlim, Curpem, Vichundrem, and Jaqui were high as compared to the other locations. Since they are open wells, the possibility of contamination is high.

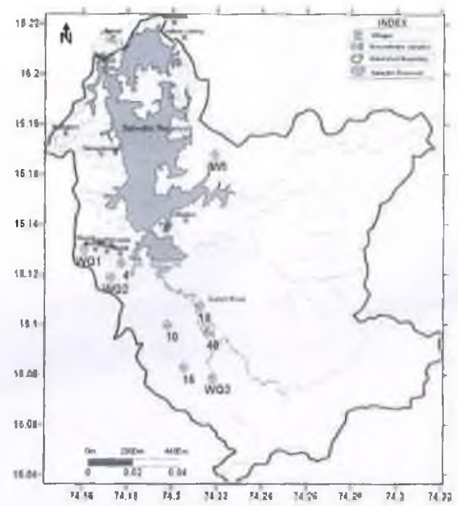


Figure 14:Sampling locations for groundwater quality monitoring

Table 1:Details of sampling locations for groundwater quality monitoring

S.N.	Well No.	Location	Watershed	Mine status / Approximate distance (km)
1	WQ 2	Sattarkarwada	Curpem	Active mine, 0.7
2	WQ 1	Naveli	Curpem	Active mine, 0.5
3	WQ 3	Savri	Guleli	Old mine, 2.0
4	Well 4	Curpem	Curpem	Active mine, 1.1
5	Well 10	Vichundrem	Guleli	Abandoned mine, 1.5
6	Well 18	Vichundremjamgar	Guleli	Old mine, 3.5
7	Well 40	Neturlim	Guleli	Old mine, 2.4
8	Well W8	Bhatimal	Kumbhari	Old mine, 2.5
9	Well 15	Jaqui	Guleli	Old mine, 1.0

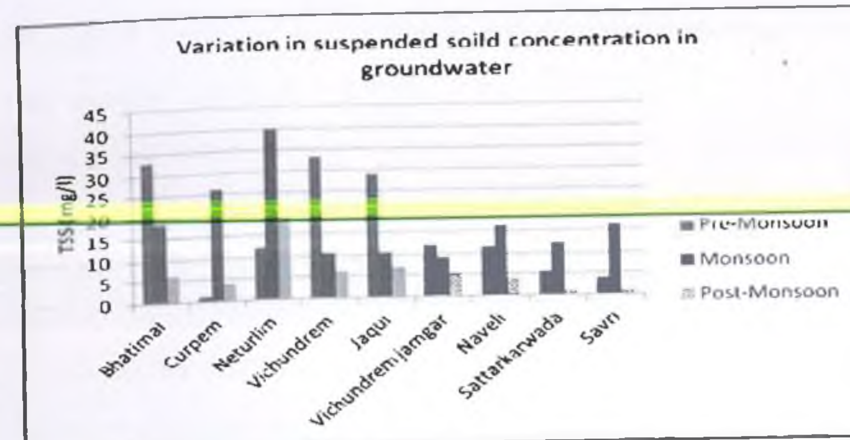
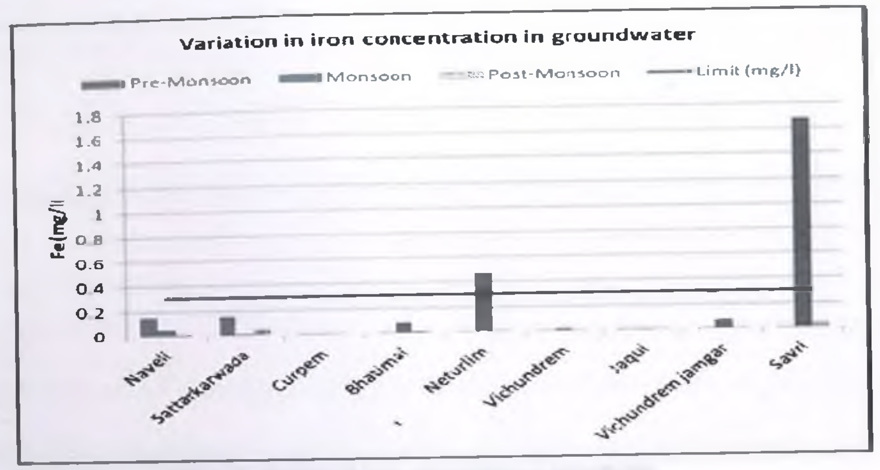


Figure 15: Variation in total suspended solid concentration in groundwater



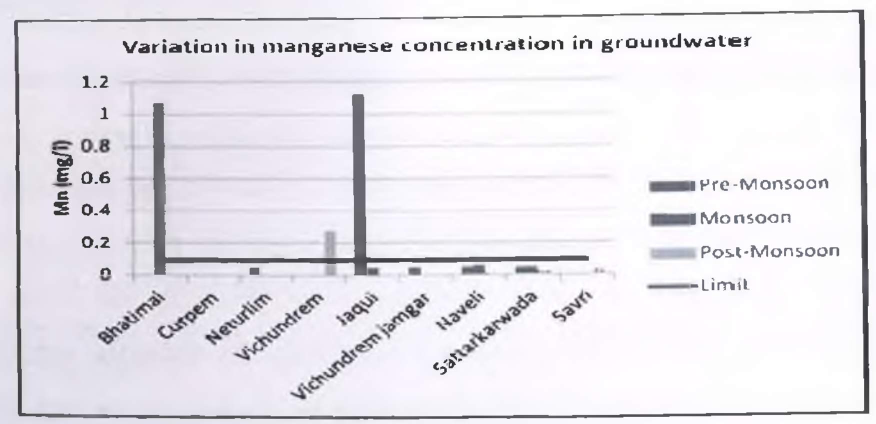


Figure 17: Variation in manganese concentration in groundwater

Groundwater quality near active mines

All the three locations (Naveli, Sattarkarwada and Curpem) in Curpem watershed which are close to the active/working mines showed increase in TSS concentration during monsoon season. This could be because erosion potential is more in the area. From the groundwater flow net diagram (Figure 10) it was observed that the flow is from Naveli towards Sattarkarwada, Curpem and finally towards reservoir. Their proximity to the active mines is also in the same order as shown in Table 1. This could also be the potential pathway of contaminant transport. The iron and manganese concentration at these locations were within the prescribed limit. The preliminary observation was that the iron concentration was more at the wells closer to the mine and decreased with the increase in the distance. However, more data would be required to analyse the trend, expected rate and chemical alterations during transport before drawing any conclusion.

Aquifer Tests in the Study Area

Aquifer tests were conducted at two different locations in the study area in order to estimate the aquifer transmissivity, storativity and hydraulic conductivity to determine the quantum of groundwater that can be safely withdrawn perennially from the aquifers. Two wells were identified typically in a lateritic terrain to carry out the pumping tests. These wells were open shallow dug wells. The aquifer was laterite with some degree of fracturing and weathering. The drawdown and recoveries in the pumped wells were recorded using the tape with millimetre division and a digital watch. The aquifer parameters that were determined are given in the Table 2.The saturated thickness of the aquifer for estimating the hydraulic conductivity was derived from vertical electrical sounding (VES) data on the well sites.

Table 2: Summary of aquifer parameters in the study area

Well No.	Transmissivity 'T' (m^2/day)	Storativity (fraction)	Hydraulic Conductivity, 'K' (m/day)	Saturated aquifer thickness (m)
14D	27	0.0014	16	1.69
6T	40	0.0086	15	2.67
Average	33.5	0.005	15.5	2.18

Based on the magnitude of aquifer hydraulic conductivity, the top shallow lateritic aquifer can be classified as moderate yielding aquifer. The average storativity values indicate that the aquifer can be classified as semi-unconfined aquifer. The aquifer parameters estimated in the above tests would represent the area in the immediate vicinity of the tested wells and hence, they can be considered as point values.

Computation of water demands and groundwater withdrawals for different sectors in the watershed

I. Demand Estimation:

1. Domestic water requirement

Water-shed	Area (ha)	Population density/ km^2	Population distribution in %		Per capita water usage Lpcd *		Total demands Per year		Total demand (Ham)
			Urban	Rural	Urban@200 lpcd	Rural@175 lpcd	Urban @73K lpc/yr	Rural @63875 lpc/yr	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*As per IS: 1172; 1993, population density as per 2011 census in SanguemTaluka is 88/km2. The rural and urban water demand values were realistic and based on the primary survey. Lpcd stands for litres per capita per day.

2. Agriculture water requirement

Watershed	Area under irrigation (ha)	Average annual water requirement *	Annual water demand (ham)
Salaulim	1800+	0.55m	990

+10% of the watershed area that is 1800 ha assumed to be under irrigated agriculture mainly under paddy, *CGWB and Department of Agriculture, Gov. of Goa 1997,

3. Industrial water requirement

Watershed Name	**Industrial Estate/Unit**	**Water requirement (ham/year)**
Salaulim	0	0

4. Livestock water requirement

Watershed Name	Livestock population	Water requirement per year @ 30 lpcd (10950lpc/yr)	Total requirement per year(ham)
Salaulim	3600*	39420000	3.9

*2007 census data, Govt of Goa, 0.2 cattle per ha of area

Therefore the total water demand for domestic, irrigation, industry, livestock and beneficiation worked out to be 1095 ham

II. Groundwater draft estimation:

1.Groundwater draft for irrigation

Watershed Name	Area (ha)	Number of structures*		Unit Drafts (ham)/yr		Total Drafts		Gross groundwater Draft(ham)/year
		DW	BW	DW	BW	DW	BW	
Salaulim	18000	22	88	0.27	0.54	5.94	47.43	53.37

*In SanguemTaluka there were106 irrigation dug wells and 426 bore wells spread over an area of 87375 hectares of the taluka. The number of units per hectare of area therefore works out to be 0.0012/ha and 0.00488/ha respectively of dug wells and bore wells, *CGWB (2011).

2. Domestic groundwater draft

Watershed Name	Area (ha)	Number of structures*		Unit Drafts*(ham)/yr		Total Drafts		Domestic groundwater Draft(ham)per yr
		DW	BW	DW	BW	DW	BW	
Salaulim	18000	90	0	0.073	-	6.57	-	6.57

*Each of the domestic wells was estimated to draw about 2m^3 of water per day. The domestic wells were used throughout the year. The density of domestic wells was estimated to be about 10 per km^2 of the settlement area which is about 5% of the total catchment area.

3. Mine pit dewatering of the groundwater from 4 active mines

S.No.	Watershed	Annual groundwater discharge (KL)	Total discharge (ham)
1	Curpem	150000	15

Total groundwater draft =74.94 ham

III Groundwater recharges estimations:

1. Groundwater recharge by water table fluctuation method

S.No.	Watershed Name	Area suitable for GW recharge (ha)	WT fluctuation (m)	Specific yield of shallow aquifer (fraction)	Monsoon recharge (ham)
1	Salaulim	5400*	1.063	0.03+	172

*30% of the watershed area is considered suitable for recharge, +specific yield value of 0.03 is adopted from CGWB (2011)

Conclusion & Recommendation

The total groundwater availability in three watersheds worked out to be 192 hectare meter per annum and the stage of groundwater development was 38.84% which, according to the Ministry of Water Resources (2009) is classified as 'Safe'. The groundwater mainly gets recharge from the forested areas as compared to the low lying plain areas. It gets discharged in the low lying paddy fields, reservoir and rivers. It should be noted that this is based on the fact that only 4 mines were working. The groundwater draft would change if more mines are allowed in the watershed.

Well hydrographs that were plotted using secondary data from CGWB indicate that, there was no decrease in groundwater levels in the study area. However, a decreasing trend was observed in a well which lies close to the watershed but not within it. Taking this as an indication, judicious development/withdrawal of groundwater in future is warranted. The groundwater flow net analysis was carried out to understand the potential pathway of contaminant. The preliminary observation was that the iron concentration was more at the wells closer to the mine and decreased with the increase in the distance. However, more data would be required to analyse the trend, expected rate and chemical alterations during transport before drawing any conclusion.

A holistic approach is essential to control and prevent further adverse impact on the Salaulim reservoir owing to point and non-point sources of pollution. For attaining the desired objective of minimizing the negative impact on water quality and reservoir capacity due to sedimentation, four strategies are recommended which should be implemented concurrently. These include (i) preventive measures for control of soil erosion at sensitive areas in the watershed; (ii) control measures; (iii) treatment measures to improve raw water quality at the reservoir; (iv)institutional and governance measures. Two key recommendations are:

- Regular monitoring of surface and groundwater quality and levels should be carried out to keep a check. For observing the impact on deeper aquifers, shallow and deep piezometers should be constructed close to the mine area for monitoring the water levels in the shallow and deeper aquifers respectively.
- The working mines should strictly implement all the control measures to prevent water pollution and should adhere to proper management plan at the time of closure. New mining activity should not be allowed in the immediate vicinity of the reservoir and especially in the micro-watersheds that have been identified as areas of high erosion potential.

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