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Impact Analyses of Industrial and Mining Activities on Groundwater Regime -Case Studies in Goa

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Abstract: In the present study analysis of impacts of industrial and mining activities on groundwater regime has been carried out. It is found that mining activities in specific locations have been impacting both shallow groundwater as well as moderately deep groundwater systems. The industrial activity at one site studied has not indicated significant change in groundwater levels during the study period. The geological data indicate that the shallow aquifers located in the peripheral areas of the Plateau region are in continuity with plateau laterites and behave as a single geological unit.

Keywords: *Hydrograph, Mining, Piezometer, Verna*

Introduction:

The measurement and analysis of ground water level fluctuations in piezometers and observation wells is an important facet of groundwater studies. Water-level fluctuations can result from a wide variety of hydrologic, meteorological, and hydrogeological phenomena. Some are natural phenomena like groundwater recharge, evapotranspiration, phreatophytic consumption, bank storage effects near streams, tidal effects near oceans, change in atmospheric pressure, earthquakes etc. and some induced by man such as external loading of confined aquifers, artificial recharge, groundwater pumping, deep-well injection, return flows from irrigation, geotechnical drainage and open pit mine pumping, land use changes etc. In many cases, there may be more than one mechanism operating simultaneously.

Well hydrographs even under natural undisturbed conditions show seasonal and diurnal fluctuations. Only the long term fluctuation (secular) is absent. Reduced rainfall or changed climatic conditions will lead to changes in groundwater levels even in the absence of anthropogenic causes. On the other hand under human induced conditions this balance can still be retained by well-managed recharge and discharge conditions in an area. This means in an area where tremendous anthropogenic activities are witnessed involving the groundwater regime and still the well hydrograph do maintain their undisturbed original trend could only mean that the groundwater regime is balanced. In other words the system has reached a steady state condition.

Aquifer response to recharge to and discharge from it is indicated in the water level changes measured at different time periods. Unconfined aquifers, which are in continuity with the ground surface and the atmospheric pressure, are quicker in responding than confined and semi confined aquifers. The magnitude of change in water level below ground at a given point depends not only on magnitude of groundwater withdrawals and recharges but also on the intrinsic characteristics of geological matrix both of saturated and unsaturated zones besides initial water table depths and antecedent soil moisture conditions. For example long and steady spell of rain on a loamy saturated soil with deep water table condition in a highly permeable geologic section could raise the water table to greater height than an intense rainfall event of shorter duration on dry clayey soil with shallow water table condition in a low permeable geologic section. Qualitative information on the saturated – unsaturated media, nature of aquifer recharges and discharges can be ascertained from the study of well hydrographs. For example identical features in rising and falling limbs of the hydrographs from different locations in the watershed should indicate similar aquifer hydraulic conditions. In order to achieve such objectives the observation wells and piezometers should have to be located carefully so that each of them represents a sizable hydrogeological regime in space and depth and should be well distributed over the entire watershed area.

Objective of the Present Study:

Groundwater regime in the State of Goa has been subjected to variety of anthropogenic stresses such as mining, industrialization and urbanization. Mining and industrialization have been on rise in the recent past and have impacted groundwater regime in several ways. It is therefore intended in the present study to evaluate impacts if any of mining and industrialization on the groundwater regime at selected locations through study of well hydrographs both from shallow as well as deep aquifers.

Methodology:

In order to achieve the set objectives two locations have been selected one representing the industrial Estate and other representing open cast iron ore mining. In the industrial Estate 24 open wells were identified and the shallow groundwater levels were monitored on monthly basis for three years and in the mining area 4 piezometers were installed and groundwater levels were monitored over a period of three years. Continuous water levels measurements were also made on one of the piezometers. Rainfall data for the corresponding period were collected. The locations of these monitoring wells are shown in the base map. After completion of the data collection the appropriate data was plotted as well hydrographs and these were subjected to analysis and interpretation. The results of these are presented in this paper.

Locations of the Study Area:

1. Study around the Industrial Estate:

In Goa there are as many as eighteen industrial Estates and many are proposed. Verna Industrial Estate is one of the largest industrial hubs located between Margao and Panaji. It is located about 20km from Panaji city side by the highway connecting Panaji to Margao. The area under study is a part of Marmagoa and Salcete taluka of South Goa district. The area is represented on Survey of India (SOI) toposheet numbered 48 E/15 and 48 E/ 15/5 of 1:25000 scale. It is situated between Latitudes: N 15° 17’ 30’’ to N 15° 25' 00’’ and Longitudes: E 73° 54’ 30’’ to E 74° 00' 00’’ and covers an area of about of 46 km^2. The north-eastern region of this area is bounded by the Zuari River. There are several villages on the periphery of this industrial estate (Fig.1). There are about 200 bore wells drilled to a depth ranging from 60m to 100m below ground to abstract ground water for various uses. These bore wells generally tap confined to semi confined aquifers. On the plateau there are few open wells and few filter points taping shallow perched aquifer in local depressions, on the foot hill regions shallow dug wells are commonly dug for domestic use by the villagers. The plateau on which the Verna Industrial Estate stands act as rainfall recharge area to the shallow aquifers located in the periphery of the plateau. Any change in the land use on plateau may affect the recharge to these shallow aquifers extent the wells dry.

Figure 1: *Location of the Verna Industrial Study Area*

The study area comprises of Barcem and Sanvordem Formation of Goa group of rocks and includes essentially metagrey-wackes, conglomerates and meta-basalts with subordinate metasediments. In most of the places these formations are capped by laterites and in the lower reaches by sands and sandy clays.

Results and Discussions-Industrial Case Study Area:

In and around the Verna industrial estate 24 open wells were established and the groundwater levels were monitored in these wells on monthly basis for three years. The monitoring well locations were transferred on the base maps (Fig.2). After completion of the data collection the appropriate data was plotted as well-hydrographs and these were subjected to analysis and interpretation. Rainfall data is also plotted for the corresponding time. Two typical well hydrographs for the study area are shown in Figs. 3 and 4.

The rainfall variation in the area during the groundwater level monitoring is such that from 2006 to 07 it increased by 12% followed by about 17% decrease during 2007 to 08. However, from 2008 to 09 and 2009 to 10 the rainfall increased by 9% and 18% respectively. In 2006 the rainfall started in May and it increased in June while the peak to groundwater levels reached in June. During 2008 the rainfall started in June but decreased in July causing the groundwater levels to reach peak levels only during August. Where as in 2009 the rains started in June but increased in July causing the groundwater levels to reach peak heights during July itself. Drastic fall in rainfall during August 2009 is reflected in the corresponding fall in groundwater levels. There was sizable rainfall during October and November during years 2009 and 2010. This late rainfall is again reflected in the less rapidly falling limb of the hydrograph during 2009-10 compared to 2008-09 especially in well number 23.

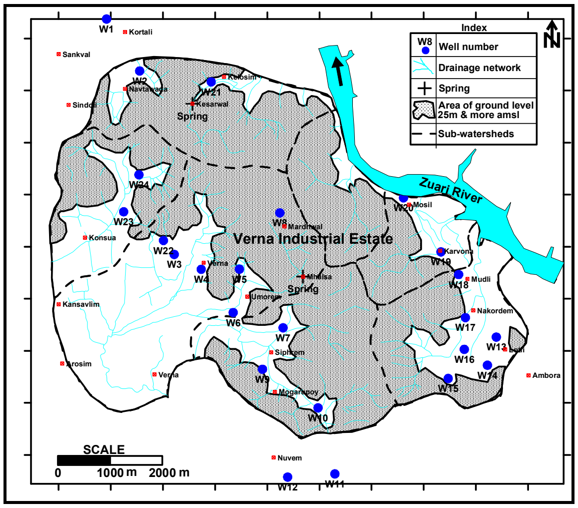

Figure 2: *Location of the Groundwater Level Monitoring Wells in and around the Study Area*

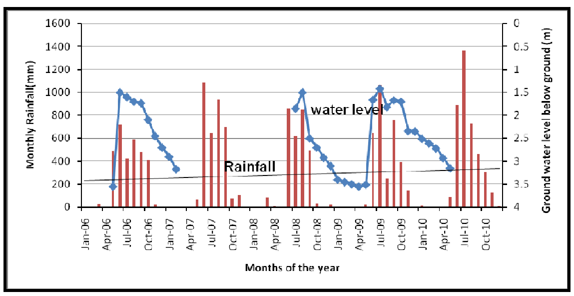

Figure 3: *Groundwater Level Hydrograph for Well no. 23 in the Study Area*

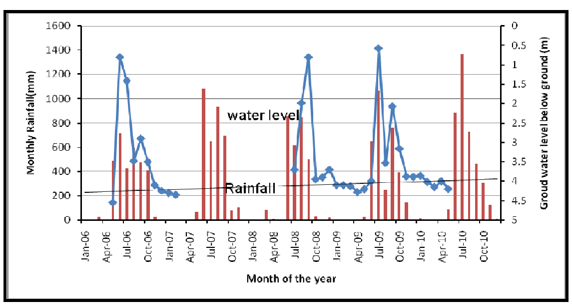

Figure 4: *Groundwater Level Hydrograph for Well no. 18 in the Study Area*

As seen from the above figures the rainfall during the period of record has increased to some extent steadily except during the year 2008. The groundwater levels show a seasonal fluctuation in their temporal behavior during those three years of recording. The distribution of rainfall intensity and duration influences the behavior of the groundwater level fluctuations.

It is observed from the hydrographs that there is no significant change in the groundwater levels over the period of recording and the fluctuations are only seasonal due to rainfall recharge and various abstractions during non monsoon season. The following conclusions can be drawn:

1. The groundwater levels show fluctuations mainly due to rainfall recharge and various abstractions. With existing short term water level data and in the absence of pre industrial groundwater level records it shall be unwise to conclude on the long term behavior of the phreatic groundwater levels in the area. However, it is learnt from the field inquiries from the well owners that the groundwater levels in the area in lateritic aquifers have not changed significantly in the past.
2. The geological data indicate that the shallow aquifers located in the peripheral areas of the Verna Plateau are in continuity with plateau laterites and behave as a single geological unit.
3. The peripheral shallow aquifers around the Verna Plateau are also fed by rainfall recharge that could be taking place on the Plateau area.

2. Study around Mining Lease Area:

Mining in Goa is considered as backbone of Goa's economic activity. Opencast iron ore mining has been on rise with mechanized means. The recent trends of iron ore markets have attracted many to enter into mining activity. This has led to widespread unscientific mining activity causing multiple impacts on other resources including groundwater. In the present study it has been attempted to evaluate the possible influences of open cast mining on groundwater regimes in the neighborhood of the mining activity. Two locations have been chosen for this study one is located in the close proximity to the Arabian sea and the other in the interior area.

Study Area Location:

This study area falls in the Survey of India Toposheet No. 48 E/4. The mine is situated at latitiude N 15^{0} 28$^{'}$ 20$^{''}$ and longitude E 73^{0} 35$^{'}$ 44$^{''}$ in Bardez taluka, North Goa. The lease area is located on the northeastern flank of the plateau extending northwest southeast (Fig.5). The plateau is elevated to about 128m above sea level and the drainage network is almost negligible. The surface run-off moves on north and south along the slopes. A village is located along the southeastern boundary of the mine lease. The present study area is an iron ore mine where in the mine pits are located at the hill bottom. The slope of the hill is fairly steep and made up of detrital laterites and siliceous clays lying above the sequence of clays. The laterites are blocky in nature and have gaps between the blocks which provide avenue for rain water percolation and saturation. Four piezometers were installed to a depth varying from 77m to 105m below ground as shown in figure 5. The fourth piezometer could not remain intact due to collapse inside and groundwater levels recording could not be continued.

The details of the lithological logs recorded during the drilling of the four piezometers in the study area are given in Table 1. As seen from the lithological sections the laterite is found upto 19m depth in the area. It is generally hard and compact on the surface and becomes gradually soft and gravelly with depth. Except at piezometer no. 2 remaining sections do not have phyllitic clay layer under laterite. Siliceous and chlorite schists are very often encountered in this area.

Figure 5: *Location of the Piezometers around the Mining Lease*

Seasonal Behavior of Groundwater Levels:

Of the 83 days of southwest monsoon recorded up to 12.8.2009 there was no rain for 26 days, and rainfall was less than 10mm for 16 days. Only two days on 6/6/09 and 1/7/09 it rained about 300mm on each day. Remaining days witness moderate rains. The uneven distributions of rainfall events have increased in the last one decade and the number of rainy days has come down drastically. Although the total monsoon rainfall in Goa does not change substantially but its time distribution has become uneven. Most of the time it rains heavily within a short time spans leaving rest of the monsoon days dry. The total southwest monsoon rainfall up to 30/6/2009 just before the second highest rainfall event was 760.20mm (Fig.6).

The groundwater level hydrographs at piezometer 1 and 2 (Fig. 6) have not shown significant rising levels during this period. This indicates that during this period the effective rainfall infiltration was used to saturate the soil moisture and the zone of aeration in the area besides interflows.

The second rainfall peak occurred on 1/7/09 and all the hydrographs soon showed a rising trend which is quick in time and has a steep rising limbs. This indicates that the aquifers tapped by the piezometers are mainly unconfined in nature. The steep falling limb of hydrographs of piezometer 1 and 2 further indicate that the aquifer is fairly permeable thereby diffusing the raised groundwater levels quickly. In piezometer 3 the falling of groundwater level is fairly slow and it decays over a period of time. No assessment could be made for piezometer 4 as the data was not complete. Except in piezometer 1 the groundwater levels in piezometer 2 and 3 continue to fall despite occurrence of rainfall events post 1/7/09 rainfall event indicating rapid aquifer drainability.

Table 1: Lithological Details of Piezometers in the Study Area

Bore hole no: PZ-1 Date 19/5/09		Depth :105.40m Water Table:84m
Depth Range(m)		**Lithology**
From	**To**	
0.00	12.00	laterite
12.00	45.00	siliceous chlorite
45.00	61.00	Chlorite Schist
61.00	90.00	Clay & Chlorite Schist
90.00	105.40	Chlorite Schist

Bore hole no: PZ-2 Date : 29/5/09		Depth : 77 m Water Table:84m
Depth Range(m)		**Lithology**
From	**To**	
0.00	18.00	laterite
18.00	27.00	phyllitic clay
27.00	48.00	Chlorite Schist & Clay
48.00	77.00	Chlorite Schist

Bore hole no: PZ-3 Date: 20/05/09		Depth :95.70m Water Table:62m
Depth Range(m)		**Lithology**
From	**To**	
0.00	19.00	laterite
19.00	95.70	Chlorite Schist

Bore hole no: PZ-4 Date :22/05/09		Depth: 80m Wate Table:60m
Depth Range(m)		**Lithology**
From	**To**	
0.00	18.00	laterite
18.00	47.00	Siliceous chlorite
47.00	57.00	Siliceous phyllite
57.00	65.00	Friable silica
65.00	80.00	powdery iron ore

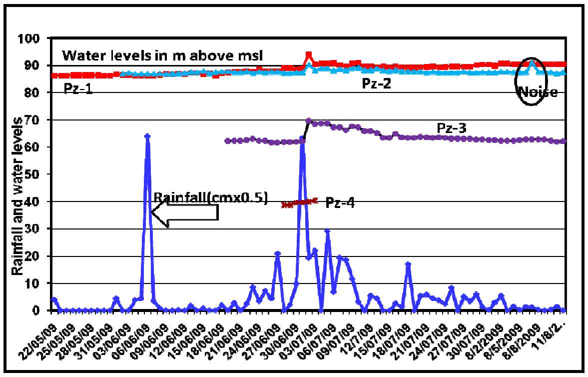

Figure 6: *Short Term Variation of Groundwater Levels and Rainfall*

Long Term Behavior:

The long term three years groundwater level hydrographs are shown in Figs. 7, 8 and 9 respectively for piezometers 1, 2 and 3. In piezometers 2 and 3 several sharp spikes, both positive and negative are seen in the non-rainy season of 2009-10 as well as 2010-11. These spikes are also seen in piezometer 1 but less pronounced. The mine pit is dewatered during non-rainy season which would cause cone of depression in the ground water levels. As the piezometers 2 and 3 are close to the mine pit than piezometer 1 the water level fluctuations are more conspicuous in the piezometers 2 and 3. These non-rainy season water level fluctuations indicate that the mine pit has hydraulic connection with the surrounding aquifers. The water levels respond very moderately to normal rainfall events. On the other hand if the rainfall is exceptionally high the spiked behavior in the water levels is conspicuously seen as shown in 2009 monsoon season. The water level in piezmeter 1 kept on rising between the two spiked rainfall events on 6/6/2009 and 1/7/2009; however, the water levels in the other two piezometers fell during the corresponding time. This might be due to hydraulic disposition and variable hydraulic parameters of the aquifer tapped by piezometers. Groundwater levels have remained within the limits of seasonal fluctuations during the period of observation.

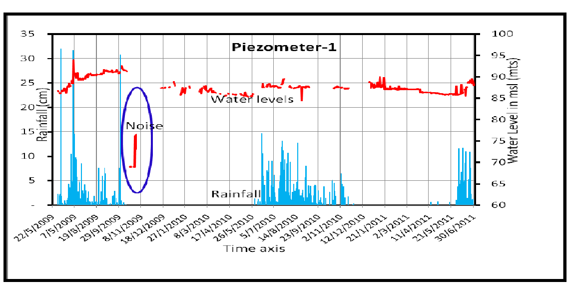

Figure 7: *Ground Water Level Hydrograph At Piezometer-1 along with Rainfall*

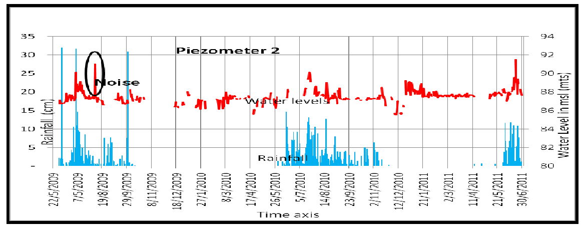

Figure 8: *Ground Water Level Hydrograph At Piezometer-2 along with Rainfall*

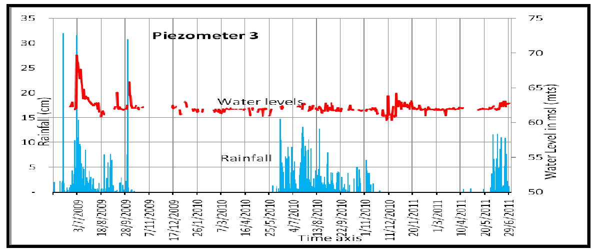

Figure 9: *Ground Water Level Hydrograph at Piezometer-3 along with Rainfall*

The impact of rainfall runoff on the mine pit water levels is shown in Fig.10 The mine pit water levels have been rising gradually till the second rainfall event that took place on 1/7/09. There is spike in the pit water level due to surface runoff contribution from the rainfall event on 1/7/09. The fact that the general pit water level is around a steady 40m amsl during the entire period except for spikes indicate normal draining of pit water by way of outflow. The gradual rise in pit water levels from June to July can be attributed to base flow and interflow contributions to the mine pit.

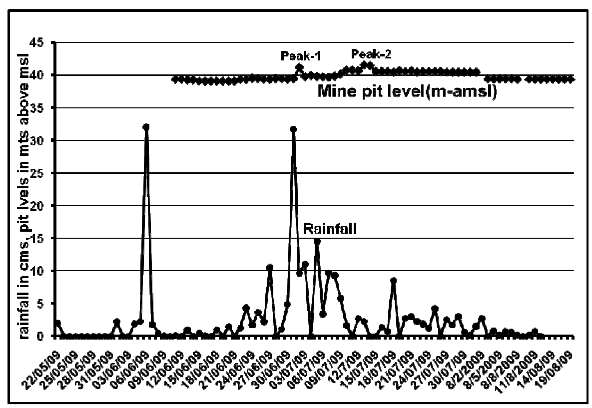

Figure 10: *Variation of Pit Water Level due to Rainfall*

Conclusions:

The Vernal plateau at Verna industrial estate act as groundwater recharge area to the peripheral shallow aquifers. The groundwater levels have not shown significant change in their trend during the period of record. Although long term water level data is necessary for drawing conclusions on the trends of groundwater levels however, inquiries from the owners of the wells show that there is no much change in the groundwater levels in the area. The fact that the mine pit water level remains constant at around 40m amsl indicates that the surrounding aquifer continuously contributes to the mine pit water and hence mining activity certainly leads to groundwater runoff in the area. Also the groundwater levels are much higher than the mine pit water levels therefore ground water flow occurs to the pit due to favourable hydraulic gradient towards the pit.

References:

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