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IMPACT ASSESSMENT OF IRON ORE MINING ACTIVITIES ON GROUNDWATER REGIME IN MINING REGION OF GOA

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ABSTRACT

In the present study, the estimation of the impacts of mining activities on the quantitative scenario of the groundwater regime in the study area and the assessment of fluctuation in the temporal behavior of groundwater level has been carried out through the approach of well hydrograph. The careful interpretation of the hydrographs has evidenced a notable trend of groundwater level for each well hydrograph. 37 well hydrographs out of 45 (82.2%) were observed with increasing trend and only 8 well hydrographs (17.8%) were observed with no trend. The increasing trend is an indicative of the surplus amount of groundwater recharge in these aquifers, while the well hydrographs showing no trend indicate the delicate balance between the recharge and discharge of the groundwater regime and represent an undisturbed condition. From this study, it is clearly apparent that the impact of mining activities on the quantitative scenario of groundwater resources in the study area is limited to the pre-monsoon season only and despite the huge stress of mining and excavation activities, the groundwater system is not under much disturbed condition.

KEY WORDS
Aquifer
Discharge
Ground water fluctuation
Laterite
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INTRODUCTION

Groundwater is a vital source of potable water for much of the world's population (Varghese and Jaya, 2011). It can be regarded as a renewable natural resource if there is a delicate balance between recharge and discharge of aquifers (Voudouris, 2006). Over the few decades rapid economic development, associated with the population explosion and growing urbanization, resulted in an increased demand of water for irrigation, domestic and industrial purposes (Ravikumar and Somashekar, 2010). These rising stresses on groundwater resources and associated concerns necessitate proper planning for sustainable development and management of groundwater resources, which requires estimation of groundwater recharge, trends of fluctuation in water level and effect of various activities on its overall availability. The estimation of ground-water recharge and fluctuation in water level is an important facet of hydrogeological studies. The fluctuations in water-level can result from a wide variety of hydrological, meteorological, and hydrogeological phenomena (Todd, 1980). The responses of aquifer to recharge and discharge are by the changes in water level, measured at different time periods. The response of unconfined aquifers, which are in continuity with the ground surface and the atmospheric pressure, is quicker than confined and semi-confined aquifers (Neuman, 1972; Chachadi and Choudri, 2004; Chachadi, 2012). Several approaches have been found in the literatures related to the estimation of groundwater recharge, which can be grouped as follows: inflow methods (soil moisture budgets), aquifer response methods (well hydrograph analyses) and aquifer outflow methods (river hydrograph analyses) (Misstear, 2000; Misstear *et al.*, 2006). Aquifer response analysis is the best method for the estimation of groundwater recharge over a short period of time in regions having shallow aquifer and exhibit sharp rises and fall in water levels (Scanlon *et al.*, 2002). The aquifer response analysis can be done by both qualitative and quantitative estimation (Misstear, 2000). The qualitative analysis comprises the examination of hydrographs (Misstear, 2000). Hydrographs show seasonal and diurnal fluctuations even under natural undisturbed conditions, but the long term fluctuation is absent (Chachadi, 2012). The patterns of fluctuation of the water table in a hydrograph primarily reflect the timing and magnitude of recharge (Winter *et al.*, 2000). Hydrographs are important for the estimation of hydrological and hydrogeological conditions of aquifers (Ferdowsian and Pannell, 2009). The trends of changes in water-level of a well hydrograph are regulated by physical characteristics of the aquifer, rainfall pattern and the correlation between recharge to and discharge from an aquifer (Ferdowsian and Pannell, 2009). Goa is a State blessed with rich groundwater resources and groundwater is the largest accessible source of fresh water for the people. The most important water bearing formations in Goa are laterites. The topographical settings of laterites influence their water bearing capacity. To extract the iron ore, mining activities have been done by cutting the top lateritic cover on the plateaus and removing the clay overburden, which invariably resulting in the disturbances of groundwater regime. Therefore, the present study envisioned towards the estimation of the impacts of mining activities on the quantitative scenario of groundwater in the study area through the approach of well hydrograph. The study also documented the response of the groundwater system to the rainfall pattern during the study period.

Study area

Goa is the 25th State of India, lies between the latitudes 14º53'54" N and 15º40'00" N and longitudes 73º40'33" E and 74º20'13" E with geographical area of 3,702 km^2 and a coastline of 105 km. The study area comprises of the areas wherein mining activities in Goa are confined along with a belt of five km from the lease boundary, situated in 5 mining Talukas namely Bicholim, Sattari, Dharbandora, Quepem and Sanguem, encompassing an area of 1513 km^2. The map of the study area with the groundwater sampling stations is depicted in Fig. 1. The details of sampling stations are presented in Table 1.

Climate and rainfall

Due to maritime influence, the diurnal range of temperature during the day is not large. The diurnal range is least being 4 to 6° C during the monsoon season and increases to the maximum of 10 to 20° C during December and January. May is the hottest month where the mean daily temperature increases to 30° C. January is the coolest with mean daily temperature of about 23° C. It is noted that the day temperature is lowest during the monsoon months of July and August and not in the cool winter months of December and January. The temperature is highest (around 33° C) during pre - monsoon months of April and May and again during post monsoon months of November and January. Due to proximity to the Arabian Sea, humidity throughout the year is more than 60% with a range from 80 to 90% during the monsoon period.

The area receives abundant rainfall during the monsoon period between June to October. The minimum and maximum temperature lies within the range of 20º C to 36ºC. The mean relative humidity varies from a minimum of 80 to 85 percent in April to a maximum of 90 to 95 percent in the month of July. The overall climate of the area can be classified as humid tropical. The average rainfall from 2009-2012 is 3591.88mm. The monthly rainfall pattern of the study area from 2009-2012 is presented in Table 2.

MATERIALS AND METHODS

For the current study, 45 groundwater sampling locations (open wells), which are mostly used for domestic and agricultural purposes were selected to monitor variation in groundwater level and to represent the impact of mining on the groundwater table and aquifer properties. The groundwater levels were measured on a seasonal basis (Chachadi, 2012) (*i.e.* post-monsoon, winter, summer, and monsoon) from October 2011 to September 2012 in all 45 monitoring wells. Details regarding the well location, dimensions, depth to static water level, aquifer material, etc. were collected and tabulated for each well. Rainfall data for the corresponding period were collected. The monthly ground water levels and monthly rainfall were compiled and plotted as well hydrographs (Moon *et al.,* 2004; Chachadi, 2012). Based on the rise and fall of water level, all the wells have been categorized accordingly during the study period (Chachadi and Choudri, 2004; Chachadi, 2012).

RESULTS AND DISCUSSION

The hydrographs obtained by plotting the monthly water level fluctuation for all the 45 selected monitoring wells and monthly rainfall have provided vital and fascinating information on the impacts of open-cast mining activities on groundwater regime in the study area. Based on the trends of water table fluctuations of hydrographs, all the well hydrographs in the study area have been categorized into two types; well hydrographs with rising trend and well hydrographs with no trend as presented in Table 3. Five well hydrographs have been presented in Fig. 2, Fig. 3, Fig. 4, Fig. 5 and Figure 6 as representative of all the hydrographs. Fig. 2, Fig. 3 and Fig. 4 represent the well hydrographs with rising trend while Fig. 5 and Fig. 6 represents the hydrographs with no trend. Increasing trend of the well hydrographs was observed at 37 locations out of 45 (82.2%) and only 8 well hydrographs (17.8%) were observed having no trend as depicted in Table 4. The increasing trend is an indicative of the surplus amount of groundwater recharge in these aquifers when the annual recharge exceeds annual discharge.

The well hydrographs showing no trend indicate the delicate balance between the recharge and discharge of the

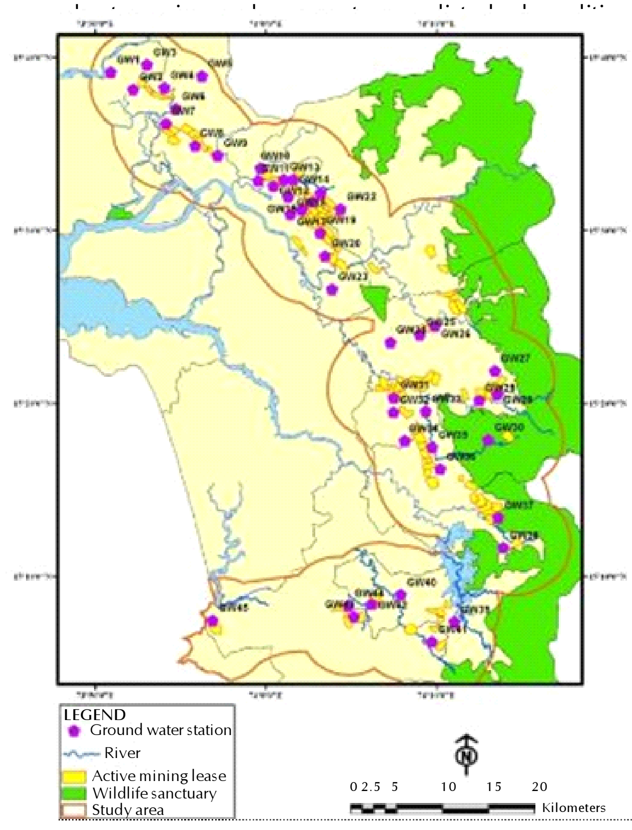

Figure 1: Map of study area with location of ground aater sampling stations

Table 1: Details of ground sater sampling stations within the study area

Well Code	Name of the village	Taluka	Latitude (North)	Longitude (East)
GW1	Revora	Bardez	73°15′54″	15°39′9″
GW2	Kansa (Tivim)	Bardez	73°52′14″	15°38′9″
GW3	Pirna	Bardez	73°53′2″	15°39′36″
GW4	Kasarpal	Bicholim	73°54′3″	15°38′15″
GW5	Advapale	Bicholim	73°56′15″	15°38′55"
GW6	Mulgao	Bicholim	73°54′44″	15°37′1″
GW7	Shrigao	Bicholim	73°54′8″	15°36′11″
GW8	Mayem(Maem)	Bicholim	73°55′51″	15°34′55″
GW9	Dhabdaba	Bicholim	73°57′11″	15°34′19″
GW10	Vajri	Bicholim	73°9′41″	15°33′36"
GW11	Virdi	Bicholim	73°59′33″	15°32′51"
GW12	Kudnem	Bicholim	74°0′36″	15°32′34"
GW13	Gauthan	Bicholim	74°1′4″	15°32′56″
GW14	Harvalem	Bicholim	74°1′37″	15°32′57″
GW15	Phal (Kudnem)	Bicholim	74°1′18″	15°31′57″
GW16	Shonshi	Bicholim	74°2′44″	15°31′39″
GW17	Dignem	Bicholim	74°2′7″	15°31′12"
GW18	Khodguinim (Surla)	Bicholim	74°1′26″	15°30′56″
GW19	Velguem (Surla)	Bicholim	74°3′12″	15°29′52″
GW20	Ambegale (Pale)	Bicholim	74°3′29″	15°28′31″
GW21	Dhandkal (Honda)	Sattari	74°3′13″	15°32′0″
GW22	Pissurlem	Sattari	74°4′23″	15°31′14″
GW23	Usgao	Dharbandora	74°3′53″	15°26′36″
GW24	Dharbandora (Tamsodo)	Dharbandora	74°7′84″	15°23′36.3″
GW25	Talasay	Dharbandora	74°9′2″	15°32′60″
GW26	Sancordem	Dharbandora	74°9′40.4″	15°24′40.2″
GW27	Mollem	Sanguem	74°13′26″	15°21′53″
GW28	Bimbal	Sanguem	74°13′34″	15°20′31″
GW29	Sigao	Sanguem	74°12′31″	15°20′10″
GW30	Kharmal (Calem)	Sanguem	74°30′ 2″	15°17′54″
GW31	Codli-Dabal	Dharbandora	74°7′41.9″	15°20′9.6″
GW32	Kirlapale	Dharbandora	74°7′29″	15°19′29″
GW33	Karmani (Carmone)	Dharbandora	74°9′23″	15°19′33″
GW34	Bandoli	Dharbandora	74°8′9″	15°17′51″
GW35	Dukarkand	Sanguem	74°9′45″	15°17′28″
GW36	Costi (Kashti)	Sanguem	74°10′13″	15°16′12″
GW37	Chinchegal (Tudou)	Sanguem	74°13′38″	15°13′23″
GW38	Bati	Sanguem	74°13′55″	15°11′47″
GW39	Curpem	Quepem	74°11′3″	15°7′22″
GW40	Colomba	Quepem	74°7′55″	15°8′56″
GW41	Sulcorna	Quepem	74°9′43″	15°6′12″
GW42	Rivona (Shinshore)	Quepem	74°6′13″	15°8′24″
GW43	Maina	Quepem	74°5′10″	15°7′40″
GW44	Kanvre (Cavrem)	Quepem	74°4′50″	15°8′18″
GW45	Betul	Quepem	73°56′53″	15°7′27″

Table 2: Rainfall pattern (monthly) from 2009-2012 for the study area (IMD)

Months	Rainfall (mm)			
	2009	2010	2011	2012
January	-	10.4	-	-
February	-	-	-	-
March	-	-	-	-
April	0.5	7.7	13.6	0.1
May	4.0	60.2	5.4	0.6
June	649.2	828.3	1084.1	1101.0
July	1381.8	1291.1	1119.5	901.5
August	347.5	811.9	889.7	821.8
September	436.1	497.9	524.6	333.0
October	354.7	312.3	88.6	118.3
November	155.2	185.9	13.4	5.0
December	-	12.6	-	-
Total	3329	4018.3	3738.9	3281.3

season as it can be seen from the hydrographs. It is discussed above that once the groundwater table attained the shallowest level during the monsoon season, it takes time to attain the level of pre-monsoon due to various natural and anthropogenic reasons. That is why, there is gradual and slow depletion of the water level due to continuous discharge of groundwater after the termination of monsoon rain and achieved the deepest level during pre-monsoon season. The discharge is aggravated due to greater depth of mine pits than the aquifers. Heavy monsoon rain in this region is primarily responsible for maintaining the balance between recharge and discharge.

Studies from Chachadi and Choudri (2004) have also claimed that the large amounts of reject dumps (about 700MT) owing to high stripping ratio have a good hydraulic conductivity. These reject dumps act as a good recharge source for the

Table 3: Classification of well hydrographs in the study area based on water table trend

Well Code	Name of the village	Rising trend	No trend
GW1	Revora	-	Yes
GW2	Kansa (Tivim)	Yes	-
GW3	Pirna	Yes	-
GW4	Kasarpal	Yes	-
GW5	Advapale	Yes	-
GW6	Mulgao	-	Yes
GW7	Shrigao	Yes	-
GW8	Mayem(Maem)	Yes	-
GW9	Dhabdaba	Yes	-
GW10	Vajri	Yes	-
GW11	Virdi	Yes	-
GW12	Kudnem	Yes	-
GW13	Gauthan	Yes	-
GW14	Harvalem	Yes	-
GW15	Phal (Kudnem)	Yes	-
GW16	Shonshi	-	Yes
GW17	Dignem	Yes	-
GW18	Khodguinim (Surla)	Yes	-
GW19	Velguem (Surla)	Yes	-
GW20	Ambegale (Pale)	Yes	-
GW21	Dhandkal (Honda)	Yes	-
GW22	Pissurlem	-	Yes
GW23	Usgao	-	Yes
GW24	Dharbandora (Tamsodo)	Yes	-
GW25	Talasay	Yes	-
GW26	Sancordem	Yes	-
GW27	Mollem	Yes	-
GW28	Bimbal	-	Yes
GW29	Sigao	Yes	-
GW30	Kharmal (Calem)	Yes	-
GW31	Codli-Dabal	Yes	-
GW32	Kirlapale	Yes	-
GW33	Karmani (Carmone)	Yes	-
GW34	Bandoli	Yes	-
GW35	Dukarkand	Yes	-
GW36	Costi (Kashti)	Yes	-
GW37	Chinchegal (Tudou)	Yes	-
GW38	Bati	Yes	-
GW39	Curpem	Yes	-
GW40	Colomba	Yes	-
GW41	Sulcorna	Yes	-
GW42	Rivona (Shinshore)	Yes	-
GW43	Maina	Yes	-
GW44	Kanvre (Cavrem)	-	Yes
GW45	Betul	-	Yes

Table 4: Summary of classification of wells using trend of hydrographs

Sl. No.	Water table trend	No. of wells	Percentage
1	Rising trend	37	82.2
2	Falling trend	0	0
3	No trend	8	17.8

aquifers underneath because during monsoon these reject dumps hold a substantial amount of water in them and transmit it to the underlying phreatic aquifer over a period of time. In this way the dumps provide sustainable recharge to aquifers and results in the augmentation of water levels. The abandoned mine pits storing rain water also act as a source of groundwater recharge and contribute markedly to the water level augmentation.

The hydrographs evidenced wide range of seasonal fluctuations in the water table for most of the monitoring wells. The fluctuations in water table might be attributed to shallow aquifers (Winter *et al.*, 2000). The hydrographs also illustrate a conspicuous response of a phreatic aquifer to rainfall. A steep rise in water level was observed with the onset of monsoon at most of the locations. There exists a significant correlation between rainfall and shallow aquifer recharge, but there is a time lag of about one to two months between rainfall peak and the shallowest ground water level. The lag of time might be attributed to the span of time for complete saturation of the soil / rock matrix above the water table. The other factor that is, quick generation of runoff during heavy downpours owing to the hilly terrain may also govern the time lag between peak rainfall and shallowest water level.

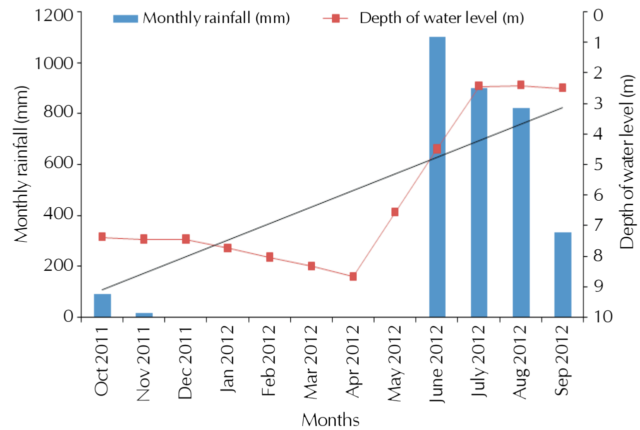

Figure 2: Well hydrograph with increasing trend for Well no. 3

The quick rise of hydrographs after the onset of monsoon indicates rapid groundwater recharge and on the other hand the slow decay of the falling hydrographs show slower discharge of the aquifer, which is considered good for the health of the ground water regime (Chachadi and Choudri, 2004). The quick rising level of groundwater is an insignia of a permeable rock/soil matrix in the top unsaturated zone. After the attainment of shallowest level of the groundwater table during the monsoon, it takes a long spell to restore the pre-monsoon level after the termination of monsoon rainfall and follow a gentle falling slope pattern. The adjournment might be attributed to the gentle ground water level gradient which is responsible for the sluggishness of groundwater drainage from the saturation zone. While the vertical flow of water in the form of rainfall recharge is not inhibited by gradient problems. Although, the gentle falling slope pattern is surprising because, in the study area where most of the excavation activities are being done below groundwater table and large quantity of groundwater is being pumped out from the mine pits after the cessation of monsoon to renew mining and excavation activities. This pattern might be achieved because of the pumped out pit water, which acts as a major source of non-monsoon recharges in the form of return flow from agricultural lands, stream beds, settling ponds etc.

From the observation, it can be concluded that, groundwater in the study area have not shown significant changes in their availability during the period of study. Although long term water level data is imperative for the portrayal of lucid conclusions on the trends of groundwater levels. Future

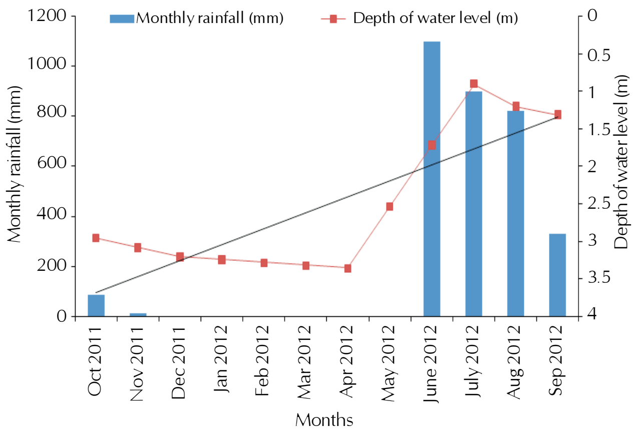

Figure 3: Well hydrograph with increasing trend for Well no. 13

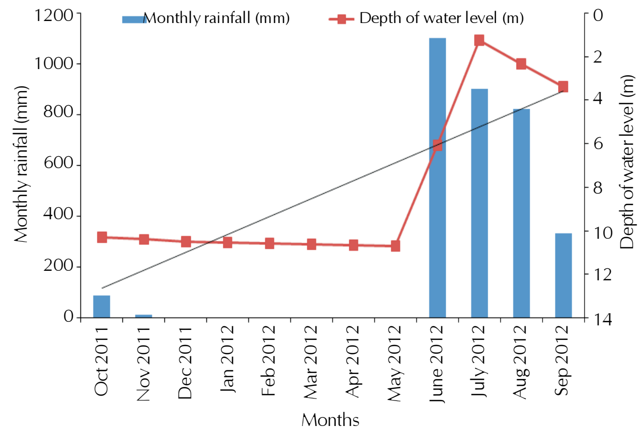

Figure 4: Well hydrograph with increasing trend for Well no. 27

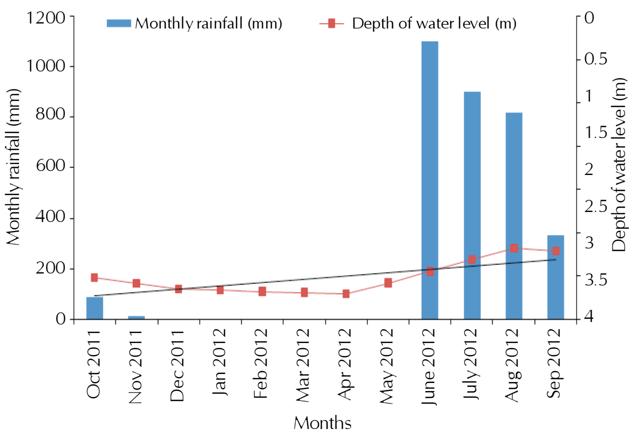

Figure 5: Well hydrograph with no trend for Well no. 16

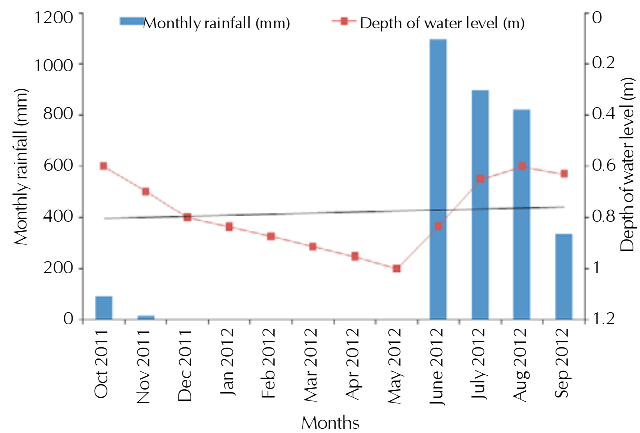

Figure 6: Well hydrograph with no trend for Well no. 44

research related to use of groundwater levels to estimate aquifer recharge in the iron ore mining areas of Goa is strongly recommended.

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