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Assessment of Groundwater Quality in the Mining Areas of Goa, India

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Abstract

Goa is a famous International tourist destination and attracts around 2 million tourists annually. Tourism is generally limited along the coastal belt of Goa, while mining is more focused in the midland of Goa. The groundwater in the State is mainly used for drinking and industrial purposes followed by agriculture to some extent. The open cast iron ore mining in Goa had induced significant changes in groundwater quality and quantity. The objective of the present study was to assess the impact of mining activities on the qualitative scenario of ground water in the study area. The monitoring of groundwater quality was done at fourty five groundwater sampling locations on a seasonal basis (i.e. post-monsoon, winter, summer, and monsoon) from October 2011 to September 2012. Assessment of Ground water quality status was done by using the Water Quality Index method, which is an effective tool to assess spatial and temporal changes in ground water quality. Based on the descriptive categories of WQI values observed, all (100%) the sampling locations in the study area were observed with very good category.

Keywords: Quality Indices, Goa, Groundwater, Monitoring, Seasonal Variations

1. Introduction

Groundwater is considered as one of the primary resources for development activities. The overexploitation of groundwater has detrimentally affected groundwater in terms of the quality and quantity. Groundwater quality can be adversely affected or degraded as a result of human activities that introduce contaminants into the environment, including disposal of domestic, agricultural and mining waste. The chemistry of groundwater is an important factor determining its use for domestic, irrigation and industrial purposes. Mining activities are known to affect both the surface and ground water regime during the last century. Changes in local topography and drainage system directly affect both quality and quantity of ground water[1]. There are several states in India, where more than 90% populations are dependent on groundwater for drinking and other purpose[2]. Groundwater is the major source of drinking water in both urban and rural areas[3]. The standards for drinking purposes as recommended by the World Health Organization[4] and Indian Standards[5] have been considered for the calculation of Water Quality Index (WQI). The first comprehensive hydrogeological study in Northern Goa was carried out by Subramaniam[6]. Govindarajan[7] have studied the lateritic soil of Goa. The former report by TERI India studied pollution of groundwater and reported that the wells at Digne in North Goa mining belt were contaminated with diesel, while several

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wells at Velguem and Pissurlem had been contaminated by excessive situation arising from mining activities. Ghosh[8] studied the rainfall contribution to groundwater recharge as 16% and evapo-transpiration and surface runoff as 32% and 52% respectively. Pathak[9] suggested the optimal design of groundwater structures together with proper selection of pumping unit in the territory to avoid hazards of seawater intrusions. Several studied also described aerial photographs and described geomorphological features of the coastal Goa. Excessive mining of Iron ore by open cast methods in the northern part of Goa has resulted in the depletion of groundwater table[10]. The depletion of ground water resources is of particular concern because its catholic importance to the mankind. Venkatraman[11] carried out environmental impact studies of iron ore mining through remote sensing in which they also studied the groundwater aspects includes depletion of groundwater due to mining. Pahala Kumar[12] carried out detailed studies in the mining areas of North Goa for evaluation of groundwater potential using remote sensing and Geographic Information System (GIS) techniques, which have indicated that iron ore beds can form aquifers. The dating of the water samples indicated that the shallow lateritic aquifers and the deeper iron ore aquifers are not hydraulically connected. (Central Ground Water Board (CGWB) 1997. Studies were carried out on the quality assessment of groundwater in and around Calangute area, in north Goa[13]. Chachadi[14] have carried out a detailed investigation of groundwater potential availability, and its vulnerability to pollution, sea water intrusion using Geographic Information System (GIS). Chachadi[15] has carried out a detailed study on impact assessment and remediation of open-cast mine dewatering on rural drinking water supplies in the mining belt of Goa. This present study deals with the extent and degree of groundwater contamination in and around mining areas of Goa from geochemical analysis of groundwater samples and by using the quality Indexing approachveloped aggregate hydroponic systems.

2. Material and Method

2.1 Study Area

Goa is the 25th State of India, attaining statehood in May 1987. It is a relatively small state which lies between the latitudes 14°53'54" N & 15°40'00" N and longitudes 73°40'33" E & 74°20'13" E with geographical area of 3,702 km^2 and a coastline of 105 km (63 miles). Goa is well connected to rest of India and some international destinations via air, road, rail and waterways. The state is divided into two districts: North Goa and South Goa. Panaji is the headquarters of the North Goa district and Margao of the South Goa district. The districts are further divided into talukas. North Goa district has six talukas viz., Pernem, Bardez, Tiswadi, Bicholim, Sattari and Ponda. South Goa district had 5 talukas viz., Salcete, Marmugao, Sanguem, Quepem and Canacona. In April 2011, a portion of Ponda taluka from North Goa district and Sanguem taluka from South Goa district were separated to form Dharbandora taluka which was added to South Goa district. Since April 2011, both North Goa district and South Goa district has six talukas each. The languages spoken are Konkani, Marathi, English and Portuguese. The State of Goa receives rainfall from southwest monsoon between the months of june-september. The average annual rainfall in the mining area varies between 3500 to over 4000 mm. The temperature ranges between 20 and 34 ^{o}C. The relative humidity is higher during the months of July to September ranges between 60 percent to 90 percent.

2.2 Field Sampling

The Groundwater quality at different 45 well locations were selected as per their distribution along the mining belt of the study area and the four seasons, i.e. post monsoon (5th Oct., 2011 to 9th Nov. 2011), winter (20th Dec. 2011 to 28th Feb. 2012), summer (10thApril, 2012 to 15th May, 2012) & monsoon (25th July, 2012 to 10th Sept. 2012) seasons were conducted. Among 45 locations of ground water, 22 locations were situated in North Goa comprising Bardez (3), Bicholim (17) and Sattari (2) Talukas while remaining 23 stations were located in South Goa including Dharbandora (8), Sanguem (8), and Quepem (7) Talukas. The ground water samples were collected in acid washed plastic container to avoid unpredictable changes in characteristics as per standard procedures. To assess the physical and chemical parameters – pH, electrical conductivity, Turbidity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Hardness, Fluoride, Chloride, Sulphate, Nitrate, Phosphate, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD).

2.3 Water Quality Index Method

A Water Quality Index (WQI) describes the general situation of water bodies by changing water quality parameters levels into a numerical score using mathematical tools16-18. It is calculated from the view of human consumption. WQI can be evaluated on the basis of physical, chemical and biological parameters. The concept of water quality to categorize water according to its degree of purity or pollution dates back to 1848 in Germany[19-21].

2.4 The Calculation Involves the Following Steps

The standards for drinking purposes as recommended by Indian Standards : 10500, have been considered for the calculation of WQI. In this method, the weightage for various water quality parameters is assumed to be inversely proportional to the recommended standards for the corresponding parameters22,23.

Accordingly, the weightage of ithparameter is calculated by following formula:

$$W_i = {}^{k}/_{s_i}$$

Where, W_i is the unit weight for the ithparameter;

s_i the recommended standard for ith parameter and i = 1, 2, 3, ..., 16; and

k the constant of proportionality

The calculation involves the following steps:

(a) First, the calculation of the quality rating for each of the water quality parameters

(b) Second, a summation of these sub-indices in the overall index

The individual quality rating is given by the expression:

$$q_i = 100\,{}^{v_i}/_{s_i}$$

Where, v_i is the measured value of the ith parameter in groundwater samples under consideration and s_i the standard or permissible limit for the ith parameter.

The WQI is then calculated as follows:

$$\mathbf{WQI} = \sum(\mathbf{q_i w_i}) / \sum \mathbf{w_i}$$

Where, Q is the sub index of ith parameter. W is the ith unit weightage for ith parameter, n is the number of parameters considered. The descriptor categories of water based on the WQI values are determined as per

Table 1. Unit weightage of different parameters is calculated and represented

Sl No	Parameter	Highest permitted value for water (Si)	Unit Weightage(Wi)
1	pH	7.5	0.030924647
2	TDS (mg/l)	500	0.00046387
3	Total Hardness(mg/l)	300	0.000773116
4	Chloride (mg/l)	250	0.000927739
5	Nitrate (mg/l)	45	0.005154108
6	Turbidity (NTU)	10	0.023193485
7	Fluoride (mg/l)	1.5	0.154623235
8	Fe (mg/l)	0.3	0.773116174
9	Calcium Hardness (mg/l)	75	0.003092465
10	Magnesium Hardness (mg/l)	30	0.007731162

Table 2. Descriptor categories of WQI Values

WQI	Status
0–25	Very good
26–50	Good
51–75	Moderate
>75	Poor

3. Result and Discussion

The WQI was calculated for all the groundwater monitoring stations in four seasons, i.e. post monsoon, winter, summer and monsoon seasons and were presented in Table 3. The overall water quality index of ground water in the study area is presented in Figure 1. The data for 3 sampling locations for the summer season was not available since they are dried up completely, namely GW7 (Shrigao),

Table 3. Seasonal Variation of Water Quality Index of Ground Water Monitoring Stations are calculated

Station Code	Station Name	Water Quality Index									
		Post Monson	Status	Winter	Status	Summer	Status	Monsoon	Status	Annual	Status
GW1	Revora	8	Very Good	11	Very Good	10	Very Good	12	Very Good	10	Very Good
GW2	Kansa (Tivim)	8	Very Good	9	Very Good	8	Very Good	10	Very Good	9	Very Good
GW3	Pirna	8	Very Good	10	Very Good	8	Very Good	5	Very Good	8	Very Good
GW4	Kasarpal	10	Very Good	11	Very Good	11	Very Good	11	Very Good	11	Very Good
GW5	Advapale	8	Very Good	10	Very Good	9	Very Good	12	Very Good	10	Very Good
GW6	Mulgao	9	Very Good	11	Very Good	10	Very Good	7	Very Good	9	Very Good
GW7	Shrigao	11	Very Good	13	Very Good	-	-	11	Very Good	9	Very Good
GW8	Mayem (Paira)	10	Very Good	12	Very Good	11	Very Good	11	Very Good	11	Very Good
GW9	Dhabdaba	7	Very Good	9	Very Good	8	Very Good	10	Very Good	9	Very Good
GW10	Vajri (Sanquelim)	7	Very Good	8	Very Good	8	Very Good	8	Very Good	8	Very Good
GW11	Virdi	8	Very Good	10	Very Good	9	Very Good	7	Very Good	9	Very Good
GW12	Kudnem	8	Very Good	15	Very Good	8	Very Good	11	Very Good	11	Very Good
GW13	Gauthan	11	Very Good	20	Very Good	12	Very Good	9	Very Good	13	Very Good
GW14	Harvalem	8	Very Good	8	Very Good	8	Very Good	10	Very Good	9	Very Good
GW15	Phal (Kudnem)	9	Very Good	12	Very Good	10	Very Good	10	Very Good	10	Very Good
GW16	Shonshi	9	Very Good	14	Very Good	10	Very Good	9	Very Good	11	Very Good
GW17	Dignem	10	Very Good	19	Very Good	-	-	11	Very Good	10	Very Good
GW18	Khodguinim (Surla)	9	Very Good	12	Very Good	9	Very Good	7	Very Good	9	Very Good
GW19	Velguem (Surla)	7	Very Good	10	Very Good	8	Very Good	7	Very Good	8	Very Good
GW20	Ambegale (Pale)	8	Very Good	11	Very Good	8	Very Good	6	Very Good	8	Very Good
GW21	Dhandkal (Honda)	9	Very Good	15	Very Good	-	-	8	Very Good	8	Very Good
GW22	Pissurlem	8	Very Good	21	Very Good	-	-	11	Very Good	10	Very Good

Station Code	Station Name	Water Quality Index									
		Post Mon-son	Status	Winter	Status	Summer	Status	Monsoon	Status	Annual	Status
GW23	Usgao	10	Very Good	11	Very Good	11	Very Good	8	Very Good	10	Very Good
GW24	Dharbandora (Tamsodo)	5	Very Good	6	Very Good	9	Very Good	6	Very Good	7	Very Good
GW25	Talasay	8	Very Good	8	Very Good	9	Very Good	6	Very Good	8	Very Good
GW26	Sancordem	9	Very Good	9	Very Good	11	Very Good	10	Very Good	10	Very Good
GW27	Mollem	9	Very Good	9	Very Good	10	Very Good	8	Very Good	9	Very Good
GW28	Bimbal	9	Very Good	11	Very Good	10	Very Good	7	Very Good	9	Very Good
GW29	Sigao	7	Very Good	11	Very Good	8	Very Good	7	Very Good	8	Very Good
GW30	Kharmal (Calem)	7	Very Good	8	Very Good	9	Very Good	7	Very Good	8	Very Good
GW31	Codli-Dabal	8	Very Good	9	Very Good	10	Very Good	6	Very Good	8	Very Good
GW32	Kirlapale (Near Balsati)	6	Very Good	9	Very Good	8	Very Good	7	Very Good	8	Very Good
GW33	Karmani (Carmone)	7	Very Good	8	Very Good	8	Very Good	6	Very Good	7	Very Good
GW34	Bandoli	8	Very Good	10	Very Good	9	Very Good	6	Very Good	8	Very Good
GW35	Dukarkand	11	Very Good	13	Very Good	11	Very Good	8	Very Good	11	Very Good
GW36	Costi (Kashti)	9	Very Good	12	Very Good	9	Very Good	9	Very Good	10	Very Good
GW37	Chinchegal (Tudou)	7	Very Good	11	Very Good	8	Very Good	8	Very Good	9	Very Good
GW38	Bati	7	Very Good	9	Very Good	8	Very Good	6	Very Good	8	Very Good
GW39	Curpem	8	Very Good	11	Very Good	9	Very Good	6	Very Good	9	Very Good
GW40	Colomba	8	Very Good	10	Very Good	8	Very Good	8	Very Good	9	Very Good
GW41	Sulcorna	7	Very Good	9	Very Good	8	Very Good	5	Very Good	7	Very Good
GW42	Rivona (Shinshore)	9	Very Good	10	Very Good	9	Very Good	9	Very Good	9	Very Good
GW43	Maina	8	Very Good	13	Very Good	9	Very Good	7	Very Good	9	Very Good
GW44	Kanvre (Cavrem)	6	Very Good	8	Very Good	7	Very Good	6	Very Good	7	Very Good
GW45	Betul	8	Very Good	11	Very Good	9	Very Good	7	Very Good	9	Very Good

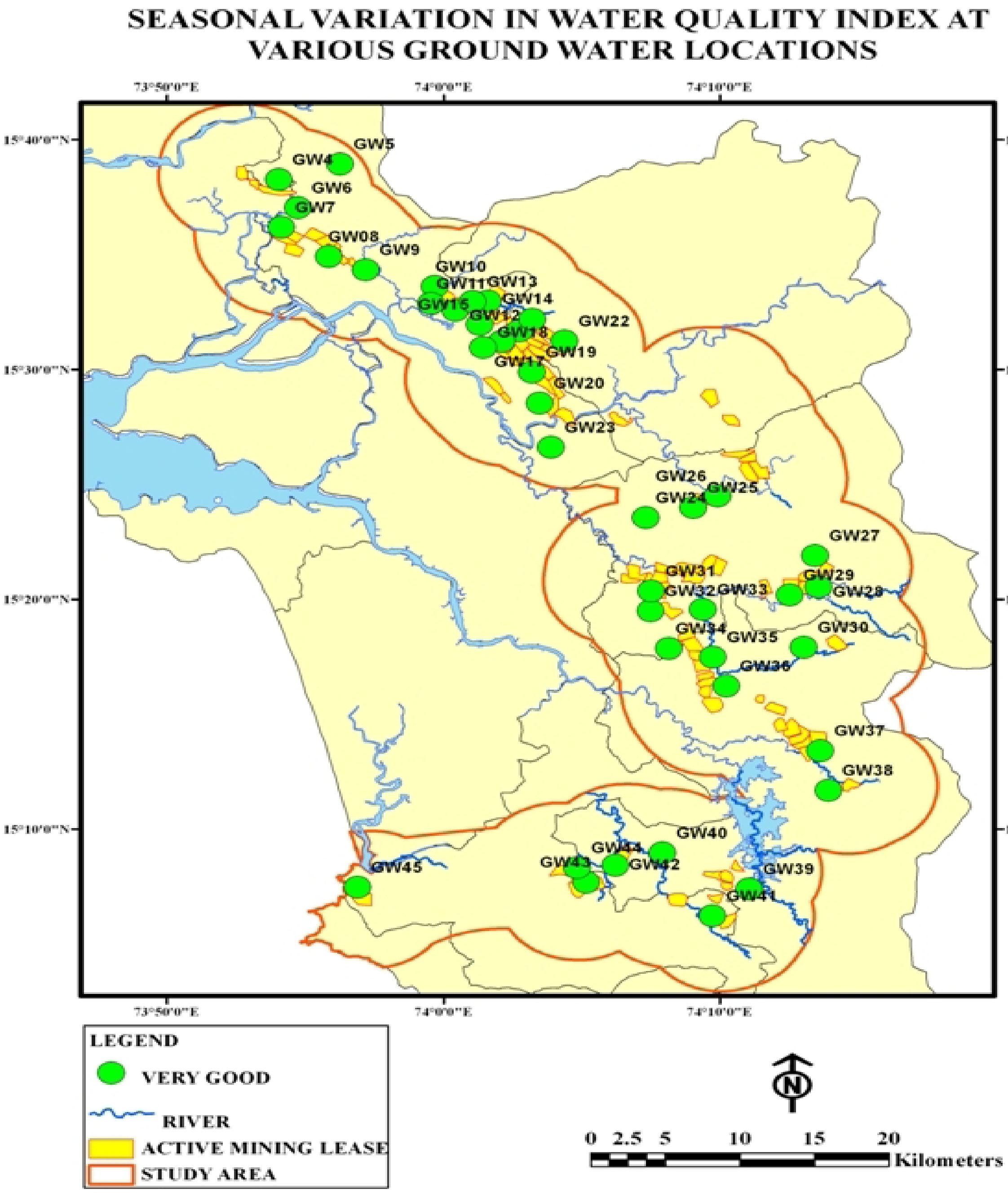

Figure 1. Seasonal variation of WQI at various locations of groundwater.

GW1 Dhandkal (Honda) and GW22 (Pissurlem). Based on the descriptive categories of WQI values, all (100%) the samples in the study area were observed with very good category. The values of WQI of the samples were found in the range of 5-11 in post-monsoon, 6-21 in winter, 7-12 in summer season and 5-12 in monsoon. The water quality of all sampling stations was observed with very good category in all four seasons showing little variation in the quality which may be accounted for seasonal changes. In general the water quality index was found comparatively higher in winter and summer seasons than post monsoon and monsoon seasons, showing maximum water quality index in the winter season. The lower value of the index during monsoon and post-monsoon seasons might be attributed to the copious recharge of groundwater due to heavy rainfall during monsoon season. Overall, it can be estimated from the above discussion that the groundwater quality of the iron ore mining region of Goa is not under very much threat due to mining activities except at some locations where drying of wells were observed during summer season. The physic-chemical properties of groundwater were observed slightly deteriorated despite of heavy stress of mining activities, which represents the proper maintenance of sufficient volume of groundwater throughout the year and plentiful recharge.

4. Conclusion

The present study was intended to assess the impact of mining activities on the qualitative scenario of groundwater in the iron ore mining region of Goa, using WQI at forty five groundwater monitoring locations on a seasonal basis (i.e. post-monsoon, winter, summer, and monsoon) from October 2011 to September 2012. The observed values of WQI at all (100%) the sampling locations in the study area were observed with very good category category in all four seasons, showing little variation in the quality which may be accounted for seasonal changes. The values of WQI of the samples were found in the range of 5-11 in post-monsoon, 6-21 in winter, 7-12 in summer season and 5-12 in monsoon. The careful observation of the water table indicates that, mining activities at specific locations have a profound impact on the quantitative scenario of both shallow groundwater as well as moderately deep groundwater systems. The study clearly evidenced that the groundwater of the study area is suitable for drinking and agriculture purposes, except few locations which needs adequate treatment before usage. Based on the observations, the study also portrays the need of effective management of water resources to protect it from the threats of the prevailing contamination.

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