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Ground Water *Vis-A-Vis* Sea Water Intrusion Analysis for a Part of Limestone Tract of Gujarat Coast, India

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Abstract

The present study analyses the hydro-chemical data of groundwater samples of three different limestone mine sites, which are in close proximity and covers a tract along the Gujarat Coast of Indian peninsula. Higher TDS (> 4000 mg/L) and Cl values (> 2000 mg/L) as well as the Chloride: Bicarbonate (HCO_3) ratio of more than one clearly support that the sea water intrusion is present in the coastal aquifer at all the three sites. In view of the economic importance of the area and the vulnerability of the coastal aquifer to sea water intrusion recommendations are made for sustainable use of groundwater by the mining companies and other stake holders.

Keywords: Coastal Aquifer, Seawater Intrusion, TDS, Limestone

1. Introduction

The Gujarat state of Indian Peninsula is bounded by latitudes N 20º02′ and N 24º42′ and longitudes E 68º04′ and E 74º30′ and has an areal extent of 196,024 km^2 (**Figure 1**). The western and southern parts of the state are bounded by the costal tract along the Arabian Sea. The state of Gujarat has a long coastline of approximately 1550 km extending in the Kuchch Peninsula, the Saurashtra Peninsula and the Central Plains of Gujarat. The Kuchch Peninsula and Rann of Kuchch adjacent to the district of Jamnagar, Junagarh, Amreli and Bhavnagar occupy the N-W part of Gujarat Coast line and is also termed as *Saurashtra Coast*. The coast is abundantly rich in commercial variety of limestone (**Table 1**).

It is used as raw material for manufacture of lime, cement fertilizers and chemicals like soda-ash, bleaching powder, calcium carbide etc. It is also used as flux in iron and steel industries, ferro-alloys and other metallurgical industries.

The limestone is commercially exploited by open cast mining in the coastal tract. Hence, it is desirable that the local hydro-geological regime and hydro-chemical studies need to be considered in mining strategy for the exploitation of limestone. Considering this fact, scientific studies have been undertaken separately by the mining companies to decipher the sea water intrusion and plan the use of groundwater in a sustainable manner accordingly. The present study seeks to integrate the findings from studies [1-3] conducted at three different sites in the Saurashtra coast. The objective is to examine the existing data and decipher the signature of sea water intrusion in the coastal aquifer at the mining sites.

2. Study Area

The present study analyses the groundwater hydro-chemistry from three different locations in the Gujarat coast (**Figure 1**). The locations are as follow:

Site 1: Kovaya Limestone Mine Area of Gujarat Cement Works (GCW) in Amreli district, Gujarat.

Site 2: Jafrabad Limestone Mine Area of Narmada Cement Company Limited (NCCL) in Amreli district, Gujarat.

Site 3: Lodhwa/Singsar Limestone Area of Gujarat Ambuja Cement Limited (GACL) in Junagarh district, Gujarat.

Three different limestone mine sites lie on a stretch covering a tract along the Gujarat Coast of Indian peninsula. They are located in proximity of one another and can be considered as representative of the identical geological formations for study purpose.

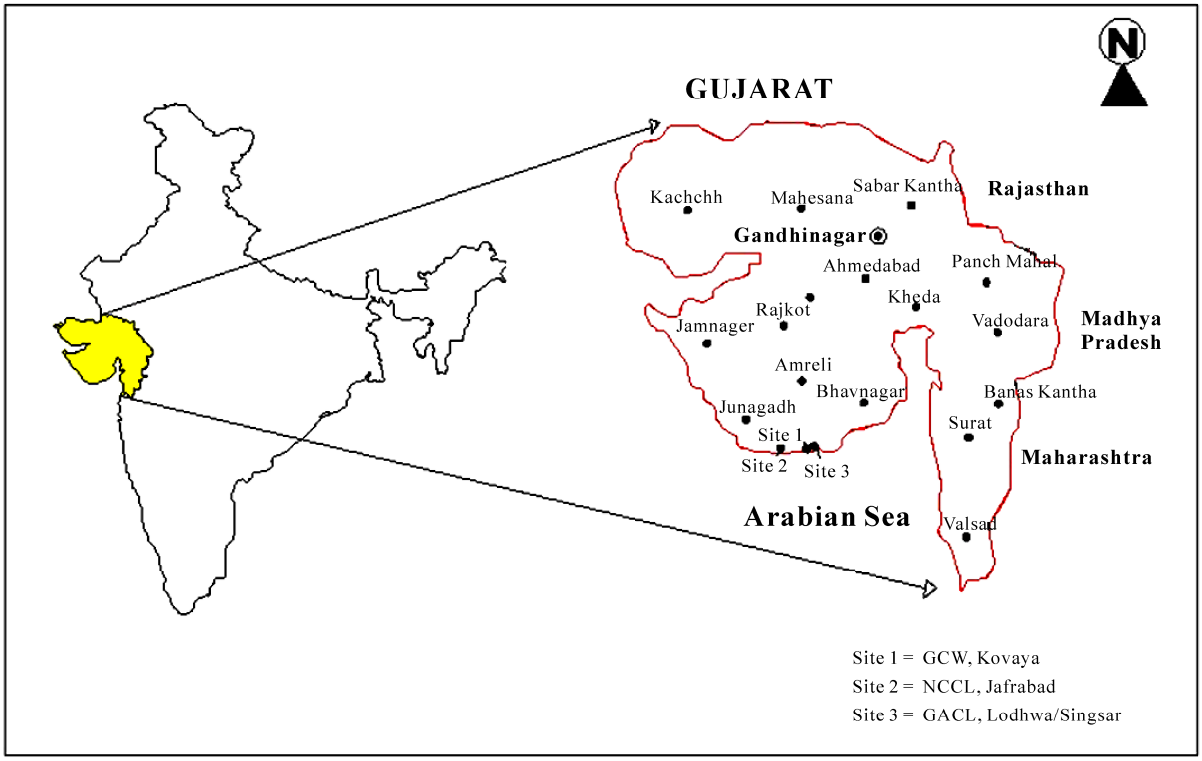

Figure 1. Location map of study area.

Table 1. Localities, geological age and formation types for limestone tract of gujarat coast, India.

S. No.	Name of District	Localities	Geological Age/Era	Formation Type
1.	Amreli	Balanivav, Una, Jafrabad , Kodinar, Mitiala, Varaswarup, Chanch bet, Dantardi, Vandha	Pleistocene age	Gaj formation, Miliolitic variety
2.	Junagarh	Adityana, Bakhrala, Bharvada, Bokira , Bolas, Boricha, Degam, Gosa, Ishwariya, Kajawardi, Kentela, Kharsa, Khera,Lati, Maraj, Palakhad, Pandavar, Parachi, Rakhej, Rampura, Ranavav, Samadhiala, Saroswa , Shantipura, simar, Supasi , sutrapra, Umba, Vavdi and Veraval.	Pliocene age and Pleistocene age	Dwarka formations and Chaya formations
3..	Kuchch	Ramania, Waghapadar, sanosra, Khari, Fulra, Kuriyani. Lakhpat, ratipur, Kharoda and Harudi	Eocene/Miocene age	Nummulitic Variety
4.	Bhavnagar	Gopnath, Mahuva, Methala, Talaja	Pleistocene age	Miliolitic variety
5.	Bharuch	Konda (Ankleshwar), Dungri ,Ghoda ,Valia etc.)	Eocene/Miocene age	Nummulitic Variety
6.	Jamnagar	Mithapur, Ranpur, Sikka, Dhrasanvel, Kalyanpur, Lalpur and Kuranga etc.	Pliocene age	Arenaceous limestone / Dwarka formations and miliolitic variety.
		Gorinja, Bhimpura,Meripur and Ashapura Mata Temple.	Pleistocene age	Gaj formations

Source: [4]

3. Hydro-geology

All the sites are situated close to the coast (with in distance of 1-2 km). In Site 1, the topography is generally flat to undulating. There are limestone cliffs along the sea coast near Jaffrabad and Babarkot villages. The Deccan Trap basalt of cretaceous to Eocene age is oldest rock formation in the study area. It is overlain by the Tertiary Gaj Bed which in turn is overlain by milliolitic limestone of Miocene-Pliocene age. The milliolitic limestone is the

major water bearing formation in Sites 1 and 2.

Alluvial formation also forms a minor aquifer system in patches in the Site 2. The pumping test carried out at Site 2 estimates the transmissivity as 62.26 m^2/day and permeability as 15.11 m/day. The water level varies from 2.50 m to 30.35 m (bgl) during the pre-monsoon period and 0.35 m to 24.40 m (bgl) during post-monsoon period. All the wells are fitted with pumps having prime movers of less than 7.5 HP which sustain pumping of 2 to 8 hrs/day with a discharge of 100 to 350 LPM.

In Site 3, the area is occupied by 0.5 m to 3.0 m of alluvium followed by Gaj limestone which acts as aquifer in major part of the south east area. In the eastern part of the site, the milliolitic limestone acts as the main aquifer. The aquifer is both unconfined (top) and semi-confined in nature. The unconfined aquifer lies between depth range of 1 to 22.5 m and the semi-confined aquifer lies between depths of 22.5 m to 50.0 m [2].

There is no industrial use of groundwater by the mining companies at the three sites. However, water is used for agriculture extensively. All the three sites receive moderate rainfall and it varies from 600 mm to 800 mm on average.

4. Methodology

The R&D analysis presented in this paper makes use of the water quality data collected by different national agencies and local organization namely Central Mining Research Institute (CMRI), National Environmental Engineering Research Institute (NEERI) and Gujarat Water Resources Development Corporation Limited (GWRDC), Govt. of Gujarat and Ground Water & Mineral Investigation Consultancy Limited (GWMICL) [1-3] during the period 2002-2007. The approach is to consolidate a large volume of available primary and secondary data and derive useful conclusions on groundwater quality vis-à-vis the sea water intrusion. The range and average values of the hydro-chemical data for the three sites are presented in **Tables 2-4**.

The well established concept of 'watershed' (for Site 1) and 'core area/buffer area zoning' (for Site 2 and Site 3) has been adopted for the data collection and collation of the study area. An observation well network consisting of representative wells was set up for monitoring of water level and water quality. Samples were collected in pre-cleaned poly-propylene bottles and analyzed for major cations and anions as per the standard procedure of American Public Health Association [5].

5. Discussions and Analysis

Evidences of sea water intrusion in different parts of the

Table 2. Qualitative analysis of ground water at site 1-Kovaya.

S. No.	Parameter▼	Unit▼	2006			
			a) ***Range***		*b*) ***Average***	
			Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1.	pH	-	7.3-8.1	7.1-7.9	7.6	7.45
2.	Elect. Conductivity	µmhos/cm	750-12300	1112-13160	4820.55	4433.37
3.	TDS	mg /L	450-7380	667.2-7896	2892	2660
4.	Total Hardness	mg /L	120-669	132-800	384.33	348.25
5.	Total Alkalinity	mg /L	122-498	176-496	318.77	315.25
6.	Calcium (Ca)	mg /L	88-516	78-470	236.83	171.87
7.	Magnesium (Mg)	mg /L	28-280	38-470	147.5	179
8.	Sodium (Na)	mg /L	97-2650	185-2550	992.83	840.06
9.	Potassium (K)	mg /L	2.0- 80.0	10- 99.5	26.38	89.375
10.	HCO_3	mg /L	148.84-601.56	215-605	388.90	384.68
11.	Chlorides (as Cl)	mg /L	103-3899	200-3500	1401.72	1280.50
12.	Sulphates (as So_4)	mg /L	10-199	16-219	75.27	88.68

Note: ND = not detected; Period–April, 2006 & Sept, 2006; nineteen sampling locations: Source: [1].

Table 3. Qualitative analysis of ground water at site 2-NCCL.

S. No.	Parameter▼	Unit ▼	Year 2004			
			a) ***Range***		*b*) ***Average***	
			Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1.	pH	-	7.24-7.85	7.03-8.1	7.52	7.57
2.	Elect. Conductivity	µmhos/cm	875-5803	942.5-7034 .3	2737.45	2784.13
3.	TDS	mg/L	560-3281.43	686.66-4040	1735.74	1760.34
4.	Total Hardness	mg/L	102.8-606.5	83.66-728 .71	258.89	228.10
5.	Total Alkalinity	mg/L	0-20	0-10	8.44	3.13
6.	Calcium (Ca)	mg/L	41-242.5	33.33-291. 42	103.44	84.44
7.	Magnesium (Mg)	mg/L	27-171	39.0-264.0	79.064	91. 49
8.	Sodium (Na)	mg/L	58.5-767 .57	83-908 .66	387.70	391.71
9.	Potassium (K)	mg/L	0.25-13.9	0.125-25.92	2.62	4.76
10.	HCO_3	mg/L	183-646 .66	262-614	342.69	417.5
11.	Chlorides (as Cl)	mg/L	84-1823.0	128-2194.3	728.02	692.55
12.	Sulphates (as SO_4)	mg/L	0-157.25	29.33	72.30	140.44

Note: Pre-monsoon and Post-monsoon data are collected from 23 locations (104 sampling points) located in Jafrabad and Rajula taluka. (a) Pre monsoon Period = April-May, 2004 and Post monsoon Period = Sept-October, 2004.
Source: [3]

Table 4. Qualitative analysis of ground water at site 3-Lodhwa/Singsar.

S. No.	Parameter▼	Unit ▼	Range (2002-2003)	Average (2002-2003)	Remarks
1.	pH	-	6.74-7.6	7.015	
2.	Elect. Conductivity	µmhos/cm	4353.3-35016.66	7407	
3.	TDS	mg/L	2612-21010	8364	
4.	Total Hardness	mg/L	850-4603	3199	
5.	Total Alkalinity	mg/L	220-368	310.5	
6.	Calcium (Ca)	mg/L	410-1908	938	Based on seven sampling points; Period of sampling—November 2002 to April 2003. Separate data for pre-monsoon and post-monsoon are not available.
7.	Magnesium (Mg)	mg/L	149.57-514.0	377.25	
8.	Sodium (Na)	mg/L	248.0-649.0	496	
9.	Potassium (K)	mg/L	16.22-63.65	32.34	
10.	HCO_3	mg/L	268.4-448.96	378.81	
11.	Chlorides (as Cl)	mg/L	435-5546.0	3682.5	
12.	Sulphates (as SO_4)	mg/L	310.17-1510.0	598.5	
13.	Total Suspended Solids (TSS)	mg/L	20-260	112.5	

Source: [2]

world have been reported through hydro-chemical studies [6-16]. The present study seeks to investigate the possible signature of sea water intrusion in the coast aquifer at three different sites on the basis of hydro-chemistry. The Cl/HCO_3 ratio has been computed for different samples to infer about the possible signatures of sea water intrusion [11].

On the basis of hydro-chemistry of groundwater following important points have been analyzed which are discussed below:

1) The ground water quality at all sites indicates higher concentration of TDS, chloride and sodium (**Table 2-4**). At most of the places TDS is higher than 1000mg/L value. The average EC in 2006 at Kovaya (**Table 2**) for pre-monsoon and post-monsoon happen to be 4820 mg/L and 4423 mg/L respectively and thereby indicate the saline character of the aquifer as per the classification by Saxena *et al.* [10]. It is observed that nearly 50% of the samples exceed the desirable limits (2000 mg/L) of TDS set by the BIS 1991. It is also evident for the sites at NCCL (**Table 3**) and GACL (**Table 4**) that the groundwater is brackish type (average EC > 1500 µS/cm).

2) The TDS versus Cl/HCO_3 for different samples has been computed for the three study areas. Since, Cl/HCO_3 is greater than 1 for most of the samples, it is indicative of sea water intrusion [11] in the study area (**Figures 2(a)-(d)**).

3) Samples have been collected from the Arabian sea and analyzed for physico-chemical parameters (**Table 5**). It is observed that pH is over 7 and seawater has very high TDS in the range of 44,545-65,866 mg/L. The high concentration of Ca, Mg, Na and K makes the seawater harder (7666 mg/L to 10,055 mg/L) and alkaline (Total Alkalinity range = 120-210 mg/L). Similarly, chloride (24,880-38,333 mg/L), sulphates (1366-4669.5 mg/L) and HCO_3 content (146.4-220 mg/L) of seawater is also observed. The coastal aquifer has good transmissivity and permeability **(Table 6).**

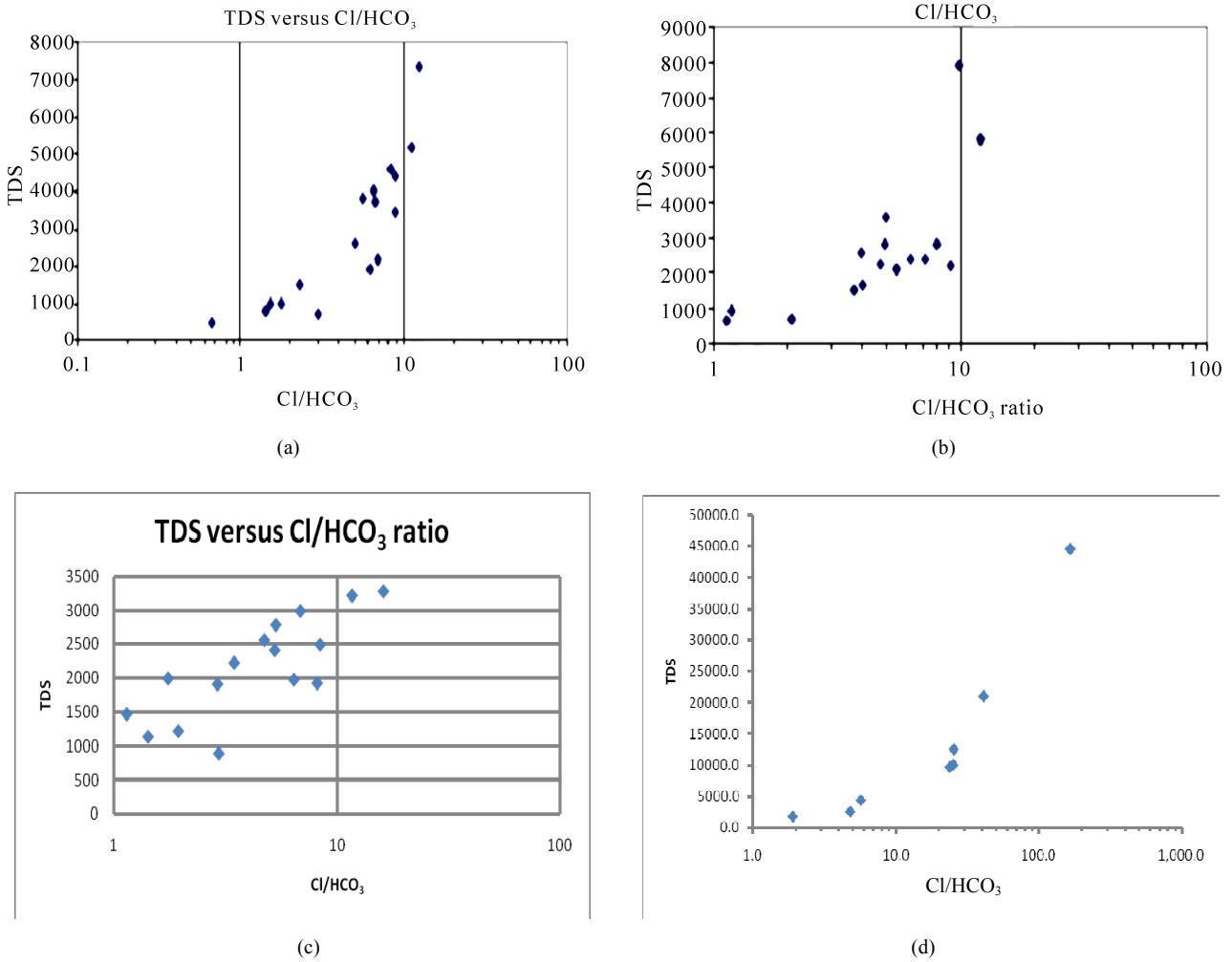

Figure 2. Cross plots of TDS vs Cl/HCO_3 ratio. ((a) & (b)) for Kovaya; (c) for NCCL and (d) for GACL Sites.

Table 5. Arabian seawater quality in gujarat coast, India.

S. No.	Sampling Station (Location)	pH	Cond. (mS/cm)	TDS (mg/L)	Turb (NTU)	T.Alk (mg/L)	T-Hard (mg/L)	Ca (mg/L)	Mg (mg/L)	SO_4 (mg/L)	Cl (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	Na (mg/L)	K (mg/L)	CO_3	HCO_3
1	Location 1 (Varahswarup)	8.0	107241	64345	5.00	120	7566	1080	6486	1366	38333	149	1.0	21299	1100	72	146.4
2.	Location2 (Varahswarup)	7.6	109777	65866	6.20	180	8400	4080	4321	1452	37000	149	2.2	23095	1362	108	220
3.	Location 3 (Dhamlage)	8.33	71,272	44545	> 10	210	10,055	2245	1080	4669.55	24880	1658	-	22.25	337.22	-	-

Note: Varahswarup and Dhamlage are located in Amreli District and Junagarh district respectively. The water sampling and analysis months for location 1, 2 & 3 are April, 2006; September, 2006 and 2005 respectively.

Table 6. Aquifer parameters at studied locations.

S. No.	Parameter	Unit	Site 1 (Kovaya)	Site 2 (NCCL)	Site 3 (Lodhwa/Singsar)	Remarks
1.	Transmissivity	M^2/day	62.26	62.26	58.82-78.15	Site 1 and Site 2 are in close vicinity to each other and hence almost same values of aquifer parameters.
2.	Permeability	M/day	15.11	15.11	-	
3.	Specific Capacity	M^3/min/m	0.080	0.080	-	
4.	Specific Yield	Fraction/ratio	0.031	0.031	0.20-0.26	

High TDS values exceeding 1000 mg/L (**Table 7**) and misbalance of *Anion* and *Cation ratio* [12] is yet another commonly observed characteristics in coastal aquifer. Both of these conditions are observed in limestone tract also as evident from the qualitative analysis of ground water at the studied sites.

Thus, geological factors (the principal rock type), aquifer present (limestone and host rocks) and hydrological conditions [porosity: 0-20% (primary & secondary both), and transmissivity of aquifer (58.82-78.15 m^2/day)] permit the solute transport process underground, which ultimately leads to the presence of sea water influx at different studied sites. Using sustainable ground water management techniques, the interface can be kept contained towards sea coast.

6. Sustainable Use of Groundwater

In the light of the data analysis the following recommendations are made.

Table 7. Ground water classification based on TDS.

S. No.	Category	Total Dissolved solids (mg/L)
1.	Fresh water	0-1000
2.	Brackish water	1000-10,000
3.	Saline water	10,000-100,000
4.	Brine water	> 100,000

1) Recharge of the coastal aquifer is one of the viable strategies to reduce the salinity of the aquifer and render it potable.

2) The recharging partially compensates the ground water exploitation and also ensures the availability of ground water [9,15,16]. The abandoned pits in mining areas and low lying land areas can be used for artificial recharge.

3) The industries operating in the studied limestone tract should install "desalination plants" for their domestic as well as industrial requirements [13].

4) Over-exploitation of the groundwater through installation of private boring wells needs to be strongly discouraged. Drip irrigation should be encouraged tominimize the use of groundwater.

5) Technique of "water barriers" as done in different countries [14] in such areas should be encouraged.

7. Conclusions

1) The hydro-chemical data from the groundwater samples *i.e.* higher TDS values and $Cl/HCO_3 > 1$ indicate that the studied Saurashtra coastal aquifer has been subjected to sea water intrusion.

2) Based on the field survey and data analysis, it is inferred that the intrusion is possibly triggered by the presence of large number of agricultural wells (excessive extraction of groundwater) in the study area. It is also observed that recharge from precipitation or other sources is not proportionate and this has not compensated the replenishment of groundwater in the study area.

3) Though there is less use of the groundwater by the industrial organization (cement companies) for their industrial requirement, the coastal aquifer is excessively exploited for agricultural use. The pumpage of water from the coastal aquifer seems to be responsible for reversal of the hydraulic gradient and inducing sea water intrusion in the mainland area.

4) Hydro-geological factors permit the solute transport process leading to the presence of sea water influx at different studied sites. The coastal aquifer of Saurashtra Coast has good permeability and transmissivity and records higher specific conductance of ground because of high salinity/alkalinity.

5) Using sustainable ground water management techniques the interface can be kept contained towards sea coast.

8. Acknowledgements

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