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SEASONAL HYDROCHEMISTRY OF GROUNDWATER IN THE BARRIER SPIT SYSTEM OF THE CHILIKA LAGOON, INDIA

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A detailed hydrochemical analysis was carried out on groundwater samples collected from the barrier-spit system of the Chilika lagoon on the east coast of India. The water quality in both pre- and post-monsoon periods and the interactions with the sea water throughout the year were characterized. The concentrations of major ions were measured quantitatively. Results show that during the post-monsoon season, the salinity level, as indicated from the TDS values, is lower, and groundwater contains higher concentrations of Ca and HCO_3 ions as compared to other major ions. In the pre-monsoon season, the TDS values increased to a high value, with all the major ions showing higher values. The high values indicate seawater encroachment into the fresh water aquifer, which was confirmed by ionic ratios. The concentration of TDS, Na and Cl in the post-monsoon groundwater was within permissible drinking water limits. The concentrations during the pre-monsoon season were not within permissible limits. It is recommended that during this period, pumping from bore wells be minimized to control seawater intrusion.

INTRODUCTION

Potable water is an important resource in the socioeconomic health of a developing country like India where more than 70% of the population depends on primary activities such as agriculture and fisheries. India, with a coastline of 4800 km, owes a lot to exploration and exploitation of good quality potable water along the coast since the coasts are becoming heavily populated as compared to other places situated inland. Large quantities of fresh water are being used in these regions both for drinking and agricultural purposes. In the present context, the study area assumes importance from the fact that it is a large barrier spit (Figure 1) that separates Chilika lagoon from its parent body, the Bay of Bengal. Chilika lagoon, the largest brackish water lagoon system in Asia is thought to have been formed in the early part of Quaternary Era when it had free access with sea. Gradually, the long shore currents gave rise to spits from either side of the lagoon. In comparison to the northern spit, the southern spit has been very active and has grown to a length of 30 km. It is a fact that a coastal lagoon gradually evolves into a lake in a later stage. Receiving both fresh water and sediments from the mainland, it gradually loses its depth and slowly perishes to become a landmass in the final stage.

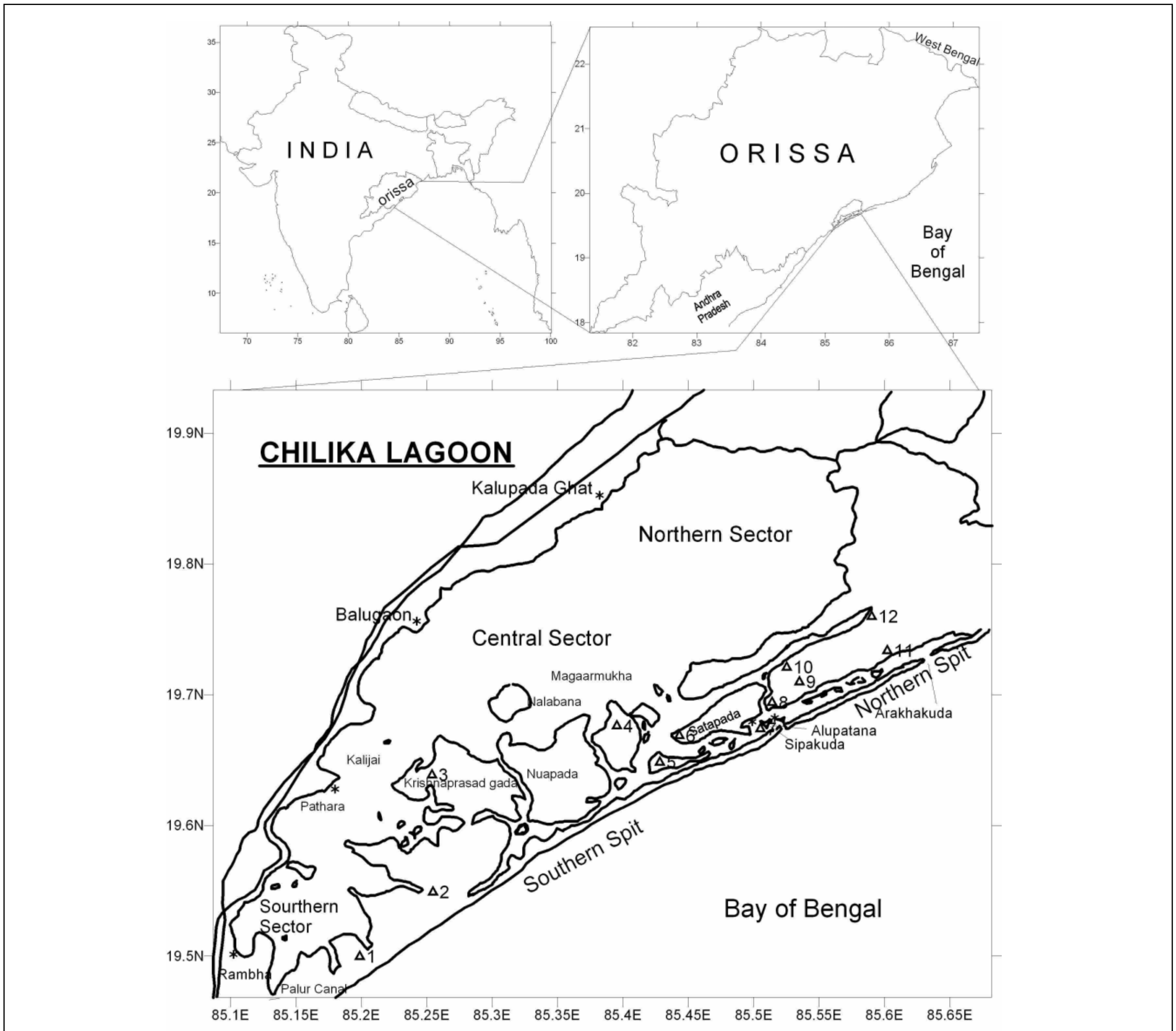

Figure 1. Study area with groundwater sampling locations.

The study area, which is identified geomorphologically as a barrier spit or a bar, extends for a length of 30 km with an average width of 1 km. It is located between latitude 19.25 and 19.45, and longitude 85.10 and 85.35. This bar sometimes coalesces with still smaller bars, occurring inside the lagoon, to form even a bigger spit system. However, these smaller bars, have very dynamic characteristics due to changes in sediment deposition and erosion and various coastal processes operating along the spit. Around 25 small settlements are situated on this spit, most of whose occupation is fishing. All along the coast, the spit is pitted with numerous sand dunes, which are the source of fresh groundwater in this region. Apart from the sand dunes, the coastal plains of the spit system also serve as good sites of for groundwater. However, the problem of salinity emerges as the groundwater aquifers approach the coast. The objective of this work is to determine the seasonal hydrochemical characteristics of the groundwater regime that is associated with the barrier spit system.

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The geology of this region is studied in detail by various authors (Pascoe, 1950; Krishnan, 1982; and Rao, 1989). The Eastern Ghats comprising the khondalites, charnockites, granite gneisses and leptynites occur at the southern extremity of the study area. Otherwise, major part of the spit system consists of sand and clay layers belonging to the Pleistocene to Recent periods. The alluvium belonging to the Quaternary Era is exposed all along the coast and is represented by sandy and black clay, marine black clay, fine and course sands.

The alluvial tract of Orissa comprises aquifers of very good groundwater potential (Raghunath, 1987). As stated earlier, the coastal aquifers in this part of the study area consist of very fine to coarse sands with intercalations of sandy clay and marine black clay. With an annual average rainfall of 115 cm, 20% may be assumed to recharge these sandy aquifers. Around 50% of the recharge potential is being utilized by dug wells and shallow bore wells. As major part of the study area is covered with sand dunes, the open wells are dug on the dunes. Almost all the dug wells are phreatic in nature and provide water only after the onset of monsoon. The water table is found at a depth of 6-8 m below ground level (BGL) over the dunes and below 2-3 m BGL on the plains. In case of bore wells, the water table fluctuates between 8-9 m BGL in the pre-monsoon to 5-6 m BGL in the post-monsoon period. However, as the water table goes beyond 8 m BGL in the summer, the groundwater begins to taste saline. Since there is no other source of drinking water available in this part of the coast, the people are constrained to drink the saline water without knowing the harmful effects. This study is undertaken to carry out a detailed hydrochemical analysis of the pre and post-monsoon groundwater regime to ascertain the exact salinity condition and to find out ways and means so that intake of saline groundwater can be minimized for the betterment of the people.

METHODOLOGY

Altogether 36 groundwater samples were collected from 12 population clusters namely Brahmandeo, Bajrakot, Krushnaprasadgarh (K.P. Garh), Nuapara, Brahmanapur, Satapada, Nuagarh, Mirzapur, Bhagabanpur, Panaspara, Arakhakuda, and Gopinathpur (Figure 1). While 12 samples were collected in the post-monsoon period (one sample each from the 12 sites), 24 samples were collected in pre-monsoon period (two samples each from the 12 sites). Most of the groundwater samples were collected from dug wells and shallow bore wells. While post-monsoon sampling was carried out in October 2003, pre-monsoon sampling was carried out in March 2004. During chemical analysis, standard procedures were observed as enumerated in APHA (1985). Some parameters like electrical conductivity, pH and temperature were measured in the field.

RESULTS AND DISCUSSIONS

The results of chemical analysis of the groundwater samples are shown in Tables 1 to 4. Tables 1 and 2 show the hydrochemistry of groundwater collected during the pre-monsoon, Tables 3 and 4 show those collected during the post-monsoon. In Tables 1 and 3, the concentration of various ions are presented in mg/l, and in Tables 2 and 4, the concentrations are presented in milliequivalents per litre (meq/l).

Table 1. Groundwater Hydrochemistry - Pre-Monsoon (mg/l)

Loc. No.	Location Name	TDS (mg/l)	EC (Micro siemens per cm)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}
				Ionic concentrations expressed in mg/l						
1	Brahmandeo	1702	2656	73	56	422	23	374	700	66
		1699	2651	70	51	428	18	352	715	57
2	Bajrakot	1625	2536	74	60	392	23	346	652	67
		1559	2433	68	51	380	18	334	647	50
3	Krushna prasadgarh	2521	3933	46	104	516	183	433	1084	142
		2449	3820	50	100	542	166	383	1086	115
4	Nuapada	3254	5076	18	216	591	284	473	1414	250
		3419	5333	286	196	540	52	887	1050	397
5	Brahmanpur	2261	3527	50	74	602	17	473	928	107
		2315	3612	113	149	384	35	483	823	321
6	Satapada	3848	6003	143	172	655	286	1106	1223	256
		3930	6131	105	156	784	288	1111	1222	258
7	Nuagarh	2652	4137	50	108	562	186	383	1103	245
		2728	4256	51	135	594	181	385	1123	245
8	Mirzapur	2331	3636	110	195	390	33	363	1191	42
		2322	3622	64	199	410	35	361	1203	40
9	Bhagabanpur	3651	5696	137	256	728	37	430	1630	385
		3914	6107	159	269	762	70	541	1698	430
10	Panaspada	2416	3769	118	211	398	35	386	1208	48
		2455	3830	120	215	406	36	394	1223	50
11	Arakhakuda	2527	3943	53	112	546	173	391	1131	111
		2612	4075	51	120	594	171	383	1119	159
12	Gopinathpur	2511	3917	47	106	567	155	373	1107	146
		2553	3983	48	118	565	166	375	1116	158

Table 2. Groundwater Hydrochemistry - Pre-Monsoon (meq/l)

Loc. No.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}	Cl^{-}/ HCO_3^{-}	Mg^{++}/ Ca^{++}	Na^{+}/ Cl^{-}
	Ionic concentrations expressed in meq/l									
1	3.692	4.688	18.357	0.613	5.703	19.775	1.394	3.467	1.269	0.928
	3.542	4.277	18.661	0.485	5.785	20.198	1.207	3.491	1.207	0.923
2	3.742	5.017	17.052	0.613	5.687	18.421	1.415	3.239	1.340	0.925
	3.443	4.277	16.573	0.485	5.490	18.280	1.061	3.329	1.242	0.906
3	2.345	8.637	22.489	4.704	7.113	30.607	2.977	4.302	3.683	0.734
	2.544	8.308	23.577	4.270	6.293	30.664	2.415	4.872	3.265	0.768
4	0.948	17.85	25.75	7.287	7.768	39.917	5.225	5.138	8.829	0.645
	14.321	16.205	23.49	1.355	14.554	29.648	8.286	2.037	1.131	0.792
5	2.544	6.169	26.187	0.460	7.768	26.207	2.248	3.373	2.424	0.999
	5.688	12.257	16.747	0.895	7.917	23.226	6.704	2.933	2.154	0.721
6	7.147	14.179	28.496	7.338	18.129	34.511	5.350	1.903	1.983	0.825
	5.247	12.907	34.106	7.389	18.211	34.497	5.392	1.894	2.459	0.988

Table 2. (Continued) Groundwater Hydrochemistry - Pre-Monsoon (meq/l)

7	2.495	8.966	24.447	4.781	6.293	31.131	5.121	4.946	3.593	0.785
	2.549	11.187	25.839	4.653	6.326	31.708	5.107	5.012	4.312	0.814
8	5.489	16.041	16.965	0.869	5.965	33.626	0.895	5.637	2.922	0.504
	3.243	16.37	17.835	0.895	5.933	33.964	0.853	5.724	5.047	0.525
9	6.86	21.069	31.683	1.892	7.063	46.002	8.023	6.513	3.071	0.688
	7.98	22.156	33.162	1.815	8.883	47.922	8.411	5.394	2.776	0.691
10	5.938	17.357	17.356	0.920	6.342	34.105	1.022	5.377	2.923	0.508
	6.037	17.686	17.704	0.946	6.474	34.529	1.061	5.333	2.929	0.512
11	2.694	9.257	23.752	4.449	6.424	31.933	2.331	4.970	3.436	0.743
	2.594	9.889	25.882	4.398	6.293	31.567	3.311	5.016	3.812	0.819
12	2.387	8.762	24.702	3.978	6.125	31.234	3.054	5.099	3.670	0.790
	2.414	9.715	24.618	4.252	6.153	31.493	3.292	5.118	4.024	0.781

Table 3. Groundwater Hydrochemistry - Post-Monsoon (mg/l)

Loc. No.	**Location Name**	**TDS (mg/l)**	**EC (Micro siemens per Cm)**	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{--}**
				Ionic concentrations expressed in mg/l						
1	Brahmandeo	681	1062	37	21	119	7	336	124	30
2	Bajrakot	679	1060	53	26	102	7	328	127	34
3	Krushna prasadgarh	618	965	32	18	114	8	320	90	28
4	Nuapada	523	815	49	27	64	7	254	81	36
5	Brahmanpur	589	919	56	31	55	8	319	71	43
6	Satapada	699	1090	84	31	49	29	334	110	56
7	Nuagarh	398	621	58	13	33	7	171	70	38
8	Mirzapur	713	1112	97	32	55	9	360	137	17
9	Bhagabanpur	726	1132	83	36	61	16	339	137	48
10	Panaspada	731	1141	86	35	67	15	327	129	62
11	Arakhakuda	797	1243	99	37	73	15	342	170	52
12	Gopinathpur	817	1275	102	38	70	13	402	115	67

Table 4. Groundwater Hydrochemistry - Post-Monsoon (meq/l)

Loc. No.	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{--}**	**Cl^{-}/HCO_3^{-}**	**Mg^{++}/Ca^{++}**	**Na^{+}/Cl^{-}**
	Ionic concentrations expressed in meq/l									
1	1.874	1.747	5.182	0.191	5.523	3.514	0.644	0.636	0.932	1.474
2	2.645	2.142	4.441	0.182	5.376	3.599	0.711	0.669	0.809	1.233
3	1.618	1.493	4.961	0.208	5.248	2.549	0.589	0.485	0.922	1.946
4	2.471	2.231	2.785	0.201	4.174	2.298	0.758	0.550	0.902	1.211
5	2.799	2.632	2.393	0.209	5.244	2.021	0.898	0.385	0.940	1.884
6	4.241	2.562	2.132	0.751	5.487	3.118	1.183	0.568	0.604	0.683
7	2.918	1.104	1.439	0.191	2.817	1.993	0.797	0.707	0.378	0.722
8	4.847	2.662	2.397	0.232	5.904	3.884	0.369	0.657	0.549	0.617
9	4.162	3.043	2.655	0.411	5.568	3.887	1.020	0.698	0.731	0.683
10	4.296	2.961	2.916	0.406	5.375	3.645	1.308	0.678	0.689	0.800
11	4.981	3.125	3.177	0.402	5.619	4.809	1.098	0.855	0.627	0.660
12	5.106	3.208	3.088	0.354	6.601	3.259	1.403	0.493	0.628	0.947

The results show the TDS values in the pre-monsoon varied from 3930-1559 mg/l with an average value of 2745 mg/l and in the post monsoon it varied from 398-817 mg/l with an average value of 604 mg/l. All the major ions are marked by wide variations in their chemical contents and this is more conspicuous from the samples collected during the pre-monsoon period with Ca ranging from 18-286 mg/l, Mg from 51-269 mg/l, Na from 390-784 mg/l, K from 17-288 mg/l, HCO_3 from 334-1111 mg/l, Cl from 647-1698 mg/l and SO_4 from 40-403 mg/l. The variation is less widespread in the case of samples collected during the post-monsoon period which have ionic concentrations that range for Ca from 32-102 mg/l, Mg from 13-38, Na from 33-119 mg/l, K from 7-29 mg/l, HCO_3 from 171-402 mg/l; Cl from 70-170 mg/l, and SO_4 from 17-67 mg/l.

The contribution of salt contents to the groundwater may be ascribed to various sources. Hydrochemistry of groundwater is a function of precipitation, chemical weathering and dissolution of minerals within the geological formations (Chebotarev, 1955). However, occurrences of a variety of salts and their varying concentrations are ascribed to their environment, movement and source of groundwater (Todd, 1980). In the present context, since the TDS level of groundwater from two different seasons differs, much consideration has to be paid regarding their sources. The results presented in Table 3 show that the post-monsoon groundwater is rich in Ca and HCO_3 ions as compared to Na, Mg and Cl ions. However, groundwater results presented in Table 1 show the opposite picture. Here, the groundwater is rich in Mg, Na and Cl ions as compared to Ca and HCO_3 ions. As we move from post-monsoon to a monsoon period, the source of salinity is found to increase. In this case, the primary salinity is likely to be contributed by the aquifer materials that hold the groundwater. Geologically, the aquifer materials consist of thick columns of marine black clay and sandy clay which occur as intercalations within the thick sand bars. These clays of marine origin actually act as basement for the underlying aquifers. Mercado (1985) considered that the concentrations of those ions and their variation over space and time may be due to cation exchange process and interaction with aquifer materials. In this context, the groundwater may come in contact with the clays, sandy clays and marine black clays, and cation exchange process may contribute the salt to the groundwater.

As we proceed to the pre-monsoon results (Table 1), they show a sudden increase in the TDS levels from an average of 604 mg/l to 2745 mg/l. As higher and higher quantities of water are extracted, the water table drops with no recharge in the pre-monsoon. The delicate balance between the fresh and saline water is disturbed, forcing the saline water to move upward and mix with the fresh water. In this process, saline sea water which has a TDS value of 35 gm/l not only increases the TDS values of the groundwater system but also increases the individual concentration of ions, especially Na, Mg and Cl. Davis and Dewiest (1966) have pointed out that sea water is more enriched in ions of Cl, Mg and Na as compared to fresh water of inland origin which actually shows enrichment of Ca and HCO_3 ions. It may be concluded that the groundwater in this region before the pre-monsoon has high salinity values only due to mixing of seawater. This fact can also be established by some ratio values such as Cl/HCO_3, Mg/ Ca and Na/Cl. The concentrations of these ions in the ratios are to be expressed in meq/l.

Since sea water has higher concentrations of Mg, Na and Cl as compared to inland fresh water, its dominance over fresh water, particularly in our context in the pre-monsoon groundwater can be fairly established by the Cl/HCO_3 and Mg/ Ca values and they also serve as best indicators of water quality. Todd (1980) has noted that Cl/HCO_3 and Mg/Ca values of more than 1 are indicative of salt water encroachment. The value of Cl/HCO_3 and Mg/ Ca is presented in Tables 2 and 4.

Table 4 shows groundwater hydrochemistry in the post-monsoon period. All the Cl/HCO_3 and Mg/ Ca values are less than 1. Here the maximum values of Cl/HCO_3 and Mg/ Ca are 0.85 and 0.94 respectively. These results indicate that groundwater in the post-monsoon is not encroached by saltwater. The salinity may have been contributed by the sandy clay, clays and marine black clays, which serve as aquifer materials. But in case of groundwater collected in the pre-monsoon, the minimum and maximum value of Cl/HCO_3 are 1.894 and 6.513 respectively. Almost all samples have a Cl/HCO3 value greater than 1. Most of the samples have values around 5, thus indicating saltwater encroachment. Similarly the minimum and maximum values of Mg/ Ca are 1.131 and 8. 892 respectively, with most of the values around 8 thus indicating salt water encroachment. The Na/Cl ratio is an important parameter to understand the dominance of seawater in a groundwater system. In the normal hydrological cycle, groundwater is characterized by a ratio of 0.86-1.0 and seawater around 0.87 (Rosenthal, 1987). In the present case, most of the samples have a ratio of around 0.87, thus indicating that the groundwater has been affected by seawater encroachment. In some samples, a lower value is also observed which is due to positive ion exchange in which Na is absorbed into the aquifer material (Schoellar, 1959). There are also a few cases where the ratio is much higher than 0.87, which may be due to larger concentration of Na ions released from the saline water medium into the fresh water system.

SUITABILITY FOR DRINKING PURPOSES

The concentration of TDS, Na and Cl in groundwater has a bearing on human health. Drinking water standards are generally based on two main criteria (Davis and Deweist, 1966) (i) the presence of objectionable tastes, color and odor and (ii) the presence of substances with adverse physiological (health effect) characteristics. As far as color, odor and taste is concerned, groundwater in the post-monsoon period is satisfactory. So far as the second criterion is concerned, the hydrochemical results are compared with the standards set by various agencies (Table 5). The groundwater during the post-monsoon has a TDS range of 398-817 mg/land is categorized as fresh water according to Carrol (1962). Results also indicate that the maximum value of all the parameters at all the locations are below the maximum permissible limits (MPL) set by Indian Standards Institute (ISI, 1983), Indian Council of Medical Research (ICMR, 1975) and World Health Organization (WHO, 1993). On the other hand, the quality of groundwater in the pre-monsoon is not acceptable, with TDS values ranging from 1559 to 3930 mg/l and an average value of 2745 mg/l. Moreover, the TDS value at many locations is found to be around 2500 mg/l, which is far above the MPL of 1000 mg/ l set by WHO. In the same manner, the concentration of Na varies between 390-784 mg/l, which is much above the MPL of 200 mg/l set by WHO. The chloride concentration varies between 647 to 1698 mg/l, which is much above the MPL of 250 mg/l set by WHO and ISI. Since all the parameters have their concentrations much above the MPL, it is advised that the groundwater in pre-monsoon period should not be used for drinking purpose.

Figure 5. Water Quality Standards of Various Agencies

Sl. No.	Parameters	Range of values (In the pre and post monsoon seasons)	Maximum Permissible limits set by ISI	Maximum Permissible limits set by ICMR	WHO standards
1	TDS (in mg/l)	1559-3930 398-817	500	1500-3000	1000
2	Ca (in mg/l)	18-286 32-102	75	200	200
3	Mg (in mg/l)	51-269 13-38	30		
4	SO_4 (in mg/l)	40-403 17-67	150	400	400
5	Cl (in mg/l)	647-1698 70-170	250	1000	250
6	Na (in mg/l)	390-784 33-119			200

CONCLUSIONS AND RECOMMENDATIONS

Groundwater samples were collected from dug wells and shallow bore wells located on the barrier spit of Chilika lagoon to evaluate their hydrochemical quality and also their fitness for drinking. Groundwater samples collected during the post-monsoon period had TDS values less than 1000 mg/l and are categorized as fresh water. They were enriched in Ca and HCO_3 ions as compared to Na, Mg and Cl ions, and the concentration of Na, Mg and Cl values are well within the recommended water quality limits set by ISI, ICMR and WHO. On the other hand the groundwater samples collected during the pre-monsoon period had TDS values greater than 1000 mg/l but less than 10,000 mg/l thereby placing them in the brackish water category. The salinity is chiefly due to enrichment of Na, Mg and Cl as compared to Ca and HCO_3 ions. During the post-monsoon, the groundwater is in equilibrium with the underlying saline water and the salt content is likely contributed by the aquifer materials, principally clays. As the rate of discharge of groundwater is not balanced by recharge during the pre-monsoons, the balance between fresh and salt water is disturbed and saline water encroaches on fresh water. Since the concentration level of TDS, Na, Mg and Cl in all the samples during the pre-monsoon are much above the MPL, it is advised that they should not be used for drinking purposes. It is recommended that the government opt for a piped water supply. During the pre-monsoon, groundwater from existing dug wells should be used, and water from bore wells should be used as little as possible to preclude saline water encroachment.

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