JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 7 1999

HYDROCHEMICAL ASSESSMENT OF GROUNDWATER IN PARTS OF SOUTH COASTAL ORISSA, INDIA

J. K. Tripathy
R.C. Panigrahy

Department of Marine Sciences
Berhampur University
Berhampur, India

Detailed hydrochemical analysis was carried out on a number of water samples collected from the coastal tract of south Orissa between the Rushikulya and Bahuda river estuaries to assess the quality of groundwater in this region. Results indicate that the groundwater of this region is highly enriched in Ca, Mg, Na, Cl and HCO_3. At some locations the concentration of these ions, as well as other parameters such as salinity, total hardness and total dissolved solids are above the World Health Organization standards for drinking water. The concentration of Na, Mg and HCO_3 at some locations near the coast suggests sea water encroachment, which is further substantiated by a general increase in the value of Cl content and Na/Cl ratio, and a decrease in HCO_3 content towards the coast. On the basis of hydrochemical studies, five groundwater types have been delineated. They are $Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $NaHCO_3$, $CaC1_2$ and NaCl. Some intermediate groundwater sub-types are also recognized in the transitional zones, thus indicating that the major groundwater types are not spatially isolated.

INTRODUCTION

Water plays a vital role in the development of human society as it is subjected to use for various purposes, amongst which the domestic use deserves more attention. This is important especially for a developing country like India, where agricultural revenue constitutes the bulk of the national income. Water resources are an important component for the smooth economic development of the country. As the study area is located in a semiarid climatic region, the agricultural activities are completely dependent on surface water, for which the monsoon plays a very important role. Frequent failures in the monsoon prompted hydrogeologists to look for groundwater resources. Several Central and State governmental agencies directed their activities towards exploration and exploitation of groundwater for drinking and agricultural purposes, causing a degradation in water quality at several coastal locations, mainly along estuaries and creeks. Though studies pertaining to groundwater quality are carried out by various agencies, they are fragmentary in nature and have yet to cover the study area under question. The result is that people living along the coast are consuming contaminated water without knowing the consequences.

The present study is undertaken to carry out a hydrochemical analysis of groundwater in a systematic manner, and to present the results to the concerned authority so that future planning can be framed accordingly.

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The study area (Figure 1) is located between latitudes 19°05'-19°30' and between longitudes 84°45'-85°15' and covers an area of about 600 km^2. The geology of this region has been studied by various authors (Pascoe, 1950; Krishnan, 1982; Mohanty et al., 1988; Rao, 1989; Mohanty and Devdas, 1989, and Tripathy et al., 1998). The Eastern Ghat Super Group of rocks belonging to the Archaeans are the oldest lithological units comprising the khondalites (quartz-feldspar-garnet-sillimanite schist/gneiss) and the charnockites (hypersthene granites). Other lithological types, such as quartzites, gneisses and leptynites are also found in this region. From among the Cenozoics, laterites ranging in age from Tertiary to Quaternary are exposed all along the coastal plain, and the alluvium belonging to the Quaternary is represented by sandy and black clay, marine black clay, and coarse and fine sands. While the Archaeans act as runoff zones without containing any groundwater, the Quaternary Formations have proven reserves of groundwater.

The alluvial tract of Orissa state comprises aquifers of very high groundwater potential (Raghunath, 1987). With an average annual rainfall of 115 cm, 20 percent may be assumed to recharge the aquifer. Around 50 percent of the recharge potential can be utilized by the installation of filter point tube wells and the remaining 50 percent can be utilized by dug wells and deep tube wells. The yield of tube wells penetrating aquifers of 7-12 m thick (located within 50 m of the surface) is about 20-50 m^3/hr.

METHODOLOGY

Forty seven groundwater samples were collected from tube wells (Figure 1) and were analyzed to determine their hydrochemistry. Standard procedures enumerated in APHA (1985) were used. One liter of each of the samples was filtered and acidified for cation analysis while the rest was preserved for anion analysis. Some parameters like electrical conductivity, pH and temperature were measured at the well head. Analysis for the major cations - Na , K, Ca, and Mg - was carried out by means of an atomic absorption spectrophotometer. Standard titration methods were used for the estimation of Cl, HCO_3, and SO_4.

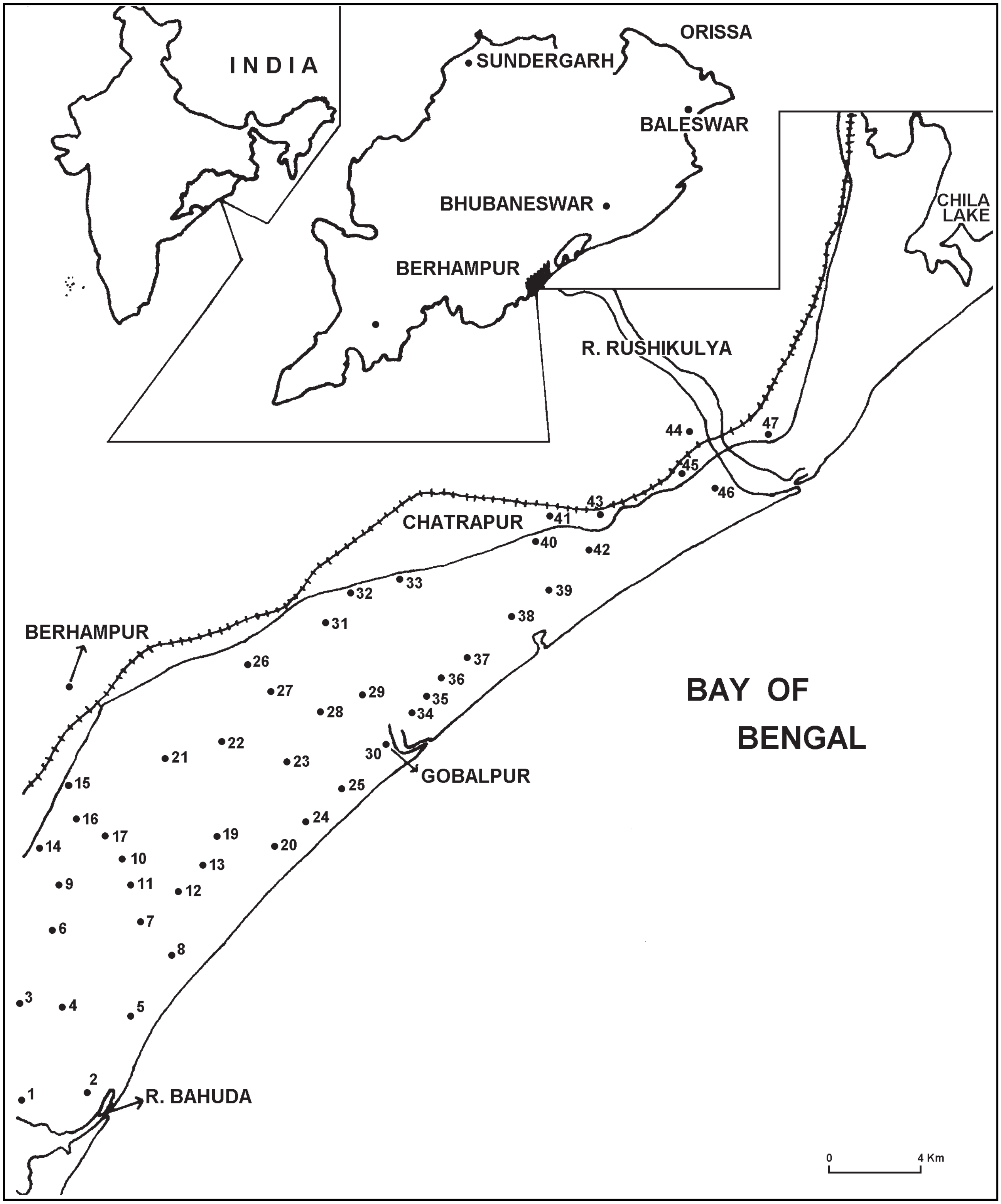

Figure 1. Map of the study area and sample locations.

RESULTS

The results of chemical analysis of the groundwater samples are presented in Table 1, and Table 2 shows the range in values along with World Health Organization (WHO, 1993) standards. The data show that the samples are enriched in Na, Ca, Mg, Cl and HCO_3 as compared to K and SO_4.

Table 1. Groundwater Well Head Parameters (in mg/l)

No.	Name	TDS	EC micro mhos/cm	TH	Ca	Mg	Na	K	HCO_3	Cl	SO_4	Cl/HCO_3	Na/Cl	Ca/Mg
1	SORALA	2602	4059	574	51	109	522	191	375	1092	242	5.01	0.74	0.28
2	SONEPUR	2052	3201	990	168	139	387	39	58	894	325	26.55	0.67	0.73
3	GOVINDPUR	902	1407	296	92	16	103	33	484	122	44	0.44	1.33	3.53
4	VISWANATHPUR	902	1407	92	17	12	224	11	366	182	30	0.85	1.91	0.85
5	CHANDANPETA	2231	3636	426	44	77	631	45	426	1006	69	4.07	0.97	0.35
6	JAGANNATHPUR	585	913	229	57	21	44	34	283	79	52	0.49	0.89	1.65
7	MANDRASPUR	905	1412	84	19	9	230	9	361	176	44	0.84	2.02	1.25
8	EKASINGI	1982	3092	472	79	67	377	96	671	602	74	1.57	0.98	0.72
9	MANTRIDI	582	908	324	82	29	41	6	252	95	39	0.65	0.67	1.70
10	SASANPADAR	916	1429	346	17	74	197	56	343	142	30	0.71	2.15	0.14
11	CHELIA	915	1427	262	41	39	168	17	396	174	63	0.76	1.49	0.63
12	TULU	1728	2696	419	74	57	422	24	348	701	67	3.46	0.93	0.79
13	KELUAPALLI	1718	268	435	74	61	392	24	348	653	67	3.22	0.93	0.74
14	GOLANTHRA	147	229	50	12	5	17	12	58	17	6	0.52	1.53	1.40
15	KANISI	715	1115	170	35	20	132	15	321	129	38	0.69	1.58	1.05
16	CHIKARADA	459	716	214	15	43	30	65	225	62	52	0.47	0.74	0.21
17	PADMAPUR	555	866	226	46	27	52	16	27~j	67	60	0.43	1.22	1.04
18	MAJHIGAON	922	1438	338	76	36	107	26	373	149	134	0.70	1.13	1.28
19	SOLABINDHA	1675	2613	545	105	69	238	74	618	381	180	1.08	0.98	0.92
20	KIRTIPUR	2303	3593	471	62	77	627	19	362	965	122	4.59	1.00	0.49
21	PHULTA	716	1117	261	42	38	83	20	348	126	33	0.63	1.04	0.68
22	GAANJU	726	1133	176	36	21	130	10	338	128	35	0.65	1.57	1.03
23	GOOLABANDHA	923	1440	266	36	43	162	19	409	176	60	0.74	1.43	0.51
24	DHABALESWAR	942	1470	167	11	34	183	40	389	199	69	0.90	1.44	0.20
25	BAISIPALLI	945	1474	464	89	59	115	11	309	296	50	1.64	0.60	0.91
26	DOORA	734	1145	227	48	26	118	10	333	132	40	0.68	1.39	1.11
27	RAMACHANDRAPUR	745	1162	283	18	58	92	21	358	152	31	0.74	0.95	0.19
28	KARAPALLI	746	1164	243	53	27	101	14	345	120	74	0.61	1.32	120
29	RANGEILUNDA	750	1170	253	88	8	75	34	351	120	58	0.60	0.97	6.70
30	GOPALPUR	1277	1992	489	130	40	122	66	579	220	100	0.66	0.87	1.98
31	MANDIAPALLI	602	939	199	45	21	89	17	249	128	27	0.90	109	1.31
32	PATRAPUR	614	958	224	55	21	48	38	311	78	62	44	0.98	1.60
33	CHAMAKHANDI	616	961	487	121	45	88	63	17	174	108	0.69	0.79	1.63
34	HARIPUR	1305	2036	477	86	64	15	52	586	282	71	0.84	0.84	0.82
35	UPALAPUTTI	1351	2108	578	169	38	140	41	615	260	70	0.74	0.85	2.70
36	BASANAPUTTI	1415	2207	529	123	54	170	66	654	285	46	0.76	0.94	1.38
37	BADAPUTTI	768	1198	251	53	29	122	12	331	146	50	0.76	1.29	1.10
38	MATIKHAL	776	1211	292	74	26	67	24	386	99	78	0.45	1.07	1.74
39	ARJIPALLI	785	1225	70	15	8	198	10	345	134	30	0.67	2.29	1.10
40	SANACHATRAPUR	628	980	211	63	13	59	38	308	87	48	0.49	1.08	2.94
41	CHATRAPUR	641	1000	130	11	25	120	26	251	134	54	0.94	1.40	0.26
42	PATA	796	1242	322	86	26	102	9	326	156	60	0.82	1.01	1.99
43	HUMMIRI	844	1317	284	48	40	120	18	409	116	60	0.49	1.60	0.73
44	BIRIPUR	1128	1760	525	82	78	153	22	352	349	52	1.71	0.68	0.63
45	PODAPADAR	2058	3210	1011	188	132	386	39	58	894	325	26.82	0.67	0.87
46	AGASTINUAGAON	5985	9337	3325	646	417	1171	44	543	3048	1084	9.67	0.59	0.94
47	GANJAM	5721	8925	1492	236	220	1511	31	462	2968	214	11.04	0.79	0.65

Table 2. Range in Values of Different Well Head and Hydrochemical Parameters and WHO Guidelines

Parameter		Range	Maximum permissible level set by WHO
TDS	(mg/l)	147-5985	1000
EC	(uS/cm)	229-9337	1400
TH	(mg/l)	51-3325	
Sodium	(mg/l)	17-1511	200
Potassium	(mg/l)	6-191	
Calcium	(mg/l)	11-646	200
Magnesium	(mg/l)	5-417	
Bicarbonate	(mg/l)	17-671	
Chloride	(mg/l)	17-3048	250
Sulfate	(mg/l)	6-1084	400

The concentration of all the major ions ranged between wide limits. Chemical analysis results indicate that the concentration of Na at locations 1, 2, 4, 5, 7, 8, 12, 13,19, 20, 45, 46 and 47, and that of Cl at locations 1, 2, 5, 8, 12, 13, 19, 20, 25, 34, 35, 36, 44, 45, 46 and 47, showed higher values than what is recommended by WHO as the maximum permissible limit for drinking water.

Total hardness (TH) indicates the trend in the concentration of Ca and Mg with a value ranging from 51-3325 mg/l. The total dissolved solids (TDS) values, representing the total salt content in the water, ranged between 147 mg/l and 5985 mg/l, amongst which at locations 1, 2, 5, 8, 12, 13, 19, 20, 30, 34, 35, 36, 44, 45, 46 and 47 the values were higher than the recommended value of 1000 mg/l, the maximum permissible limit for water. The electrical conductivity values ranged between 229 and 9337 mS/cm, indicating higher salinity values.

Drinking water standards are generally based on two main criteria (Davis and DeWiest, 1966): (1) presence of objectionable tastes, odor and color and (2) presence of substances with adverse physiological (health effects) characteristics. The chemical analysis results showed that the groundwater in the landward locations of the study area is potable, but waters close to the coast are unfit for drinking as they contain objectionable levels of TDS, Na and Cl.

DISCUSSION

Table 1 shows that the groundwater of this region is characterized by wide ranges in the concentration levels of the major ions. Although the most significant geohydraulic influence on groundwater chemistry arises from the source and circulation of groundwater itself, regional geology plays a very important role in determining the hydrochemistry of the groundwater system (Amadi, 1987). In the present context, the ionic species of Na, K, Ca and Mg may have been derived from the chemical weathering of a range of silicates, such as feldspars, pyroxenes, amphiboles and micas which are abundantly distributed among the Eastern Ghats Group of rocks. But the erratic concentration levels of all the four major cations may be ascribed to the fact that they are constantly involved in cation-exchange process and interaction with aquifer material (Mercado, 1985).

Excepting location 46, the sulfate levels at other locations of the study area are below the WHO standards for drinking water, thereby posing no risk for consumption. These low values have been made possible by the removal of sulfate from the water by bacteria. The reduction of sulfate ions produces H_2S (Freeze and Cherry, 1979), and this may be the reason why groundwater collected around the creeks and swamps has an unpleasant odor.

The levels of chloride in groundwater showed a particular trend in its pattern of variation wherein relatively small values occurred around the landward locations and very high values occurred towards the sea. Higher values are indicative of salt water encroachment. According to Lusczynski and Swarzenski(1966), 50 mg/l of chloride in groundwater is indicative of salt water encroachment on Long Island, USA. On the other hand Trembley et al. (1973) state that chloride concentrations greater than 40 mg/l are indicative of salt water contamination in the Summerside area of Prince Edward Island. Amadi (l989) considered chloride contents greater than 50 mg/l to be indicative of salt water contamination in the Niger delta, Nigeria.

In the present study, the concentration of chloride recorded was much higher, suggesting salt water encroachment along the coast, which is in agreement with the results obtained by earlier works in other parts of the world. This fact is also supported by the parameter Na/Cl (Table 1) which falls below both fresh water(~ 1) and sea water (~ 0.85) as one goes towards the sea. Sea water encroachment is likely at location 1, 2, 13, 25, 44, 45, 46 and 47. The concentrations of HCO_3 ion at these locations are much lower than those of landward locations, thereby substantiating the fact that aquifer salinization has taken place.

The encroachment of sea water may be responsible for the general variation in the chloride content between landward and seaward locations. Proximity to the sea and/or excessive exploitation of water may have caused the encroachment. Results also reveal that seaward locations are more enriched in Mg than Ca. An increase in Mg values is indicative of salt water encroachment (Davis and DeWiest, 1966).

The wide range of variations of ionic contents have given rise to several groundwater types (Figure 2) with the bicarbonate water type occurring towards the land and chloride types towards the sea. The first water encountered is calcium bicarbonate (Type 1) with Ca as the major cation and Mg and Na as secondary cations (locations 15, 33, 40, 41, 43, 48). As one moves towards the sea, groundwaters are more enriched in Mg and Na, thereby giving rise to magnesium bicarbonate water (Type 2), and sodium bicarbonate water (Type 3), respectively. Type 2 water occurs at locations 9, 14, 16, 26, 27, 31 and 32, and Type 3 water occurs at locations 3, 4, 6, 7, 10, 11, 21, 22, 23, 28, 29, 30, 34, 35, 36, 37, 38 and 39. Calcium chloride water (Type 4) occurs only at few locations (17, 18, 25 and 44) and sodium chloride water (Type 5) occurs at locations 1, 2, 5, 8, 12, 13, 19, 20, 24, 45, 46 and 47. Apart from the above major water types, several other intermediate water types might exist at the interface zones.

The evolution of groundwater types can, to a satisfactory extent, be explained with the help of the "theory of encounter" proposed by Freeze and Cherry (1979). The theory states that the order in which groundwater encounters strata of different mineralogical composition can exert important control on the final water chemistry. As groundwater moves through varying mineralogical strata, the water composition undergoes adjustment of various ionic species, caused by imposition of new mineralogically controlled thermodynamic constraints.

Evolution of groundwater from alkaline earth carbonate type to sodium chloride type was

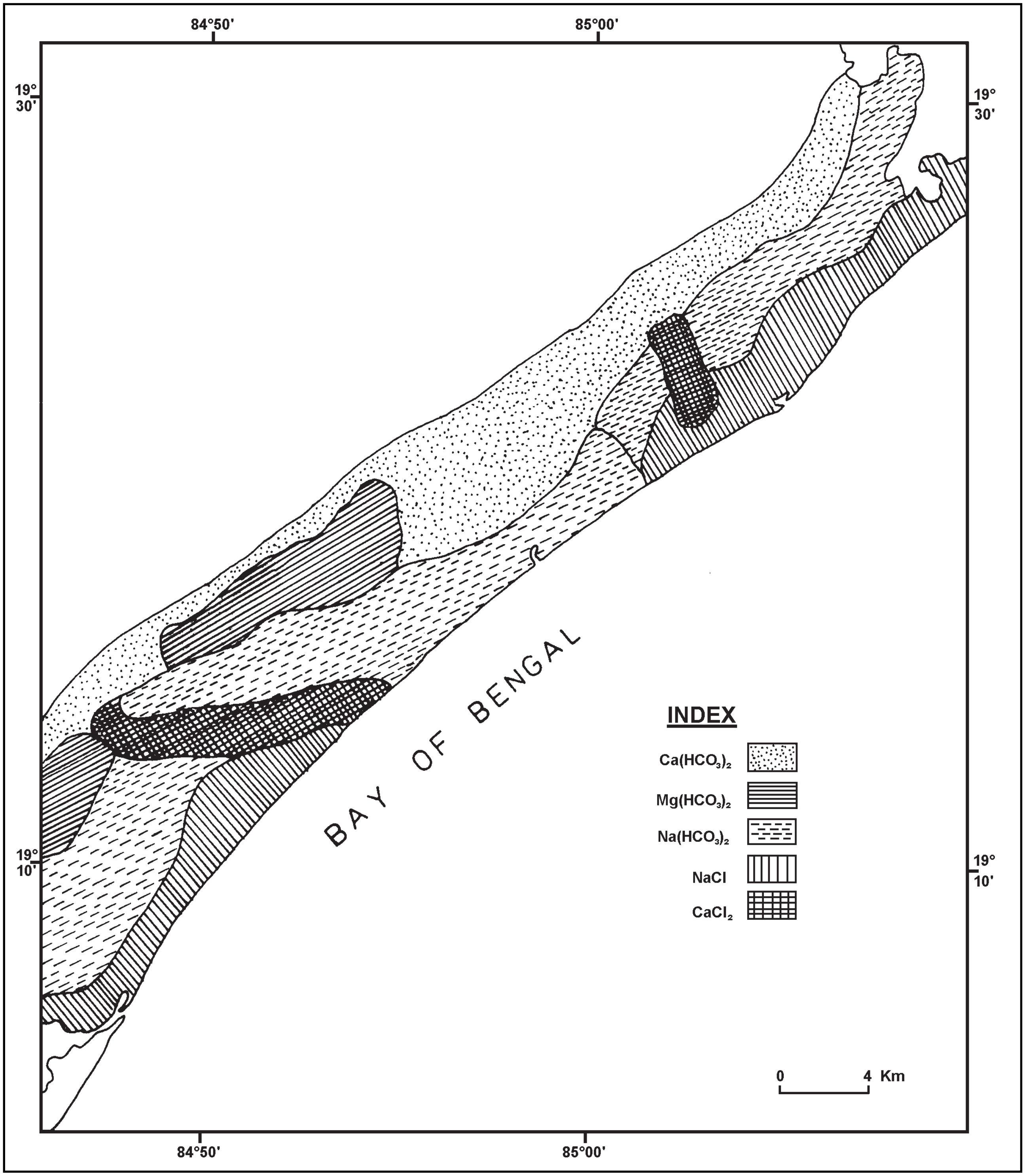

Figure 2. Occurrence of different groundwater types.

discussed in detail by Tijani (1994). The author observed that in a basement complex terrain, alkaline earth carbonate type water occurs in the primary stage of evolution, whereas sodium chloride type occurs in the final stage. The geological literature shows that a major part of the study area covers the Eastern Ghats, which form the basement complex of the study area, and the occurrence of calcium bicarbonate water type conforms with the observation made by Tijani (1994). Generally, within the evolutionary trend, groundwater tends to acquire a chemical composition similar to that of sea water (i.e. more dissolved solids and a relative increase in chloride ion) the longer it remains underground and the further it travels (Driscoll, 1986). Following the above logic, in this study, the alkaline earth carbonates, while flowing through the Quaternary sediments, finally emerge as NaCl type water, with magnesium bicarbonate and sodium bicarbonate type waters occurring as intermediate waters (exchange waters), as seen in other places in the world (see Tijani, 1994). However, the occurrence of the calcium chloride water type at a few locations may be due to interactions between calcium bicarbonate and sodium chloride water types, with the cation exchange process playing the leading role.

SUMMARY AND CONCLUSION

Chemical analysis results indicate that the groundwater of this region is highly saline with TDS values ranging from 147-5985 mg/l. Apart from that, the water is found to be enriched in Na, Ca, Mg, Cl , SO_4 and HCO_3 ions. Higher concentrations of Ca and Mg are also confirmed by TH values that range from 51-3325 mg/l. Salt water encroachment is considered responsible for increasing values of Na, Mg and Cl towards the coast. This is further substantiated by Na/Cl ratios which, as one approaches the coast, are below values for sea water and fresh water, as well as decreasing HCO_3 concentration towards the coast.

The results, as well as the assessment of the possible geohydrologic controls on water chemistry, indicate that the overall hydrochemistry of groundwater is controlled by the chemical inputs from precipitation, chemical weathering of the Eastern Ghats Group of rocks, as well as the thick sequence of Quarternary sediments covering a large portion of the study area. Around the creeks, salt water contributes significantly to the TDS values.

Groundwater at most locations is potable taking into consideration their TDS as well as various other ionic contents. However, groundwater at locations 1 2, 5, 8, 12, 13, 19, 20, 24, 34, 36, 44, 45, 46 and 47 show values of TDS, Na and Cl higher than the WHO standards for drinking water. Therefore consumption of tube well water at these locations poses a health risk. In this connection it is advisable that people living around these areas should avoid consuming tube well water preferring instead dug well water which is safer from the health point of view.

In all, five groundwater types are delineated based on the major ions. They are: Type I- calcium bicarbonate; Type II - magnesium bicarbonate; Type III - sodium bicarbonate; Type IV - calcium chloride, and Type V - sodium chloride. Though various other groundwater types exist in the transitional zones, only the major ones are represented in the groundwater map.

The evolution of water from calcium bicarbonate to sodium chloride type can satisfactorily be explained by means of the theory of "order of encounter". The concept of Driscoll (1986) that "within the evolutionary trend groundwater tends to acquire the chemical composition similar to that of sea water", also substantiates the fact that a complete evolution process can be seen in the groundwater of the study area.

ACKNOWLEDGMENT

The first author is thankful to the University Grants Commission for the financial assistance. We also acknowledge our gratitude to Mr. B .K. Pandit, Geologist, Gujarat Water Services and Sewerage Board for his cooperation.

REFERENCES

APHA; (1985). Standard methods for examination of water and waste water. 16th Ed. Washington, D.C..

Amadi, U.M.P.; (1987). Mixing phenomenon in groundwater systems and its relevance in water quality assessment in Nigeria. Iwugo K (Ed), Paper presented at 2nd annual Symposium/Conference of the Nigerian Water and Sanitation Association, pp 17.1-17.31.

Amadi, P.A.; C.O. Ofoegbu and T. Morrison; (1989). Hydrochemical assessment of groundwater quality in parts of Niger Delta, Nigeria. Environ. Geol. Water Sci., vol. 14, no.3, pp. 195-202.

Davis, S.N. and R.J.H. DeWiest; (1966). Hydrogeology. New York, John Wiley & Sons.

Driscoll, F.G.; (1986). Groundwater and Wells. 2nd Ed, St. Paul, Minnesota: Johnson Filtration Systems, Inc.

Freeze, R.A. and J.A. Cherry; (1979). Groundwater, Prentice Hall Inc., Englewood Cliffs, New Jersey.

Krishnan, H.S.; (1982). Geology of India and Burma. New Delhi, CBS Publishers and Distributors.

Lusczynski, N.J. and W.V. Swarzenski; (1966). Salt water intrusion in Southern Nassau and South Eastern Queens Countries. Long Island, New York, U.S. Geological Survey Water Supply Paper 1613F.

Mercado, A.C.; (1985). The use of hydrochemical patterns in carbonate, sand and sandstone aquifers to identify intrusion and flushing of saline water. Groundwater, vol. 23, pp. 635-645.

Mohanty, B.K., K.K. Bhatt and V. Devdas; (1988). Geomorphological and Quaternary Geological studies in the Southern Orissa Coast. Paper presented at Workshop on Coastal Geomorphology, Calcutta.

Mohanty. B.K. and Devdas, V.; (1989). Geological mapping of Quaternary Formations in Rushikulya river basin in parts of Ganjam dist., Orissa, Records GSI 122(3), pp. 5-6.

Pascoe, K.H.; (1950). A manual of the geology of India and Burma, Vol. 1, Calcutta, Govt. of India Press.

Raghunath, H.K.; (1987). Groundwater, New Delhi, Wiley Eastern Limited.

Rao, K.B.; (1989). Origin and evolution of the sand dune deposits of Ganjam coast, Orissa, India. Exploration and Research for Atomic Minerals, vol. 2, pp. 133-148.

Tijani, H.H.; (1980). Hydrochemical assessment of groundwater in Horo area, Kwara State, Nigeria, Environ Geol; vol. 24, pp. 194-202.

Trembley, J.J., J. Dtruz and H. Anger; (1973). Salt water intrusion in the Summerside area, P.E.I. Groundwater, Vol. 11, p. 4.

Tripathy, J.K., K.V. Kumar and R.C. Panigrahy; (1998). Geological and Geomorphological studies of a part of Ganjam district, Orissa by remote sensing techniques, Photonirvachak, Journal of the Indian Society of Remote Sensing, Vol. 24, no. 3, pp. 189-177.

World Health Organization; (1993). Guidelines for drinking water quality recommendations, Geneva.

ADDRESS FOR CORRESPONDENCE

Dr. J. K. Tripathy
Department of Marine Science
Berhampur University, Bhanja Bihar
Berhampur 760007
India