



APPLICATION OF ISOTOPE TECHNIQUES TO INVESTIGATE GROUNDWATER POLLUTION IN INDIA

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Abstract -Environmental isotopes (^2H , ^{18}O , ^{34}S , ^3H , and ^{14}C) techniques have been used along with hydrogeology and hydrochemistry to investigate:(a) the source of salinity and origin of sulphate in groundwaters of coastal Orissa, Orissa State, India and (b) to study the source of salinity in deep saline groundwaters of charnockite terrain at Kokkilimedu, South of Chennai, India. In the first case, as a part of a large drinking water supply project, thousands of hand pumps were installed from 1985. Many of them became quickly unacceptable for potable supply due to salinity, increased iron and sulphate contents of the groundwater. In this alluvial, multiaquifer system, fresh, brackish and saline groundwaters occur in a rather complicated fashion. The conditions change from phreatic to confined flowing type with increasing depth. The results of the isotope geochemical investigation indicate that the shallow groundwater(depth;<50m) is fresh and modern. Groundwater salinity in intermediate aquifer (50 - 100m) is due to the Flandrian transgression during Holocene period. Fresh and modern deep groundwater forms a well developed aquifer which receives recharge through weathered basement rock. The saline groundwater found below the fresh deep aquifer have marine water entrapped during late Pleistocene. The source of high sulphate in the groundwater is of marine origin.

In the second case, under the host rock characterization programme, the charnockite rock formation at Kokkilimedu, Kalpakkam was evaluated to assess its suitability as host medium for location of a geological repository for high level radioactive waste. Four deep boreholes were drilled in this area, the depth varying from 200 to 618 m. In these boreholes, large variations in groundwater salinity were observed over a distance of only a few hundred meters and no regional pattern could be identified. The results of the isotope investigation show that there are two different sources of salinity in this area. Among the four, in borehole BH-1, the salinity could be attributed to infiltrated sea water together with the contribution of solute from the pseudotachylites observed along the fractures and shear zones in the host rock. In the other three bore holes (BH-2, BH-3 & BH-4), the solutes which are responsible for salinity of these waters are mostly from sheared and fractured charnockite rock. Further, tritium results show that these well are getting local recharge.

1. THE SOURCE OF SALINITY AND ORIGIN OF SULPHATE IN COASTAL AQUIFERS OF ORISSA

1.1 Background

As part of a large drinking water project, thousands of hand pumps were installed from 1985 onwards in the coastal areas of Orissa State. Many of them became quickly unacceptable for potable supply due to the salinity of the groundwater (Chloride content: 6 - 7400 mg/L) as well as increased iron (Fe^+ : 0.0 - 19 mg/L) and sulphate content (SO_4^{-2} : 2.0 - 1400 mg/L).

Generally groundwater salinity originates from one or more of the following mechanisms: (a) intrusion of old or modern marine water, (b) mixing of meteoric water with connate water or fluid inclusions, (c) concentration of dissolved salts by evaporation near the

soil surface during slow diffuse recharge, (d) dissolution of aquifer material and (e) anthropogenic sources. Each of these mechanisms will have a distinct effect on some of the geochemical and isotopic relationships of the groundwater. If the mixing of meteoric water with recent or connate marine water is the primary cause of salinity, then variations in the salinity of the aquifer are expected as a result of variations in the degree of mixing. The $\delta^{18}\text{O}$ against either deuterium or chloride values of groundwater should then be positively correlated and plot on the mixing line between the compositions of sea water and fresh water [6]. If salinity is primarily due to the concentration of dissolved salts by evaporation, then the $\delta^{18}\text{O} - \delta^2\text{H}$ relationship will have a low slope reflecting kinetic fractionation. In addition, a plot of chloride against either isotope will be positively correlated, as increased evaporation would result in isotopic enrichment as well as increased chloride concentration. If salinity is due to the leaching of evaporitic salts by rapid percolation through preferential pathways, then the groundwater should retain a $\delta^2\text{H} - \delta^{18}\text{O}$ relationship similar to that of regional rainfall. As the leaching processes do not affect the isotopic composition of water, there would be no correlation between chloride and isotopic composition. Apart from ^2H and ^{18}O , the ratios of stable isotopes of sulphur ($^{34}\text{S}/^{32}\text{S}$) suggest the source of dissolved sulphur species and provide information about the reactions and geochemical processes affecting them. Hence, the Delang - Puri Sector in coastal Orissa was chosen for isotope hydrological investigation to identify the source of salinity, origin of sulphate and hydrodynamic conditions of saline groundwaters.

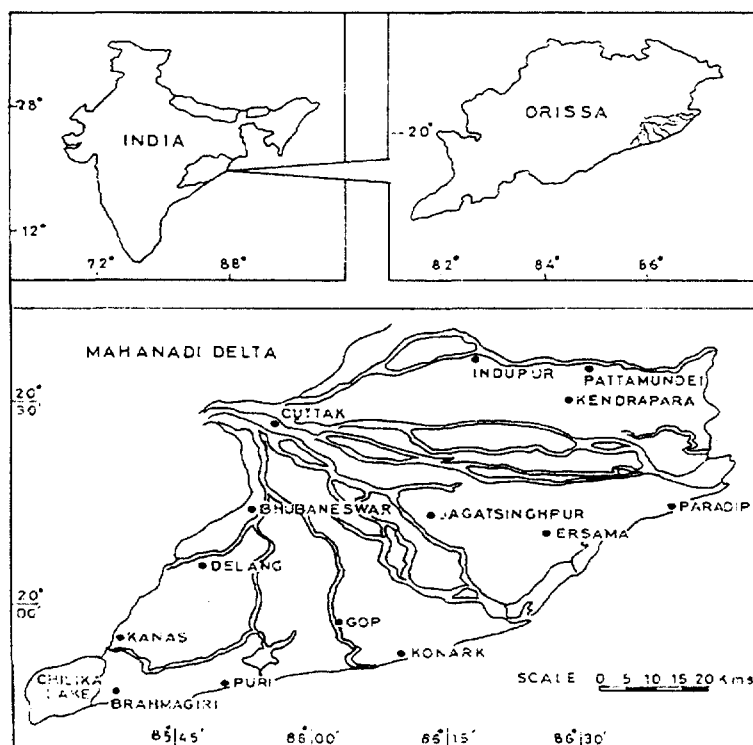


FIG. 1: Location map of Mahanadi delta

1.2 Hydrogeology of the area

The Delang - Puri sector in coastal Orissa forms the southwestern part of the Mahanadi delta which is an arcuate type of delta with an aerial extent of about 9000 km². It lies between 19° 40' N to 20° 35' N and 85° 40' E to 86° 45' E. The annual average rain fall in this area is about 1800 mm. The delta was formed during the last few thousands of years by continuous supply of sediment load from a huge catchment which has been deposited into a subsiding

faulted basin, partly fluvial and partly marine, under varying energy conditions (Fig.1). On the landward side, to the West and Northwest of Delang, the area is an undulating upland with isolated hills and lateritic peneplains. The hills are mostly the resistant remnants of charnockite, kandalite and granitic gneisses, belonging to the Archean complex. The deltaic land is represented by vast plains of fluvial, lacustrine and marine origin intersected by less prominent rivers.

The Delta is covered by thick alluvium underlain by Archean rocks. The thickness of the alluvium varies from 20 m at Jagadlupur to more than 600 m at Puri (Fig.2). The dark grey sediment horizons were deposited in a near shore shallow marine basin. The unfossiliferous yellow brown sediment horizon is sandwiched between two dark grey sediment horizons indicating a change in environmental conditions during evolution of the delta.

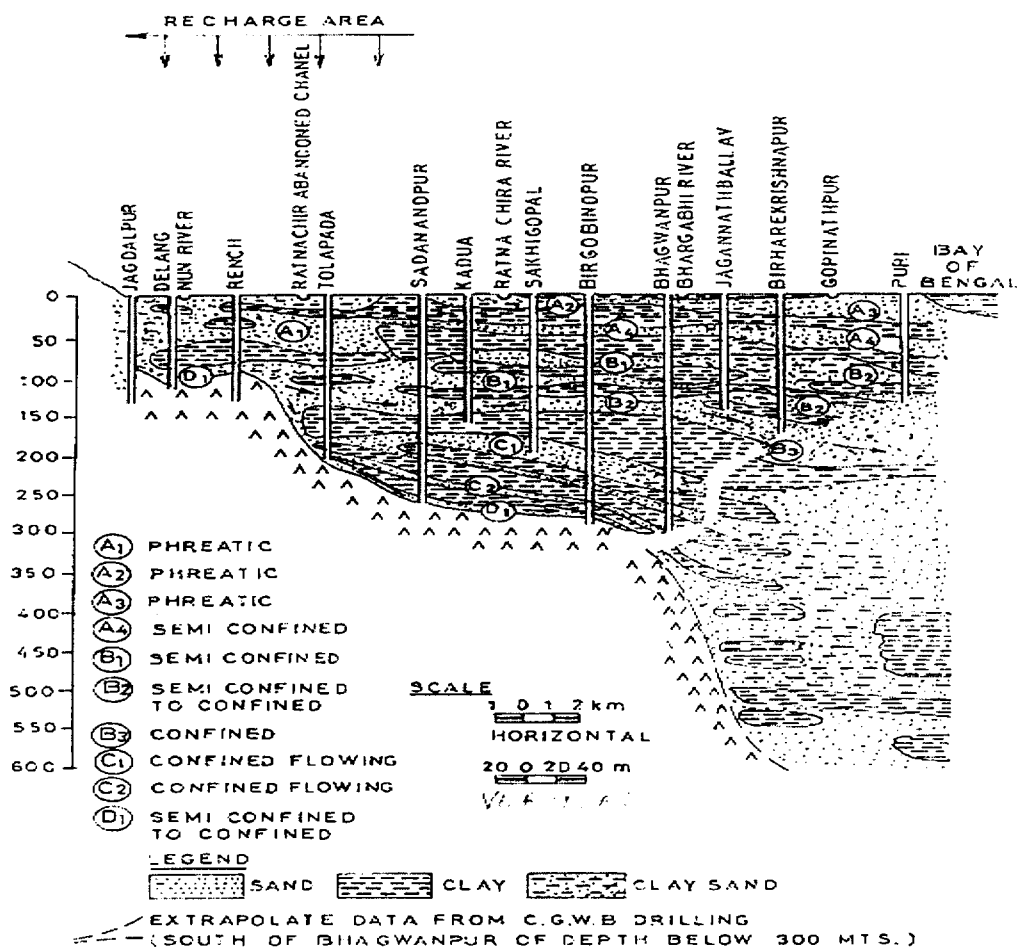


FIG. 2: Hydrogeological section along Delang - Puri sector

A number of piezometers which were drilled by the Danish International Development Agency (DANIDA) for hydrogeological investigation revealed the presence of a multiaquifer system down to a depth of about 300 m. These aquifers have been divided as shallow (Depth: <50 m), intermediate (Depth: 50 -100 m) and deep (Depth >100 m) aquifers. Fresh, brackish and saline groundwaters occur in a rather complicated fashion. Both lateral and depth wise variation in salinity is noticed. The shallow aquifer occurs under phreatic conditions and deeper aquifers change from leaky confined to artesian flowing type with increasing depth. The large number of exploration boreholes carried out by DANIDA [1] suggest that the depth to the water table (fresh water) varies from 2 to 17 m below ground level. The thickness of this phreatic aquifer ranges from 5 to 40 m. The deep fresh water aquifer is found extensively

along the Delang - Puri sector, and occurs at water aquifer is found extensively along the Delang - Puri sector, and occurs at depths between 102 m and 165 m. The total thickness of this aquifer ranges from 25 to 80 m and generally the thickness increases towards the South. The fresh water aquifer is sandwiched between saline water aquifers. The general trend of groundwater flow is towards the southeast and the gradient is steeper towards the inland side (Delang area 2.2 m/km) compared with the coastal area (0.6 m/km near Puri). The steeper gradient, deeper water levels and diverging flow lines in the Delang area close to Kumundal hills indicate the recharge area. The converging flow lines and shallow water table in the southern part indicate the discharge area (Fig.3). The peizometric surface contour map (Fig. 4) shows the movement of groundwater to the south. A groundwater mound is observed in the Eastern part sloping towards the south. The groundwater mound may possibly be due to upward leakage from the artesian aquifer. The hydraulic gradient of the peizometric surface varies from 0.2 to 0.3 m/km.

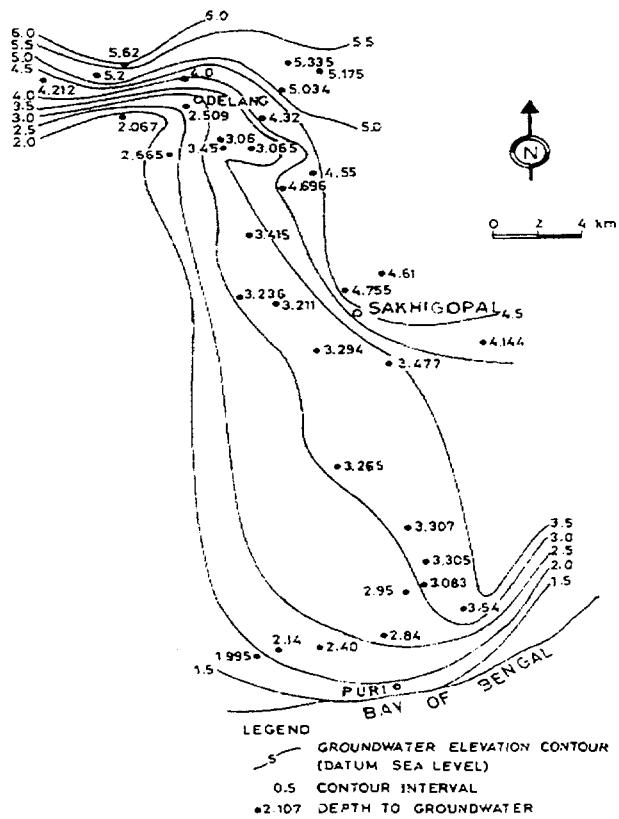


FIG. 3: Water table contour map

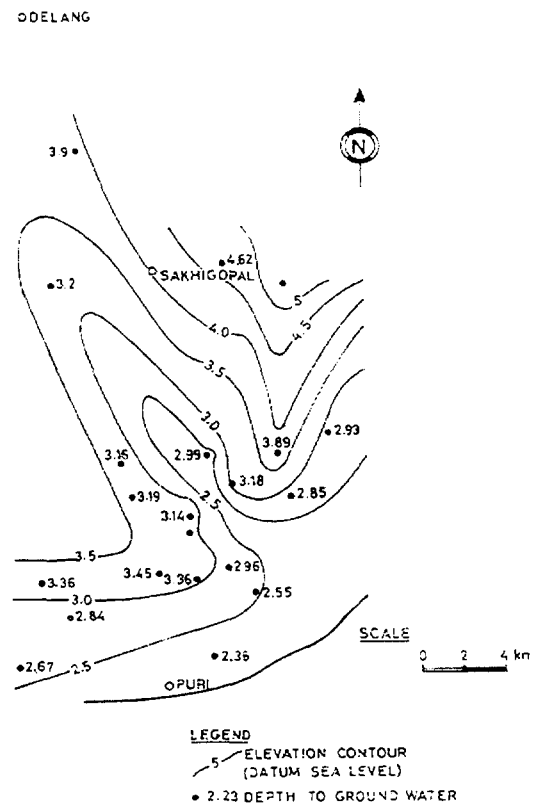


FIG. 4: Peizometric contour map

1.3 Hydrochemistry

In the Delang - Puri Sector, groundwater quality varies from fresh water to saline with electrical conductance (EC) ranging from 250 $\mu\text{S}/\text{cm}$ to 29700 $\mu\text{S}/\text{cm}$. In the Delang area, mostly shallow groundwaters are fresh, with average EC of 1200 $\mu\text{S}/\text{cm}$ and average chloride content of 150 mg/L. Fresh waters are of Ca-Mg- HCO_3 type. The hydrochemical facies in this area in general changes from $\text{HCO}_3 \rightarrow \text{HCO}_3 + \text{Cl} \rightarrow \text{Cl} + \text{HCO}_3 \rightarrow \text{Cl}$. This deviates from the general depthwise hydrochemical sequence given by Schoeller [7]. The presence of H_2S in

saline groundwaters has been observed. This possibly explains the absence of $\text{SO}_4 + \text{HCO}_3$, $\text{SO}_4 + \text{Cl}$ facies. The brackish waters are of NaHCO_3 type, indicating base exchange where as saline waters are of NaCl type. A few groundwater samples were analysed for bromide, strontium and iodide and the results are presented in Table 2. Most of the saline groundwaters show enrichment of Sr, Br and I, indicating long residence times as well as the influence of sea water (Fig. 6, 7 and 8).

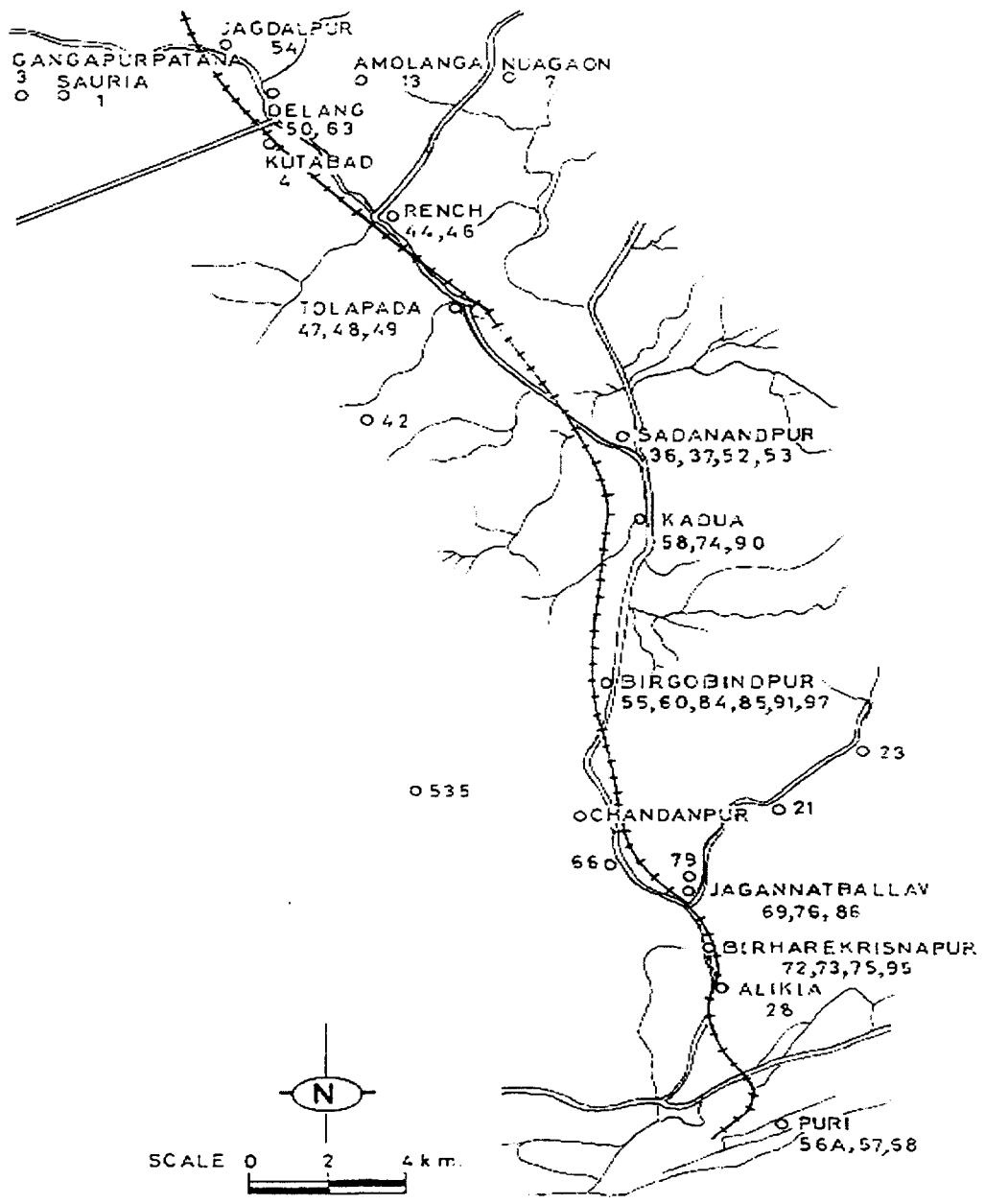


FIG. 5: Location of samples in Delang - Puri sector

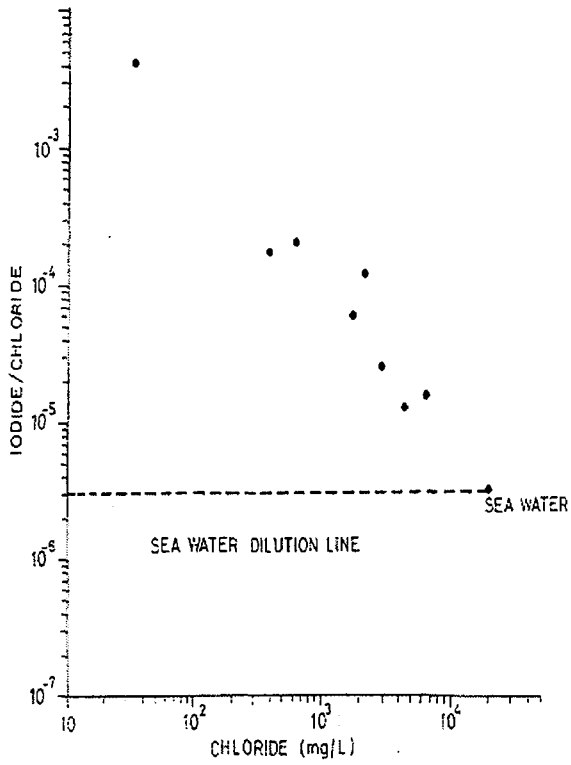


FIG. 6: Iodide/Chloride Vs Chloride plot

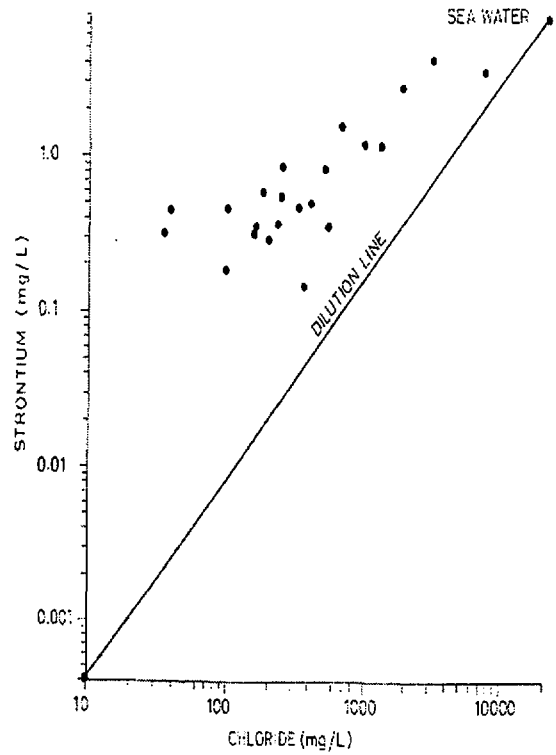


FIG. 7: Strontium Vs Chloride

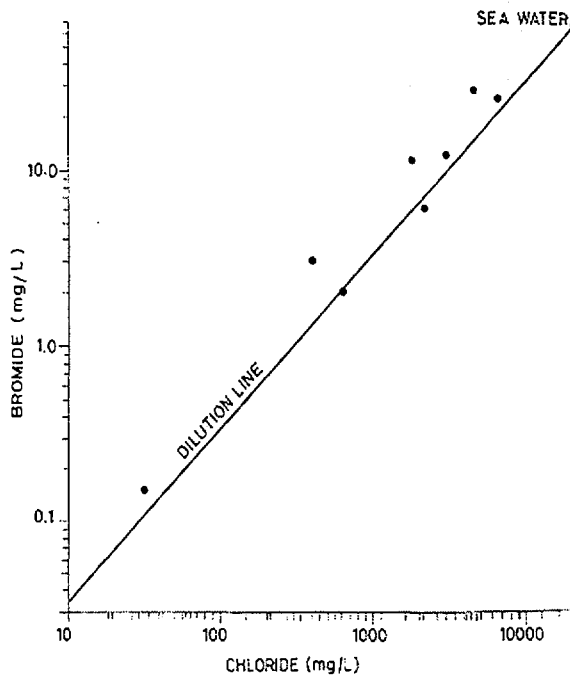


FIG. 8: Bromide Vs Chloride plot

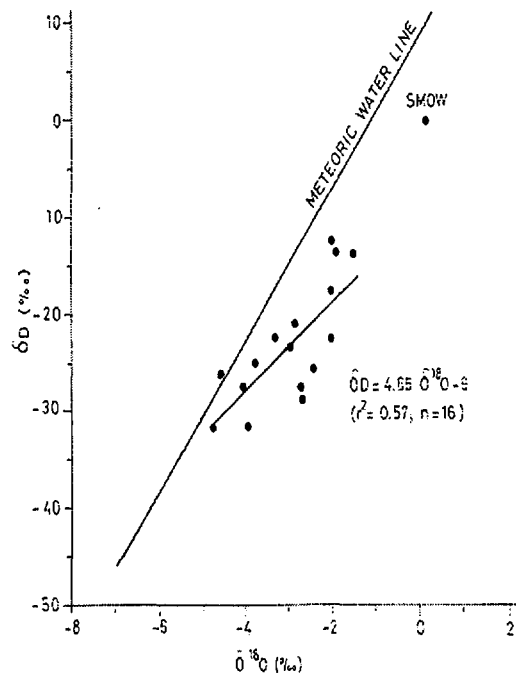


FIG. 9: $\delta^2\text{H}$ Vs $\delta^{18}\text{O}$ plot of surface water

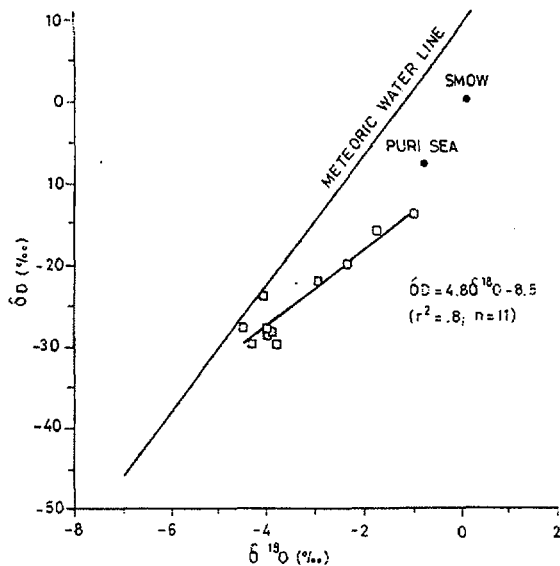


FIG. 10: $\delta^2\text{H}$ Vs $\delta^{18}\text{O}$ plot of shallow zone (<50m)

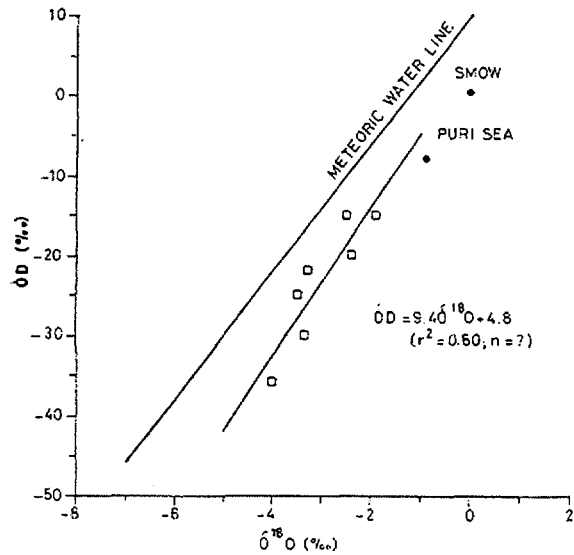


FIG: 11 $\delta^2\text{H}$ Vs $\delta^{18}\text{O}$ plot of intermediate zone (50 - 100m)

1.4 Isotope studies

From the Delang - Puri Sector, more than one hundred water samples from different depths as well as surface water bodies were collected for ^2H , ^{18}O , ^{34}S , ^3H and ^{14}C measurement. Sample locations are shown in Fig.5. Selected samples were measured for ^2H and ^{18}O using a 602E mass spectrometer supplied by VG ISOGAS, UK. For saline groundwaters, carbon -14 sampling was carried out using the gas evolution method. This method is used because of low total dissolved inorganic carbon, high salinity and presence of H_2S in the samples. In the case of fresh water, the precipitation method was used and ^{14}C content was measured using LKB liquid scintillation counter (model 1215 Rock Beta-II). Radiocarbon ages were corrected using 67 pMC (highest radiocarbon content of deep groundwater with high ^3H content sampled in the recharge area) as initial activity for those samples where ^{13}C of carbonate could not be measured. For a few samples where ^{13}C could be measured the ^{14}C ages were corrected using the Pearson's model [4]. For tritium, samples collected from the field were distilled initially and 500 g of water is electrically reduced to about 12g and counted using LKB scintillation counter (model 1215) For ^{34}S , barium sulphate was precipitated at site and ^{34}S of aqueous sulphate were analysed at Atomic Minerals Division, Hyderabad. Isotope as well as selected chemical results are given in Table 1, 2, 3 and 4.

Table I. Isotope data of surface waters of coastal Orissa

Source	$\delta^2\text{H}$ (‰)	$\delta^{18}\text{O}$ (‰)	^3H (TU)
Puri Beach	-12.3	-2.1	4.1
Puri Sea	-08.0	-0.9	5.0
Chilka Lake	-19.0	-2.1	3.9
Mangala River	-13.6	-1.59	7.1
Dhakupada Pond	-31.5	-4.8	6.1
Birpratappur Pond	-24.9	-3.83	6.5
Precipitation	-26.0	-4.6	7.0
Ratnachira River	-31.4	-4.0	-NA-
Nun River	-21.0	-2.9	-NA-
Daya River	-22.3	-3.4	-NA-
Chandanpur River	-23.2	-3.0	-NA-
Birhara Pond	-25.4	-2.47	-NA-
Bhargavi River	-27.5	-2.75	-NA-

NA - not analysed

Table II. Isotope and chemical data of groundwaters of coastal Orissa

Well No.	Location	Depth m	EC $\mu\text{S/cm}$	$\delta^2\text{H}$ ‰	$\delta^{18}\text{O}$ ‰	^3H TU	Br mg/L	I $\mu\text{g/L}$	Cl mg/L
PT-1	Sauria	40	540	-30	-4.3	0.6	-	-	60
PT-3	Gangpurpatna	16	780	-16.0	-1.8	1.0	-	-	78
PT-4	Kothabada	26	590	-22.0	-3.0	2.5	-	-	55
PT-7	Naugaon	26	380	-28.5	-3.9	0.8	-	-	32
PT-13	Amolanga	28	750	-	-3.6	0.9	-	-	46
PT-21	Chalis Batia	148	1530	-24	-2.7	0.5	-	-	241
PT-23	Tarasramhanspur	127	1380	-18.3	-2.5	0.5	-	-	188
PT-28	Alikia	18	1050	-28.0	-4.0	0.8	-	-	145
PT-36	Sadanandpur	109	7250	-27.0	-4.2	1.4	6.1	239	2067
PT-37	Sadanandapur	128	2530	-14.2	-1.5	1.9	2.0	124	610
PT-42	Dasbidyadharpur	-	580	-31.0	-4.3	0.0	-	-	57
PT-44	Rench	64	6230	-20.0	-2.4	2.4	11.5	98	1702
PT-46	Rench	126	660	-22.0	-2.7	8.0	0.9	-	89
PT-47	Tolapada	25	530	-30.0	-3.8	1.7	0.15	133	32
PT-48	Tolapada	53	560	-29.0	-4.0	-	-	-	35
PT-49	Tolapada	190	3580	-19.0	-2.4	-	4.8	-	900
PT-50	Delang	108	920	-	-	0.2	-	-	92
PT-52	Sadanandapur	31	11100	-20.0	-2.4	1.1	30.7	-	3474
PT-53	Sadanandpur	128	2430	-15.0	-2.3	0.6	-	-	613
PT-54	Jagadapur	118	880	-29.0	-4.4	0.8	-	-	124
PT-55	Birgovindpur	136	1940	-21.0	-2.8	3.0	3.0	66	379
PT-56	Puri	33	120	-24.0	-4.1	2.0	-	-	18
PT-57	Puri	118	12200	-18.0	-2.9	1.4	28.0	53	4254
PT-58	Kadua	125	1580	-15.0	-2.2	2.0	-	-	259
PT-60	Birgovindpur	76	19970	-15.0	-1.9	1.1	25.0	96	6168
PT-63	Delang	106	1540	-15.0	-2.5	1.7	-	-	347
PT-66	Birbalbhadrapur	109	1280	-15.0	-2.5	1.7	-	-	216
PT-67	Chandanpur	161	260	-13.0	-1.3	8.2	0.3	-	21
PT-68	Puri	91	8200	-22.0	-3.3	1.6	12.0	70	2836
PT-69	Jaganathballav	124	890	-18.0	-2.8	1.3	-	-	89
PT-72	Birharekrishnapur	16	1670	-13.9	-1.0	3.9	-	-	227
PT-73	Birharekrishnapur	140	940	-21.7	-2.5	3.7	-	-	160
PT-74	Kadua	125	1440	-17.0	-1.9	4.0	-	-	230
PT-75	Birharekrishnapur	173	1660	-20.0	-2.0	4.2	-	-	312
PT-76	Jagannathballav	173	890	-16.0	-2.2	4.9	-	-	92
PT-78	Erabang	94	1660	-36.0	-4.0	6.3	-	-	351
PT-79	Balia Neelkantha	130	1050	-15.0	-2.5	4.9	-	-	167
PT-84	Birgovindpur	193	5570	-15.0	-1.6	0.5	10.1	-	1659
PT-85	Birgovindpur	243	21120	-14.0	-2.0	0.6	34.9	-	7374
PT-86	Jagannathballav	124	830	-20.0	-1.6	-	-	-	78
PT-87	Erabang	56	1810	-30.0	-3.4	2.0	-	-	411
PT-90	Kadua	125	3890	-09.0	-1.0	1.4	-	-	1042
PT-91	Birgovindpur	135	1820	-16.0	-1.8	0.0	1.7	-	440
PT-95	Birharekrishnapur	174	-	-17.0	-2.3	-	-	-	-
PT-97	Birgovindpur	250	29700	-10.0	-1.5	-	103	-	-

Table III. Carbon -14 ages of groundwaters of coastal Orissa

Well No.	Location	EC ($\mu\text{S/cm}$)	Depth (m)	^{14}C age (years)
PT-1	Sauria	540	40	450*
PT-3	Gangpurpatna	780	16	modern
PT-37	Sadanandpur	2530	128	17100*
PT-46	Rench	660	126	modern
PT-47	Tolapada	530	21	650*
PT-48	Tolapada	560	53	900*
PT-49	Tolapada	3580	187	33300*
PT-52	Sadanandpur	11100	artesian	24200*
PT-57	PURI	12200	115	12550
PT-84	Birgovindpur	5570	184	19200*
PT-85	Birgovindpur	21120	240	23450*
PT-97	Birgovindpur	29700	250	23100
PT-X	Ramchandrapur	16200	60	7350*
PT-Y	Rench	2230	31	700*

Note: • - Ages corrected using 67 pMC as initial activity. * - Ages corrected using $\delta^{13}\text{C}$ values.

Table IV. Sulphur -34 results of coastal Orissa

well no.	Location	Depth (m)	EC ($\mu\text{S/cm}$)	SO_4 (mg/l)	$\delta^2\text{H}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\delta^{34}\text{S}$ (‰)	^3H (TU)	^{14}C age (years)
PT-36	Sadanandpur	106	7250	360	-27	-4.2	22.8	1.4	17100
PT-26	Rench	65	6230	269	-20	-2.4	8.4	2.4	-
PT-74	Kadua	125	1440	192	-17	-1.9	16.4	4	-
PT-57	Puri	118	12200	326	-18	-2.9	20.8	1.4	12550
PT-60	Biragobindpur	76	19970	730	-15	-1.9	24	1.1	-
PT-85	Biragobindpur	243	21120	259	-14	-2	43.8	0.6	24450
PT-95	Birharekrishnapur	175		19	-17	-2.3	11.5		-
	Puri sea			2208	-08	-0.9	21	5.0	
	Chilka lake			864	-19	-2.1	20.1	3.9	

1.5 Results and Discussion

A few surface water samples were analysed for ^2H , ^{18}O and ^3H content. The $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values vary from -32 ‰ to -12‰ and -5‰ to -1.5‰ respectively. Precipitation samples collected during field work have $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values of \sim -28 ‰ and -4 ‰ respectively. ^3H content in precipitation and other surface waters varies from 4 TU to 7 TU. These samples show the effect of evaporation on the $\delta^2\text{H}$ - $\delta^{18}\text{O}$ plot (Fig.9).

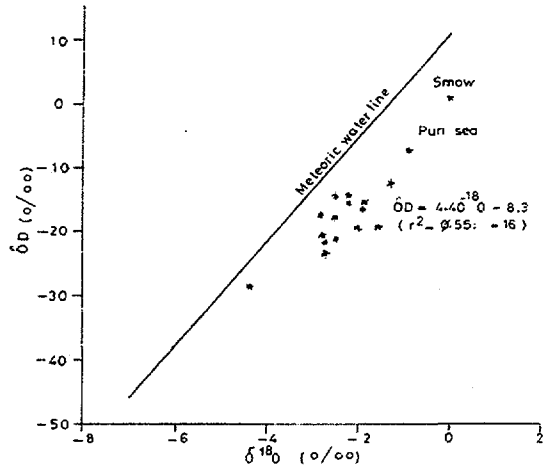


FIG. 12: $\delta^2\text{H}$ Vs $\delta^{18}\text{O}$ plot of deep zone fresh groundwater (>100m)

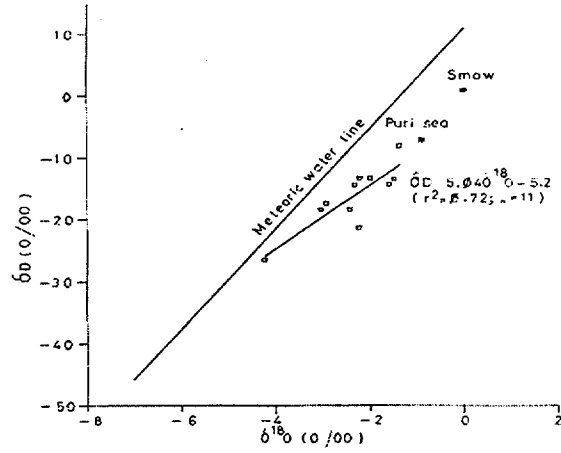


FIG. 13: $\delta^2\text{H}$ Vs $\delta^{18}\text{O}$ plot of deep zone saline groundwater (>100m)

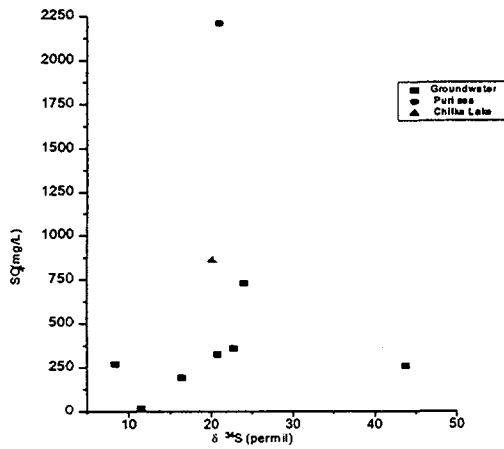


FIG. 14: Sulphate Vs Sulphur-34 plot

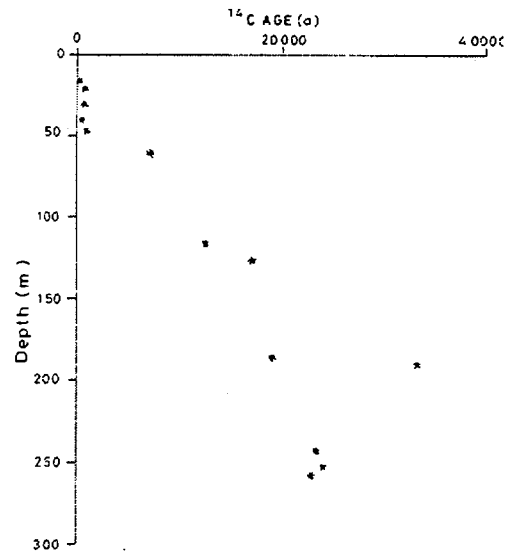


FIG. 15: ^{14}C age Vs Depth plot of groundwaters

For shallow groundwaters, $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values are in the range of -30 ‰ to -15 ‰ and -4 ‰ to -1.0 ‰. These samples fall on an evaporation line on the $^2\text{H} - ^{18}\text{O}$ plot similar to that of surface waters (Fig.10). This indicates that the shallow aquifers of Delang area receive recharge through outcrops of basement rocks exposed on the northwestern parts of Delang area (Fig.2). In the southern plain, the recharge could be infiltration of surface waters.

In the intermediate zone groundwater samples fall parallel to global meteoric line in $\delta^2\text{H}$ and $\delta^{18}\text{O}$ plot.(Fig.11) The level of tritium in this aquifer is negligible, indicating absence of modern recharge. The EC of the samples varies from 1500 $\mu\text{S}/\text{cm}$ (Delang) to 20,000 $\mu\text{S}/\text{cm}$ (Birgobindpur) and most of the samples are saline (Fig.2-B1). Some of the samples collected from Rench, Birgobindpur, and Puri show Cl/Br ratios of 148, 247 and 236 respectively. A saline sample collected from Birgobindpur is enriched in $\delta^{34}\text{S}$ (+24 ‰) compared to the sea water value of +20‰ and at Rench $\delta^{34}\text{S}$ value is +8.4 ‰. The sample which is collected from Pratapramchandrapur shows ^{14}C age of about 7600 years BP. The saline groundwaters of this zone could be a mixture of fresh water and sea water entrapped during sea transgression in the Holocene.

The deeper aquifer (Fig.2-B2) fresh groundwaters isotopic composition is similar to surface water (Fig.12). Fresh groundwaters collected from the deep aquifer show high tritium (3-8 TU) and depleted $\delta^{34}\text{S}$ values (Kadua: +16.4‰ and Birharikrishnapur:+11.5‰) compared with the sea water value. This aquifer could be receiving recharge from the western side and mostly through fractures and joints of the basement rocks. The deepest fresh water aquifer (Fig.2-D1) near the basement show very high ^{14}C age (29,000 years BP)

The saline groundwaters of deep aquifer fall along a line in $\delta^2\text{H} - \delta^{18}\text{O}$ plot with $\delta^2\text{H} = 5.4 \delta^{18}\text{O} - 5.2$ ($r^2 = 0.72$, $n = 11$, (Fig.13). Most of the deep aquifer saline samples show enriched $\delta^{34}\text{S}$ values (+20.8‰ to +43.8‰) compared with sea water value and radiocarbon ages are in the range of 12,000 years BP to 24,000 years BP with negligible tritium (Fig.14 &15). The EC values range from 2400 to 30,000 $\mu\text{S}/\text{cm}$. These old saline waters could have been entrapped during a marine transgression in the late Pleistocene.

1.6 Discussion

During the late Quaternary, a major glacial episode started at about 25000 years BP and produced a major eustatic decrease with minimum ocean level of about -90 m to -120 m at 18000 years BP [3]. Then climatic set back produced melting of ice caps and rise in sea levels, which was practically terminated at 7000 years BP. The end of the Pleistocene was marked by world wide warming. During this post glacial period, the Flandrian transgression occurred which affected most parts of globe, up to 6000 years BP, where after, recession took place to the present conditions [2].

The hydrogeological and isotope studies indicate the two episodes of sea level fluctuation took place in the Delang - Puri sector up to Tolapada. The first one corresponds to the Pleistocene interglacial stage and the other during Flandrian in the Holocene. The saline groundwaters of the deep aquifer in the Delang- Puri Sector could have been entrapped during eustatic rise in the late Pleistocene interglacial episode and shallow saline groundwaters during the Flandrian transgression.

It can be observed that most of the saline samples fall on a sea water - fresh water dilution line in the Bromide - chloride plot. This indirectly indicates that the source of the salinity of the groundwater is sea water. In strontium - chloride as well as iodide - chloride plots, most of the saline groundwater samples fall above the mixing line indicating enrichment of strontium and iodide. These saline waters could possibly have acquired these chemical species from sediment and this indirectly indicates the long residence of groundwater in the aquifer. Most of the saline groundwaters have been considerably enriched in $\delta^{34}\text{S}$ (+20.8 ‰ to +43.8 ‰) with respect to the sea water value (Fig.14). Occurrence of H_2S and - Ve Eh (-35 mv) show reducing conditions. This large enrichment could be due to continued bacterial reduction of marine sulphate to sulphide over a period of time. This is further confirmed by very low SO_4/Cl ratio of 0.035 compared to sea water value of 0.13. Fresh groundwater samples from Rench, Kadue and Birharekrishnapur show $\delta^{34}\text{S}(\text{SO}_4)$ values from +8 to +16‰ below the marine sulphate value. They receive recharge from basement rocks and flood plains in the western part. Hence they have some component of non marine sulphates

1.7 Conclusion

The isotope geochemical studies of saline groundwaters of coastal Orissa indicate that:

- Shallow fresh groundwaters are modern and they are recharged through flood plains and outcrops of basement rocks.
- Saline groundwaters of the intermediate zone are mostly due to the Flandrian transgression during Holocene.
- Deep fresh groundwaters receive recharge through basement rocks.
- The deep fresh water occurring in weathered basement rock is a potential source for exploitation.
- Deep saline groundwaters are connate marine waters which were entrapped during late Pleistocene interglacial stage.
- The source of sulphate in saline groundwater is due to marine sulphates which has undergone bacterial reduction.

2. STUDIES ON DEEP SALINE GROUNDWATERS OF CHARNOCKITE TERRAIN AT KOKKILIMEDU

2.1 Background

Kokkilimedu is located 80 km south of Chennai City. It lies between longitude $80^\circ 3'$ to $80^\circ 12'E$ and latitude $12^\circ 27'$ to $12^\circ 38'N$. The topography is an Easterly gentle sloping terrain between the Eastern Ghats and the Bay of Bengal. The mean annual rainfall is about 1237 mm. Under the host rock characterisation programme for safe disposal of radioactive waste, four deep bore holes were drilled in this area (Fig.16). One bore hole (BH-1) was drilled to 600 m depth and the other three (BH-2, BH-3 and BH-4) were drilled to 618 m, 566 m and 200 m respectively.

In BH-1, it was observed that the groundwater salinity increases with depth. Below a depth of 350 m, the chloride concentration is more than twice that of sea water (chloride concentration-41,200 mg/L). In BH-2, the salinity increases with depth but it is less than sea water. The maximum chloride concentrations encountered in this bore hole is 9800 mg/L at 500 m depth. The BH-3 and BH-4 show low salinity at the deeper level compared to shallow depth. The maximum salinity observed in these bore hole is 880 mg/L and 2500 mg/L at 75m

and 200m depth respectively. Therefore isotope geochemical investigations were carried out in this host rock characterisation programme to understand the salinisation mechanism and the hydrodynamic conditions of deep groundwaters.

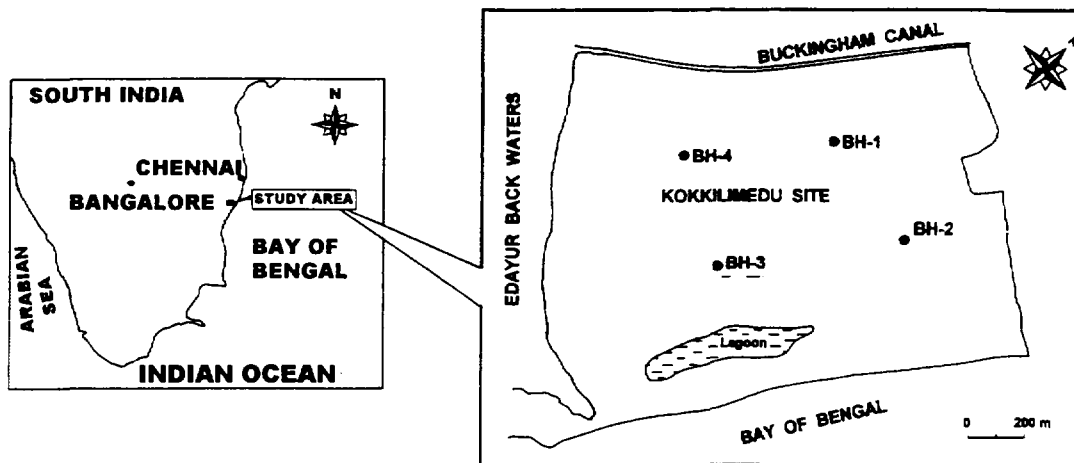


Fig. 1 Sample location map (Kokkilimedu)

2.2 Hydrogeology

The investigated area is covered by 15 to 20 m thick alluvium, underlain by hard and compact charnockite rock. The alluvium forms the top aquifer, bearing meteoric water. The charnockite rock consists of quartz, feldspar, biotite and pyroxene. These minerals are resistant to weathering. Hence the rate of reaction and the transfer of solutes into the groundwater is slow. Borehole cores of the study area indicate the presence of pseudotachylites along the fractures and joints indicate tectonic upliftment associated with retrograde metamorphism. Pseudotachylites are mostly greenish dark materials, predominantly clay, altered feldspar, quartz, chlorite, biotite, etc.. [5]. Fracture fillings varying in thickness from 3.0 mm to 0.5 m. As these rocks are dense and compact, groundwater is restricted to joints and fractures which form a limited confined aquifer. Groundwater flow follows the topography and flows towards the southeast. Groundwater levels vary between 7.0 to 9.0 m above mean sea level.

Water samples were collected from boreholes (from different depths using a depth sampler), rain water and a few surface waters such as the Buckingham canal and the Bay of Bengal. These samples were analysed for major ion chemistry and a few samples were analysed for ^2H , ^{18}O and ^3H . The results are given in Table V. The regional meteoric relationship between ^2H and ^{18}O was established from the regression of rain fall data collected at Chennai by the Institute for Water Studies in 1995.

2.3 Major ion trend and water - rock interaction

Water samples collected from BH-1 show low pH (5.8 to 7.3) whereas the pH of BH-2, BH-3 and BH-4 groundwaters are in the range of 7.4 to 8.8. The entire boreholes were sampled with a vertical interval of 50 m and the variability of chemical composition with depth was observed. Both increase and decrease in the concentration of chloride and other species occurred with depth in all four boreholes. This is indicative that the water in the borehole is stratified.

The groundwaters of the Kokkilimedu area have interacted to a considerable extent with the weathered charnockite rock. This can be seen from the variations of the dissolved species Na^+ , K^+ , Mg^{+2} and Ca^{+2} with chloride content in Figs. 17 and 18.

In BH-1, plots of chloride against Na^+ , K^+ , Mg^{+2} and Ca^{+2} (Fig.2) indicate linear relationships with a lesser slope than the sea water - fresh water mixing line. A linear relationship generally indicates the mixing of saline and fresh groundwater. Ion exchange processes is possibly responsible for the depletion of significant amounts of Na^+ and K^+ as well as the enrichment of Ca^{+2} and Mg^{+2} .

In BH-2, Cl^- against Na^+ , K^+ , Ca^{+2} and Mg^{+2} plots show bimodal slopes (Fig.18). It occurs over a depth range of 150-300 m. The change in the slope is important because it occurs where the hydraulic conductivity is rapidly increasing or decreasing. The two different clusters of samples with different slope observed in chloride against cation plots suggest a transition of water from the weathering zone at shallow depth to permeable rocks, where the salts are leached to obtain the final salinity. Similar situation was also observed at 75-150 m in BH-3.

2.4 Isotope Results

The isotope and chemical data are interpreted and the $\delta^2\text{H}$ - $\delta^{18}\text{O}$ and $\delta^{18}\text{O}$ - Cl^- relationships are shown in Fig-4 & 5. Samples collected from different depths in BH-1 have enriched $\delta^2\text{H}$ and $\delta^{18}\text{O}$ content ($\delta^2\text{H}$: -6 to -4‰ and $\delta^{18}\text{O}$: -1.8 to -0.6‰) compared with samples of BH-2 and BH-3. They fall away from the meteoric line in one cluster indicating evaporation effect or influence of sea/Buckingham canal water. On $\delta^{18}\text{O}$ - Cl^- plot, the shallow zone sample in BH-1 show some mixing trend with sea water/Buckingham canal water. The deep zone samples in BH-1 show similar $\delta^{18}\text{O}$ compared to the shallow zone sample, indicating that further, salinization could be due to leaching processes.

Samples of BH-2 and BH-3 are more depleted than BH-1 samples in stable isotopic content and their $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values are in the range of -32.8 to -26.3‰ and -6.6 to -4.4‰. These samples fall close to the regional meteoric line. In this case no relationship can be observed between isotopic content and increasing salinity in the $\delta^{18}\text{O}$ - Cl^- plot (Fig.20). The poor correlation between $\delta^{18}\text{O}$ - Cl^- indicates that the salinity in this case is mostly due to dissolution of aquifer matrix, and fracture fillings. Further, the high tritium content was observed in surface water such as pond water (145 - 479 TU), Buckingham canal (62 TU), Bay of Bengal water (23 TU) as well as in shallow groundwater (62 - 119 TU). This high tritium content is mainly due to effluent from nuclear power plant which is located just 0.5 km West of this site. The groundwaters of BH-1, BH-2, BH-3 and BH-4 also show high tritium content (15 to 155 TU). This could be due to the mixing of surface water with groundwater.

2.5 Conclusion

The isotope geochemical investigations suggest that the observed high salinity in BH-1 can be attributed to infiltrated sea water/Buckingham canal, together with the contribution of pseudotachlight observed along the fractures and shear zones in charnockite rock. In the case of BH-2 and BH-3, mixing of sea water does not contribute to saline conditions as the isotopic and chemical relationships do not correlate with sea water. Their salinity is mostly from solute acquired from sheared and fractured host rock.

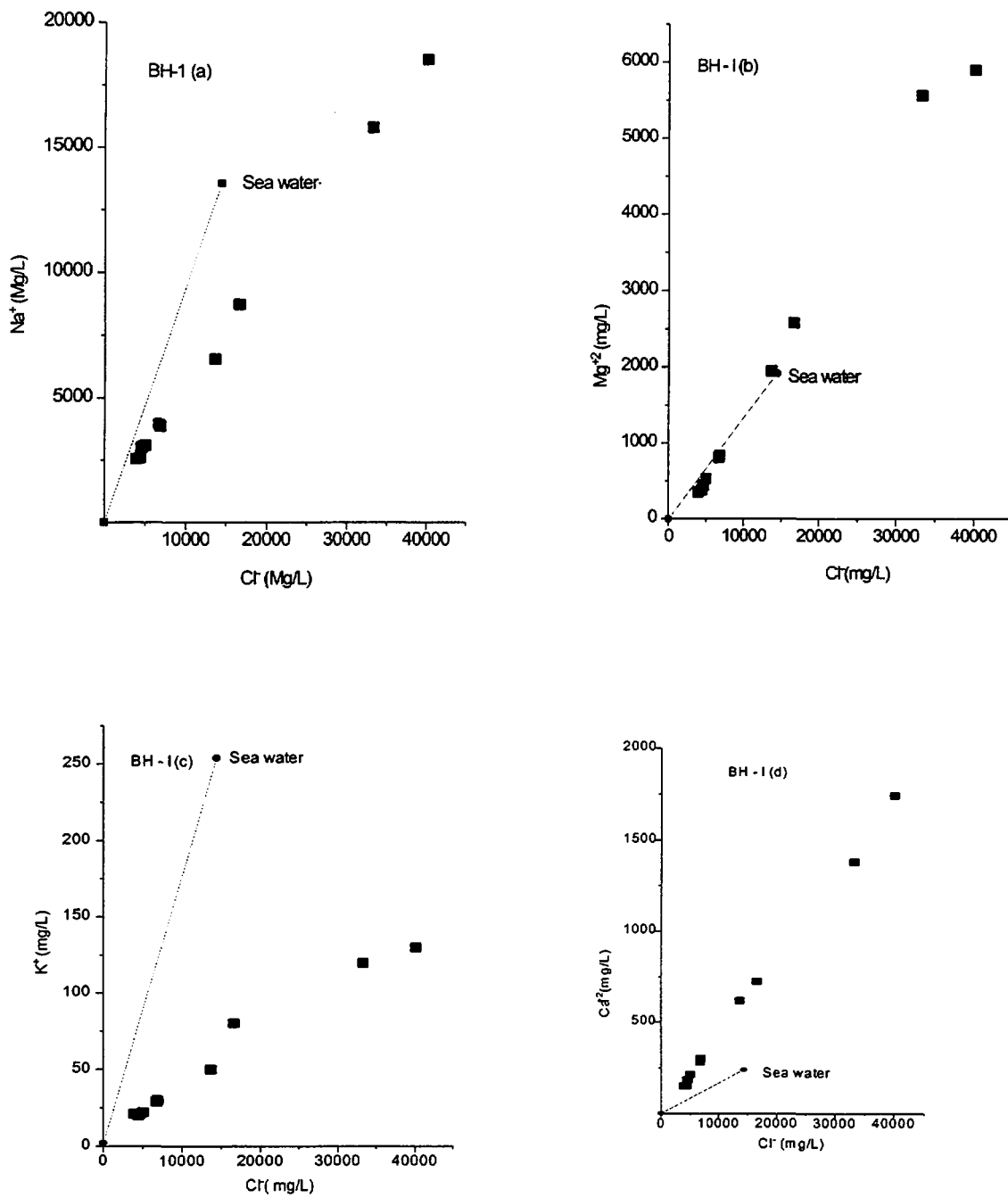


FIG. 17(a-d): Variation of the dissolved species Na^+ , K^+ , Mg^{+2} & Ca^{+2} with Cl^- content in BH-I

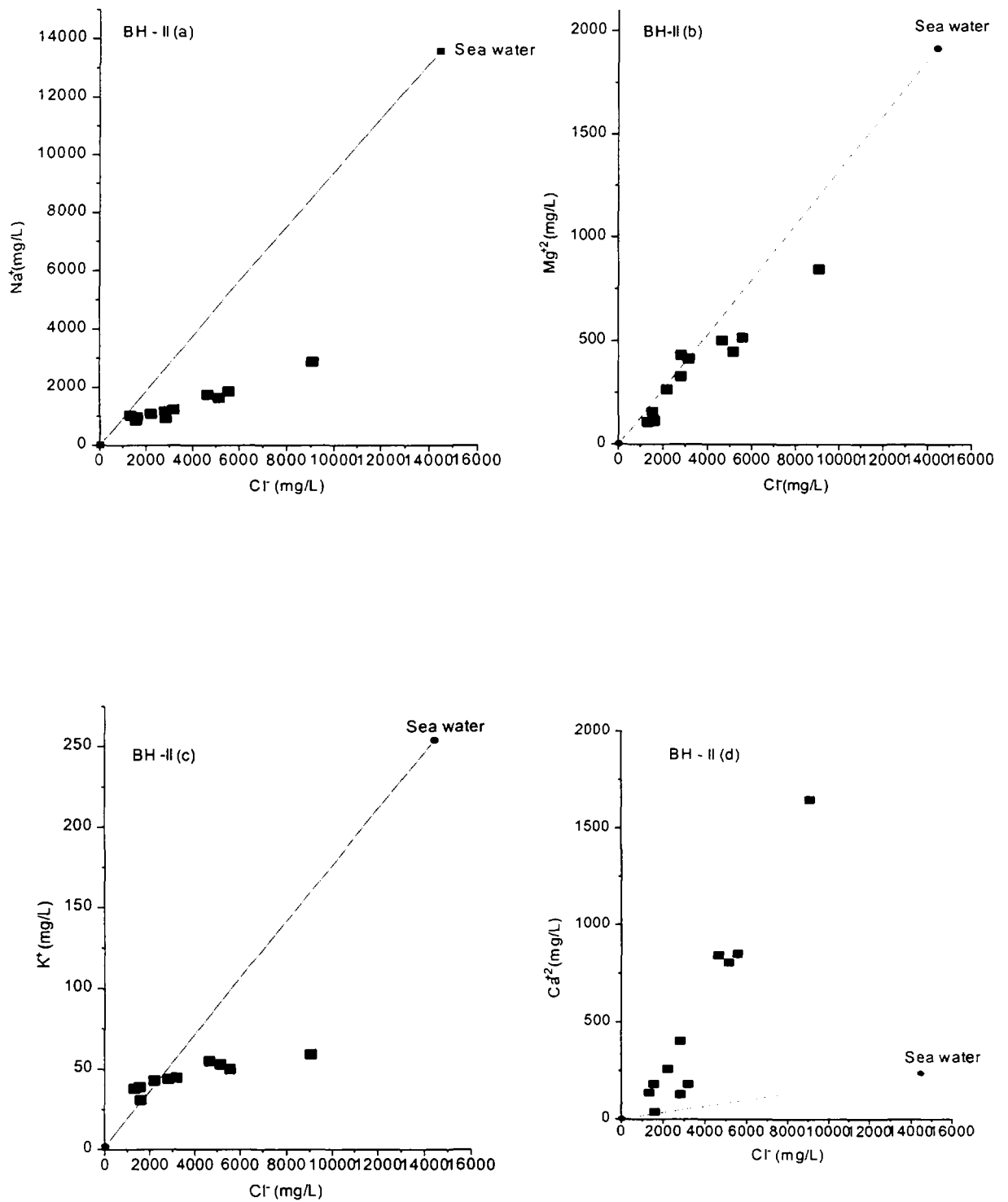


FIG. 18(a-d): Variation of the dissolved species Na⁺, K⁺, Mg⁺² & Ca⁺² with Cl⁻ in BH-II

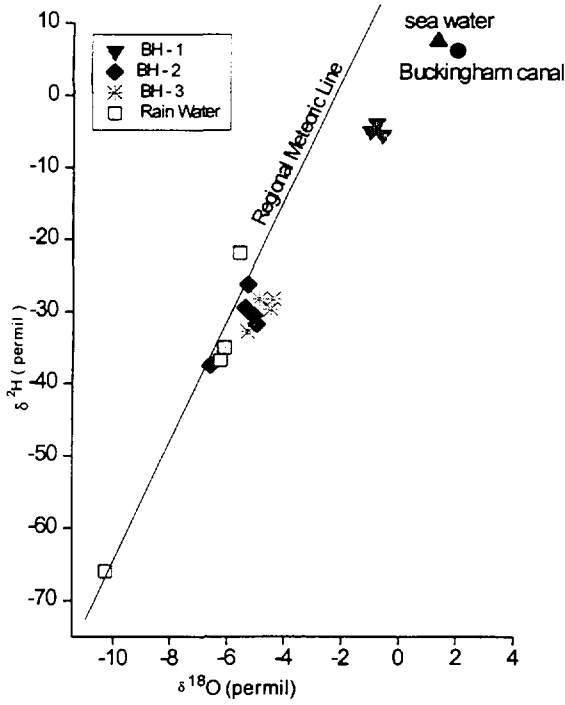


FIG. 19: $\delta^2\text{H} - \delta^{18}\text{O}$ plot

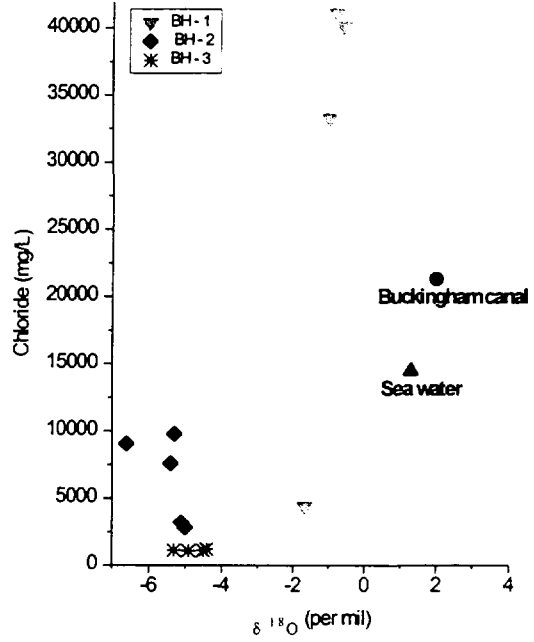


FIG.20: $\delta^{18}\text{O} - \text{Cl}^-$ plot

Table V. Isotope results of groundwaters of Kokkilimedu

Sample identification & at what depth sample collected (m)	Chloride (mg/L)	Sulphate (mg/L)	$\delta^2\text{H}$ (‰)	$\delta^{18}\text{O}$ (‰)
Rain water			-36.8	-6.26
Rain water			-21.9	-5.57
Rain water			-35.0	-6.1
Rain water			-66.0	-10.3
Sea water	14455	2500	+07.5	+01.3
Buckingham canal	21315	3000	+06.2	+02.0
BH-1 (400)	41160	3500	-3.9	-0.8
BH-1 (450)	33320	3200	-5.0	-1.0
BH-1 (500)	40180	2800	-5.5	-0.6
BH-2 (20)	2816	0038	-31.8	-5.0
BH-2 (40)	3185	0045	-30.6	-5.1
BH-2 (400)	7595	0450	-29.9	-5.4
BH-2 (450)	9065	0650	-37.5	-6.6
BH-2 (500)	9800	0800	-26.3	-5.3
BH-3 (20)	1176	-	-28.3	-4.4
BH-3 (40)	1,127	1,450	-32.8	-5.3
BH-3 (350)	1,070	1,350	-28.3	-4.9
BH-3 (400)	1,078	1,480	-29.7	-4.5

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