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Geoelectric and Geochemical Studies for Hydrological Characterization of Canning and Adjoining Areas of South 24 Parganas District, West Bengal

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Abstract: Integrated geoelectric and geochemical investigation were carried out in the Canning and adjoining areas to assess the prevailing groundwater conditions and chemical quality of groundwater. Geologically, the area is constituted of alluvial sediments of Quaternary age. Vertical electrical soundings (VES) in the area of investigation mostly show six layers consisting of top soil, saline water, clay layer, brackish water, clay layer and fresh-water bearing zone of appreciable thicknesses at depths of 137 to 182 meter at six locations and from 370 to 430 meter for other two locations under confined conditions. The result of VES studies significantly correspond with the borehole litholog and well log data. A litho-resistivity relationship is established for this area of investigation A Fence diagram is constructed to show the spatial variation of the sub-surface lithology and hydrological characteristics. Chemically the ground water is fresh and mixed cation and anion type as revealed from Piper-Trilinear diagram with TDS ranging from 699 to 1547 mg/l. The geochemical parameters like Total hardness (TH), Sodium absorption ratio (SAR), Soluble sodium percentage (SSP), Percentage of sodium (PS), Kelley's ratio (KR), Residual sodium carbonate (RSC), Corrosivity ratio (CR), Gibbs ratios (GR), Chloro alkaline indices (CAI), Sea water contamination (SWC) are also calculated for examining the quality of groundwater in the area. The depth of occurrences of freshwater bearing ground water zones for drinking and irrigation purposes are occurring at depths from 137 meter to 430 meter in this area.

Keywords: Vertical electrical sounding (VES), litho-resistivity relation, seawater contamination, confined aquifer, saline water, total dissolved solids (TDS), West Bengal.

INTRODUCTION

The area of the coastal plain of West Bengal in eastern India covers Midnapur, Howrah, South 24 Parganas and North 24 Parganas. The district of South 24 Parganas is considered as a salinity prone area mostly in its south-eastern part. The area consists of administrative block Canning-I of South 24 Parganas district situated in the coastal tract of West Bengal. Groundwater, here is mainly of saline, brackish and fresh water types. Saline and brackish water is found in upper or intermediate to sometimes deeper aquifer while sweet water is prevailing under confined condition in the lower aquifer in most of the cases. With the growing population in this coastal plain, demand of groundwater for drinking, agriculture and industrial purposes is increasing tremendously. Although plenty of agriculture land is available here, scope for irrigation is very limited due to non-availability of sufficient fresh water. Available surface water at shallower depth is brackish in nature mostly in the Canning and its adjoining region. Under this backdrop, present study comprises an integrated geological, geoelectric and geochemical investigation to assess the prevailing sub-surface lithology, hydrological characteristics, chemical qualities of groundwater, type of groundwater, aquifer dispositions and depth to the fresh water bearing aquifer.

GEOLOGY OF THE STUDY AREA

The Bengal basin constitutes the plain regions of West Bengal and Bangladesh. Underneath the alluvium cover, the Bengal basin contains a thick pile of marine, estuarine, lagoonal, deltaic and fluviatile sediments ranging from partly middle-upper Cretaceous to Pleistocene. The sediments are homoclinal with gentle dip towards ESE and occasional NNE trending broad flexures. The thickness of the sediment increases towards east and three structural zones such as

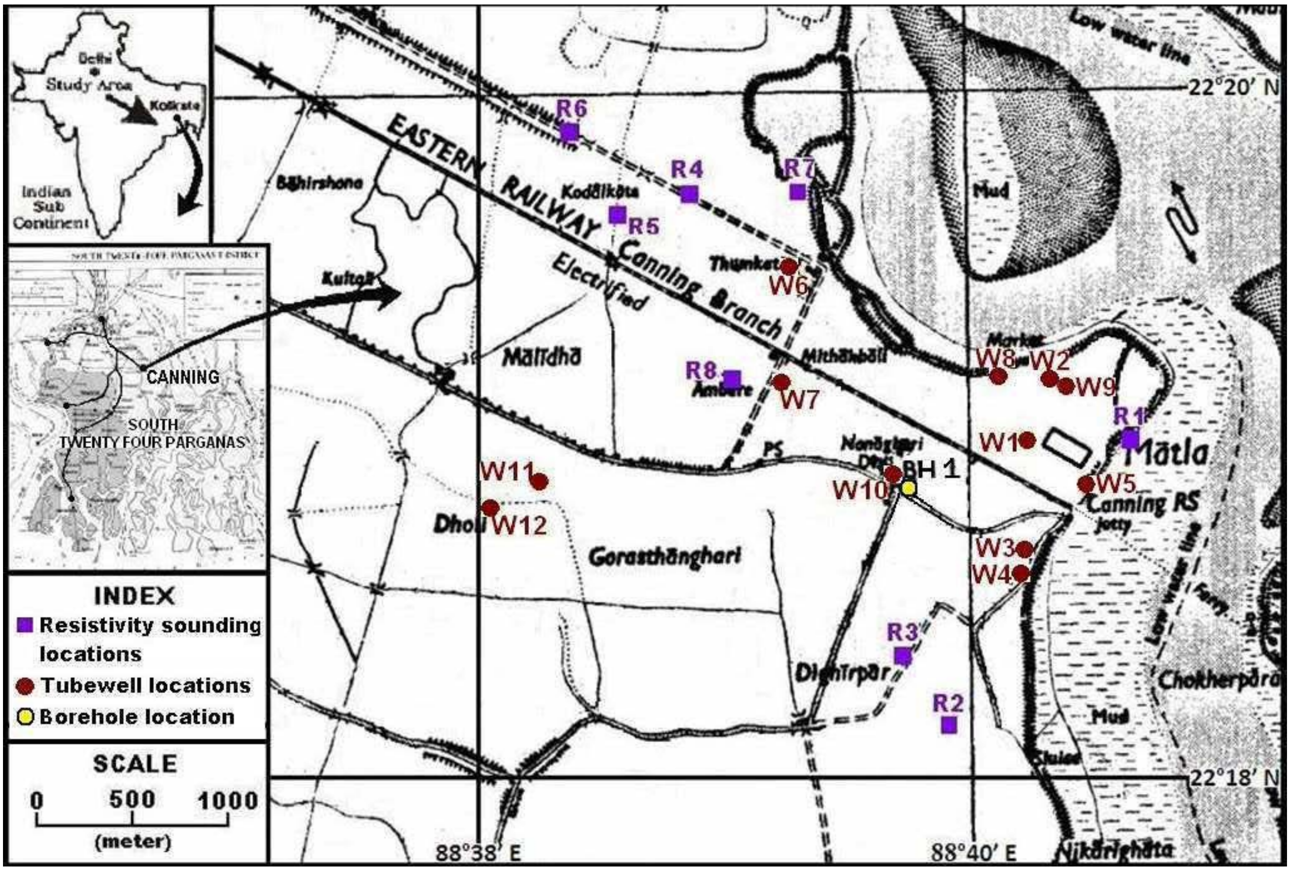

Fig.1. Location map of the study area. *VES locations are as follows:* R1-Canning complex Field; R2-Nona fishery bheri; R3-Dighir par; R4-Thumkatir more; R5-Kumrokhali near level-crossing; R6-Kumrokhali club; R7-Thumkati; R8-BCKV ground. *Tubewell locations are as follows:* W1-Beside Canning Railway station; W2-Near Canning-port; W3-Behind Canning SBI; W4-Opposite Nabarun sangha club; W5-Canning 1No. Grampanchayet; W6-Thumkati FP school; W7-Near Amberia; W8-Near Tinraster more; W9-Rajarlat; W10-Canning Hospital, W11-Opposite Krishi bank, Dholi; W12-Dholirbati. *Borehole and Welllog location is*: BH 1-Canning Hospital.

basin margin, shelf zone and deep basin can be recognized from west to east.

The proposed area (Fig.1) with lat. 22º18'N to 22º20'N and long. 88º37'E to 88º41'E lies at the southern part of the Indo-Gangetic plain, which is the largest alluvium tract in the world, and Quaternary alluvial fill of this plain is carried and deposited by the river Piali, Matla and its tributaries/ distributaries. Here Quaternary sediments is underlain by Tertiary sediments (upper Cretaceous to Pleistocene) indicating an accumulation in a subsiding tectonic trough. The Quaternary sediments of the Bengal plain are flood plain deposits as well as deltaic deposits and may be sub-divided into two major groups (Roychoudhuri, 1974): (a) newer alluvium: Recent to sub-recent, (b) older alluvium: Pleistocene to recent.

HYDROLOGY

The groundwater bearing aquifers in this district are present within Quaternary and Tertiary sediments and generally occur under confined condition in the depth range of ~75 to ~360 meters with numerous alternations of clayey and sandy layers of varying thicknesses. The confined aquifers can be divided into two groups from north to extreme south. The upper one, usually in the depth span of ~20 to ~160 meters has a sandy gravel layer as a marker bed at its base which pinches out eastward (CGWB, 2006). The groundwater in general except at a few places occurring in this upper group of aquifers, is brackish to saline and not in use The lower group of aquifer occurring in the depth range of ~160 to ~360 meters is separated from upper group by a impermeable sticky clay bed with varying thicknesses. The ground water occurring in this lower group of aquifer is used extensively for drinking and irrigation.

GEOELECTRIC FIELD INVESTIGATION

Geoelectric resistivity method has been extensively used

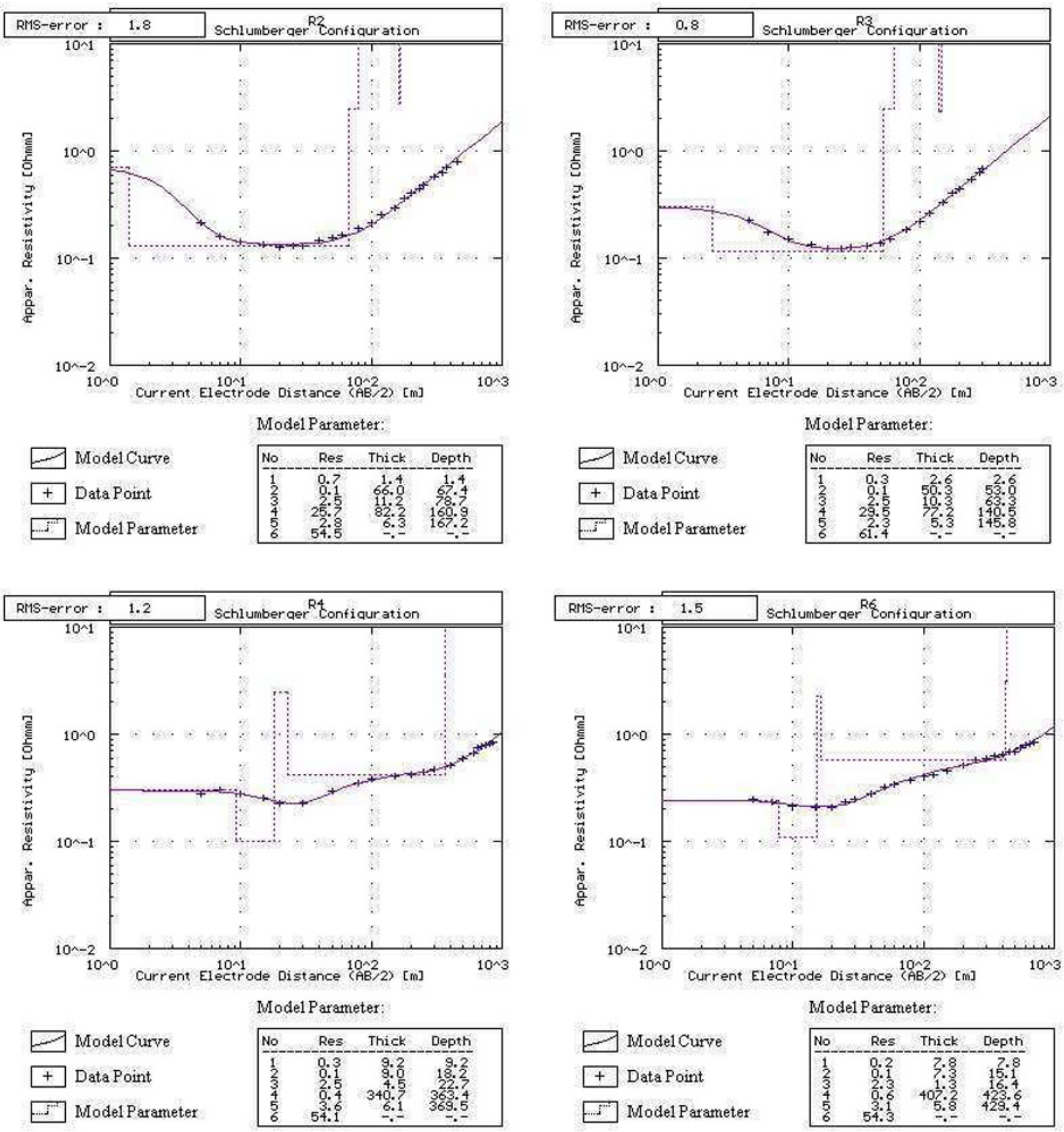

Fig.2. Typical resistivity field curve with model parameters at location R2, R3, R4 and R6

for structural, hydrological and geothermal investigation (Majumdar et al., 2000; Pal and Majumdar, 2001; Majumdar and Pal, 2005; Majumdar and Das, 2009, 2011; Yadav and Abolfazli, 1998; Stewart et al, 1983). Here vertical electrical sounding(VES) with Schlumberger array has been carried out in the central part of Canning for ascertaining the vertical distribution of ground water bearing zone.

DATA ACQUISITION AND INTERPRETATION

The VES investigation was conducted at eight locations (i.e. R1, R2, R3, R4, R5, R6, R7 and R8) with maximum current electrode spacing of 1700 meter (Fig.1). The resistivity sounding curve is interpreted by one dimensional (1-D) inversion technique using the software "RESIST". Preliminary values of the model parameters are obtained by matching the field VES curves with the theoretical master curves and auxiliary point charts. These model parameters are subsequently used as input (starting model) in "RESIST" for further refinement of the results of the 1-D inversion algorithm. The resistivity of different layers and corresponding thicknesses are reproduced by a number of iterations until the model parameters of all VES curves are totally resolved with minimum RMS error. The 1-D inversion

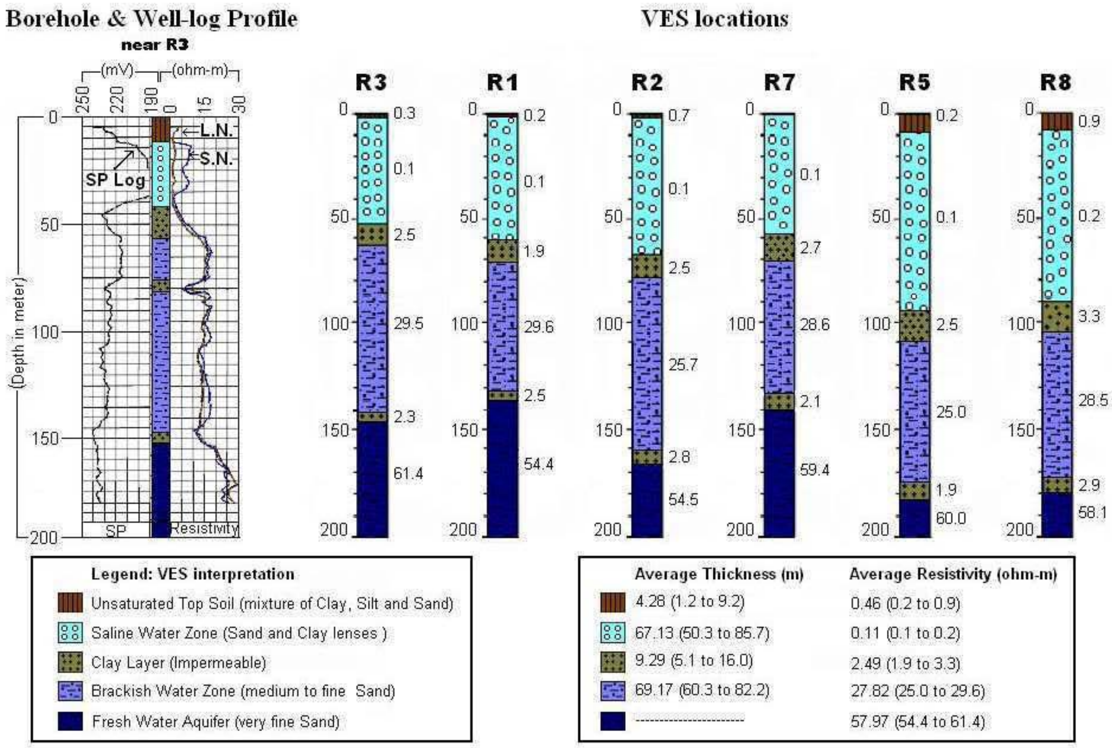

Fig.3. Combined borehole and well log prescribed by PHED near location R3 (left) and Layer parameters depicting VES interpretation for different locations (right).

model parameters can serve as the starting model for 2-D and 3-D approaches to improve the approximation of the sub-surface geology. In such cases, 1-D interpretation is usually found to be fairly consistent with those observed in 2-D and 3-D inversions. The results of VES are interpreted in terms of the sub-surface geology and aquifer characteristics under the prevailing hydrodynamic conditions and some interpretations are shown in Fig.2. Inversion results of all above eight VES locations are interpreted and subsequently correlated to resolve the lithologic condition of the area. The nature and distribution of different lithologic layers along with thicknesses and resistivity values are shown in Fig.3. The results of VES are then finally compared with one borehole (Fig.1) litholog and well-log data prescribed by Public Health Engineering Department (PHED, 2012) (Fig.3).

The VES studies have delineated the six distinct layers in six locations (R1, R2, R3, R5, R7, and R8). The top soil layer consist of clay, silt and sand. The second layer represents saline water saturated zone consisting of sand and clay lenses. The third layer consists of impervious clay bearing zone separating the saline and brackish water bearing zone (fourth layer). The brackish water bearing zone consists of medium to fine sand. The fifth layer is another impervious clay layer which separates the most important underlying confined fresh water bearing aquifer consisting of fine sand (sixth layer). The fresh water aquifer is located at depth level of 136.6 to 182.2 meter for six locations (R1, R2, R3, R5, R7, and R8) and from 369.5 to 429.4 meter for other two locations (R4, R6). The fresh water aquifer has resistivity value ranging from 54.4 to 61.4 ohm.meter. The borehole litholog data shows presence of three impervious clay layers ranging from 42 to 56 meter (between saline and brackish water zone), 76 to 82 meter (between two brackish water zone) and 147 to 152 meter (between brackish and bottommost freshwater zone). The first and third clay layers shown by borehole data are well represented in VES interpretation for the adjacent VES locations. The second thin clay layer between the brackish water zones of borehole litholog is not reflected in VES results. This thin

Table 1. Litho-resistivity relationship

Probable lithology	Resistivity range
Unsaturated top soil (mixture of Clay, Silt and Sand)	0.2 to 0.9 ohm.m
Saline water zone (Sand and Clay lenses)	0.1 to 0.2 ohm.m
Clay layer (Impermeable)	1.9 to 3.3 ohm.m
Brackish water zone (medium to fine Sand)*	25.0 to 29.6 ohm.m
Fresh water aquifer (fine Sand)	54.4 to 61.4 ohm.m

*(Batayneh, A. T., 2006)

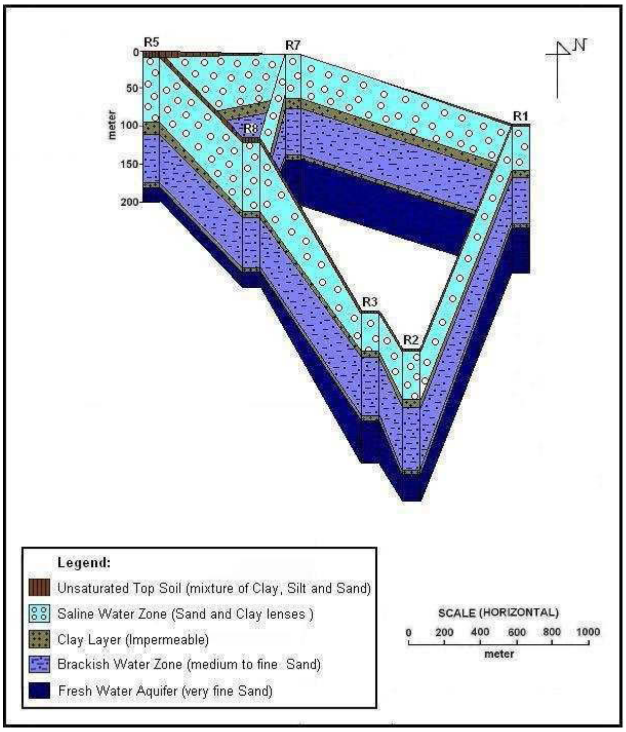

Fig.4. Fence diagram from VES data showing litholological and hydrological characteristic

layer may pinch out at these VES points. The self-potential, short and long normal resistivity log results correspond well with the results of VES interpretation showing high self potential and high SN and LN resistivity values across the fresh water bearing zone. A Fence diagram is constructed from VES interpretation showing litho-logical and hydrological characteristics of the area (Fig.4). Using the results of VES and borehole litholog, a litho-resistivity relationship has been established and is given in Table 1.

GEOCHEMICAL STUDIES

Geochemical investigation was carried out in the present study area to find the suitability of the water for irrigation and drinking purposes and examine the interaction between seawater and groundwater. Groundwater samples were collected from twelve tube wells at a depth ranging from 50 to 180 meter. The water samples of pre-monsoon period were collected in pre-cleaned transparent plastic bottles. Before collection of water samples, the bottles were thoroughly rinsed with the same. Concentrations of major cations and anions are measured and calculated using Flame photometer, Atomic Absorption Spectrometer, Mass Spectrophotometer and Titration technique. The results of chemical analysis are given in Table 2.

DISCUSSION OF RESULTS

The twelve chemical parameters are calculated for the twelve groundwater samples and the results are given in Table 3.

Total dissolved solid (TDS) content ranging from 695 mg/l to 1559 mg/l clearly indicates that the samples have different TDS values with respect to different depth. TDS vs Electrical Conductivity (EC) plot (Fig.5) shows a linear trend with strong correlation ($R^2 = 0.998$). The ratio of TDS and EC is 0.614 which is similar to the value (0.627) determined by Chaterji and Karanth (1963), and Majumdar and Das (2006, 2007) for the water from Gangetic alluvium and Tarai-Bhabar. According to IS standard, the value of major cations and anions are with in the permissible limit for drinking and irrigation purposes mostly at deeper confined aquifer having depth from 137 to 430 meter in this area.

The Total Hardnesses (TH) [2.497*Ca+4.115*Mg] is expressed in mg/l (Karanth, 2004). The TH values are ranging from 315.82 to 1295.64 mg/l and higher TH values are found mostly for the groundwater samples from deeper level. Here all the values are above 300 mg/l indicating that the groundwater of the entire area is very hard in nature. The value of ionic species Ca^{++} in mg/l at location W1, W4, W5, W6, W7, W8, W11 and W12 are slightly to moderately higher than the standard permissible value (200) of IS standard. This is also responsible for the increase of TH value.

The concentrations of major cations and anions of the groundwater samples are plotted on the Piper's trilinear diagram (Piper, 1944) which provides facilities to display analysis in a multi coordinate field (Fig.6) and are clustered in the resh water zone demarketed on the Piper's diagram. It is chemically classified as ($Ca+Mg+Cl+SO_4$ type) facies.

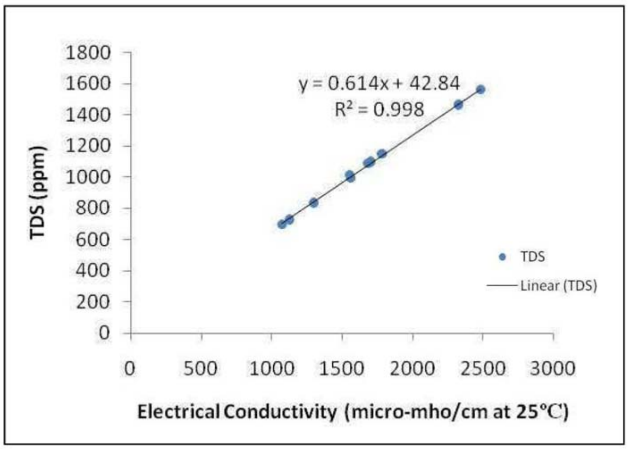

Fig.5. Variation of TDS vs EC for groundwater samples

Table 2. Chemical composition of groundwater samples in Canning and adjoining areas

Sample No	pH	EC (µs/cm)	TDS (mg/L)	Na	K	Ca	Mg	Sum of total cations	CO_3	HCO_3	Cl	SO_4	Sum of total anions	Depth (ft)
W1(ppm)	7.55	1552	998	34.4	0.62	330	30.0	395.02	NIL	439.2	149.1	53.47	641.77	480
W1(epm)	—	—	—	1.49	0.02	16.5	2.50	20.51	—	7.20	4.20	1.11	12.51	
W2(ppm)	7.85	1295	832	29.56	0.50	100	20.0	150.06	36.0	317.2	156.2	53.65	563.05	600
W2(epm)	—	—	—	1.29	0.02	5.00	1.67	7.98	1.02	5.20	4.40	1.12	11.74	
W3(ppm)	7.30	2480	1559	50.30	1.01	110	10.0	171.31	NIL	463.6	255.6	44.45	763.65	380
W3(epm)	—	—	—	2.18	0.03	5.50	0.83	8.54	—	7.60	7.20	0.93	15.73	
W4(ppm)	7.95	1072	695	32.40	0.48	400	20.0	452.88	NIL	488.0	71.0	64.64	623.64	600
W4(epm)	—	—	—	1.41	0.01	20.0	1.67	23.09	—	8.00	2.00	1.35	11.35	
W5(ppm)	7.75	1559	992	41.15	0.68	340	20.0	401.83	NIL	414.8	113.6	66.31	594.71	480
W5(epm)	—	—	—	1.79	0.02	17.0	1.67	20.48	—	6.80	3.20	1.38	11.38	
W6(ppm)	7.45	1703	1097	41.40	0.48	210	30.0	281.88	NIL	414.8	156.2	35.90	606.9	350
W6(epm)	—	—	—	1.80	0.01	10.5	2.50	14.81	—	6.80	4.40	0.75	11.95	
W7(ppm)	7.75	1683	1085	43.40	0.59	330	30.0	403.99	NIL	390.4	156.2	58.54	605.14	540
W7(epm)	—	—	—	1.89	0.02	16.5	2.50	20.91	—	6.40	4.40	1.22	12.02	
W8(ppm)	7.55	2325	1462	34.28	0.62	210	30.0	274.90	NIL	414.8	220.1	40.28	675.18	480
W8(epm)	—	—	—	1.49	0.02	10.5	2.50	14.51	—	6.80	6.20	0.84	13.84	
W9(ppm)	7.60	1780	1146	41.40	0.91	140	40.0	222.31	NIL	439.2	177.5	74.65	691.35	480
W9(epm)	—	—	—	1.80	0.02	7.00	3.33	12.15	—	7.20	5.00	1.56	13.76	
W10(ppm)	7.95	1125	725	31.04	0.52	190	50.0	271.56	NIL	414.8	78.1	59.12	552.02	600
W10(epm)	—	—	—	1.35	0.01	9.50	4.17	15.03	—	6.8	2.20	1.23	10.23	
W11(ppm)	7.35	2150	1346	61.00	0.56	290	10.0	361.56	NIL	463.6	220.1	69.33	753.03	160
W11(epm)	—	—	—	2.65	0.14	14.5	0.83	18.12	—	7.60	6.20	1.44	15.24	
W12(ppm)	7.65	1250	813	31.85	0.55	420	60.0	512.40	NIL	439.2	85.2	70.06	594.46	600
W12(epm)	—	—	—	1.39	0.14	21.0	5.00	27.53	—	7.20	2.40	1.46	11.06	
WHO* (ppm)	6.5-8.5	1400	500	200	—	200	150	—	500	500	600	500	—	
IS* (ppm)	6.5-8.5	1400	1000	200	—	200	100	—	600	600	1000	400	—	

*Desirable limit for drinking purpose, WHO- World Health Organization, IS- Indian Standard.

Table 3. Chemical parameters of groundwater samples in Canning and adjoining areas

Sample No.	Hardness (mg/L)	SAR*	SSP*	PS*	KR*	RSC* (meq/L)	CR*	Gibbs' Ratio-I*	Gibbs' Ratio-II*	CAI-I*	CAI-II*	SWC*
W1	947.46	0.48	7.36	7.26	0.08	-11.80	0.60	0.37	0.08	0.64	0.32	0.58
W2	332.00	0.71	16.42	16.17	0.19	-1.47	0.78	0.46	0.21	0.70	0.42	0.85
W3	315.82	1.23	25.88	25.53	0.34	1.27	0.88	0.49	0.29	0.69	0.58	0.95
W4	1081.10	0.43	6.15	6.11	0.07	-13.67	0.34	0.20	0.07	0.29	0.06	0.25
W5	931.28	0.59	8.88	8.74	0.10	-11.87	0.55	0.32	0.10	0.43	0.17	0.47
W6	647.82	0.71	12.22	12.15	0.14	-6.20	0.62	0.39	0.18	0.59	0.34	0.65
W7	947.46	0.61	9.13	9.04	0.10	-12.60	0.72	0.41	0.11	0.57	0.33	0.69
W8	647.82	0.58	10.41	10.27	0.11	-6.20	0.85	0.48	0.13	0.76	0.61	0.91
W9	514.18	0.79	14.98	14.81	0.17	-3.13	0.75	0.41	0.21	0.64	0.36	0.69
W10	680.18	0.52	9.05	8.98	0.10	-6.87	0.41	0.24	0.13	0.38	0.10	0.32
W11	765.28	0.96	15.40	14.62	0.17	-7.73	0.82	0.45	0.16	0.55	0.38	0.82
W12	1295.64	0.39	5.56	5.05	0.05	-18.80	0.44	0.25	0.07	0.36	0.10	0.33

*full names and equations for chemical parameters are shown in the text (Discussion of Results)

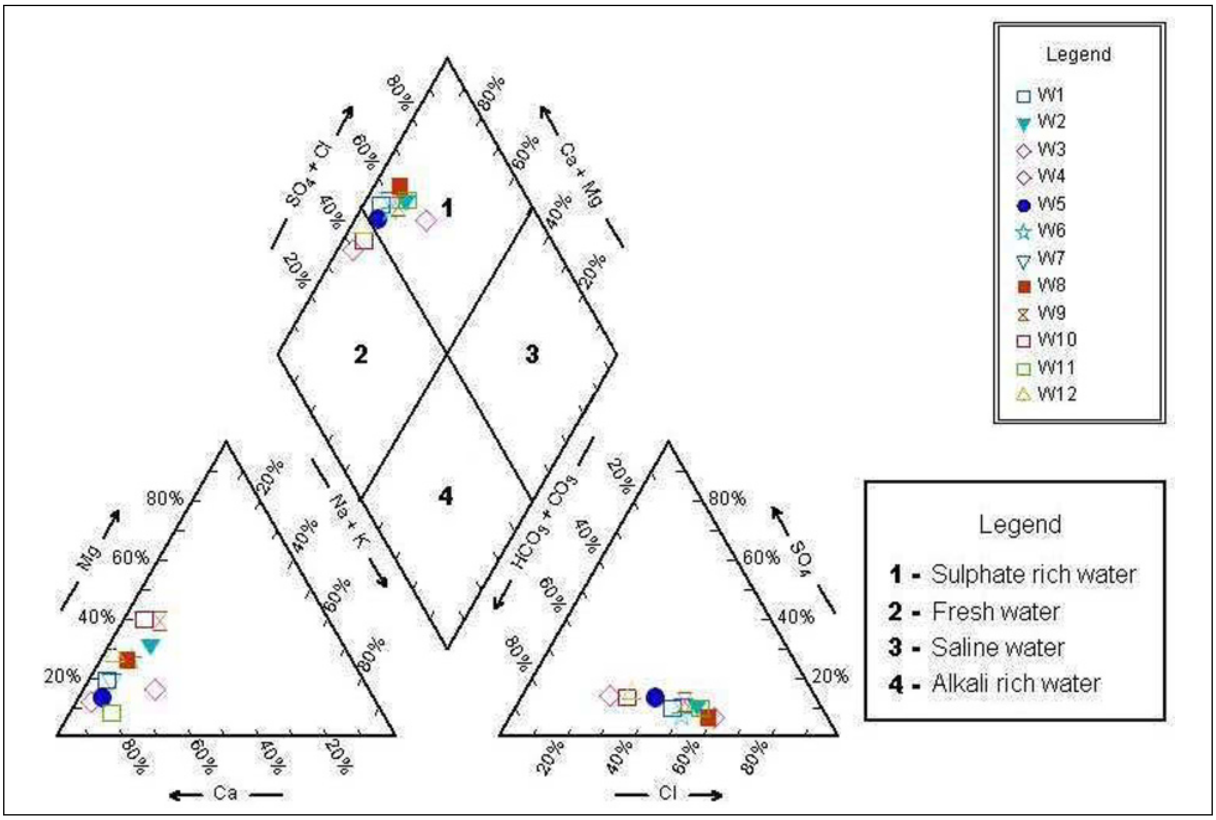

Fig.6. Piper trilinear diagram for groundwater samples

Sodium Absorption Ratios (SAR) [Na/{(Ca+Mg)/2}$^{1/2}$], expressed in meq/l are calculated and plotted against EC in the diagram (Richards, 1954) to determine the suitability of water for irrigation purpose (Fig.7). The observed values for all the samples are less than 6 (0.39 to 1.23). The plot indicates that the samples are suitable for irrigation in term of sodium and salinity.

Soluble Sodium Percentages (SSP) [{(Na+K)/(Na+K+Ca+Mg)}*100], expressed in meq/l (Todd, 1980) also show low values 6.15 to 25.88 (<60) indicating that the groundwater of the area is excellent in quality for irrigation purpose.

Percentages of Sodium (PS) [{Na/(Na+K+Ca+Mg)}*100], expressed in meq/l are also calculated and plotted against EC in the diagram (Wilcox, 1955) to determine the suitability of water for irrigation purpose (Fig.8) and suggest that the ground water is good to permissible for irrigation purpose.

Kelley's Ratios (KR) [Na/(Ca+Mg)], expressed in meq/l (Kelley, 1940) also show low values from 0.05 to 0.34 (<1) suggesting that the water is good for irrigation purpose.

Residual Sodium Carbonates (RSC) [(HCO_3+CO_3) – (Ca+Mg)], expressed in meq/l (Eaton, 1950 and Richards, (1954) are ranging from -18.8 to 1.27 meq/l (<2.5 meq/l) and can be used for irrigation, supporting the results of (Fig.7) and (Fig.8).

Corrosivity Ratios (CR) [{(Cl/35.5)+2*(SO_4/96)}/{2*(HCO_3+CO_3)/100}], expressed in mg/l are also calculated for the water samples. High CR decreases the hydraulic capacity of metallic piper (Raman, 1985). The observed values for all the samples are less than 1. So any type of metallic pipe can be used in the study area.

Gibb's Ratios I (GR-I) [Cl/(Cl+HCO_3)] and Gibb's Ratios II (GR-II) [(Na+K)/(Na+K+Ca)], expressed in meq/l (Gibbs, 1970) are plotted against TDS (Fig.9, Fig.10) to determine whether the water is in evaporation or rock or precipitation dominance. The plot (Fig.9) suggests that major anions i.e. Cl^- and HCO_3^- in ground water are mainly originated from rock i.e. formation material. whereas, the plot (Fig.10) indicates major cations such that Na^+, K^+ and Ca^{++} are concentrated in groundwater due to evaporation.

Chloro Alkaline Indices (CAI) (Schoeller, 1967) i.e. CAI-I [{Cl – (Na+K)}/Cl] and CAI-II [{Cl – (Na+K)}/(SO_4+HCO_3+CO_3+NO_3)], expressed in meq/l are positive which indicates that there is no base exchange between (Na+K) with (Ca+Mg) in rocks.

Sea Water Contaminations (SWC) [Cl/(CO_3+HCO_3)],

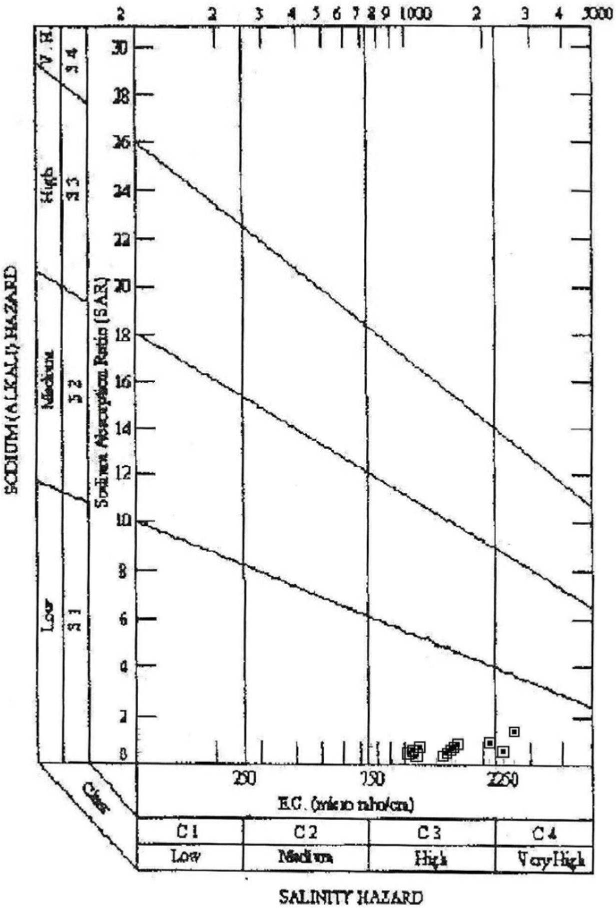

Fig.7. Plots of SAR values against salinity hazards (EC) for groundwater samples

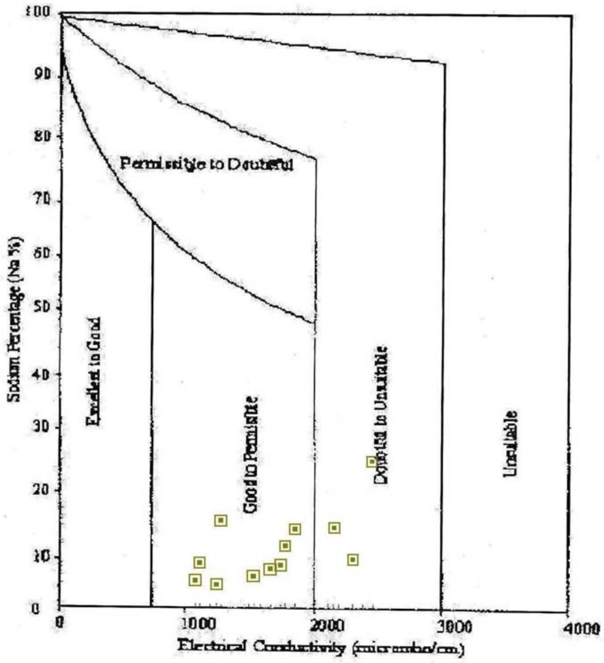

Fig.8. Plots of SSP values against salinity hazards (EC) for groundwater samples

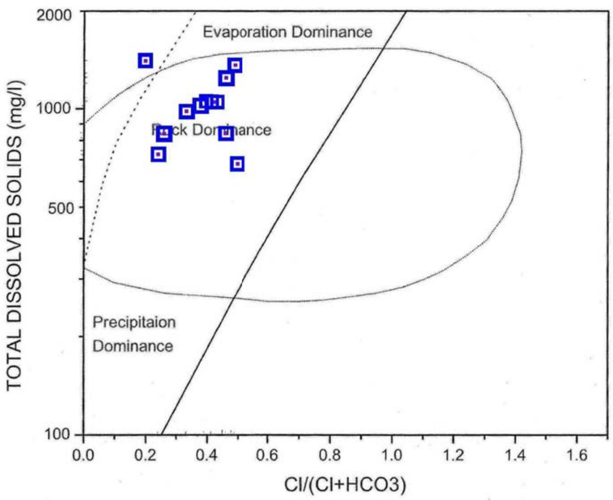

Fig.9. Plots of TDS vs Gibbs Ratio-I for groundwater samples

expressed in meq/l as suggested by Revelle (1941) are calculated for the samples. The SWC value for Bay of Bengal is 243 and below 0.5 for fresh water (Majumdar et al., 2002). This ratio for the water samples from the study area ranges from 0.25 to 0.95 with an average of 0.63. So the calculated value of SWC for most of the samples is around 0.5 indicating absence of saline water intrusion excepting weak sea water contamination at location (W8) i.e. mixing of sea water with fresh ground water.

CONCLUSION

Following conclusions can be drawn from the above integrated geoelectric and geochemical studies:

1. Vertical electrical sounding (VES) has delineated the six distinct layers i.e. topsoil, the saline water zones, impervious clay layer, brackish water zone, another impervious clay layer and the fresh water bearing aquifer in the sub-surface geological formations. The fresh water aquifer is located at depth of 136.6 to 182.2 meter in six locations (R1, R2, R3, R5, R7, and R8) and from 369.5 to 429.4 meter in another two locations (R4, R6). The resistivity of the fresh water bearing zone ranges from 54.4 to 61.4 ohm-meter. The ground water condition of the region, as discerned from the VES study, significantly corresponds with the borehole and well-log data.
2. VES findings show promising fresh ground water bearing zone of appreciable thickness. This zone can be tapped for drinking water purpose.
3. A Fence diagram is constructed from VES to show lithological and hydrological characteristics, aquifer

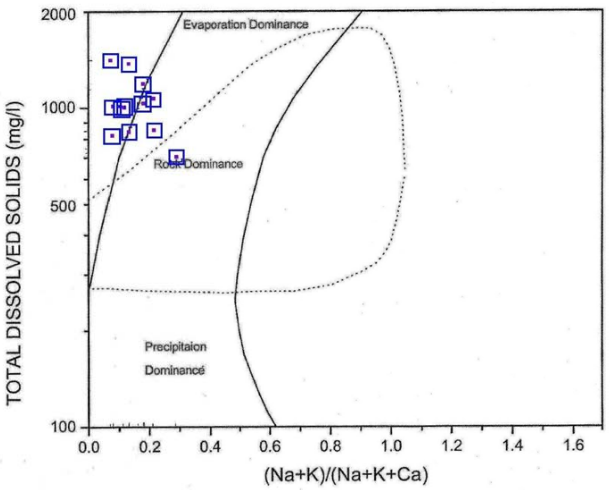

Fig.10. Plots of TDS vs Gibbs Ratio-II for groundwater samples.

dispositions and depth of the fresh water bearing aquifer in the study area.

4. A litho-resistivity relationship is established for this area of investigation and this relation can be used in other areas of similar geological environment.
5. Study of chemical parameters shows that the fresh groundwater of deeper confined aquifer at depths from 137 to 430 meter in this area is safe for drinking and irrigation purpose and the groundwater at shallower depth in Canning and adjoining areas is mostly brackish in nature.
6. According to Piper trilinear diagram, the groundwater in the area is fresh to mixed cation and anion type and is chemically classified as ($Ca+Mg+Cl+SO_4$ type) facies.
7. Ca^{++} content is significantly higher than the usual values found in ground water and this is also responsible for high TH value.
8. There is no mixing of sea water excepting slight contamination at locatin W8.

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