

Hydrogeological investigation of groundwater resources in the district of South 24 Parganas, India

R. K. MAJUMDAR & S. KAR

Department of Geological Sciences, Jadavpur University, Kolkata-700032, West Bengal, India
ranjit_mazumdar2000@yahoo.co.in

Abstract The South 24 Parganas district in India, consists of alluvial and marine sediment of Quaternary age. In this region, groundwater from a confined aquifer is the major source of drinking water. The aquifer is located at a depth of between 160 m and 335 m. This paper reports the results of integrated geological and geochemical investigations to assess the subsurface lithology, hydrological characteristics, groundwater chemistry, depth to the freshwater and seawater intrusion in this critical aquifer. Vertical electric soundings (VES) were conducted to determine facies change in the subsurface lithology and the existence of a saline water zone overlying the aquifer. The VES curves are interpreted by the 1-D inversion technique and the results show the presence of five to six prominent layers consisting of alluvial top soil, saline water, brackish water, an impermeable clay layer, freshwater and the bottom clay with silt and sand lenses, under the prevailing hydrodynamic conditions. The average depth of the confined aquifer is 180 m and the average resistivity of the freshwater zone is about 62 Ohm-m. Lithological characteristics of the area constructed from VES analyses are used to identify potential zones in the aquifer for abstracting drinking water. Geochemical investigations demonstrate that the TDS of the aquifer ranges from 590 to 965 mg/L and is a suitable source for drinking water supply.

Key words VES studies; brackish water; confined aquifer; TDS; Sodium Adsorption Ratio

INTRODUCTION

The coastal plain of West Bengal in eastern India includes the districts of Midnapur, Howrah, South 24 Parganas and North 24 Parganas. The district of South 24 Parganas has predominantly saline water found mainly in the upper to intermediate aquifer while “sweet” water is located in confined lower aquifers. The growing population in this area has increased the water demand from groundwater resources for drinking, agriculture and industry. This paper reports the results of a hydrogeological investigation of water resources in the district of South 24 Parganas, India. Such information is required to sustainably manage groundwater resources in this district.

METHODS

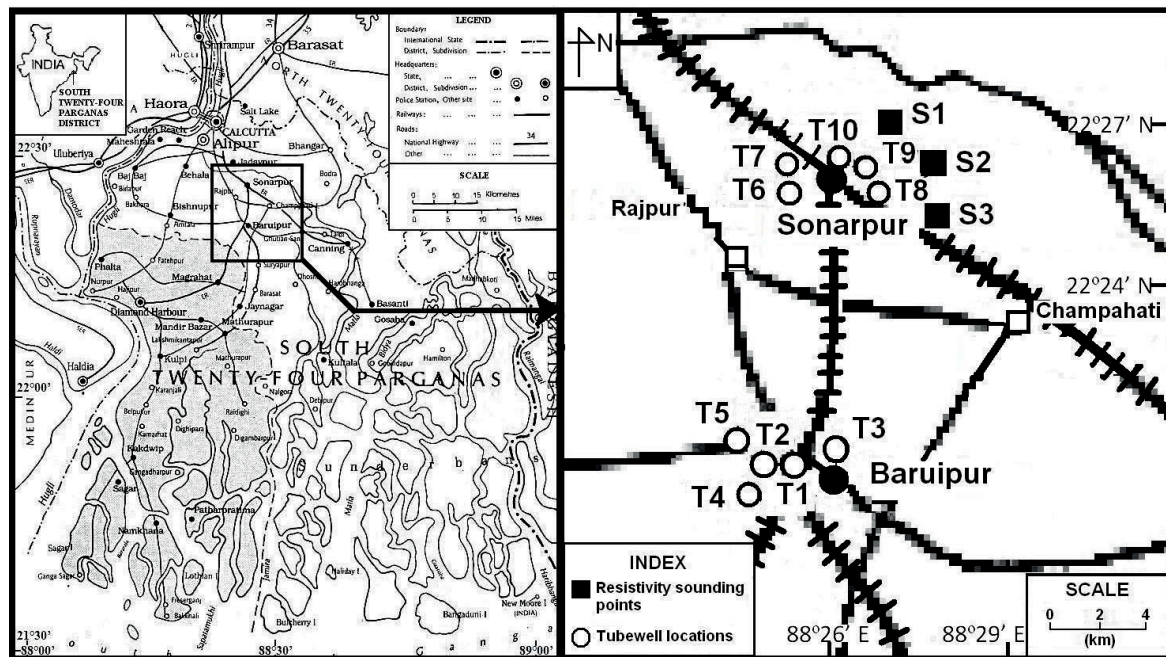
Geology of the study area

The study was conducted in an area of the Bengal basin (latitude 21°45'N to 22°30'N, longitude 88°15'E to 88°30'E) situated in the southern part of the Indo-Gangetic Plain, which is the largest alluvial tract in the world. The Quaternary alluvial fill of the plain continues to be reworked and deposited by the River Ganga and its tributaries/distributaries. Here the Quaternary sediments are underlain by Tertiary sediments (upper Cretaceous to Pleistocene) indicating an accumulation in a subsiding tectonic trough. The Quaternary sediments of the Bengal Plain consist of flood plain deposits as well as deltaic deposits and are classified into two major groups: Quaternary (a) Newer alluvium: Recent to sub-recent, and (b) Older alluvium: Pleistocene to recent (Roychoudhuri, 1974).

Hydrology

The aquifers in South 24 Parganas district are situated in Quaternary and Tertiary sediments at depths ranging from ~75 to ~360 m. The overlying materials consist of a complex mixture of clay and sand layers of varying thickness. In this district of South 24 Parganas, the confined aquifers are divided into two groups based on vertical location. The shallow aquifer (~20 to ~160 m) has sandy gravel layers at its base (CGWB, 2006). The groundwater quality in this upper aquifer is typically brackish to saline and not suitable for use. The lower aquifers (~160 to ~360 m) are separated from the upper group by a clay aquitard of varying thickness. Groundwater quality in the lower aquifer is generally fresh and it is used extensively for drinking water supply.

(a)



(b)

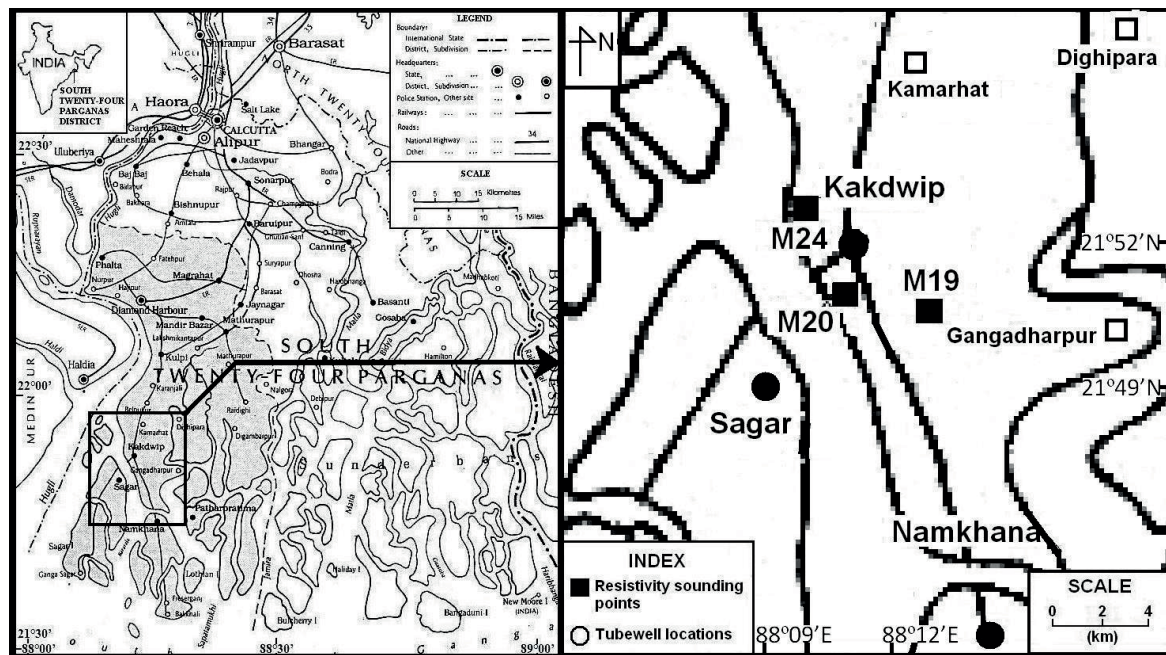


Fig. 1 (a) Location map of Sonarpur and adjoining area. (b) Location map of Kakdwip and adjoining area. VES locations are as follows: S1-Khurigachi; S2-Ghasiara; S3-Sitala; M19-Natunbazar; M20-Kakdwip town; M24-Near Laxmipur. Tubewell locations are as follows: T1-Near Baruipur Railway Station; T2-Near Baruipur Kulpi Road; T3-Subuddhipur; T4-Khodar Bazar; T5-Padmapukur Kazipara; T6-Sonarpur Aghore Sarani; T7-Near Netaji Sangha Club; T8-Gorkhara; T9-Gorkhara Ghoshpara; T10-Sonarpur Railway Station.

Geoelectrical field investigation

Geoelectric resistivity methods have been extensively used for structural, hydrological and geothermal investigations (Yadav & Abolfazli, 1998; Majumdar *et al.*, 2000; Majumdar & Pal, 2005; Majumdar & Das, 2011). In this study, vertical electrical sounding (VES) using a

Schlumberger array was used in the Sonarpur area to ascertain the vertical distribution of the groundwater bearing zone.

The VES study was conducted at three locations (S1, S2 and S3) in Sonarpur (Fig. 1(a)). The resistivity sounding curve was interpreted using a one dimensional (1-D) inversion technique using the “RESIST” software. Preliminary values of the model parameters were obtained by matching the field VES curves with the theoretical master curves and auxiliary point charts (Bhattacharya & Patra, 1968). Model parameters were 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 resolved with minimum RMS error. The 1-D inversion model parameters serve as the starting model for 2-D and 3-D approaches to improve the approximation of the subsurface geology. In such cases, 1-D interpretation is fairly consistent with those observed in 2-D and 3-D inversions. The results of VES are interpreted in terms of the subsurface geology and aquifer characteristics under the prevailing hydrodynamic conditions.

Geochemical studies

The geochemistry of the groundwater was measured to determine its suitability for irrigation and drinking and to examine possible interactions between seawater and groundwater. Groundwater samples were collected from ten water wells at depths ranging from 12 to 300 m in November, 2011. The ten water samples were collected in the post-monsoon period with pre-cleaned transparent plastic bottles. Before collection of water samples, the bottles were thoroughly washed with nitric acid and then rinsed three times with the specimen water. Concentrations of major cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) and anions (HCO_3^- , CO_3^{2-} , Cl^- and SO_4^{2-}) were measured using standard methods.

RESULTS AND DISCUSSION

VES Analysis of aquifer lithology

Inversion results were interpreted and subsequently correlated to resolve the lithological conditions of the area and the results are presented for one borehole (Fig. 2). The data in Fig. 2 show a top soil layer consisting of clay, silt and sand. The second layer represents a saline water saturated zone consisting of sand and clay lenses. The third layer consists of an impervious clay zone separating the saline and brackish water bearing zone. The fourth, 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 freshwater bearing aquifer (sixth layer) consisting of fine sand.

The freshwater aquifer is located at depths from 163.4 to 180.4 m at Sonarpur and adjoining areas, and has resistivity values ranging from 55.4 to 69.6 ohm.m. The borehole lithological data at Sonarpur (Fig. 2) from the Central Ground Water Board (Ghosh & Roy, 1996) shows the presence of two impervious clay layers at depths ranging from 78 to 108 m (between the saline and brackish water zones) and at 198.0 to 227.1 m (between the brackish and lowest freshwater zone). The clay layers shown by the borehole data are well represented in the VES interpretation for the adjacent VES locations. A gravel layer containing brackish water is found in the borehole lithology of Sonarpur, which is not marked in VES results due to its small thickness. The above interpreted VES results are compared with the VES results of three more locations (i.e. M19, M20 and M24) in Kakdwip (Fig. 1(b)) and adjoining areas (Das, 2011). In Kakdwip area, the clay layer is not present in between the saline and brackish water zone, which may be due to the changes in the depositional environment. The resistivity values show that groundwater of the southern part (Kakdwip area) is more brackish compared to the northern part (Sonarpur area) of the south 24 Parganas district. The resistivity values show that water salinity increases towards the southern part (near the sea coast).

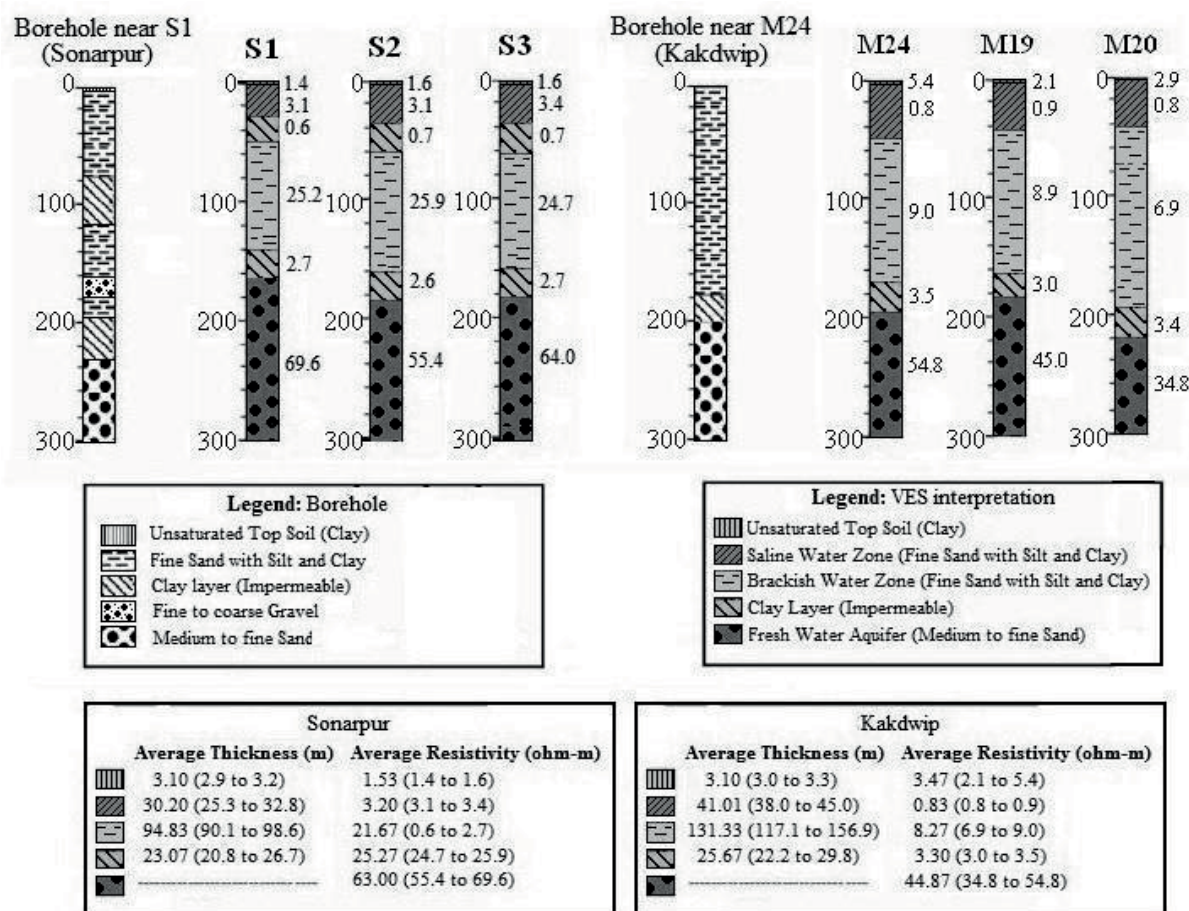


Fig. 2 Borehole lithologies described by CGWB and PHED near VES locations S1 and M24. Resistivity and thickness parameters interpreted from VES studies are shown for Sonarpur and Kakdwip areas.

Geochemistry of the aquifer

The geochemistry of the 12 groundwater samples is shown in Tables 1 and 2. Total dissolved solid (TDS) contents ranged from 695 to 1559 mg/L and show considerable variation with depth. A plot of TDS vs electrical conductivity (EC) shows a linear trend (Fig. 3) with a strong correlation ($R^2 = 0.998$). The ratio of TDS and EC is 0.64, which is similar to the value of the same ratio (0.627) for the water from the Gangetic alluvium and Tarai-Bhabar determined by Chatterji & Karant (1963), and Majumdar & Das (2007). The same result was found near the sea coast, i.e. in Kakdwip and adjoining areas (Das, 2011). According to the IS standard, the values of major cations and anions of most of the groundwater samples are within permissible limits for drinking and irrigation purposes.

Total hardness ranged from 182.7 to 1132.5 mg/L. Values above 300 mg/L indicate that the groundwater for the entire area of Sonarpur is very hard. However, the water at T2 is soft to moderately soft (Das, 2011). The concentrations of major cations and anions of the groundwater samples of Sonarpur are plotted in the Piper trilinear diagram (Piper, 1944) which provides facilities to display analyses in a multi coordinate field (Fig. 4). They cluster in the freshwater zone of the Piper diagram with mixed cation and anion type; chemically it is classified as a (Ca+Na+HCO₃+Cl type) facies.

Sodium absorption ratios (SAR) $[Na/\{(Ca+Mg)/2\}^{1/2}]$, soluble sodium percentages (SSP) $[\{(Na+K)/(Na+K+Ca+Mg)\} \times 100]$, percentages of sodium (PS) $[\{Na/(Na+K+Ca+Mg)\} \times 100]$, Kelley's ratios (KR) $[Na/(Ca+Mg)]$ and residual sodium carbonates (RSC) $[(HCO_3+CO_3) - Ca+Mg]$ are the chemical parameters that were calculated to determine the quality of the

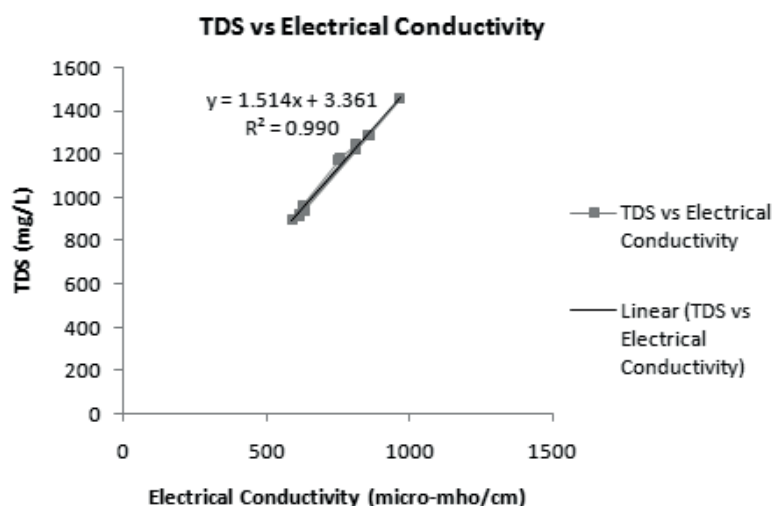
Table 1 Chemical composition of groundwater samples in Sonarpur and adjoining areas.

Sample no.	EC at 25°C (µs/cm)	TDS (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	Depth (m)
T1	1220	810	70.00	13.80	115.45	14.28	NIL	460	70.0	7.52	12
T2	896	590	96.30	3.50	50.21	13.93	NIL	400	40.0	5.89	300
T3	1242	811	127.30	4.40	67.50	23.89	NIL	360	120.2	6.21	75
T4	1178	755	130.50	6.67	245.00	11.58	NIL	528	170.4	26.98	30
T5	1172	753	101.40	5.02	125.00	13.29	NIL	360	163.3	7.29	18
T6	959	627	100.92	3.81	435.00	11.25	NIL	576	131.4	29.45	300
T7	916	615	98.93	3.72	135.00	11.08	NIL	528	103.0	36.38	300
T8	1285	858	100.28	3.58	95.00	16.50	NIL	504	156.2	88.13	30
T9	1454	965	193.75	4.44	115.00	15.13	NIL	528	181.0	85.11	15
T10	939	629	100.27	3.67	145.00	10.86	NIL	552	110.0	45.51	300
WHO*	750	500	200.00	-	200.00	150.00	500	500	600.0	500.00	
IS*	1400	1000	200.00	-	200.00	100.00	600	600	1000.0	400.00	

* Desirable limit for drinking purposes.

Table 2 Chemical parameters of groundwater samples in Sonarpur and adjoining areas.

Sample no.	Hardness (mg/L)	SAR	SSP	KR	RSC	SWC	PS
T1	347.04	8.69	32.75	0.44	0.58	0.26	29.37
T2	182.70	17.01	53.72	1.14	2.89	0.17	52.59
T3	266.85	18.83	51.22	1.03	0.54	0.57	50.23
T4	659.42	2.21	30.64	0.43	-4.56	0.55	29.75
T5	366.81	2.30	38.15	0.60	-1.46	0.78	37.06
T6	1132.49	1.30	16.52	0.19	-13.26	0.39	16.15
T7	382.69	2.20	36.45	0.56	-1.01	0.44	35.63
T8	305.11	2.49	42.06	0.71	2.13	0.53	41.21
T9	349.41	4.50	54.89	1.20	1.65	0.59	54.18
T10	406.75	2.16	35.23	0.53	0.89	0.34	34.05

**Fig. 3** Variation of EC vs TDS for groundwater at 25°C.

groundwater of the entire study area for irrigation purposes. The concentrations of the measured ions are expressed in meq/L. Calculated SAR values (from 1.3 to 8.69, excepting location T2 (17.01) and T3 (18.83)) are plotted against EC in Richards diagram (Richards, 1954) (Fig. 5(a)) which indicates that the samples are suitable for irrigation in terms of sodium and salinity hazard

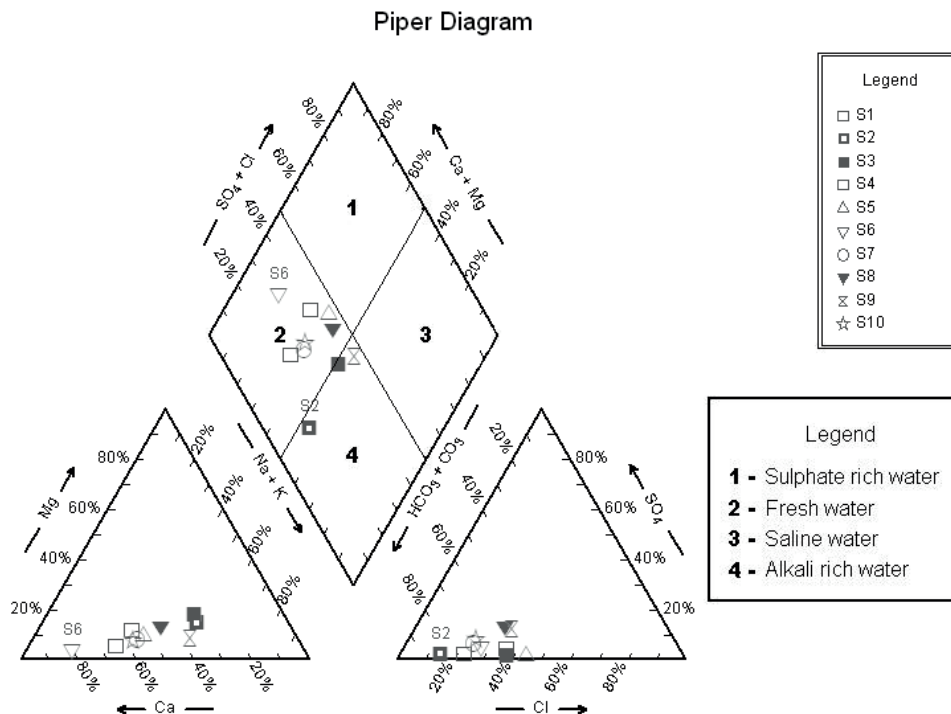


Fig. 4 Piper trilinear diagram for groundwater samples.

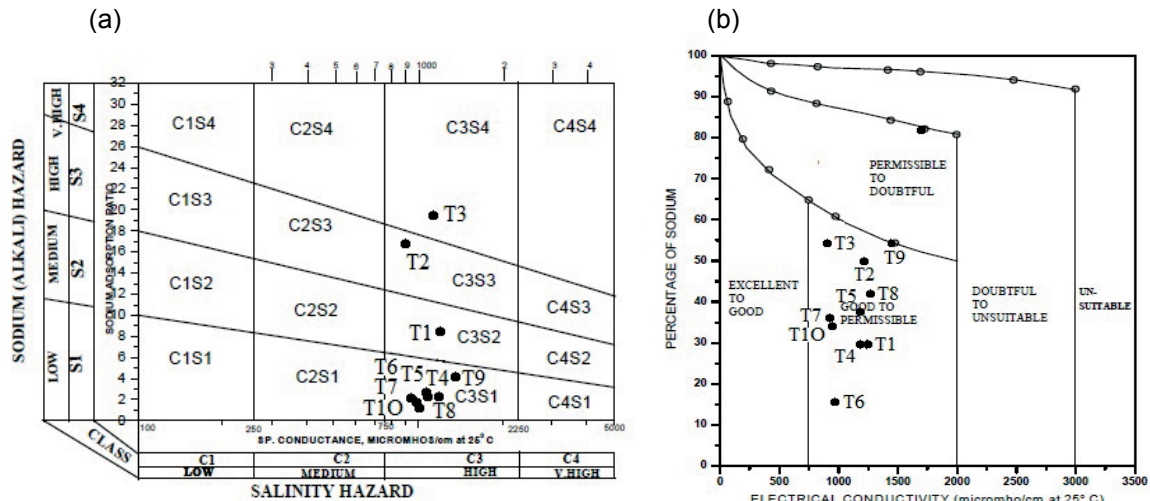


Fig. 5 (a) Richards diagram for classification of irrigation waters (EC vs SAR). (b) Wilcox diagram for classification of irrigation waters (EC vs %Na).

except at locations T2 and T3. SSP (from 16.52 to 54.89 (<60)), KR (from 0.19 to 1.14 (<1)), RSC (from -13.26 to 2.89 (<2.5)) and a plot of PS vs EC values in the Wilcox diagram (Wilcox, 1955) (Fig. 6) for the entire groundwater of the study area indicate that the water has good quality for irrigation purposes. Seawater contamination, $SWC = [Cl/(CO_3 + HCO_3)]$, where ions are expressed in meq/L (Revelle, 1941) for the water samples are calculated and range from 0.17 to 0.78, with an average of 0.46. The SWC value for the Bay of Bengal is 243 and below 0.5 for freshwater (Majumdar *et al.*, 2002). So the calculated value of SWC for most samples is less than 0.5, indicating the absence of saline water intrusion except for weak seawater contamination at location (T5).

CONCLUSION

Vertical electrical sounding (VES) analyses are useful for delineating groundwater zones with potential for drinking water purposes. The VES identified the six distinct layers, i.e. topsoil, the saline water zones, impervious clay layer, brackish water zone, lower impervious clay layer and the freshwater bearing aquifer in the subsurface geological formations. The freshwater aquifer is located at 163.4–180.4 m depth at Sonarpur and adjoining areas, and has resistivity values of 55–70 ohm.m. The groundwater conditions of the region, as discerned from the VES study, correspond significantly with the borehole results. The resistivity profile shows the lithological and hydrological characteristics, aquifer positions and depth to the freshwater-bearing aquifer in Sonarpur and adjoining areas. The increase in salinity in the Kakdwip area may be due to over pumping in the coastal zone near to the sea. A litho–resistivity relationship established for this area of investigation can be used for other areas of similar geology environment. Study of the chemical parameters shows that the fresh groundwater of the deeper confined aquifer is safe for irrigation and drinking purposes except at tube wells T2, T3 (high SAR) and T5 (more SWC). The Piper trilinear diagram indicates that the groundwater in the Sonarpur area is fresh compared to the Kakdwip area, which is alkaline type, and that there is no mixing with seawater excepting slight contamination at location T5 in the Sonarpur area.

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