Asian Journal of

Earth Sciences

ISSN 1819-1886

Academic
Journals Inc.

www.academicjournals.com

Asian Journal of Earth Sciences 4 (2): 60-74, 2011
ISSN 1819-1886 / DOI: 10.3923/ajes.2011.60.74

Hydrological Characterization and Estimation of Aquifer Properties from Electrical Sounding Data in Sagar Island Region, South 24 Parganas, West Bengal, India

R.K. Majumdar and D. Das
Department of Geological Sciences, Jadavpur University, Kolkata-700032, India

Corresponding Author: R.K. Majumdar, Department of Geological Sciences, Jadavpur University, Kolkata-700032, India Tel: +91-9830905289 Fax: +91-33-24731484

ABSTRACT

Geoelectric investigation is carried out in the Sagar Island region to assess the prevailing groundwater condition. The Vertical Electrical Soundings (VES) are carried out in thirty-eight locations of South, Central and Northern parts of Sagar Island region to determine the subsurface hydrological conditions. Maximum current electrodes spacing (AB) of 1200 m are used. Four soundings were carried out near existing boreholes. A combination of curve matching techniques and computer iterative software are used for processing the data. VES results show mostly six layers and constitutes of topsoil layer, saline water, brackish water, impermeable clay layer, fresh water and bottommost clay with silt and fine sand lenses. The results of VES studies significantly correspond with the borehole data and a litho-resistivity relationship is established for this area. The diagnostic constant (A) calculated from the product of hydraulic conductivity and electrical conductance obtained from prescribed known value is used to find the aquifer conductivity and Transmissivity parameters in other locations under the similar hydrodynamic condition of the same region where no pumping test results of boreholes are available. Hydraulic conductivity values vary between 9.92 m day^{-1} at R8 to 13.56 m day^{-1} at R24. Transmissivity values also vary between 1687 m^2 day^{-1} at R11 to 2868 m^2 day^{-1} at R24.

Key words: Geoelectric, Schlumberger array, true resistivity, fresh water aquifer, hydraulic conductivity, Sagar Island

INTRODUCTION

Sagar Island, the largest island in the Ganga Delta [{21° 37′ N (21.6167)° N} to 21° 52′ N, {(21.8667)° N}, 88° 02′ 35″ E {(88.0430)° E} to 88° 11′ E {(88.1834)° E}], is elongated in N-S direction (~30 km) and has varying width in E-W direction. The southern portion of the Island widens to ~12 km (Fig. 1). It is bordered in the north, west, east and south by Hooghly, Gabtala, Muriganga rivers and Bay of Bengal, respectively (Fig. 1).

Sagar Island has a flat topography with no significant variation in elevation from mean sea level (~3 m). The Island of 235 km^2, constitutes 46 villages with a total population of 0.25 million (Majumdar *et al.*, 2002) and offers a holy Kapil Muni temple for Hindus at Gangasagar village (Fig. 1). Besides that, Gangasagar has been selected by the Government as a tourist center. For drinking water, this Island is solely dependent on the deeper aquifers between 180 to 330 m Below

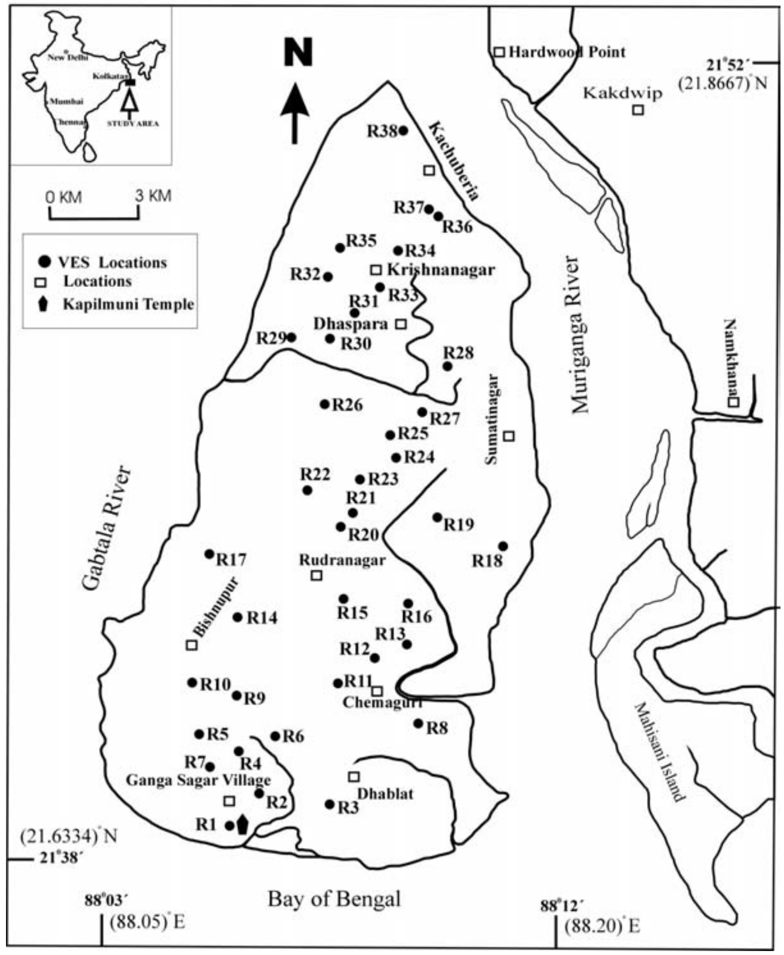

Fig. 1: Locations map of the study area

Ground Level (BGL) (Das, 1991). Fresh groundwater in the deeper aquifers occurs under confined condition and is tapped by means of small diameter tube-wells fitted with hand pump. Dug-wells in this area produce saline water.

Geoelectric Vertical Electrical Sounding (VES) have been conducted in the 38 locations in the study area to identify various lithologic units, evaluate groundwater condition, find potential aquifer zone. The present study is also dealt with the estimation of Hydraulic conductivity and Transmissivity of the aquifer in the central portion of the Sagar Island.

The results from the present study would help to determine aquifer characteristics of the area without further boreholes pumping test studies.

GEOLOGY OF THE STUDY AREA

Sagar Island lies at the southern most part of the Indo-Gangetic Plain, which is the largest alluvial tract of the world, and the Quaternary alluvial fill of this plain is carried and deposited by the river Ganga 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 constituted of flood plain deposits as well as deltaic deposits and may be subdivided into two major groups (Roychoudhuri, 1974):

- Quaternary: Newer alluvium: Recent to sub-recent
- Older alluvium: Pleistocene

The southern extremity of the Bengal Plain is characterized by the presence of extensive coastal belt. Chakrabarti (1995) divided this belt into two zones on the basis of coastal environment. Sagar Island, being a part of this coastal belt, falls under the 'macro tidal Hooghly estuary' zone. It has been established that Hooghly estuary is characterized by a broad expanse of syn-depositional fluviotidal and marine coastal sediments (viz. sand, silt and clay) resulting in Flandrian Transgression around 6000 years B. P. (the on-lapping sequence) and subsequent delta progradation (the off-lapping sequence) (Chakrabarti, 1995). In the present day scenario, the Hooghly estuary is the abandoned part (for the last 200 years ago) of the lower deltaic plain of Ganga-Brahmaputra. From the early part of this century, it underwent a destructive phase (Chakrabarti, 1992). The present day configuration of Sagar Island reveals that a number of small isolated islands, earlier separated by tidal creeks, are now welded almost into a single landmass due to gradual reduction of the width of the tidal creeks.

It is a tide dominated deltaic island where the high tide zone ranges from 5 to 6 m. Coastal marshes, mangrove swamps, tidal flats, mudflats, sand dunes or ridges, marine terraces and tidal inlets are the coastal features of this island (Paul and Bhandyopadhyay, 1987).

HYDRO GEOLOGY

Sagar Island is criss-crossed by numerous tidal creeks and man-made canals. These creeks and tanks are the main sources of surface water, which is highly saline and hard (Chakrabarti, 1995). In rainy seasons, the salinity of the water of the tanks decreases and turn to brackish water. The average annual rainfall of Sagar Island is about 200 cm with mean temperature of 22°C. The area is characterized by the presence of fluvio-tidal and marine coastal facies deposits (Chakrabarti, 1991). These deposits, being in general, porous in nature, serve as repository of potable groundwater. Freshwater group of aquifers occur within the depths of 180 to 350 m. The upper group of aquifers overlying the deep freshwater aquifers contains saline water in its upper part and brackish water in its lower part. The freshwater group of aquifers occurring beneath the brackish-water aquifer(s) is under confined condition and separated from overlying brackish aquifers by around 30 m thick impermeable clay layer.

GEOELECTRIC RESISTIVITY INVESTIGATION

Geoelectric resistivity method has been extensively used for structural, hydrological, geothermal (Majumdar *et al.*, 2000, 2006; Majumdar and Das, 2007; Majumdar and Pal, 2005; Pal and Majumdar, 2001; Yadav and Abolfazli, 1998; Stewart *et al.*, 1983) and aquifer hydraulic characteristic investigation (Niwas and Singhal, 1981; Ekwe *et al.*, 2006). Here, Schlumberger Vertical Electrical Sounding (VES) array is carried out in the whole part of Sagar Island region for ascertaining the vertical distribution of water bearing zones contributing the aquifer bodies and estimation of aquifer hydraulic characteristics from electrical sounding in the region.

Interpreted results of VES furnish information for resistivities and thicknesses of different layers at the sounding point. For this reason, the method is useful for investigation on horizontal or nearly horizontal stratified earth. In electrical resistivity sounding method, the spacing of the current electrode is gradually increased symmetrically keeping the centre of the electrode system fixed. As a result, the current is made to penetrate deeper and deeper and the apparent resistivity is measured for each current electrode separation to find the variation of apparent resistivity with increased current electrode spacing (Bhattacharya and Patra, 1968; Koefoed, 1979).

MATHEMATICAL FORMULATION

There is an analogy between fluid flow and current flow; one obeys the Darcy's law and other follows the Ohm's law. In Darcy's law, the quantity of water discharged in unit time is given as:

$$Q = KAI \tag{1}$$

Where:
K = Hydraulic conductivity
A = Total cross-sectional area through which the water percolates
I = Hydraulic gradient

Here Q is the scalar quantity. On the other hand, the differential equation of Ohm's law for current flow can be written as:

$$\vec{J} = \sigma \vec{E} \tag{2}$$

where, $\vec{J}$ is the current density, $\vec{E}$ is the electrical field intensity and σ is the electrical conductivity = $1/\rho$, ρ being the resistivity. Here, J and E are vector quantities.

Considering a prism of aquifer material with unit cross sectional area and thickness 'h', the two fundamental laws can be combined (Niwas and Singhal, 1981) to find a probable relationship between electric and hydraulic characteristic of the formation.

The Transverse resistance 'R' (resistance normal to the surface of the prism) can be written as:

$$R = h*\rho \tag{3}$$

and Longitudinal conductance 'S' (resistance parallel to the face of the prism) (Zohdy, 1976) can be shown as:

$$S = h/\rho = h*\sigma \tag{4}$$

Again aquifer Transmissivity 'T' (product of aquifer thickness and hydraulic conductivity) is related to the Hydraulic conductivity (K) and aquifer thickness (h) and this can be expressed as:

$$T = K * h \tag{5}$$

Combining the Eq. 3, 4 and 5:

$$T = K * h = K*(R/\rho) = K*\sigma* R=K*(S/\sigma) \tag{6}$$

In the areas of similar geologic setting and water quality, the product, $K*\sigma$ remains fairly constant (A) (Niwas and Singhal, 1981; Onuoha and Mbazi, 1988).

Thus it is possible to determine Transmissivity and its variation from place to place including those areas where borehole pumping tests data are not available provided one knows the 'K' value from the exiting borehole pumping test data and σ from the interpreted VES data of the aquifer at bore hole.

Data acquisition and interpretation: The locations of the sounding points are shown in Fig. 1. Thirty Eight (38) Schlumberger array-Vertical Electrical Sounding with maximum current electrode spacing (AB) of 1200 m are carried out in the study area using resistivity equipment DDR-4 manufactured by Integrated Geo-Instrument and Services Pvt. Ltd, Hyderabad.

The resistivity Sounding curves are interpreted by 1D inversion technique using software 'RESIST (Velpen, 1988). Preliminary values of the model parameters are obtained by matching the VES field curves with the theoretical master curves and auxiliary point charts and these model parameters are subsequently used as input (starting model) in 'RESIST' for further refinement of results of different layers and corresponding thickness are reproducing by a number of iterations until the model parameters of all VES curves are totally resolved with minimum RMS error. 1D inversion reserves its importance and utility, as interpreted parameters can serve as starting model for 2D and 3D approach for better approximation of the subsurface geology of an area. In such cases, 1D interpretation is usually found to be fairly consistent with these observed in 2D and 3D inversion (Monteiro Santos *et al.*, 1997; Olayinka and Weller, 1997).

The results of VES are interpreted in terms of subsurface geology under the prevailing hydrodynamic conditions.

RESULTS AND DISCUSSION

VES curves: In the southern and northern parts, seven (R1 to R7) and ten (R29 to R38) VES studies were done with maximum electrode separation of 800m and reveal five layers below the earth surface. In the Central part, twenty-one (R8 to R28) VES investigation were done with maximum electrodes separation of 1200 m and the results show six layers. The area is comprised of forests, creek and marshy land and maximum current electrode spacing 800 and 1200 m were possible in this study area. The representative VES curves for location R1, R20 and R33 near boreholes in Southern, Central and Northern parts are shown respectively in Fig. 2. The resistivity layers parameters for these locations are shown in Table 1. The VES results for all locations along the depth in southern, central and northern part of Sagar Island are shown in Fig. 3a and b and Fig. 3c, respectively. The top layer is interpreted as alluvial clayey soil. The second and third layers represent saline and brackish water saturated zones. Both the layers are constituted of clay with

Table 1: VES layer parameters for locations R1, R20 and R33 near boreholes in southern, central and northern parts of Sagar Island, respectively

VES No.	ρ_1 (Ωm)	h_1 (m)	ρ_2 (Ωm)	h_2 (m)	ρ_3 (Ωm)	h_3 (m)	ρ_4 (Ωm)	h_4 (m)	ρ_5 (Ωm)	h_5 (m)	ρ_6 (Ωm)	h_6 (m)	RMS error
R1	5.7	3.4	0.8	24.8	6.0	159.3	2.6	24.0	41.0	∞			2.0
R20	2.2	4.6	0.7	31.3	8.3	97.2	3.3	21.0	64.9	187.9	19.1	∞	1.9
R33	2.4	3.1	0.8	33.1	6.3	145.9	3.1	22.4	44.4	∞			1.9

$\rho_1, \rho_2, \rho_3, \rho_4, \rho_5$ and ρ_6. true resistivity of six layers. h_1, h_2, h_3, h_4, h_5 and h_6 . thickness of six layers. R1- VES location in southern part of Sagar Island. R20- VES location in central part of Sagar Island.. R33- VES location in northern part of Sagar Island

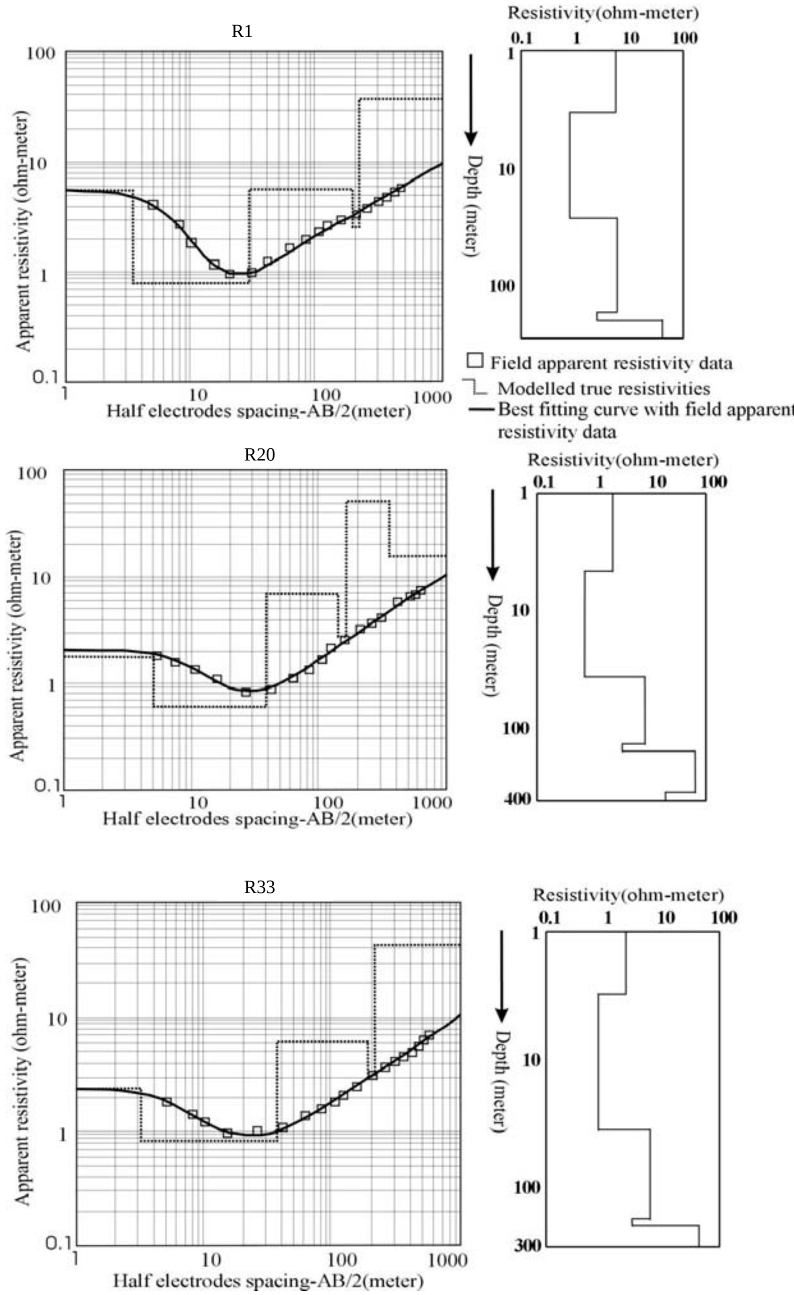

Fig. 2: Typical resistivity field curves with interpreted results for VES locations R1, R20 and R33 near boreholes in southern, central and northern parts of Sagar Island, respectively

silt and sand lenses. The fourth layer is constituted of clay (impermeable) with average thickness of 23 m. This impervious layer separates the overlying brackish water zone from underlying freshwater bearing formation. The most important layer is the 5th layer in southern, central and northern part of the study area. This is interpreted as fresh water bearing sandy zone. The fifth layer in the central part is only resolved due to increased current electrode spacing of 1200 m and

Table 2: Litho-resistivity relationship for the whole part of the Sagar Island

Probable lithology	Resistivity range (Ωm)
Unsaturated top soil (Clay)	1.5 to 7.7
Saline water zone (Clay with silt and sand lenses)	0.7 to 1.5
Brackish water zone (Clay with silt and sand lenses)	5.3 to 10.2
Clay , grey, sticky layer (impermeable)	2.6 to 5.0
Fresh water aquifer (Medium to fine sand with clay lenses)	30.9 to 75.5
Clay with fine sand and silt lenses (poor yielding properties)	16.0 to 21.0

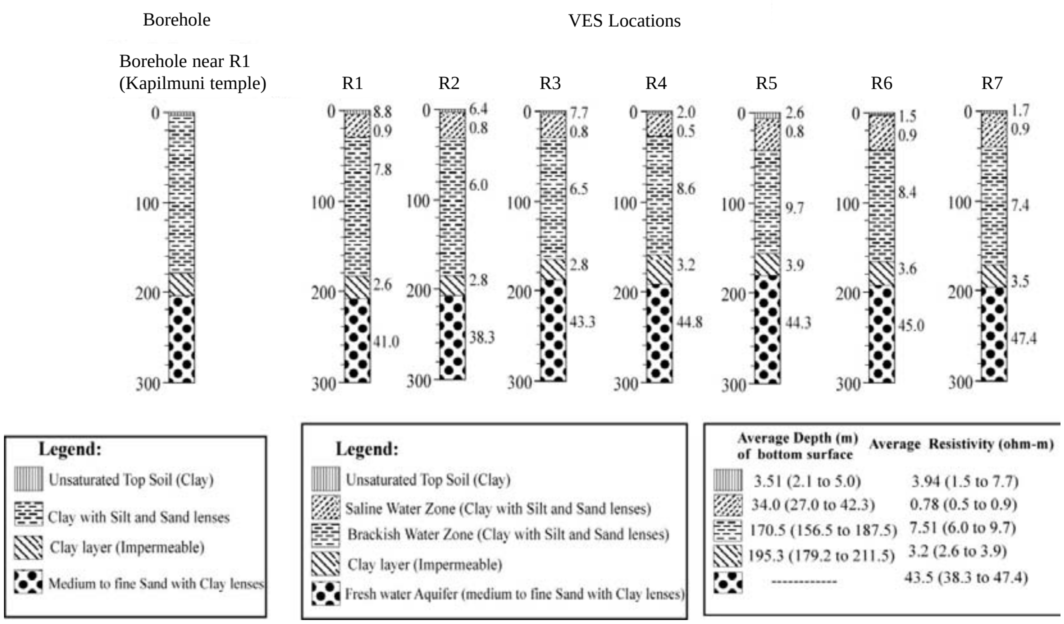

Fig. 3a: Combined borehole litholog prescribed by PHED and CGWB near VES R1. Layer parameters are shown in VES interpretation for R1 to R7. Numbers in the left and right-hand side of the logs show depth from ground level (m) and true resistivity values (Ωm), respectively

its average thickness is around 184 m with average resistivity of 59 Ωm. The average depth of the upper surface of this aquifer is 171 m. The bottom most 6th layer in the central part is constituted of clay with fine sand lenses. This layer shows low water yield with low resistivity (16.0 to 19.0 Ωm) values. Field studies confirm the presence of saline water within few meters below the ground water level (bgl).

Generalized borehole lithologies prescribed by the Public Health Engineering Department (PHED, 1987) near R1 (Fig. 3a) and Central Ground Water Board (CGWB, 1994) near R20 (Fig. 3b) and near R33 (Fig. 3c) match significantly with layer parameters obtained from VES investigation. Comparing the results of VES and boreholes lithologs, a litho-resistivity relationship has been established and is shown in Table 2.

Three fence diagrams are drawn to show the existing hydrological environment in the region (Fig. 4a-c). The average upper and lower depths of fresh water bearing aquifer obtained from

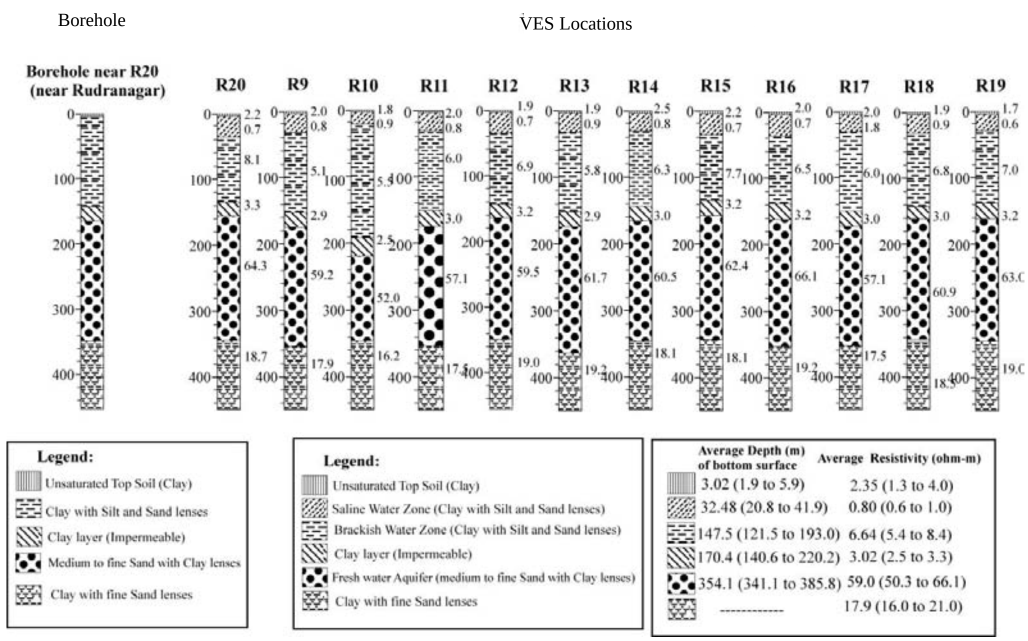

Fig. 3b: Combined borehole litholog prescribed by CGWB near VES R20. Layer parameters are shown in VES interpretations for R9 to R20. Numbers in the left and right-hand side of the logs show depth from ground level (m) and true resistivity values (Ωm), respectively

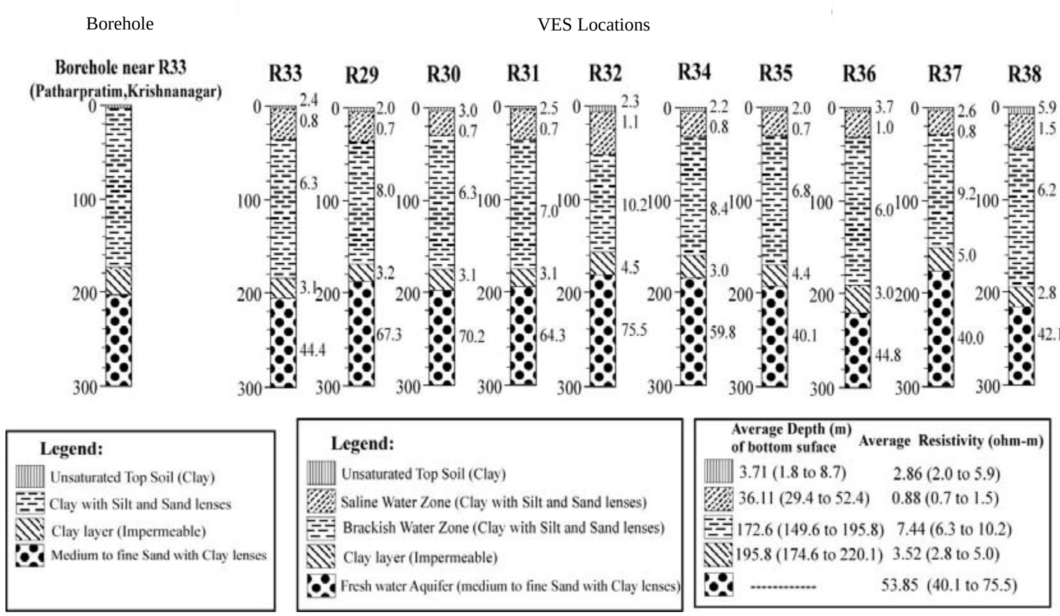

Fig. 3c: Combined borehole litholog prescribed by CGWB near VES R33. Layer parameters are shown in VES interpretation for R29 to R38. Numbers in the left and right-hand side of the logs show depth from ground level (m) and true resistivity values (Ωm), respectively

Table 3: Aquifer parameters of the various sounding locations across the Central part of study area

VES No.	Aquifer thickness- b (m)	True resistivity- ρ(Ωm)	Transverse resistance-R (b*ρ)(Ωm²)	Hydraulic conductivity from pump-test (m day⁻¹)	A(constant) = Kσ= K/ρ	Calculated transmissivity – T = KσR (m² day⁻¹)	Calculated Hydraulic conductivity (m day⁻¹)
R8	182.2	50.2	9146.44	----	----	1809.16	09.929
R9	178.8	59.2	10584.96	11.24	0.1898	2093.70	11.709
R10	165.7	52.0	8616.40	----		1704.32	10.280
R11	169.6	50.3	8530.88	----	----	1687.40	09.949
R12	185.0	59.5	11007.50	----	----	2177.28	11.769
R13	185.4	61.7	11439.18	----	----	2262.66	12.204
R14	180.7	60.5	10932.35	----	----	2162.42	11.966
R15	183.1	62.4	11425.44	----	----	2269.95	12.342
R16	189.9	66.1	12552.39	----	----	2482.86	13.074
R17	178.2	57.1	10175.22	----	----	2012.65	11.294
R18	180.7	60.9	11004.63	----	----	2176.71	12.046
R19	183.4	61.9	11352.46	----	----	2245.50	12.243
R20	187.0	64.3	12024.00	13.23	0.2057	2378.34	12.710
R21	185.4	55.3	10252.62	----	----	2027.96	10.938
R22	202.5	61.4	12433.50	----	----	2459.34	12.144
R23	185.0	58.1	10748.50	----	----	2126.05	11.492
R24	211.4	68.6	14502.04	----	----	2868.50	13.569
R25	184.6	59.8	11039.08	----	----	2183.53	11.828
R26	181.0	53.9	9755.90	----	----	1929.71	10.661
R27	187.7	65.0	12200.50	----	----	2413.25	12.857
R28	171.6	50.9	8734.44	----	----	1727.67	10.068

interpretation of different VES curves for all locations are 187 and 354 m, respectively and resistivity values are ranging from 32 to 75.5 Ωm with average value of 52 Ωm.

Aquifer hydraulic conductivity and transmissivity: The Hydraulic conductivity (K) of aquifer can be obtained from Eq. 7 as shown below, even when no borehole pumping test data is available (Niwas and Singhal, 1981):

$$K = A\ (\text{Constant}) / \sigma \quad (7)$$

The A (Siemen/day) value for the whole Sagar Island is calculated from pumping test results near R9 (Gangasagar) and R20 (Rudranagar) (CGWB, 1994). Pumping test was carried out to determine certain parameters like Transmissivity and Permeability.

Transmissivity and Permeability values of the aquifer are determined, employing Jacob's straight line method for draw down data and Theis's recovery method for residual draw down data.

The average A (constant) value for the whole Sagar Island is 0.1978 Siemen/day for the same hydro-geological regime.

The computed K values are shown in Table 3 and the value varies between 9.92 m day^{-1} and 13.56 m day^{-1} and corresponding aquifer Transmissivity values are calculated for the all sounding locations using Eq. 6 and shown Table 3 for the same environment.

Calculated Transmissivity values in the whole study area vary between 1687 and 2865 $m^2\ day^{-1}$.

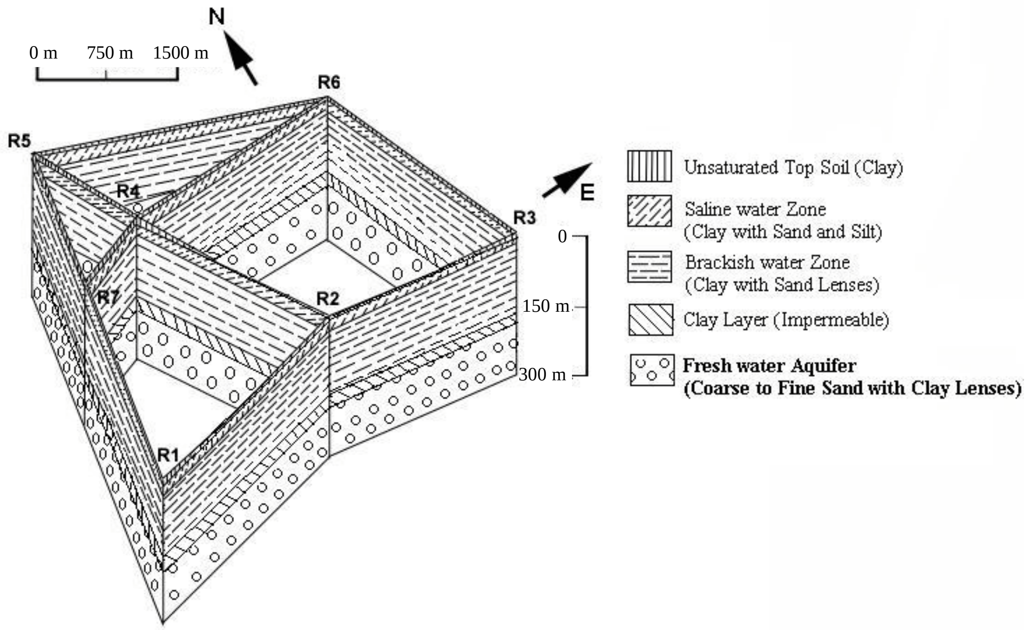

Fig. 4a: Fence diagram constructed from VES interpretations showing lithological and hydrological characteristics in the southern part of Sagar Island

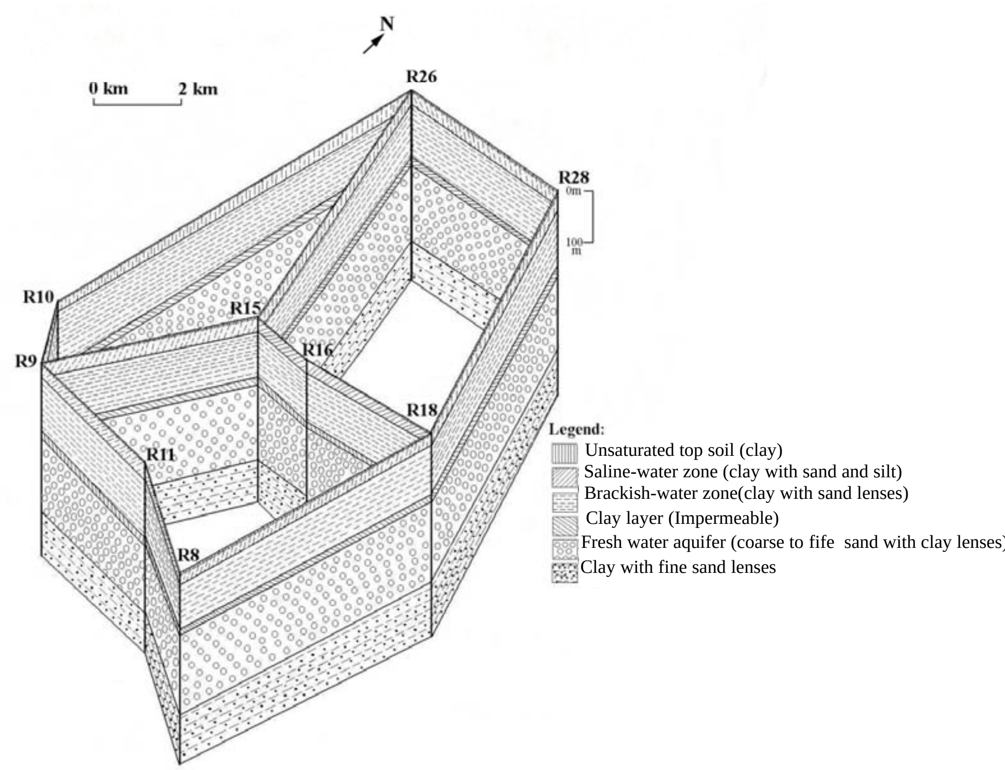

Fig. 4b: Fence diagram constructed from VES interpretations showing lithological and hydrological characteristics in the central part of Sagar Island

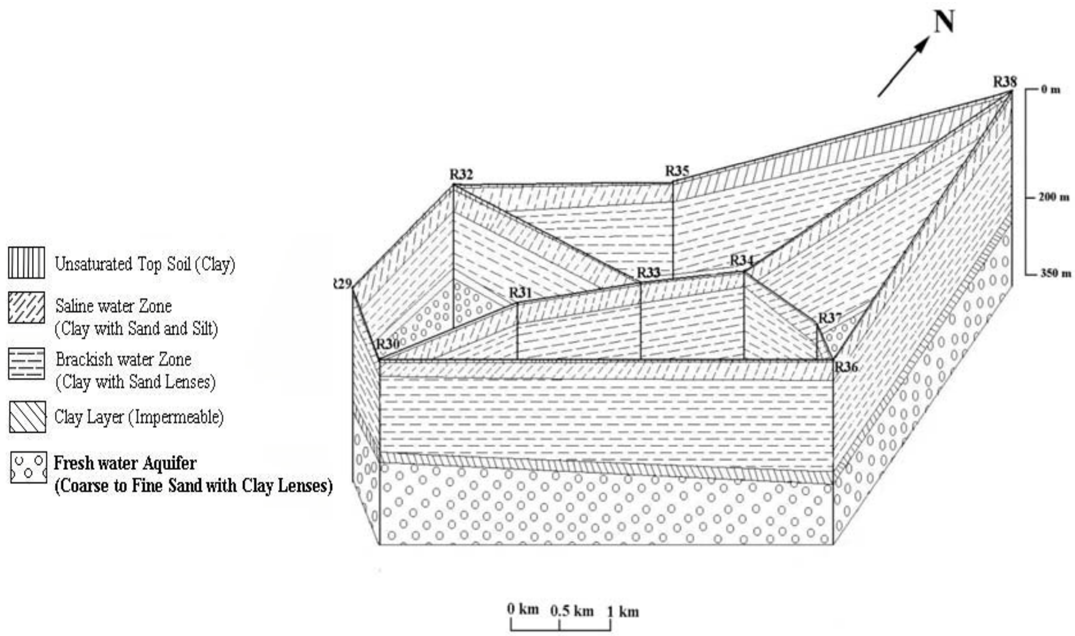

Fig. 4c: Fence diagram constructed from VES interpretations showing lithological and hydrological characteristics in the northern part of Sagar Island

RESISTIVITY CONTOUR MAPS AT DIFFERENT DEPTH LEVELS

The mean resistivity ρ_m is defined by,

$$\text{In}\rho_m = \frac{1}{Z_2 - Z_1}\int_{Z_1}^{Z_2} \text{In}\rho\ (Z)\ dz$$

where, (Z_2 - Z_1) are the depths to the lower and upper boundaries of the subsurface zone, where mean, resistivity is calculated, and ρ(Z) indicates the resistivity of the formation at a depth Z (Choudhury *et al.*, 2001).

Interpreted data from 38 sounding are utilized for the preparation of mean resistivity contour maps at the depth ranges 0-5, 5-30, 100-150 and 200-300 m (m) (Fig. 5), which bring out the horizontal extent of the saline water intrusion and fresh water aquifer zones.

Figure 5a shows the contour map of mean resistivity in the depth range of 0-5 m. It is interpreted that in the depth range of 0-5 m, the major part of the area is occupied by alluvium clay soil. But some parts of southeastern (Chemaguri and Sumutinagar) and Southern part (near Kapilmuni Ashram) of Sagar Island show little saline water intrusion due to presence of nearby river and sea, respectively.

Figure 5b shows the mean resistivity contour map in the range of 5-30 m. It shows entirely saline water formation with very low resistivity. Salinity is occurred due to infiltration of saline water by numerous canals and tidal creeks which carry saline water.

Figure 5c shows the mean resistivity contour map in the depth range of 100-150 m. The zone is characterized by resistivity more than 5 Ωm but less than 10 Ωm representing brackish water.

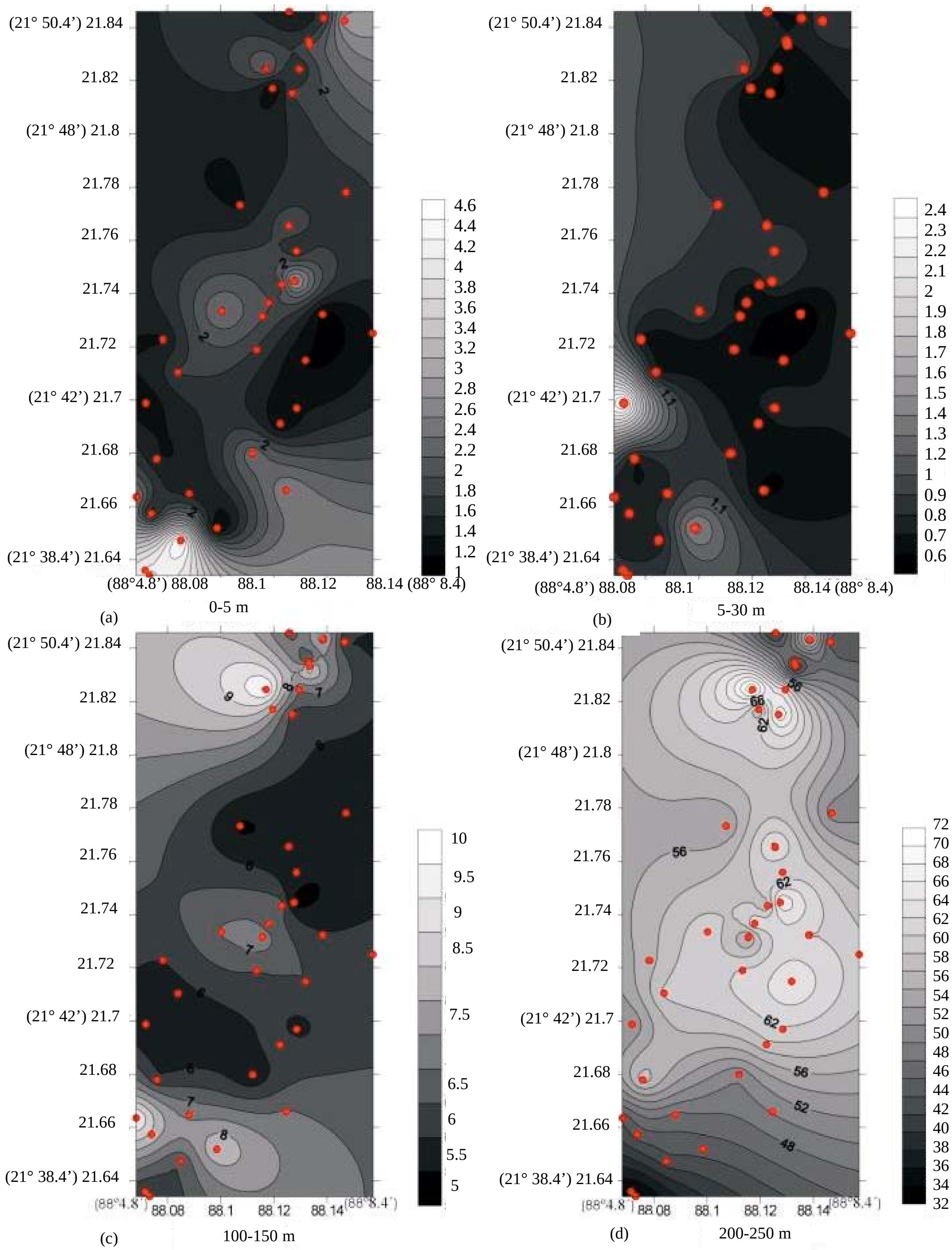

Fig. 5: Mean resistivity contour maps at different depth ranges in Sagar Island region

Figure 5d shows the mean resistivity contour map in the depth range of 200-3000 m which shows thick fresh water bearing saturated zone with resistivity values ranging from 32 to

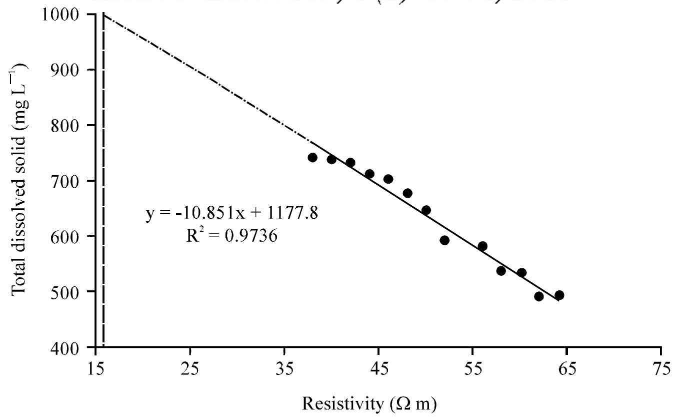

Fig. 6: Variation of TDS values of tube wells with the resistivity of the aquifer obtained from VES interpretations from the depth level of 200 to 300 m

75.5 Ωm. Southwestern (near R1 and R2) and Northeastern (near R38) parts show relatively low resistivity due to presence adjacent sea and river.

The optimum permissible value of TDS for drinking water from tube well is 1000 ppm (Klimentov, 1983; Todd, 1959) and there is an inverse relationship between TDS and resistivity.

In the present area of investigation, the TDS values of aquifer is ranging from 470 ppm near VES location R29 to 745 ppm near VES location R1. However one can calculate the limiting minimum value of resistivity of the aquifer for drinking purpose in similar hydrodynamic condition where permissible value of TDS is 1000 ppm.

The required minimum value of resistivity corresponding to the optimum TDS value of 1000 ppm can be obtained by plotting TDS values of different wells against the resistivity values obtained from resistivity contour (from depth level of 200 to 300 m) passing through or near the tube wells (Fig. 6).

Figure 6 shows that the required the minimum permissible resistivity value for drinking purpose is 16 Ωm.

So it is suggested that if the resistivity value of the aquifer obtained from VES interpretation is less than 16 Ωm, the water is unsafe for drinking purpose.

CONCLUSION

Following conclusions can be drawn from the above studies:

- Vertical electrical soundings (VES) have delineated the topsoil, the saline water zone, brackish ground water zones, impermeable clay layer, the fresh water aquifer and bottom (clay with fine sand and silt lenses) in subsurface geological formations
- VES findings show promising ground water bearing zones of 184 m average thickness (ranging from 175 to 190 m) at an average depth of 171 m. The potential groundwater-bearing zone is under confined condition and this zone can be tapped for drinking water purposes in central part of Sagar Island region
- A litho-resistivity relationship is established in the area of investigation and this can be used for finding the lithology of an unknown area under the similar hydrodynamic condition.
- Using VES studies aquifer Hydraulic Conductivity and Transmissivity can be calculated for any location in whole area or similar areas even when no borehole pumping tests data are available. In this investigation, the hydraulic conductivity value varies between 9.92 and 13.56 m day^{-1} and Transmissivity in the whole study area varies between 1687 and 2868 m^2/day

- The aquifer having resistivity value less than 16 Ωm from depth level 200 to 300 m should be avoided for drinking purposes

REFERENCES

Bhattacharya, P.K. and H.P. Patra, 1968. Direct Current Geoelectric Sounding Principles and Interpretation. Elsevier, Amsterdam, pp: 139.

CGWB, 1994. Hydrological atlas of West Bengal. Plate VIIB. Ministry of Water Resources, Govt. of India.

Chakrabarti, P., 1991. Morphostratigraphy of coastal quaternaries of west bengal and subarnarekha delta orissa. Indian J. Earth Sci., 18: 219-225.

Chakrabarti, P., 1992. Geomorphology and quaternary geology of Hooghly eatuary, West Bengal, India. Ph.D. Thesis, University of Calcutta.

Chakrabarti, P., 1995. Evolutionary history of the coastal quaternaries of the bengal plain, India. Proc. INSA, 61: 343-354.

Choudhury, K., D.K. Saha and P. Chakraborty, 2001. Geophysical study for saline water intrusion in a coastal alluvial terrain. J. Applied Geophys., 46: 189-200.

Das, S., 1991. Hydrological features of delta's of India. Mem. Geol. Soc. India, 22: 183-225.

Ekwe, A.C., K.M. Onuoha and N.N. Onu, 2006. Estimation of aquifer hydraulic characteristics from electrical sounding data: The case of middle imo river basin aquifers, south-eastern Nigeria. J. Spatial Hydrol., 6: 121-131.

Klimentov, P.P., 1983. General Hydrology. Mir Publishers, Moscow, pp: 97.

Koefoed, O., 1979. Geosounding Principles 1: Resistivity Sounding Measurements. Elsevier Science Publishing Company, Amsterdam, pp: 635.

Majumdar, R.K., N. Majumdar and A.L. Mukharjee, 2000. Geoelectric investigations in Bakreswar geothermal area, West Bengal, India. J. Applied Geophys., 45: 187-202.

Majumdar, R.K., A.L. Mukharjee, N.G. Roy, K. Sarkar and S. Das, 2002. Groundwater studies on south sagar Island region, South 24-Parganas, West Bengal. Proceedings of the International Conference on Water Related Disasters, December 2002, New Age International Publishers, Calcutta, India, pp: 175-183.

Majumdar, R.K. and S.K. Pal, 2005. Geoelectric and borehole lithology studies for groundwater investigation in alluvial aquifers of Munger District, Bihar. J. Geol. Soc. India, 66: 463-474.

Majumdar, R.K., A. Ghosh and D. Das, 2006. Geoelectric and geochemical methods for Hydrological characterization of southern part of Sagar Island, South 24 Parganas, West Bengal, India. J. Geophys., 27: 109-118.

Majumdar, R.K. and D. Das, 2007. Geoelectric and Geochemical studies for hydrological Characterization of Sagar Island region, South 24 Parganas, West Bengal, India. IAHS-AISH Publ., 312: 50-59.

Monteiro Santos, F.A., A. Afonso, A.R. and L.A. Mendes Victor, 1997. Study of the Chaves geothermal field using 3D resistivity modeling. J. Applied. Geophys., 37: 85-102.

Niwas, S. and D.C. Singhal, 1981. Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. J. Hydrol., 50: 393-399.

Olayinka, A.I. and A. Weller, 1997. The inversion of geoelectrical data for hydrological application in crystalline basement areas of Nigeria. J. Applied. Geophys., 37: 103-115.

Onuoha, K.M. and F.C.C. Mbazi, 1988. Aquifer Transmissivity from Electrical Sounding Data: The Case of Ajali Sandstone Aquifers South West of Enugu, Nigeria. In: Ground Water and Mineral Resources of Nigeria, Ofoeglu, C.O. (Ed.). Vieweg-Verlag, Nigeria, pp: 17-30.

PHED, 1987. Unpublished borehole data by public health engineering department. Government of West Bengal, India.

Pal, S.K. and R.K. Majumdar, 2001. Determination of ground water potential zones using iso-resistivity maps in alluvial areas of Munger district, Bihar. J. Earth Sci., 1-4: 16-26.

Paul, A.K. and M.K. Bhandyopadhyay, 1987. Morphology of Sagar Island, a part of Ganga delta. J. Geol. Soc. India, 29: 412-423.

Roychoudhuri. M.K., 1974. Geology and mineral resources of the States of India, Part-I, West Bengal. Geol. Surv. India Misc. Publ., 30: 1-30.

Stewart, M., M. Layton and T. Lizanec, 1983. Application of resistivity surveys to regional hydrologic reconnaissance. Ground Water, 21: 42-48.

Todd, D.K., 1959. Ground Water Hydrology. Willey, London, pp: 185.

Velpen, B.P.A.V., 1988. A computer processing package for D.C. resistivity interpretation for an IBM compatibles. ITC J., Vol-4, The Natherlands.

Yadav, G.S. and H. Abolfazli, 1998. Geoelectrical sounding and their relationship to hydraulic parameters in semiarid regions of Jalore, northwestern India. J. Applied Geophys., 39: 35-51.

Zohdy, A.A.R., 1976. Application of surface geophysics (Electrical methods to groundwater investigations) in: Techniques for water resources investigations in the United States. Section D, Book 2., pp: 5-55.