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Geoelectric Resistivity Survey for Suitable Freshwater Aquifer Identification in the Coastal Belt of South-West Bangladesh

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Bangla Desh
Coastal Belt
Hydrogeology
Hydrochemistry
Geoelectric Resistivity

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Geoelektrische Widerstandsuntersuchungen zu Trinkwassersuche im Küstengürtel von SW-Bangladesh

Zusammenfassung

Das Küstengebiet der Republik Bangladesch, es stellt 30 % der kultivierbaren Fläche des Landes dar, wird landwirtschaftlich wenig genutzt. Der Anbau von nutzbaren Planzen hängt in der Trockenzeit von der Verfügbarkeit von Süßwasser für die Bewässerungsanlagen ab, weil die Oberflächenwässer während des gesamten Jahres brackig sind. Tiefengrundwässer stellen die einzige Quelle für die Bewässerung und für Süßwasserversorgung der Bevölkerung dar. Es wurde daher im südwestlichen Küstengebiet (Satkhina Distrikt) in einer ersten Erkundungsphase geoelektrische Tiefensondierungen zur Abgrenzung des Süßwasserkörpers im Untergrund durchgeführt. Das Untersuchungsprogramm hat gezeigt, daß einerseits der Aufbau der Sedimentfolgen sowie andererseits die Wasserqualität sehr heterogen ist, sowohl in horizontaler als auch in vertikaler Erstreckung.

Abstract

Bangladesh coastal area, constituting over 30 % of the cultivable lands, is poor in agricultural land use. Crop cultivation on the land dependent upon the availability of irrigation water during the dry months and as the surface water is saline throughout the year, groundwater is the only source of freshwater for irrigation and drinking purposes. Geoelectric resistivity sounding survey has been carried out in the south-west coastal belt in Satkhira district as a reconnaissance survey for the demarcation of suitable freshwater zones in the subsurface. The study indicates the heterogeneity of the subsurface sediments and changes in water quality in both, vertical and horizontal direction. Geoelectric resistivity survey has proved to be effective in identifying the possible zones of freshwater bearing formations providing the opportunity to minimise the number of test drillings.

1. Introduction

Over 30 % of the cultivable lands of Bangladesh is situated within the coastal belt. Agricultural land use in these areas is very poor and is much lower than the country's average crop intensity. Much of the lands in the coastal belt has been reclaimed or protected from flooding of saline estuary water by embankments and polder construction. During the summer months crop cultivation on the lands with residual saline soil is dependent upon the avail-

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ability of irrigation water. As the surface water is saline throughout the year, groundwater is the only source of freshwater for irrigation and drinking purposes.

Coastal tracts are endowed with prolific aquifers in coastal and deltaic sediments. These aquifers extended in lands from a few kilometres to tens of kilometres. Quality of groundwater in the coastal tract is, in general, poor and even sometimes beyond potable limits. It is a considerable hurdle to the socio-economic development in the area and freshwater investigation through modern geophysical techniques is imperative.

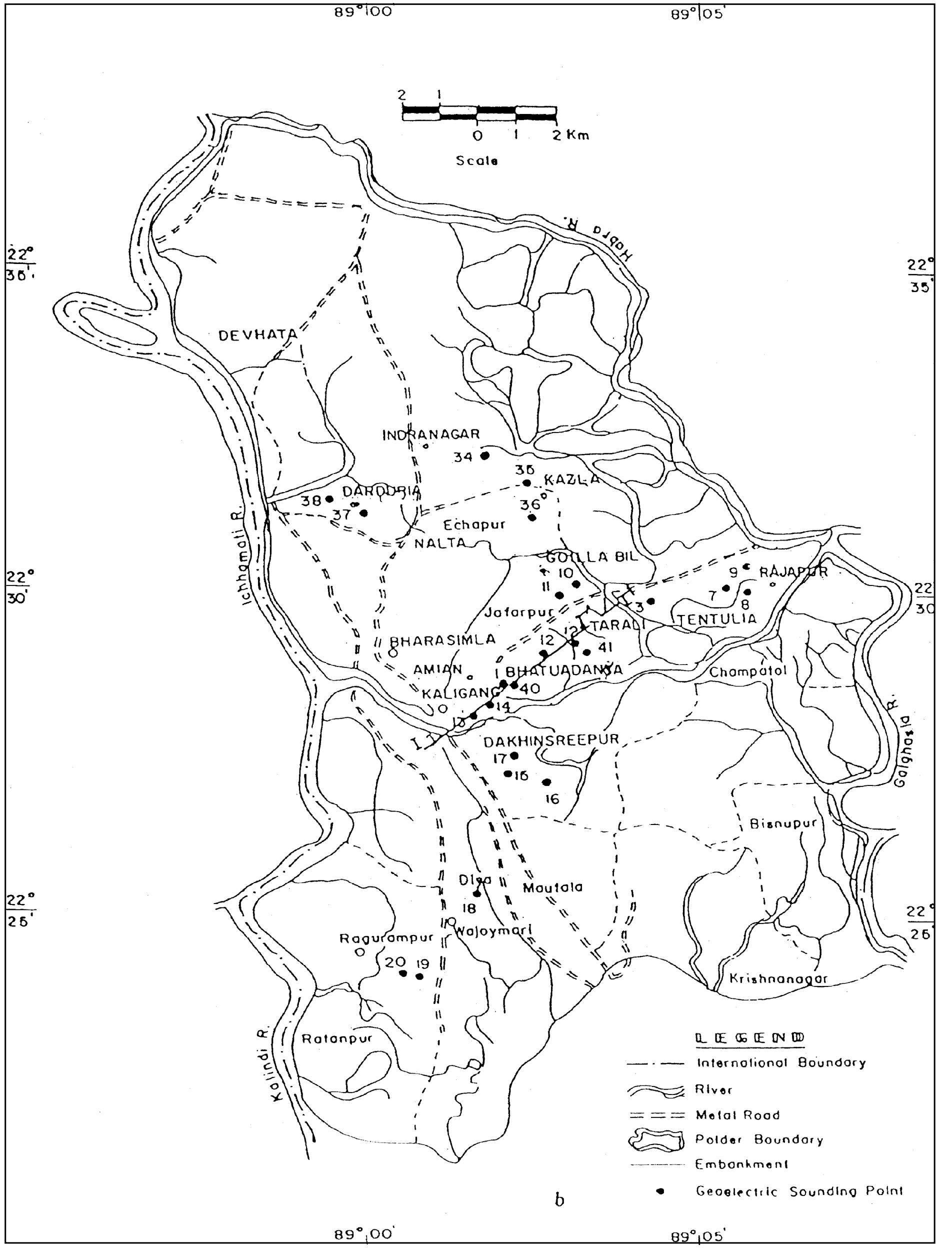
The normal practice in Bangladesh is to sink boreholes to locate water bearing formations. However, being a non-economic endeavour, as the results are not always favourable alternative modern geophysical methods have to be applied to decipher the hydrogeological and hydrochemical situation. Many geophysical methods find application in locating and defining subsurface water resources. The geophysical survey minimise the number of necessary exploration wells to be sunk for both aquifer tests and control of geophysical interpretation. The most widely used geophysical methods in hydrogeology are methods employing artificial electric sources (BUGG & LLOYD, 1976; SERRRES, 1969; WORTHINGTON, 1977; ZOHDY, 1969). The surface geoelectric resistivity method is a tool uniquelly suited to ground water exploration in the coastal zone and its capapility to detect changes in pore-water conductivity makes its highly responsive to the fresh-water / salt-water interface to be found in coastal regions, (URISH & FROHLICH, 1990; GONDWE, 1991; EL-WAHEIDI et al., 1992). The resistivity method is fast, cheap and provides adequate depth penetration and qualitative results (KELLER & FRISCHNECHT, 1966; ZAKHAROV, 1982). The applicability of geoelectrics, here: resistivity methods, for dealing with hydrogeological problems is based on the marked contrast in electrical conductivities between sandy-gravely permeable beds and clayey-silty impermeable sediments. Geoelectric resistivity surveys are carried out in the area to delineate the aquifers at various depths, to asses the water quality and to demarcate the suitable locations for test drillings.

2. The Location and Geology of the Area

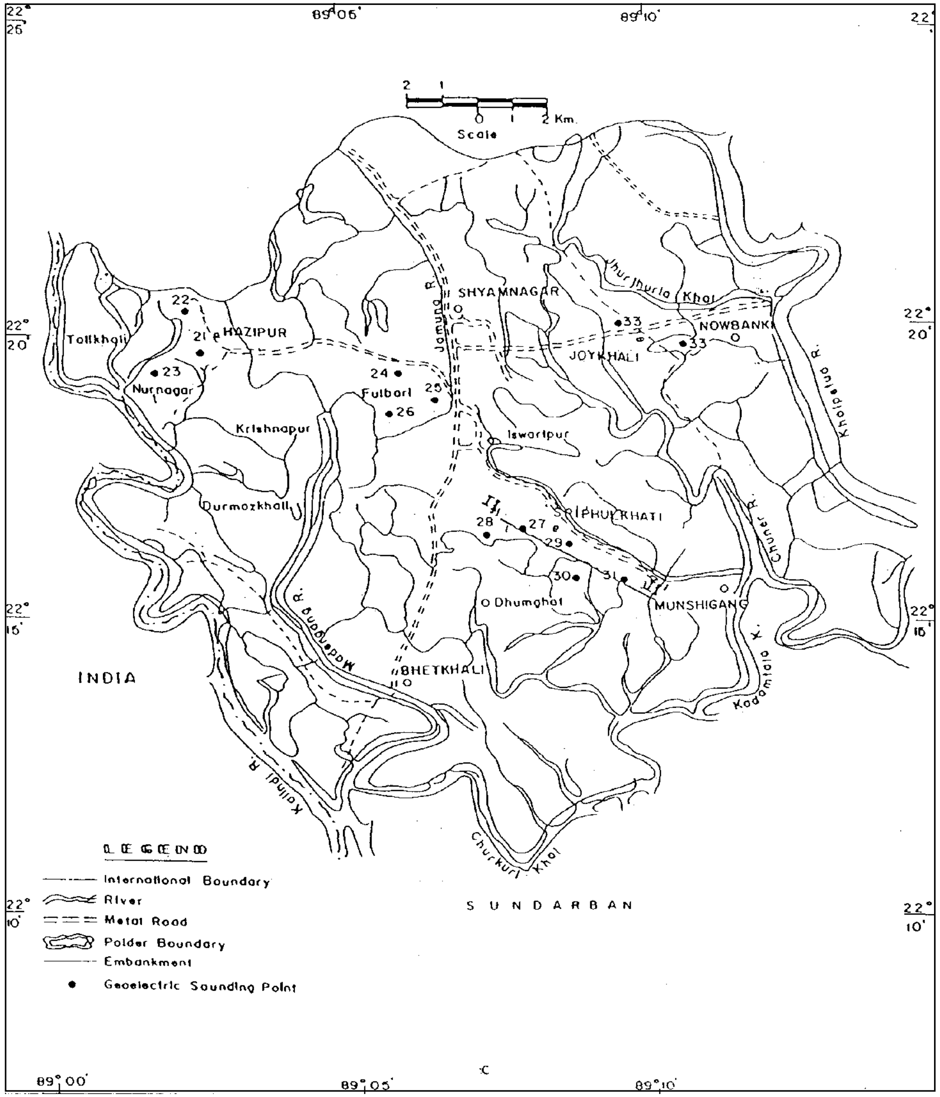
The study area includes the coastal belt of south-western Bangladesh covering Kaliganj, Assasuni and Shyamnagar Thanas of Satkhira District (Figs. 1–3). The area is characterised by monsoonal climate where the mean annual rainfall is about 1800 mm. About 80 % of the rainfall occurs in the monsoon months with almost no rainfall during the winter times. The rivers give rise to an overall dendritic pattern and control the hydrological regime of the study area. Much of the cultivable lands in the area have been reclaimed from estuary saline water flooding by coastal embankments and polder construction. The main crop in the area is transplanted Aman rice. Apart from crop cultivation, saline water shrimp cultivation is in use.

The geology of the coastal area is part of the overall Quaternary geology of the Bengal Basin (BAKR, 1976; MORGAN & MCINTIRE, 1959). Sediments from

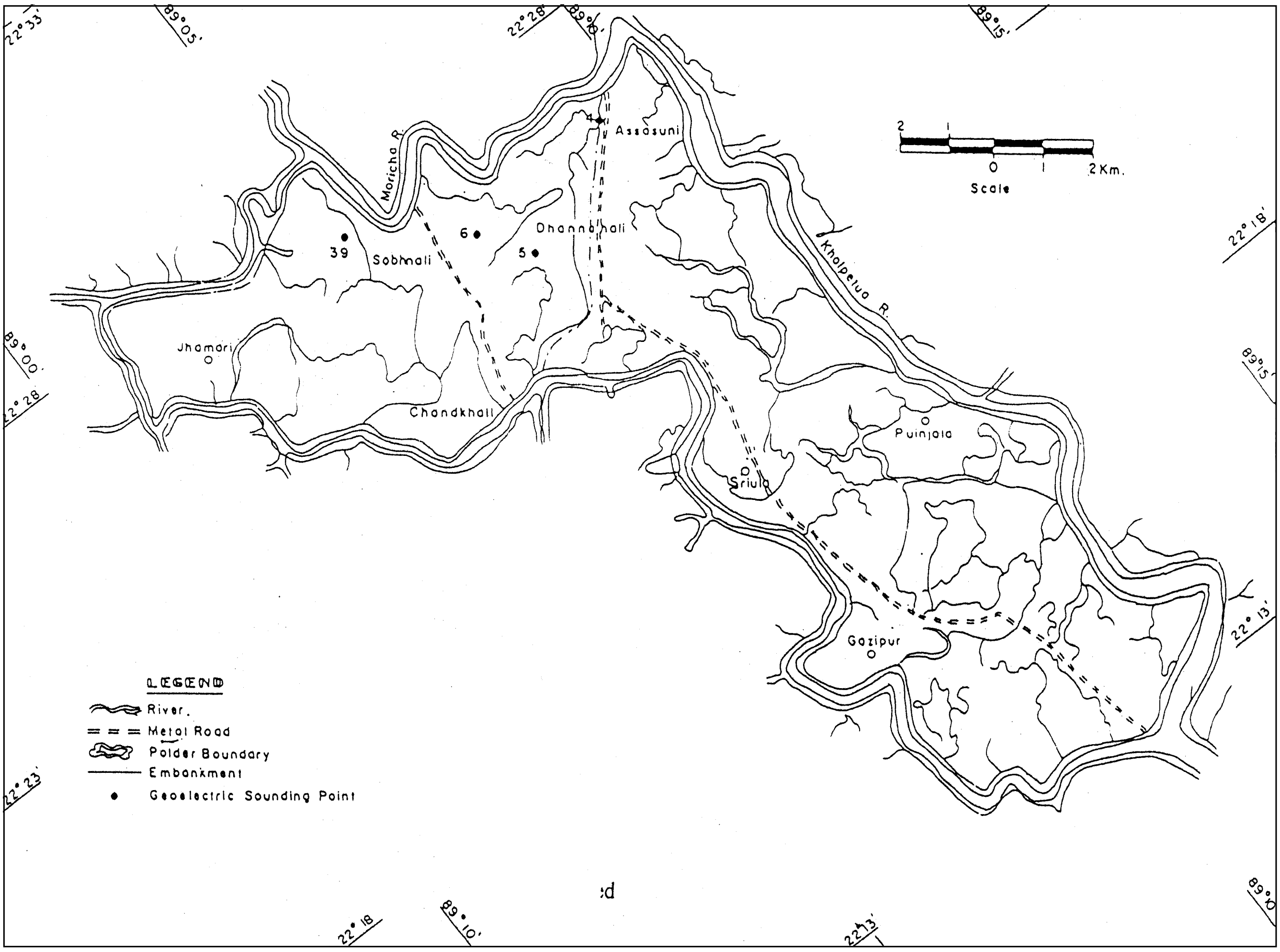
Text-Fig. 1.
Location map of the survey area.



Text-Fig. 2.
Map showing the sounding point locations in Kaliganj upzila.

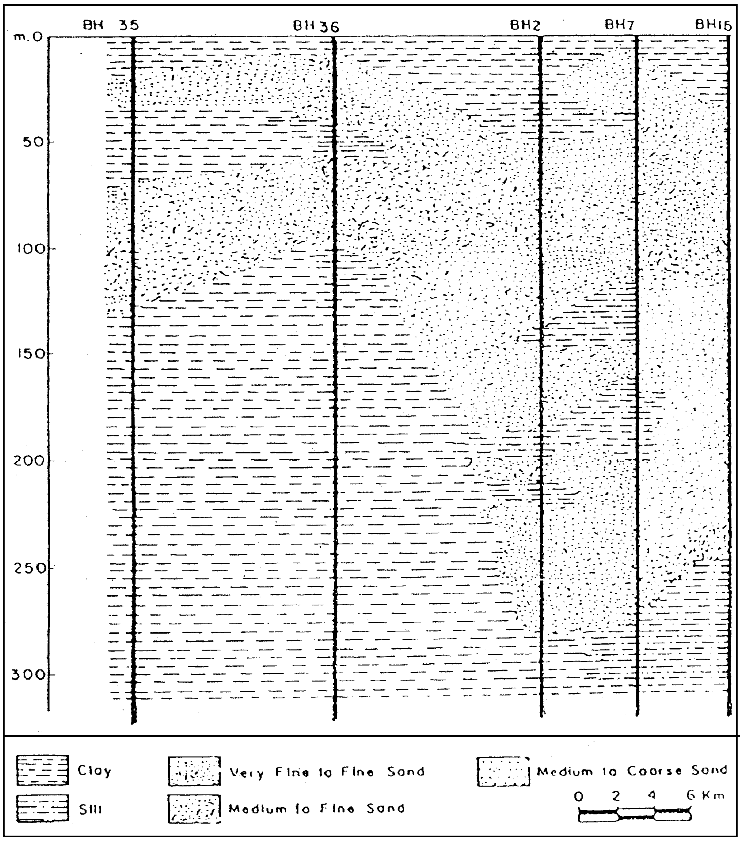


Text-Fig. 3.
Map showing the sounding point locations in Shyamnagar upzila.



Text-Fig. 4.
Map showing the sounding point locations in Assasuni upzila.

early Ganges-Brahmaputra-Meghna river systems were deposited over the northern and eastern parts of the basin during Pleistocene period. Tectonic movements and sea level changes between Pleistocene and recent periods have allowed deep erosion and deposition on the Pleistocene surface. Fluviatile environment of sedimentation in the southern downward area of Bengal Basin formed overlapping deltaic arcs of Ganges-Brahmaputra-Meghna river systems in recent time. The coastal belt of Khulna-Satkhira is within Ganges delta. Floodplain sediments in Satkhira coastal belt, according to borehole information drilled in the area up to a depth of 300 m, are mainly composed of medium and fine sands, clay, silty clay and sandy clay units (Fig-5). A continuos clay-silty clay layer of varying thickness from few centimeter to 50 m occurs at the top. This top clay layer is underlain by medium to fine sand, silty sand and sandy clay alternations and is followed by a clay, silty-sandy clay layer occurring at different depths ranging from 75 to 270 m. The lower boundary of this regionally extending clay layer has not been penetrated by boreholes.



Text-Fig. 5.
A geological cross section along profile C-C'.

3. Hydrogeology and Hydrochemistry of the Area

In the coastal belt of Khulna-Satkhira hundreds of tube wells have been developed under the supervision of the Department of Public Health and Engineering (DPHE) for water supply. Drillers log shows no regular or sequential succession in the area, rather it shows a heterogeneous mixture of clay, silt and sand.

The topmost zone is a predominantly clay layer with varying thickness (Text-Fig. 5). This clay layer is followed by a complex mixture of medium and fine sands, silts and clay and can be considered as one complex semiconfined aquifer.

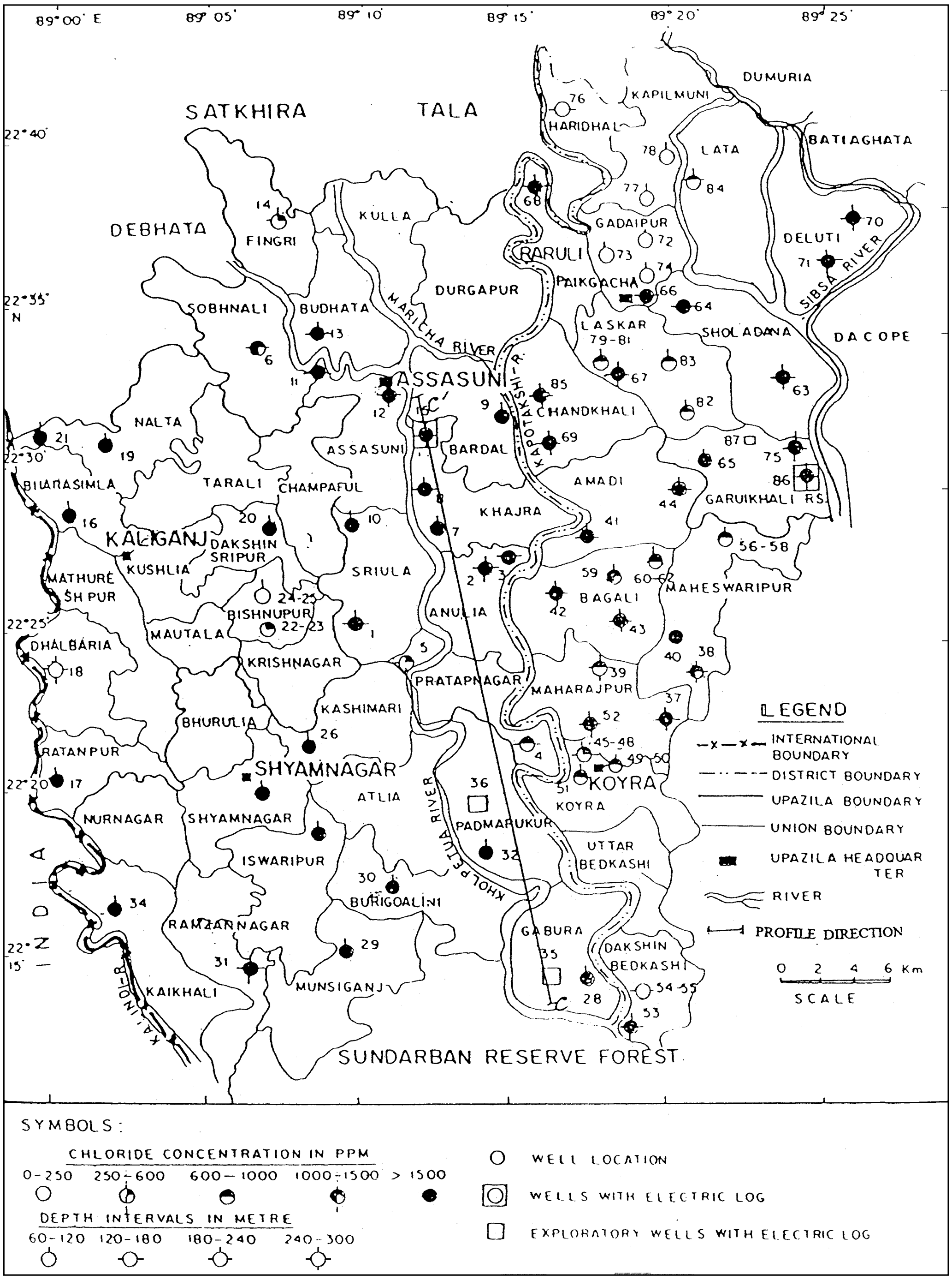
This shallow aquifer is made up of sand lenses at multiple levels interbedded with silts and clays, but over large areas there is sufficient overlapping and intersection of sand lenses to consider this as one complex hydraulic unit. There is considerable lateral variation in the thickness of these sediments which is characteristic to the deltaic sediments.

This permeable zone is underlained by the lower confining clay, silty-sandy clay bands. The base of this zone is not penetrated in any of the drill holes in the study area where the drilled thickness varies from 30 to 125 m.

The salinity of the abstracted groundwater in the study area is extremely variable and changes rapidly over short distances (Bangladesh Water Developmenl Board, 1978; Samad, 1986). Water from the shallow aquifer is, normally, too saline for domestic or irrigation use.

However, some isolated pockets, where sufficient flushing has taken place to remove the saline water, serve as a limited source of freshwater for domestic uses. The flushing action mainly takes place during the monsoon time by the lateral infiltration of freshwater from the river into the shallow aquifer (Hyde, 1979; Morton & Quamruzzaman Khan, 1979). A vertical study of water quality from the shallow aquifer shows that within 120 m depth range, chloride concentration over most of the area is above 1500 ppm except a few patches of areas (Woobaidullah, et al., 1994) (Text-Fig. 6).

The deep aquifer which occurs beneath most of the area is confined and protected from vertical leakage of saline water by thick overlying clay layer. The abstracted water from the deep aquifer occurring beneath the lower thick clay zone in most of the coastal areas of Patuakhali, Noakhali and Chittagong is fresh. Recharge of this deep aquifer occurs mostly by vertical percolation of freshwater in areas north of the coastal zone where the overlying confining bed is absent and out of reach of surface flooding by saline water



Text-Fig. 6.
Map showing the chloride concentration with depth of the study area.

(Bangladesh Water Development Board, 1978). However, this deep aquifer has not been penetrated by the drill holes in the study area.

4. Subsurface Resistivity Characteristics from Electric Log

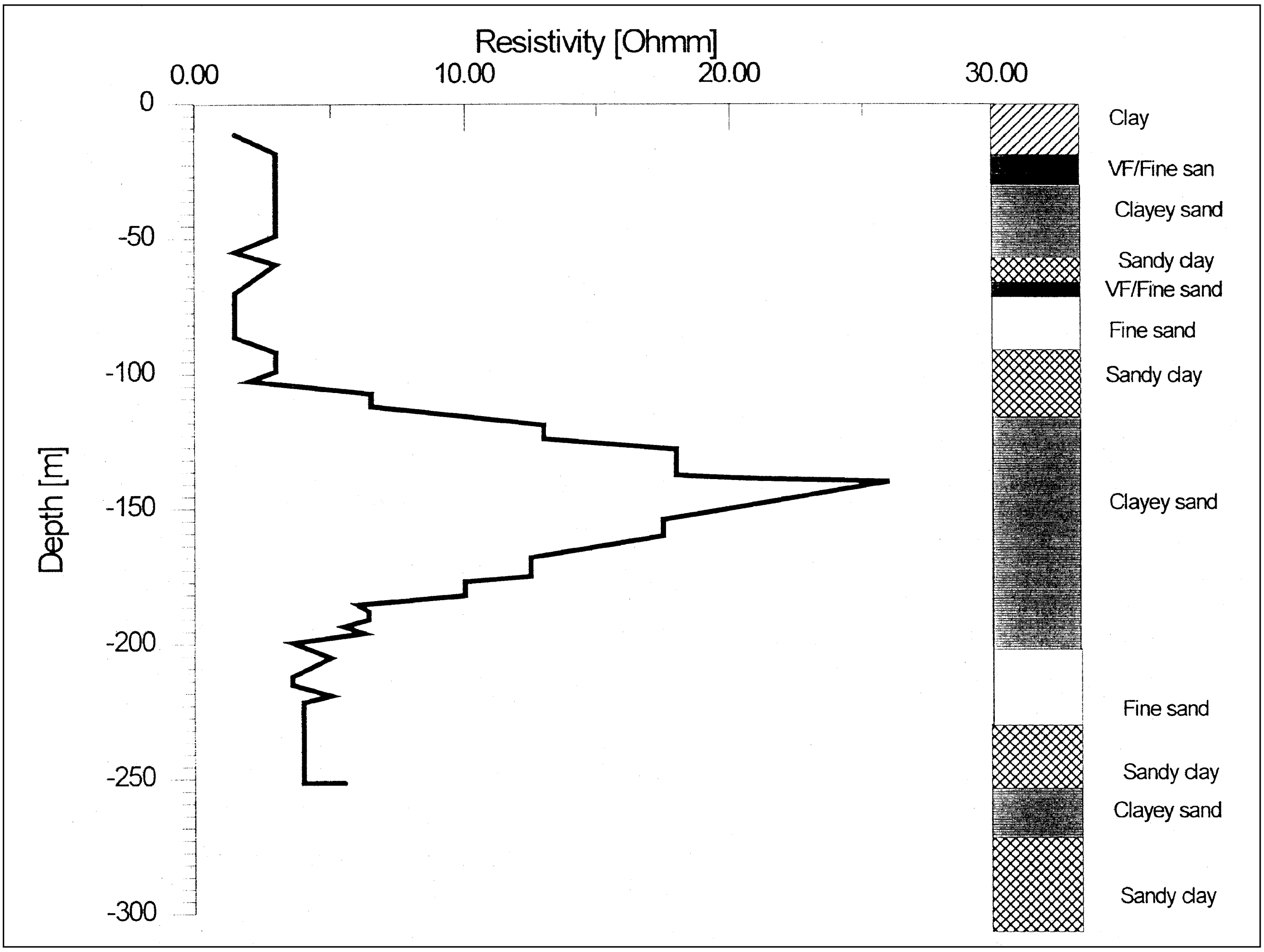
The resistivity of formations depends mainly on the rock type, porosity, nature of pore filling and on the formation factor. The sediments up to 300 m (maximum drilled depth) consist of clay, silt and sands of various grain sizes. The resistivity of these sediments is controlled by the amount and mineralization of pore fluids contained in them. Clays and silts, normally rich in water soluble minerals, have low resistivity even if the water content is low. The clayey and silty sediments are characterized by a resistivity range from 1 to 15 Ω, depending on the porewater mineralization and presence of sandy materials. The conductivity of sands and gravels is mainly due to the presence of water in the pore spaces as they are composed of electrically non-conducting minerals. Sands occurring above the groundwater level show high resistivity values and below the water table the values depend on the nature of the contained water. Sand may show resistivity in the range of clays when the pore space water is highly mineralised. In the case of fresh or brackish water sand shows higher resistivity than shale (Keller & Frischnecht, 1966; Rider, 1986).

DPHE as to resistivity and SP logs at three bore holes in the study area. These logs in the study area show that the resistivity responses are governed by water quality of the formations and the same formation shows different resistivity responses depending on the pore water mineralization in the formation. The influence of lithological changes on resistivity log is less compared to the influence from porewater mineralization changes.

The resistivity log at Napitkhali, Shyamnagar, (Text-Fig. 7) up to a depth of 110 m shows the resistivity within the range of 1.5 to 3.0 Ω against clay, sandy clay, very fine and fine sand lithologies. It is very difficult to distinguish between clay, sandy clay and sand layers from resistivity logs, as the water in this depth range is saline. At a depth of 110 m a sudden increase of resistivity reaching up to 28.0 Ω is observed and continues to a depth of about 185 m with an average resistivity value of 20.0 Ω against a sand / or clayey sand sequence. The water from this depth is fresh to brackish. Just below this comparatively high resistive zone a layer of fine sand occurs with a thickness of 30 m. The log response is low in the range of 4.0 Ω reflecting the water quality as saline.

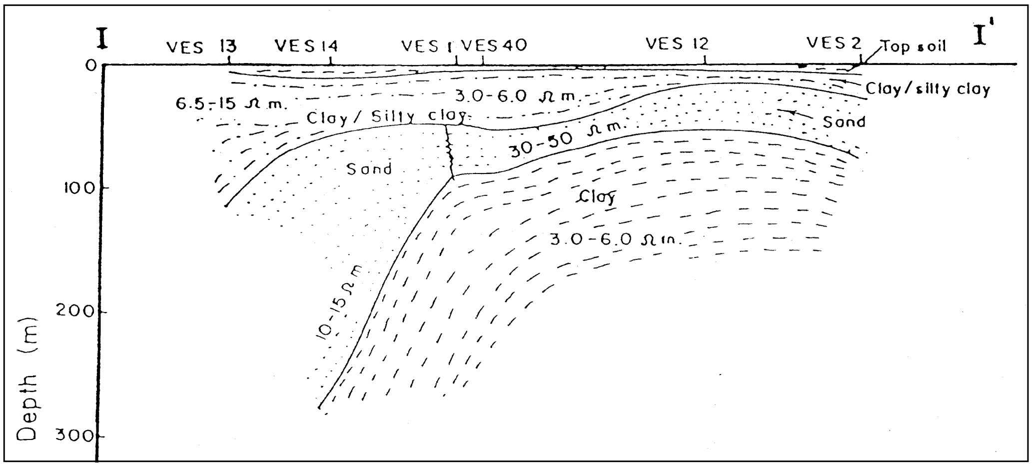
5. Geoelectric Resistivity Soundings

The resistivity method for dealing with hydrogeological problems is based on the differences in electrical conductivities between permeable beds and low permeable



Text-Fig. 7.
An electric log at Napitkhali, Gabura, Shyamnagar upzila.

Text-Fig. 8.
A geoelectric section along profile I-I in Kaliganj upzila.



clayey beds. The water of the pore filling acts as electrolytes and the resistivity of the water bearing formations thus depends on the quality and the spacial distribution of the groundwater (KEAREY & BROOKS, 1984).

In geoelectric resistivity sounding measurements, normally, a direct current is sent into the earth through two current electrodes and the potential difference produced as a result of current flow is measured with the help of another pair of potential electrodes at the surface.

The magnitude of potential difference is closely related to the current distribution in the underground. For a series of increasing electrode separations at a certain measuring point, the apparent resistivity values are influenced more and more by the specific resistance of deeper layers. The calculated resistivity, from the measured potential difference Δ, amount of current I and the electrode configuration, is called apparent resistivity ρ_a and for SCHLUMBERGER array where the current electrode separation is much more compared to potential electrode separation, the following equation is used to calculate apparent resistivity.

$$\rho_a\left(\frac{L}{2}\right) = \frac{\pi\left(\frac{L}{2}\right)^2 - \left(\frac{l}{2}\right)^2}{l} \times \frac{\Delta V}{I} \qquad (1)$$

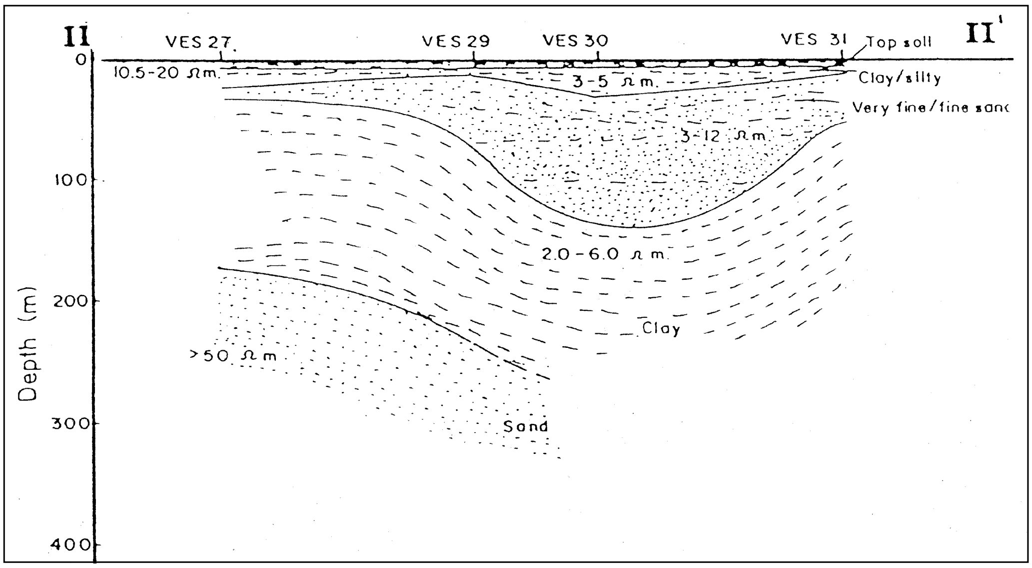
with L/2 half of the current electrode separation
l/2 half of the potential electrode separation

A McOHM -produced (Model 2115) by Digital Electrical Prospecting System/Japan was used to collect the data. A McSeis software package XTS-15, GRIVEL was used to process the raw-data. This software package has the flexibility to choose between a manual fitting MARQUARDT algorithm of a theoretical sounding curve to the field dadata and an automatic fitting of model parameters through DAR-ZARROUK functions. In this technique, the field data are compared with the data computed from approximated layered models. If the agreement between two sets of data is unsatisfactory, then the parameters of the layered model is adjusted. The adjustment procedure is repeated until sufficient agreement between the computed data and observed data is obtained. In our case, the initial layered model parameters are obtained by partial curve matching technique (BHATTACHARYA & PATRA, 1968). These manually computed layered parameters are fed into the computer to match the field data. The adjustments of the parameters are also done manually. But during optimisation care should be taken so that the parameters did not cross the practical limit.

6. Results and Discussions

The sediments comprising the study area are clays, silts and sands of various grain sizes. The resistivity of these sediments is determined mainly by the amount and mineralization of the fluids contained in the pore spaces.

Clays and silts normally have low resistivities compared to sands. In the study area clayey and silty sediments show resistivities in the range of 1 to 15 Ω depending on the quality of the porewater and inclusion of sandy materials. The conductivity of sands and gravels is mainly due to movements of ions present in the intergranular water and the resistivity of sands and gravels is thus controlled by the volume of water present and will decrease as the salinity of the water increases. Consequently, in an homogeneous aquifer, it is possible to distinguish fresh from saline groundwater and even to trace the subsurface flow of con-



Text-Fig. 9.
A geoelectric section along profile II-II in Shyamnagar upzila.

Table 1.
Interpretation Results of Sounding Curves at Kaliganj.

Sounding No.	Thickness (m)	Resistivity (Ωm)	Sounding-No.	Thickness (m)	Resistivity (Ωm)	Sounding-No.	Thickness (m)	Resistivity (Ωm)
1.Amian	1.2 36.0 48.8 ---	9.0 4.0 45.0 4.0	12 Batuadanga	1.o 1.5 17.5 90.0 ---	6.7 3.0 50.0 4.0 15.0	20.Minhazkathi	1.0 11.0 83.0 ---	11.0 9.5 4.5 14.0
2.Tarali	1.8 18.2 50.0 ---	11.0 6.0 30.0 3.0	13 Mirzapur	1.7 108.0 ---	10.6 4.7 15.0	34. Indranagar	0.9 7.1 42.0 ---	10.0 4.2 30.0 7.0
3.Tarali	0.7 2.3 84.0 ---	13.0 4.0 30.0 4.0	14 Narayanpur	0.8 15.0 275.0 ---	15.4 4.4 10.8 5.0	35.Kazla	0.3 7.1 53.0 120.0 ---	10.1 8.3 24.0 5.0 17.0
7 Tetulia	1.4 4.6 93.0 ---	6.0 3.8 8.0 12.0	15. Kashempur	0.9 1.9 45.0 117.0 ---	17.5 6.3 10.0 4.1 18.0	36.Kazla	1.04 50.0 ---	16.4 25.0 6.7
8 Tetulia	13.0 35.0 102.0 ---	5.8 3.0 30.0 5.0	16. Kashempur	0.55 29.45 17.0 ---	19.0 9.6 25.0 5.9	37.Nalta	1.96 38.0 152.0 ---	25.7 6.2 19.3 6.0
9. Rajapur	1.0 13.0 66.0 120.0	8.0 4.5 15.0 3.0 9.0	17.Kashempur	0.70 29.0 20.0 ---	21.0 7.6 28.0 5.0	38.Shehara	1.1 12.1 159.0 ---	15.3 7.1 14.8 8.0
10.Tarali	1.2 8.8 190.0 ---	10.5 9.0 4.0 50.0	18.Diyacharar Bil	0.88 26.12 148.0 ---	13.5 11.5 3.2 60.0	40.Amian	1.2 52.5 27.0 ---	15.0 4.0 45.0 6.1
11.Tarali	0.75 1.75 11.50 288.0 ---	12.0 7.8 30.0 6.5 45.0	19.Raghurampur	0.9 24.0 83.0 ---	14.6 12.7 2.8 62.0	41.Tarali	1.1 15.9 103.0 ---	6.5 4.0 30.0 3.5

taminated groundwater resulting from pollution if the polluted water has a distinctive resistivity. In case of fresh or brakish intergranular water sands show higher resistivity than shale.

To assess the water quality from the interpreted resistivity values a simple equation relating the resistivity of the formation water ρ_w to the defined resistivity ρ occurs

$$\rho = F\rho_w$$

where, F is the formation factor and depends upon the rock textures or the geometry of pore space and pore connection.

For the loose, unconsolidated recent sediments of clay, silts and sands F varies from 1 to 6. From the knowledge of formation factor, it is possible to judge the water quality

Table 2.
Interpretation Results of sounding curves of Shyamnagar.

Sounding number	Thickness (m)	Resistivity (Ωm)	Sounding number	Thickness (m)	Resistivity (Ωm)
21. Hazipur	1.5	8.5	27.Sriphulkathi	1.5	19.2
	25.0	4.3		13.5	4.0
	44.0	15.0		12.5	12.6
	---	3.5		167.0	3.2
				---	50.0
22.Anantapur	0.5	9.7	28.Sriphulkathi	1.4	12.4
	5.5	3.5		73.5	3.4
	70.0	16.3		---	5.9
	---	3.7			
23.Tungipur	2.0	14.5	29.Sriphulkhati	1.6	14.0
	9.0	4.2		4.7	4.0
	21.0	20.0		31.0	3.0
	---	4.5		100.0	5.2
				---	45.0
24.Mahmudpur	1.2	7.2	30.Sriphulkathi	1.4	10.2
	10.0	10.8		27.0	3.1
	100.0	6.8		204.0	8.3
	---	15.0		---	2.0
25. Mahmudpur	0.5	27.0	31.Sriphulkhati	1.0	12.5
	0.5	2.8		1.9	6.8
	48.0	9.1		46.0	2.8
	156.0	4.6		---	6.8
	---	24.2			
32. Atulia	0.8	7.0	33. Joykhal	1.2	9.0
	4.5	3.6		10.0	4.6
	7.5	43.6		80.8	10.7
	19.6	2.3		---	5.6
	---	17.0			

from the interpreted resistivity values of the sounding curves.

The geoelectric measurements in the study area reflect the variability of the subsurface conditions over distances. The sounding curves differ in shape and their extreme positions. Most of the curves are of four layer HK ($\rho_1 > \rho_2 < \rho_3 > \rho_4$) types. Some four layer HA ($\rho_1 > \rho_2 < \rho_3 < \rho_4$) type, three layer H ($\rho_1 > \rho_2 < \rho_3$) and K ($\rho_1 < \rho_2 > \rho_3$) types and five layer HKH ($\rho_1 > \rho_2 < \rho_3 < \rho_4 > \rho_5$) type curves are also found. Curve type reflects the subsurface geoelectric sequence.

At Amian of Kaliganj Thana two soundings (VES 1 & 40) were executed. (Table-I). The sounding curves are almost identical and of HK type. The third of the four layer sequence show a resistivity in the range of 45 Ω. This layer might be a freshwater zone occurring at a depth of 37 to 54 m from the surface with a thickness varying from 49 to 27 m. A zone of fresh/brackish water may occur at a depth range of 5 to 80 m at locations of VES 2 & 3 (Tarali), VES 12 (Batuadanga) and VES 34 (Indranagar). A deep freshwater-bearing zone at a depth of 110 m and above is possible to occur at locations of VES 11 (Tarali North), VES 18 (Diya-chara Bil) and at VES 19 (Raghurampur). The sounding curves at other sites of Kaliganj show no suitable zone for freshwater occurrence.

In Shyamnagar the sounding curves VES 21, 22 and 23 are located at Hazipur, Anantapur and Tungipur of Nurunagar union (Table-II). The curves are of HK type. Interpretation of the sounding curves in the union showed a maximum resistivity of 20 Ω.Sounding curves at Mahmudpur (VES 24, 25 and 26) show almost straight lines with less fluctuation in the resistivity values. Right hand portion of the curve shows maximum resistivity of 24 Ω. The sounding curves (VES 27, 28, 29, 30 and 31) at Sriphulkathi are three layer H type in nature except VES 27 which shows an intermediate increase in resistivity giving the curve HKH shape.The interpreted resistivity values (Table II) are low. However, there is an increase in resistivity values at maximum current electrode separation (AB/2 = 400 m) at location of VES 27, 29 (Table II). Interpretation of sounding curves (VES 32 and 33) at Atulia also gives low resistivities.

The possibilities of freshwater occurrence in the investigated areas of Shyamnagar Thana within the penetrated depth is minimum.

Table 3.
Interpretation Results of Sounding Curves of Assasuni.

Sounding Number	Thickness (m)	resistivity (Ωm)	Sounding Number	Thickness (m)	Resistivity (Ωm)
4. Srikalas	0.8	6.0	6.Shobnali	1.0	10.5
	9.2	4.0		0.6	6.8
	90.0	8.0		7.2	19.0
	---	5.0		33.0	7.8
				98.0	18.0
				---	6.0
5.Dhannahati	1.0	16.0	15. Shobnali	1.3	13.0
	10.0	23.0		2.1	23.0
	89.0	15.0		12.0	20.4
	---	9.0		70.5	16.4
				---	8.0

Four soundings (VES 4, 5, 6 and 39) were executed in Assasuni at different locations. Interpretation of sounding curves 5, 6, 39 (Table III) show that the zone with resistivity 20–23 Ω with a thickness of 8 to 15 m may serve as a limited source of brackishwater. VES 4 (Srikalas) shows resistivity in the same depth range, less than 10 Ω. The cause of low resistivity might be due to the lateral flow of very saline water from the closely flowing river (Text-Fig. 1).

In Shyamnagar the sounding curves VES 21, 22 and 23 are located at Hazipur, Anantapur and Tungipur of Nurunagar union (Table-II). The curves are of HK type. Interpretation of the sounding curves in the union showed a maximum resistivity of 20 Ω.Sounding curves at Mahmudpur (VES 24, 25 and 26) show almost straight lines with less fluctuation in the resistivity values. Right hand portion of the curve shows maximum resistivity of 24 Ω. The sounding curves (VES 27, 28, 29, 30 and 31) at Sriphulkathi are three layer H type in nature except VES 27 which shows an intermediate increase in resistivity giving the curve HKH shape.The interpreted resistivity values (Table II) are low. However, there is an increase in resistivity values at maximum current electrode separation (AB/2 = 400 m) at location of VES 27, 29 (Table II). Interpretation of sounding curves (VES 32 and 33) at Atulia also gives low resitivities. The possibilities of freshwater occurrence in the investigated areas of Shyamnagar Thana within the penetrated depth is minimum.

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The geoelectric section along I-I (Text-Fig. 5) shows that the surface layer alluvium soil consisting of silty clay has the resistivity in the range of 7–15 Ω. The surface layer is underlain by a layer of low resistivity (3–6 Ω) consisting mainly of clayey materials. The thickness of this layer decreases from south west to north east. This clayey layer is followed by a sand predominant layer at a depth of 25 to 100 m. A decrease in resistivity is observed from north-east to south-west along this profile. Resistivity from the range of 30–50 Ω decreases to 10–15 Ω south-west of location VES 1. The decrease in resistivity in the south-western part of this sandy layer can be related to intrusion of saline water from the tidal river. The thickness of this sandy layer increases towards south-west direction. The water quality of this zone up to the site of VES 1, Batuadanga, from the north-east, may be within acceptable limit. The following layer is most probably a clay layer with very low resistivity in the range of 3–8 Ω. The thickness of this layer can not be determined.

The geoelectric section along profile II-II in Shyamnagar thana (Text-Fig. 6) shows that the surface soil of about 1.5 m thickness has the resistivity of 10–19 Ω and is followed by a clay predominant layer showing the resistivity of 3 -5 Ω with a thickness varying from 2–27 m. The third layer shows the resistivity from 3 to 13 Ω consisting predominantly of fine to very fine sandy, silty and clayey materials. This layer is followed by a very low resistive layer of 3 to 6 Ω consisting of clay. The sounding curves 27 and 29 show the presence of another layer with resistivity more than 50 Ω indicating a permeable bed containing probably freshwater. However, this layer has not been identified at other sounding locations along this profile might be due to its higher depth of occurrence.

7. Conclusion and Outlook

Geoelectric soundings carried out along the coastal belt of Sathkhira reflects the heterogeneity in the distribution of deltaic subsurface sediments and the changes in water quality in vertical as well as in lateral directions in the nature and extreme positions of the sounding curves.

A number of possible freshwater zones at various depths are demarcated in the study area. No continuous aquifer of freshwater is identified within the investigated depth.

The study showed that geoelectric resistivity sounding is effective in demarcating possible freshwater bearing zones in the coastal areas and thus can minimise the number of test drillings.

Test drilling in the recommended locations and electrical logging will help to control and improve the interpretation of surface geoelectric measurements.

Geoelectric resistivity survey permits to differentiate freshwater bearing permeable zones but not capable of distinguishing permeable formations containing salinewater from impermeable clay.

Geoelectric surveys may be extended in the other parts of the coastal belt as well as in the northern areas of the country for better insight into the hydrogeological conditions.

Due to its simplicity and relatively low cost equipment the application of direct current (DC) resistivity methods for ground water exploration became very popular. However major disadvantage of this method which may explain the ambiguity of the derived results is its very high sensitivity to the influence of lateral, near surface inhomogenities.

One possiblility to overcome this shortcoming is the application of other electrical methods, notably frequency domain electromagnetics (FDEM) and time domain electromagnetics (TDEM) (GOLDMAN et al., 1991). Both EM methods can be used for profiling as well as for sounding. TDEM posses excellent lateral and vertical resolution, measurements are minimally influenced by surface inhomogenities and particularly compared to DC-sounding methods, the non-uniqueness of interpretation is significantly less (RABINOVICH, 1973). Although, like all EM systems, the TDEM is poor at resolving the resistivity and thickness of an intermediate resistive layer.

RAICHE et al. (1985) and FITTERMANN et al. (1988) give examples where DC and TDEM methods are applied jointly and thus vastly improve interpretation of layered earth parameters.

In addition to resistivity surveys, the application of induced polarization (IP) soundings may improve the resolution of sand and shale formations.

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