Journal of Nepal Geological Society, 2011, Vol. 42, pp. 107–116

Geoelectric resistivity sounding for deciphering hydrogeology and locating deep tubewell installation sites in Pouroshava area of Bagerhat, Bangladesh

***A. S. M. Woobaidullah[1] and Mohammad Zohir Uddin[2]**
[1]Department of Geology, University of Dhaka, Bangladesh
[2]Geological Survey of Bangladesh, Bangladesh
*(*Email: woobaid.du@gmail.com)*

ABSTRACT

The study area includes Bagerhat Pouroshava and its surroundings under Bagerhat Sadar Upazila covering an area of 7.53 sq. km with a population of about 50,000. Bagerhat is a coastal district and the subsurface geology is complicated. As in other areas of the coastal belt the quality of ground water in the area is also variable. For ground water development in the study area the shallow aquifer is not suitable as the water is mostly saline to brackish except some isolated fresh water pockets of limited yielding capacity. The deep aquifer is also not very homogeneous in water quality. In the northwestern part it bears fresh water but water quality deteriorates south-southeast with higher depth of occurrence. A comprehensive study is carried out to demarcate the aquifers and to judge the water quality to find the suitable location of the deep tube wells in Bagerhat Pouroshava area.

Fifteen geoelectric soundings have been executed in the study area using Schlumberger configuration with maximum spreading of 1200 m. Based on the vertical electrical sounding interpretation results the subsurface sequence is divided into following geoelectric units: The top unit has resistivity less than 5.0 Ωm with a thickness of 1.5 to 20 m and represents the top clay-silty/sandy clay layer. The second geoelectric unit represents a very fine to medium sand with thin clay lenses and resistivity varying from 5.0 Ωm to more than 100.0 Ωm with a thickness of 16 to 135 m. The resistivity of the following unit ranges from 1.40 Ωm to 4.8 Ωm and thickness varies from 100 m to more than 300 m. The deepest geoelectric unit shows resistivity from 8.0 Ωm to 18.0 Ωm and represents the deep aquifer. The depth to the aquifer varies from 235 m to 355 m. The most suitable site for groundwater development from the deep aquifer is in the vicinity of East Saira of Shatgambuj union.

Keywords: Resistivity sounding, hydrogeology, deep tube well, water quality, electrical conductivity, Bagerhat area

Received: 23 December 2010 **revision accepted:** 4 May 2011

INTRODUCTION

The study area includes Bagerhat Pouroshava and its surroundings under Bagerhat Sadar Upazila covering from 22°34'N to 22°48'N latitude to 89°38'E to 89°52'E longitude (Fig. 1). Bagerhat Pouroshava under Bagerhat Sadar Upazila was established in 1958. It has an area of 7.53 sq. km with a population of about 50,000. Annual average temperature is maximum 34.3°C and minimum 20.8°C. Annual average rain fall is 1817 mm. Main rivers in the area are Poilhat, Bhairab, Chitra, Daudkhali and Jarantali.

In the study area like in most part of the coastal belt, lack of adequate fresh drinking water is an acute problem. As the surface water is saline almost throughout the year, specially, in the dry months when ponds, lakes and other man made water reservoirs are dried up, ground water becomes the only alternative source of fresh water for thousands of people.

Water quality of the shallow aquifers is saline except in some isolated fresh water pockets which are also arsenic contaminated and are of limited capacity. Previous hydrogeological investigations through exploratory drillings and electric loggings generated scattered information about the water quality in the shallow and deep aquifers in the study area.

As the exploratory drilling is very costly, a cheap alternative surface resistivity method is applied to locate the suitable groundwater sources within or nearby areas for future ground water development to use as a dependable source for water supply system in the Pouroshava area. Resistivity survey is routinely employed in ground water exploration, specially, in the coastal belts to locate fresh water lenses constituting major sources of potable water (Bugg and Lloyd 1976; Serres 1969; Woobaidullah et al. 2002, 2007, 2008). The method provides along with lithological and structural information, also the indications of quality of ground water. Besides, the method is cheap and provides adequate depth of penetration and quantitative

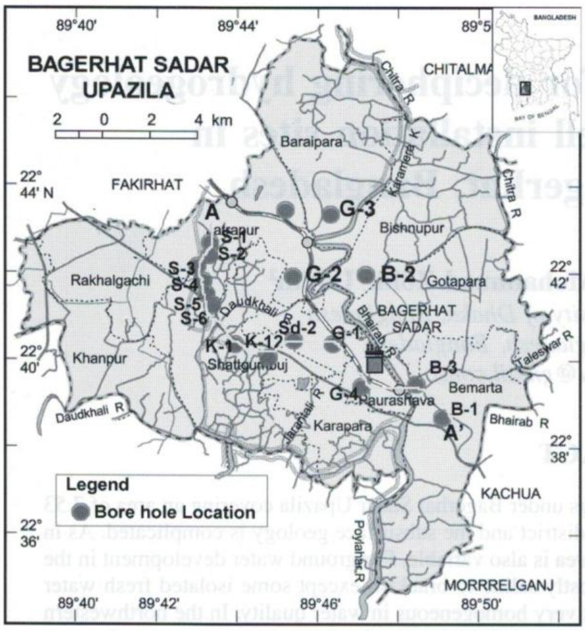

Fig. 1: Location map of the study area (Banglapedia 2009)

interpretation. The major objectives of the geoelectric resistivity survey carried out in the area are to delineate the aquifer at various depths, assess the water quality and to identify the fresh and saline water interfaces and recommends the suitable locations for test drillings and to minimize test hole numbers.

GEOLOGY AND HYDROGEOLOGY

The study area is in the southern coastal belt and is entirely underlain by sandy alluvial sediments deposited by the early Ganges delta and is inter-bedded with discontinuous wedges of tidal clay and sands. The thickness of the Holocene sediments is probably at least several thousands meters in the area.

The lithostratigraphy of the upper 300 m of this formation is rather well known from numerous deep and shallow tube wells drilled in the area and mainly consists of medium to fine sands, clay, silty clay and sandy clay units. A continuous clay-silty clay layer of varying thickness varying from few centimeters to tens of meters occurs at the top. A continuous clay-silty/sandy clay layer occurs at varying depths ranging from 75 to 270 m.

Throughout the study area no regular sequential succession occurs, rather it shows a heterogeneous mixture of clay, silt and sand (Fig. 2). The topmost layer is a clay dominant layer with varying thickness. The following layer is a complex mixture of medium and fine sands, silts and clays which can be considered as a shallow semi-confined aquifer. This shallow aquifer is made up of sand lenses at multiple levels inter-bedded with silts and clays having intersection in sand lenses to consider this as one complex hydraulic unit. Considerable variation in the thickness of these sediments is a characteristic of the deltaic depositional condition. The water of the upper aquifer is generally brackish or saline with few isolated fresh water pockets and is mostly contaminated with arsenic. Around 60% of the tube wells in the shallow aquifer of Bagerhat area show arsenic content in water beyond acceptable limit (Arsenic 2002, 2003). The shallow aquifer is underlain by a confining clay and sandy clay layer. The deep aquifer occurs below this confining clay-sandy clay layer and mostly contains fresh water.

RESISTIVITY METHOD

In resistivity method, artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Apparent resistivities are computed from the measurements of current and potential differences between two pairs of electrodes placed in the ground surface. Actual resistivities are determined generally from apparent resistivities, after treatment with appropriate softwares (Keller and Freischnecht 1966; Telford et al. 1976; Parasnis 1979; Keary and Brooks 1984).

The procedure involves measuring a potential difference between two potential electrodes (M and N) resulting from an applied current through two current electrodes (A and B) outside but in line with the potential electrodes (Fig. 3). Thus, the measured current and potential differences yield an apparent resistivity over an unspecified depth. If the spacing between the electrodes is increased, deeper penetration of the electric field occurs and a different apparent resistivity is obtained. Two main types of procedure related to the resistivity survey are: (i) Vertical electrical sounding (VES), and (ii) Constant separation traversing (CST). In ground water exploration vertical electrical sounding is widely used to identify the aquifer position, their lateral extent, and variation in thickness and to judge about the water quality.

In vertical electrical sounding method, the current and potential electrodes are progressively expanded about a fixed central point. Consequently, readings are taken as the current reaches progressively to greater depths. In this case Schlumberger configuration is preferred (Fig. 3).

The obtained apparent resistivity values r_a from measured data are plotted against half of the current electrode separation AB/2 (where AB is the current electrode separation) on a semitransparent log-log paper and the graph is known as Vertical Electrical Sounding (VES) curve. Interpretation of VES curves, i.e. determination of thickness and resistivity of individual layer of the section can be obtained manually or by computer to obtain resistivity and thickness of individual layer of the subsurface sequence.

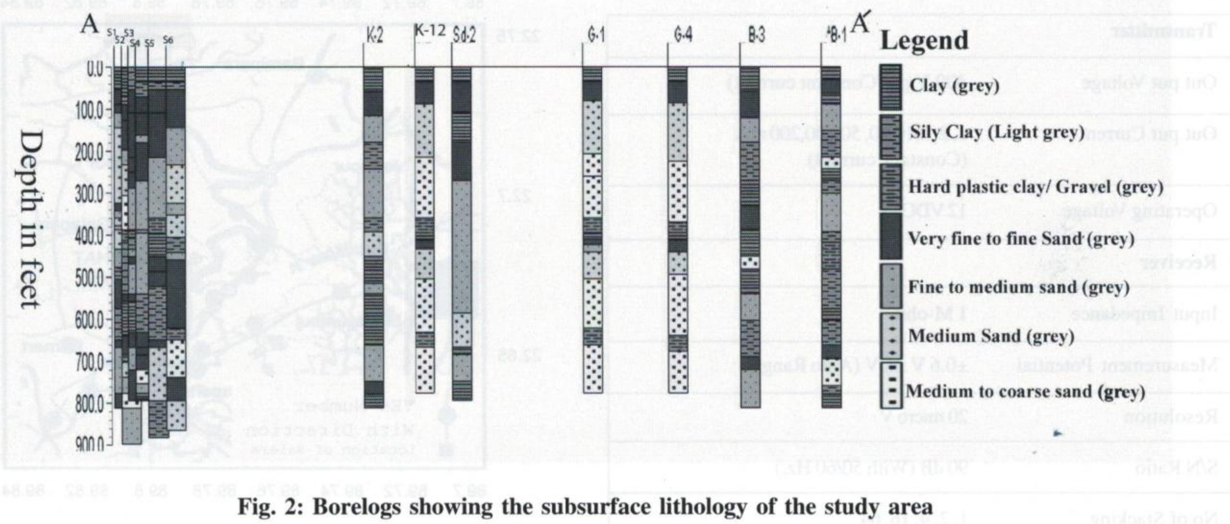

Fig. 2: Borelogs showing the subsurface lithology of the study area

For resistivity survey comprising of Vertical Electrical Sounding (VES) the following equipments are used: McOHM Resistivity meter (Model 2115), Electrodes (each 3 ft. long and ½ inch diameter), Cable reels, Battery, Walky – talky, GPS and other accessories (Fig. 4).

Specification of resistivity meter

A McOHM (Model-2115), OYO corporation, Tokyo, Japan, Digital Electrical Prospecting System was used to collect the field data. The instrument is incorporated with stacking processing function to improve signal/noise ratio as desired. It is a compact device housing the transmitter (current supply unit) and the receiver (potential measuring unit) in a case. McOHM can effect measurement in simple manner by merely pressing the switch measure. For the measurement of resistivity, the device automatically cancels spontaneous potential, achieves high measurement resolution and renders the measurement so highly accurate as to surpass 90 dB, in noise elimination ratio. Its internal memory is capable of mass storage of measured data as many as 2000 measurements. These data can be transferred to external computer via RS-232 C interface. Specification of the McOHM (Model-2115) is provided in Table 1.

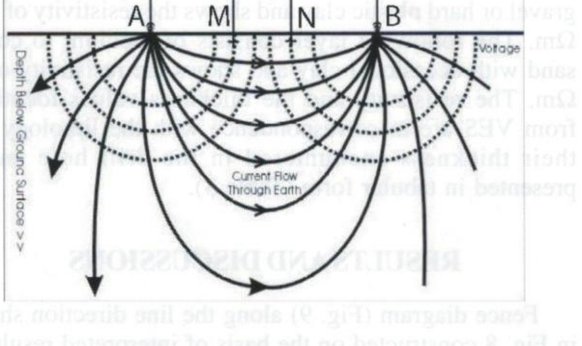

Fig. 3: Electrode array: Schlumberger configuration

DATA COLLECTION

Field work had been carried out from 10 February to 15 February, 2007. Vertical electrical sounding survey was executed to follow resistivity variation with depth. Fifteen geoelectric soundings have been executed in the study area using Schlumberger configuration (Keller and Freischnecht 1966; Telford et al. 1976; Parasnis 1979; Keary and Brooks 1984). The centre of the array (VES location) and the array direction of sounding survey are shown in Fig. 5. Maximum current electrode separation

Fig. 4: Survey required instruments (Resistivity meter, Battery, Cable reels)

Table 1: Standard specifications for McOHM (Model-2115)

Transmitter	
Out put Voltage	400 V pp (Constant current)
Out put Current	1, 2, 5,10,20, 50,100,200 mA (Constant current)
Operating Voltage	12 VDC
Receiver	
Input Impedance	1 M-ohm
Measurement Potential	±0.6 V ±6 V (Auto Range)
Resolution	20 micro V
S/N Ratio	90 dB (With 50/60 Hz.)
No of Stacking	1, 2, 4, 16, 64
Time of One Measurement	
Cycle	3.5 sec
Data memory	
Max No. of Files	128
Max No. of Data	2000
Max No. of Data Files	110
Interface	RS-232C
Power	DC 12 V Internal Rechargeable Battery, External 12 V Battery applicable
Operation Temperature	**Ranges** 0-50^{0}C
Dimensions	(W) 206 X (H) 281 X (D) 200 mm
Weight	Approx. 7.5 Kg (Including Battery)

used throughout the survey area is 1200 m. After selecting the site, the centre of the array is marked. Survey equipment is kept at the centre. From the centre along a straight line a lay out is prepared according to the spread length. Potential electrode spacing is selected depending on the potential difference measurement.

DETERMINATON OF GEOPHYSICAL PARAMETER

Geoelectric measurements in the study area reflect the variability of subsurface conditions over distance. The sounding curves differ in shape and extreme positions. Most of the curves are complicated 6 layers AAKH type, some are 5 layers AKH and some are simple 4 layers KH type (Fig. 6). Curve types reflect subsurface geoelectric sequence. Manually interpreted parameters are used as

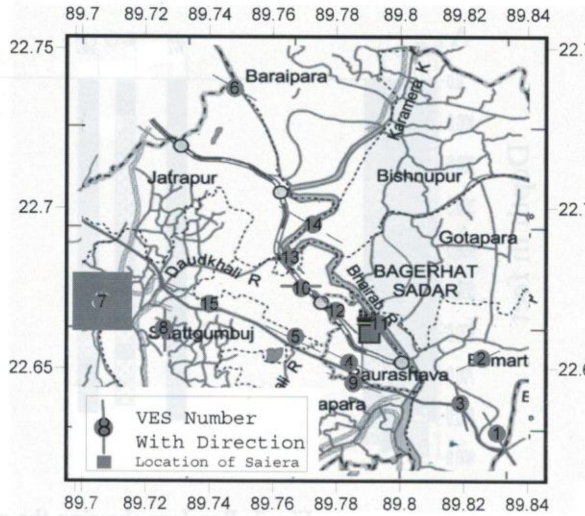

Fig. 5: Map showing the VES location with array direction of sounding survey

initial model for software matching. Targeted depth (TD) of interpretation is taken as 460 m as bore log data available in the area, is maximum up to a depth of 1500 ft (H"460 m). Final interpretation results are presented in Table 2.

VALIDATION OF GEOPHYSICAL PARAMETERS

Resistivity parameter is interpreted into geology by comparing resistivity and thickness values obtained from VES curve matching to bore logs close to VES location. The VES location 8 is very close to the bore hole located in Saira, Satgumbuj (S-3). From bore log data the top layer of about 25 m appears to consist of clay with silty clay and VES shows the same thickness with resistivity 5 Ωm (Fig. 7).

The second layer of thickness 90 m consists of very fine to medium sand and VES result shows the resistivity 15 Ωm. The third layer consists of very fine sand with gravel or hard plastic clay and shows the resistivity of 1.40 Ωm. The following layer consists of medium to coarse sand with occasional clay and shows the resistivity of 16 Ωm. The resistivity and the thickness values identified from VES are in correspondence with the lithology and their thickness encountered in the drill hole and is presented in tabular form (Table 3).

RESULTS AND DISCUSSIONS

Fence diagram (Fig. 9) along the line direction shown in Fig. 8 constructed on the basis of interpreted results of VES curves shows that the subsurface sequence consists of four geo-electric units.

Table 2: Interpreted parameters of the vertical electrical sounding curves

YES No.	Thickness of layers (m)	Resistivity of layers (Ωm)	Equiv.Chloride Concent. (ppm)	YES No.	Thickness of layers (m)	Resistivity of layers (Ωm)	Equiv.Chloride Concent. (ppm)
VES-1	4.00	2.70		VES-2	1.10	1.30	
	15.20	5.00			16.0	11.0	
	30.00	13.50			280.0	3.50	
	300.0	1.80			~163	12.00	550
	~110	12.00	550		TD~460		
	TD~460						
VES-3	1.50	1.40		VES-4	2.50	6.60	
	4.65	4.90			45.00	13.50	
	32.00	5.80			280.00	4.80	
	250.36	3.50			132.5	13.00	500
	171.49	8.75	800		TD~460		
	TD~460						
VES-5	1.40	1.50		VES-6	1.70	1.90	
	120.0	10.00			3.00	19.00	
	180.00	3.50			25.00	25.00	
	158.6	13.30	470		250.0	2.80	
	TD~460				180.3	11.56	590
					TD~460		
VES-7	1.20	1.00		VES-8	1.20	2.90	
	3.00	30.0			11.20	4.20	
	60.00	6.00			135.0	5.15	
	180.0	3.50			150.0	1.40	
	215.8	18.00	310		162.6	15.50	380
	TD~460				TD~460		
VES-9	1.20	1.90		VES-10	4.00	1.30	
	12.00	9.55			3.00	100.00	
	46.00	8.25			6.00	40.00	
	175.00	2.45			100.00	150.0	
	225.8	15.00	400		240.0	2.40	
	TD~460				107	15.00	400
					TD~460		
VES-11	1.20	1.30		VES-12	1.40	0.96	
	0.60	3.25			1.00	1.10	
	4.50	30.0			15.00	21.00	
	10.71	12.0			50.00	6.00	
	150.0	3.50			186.00	2.50	
	100.0	1.00			206.66	10.00	620
	192.99	8.00	920		TD~460		
	TD~460						
VES-13	1.10	2.30		VES-14	1.10	1.30	
	3.00	9.10			1.55	4.50	
	6.25	4			40.0	3.70	
	20.00	50.0			55.00	4.20	
	220.0	1.90			170.00	2.50	
	460	8.00	920		192.35	16.40	360
	TD~460				TD~460		
VES-15	3.00	2.00					
	6.00	5.00					
	15.00	11.0					
	240.0	2.50					
	196	14.00	440				
	TD~460						

Table 3: Overall comparison between bore log and VES results

BORELOG		VES Result		
Thickness of layers (m)	Lithology	Thickness of layers(m)	Resistivity of layers (Ωm)	Lithology
12- 25	Clay/ Silty Clay	1.5- 20	<5	Clay/ Silty Clay
90- 120	Very fine to medium sand	16- 135	5- 110	Sand with fresh water and sometimes with brackish water
80- 260	Very fine sand with hard plastic clay or clay	100- 300	1.4- 4.8	sand with brackish water or clay
>250	Medium to coarse sand with occasional clay	>300	8- 18	Sand with fresh water and sometimes with brackish water

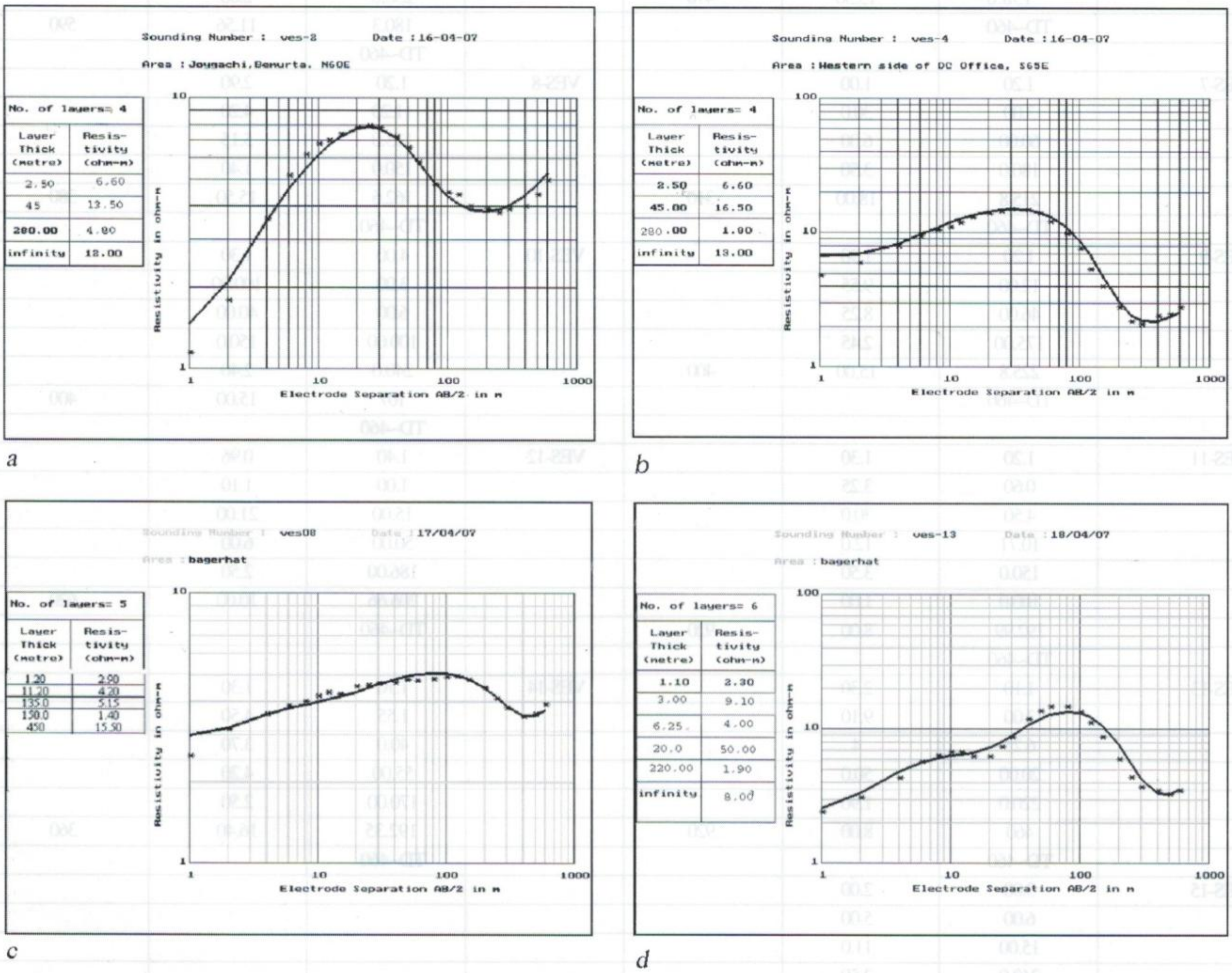

Fig. 6: Field VES curves and their interpreted parameters: (a) VES 2, (b) VES4, (c) VES 8, and (d) VES 13

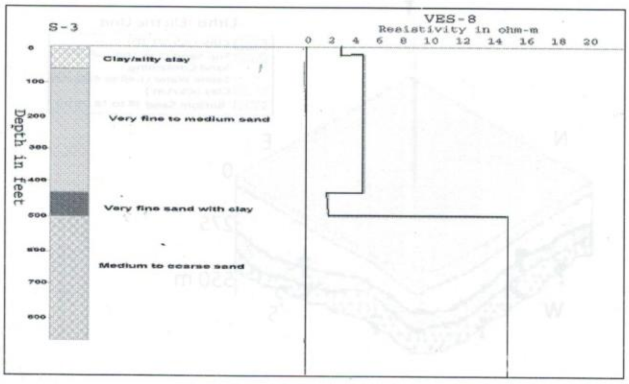

Fig. 7: Comparison of result of VES 8 and bore hole lithology of Saira, Shatgambuj (S-3) in the study area

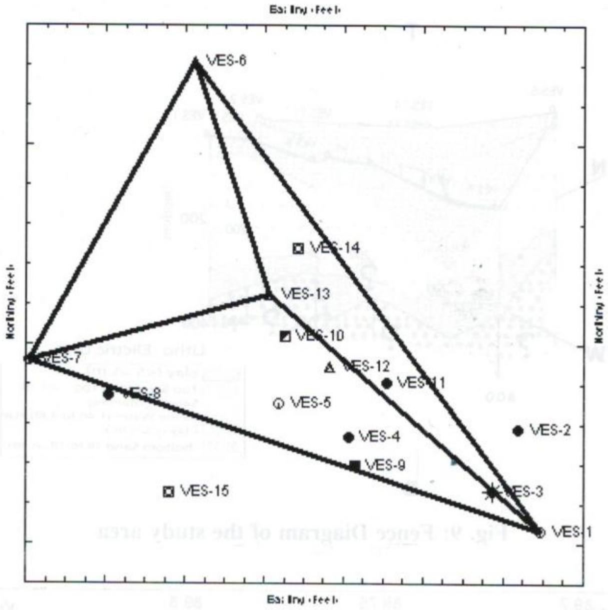

Fig. 8: Line direction of the Fence diagram

The top unit of clay-silty/sandy clay composition shows minimum thickness in north western margin while maximum thickness occurs at central southern part. The following unit is a medium to fine sand layer having low to moderate resistivity contains mostly saline to brackish water with some isolated pockets of fresh water. Thickness of the unit is uniform in north western part but gradually increases towards the central part and then gradually decreases towards east-south east reaching about 50 m. The underlying unit is a very low resistive and from bore log data, the unit is composed of sand having saline water at its upper part and of clay at its lower part. This is a very thick unit of 100 m to 300 m. The deepest unit shows low to moderate resistivity indicating sandy composition and bearing fresh to brackish water. The depth to this aquifer varies from 235 m to about 350 m.

3D model diagram (Fig. 10) constructed based on VES interpreted parameters shows thickness variation of individual units. The thin top unit of clay-silty clay composition shows minor variation in the thickness throughout the area.

The unit shows its maximum thickness in the south-western part. The following unit is a sand layer representing the shallow aquifer of brackish water with isolated fresh water pockets. The maximum thickness of this unit as seen in the model occurs at central west. The next layer is of very low resistivity of having thickness from 100 m to more than 300 m. Bore log data suggests that the upper part of the layer is of medium to fine sand with saline water content and the lower part of it is of clay-silty clay composition. Model diagram shows maximum thickness of this unit at south east. The deepest unit is sand layer containing fresh to brackish water. The depth to this aquifer varies from 235 m to about 350 m and minimum depth is at the central west while maximum is at south south-east.

Depth contours along the upper surface of the deep aquifer (Fig. 11) suggest the increase in depth of the aquifer from north to southward with greater depths in the southeast direction. The minimum depth of the aquifer is at the sounding locations VES 7 at East Saira of Shatgambuj union with a depth of around 245 m. At sounding location VES 8 in the south-western part the depth is about 295 m while at sounding location VES 1 in the south east south of Bemurta the depth is about 350 m.

Cross section AB (Fig. 13) along line shown in Fig. 12 shows the lithological distribution up to the depth of about 460 m. The top sand, the upper aquifer, has higher thickness in the central part of the section. Interpretation of sounding curve VES 6 shows the resistivity in the range of 25.0 Ωm indicating the water quality as fresh but towards south east direction the resistivity values obtained from interpretation of VES 13, 11, 3 and 1 are less than 13.0 Ωm signifying the water quality as brackish to saline.

The third unit of very low resistivity shows gradual increase in thickness towards southeast reaching 350 m. This unit, a continuity of the second unit, in its upper part is also composed of mainly fine to medium sand containing saline water but the lower part is composed of clay silty clay sediments. The bottom unit, a fresh to brackish water sand is separated from the top sand by the continuous clay silty clay layer present at the lower part of the sand/clay layer. This layer occurs at relatively shallower depth in the north western part increasing its depth towards south east. The lower sand contains fresh water in the north western part but in the south east the water is brackish.

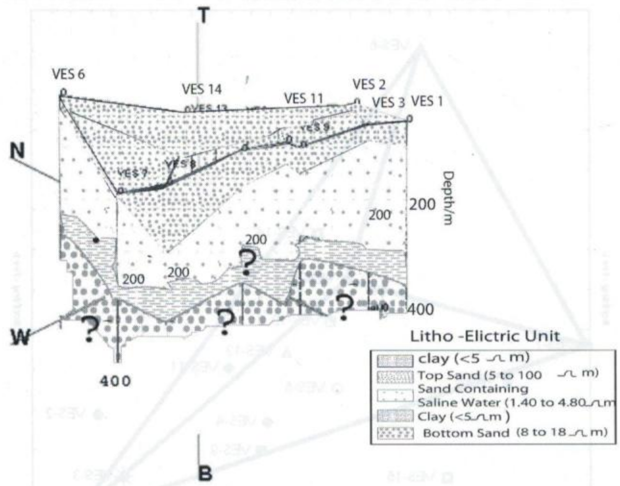

Fig. 9: Fence Diagram of the study area

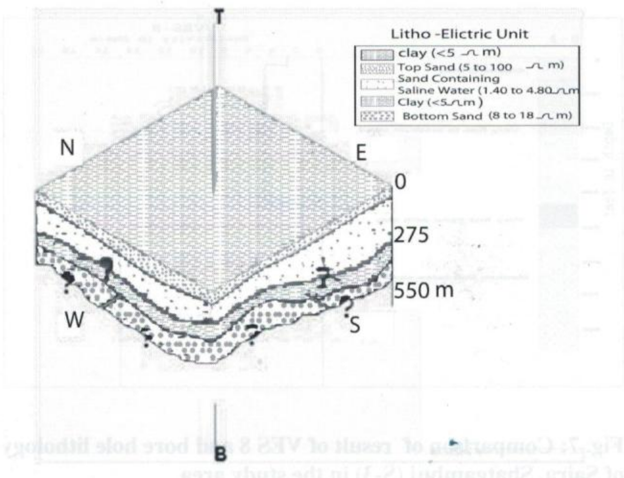

Fig. 10: Subsurface 3D model diagram of the study area

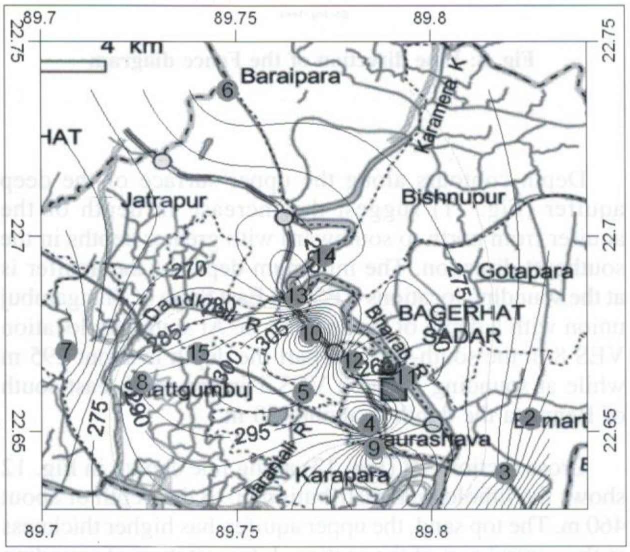

Fig. 11: Depth contour along the upper of surface of the deep aquifer

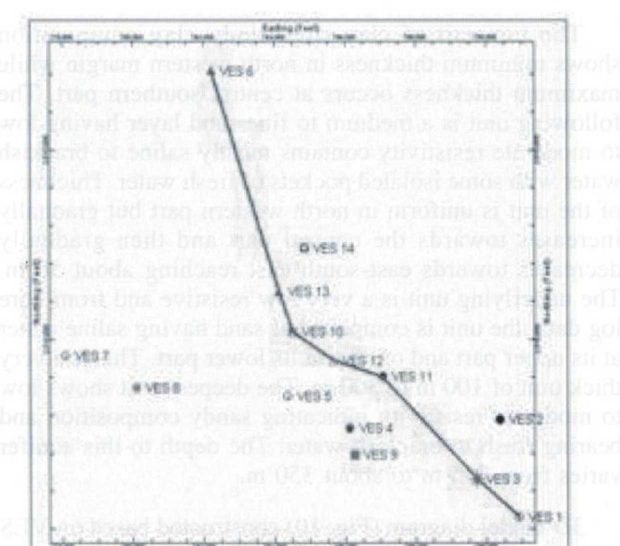

Fig. 12: Location map showing the cross-sectional direction

WATER QUALITY ASSESSMENT FROM SURFACE SOUNDING SURVEY

Resistivity of different rocks is not uniform and sometimes this characteristic may be used to identify the rock types. Normally clays and silts rich in water soluble minerals have low resistivity even if the water content is low. On the contrary, the conductivity of sands is mostly due to the presence of formation water as sands are composed mostly of quartz, a non-conductive mineral. As formation water is responsible for the conductance of sands, the mineralization of pore water is a major factor to resistivity of sand bodies. Sands containing fresh water show higher resistivity than clays and saline water bearing sands. But saline water bearing sand layer may show resistivity within the range of clay resistivity, and in such situations resistivity measurements alone will not allow to distinguish clay from saline water bearing sand (Acworth 2001, Kearey and Brooks 1984, Telford et al. 1976).

The interpreted resistivity ρ of the subsurface formation from surface geoelectric measurements can be related to formation water resistivity ρ_w using the following equation (Archie's Formula).

$$\rho = F \rho_w$$

Where F is the formation factor and depends upon rocks texture or the geometry of pore space and pore connection.

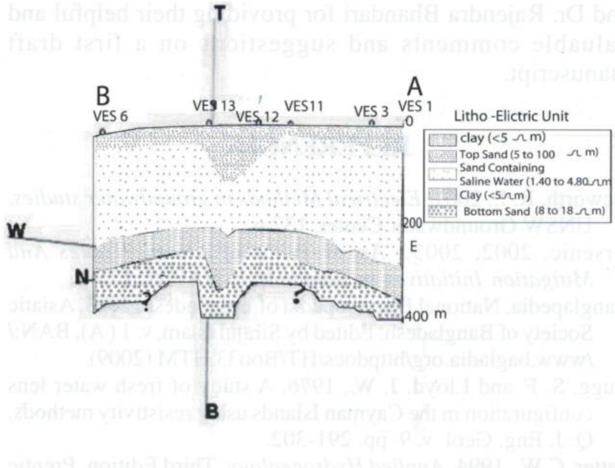

Fig. 13: Geoelectric cross section along line AB

Normally there is a good connection between the measured resistivities of the formations and the electrical resistivities (electrical conductivities EC) of water samples from the formation (Hasan et al. 1997, Fetter 1994, Lloyd and Hathcote 1985). On the basis of lithological information available in the area the formation factor value has adopted as 3 (for fine sand).

Considering the limited variation in formation factor value (3 to 6 for different sand sizes) and great variation in ground water salinity (electrical conductivity of ground water) the calculated EC values demonstrate a clear picture of salinity variation. Geoelectric soundings thus allow to predict whether an aquifer contain saline or fresh water but no prediction can be made on the water bearing characteristic of the formation.

Chloride concentration from calculated EC values of formation water is obtained from the calibration graph "chloride content versus electrical conductivity EC for ground water in Khulna region" (Fig. 14). Chloride concentration using this calibration graph may provide a bit higher values, as the temperature of deeper water samples is higher than considered in the graph.

The contours of calculated chloride concentration obtained from interpreted formation resistivity of surface resistivity soundings show the increase in chloride concentration towards south east (Fig. 15). The highest chloride concentration of about 1500 ppm is found to occur in Pouroshava area at sounding location VES 11 besides Bhairab River and minimum concentration of 350 ppm is found at East Saira area of Shatgambuj around VES 7 and VES 8 indicating improving of water quality in the north west direction.

CONCLUSIONS AND RECOMMENDATIONS

The data collected during the geoelectric survey are of good quality and reflect the subsurface geology and

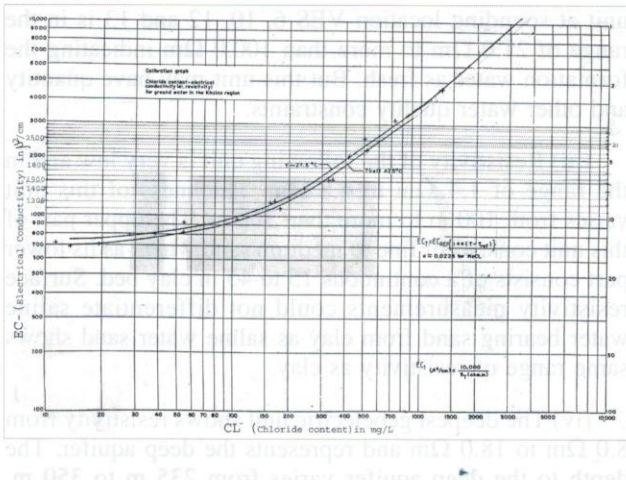

Fig. 14: Calibration graph for surface measured formation resistivity ρ (converted to EC) versus chloride concentration of shallow water samples of Khulna region

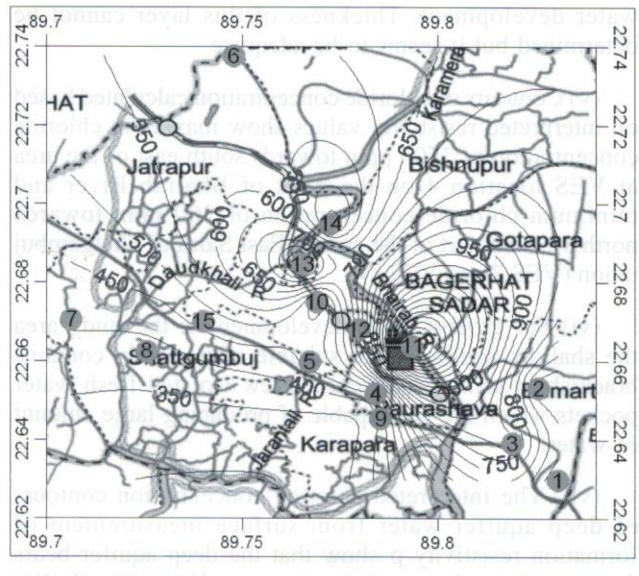

Fig. 15: Chloride concentration contours of Bagerhat Pourashava area

water quality. Model parameters obtained through interpretation of the field sounding curves characterize the subsurface and the following conclusions are made considering the geology and hydrogeology of the area:

(i) The top unit shows resistivity less than 5.0 Ωm with a thickness of 1.5 to 20 m and represents the top clay-silty/sandy clay layer.

(ii) The second geoelectric unit shows a very wide range of resistivity varying from 5.0Ωm to more than 100.0Ω m and represents the fine to medium sand layer. Thickness of this unit varies from 16 to 135 m. The wide range of resistivity variation is mainly controlled by the variation in water quality of the unit. Resistivity of this unit at sounding location VES 6, 10, 12 and 13 is in the range of 21.0 Ωm to more than 100.0 Ωm indicating the formation water as fresh. But this unit may have quantity and other water quality constraints.

(iii) Resistivity of the following unit is very low and in the range of 1.4 Ωm to 4.8 Ωm. Thickness of this unit varies from 100 m to more than 300 m. The upper part of this unit consists of fine to medium sand where as its lower part consists of a continuous 15 to 45 m clay bed. Surface resistivity measurements could not differentiate saline water bearing sand from clay as saline water sand shows same range of resistivity as clay.

(iv) The deepest geoelectric unit shows resistivity from 8.0 Ωm to 18.0 Ωm and represents the deep aquifer. The depth to the deep aquifer varies from 235 m to 350 m. Water quality of this unit is variable and is reflected on resistivity values. Soundings locations at VES 7 and VES 8 show the maximum interpreted resistivity of the unit of about 18.0 Ωm reflecting the sites suitable for ground water development. Thickness of this layer cannot be determined but it seems to be adequate.

(v) Contours of chloride concentration calculated based on interpreted resistivity values show maximum chloride concentration of 1500 ppm towards south east of the area at VES location 4 on the bank of Bhairab River and minimum chloride concentration of 300 ppm towards north-western part of the area at East Saira of Shatgambuj union (VES 7 and VES 8).

(vi) For ground water development in the study area the shallow aquifer is not suitable as it mostly contains brackish to saline water except few isolated fresh water pockets which are not capable of producing large amount of water.

(vii) The interpreted chloride concentration contours of deep aquifer water from surface measurement of formation resistivity ρ show that the deep aquifer bears fresh water in the north-western part but water quality deteriorates towards south-southeast with higher depth of occurrence. The most suitable site for groundwater development is in the vicinity of East Saira surrounding VES 7 and VES 8 of Shatgambuj union especially at the north western part of it where depth of the deep aquifer is approximately below 250 m.

ACKNOWLEDGEMENTS

The data used in the article are collected by the authors in a project work under AQUA consulting farm. The authors express their thanks to AQUA consulting farm for allowing them to publish the paper based on the report prepared for AQUA. The authors are thankful to Mr. Nabaraj Shrestha and Dr. Rajendra Bhandari for providing their helpful and valuable comments and suggestions on a first draft manuscript.

REFERENCES

Acworth, R. I., 2001, *Electrical Methods in groundwater studies.* UNSW Groundwater Center. 132 p.

Arsenic, 2002, 2003, *An overview of Arsenic Issues And Mitigation Initiatives in Bangladesh,* NAISU, 125 p.

Banglapedia, National Encyclopedia of Bangladesh, 2003, Asiatic Society of Bangladesh, Edited by Sirajul Islam, v. 1 (A), BAN:/ /www.bagladia.org/httpdocs/HT/Boo33.HTM (2009).

Bugg, S. F. and Lloyd, J. W., 1976, A study of fresh water lens configuration in the Cayman Islands using resistivity methods. Q. J. Eng. Geol. v. 9. pp. 291-302.

Fetter, C.W., 1994, *Applied Hydrogeology*, Third Edition. Prentic Hall, 691 p.

Hasan, M. A., Woobaidullah, A. S. M., Ahmed K. M. U. and Rahman, M. M., 1997, Geochemistry and origin of saline groundwater in Manda Upazila, Naogaon District, NW Bangladesh. Ind. J. Earth Sci., v. 24(3-4), pp. 26-32.

Kearey, P. and Brooks, M., 1984, *An introduction to geophysical exploration.* Blackwell Scientific Publications, London, 296 p.

Keller, G. V. and Frischnesht, F. C., 1966, *Electrical methods in geophysical prospecting.* Pergamon, Oxford. 526 p.

Lloyd, J. W. and Hathcote, J. A., 1985, *Natural inorganic hydrochemistry in relation to groundwater.* Oxford University Press, Oxford, 291 p.

Parasnis, D. S., 1979, *Principles of applied geophysics.* Chapman & Hall, London. 402 p.

Serres, Y. F., 1969, Resistivity prospecting in a United Nation Groundwater Project of Western Argentina. Geophysical Prospecting, v. 17, pp. 449-467.

Telford, W. M., Geldert, L. P., Sheriff, R. E., and Keys, D. A., 1976, *Applied geophysics.* Cambridge University Press, Cambridge, 770 p.

Woobaidullah, A. S. M., Ahmed, K. M. U., Aziz, Z., and Uttam Karmakar, 2002, Study on Groundwater salinity and its effect on soil and the crop productivity in and around Manda Upazila, Naogoan, Bangladesh, A geoelectrical approach, NESDA Int. Conf. Dhaka., pp. 62.

Woobaidullah, A. S. M., Ahmed, K. M., Hasan, M. A., Aziz, Z. and Islam, M.S., 2002, *Electrical Resistivity and Hydrogeological Study for Saline Groundwater Investigation in Manda and Surroundings, Lower Atrai Basin of Naogaon District.* Final Report, Research Project of Bangladesh University Grants Commission. 67 p.

Woobaidullah, A. S. M., Shah-Newaz, S. M., Masud, M., Shahid Chowdhury, H., and Zohir Uddin, M., 2007, Role of Geoelectric Survey in Groundwater Modelling: A Case Study in Barind Area.; Int. Conf. Water and Flood Management, 12-14 March, 2007, Dhaka, Bangladesh, v. 2. pp. 163-172.

Woobaidullah, A. S. M., Shahid H. Ch., Ahmed, K. M. U., Rahman, M. W., Khandker, S. A. and Obaidullah, A., 2008, Geo-electric Resistivity Survey in the Evaluation of Hydrogeological Condition in Haziganj Upazila, Chandpur District, Bangladesh, Jour. Geol. Soc. India, v. 72(6), pp. 753-763.