Government of the People's Republic of Bangladesh

REPORT ON

GROUNDWATER INVESTIGATION IN MIRSHARAI ECONOMIC ZONE

Department of Public Health Engineering (DPHE)

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Prepared by:
Engr. Sudhir Kumar Ghosh
Superintending Engineer, GWC, DPHE

Engr. Md. Saifur Rahman
Executive Engineer, R&D Division, DPHE

Supervised BY:
Engr. Md. Wali Ullah
Addl. Chief Engineer (Planning), DPHE

Printed at:
Research and Development Division
Department of Public Health Engineering
14 Shahid Captain Monsur Ali Sarani, Dhaka 1000

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Abbreviations

As	Arsenic
BEZA	Bangladesh Economic Zones Authority
BSRM	Bangladesh Steel Re-rolling Mills Ltd
COD	Chemical Oxygen Demand
DGL	Declining Groundwater Level
DHTW	Deep Hand Tubewell
DPHE	Department of Public Health Engineering
DTWs	Deep Tubewells
DU	Dhaka University
EC	Electric Conductivity
Fe	Iron
Ft	Feet
GIS	Geographic Information System
GoB	Government of Bangladesh
GW	Ground Water
GWL	Ground Water Level
GWC	Groundwater Circle
lpcd	liter per capita per day
MOU	Memorandum of understanding
mg/l	Milligram per liter
NDL	Not Detectable
PTW	Production Tubewell
ppb	parts per billion
ppm	parts per million
PVC	Poly Vinyl Colloid
R&D	Research and Development
TW	Tubewell
VES	Vertical Electrical Sounding
WSS	Water Supply and Sanitation
WT	Water Table
Ωm	Ohm meter
µS/cm	Micro-semen's per centimeter

EXECUTIVE SUMMARY

In response to the request of Bangladesh Economic Zones Authority (BEZA), the Department of Public Health Engineering (DPHE) is currently providing technical support towards the establishment of water supply facilities in Mirsharai, Chittagong. The first step of this work is to identify a potential source of water supply. In this regard, a preliminary assessment on existing water sources was carried out during August 2015. During the assessment both groundwater and surface water sources were examined following the available secondary data sources. It was revealed that, as a potential source of surface water, there are Feni River and Mohamaya Lake which are about 20 km away from the target site. The water of Feni River was reported to be high in COD but it needs detailed investigation on water availability and quality. On the other hand the Lake Mahamaya could have been a potential source of water supply (though it needs detailed investigation) but there is a railway and a highway to cross if the water is to transmit to BEZA areas. Therefore, initially it was decided to explore the potentiality of groundwater in the vicinity of BEZA area. The assessment report recommended conducting Vertical Electrical Sounding (VES) Survey followed by few test boring. Based on the recommendations, VES was conducted in 6 locations during November 2015. After the analysis of VES reports, test tubewells were installed in five locations in December 2015. During installation of test wells, litho-logs were prepared and resistivity logging was done. Based on the results of logging, location of well screen was determined. Finally, the water samples were analyzed in laboratory to determine its quality in terms of Arsenic, Iron, Manganese and salinity.

The VES report suggested conducting exploratory drilling at a depth of 200m and it also indicated that potential fresh water aquifer might be available in the southern east corner of the study area. Keeping this as base line information, 5 exploratory drillings were done to a depth of 300m. Soil sample were collected at every 10 feet interval of each drilling and by visual analysis of samples two potential aquifers were identified including some pocket aquifers in and around the study areas. The depth of aquifers varies from 60m to 180m. On the other hand, the resistivity logging indicates the possibility of fresh water at the deeper section of the aquifer. Therefore, the screens of test well were fixed at a depth of 180-200m. Wells were developed until it yields sand free clean water and water samples were collected (acidified & non acidified bottle) for its quality analysis in labs.

The laboratory water quality test results indicate that the water at the targeted depth is acceptable in terms of three dominating parameters i.e. Arsenic, Manganese and Salinity. The iron content in two cases is beyond the acceptable limit (greater than 1mg/l). The study recommends that during the design of Production Tube well (PTW) the grain size analysis of present exploratory drillings might be used but it will require installing a site specific test well before each PTW design is confirmed. As water table lies with 3 to 4 meter, the housing pipe is suggested to be kept within 20 to 25 meter. However, to have the acceptable water quality particularly for Iron as exceeding Bangladesh Standard (0.3 to 1.0 mg/l), treatment plant will require to be considered for construction after reviewing the requirement of water quality for industries planned for Mirsharai BEZA area. On the other hand, to reduce the load on groundwater abstraction, the provision to reuse the used water (specifically the water used for cooling and cleaning) needs to be included in the development plans.

1 Background

In the near future, Bangladesh Economic Zone Authority (BEZA) is going to establish a number of economic zones in the country. During its development, the zones will require a number of basic utility services. Water supply, sanitation and drainage services are one of them. Therefore, BEZA contacted the Department of Public Health Engineering (DPHE) to obtain technical supports in this regard. In response to the request of BEZA, DPHE expressed its willingness to install water supply facilities in Mirsharai, Chittagong and Sreehatta (Sherpur), Maulvibazar Economic Zones as deposit works following the government procedure. In this regard a Memorandum of Understanding (MoU) between the DPHE and BEZA towards installation of water supply systems was signed during September 2015.

Based on the signed MOU, DPHE will be providing technical support to BEZA through carrying out the following activities:

1. Assessing the hydrogeological situation of the area to find water supply source;
2. Installation of Production Tube wells including Test Tube wells;
3. Construction of Water Treatment Plants (if require) and
4. Installation of water transmission and distribution pipelines

With regard to sl. no (i) DPHE is responsible to conduct the groundwater investigation in quest of potential groundwater source for Mirsharai Economic Zone. Based on the systematic processes, the report of groundwater investigation has been prepared by DPHE.

2 Objective of the investigation

The objectives of the investigation are:

1. Assesse the existing groundwater availability;
2. Demarking the different aquifer system;
3. Identify the potential aquifer in terms of quality and quantity.

3 Approach and Methodology

The groundwater investigation has been carried out following the three major steps (i) Reconnaissance survey (ii) Vertical Electrical Sounding (VES) (iii) Exploratory drilling and (iv) Water Quality analysis.

3.1 Reconnaissance survey

A field visit was carried out by the team comprising DPHE officers from Headquarter and field level on 22 August 2015 with a boarder objective as (i) To get the idea about the site where the planned activities to be carried out (ii) To review the existing water supply information and

(iii) To assess the preliminary hydrogeological situation and to identify the probable VES location.

Following the field visit, a report was submitted to BEZA. The main substance of the report is stipulated below.

3.1.1 Findings

The findings are as follows:

i) Two aquifer systems exist; shallow aquifer starts from 12 meters and deep aquifer starts from around 200 to 250 meter. Clay or silty clay exists at different depth interval. It was reported that shallow aquifer is contaminated with arsenic, iron and sometimes with salinity. On the other hand, Deep aquifer is expected to be safe from arsenic and salinity but mostly contaminated with iron.

ii) During field visit, water quality of existing tubewells as shown in Figure-1 have been measured using field kits.

Table 1: Water quality and reported depth of existing well

Well no.	Name of Place	Reported Well depth	Water quality			
			pH	Fe (mg/l)	EC (µS/cm)	As (mg/l)
TW 1	Maddhya Para	500ft	7.7	0.5	900	0
TW 2	Banglabazar	530ft	7.5	0.5	765	-
TW 3	School	520ft	7.4	0.8~1	816	-
TW 4	BEAT office, Forest office, Char Sharat	250 ft	-	NDL	421	-

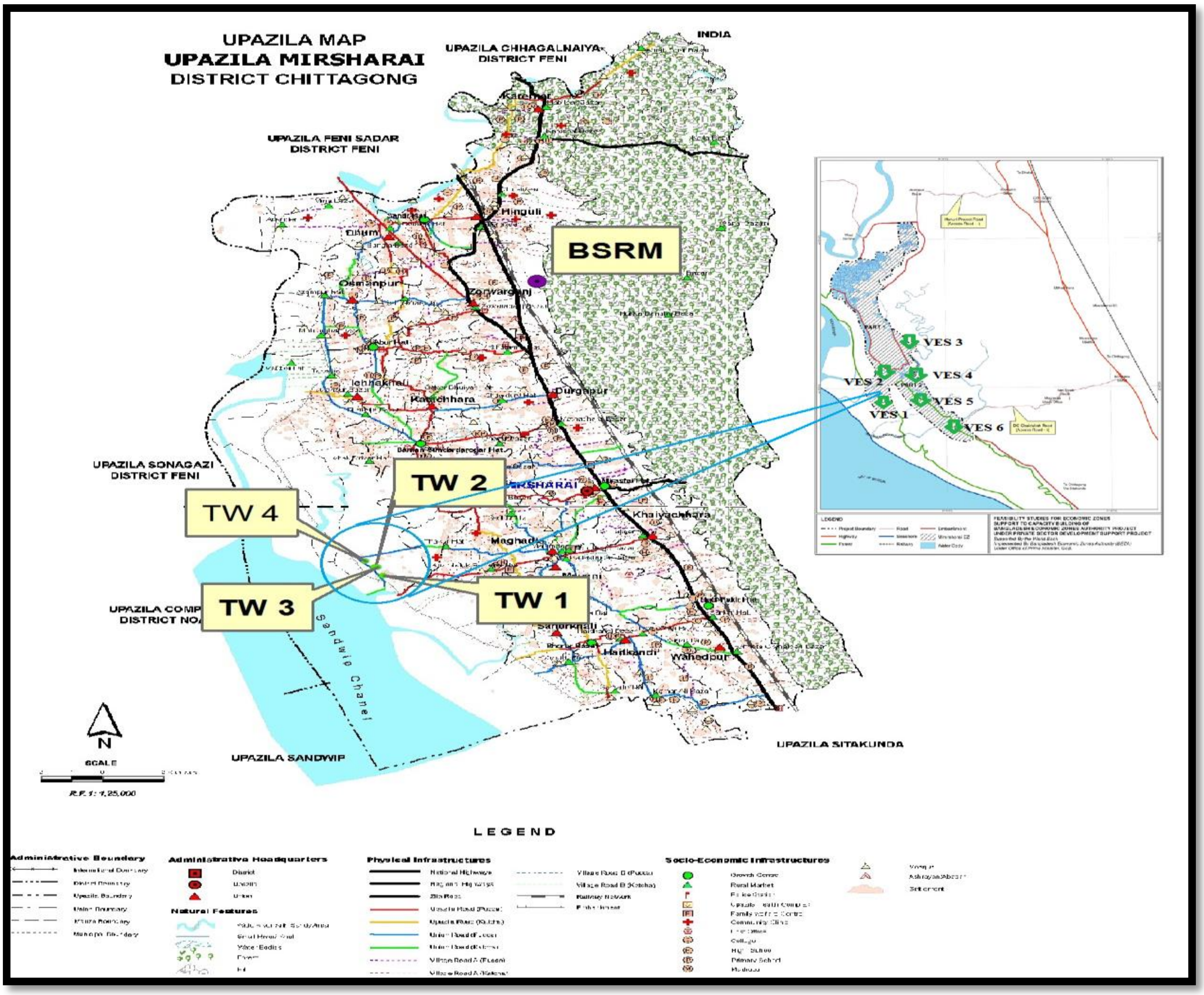


Figure 1: Location of preliminary surveyed tubewell and proposed location for VES

3.1.2 Conclusion on Field Visit

The Source of water supply is complex in Mirsharai due to diversity of geology and water quality as well. In case of groundwater source shallow aquifer is not acceptable due to arsenic and iron. Deep aquifer is arsenic safe but in many parts of the upazila, deep aquifer contains high level of iron. But rapid survey identified four tubewells having low iron concentration along the southern part of the site within 5 km particularly TW no 4 was promising with respect to iron content but the thickness of the aquifer was yet to be ascertained.

However, existence of fresh aquifer can preliminary be explored by carrying out Vertical Electrical Sounding (proposed location shown in Fig-1) which will require to be confirmed by installation of test wells at the end.

Surface water sources are (i) Mahamaya lake (ii) Feni river. But both the sources are located about 20 km from the targeted sites. On the other hand, it has a highway to cross and in every case, treatment will be required. Moreover, COD of Feni River was reported high.

Even if the surface water is not being considered as main source of water supply but it can be used as **supplementary source**. As the site is in low lying area, a lake for preserving water can be constructed to supplement the supply of water (after treatment). Another advantage of the lake will be to **recycle the cooling and washing (excluding heavy and hazardous chemical) water** using the lake for retention.

Reviewing the situation overall, the following initiatives were recommended to execute as a part of the Groundwater investigation:

I. 5-6 locations were identified for Vertical Electrical Sounding (VES) to get the preliminary idea about the existence of aquifer and its extent;

II. Following the analysis of VES result, 4-5 nos exploratory drillings to be done to confirm the water quality and thickness of aquifer preparing the boring log;

III. Based on results of VES and exploratory drillings, the potential aquifer will be identified.

3.2 Vertical Surface Sounding (VES)

VES has been conducted with the support from Dhaka University to have the knowledge about existence and extent of aquifer in and around the economic zone, Mirsharai, having the following specific objectives.

3.2.1 Specific objectives of the study are as follows:

- To identify the suitable aquifer, it`s thickness and water quality;
- To prepare subsurface geological cross section as well as hydrogeological maps based on survey data and available bore log information;
- To provide recommendation for the development of the existing water resources.

3.2.2 Field procedure of Vertical Electrical Soundings (VES)

Figure 2: Conducting VES

Vertical Electrical Soundings have been executed in 6 (six) locations of the study area using Schlumberger configuration. The VES location is shown in figure-3. Maximum spreading used throughout the survey area is 500m with penetration depth of about 200m. The sites were selected covering the whole area based on the availability of space. From the center 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. Four folds stacking were used during the measurement. The measured resistance values are then multiplied with the appropriate pre-calculated geometric factors to obtain the value of apparent resistivity for each position of electrodes. In case of large variations, subsequent values of apparent resistivity measurements were repeated to find the steadiness in the measurements.

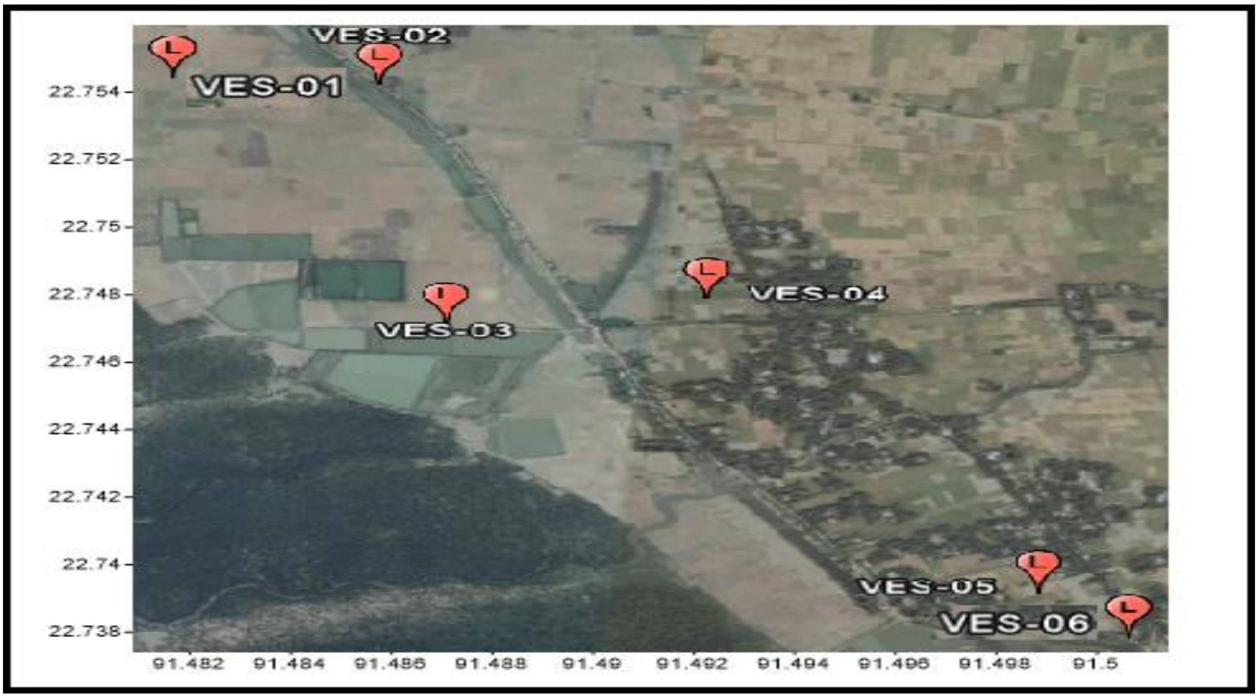


Figure 3: Map showing location of VES point

3.2.3 Results of sounding survey

The result obtained from VES are shown in Table-2

Table 2: Interpretation result of VES

VES-01			**VES-02**			**VES-03**		
Resistivity(Ωm)	**Thickness m**	**Depth m**	**Resistivity (Ωm)**	**Thickness m**	**Depth m**	**Resistivity (Ωm)**	**Thickness m**	**Depth m**
6.7174	0.30667	0.30677	1.8293	0.25688	0.25688	5.6512	0.4255	0.42555
9.9083	4.2530	4.5597	7.6442	0.46425	0.72112	6.7818	2.7301	3.1557
3.3174	60.783	65.343	3.0755	4.7907	5.5118	3.2791	11.129	14.285
			1.1900	30.606	36.118	1.9721	27.249	41.534
12.823	131.75	197.09	7.8477	54.867	90.985	12.823	123.00	164.54
46.817	Base not seen		26.559	Base not seen		1.5937	Base not seen	
VES-04			VES-05			VES-06		
Resistivity (Ωm)	**Thickness m**	**Depth m**	**Resistivity (Ωm)**	**Thickness m**	**Depth m**	**Resistivity (Ωm)**	**Thickness m**	**Depth m**
14.615	0.70734	070734	3.7740	0.26982	0.26982	2.0931	0.50542	0.5054
9.2215	3.1652	3.8726	5.0656	3.2898	3.5596	2.2732	10.484	10.989
11.760	8.4717	12.344	7.1242	6.3731	9.9327	6.3445	28.267	39.256
3.0875	49.486	61.830	2.1242	72.865	82.798	1.5937	75.488	114.74
9.9083	42.754	104.58	15.937	90.876	173.67	12.474	138.55	253.29
38.300	Base not seen		24.525	Base not seen		32.689	Base not seen	

VES 01 shows a 5 layer geo-electric model (Table-2). The top layer composing of surface soil shows resistivity 6.72 Ωm of about 0.5m thickness. The 2nd layer shows resistivity of 9.90 Ωm with a thickness of 4m and may be composed of silty sandy. 3rd layer shows resistivity of 3.3 Ωm. The lithology is composed of fine sand, silt and clay with a thickness of about 70m. 4th layer shows resistivity around 12 Ωm reflecting lithology as fine sand and silt and the thickness is around 130m. The bottom layer shows resistivity 46.8 Ωm indicating the layer as sandy one with fresh water. VES 02 shows a 6 layer geo-electric model (Table-2). The top layer composing of surface soil shows resistivity 1.83 Ωm of about 0.25m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 1.19 to 7.87 Ωm with a cumulative thickness of around 90m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom layer shows resistivity 26.55 Ωm indicating the layer as sandy one with fresh water. VES 03 6 layer geo-electric model (Table 2). The top layer composing of surface soil shows resistivity 5.65 Ωm of about 0.42m thickness. The 2nd, 3rd, and 4th layers show resistivity of 1.97 to 6.78 Ωm with a cumulative thickness of around 41m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The 5th layer shows resistivity 12.82 Ωm indicating the layer as sandy one with fresh water with a thickness of 123 m. VES 04 shows a 6 layer geo-electric model (Table 2). The top layer composing of surface soil shows resistivity 14.61 Ωm of about 0.70m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 3.1 to 11.76 Ωm with a cumulate thickness of around 104m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom layer shows resistivity 38.3 Ωm indicating the layer as sandy one with fresh water.

Vertical electrical sounding 05 shows a 6 layer geo-electric model (Table 2). The top layer composing of surface soil shows resistivity 3.77 Ωm of about 0.27m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 2.12 to 7.12 Ωm with a cumulative thickness of around 82m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom 5th and 6th layers show resistivity 15.94 to 24.53 Ωm respectively indicating the layer as sandy one with fresh water. Thickness of the layer of the 5th layer is around 90m.VES 06 shows a 6 layer geo-electric model (Table 4). The top layer composing of surface soil shows resistivity 2.09 Ωm of about 0.51m thickness. The 2nd, 3rd, and 4th layers show resistivity of 1.59 to 6.34 Ωm with a cumulative thickness of around 114m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom 5th and 6th layers show resistivity 12.47 to 32.68 Ωm respectively indicating the layer as sandy one with fresh water.

3.2.4 Depth Contour along the Top of the Aquifer

The depth contours along the top of the aquifer (Figure 4) shows that the depth to the aquifer increases from northwest to southeast with minimum depth around 100m at VES 02. Maximum depth around 200m is found at VES 06.

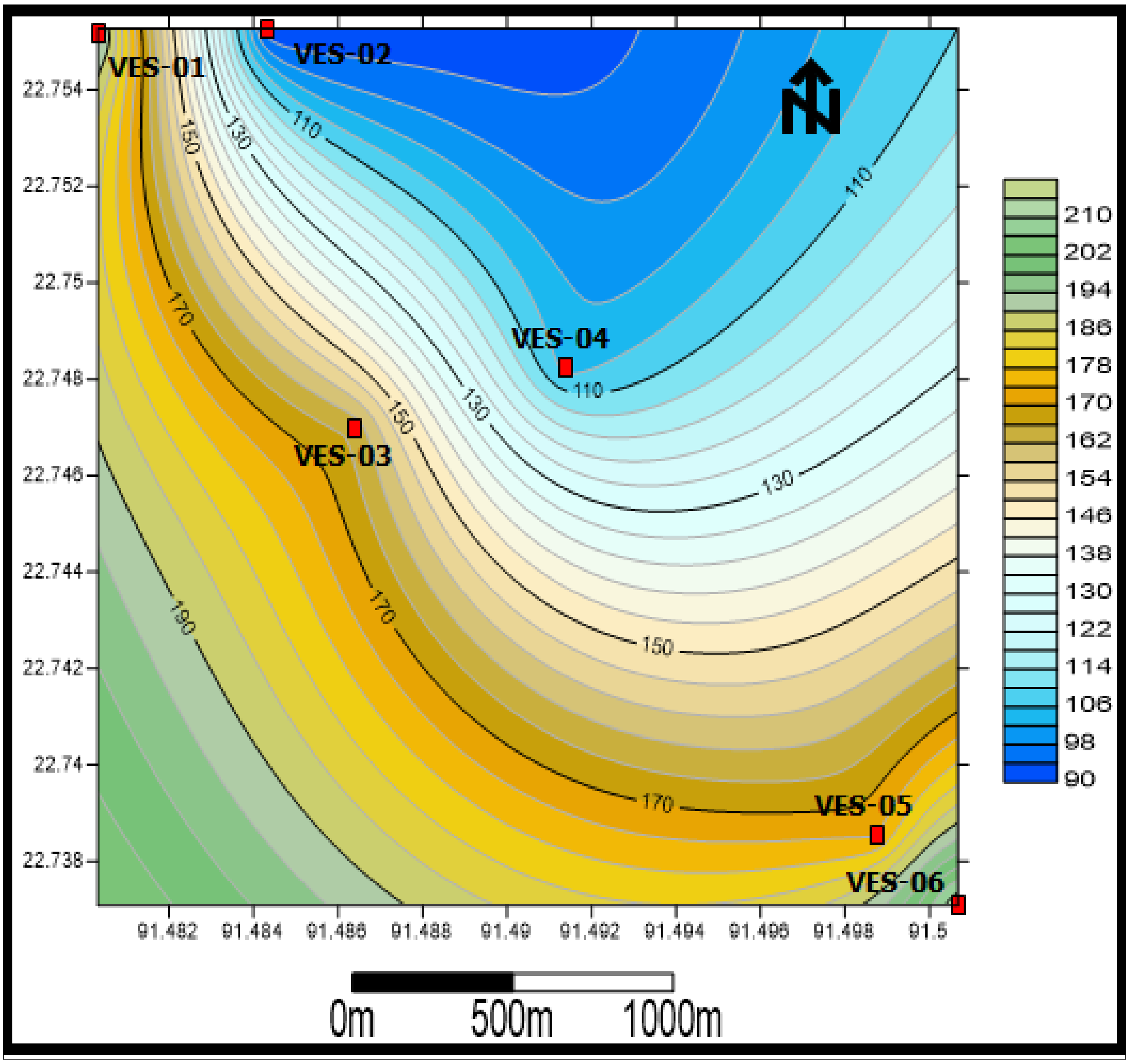


Figure 4: Resistivity contour showing depth variation of fresh waterh

3.2.5 Conclusions and recommendations of VES study

Electrical Resistivity Sounding survey data obtained from 6 locations of the area has been analyzed for the assessment of subsurface hydro-geological conditions of the study area. Interpretation of VES data shows existence of six geo-electric layers up to a depth of 250m.

i) The geo-electric layer of the top soil shows a wide range of resistivity (1.8 to 14.6 ΩM) variation regulated by the composition and the moisture content.

ii) Geo-electric layers of II to V for VES 02 and VES 04 show resistivity 1.19 to 9.90 Ωm representing either silty clay or sandy clay composition or sand saturated with saline to brackish water. In either case the layers are not suitable for ground water development. The cumulative thickness of these layers vary from around 100m

iii) The bottom layers VI and V for VES 03, VES 05 and VES 06 show resistivity in the range of 12.47 to 46.8 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer of the 5th layer is around 123m, 90m, and 138m respectively for VES 03, VES 05 and VES 06 and thickness of the 6th layer cannot be determined.

iv) Interpretation results of VES data (not so consistent) and constructed resistivity and depth maps in the study area suggest the layers showing resistivity above 12 Ωm are suitable for further studies. Depth to this suitable zone increases from north northeast to northwest and south southeast with minimum depth around 100m at VES 02 to 200m at VES 06.

v) VES location 1 may be the first site for test drilling. The site shows high resistivity (46 Ωm) at a depth of around 190m. 2nd test drilling site may be the VES location of 5 or 6 in the southeast corner of the area. Interpretation of VES 5, 6 shows resistivity around 24 to 32 Ωm at a depth more than 200m. 3rd test drilling site may be the VES location 4 in the central part of the area. Interpretation of VES 4 shows resistivity around 38 Ωm at a depth more than 104m. VES 3 located to the west of VES 4 not very far shows relatively low resistivity (12 Ωm).

3.3 Exploratory Drilling

Total five (5) nos of exploratory drillings have been executed based on VES results and field visit to confirm the thickness of aquifer and water quality as well. Locations of wells are shown in fig-5 along with the VES station.

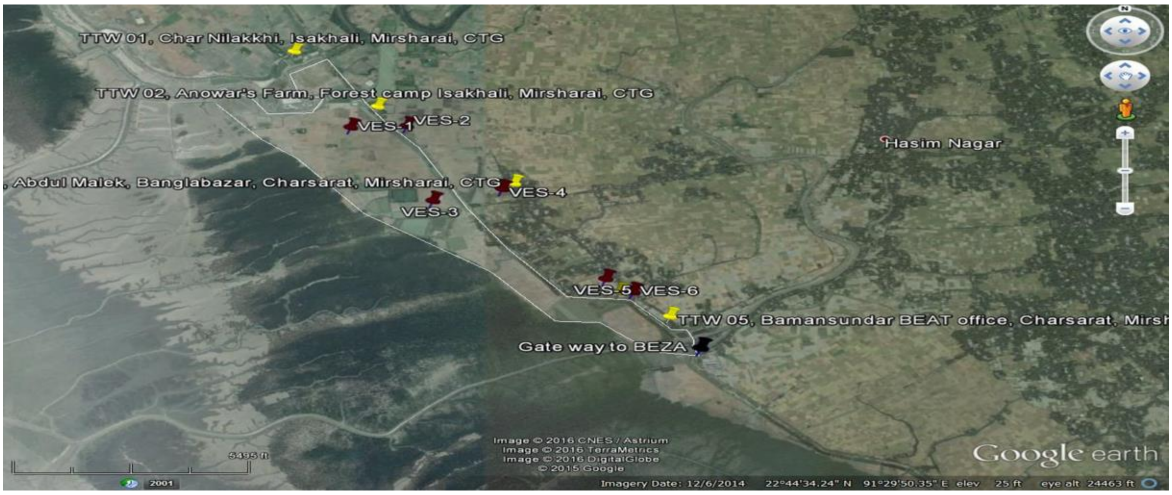


Figure 5: Location of TW along with VES

3.3.1 Existence of Aquifer

The depth of boring was around 900ft which was carried out adopting water jet method using donkey instrument. During boring, disturbed soil samples were collected at 10′-0″ intervals and at every change of soil strata by split spoon sampling method. These soil samples were studied visually and the soil classification were done to prepare strata chart of soils up to the explored depth. Before collecting soil samples, the hole was washed and cleaned. All the samples are first kept in wooden box and completing the drilling work, these were kept in polythene packet.

Figure 6: Wooden box filled with sample

Figure 7: Drilling of Test Well

Based on collected sample, field litho-log was prepared following the standard format classifying the lithology such as clay, silt, sand, gravel etc. After completion of the boring, lithological information was processed in a software called "Hydro-geo-analyst "to have the boring log of individual well and cross-sectional view of study area. Apart from that resistivity logging had been done in uncased well to get the idea about characteristics of aquifer in terms of water quality particularly for salinity. A sample individual boring log incorporating resistivity logging has been shown in Fig-8 and the cross section of aquifer incorporating the five boring log has been shown in Fig-9 respectively.

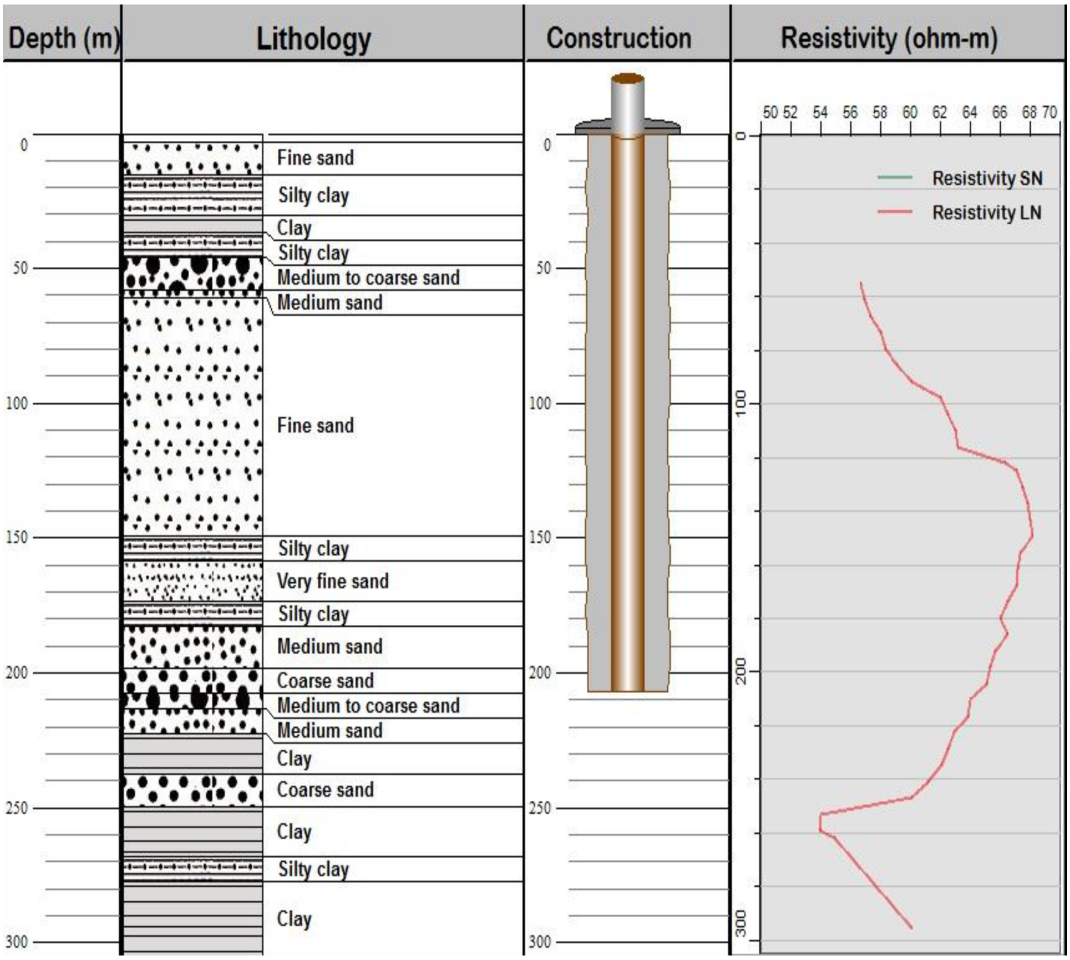


Figure 8: Individual Boring log

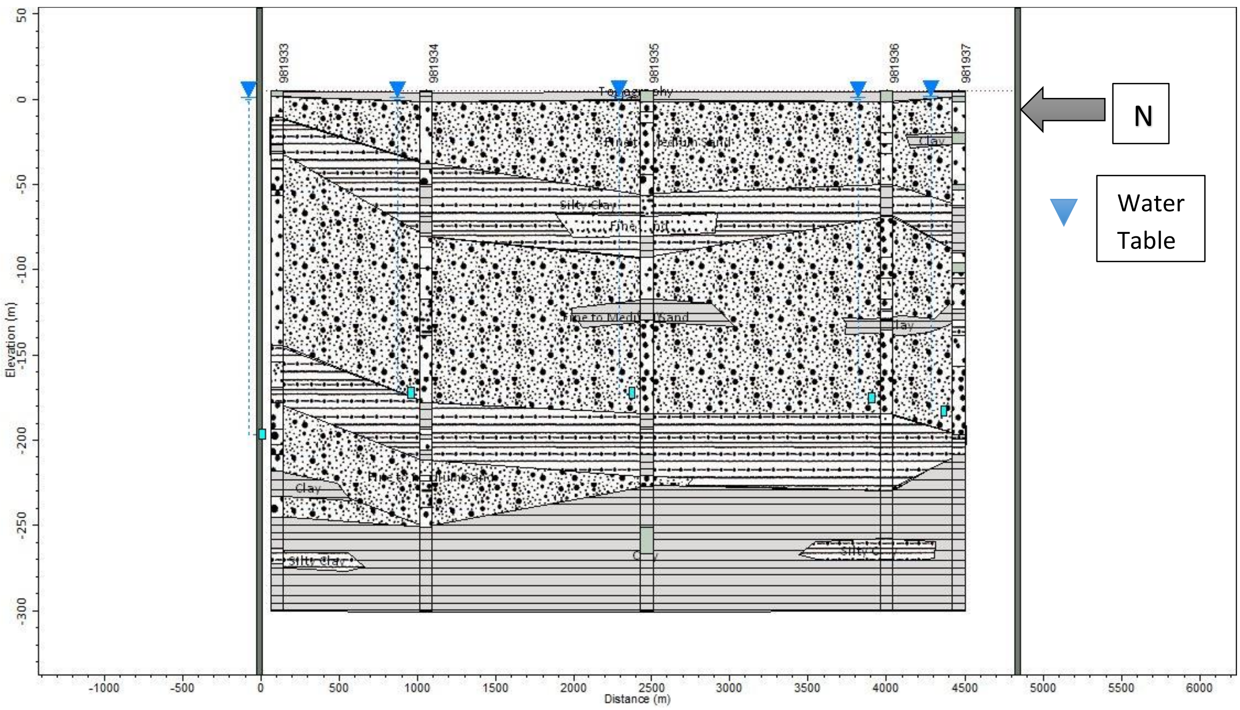


Figure 9: Cross section of aquifer over the study area

3.3.2 Water Quality of Targetd Aquifer

Figure 10: Test well

Five nos of 38 mm PVC well has been installed to know the aquifer water quality. Before taking the sample for water quality testing, proper development had been done and platform was constructed. For each well, two water samples were collected in acidified & non-acidified bottles and finally water samples were analyzed in the laboratory processes. However, the depth of well vaires based on the first hand analysis of field boring log and resistivity loging. The depth of screen, depth of water table and water quality for four dominating parameters are shown in Table-3.

Table 3: Depth and water quality of test well

Well No	Boring Depth (m)	Location of screen (m)	Water Quality Parameters							
			Arsenic (As)		Chloride (Cl)		Iron (Fe)		Manganese (Mn)	
			Value	Unit	Value	Unit	Value	Unit	Value	Unit
TTW1	300	Around 200	0.001	mg/L	21.45	mg/L	1.02	mg/L	0.10	mg/L
TTW2	300	Around 180	0.001	mg/L	16.97	mg/L	0.96	mg/L	0.01	mg/L
TTW3	300	Around 180	>0.001	mg/L	24.95	mg/L	2.24	mg/L	0.30	mg/L
TTW4	300	Around 190	>0.001	mg/L	66.38	mg/L	0.88	mg/L	0.01	mg/L
TTW5	300	Around 200	0.001	mg/L	32.44	mg/L	0.96	mg/L	0.01	mg/L

3.3.3 Water Table

Water table of each test well was measured by simple local tools (plum bob and measuring tape).The depth of water table found within the suction limit that varies from 10 to 12 feet. It indicates that number 06 hand pump can be used for taping water in the vicinity. The depth was measured from the ground surface without adjustment of Rudced Level (RL). The following table represents the depth of water table of test wells;

Table 4: Depth of water table

Well No	Boring Depth (m)	Location of screen (m)	Water Table, m
TTW1	300	Around 200	3.66
TTW2	300	Around 180	3.66
TTW3	300	Around 180	3.05
TTW4	300	Around 190	3.66
TTW5	300	Around 200	3.05

Figure- 11 shows the trend of water flow based on apprent depth (without RL) of water table.

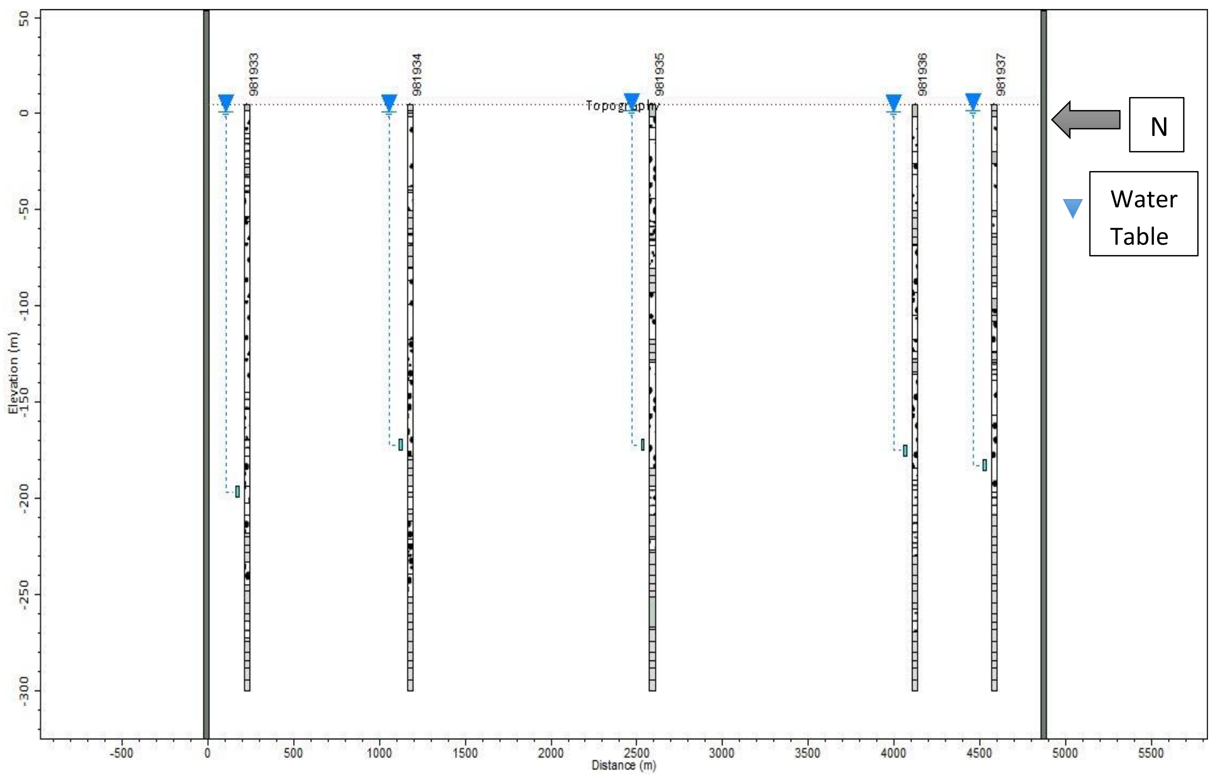


Figure 11: Water table at different point

3.4 Interpretation of result Exploatory Drilling

Interpretation has been made reviewing lithology, resistivity logging, water quality analysis and also considering the findings of VES study.

Result of Test well-1 (TW) shows that there exist two distinct aquifer; (i) 50 to 150 meter (thickness is 100m) comprising fine sand (ii) 82 to 122 meter (thickness is 40 m) comprising medium to coarse sand (Table-3 and annex-B). The resistivity logging shows low resistivity in 1st aquifer and high resistivity in 2nd aquifer indicating less possibility of salinity in the second aquifer. The thickness was more in 1st aquifer but its grain size is finer compare to 2nd aquifer. Therefore, screen was dropped in 2nd aquifer.

Unlike TW-1, Test Well (TTW-2) shows three aquifers with shallow one (50 to 120m), 2nd aquifer (140-185m) and 3rd aquifer (230-250m). 1st aquifer is composed of sand of low resistivity whereas 2nd & 3rd aquifers are composed of medium to coarse sand with high resistivity (Table-3 and annex-B). Considering its thickness and continuity, screen was dropped into second aquifer.

Test Well-3 (TW-3) shows an upper aquifer at the top (0-60m) and 2nd one is in between 135-190m (55m thickness). 1st aquifer is composed of fine sand with low resistivity and 2nd one is composed of medium sand with low resistivity. Two other pocket aquifers are also envisaged around 70m and 220m. However considering the potentiality, screen is dropped in 2nd aquifer.

Like TW-2, Test Well-4 (TTW-4) shows the aquifers at top most one (0-50m), 2nd one lies in between 70 to 120m and 3rd one lies in between 140 to 190m. As the grain size is better and resistivity is high, 3rd aquifer has been selected for location of the Screen.

Like TTW-2 & TTW-4, Test Well-5 (TTW-5) shows three aquifers. Upper part lies in between 10 to 60m, 2nd one lies within 90 to 130m and 3rd aquifer lies in between 140 to 190m. Thickness, Grain size and Resistivity readings led to locate the screen in the 3rd aquifer as the best potential location.

The cross-sectional view (Figure 9) indicates the elevation of aquifer at east part (TTW-1) is comparatively higher. But Reduced Level (RL) has not been taken, so elevation along the site could not be confirmed.

It was found that (Figure 9) there exist two distinct aquifers in the study area. 1st aquifer is the upper one whose thickness is less and resistivity is high. But 2nd aquifer is potentially ranging from 60 to 160m. Another aquifer is found at the depth of 200m (near to TTW-2) which could be termed as pocket aquifer. 2nd aquifer has been identified as continues, but two pocket of clayey soil was also envisaged.

Water quality in terms of Chloride, Arsenic, Manganese and Iron of Test Wells was examined for target aquifers. All the parameters of water quality were found acceptable except Iron, in one case, exceeds the cut-off value (0.3 -1.0 mg/l).

Depth of water table (Fig-11 and Table-4) shows apparently that direction of groundwater movement groundwater flows towards south to north. However, it could not be confirmed as the data is minimum within short distance (about 5 km).

4 Conclusion

VES study suggested that at the depth 100m to 200m fresh aquifer might be available. Result of Test Wells in terms of lithology and water quality indicates that the aquifer in between 80 to 180m would be most potential for future development. However, the site specific design of production tube well (PTW) will be done in particular for screen location. Moreover, attention needs to be taken to avoid pocket clay layer (as the case for TTW-1 and TTW-2). It can be suggested that production well is preferred to be installed within 50m from test wells. A test wells shall be bored near the selected site before finalizing the PTW design. Grain size analysis of target aquifer should be done before the finalization of PTW design.

As Iron content varies from 0.88 mg/l to 2.46 mg/l exceeding the acceptable limit for drinking water as per Bangladesh standard. Other parameter was found acceptable. However, water quality will require further review in respect to the requirement concern industries to take decision about treatment plant. It was found that the area located in high water table area. The depth of water table varies within 3 to 4m. So the Housing pipe would be better to keep within 20 to 25 meter. Moreover, aquifer properties will require to be determined through pumping test. Therefore, construction of production tube well shall be followed by pumping test to ascertain the productivity of the aquifer for future groundwater development.

Referring the article 3.2.4, it is suggested that if some part of used water particularly cooling and washing (excluding heavy and hazardous chemical) water can be recycled after retaining it into ponds that might reduce the load of groundwater abstraction which, in turn, will be useful for the sustainability of water resources in the vicinity of BEZA area in Mirsharai, Chittagong. Moreover, this intervention will be helpful to improve the environmental situation and ecological balance including the beautification of the area.

ANNEX-A

Report

GEOELECTRICAL RESISTIVITY SURVEY FOR GROUNDWATER ASSESSMENT OF MIRERSHARAI ECONOMIC ZONE

Submitted by
Dr. A.S.M. Woobaidullah
Department of Geology
University of Dhaka
Dhaka 1000
December 2015

Abstract

The study area is located in the southeastern region of the country, at the hilly terrain of Mirsharai and facing the Bay of Bengal. Due to the presence of main aquifer in contact with seawater of the Bay of Bengal, there is a risk of contamination of the aquifer. The Electrical Resistivity Sounding survey data of the area have been analyzed for the assessment of subsurface hydro-geological conditions of the area. The collection and analysis of hydro-geological data are the vital need to determine the basic parameters required for the characterization of aquifer. Geophysical methods, especially the electrical resistivity survey technique, can provide immense subsurface information related to ground water condition in conjunction with borehole information.

Electrical Resistivity Sounding survey data obtained from 6 locations of the area has been analyzed for the assessment of subsurface hydro-geological conditions of the study area. Interpretation of VES data shows existence of six geo-electric layers up to a depth of around 250m.

The geo-electric layer is the Top soil shows a wide range of resistivity (1.8 to 14.6 ΩM) variation regulated by the composition and the moisture content. Thickness of this unit varies from 0.25 to 0.7m.

Geo-electric layers is II, III, IV and V for VES 02 and VES 04 show resistivity 1.19 to 9.90 Ωm representing either silty clay or sandy clay composition or sand saturated with saline to brackish water. In either case the layers are not suitable for ground water development. The cumulative thickness of these layers vary from around 100m

The depth contours along the top of the aquifer show that the depth to the aquifer increases from north northeast to northwest and south southeast with minimum depth around 100m to 200m.

The bottom layers VI and V for VES 03, VES 05 and VES 06 show resistivity in the range of 12.47 to 46.8 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer of the 5th layer is around 123m, 90m, and 138m respectively for VES 03, VES 05 and VES 06 and thickness of the 6th layer cannot be determined.

Interpretation results of VES data (not so consistent) and constructed resistivity and depth maps in the study area suggest the layers showing resistivity above 12 Ωm are suitable for further studies. Depth to this suitable zone increases from north northeast to northwest and south southeast with minimum depth around 100m at VES 02 to 200m at VES 06.

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

The quest for good quality water to sustain life on and in the planet earth, has caused a reasonable drift from ordinary search of surface water to prospecting, exploring and exploitation of sub-surface or groundwater potentials for steady and reliable supply. Bangladesh is a small country with its large population. Like other countries Bangladesh largely depends on groundwater resources to supply a large fraction of their domestic demand for potable water.

Electrical resistivity method is one of the most useful techniques in groundwater geophysical exploration, because the resistivity of rocks is sensitive to its ionic content (Alile, et al., 2011). The method allows a quantitative result to be obtained by using a controlled source of specific dimensions. Records show that the depths of aquifers differ from place to place because of variation in geo-thermal and geo-structural occurrence (Okwueze, 1996). Few available boreholes in the area often fail to sustain regular water supplies, because of the complex sub-surface geology (Okereke, et al., 1998), therefore, the need to study an area for groundwater potential to be properly delineated, if present at all. The present study has been carried out to decipher the ground water potential and to study aquifers of the area.

1.2. OBJECTIVES

The main objective of the proposed study is to support in delineating subsurface geology and aquifer in conjunction with borehole information in the study area.

The specific objectives of the study are as follows:

- To identify the suitable aquifer, it`s water quality and conditions.
- To prepare subsurface geology as well as hydrogeological maps based on survey data and available bore log information.
- To give recommendation for the development of the existing water resources.

1.3. THE STUDY AREA

1.3.1. LOCATION, EXTENT AND ACCESSIBILITY

Chittagong is the second-largest city of Bangladesh. It is located in the southeastern region of the country, at the mouth of the Karnaphuli River, straddling hilly terrain and facing the Bay of Bengal. The district is bounded on the north by Tripura State of India, on the east by Khagrachhari, Rangamati and Bandarban, on the south by Cox's Bazar and on the west by the Bay of Bengal and Feni and Noakhali districts. The total area of the districts is 5282.92 sq. km. (2039.00 sq. miles) of which 1700 sq. km. (456.37 sq. miles) including coastal area is under forest. The district lies between 21º54' and 22º59' north latitude and between 91º17' and 92º13' east longitude. The study area lies under Mirersharai Upozilla of Chittagong district of latitude 22.738 N to 22.754 N and longitude 92.482 E to 91.500 E.

Chittagong district is quite different from other districts of the country for its unique natural beauty characterized by hills, rivers, sea, forests and valleys. The area is well communicated with Dhaka and nearby districts by highways and railways. The distance between Dhaka and Chittagong by road is 266km and by railway 297km.

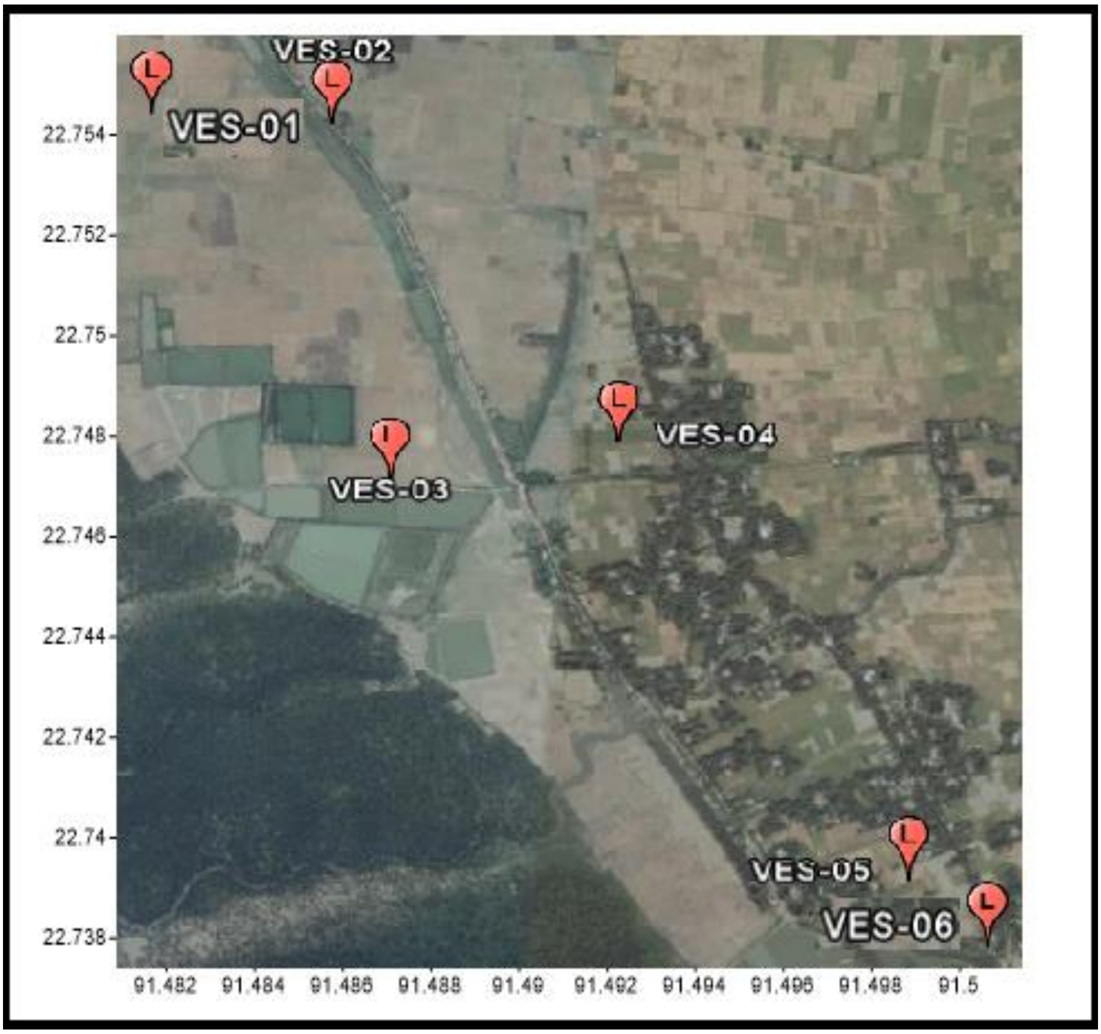


Figure 1: Location map of the study area (LGED)

1.3.2. POPULATION AND CULTURE

Chittagong has a population of 6.5 million with the Metropolitan Area having a population of 4,009,423. By gender, the population was 54.36 male and 45.64 percent female. The literacy rate in the city is 60 percent. Muslims form 83.92 percent of the population. Other major religions are Hinduism (13.76 percent), Buddhism (2.01 percent), Christianity (0.11 percent), and others (0.2 percent). (Census: 2011)

Bengalis constitute the largest ethnic group, followed by adivasi ethnicities such as the Chakmas and Marmas. Many Ismailis and Indo-Iranians settled in the city during the 1940s and 1950s. The descendants of Portuguese settlers, who are often known as Firingis, also live in Chittagong, as Catholic Christians, in the old Portuguese enclave of Paterghatta. There is also a small Urdu-speaking Bihari community living in the ethnic enclave known as Bihari Colony.

1.3.3. METEOROLOGY AND CLIMATE

Chittagong is located in the NE part of Bangladesh .The city is known for its vast hilly terrain that stretches throughout the entire district and eventually into India. It is located on the banks of the Karnaphuli River. As Bangladesh belongs to the tropical zone, the study area experiences a hot, wet and humid tropical climate. Under the Koppen climate classification Chittagong has a tropical monsoon climate. Temperatures in Chittagong range from 13.8 to 32.05 (Celcius) and the Rainfall in Chittagong varies from 18.0 to 2688.0 (mm/month). The area has rainfall equivalent to 85 percent of annual rainfall in the monsoon season between April and October. Average relative humidity (%) is between 70 to 85%.A correlation between precipitation and humidity values of the study area can be found. Higher humidity has occurred in the low precipitation year.

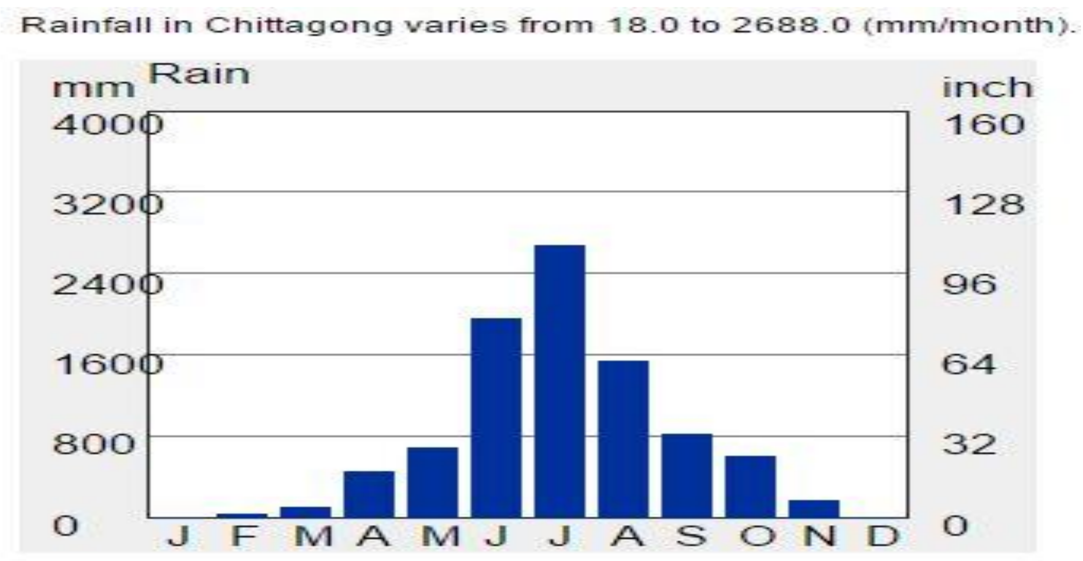


Figure 2: Monthly rainfall pattern (BBC Weather (humidity and sun))

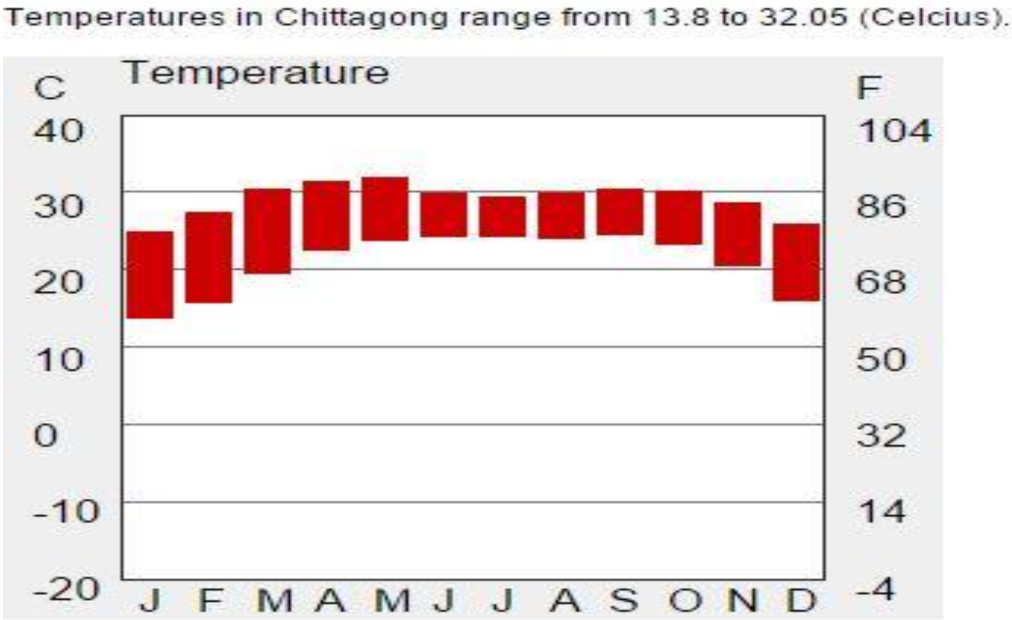


Figure 3: Monthly temperature (BBC Weather (humidity and sun))

1.3.4. PHYSIOGRAPHY

Chittagong district is wholly occupied by high north south striking hill ranges. The anticlines form the hills and the synclines, the valleys. The lowest ranges generally follow the eastern coast of Bay of Bengal from Feni river to Naf river. This continues to the south-word across the border of Mayanmar. A narrow stretch of coastal plain about 60 miles long and six miles wide, develops due to a thrust fault along the western flank of the Sitakund anticline.

Towards the east the ranges get higher and the slopes steeper until they rich the highest hill range in the east that marks the boundary Myanmar, India and Bangladesh. The highest peak of the hill ranges reaches a height of 1100 feet from the mean sea level in its westernmost of Sitakund.

1.3.5. DRAINAGE

The entire study area is surrounded by two major river system Karnaphuli and Sangu. The Karnaphuli originates from higher Arakan Yoma and cut across the main ranges of hill tracts and fall into the Bay of Bengal. The other river Sangu originates from Sangu reserve forest in the southeast of the hill range. It flows northwest for most of its course and falls in the sea just ten mile south of the mouth of the Karnaphuli river. Besides this river, numerous streams from the westernmost hill ranges directly carry tremendous quantity of water to the Bay of Bengal. More over frequently occurring flash flood destroys and damage human lives and properties and very large areas of agricultural land.

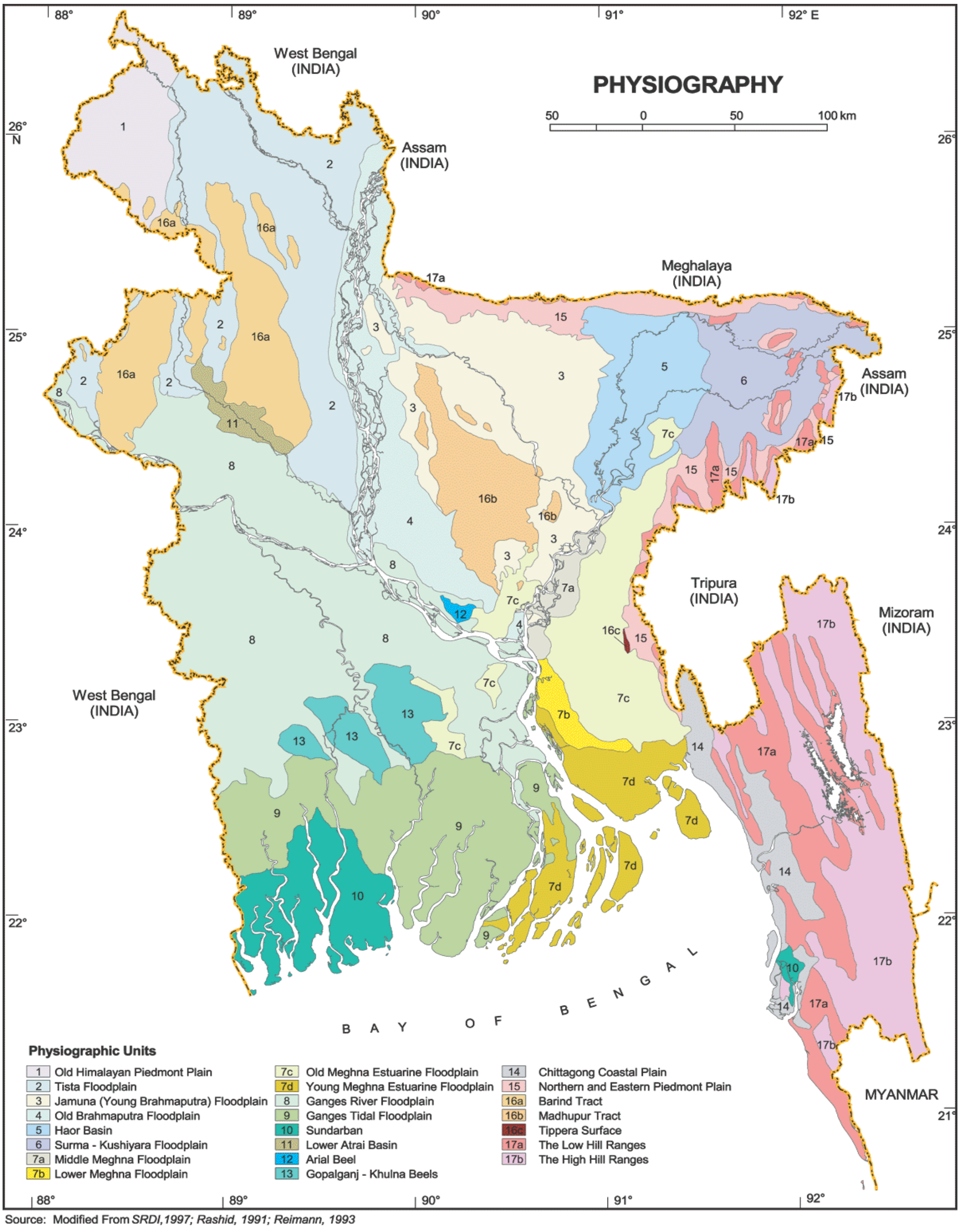


Figure 4: Physiographic map of Bangladesh

CHAPTER 2

METHODOLOGY

2.1 **INTRODUCTION**

Electrical resistivity (ρ) an inverse of electrical conductivity is an inherent property of all earth materials and is defined as a measurement of material resistance to the flow of electrical current (Fretwell and Stuart, 1981). Electrical current may be propagated into the subsurface through conductive, electrolytic or dielectric conduction. Resistivity of a medium is a physical property, which determines the behavior of electromagnetic fields in the medium. It is usually the most important property in determining electric current flow. The electrical resistivity method is an active geophysical method. It employs an artificial source which is introduced into the ground though a pair of electrodes. The procedure involves measurement of potential difference between other two electrodes in the vicinity of current flow. Apparent resistivity is calculated by using the potential difference for the interpretation.

2.2. **THEORITICAL CONSIDERATION OF RESISTIVITY METHODS**

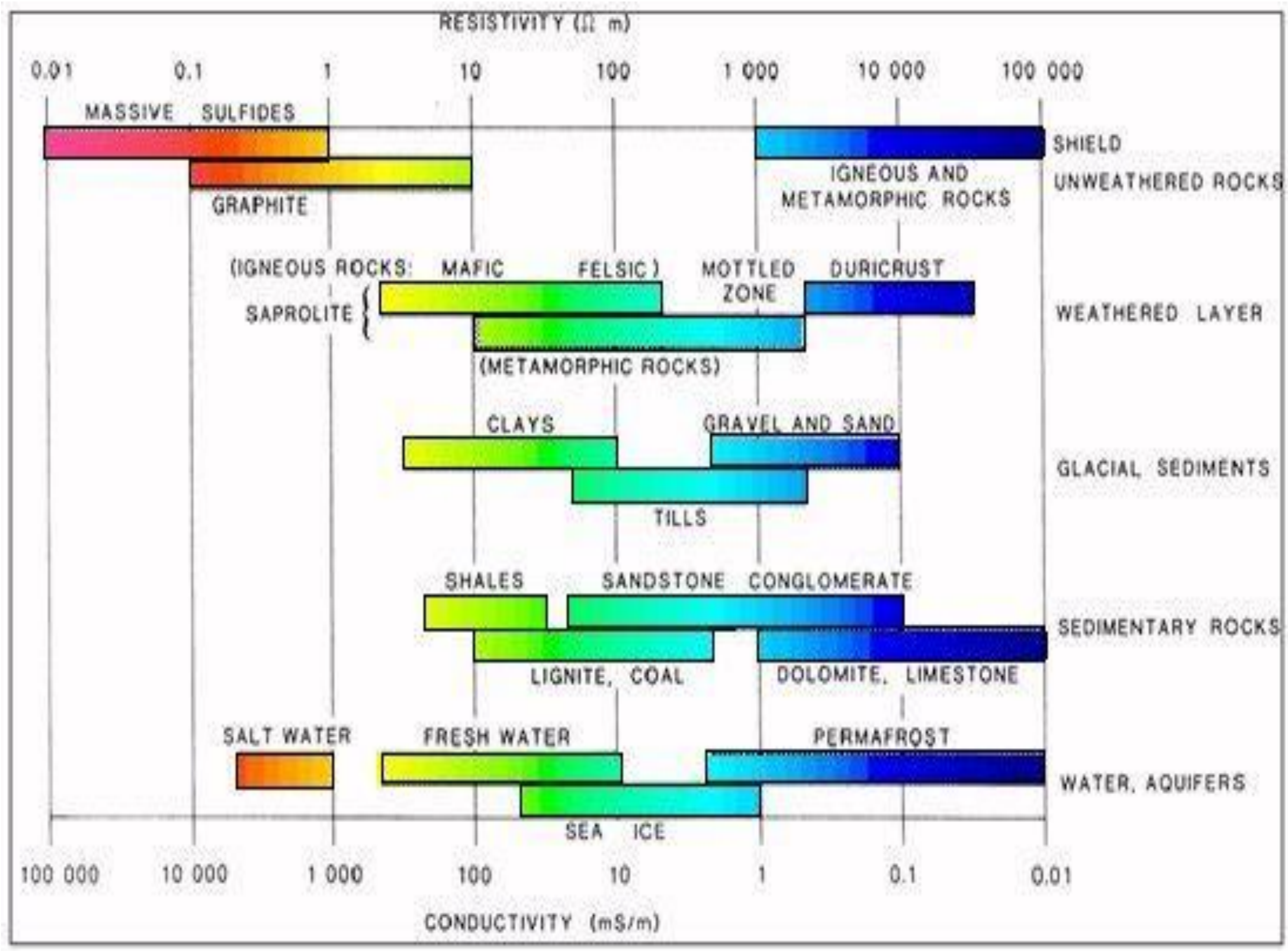
2.2.1. RESISTIVITY OF ROCK

Most rock forming minerals are insulators, while their enclosed fluids are conductors, and is defined as a measurement of material resistance to the flow of the subsurface through conductive, electrolytic or dielectric conduction. Resistivity of a medium is a physical property, which determines the behavior of electromagnetic fields in the medium. It is usually the most important property in determining electric current flow. The electrical resistivity method is an active geophysical method. It employs an artificial source which is introduced into the ground though a pair of electrodes. The procedure involves measurement of potential difference between other two electrodes in the vicinity of current flow. Apparent resistivity is calculated by using the potential difference for the interpretation. Electric current is carried through a rock by the passage of ions in pore waters. Thus most rocks conduct electricity due to the electrolytic conduction of pore fluid interconnection (Keller and Freschknecht, 1982). Under this condition major factors affecting the electric conductivity of the bulk soil or rock are:

- Porosity
- Conductivity of included soil moisture
- Shape of the soil/ rock pore spaces
- Degree of saturation
- Temperature and presence of clays with moderate to high cation exchange capacity

Resistivity of rocks varies considerably with the lithology and nature of pore fluid. Sand, sand and gravel, sandstone and lignite coal have high resistivity; clay and shale have the lowest. Saline water causes low resistivity without considering whatever the formation matrixes are.

Figure 5: General Resistivity range of different rocks



2.2.2. RESISTIVITY PRINCIPLES

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. For a conducting cylinder of resistance δR with a cross-sectional area δA and a length δL (Fig. 6), the resistivity of the cylinder can be expressed as

$$\rho = \delta R . \delta A / \delta L$$

The SI unit of resistivity is ohm-meter (Ω-m). The reciprocal of resistivity is termed as the conductivity and the SI unit of conductivity is mho per meter or Siemens.

The ohm's law, which states that temperature remaining constant, the potential difference 'V' across a current bearing conductor is given by the product of the current 'I' and the resistance 'R' of the conductor

$$V = IR \quad (1)$$

Let the conductor be a plate of thickness 'L' and area of cross-section 'A', then

$$R = \rho L/A \qquad (2)$$

Where, ρ is the resistivity of the plate

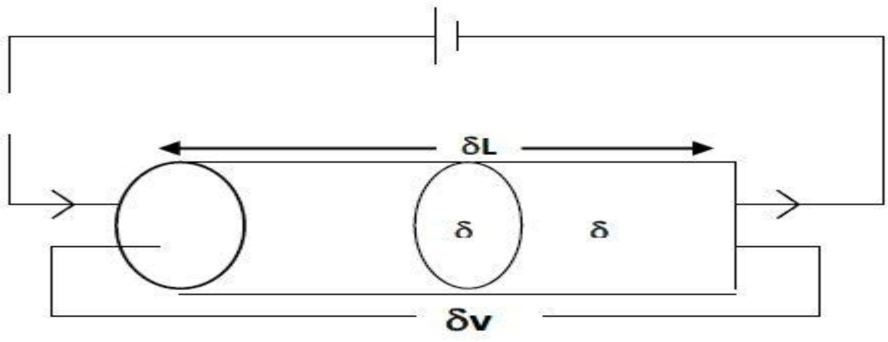


Figure 6: The parameters used in defining resistivity

Putting equation (2) in equation (1) we get

$$V = I\rho L/A,$$

$$\text{Or, } V = j\,\rho\,L, \quad [j = I/A = \text{current density}]$$

If 'L' is very small, the potential difference 'v' will also be small δv, then the ratio –δv/δl is given by the potential gradient E

Therefore, $-\delta v/\delta l = E = j\rho$ or

$$\mathbf{j = E/\rho = \sigma E} \qquad (4)$$

Where, σ is the conductivity of the plate.

2.2.3. RESISTIVITY OF HOMOGENEOUS ISOTROPIC MEDIA

The simplest approach to the theoretical study of earth resistivity measurements is to consider first the case of a completely homogeneous isotropic path. An equation giving the potential about a single point source of current on the spherical surface can be developed from ohm's law. In homogeneous isotropic ground where there is a point source of current below the ground surface, the current radiates equally in all directions. Hence the equipotential surfaces are spherical with center at source point. For two such equipotential surfaces very near to each other the potential difference would be $v_1-v_2=\Delta v$ between them. If the radial distance between them is □r, then potential gradient E at any point between them is

$$-\Delta v/\Delta r = E$$

The current density 'j' at any point on the equipotential surfaces would be

$$j = I/4\Delta r^2$$

By ohms law, $j = I/4\pi r2=\sigma E= -\sigma\ \delta v/\delta r$

Or, $\delta v/\delta r = - 1/\sigma.\ I/4\pi r2$

$\therefore\ \delta v = - 1/\sigma\ .I/4\pi r2.\delta r$ (5)

Now, integrating the equation (5) we get,

$V = 1/\sigma\ .I/4\pi r + C$ (6)

$V = \rho I/4\pi r$ (6)

When $r = \alpha \rightarrow C = 0$.

If the point source of current is at the ground surface, then the current will flow hemi spherically, then equation (6) can be expressed as

$V = \rho I/2\pi r$ (7)

Potential functions are scalars and so, may be added arithmetically. If there are several sources of current rather than the single source assumed so far, the total potential at an observation point may be calculated by adding the potential contributions from each source independently. Thus, for n current sources distributed in a uniform medium, the potentials at an observation point, M will be-

$VM = \rho/2\pi$ *I1/a1 + I2/a2 +------- + In/an+ (8)

Where, I_n is the current from the n^{th} in a series of current electrodes and a_n is the distance from the n^{th} source to the point at which the potential is being observed.

Equation (8) is of practical importance in the determination of earth resistivities.

The physical quantities measured in a field determination of resistivity are the current I, flowing between two current electrodes; the difference in potential □V, between two measuring points and the distance between the various electrodes.

When there are two current electrodes (A&B) on ground surface and the distance between two current electrodes is finite (Fig. 7), the potential at any nearby surface point will be affected by both current electrodes.

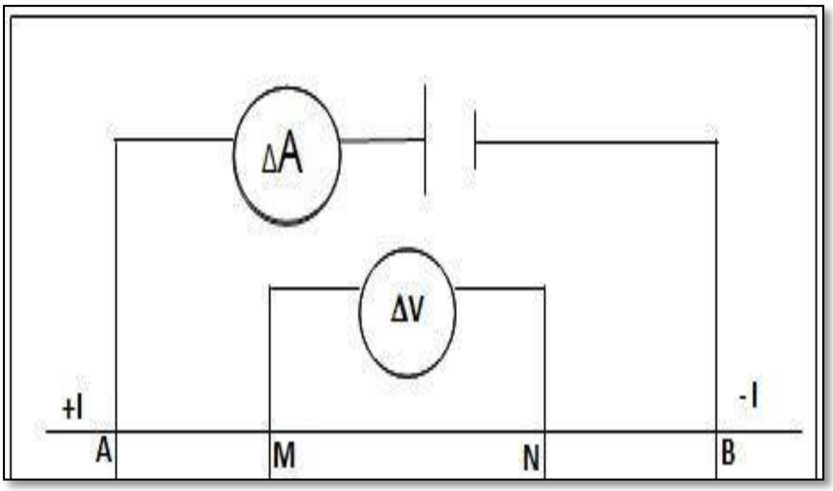


Figure 7: Generalized form of the electrode configuration used in resistivity measurements.

The potential V_m at an internal potential electrode M_c is the sum of the potential contributions V_A and V_B from the current source at A and the sink at B.

$V_M = V_A - V_B$

From the equation (7) we get,

$$VM = \rho I/2\pi(1/AM - 1/BM) \qquad (9)$$

Similarly,

$$VN = \rho I/2\pi(1/AN - 1/BN) \qquad (10)$$

Absolute potentials are difficult to monitor so the potential difference ΔV between two electrodes ‘M’ and ‘N’ is measured

$$\Delta V = VM - VN = \rho I/2\pi,(1/AM - 1/BM) - (1/AN - 1/BN)-$$

$$\text{Thus, } \rho = 2\pi\Delta V/I \{(1/AM - 1/BM) - (1/AN - 1/BN)\} \qquad (11)$$

The equation (11) is applied for the ordinary four terminal arrays in measuring the earth resistivity in the field. Where the ground is uniform, the resistivity calculated from equation (11) should be constant and independent of both electrode spacing and surface location. When subsurface in homogeneities exists, the resistivity will vary with the relative positions of the electrodes. Any computed value is then known as the apparent resistivity ((ρa)) and will be a function of the form of the inhomogeneity. Equation (11) is basic equation for calculating the apparent resistivity for any electrode configuration.

2.2.4 ELECTRODE CONFIGURATIONS/ ELECTRODE ARRAYS

The electrodes by which current is introduced into the ground are called Current electrodes and electrodes between which the potential difference is measured are called Potential electrodes. The arrangement of current and potential electrodes on or in the ground for the purpose of making an electrical survey is called electrode configuration. The current electrodes are generally placed on the outside of the potential electrodes. Based on the position of current or potential electrodes and variation in distance between them, a variety of electrode configurations are possible of which some are mentioned below:

1. Wenner configuration
2. Schlumberger configuration
3. Dipole-dipole configuration
4. Pole–dipole configuration
5. Gradient configuration
6. Square array

The choice of array and distance between the electrodes is very important for obtaining the best possible information of the subsurface geology of a given area. In this research work, among these arrays these, only the Schlumberger configuration has been used. This Array is described below in detail.

SCHLUMBERGER CONFIGURATION:

Schlumberger proposed this configuration in 1916. This is the only array to rival the Wenner in availability of interpretational material. The Schlumberger configuration is widely used in measuring the earth resistivity, which isdesigned to measure approximately the potential gradient. In this array four electrodes are placed symmetrically from the center, where the outer two electrodes are current electrodes. The current electrodes (A &B) are spaced much further apart than the potential electrodes (M &N). The distance between the potential electrodes is 1/5 to 1/10th of the current electrodes.

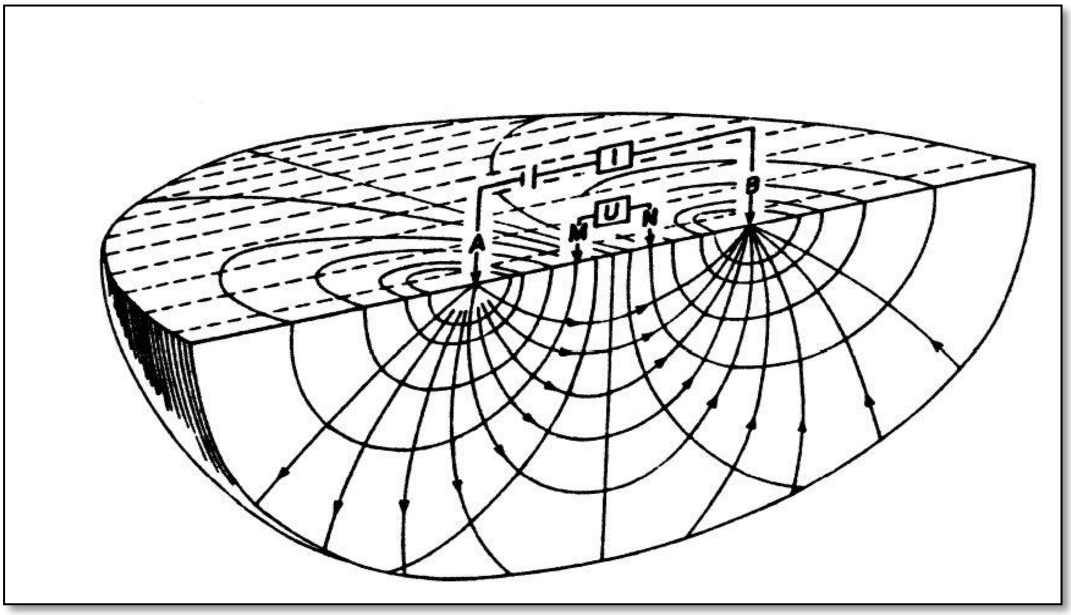


Figure 8: Schlumberger Configuration (A & B is current electrode and M & N is Potential electrode)

In depth probing the potential electrodes remain fixed while the current electrodes spacing is expanded symmetrically about the center of the spread. For large values of current electrode separation, it may be necessary to increase the potential electrode separation in order to maintain a measurable potential. In case of lateral exploration, the electrode spacing remains fixed and the whole array is moved along the line in suitable steps (Figure 7).

For Schlumberger configuration the apparent resistivity is determined by the following equation:

$\rho a = \pi\ (L2 - l2)/2l \times \Delta V/I$

Where, L = the half of the current electrode separation.

l = the half of the potential electrode separation.

ΔV = the measured potential difference.

I = the supplied amount of current.

The equation, $\rho a = \pi(L2\text{-}l2)/2l \times \Delta V/I$ can be derived from the general equation (11) of four terminal arrays. The general equation is-

□□= 2□/ ,(1/AM- 1/BM) - (1/AN- 1/BN)- x □V/I

= 2□/ (1/AM- 1/BM- 1/AN+ 1/BN) x □V/I

= K. □V/I (12)

Hence, the geometric factor, $K = 2\pi/\ (1/AM\text{-}\ 1/BM\text{-}\ 1/AN+\ 1/BN)$ (13)

From Fig.2.3 we get

AM = L-l; BM = L+l; AN = L+l; BN = L-l

Putting these values in equation (13) we get

K = 2π/ ,1/ (L-l) - 1/ (L+l) - 1/ (L+l) + 1/ (L-l)-

= 2π/ ,(L+l-L+l-L+l+L+l)/ (L+l) (L-l)-

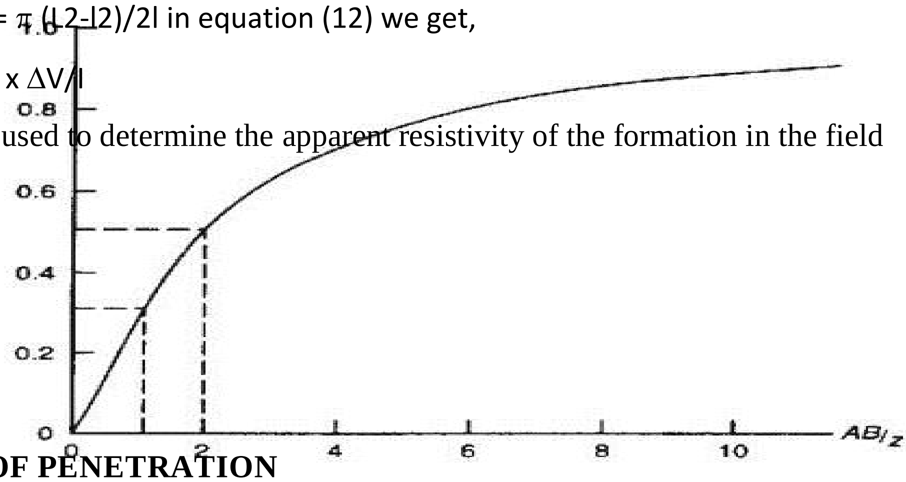
= 2π (L2-l2)/4l

= π (L2-l2)/2l

Now, putting K = π (L2-l2)/2l in equation (12) we get,

ρa = π (L2-l2)/2l x ΔV/I

This equation is used to determine the apparent resistivity of the formation in the field



2.2.5 **DEPTH OF PENETRATION**

In homogeneous ground the depth of current penetration increases as the separation of the current electrodes is increased. Figure 2.5 shows the proportion of current flowing beneath a given depth Z as the ratios of electrode separation L to depth Z increases.

When L=Z about 30% of the current flows below Z and when L=2Z about 50% of the current flows below Z. The current electrode separation must be chosen so that the ground is energized to the required depth, and should be at least equal to this depth.

Figure 9: Fraction of current penetrating below a depth Z for a current electrode separation AB
Proportion of current flowing below depth Z

2.2.6 GEO-ELECTRIC CHARACTERISTICS OF LAYERED MEDIA

Maximum rocks of sedimentary occurrence can be represented in the form of models of layered media with high and low specific resistance. In relation to the electrical currents, a homogeneous ground is one in which for instance, resistivity or conductivity remains the same at every point in the ground. Strictly speaking, the ground is therefore, never homogeneous, because the resistivity changes from point to point in small detail even in a given formation. The resistivities measured in exploration are actually average values for large volume of earth in place. The textural and structural properties, the way the mineral water gets distributed and the nature of the water influence the measured resistivities on the ground. The resistivity of a given rock depends on the direction of the current flow through the rock. In such a case the rock is said to be anisotropic. This anisotropy may be due to the microstructure of the rock.

For large volumes that are involved in measurements in exploration, there may also be an apparent anisotropy. A succession of beds alternating resistant and conducting will appear to have a higher resistivity normal to the bedding. The average electrical properties of each unit in a layered geoelectric section may be described with the following five parameters (Frischknecht and Keller, 1996):

1. The average longitudinal resistivity ρ_e along the bedding planes.
2. The average transverse resistivity ρ_t across the bedding planes.
3. Total longitudinal conductance S in the direction of bedding plane.
4. Total transverse resistance T perpendicular to the bedding plane.
5. Coefficient of anisotropy λ.

The above geoelectric parameters may be defined in terms of a column of rock of 1 meter square cut from the geoelectric unit. This column consists of m horizontal beds each with its own characteristic resistivity, ρI, and thickness, hi. The total thickness is H, the thickness of the geoelectric unit. The total resistance presented to current flowing vertically through such a column is found simply by adding in series the resistance of a single layer, the i^{th} layer, is found from the definition of resistivity to be

$$Ri = \rho i.\ l/A \qquad \text{(i)}$$

Where l is the width of the column through which current flows in the i^{th} layer with a thickness, h_i, and A is the cross-sectional area presented for current flow.

Since the column is $1m^2$, equation (i) reduces to:

$$Ri = \rho i\ hi \qquad \text{(ii)}$$

The sum of resistances contributed by all the beds in the section is the total transverse resistance.

This is one parameter in describing the geoelectric unit.

$$T = \sum_{i=l}^{m} \rho_i * h_i \qquad \text{(iii)}$$

This is one parameter in describing the geoelectric unit.

A second parameter, the average transverse resistivity □t across the bedding planes is found dividing the transverse resistance, T, by the total thickness of the unit, H:

$$\rho_t = \frac{T}{H} = \frac{\sum_{i=l}^{m} \rho i h i}{\sum_{i=1}^{m} hi}$$

The conductance for current flowing horizontally through the column of rock is found by summing the conductance through each individual layer. For the i^{th} layer, the conductance is designated the total longitudinal conductance as S, it is found to be:

$$Si = \frac{1}{Ri} = \frac{1}{\rho i} * \frac{A}{l} = \frac{hi}{\rho i}$$

This is another parameter in describing the geoelectric unit.

$$\sum_{i=l}^{m} Si = S = \sum_{i=l}^{m} \frac{hi}{\rho i}$$

The average conductivity for horizontal current flow is determined by dividing the total conductance by the height of the column

$$\sigma l = S/H$$

The reciprocal of the average conductivity is the average longitudinal resistivity,

$$\rho_l = \frac{H}{S} = \frac{\sum_{i=l}^{m} hi}{\sum_{i=l}^{m} \frac{hi}{\rho i}}$$

This is also a parameter in describing the geo-electric unit.

The longitudinal resistivity (ρl) is always smaller than the transverse resistivity ($\dot{\rho} t$).

$$\lambda = \sqrt{\frac{\rho t}{\rho i}} = \frac{\sqrt{ST}}{H^2} = \frac{\sqrt{(\sum hi\rho i.\sum hi/\rho i)}}{\sqrt{(\sum h_i^2)}}$$

The dependence of resistivity on the direction of current flow is anisotropy. A co-efficient of anisotropy may be defined by taking the square root of the ratio of resistivity measured in the two principal directions, across the bedding planes and along the bedding planes (Frischknecht & Keller, 1966).

(i)

2.3 BASIC IDEA AND FUNDAMENTALS OF RESISTIVITY SURVEY

Geo electrical resistivity survey has long been used for ground water survey and the method is found to be very successful. As a preliminary step for the development of ground water, geo electrical resistivity survey proved to be very effective- (Bugg &Lloyed, 1976; Serres, 1969; Urish & Frohlich, 1990; Woobaidullah *et al*, 1996). In resistivity method, artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Generally actual resistivities are determined from apparent resistivities, which are computed from the measurements of current and potential differences between two pairs of electrodes placed in the ground surface. The procedure involves measuring a potential difference between two potential electrodes (M & N) resulting from an applied current through two other current electrodes (A & B) outside but in line with the potential electrodes. Thus, the measured current and potential differences yield an apparent resistivity over an unspecified depth. If the spacing between the electrodes is increased deep penetration of the electric field occurs and a different apparent resistivity is obtained. Two main types resistivity surveys are-

(i) Vertical Electrical Sounding and

(ii) Constant Separation Traversing (CST/ Profiling).

2.3.1 VERTICAL ELECTRICAL SOUNDING (VES)

This method is used in geotechnical survey to determine overburden thickness and also in hydrogeology to define horizontal zones of porous strata. In this method, the current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. Consequently readings are taken as the current reaches progressively greater depths. In this case Schlumberger configuration is favored.

2.3.2 CONSTANT SEPARATION TRAVERSING (CST)/PROFILING

This method is used to determine the lateral variations of resistivity. The current and potential electrodes are maintained at a fixed separation and progressively moved along a profile. This method is employed in mineral prospecting to locate faults or shear zones and to detect localized bodies of anomalous conductivity. It is also used to determine variation in bedrock depth and the presence of steep discontinuity. Results from a series of CST traverses with fixed electrode spacing can be employed in the production of resistivity contour maps. In this case Wenner configuration is favored

In this research work, only vertical electrical sounding (VES) survey has been carried out.

4.1 2.4. Interpretation Techniques of Sounding Data

Normally, the sounding data are plotted on double logarithmic paper of the same scale as in the master curve to obtain a field sounding curve. In interpretation of vertical electrical sounding curves, generally the field curve is matched with some standard curve computed for large number of models. Album is available for standard curves of two, three and four layer models (Orellana & Mooney, 1972). There are four approaches, which may be used in interpreting multiple-layer resistivity sounding data:

Complete curve matching, using curves computed for mathematical models with two, three and four layers covering infinity uniform substratum. Partial curve matching in which portions of the field data are matched with the curves computed for a single overburden.

Equivalent curve matching, in which all theoretical curves having similar shapes are grouped to form a single equivalent curve for comparison with field data. Observation of the positions of the maxima and minima of the field data:

For convenience in selecting the method of interpretation, sounding curves are classified depending upon the magnitudes of resistivity. A curve which has a minimum is called a type H curve (Fig.10A), and indicates the presence of a three layer sequence with the resistivity ratios varying as $\rho1>\rho2<\rho3$. If the field curve shows a maximum $\rho1<\rho2>\rho3$, it is classified as type K (Fig. 10C). In this case the middle layer is more resistive than the layer above and below. A three layers resistivity model in which the resistivity decreases with depth is called type Q i.e. $\rho1>\rho2>\rho3$ (Fig. 10D). A three layers resistivity model in which the resistivity increases with depth is called type A i.e. $\rho1<\rho2<\rho3$ (Fig. 10B).

When there are more than three layers with different resistivity apparent on a field curve, several letters are used to classify the curve. For example, an HK curve indicates a sequence of resistivity $\rho1>\rho2<\rho3>\rho4$.

Normally the measured apparent resistivity values are plotted against half of the current electrode separation on double logarithmic paper and is called vertical electrical sounding (VES) curve. Among the above four approaches, complete curve matching and partial curve matching techniques are described.

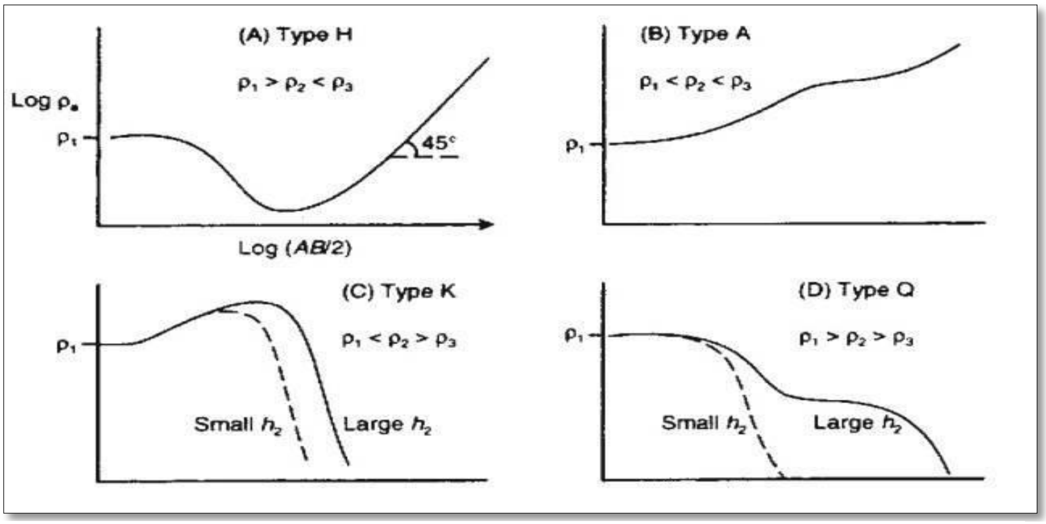


Figure 10: Various types of curve A. H-type; B. A-type; C. K-type; D. Q-type

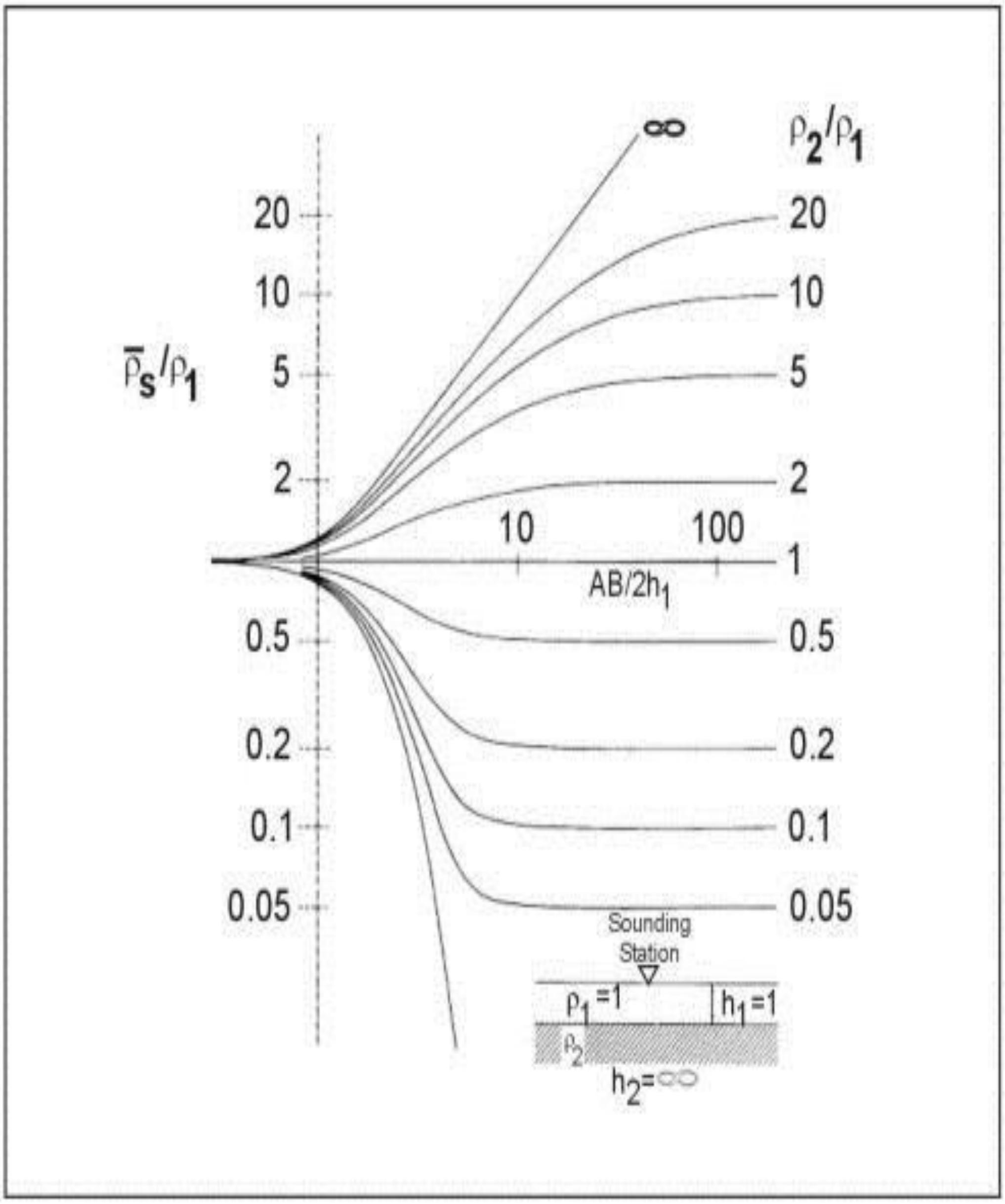
2.4.1 TWO AND THREE LAYERED MASTER CURVES

Interpretation procedures of two layer and three layer resistivity sounding curve using curve matching technique are described below:

Two layer Master Curve:

In two-layer case involving a single layer of specified thickness h overlying an infinitely thick homogeneous substratum, a family of curves is plotted for different values of h and k. The correct values of h and k are established from the characteristics of master curve giving the best match. Originally the master curves were plotted on a linear scale as demonstrated by Tagg. It is now customary to plot such curves on a logarithmic scale like that shown in (Fig. 10) for the Schlumberger configuration. The abscissa is the logarithm of a/h, the ratio of the potential electrode separation to 1st layer thickness. The ordinate is the logarithm of the ratio of the apparent resistivity to its limiting value ρ1. It will be seen that ρa approaches ρ1 when the current electrode separation is small compared with the thickness of the top layer and ρ1 when it is large.

Figure 11: Typical master curves for Schlumberger electrode arrangement when layer of



Resistivity ρ1 and thickness h overlies substratum of resistivity ρ2 (Parasnis).

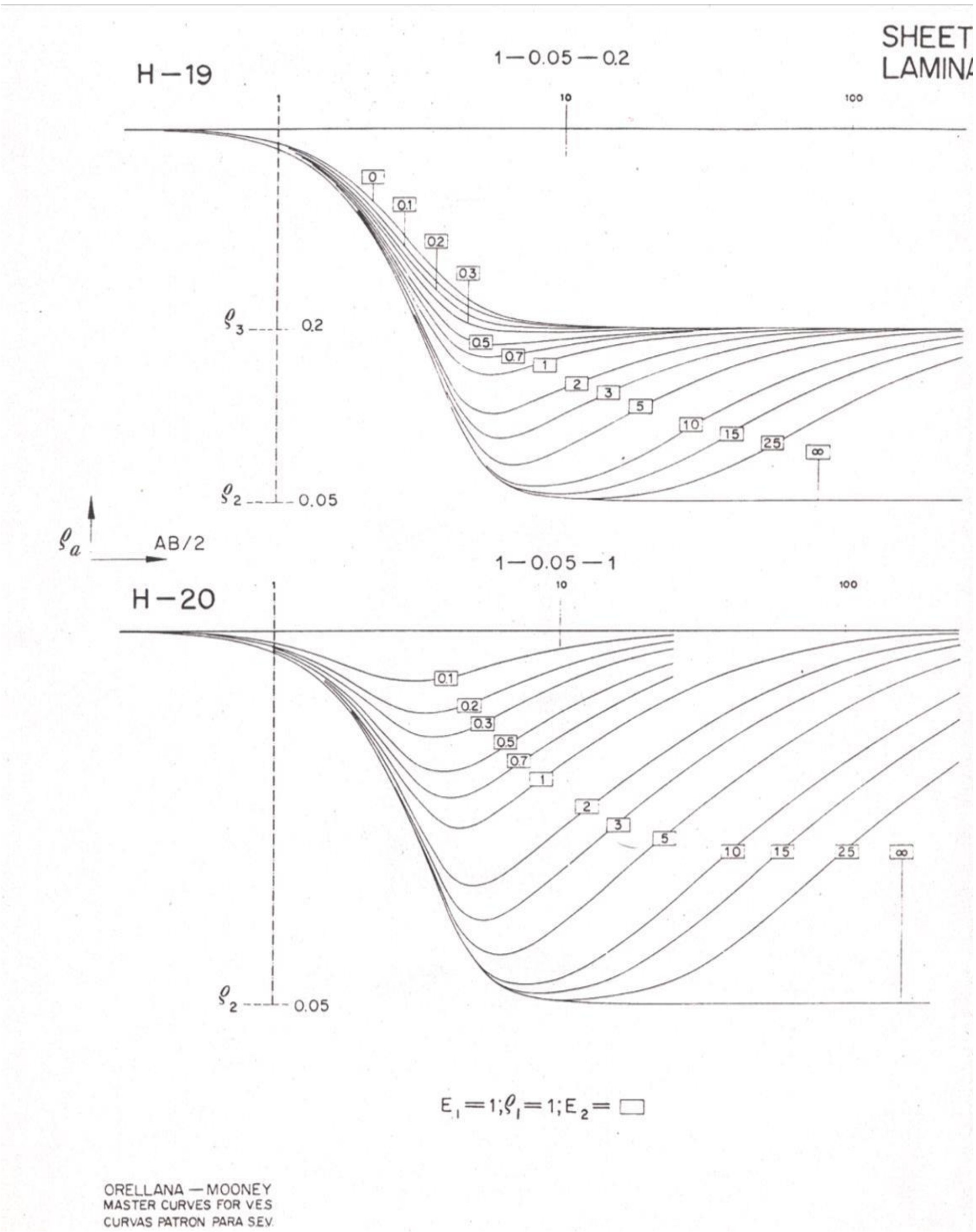


Figure 12: Typical set of logarithmic three layer curves (Milton B. Dobrin)

Three Layer Master Curve

In this case, two layers of specified thickness h_1 and h_2 and corresponding resistivity of ρ_1 and ρ_2 respectively are overlying a layer of infinitely thickness and resistivity ρ_3 (Fig. 11). The curves have been computed for the Schlumberger electrode configuration on the assumption that only the spacing of the current electrodes has been increased. The data points for ρ_a versus AB/2 (where AB is the current electrode separation) are plotted on semitransparent log-log paper. The graph paper is then superimposed on the sheet containing the set of curves chosen for comparison and its position is shifted horizontally and vertically to obtain the best possible fit.

2.4.2: MANUAL INTERPRETATION OF SOUNDING CURVES BY COMPLETE CURVE MATCHING TECHNIQUE

Some pre-calculated catalogues of theoretical curves can rarely be used in complete curve matching in view of the large number of parameters needed to specify the contrasts in resistivities and ratios of thickness when several layers are present. With a single overburden, only one parameter is necessary, the ratios of resistivities for the overburden and the bedrock. With two layers resting on basement, three parameters are required to specify completely the combinations of resistivities and thickness: ρ_2/ρ_1, $\rho_3/\rho_2$and h_2/h_1 (Frischknecht & Keller, 1966). With each additional layer two more parameters are required. Several steps are required for the interpretation of the three layers VES curve by complete curve matching technique and they are as follows:

1. The sounding data are plotted on a bi-logarithmic paper of the same scale as in the master curve.
2. Based on the shape of the field VES curve, selection of a three-layer muster curve sheet or sheets, which exhibit the general shape.
3. The transparent paper is superimposed containing field VES curve on to the master curve sheet.
4. The transparent sheet is moved over the master curve sheet always keeping the axes strictly parallel until the field curve matches with one of the master curve or lies between any two of them.
5. The cross of the master curves is drawn over the transparent sheet and also the two resistivity marks (for ρ_2& ρ_3) are noted. A note of the thickness ratio value given for the matched master curve is made.

6. The cross on the transparent sheet gives the resistivity ($\rho 1$) and thickness ($h1$) of the first layer.
7. The resistivity of the second layer is calculated from the resistivity ratio. It is equal to the resistivity index for the matched curve multiplied by the resistivity of the first layer. Similarly resistivity of the third layer ($\rho 3$) is equal to the resistivity index for the matched curve multiplied by the resistivity of the first layer.
8. The thickness of the second layer ($h2$) is equal to the thickness ratio value for the matched curve multiplied by the thickness of the first layer ($h1$).

When a perfect match is not obtained with any of the theoretical curves but lies between two theoretical curves, then the thickness of the 2nd layer has to be found out by interpolation.

2.4.3 MANUAL INTERPRETATION OF SOUNDING CURVES BY PARTIAL CURVE MATCHING TECHNIQUE

For manual interpretation of sounding curves, they should be on the same log scale as the master curves. Partial curve matching method of interpretation using auxiliary points and charts has been proposed by Hummel (1932), Evert (1943) etc. This method of interpretation can be employed for interpreting three or more layered field VES curves.

However, the error range will increase rapidly in case of four or more layers.

In partial curve matching, short segments of a resistivity sounding curve are selected for interpretation using the theoretical curves for the single overburden, usually starting with the shorter spacing and working towards the longer spacing.

As each portion of the curve is interpreted the layers comprising the interpreted portion of the sounding curve are lumped together to form a fictitious uniform layer with a lumped resistivity, ρe and a lumped thickness, he. This fictitious layer is then used in place of the surface layers when the next portion of the curve is analyzed (Frischknecht & Keller, 1966).

The manual interpretation procedure of three or more layer sounding curve by partial curve matching technique using two layer master curves and auxiliary point charts is as follows:

Field VES curve should be drawn and on a transparent log-log paper of same modulus as that of the master curves and smoothened. Then the left-hand branch of the field curve is to be matched with the two layers theoretical curve by moving the field curve in vertical and horizontal directions. In this movement the axes of the field curve and theoretical curve must be parallel. When a match is obtained with any of the theoretical curves, the origin is marked on the transparent sheet and the value of $\rho 2/\rho 1$ of the master curve is also noted.

Depending on the curve types the same type of auxiliary point chart from catalogue is selected. The transparent sheet is kept on the auxiliary point chart, so that the cross or the point ρ_2/ρ_1 coincides with origin of the chart. Then the auxiliary line for the value of ρ_2/ρ_1 which is already noted is drawn.

Again the transparent sheet is placed on the two layer theoretical curves and it is moved in horizontal and vertical directions over the two layer set such that the auxiliary line always passes through the origin of the theoretical curves. This process is continued till a match between the right hand branch of the sounding curve and theoretical curve is obtained. In matching situation the origin of the theoretical curve on transparent sheet is traced and the resistivity index (ρ_3/ρ_e) of the matched master curve is noted.

The second cross yields parameters of a fictitious/equivalent layer (ρ_e, h_e). Resistivity of the third layer (ρ_3) is obtained by multiplying ρ_e with resistivity index.

To calculate the thickness (h_2) of the second layer, the transparent sheet is placed over the same auxiliary point chart so that the first cross coincides with the origin of the chart. The position of the second cross is noted which is equal to h_2/h_e. Since h_e is known h_2 can be calculated.

Four or more layer field curves also can be interpreted by partial curve matching technique by extending the process.

2.4.4: INTERPRETATION BY COMPUTER

After manually determining different parameters all the data were fed into a computer. A software Maq Resistivity was used to analyze the field data by computer. Maq Resistivity is an interpretative, graphically oriented modeling program for interpretation of resistivity sounding data.

For computer interpretation the field data are compared with the data computed from approximated layered model. If the agreement between two sets of data is unsatisfactory, then the parameters of the layered model are adjusted. The adjustment of the layered parameters can be done manually or by computer using iterative inversion algorithm. The adjustment procedure is repeated until sufficient agreement between the computed data and observed data is obtained.

CHAPTER 3

FIELD SURVEY

3.1. INTRODUCTION

To perform the geophysical survey a number of instruments are required. For introducing the current into the ground, power source either battery or generator is needed. The amount of current introduced into the ground and the voltage difference produced between the potential electrodes due to the current flow are measured by an amperemeter and a voltmeter respectively. In a modern Resistivity meter these two measuring instruments are put together. To increase the range of exploration Power Booster can be used. By the use of Power Booster, continued improvement of measurement accuracy (Signal-Noise Ratio) can be expected along with expansion of the scale on which exploration can be conducted. To introduce the current into the ground from power source electrodes (metallic spikes) and cables (for connecting ampere meter and voltmeter to the electrodes) are used. For communication at large distances with the resistivity crew dealing with the electrodes like walky-talky and for getting the location of the centre of the array GPS are also required.

3.2 LIST OF EQUIPMENT

To perform Resistivity survey comprising of Vertical Electrical Sounding (VES) the following equipment is required:

- Resistivity meter
- Battery
- Electrodes (each 3 ft long and ½ inch dia)
- Cables
- Power Booster
- Walky –talky and GPS
- Other Accessories

3.3 DESCRIPTION AND SPECIFICATION OF MAJOR EQUIPMENTS

RESISTIVITY METER

A **Terrameter** (Model- **SAS 1000**), 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. **Terrameter** 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. These data can be transferred to external computer via multifunction connector with current and potential including RS232 communication for external devices as PC, LOG and Imaging Banana connectors for current and potential via RS-232 C interface. Specification of the **Terrameter** (Model-SAS 1000) is provided in table 2.

Table 2: Standard specifications for **Terrameter** (Model-SAS 1000)

Terrameter SAS 1000

Receiver______________________________________

Isolation Input channel is galvanically separated

Input Voltage Range + / - 400 V

Input Impedance 10 MOhm minimum

Precision Better than 0.1 % (in the range 4 - 200 ohm at 1 s integration

Accuracy 1 % typical

Resolution Theoretical 30 nV

Dynamic range Up to 140 dB plus 64 dB automatic gain (at 1 s integration)

Automatic ranging + /- 2.5 V + / - 10 V + / - 400 V

Measuring___________________________________

Resistivity YES SP YES IP YES

Current pulse length from 0.1 s to 4 s User selectable

IP Windows Up to ten time windows IP integration interval Up to 8 s

Transmitter___________________________________

Output power 100 W Current transmission True Current Transmitter

Output Current Accuracy Better than 0.5 % at 100 mA

Output Current 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 mA (operator set or auto ranging) Maximum Output Voltage +/- 400 V (800 V peak-to-peak) Cycle type in resistivity mode Plus-Minus-Minus-Plus Cycle type in IP mode Plus-Zero-Minus-Zero

General_______________________________________

Casing Rugged Aluminium case meets IEC IP 66

Computer PC compatible

Display LCD, 200 x 64 pixels, 8 lines of 40 characters

I / O ports Multifunction connector with current and potential including RS232 communication for external devices as PC, LOG and Imaging Banana connectors for current and potential

POWER SOURCE (BATTERY):

An external DC 12V battery was used during the field survey. The red clip of the power cord is positive (+ve) and the black clip of the power cord is negative (-ve).

ELECTRODES:

The electrodes used during the survey were merely metal stakes. Four electrodes were used in the survey: two for current insertion into the ground and the other two for potential measurements. Each electrode is about 1 m long.

CABLES:

Single core, multi-strand copper wires insulated with PVC cables, was used in resistivity works. Four large and two small reels were used during the survey: four large reels of 400m cable each for current flow and the other two small reels of 100m cable for potential measurements.

GPS:

A GPS is used to determine the VES locations. The position of the vertical electrical resistivity i.e latitude and the longitude is noted. Survey related equipment are shown in figure 13.

Figure 13: Survey required instruments (Resistivity meter, Battery, Cable reels)

4.2 3.4 Field Investigation

Field work has been carried out in the month of April 29 to May 03, 2015. Vertical electrical sounding survey was executed at 12 locations to follow resistivity variation with depth. Latitude and longitude of each location is given in Table 3.

Table 3: Locations of the mid points of VES

VES name	Latitude	Longitude
VES 01	22^{0}45’18.63’’	91^{0}28’49.12’’
VES 02	22^{0}45’18.94’’	91^{0}29’03.60’’
VES 03	22^{0}44’49.12’’	91^{0}29’11.08’’

VES 04	$22^0$44’53.68’’	$91^0$29’29.01’’
VES 05	$22^0$44’18.70’’	$91^0$29’18.70’’
VES 06	$22^0$44’13.52’’	$91^0$30’02.41’’

4.3

4.4 3.5 Field procedure of Vertical Electrical Soundings (VES)

6 Vertical Electrical Soundings have been executed in the study area using Schlumberger configuration. The VES location is shown in figure 14. Maximum spreading used throughout the survey area is 500m with penetration depth of about 200m. The sounding array direction was chosen along the strike following the attitude of beds. The sites were selected covering the whole area based on the availability of space. After selecting the site, the center of the array is marked. Survey equipment is kept at the center. From the center 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. Four folds stacking are used during the measurement. The measured resistance values are then multiplied with the appropriate pre-calculated geometric factors to obtain the value of apparent resistivity for each position of electrodes. If large variations are observed in the subsequent values of apparent resistivity measurements are repeated to find the steadiness in the measurements.

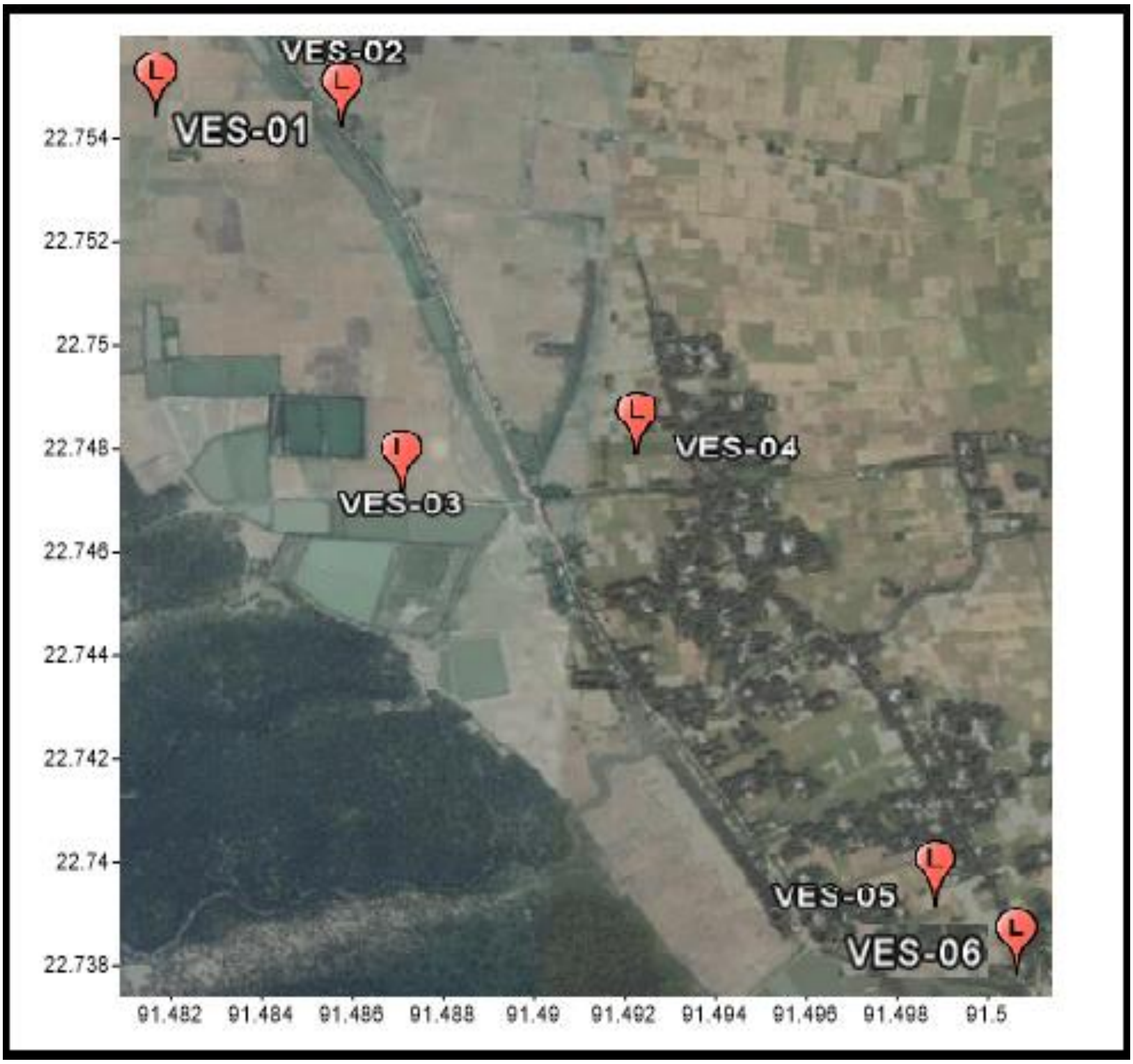


Figure 14: Map showing VES location along with Borehole location

CHAPTER 4

INTERPRRETATION OF GEOELECRRIC

RESISTIVITY DATA

4.5 4.1 Introduction

The sounding data are plotted on double log sheet to see the smoothness of the data as well as for manual interpretation. The data obtained thus show high regularity and smooth curves on log sheets reflect the quality of the data. The observed sounding curves are KHA, KQH, KHK,QKH, AH and AKHA types. This field sounding curve is then matched with master/theoretical/standard curves. The master curves are based on some layered mathematical models following theoretical equations. The observed sounding curves are matched with master curves manually using partial curve matching technique to determine the input model for software based interpretation. The positions of peaks and troughs and the rising and falling slopes of the individual curves are not uniform and similar. These variations in the characteristics of observed curves indicate variable subsurface condition.

4.6 4.2 Interpretation through Software

The model obtained through manual matching is used as input model for software based interpretation. The software used for the interpretation is 1X1D. The final model obtained through software based matching is taken to be the subsurface layered geo-electric model of VES point (figure 15).

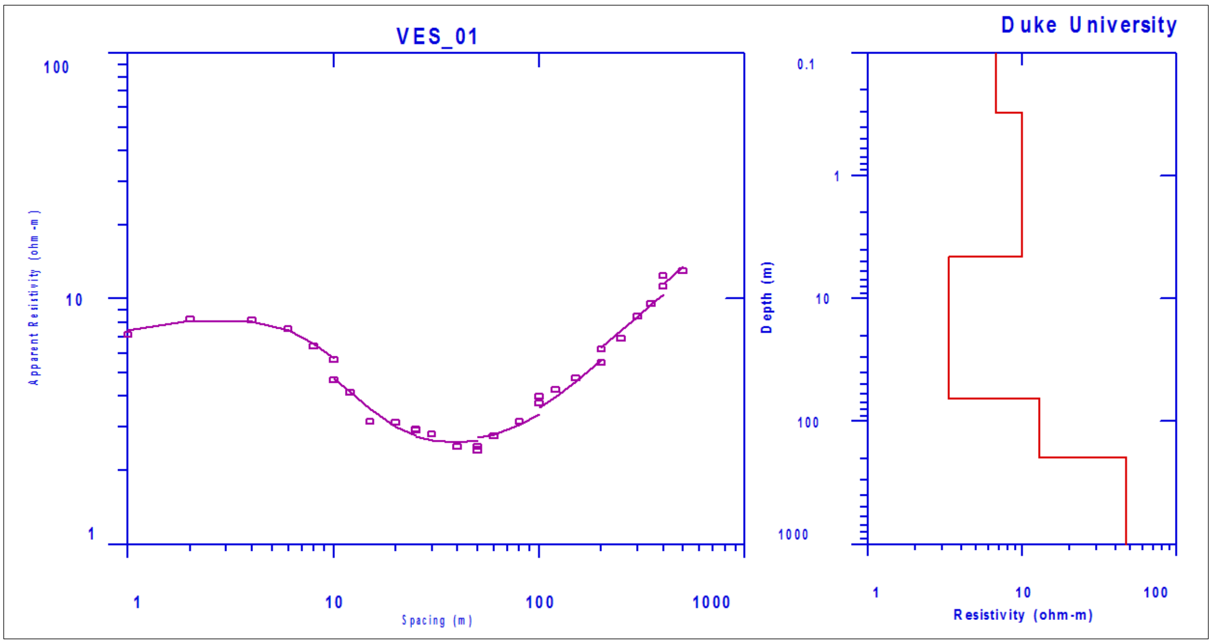


Figure 15: Sounding Curve VES 01 (Left) and the respective subsurface geo-electric model (Right)

4.7 4.3 Interpreted Results of VES data

Six vertical electrical soundings (VES) are executed following Schlumberger configuration with a maximum spread (AB/2) of 500m. Locations of these VES points are shown in figure 1. The area is a northwest southeast trending strip of land and the soundings are distributed throughout the whole area.

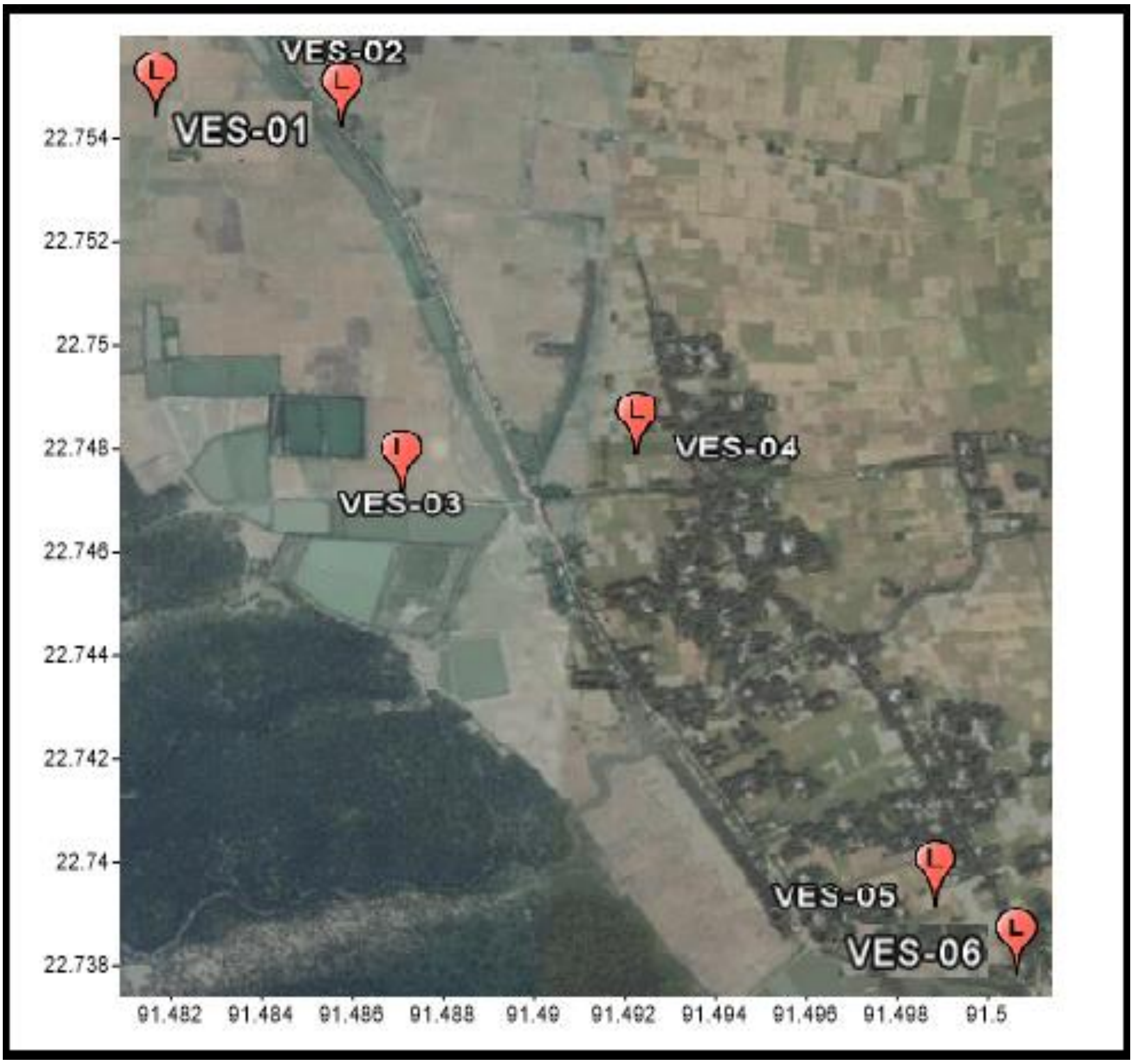


Figure 16: Map of the Mirersharai BEZA area showing VES Location

4.3.1 Results of sounding survey

Table 4: Interpretation results of VES conducted in Mirersharai at BEZA

VES-01			VES-02			VES-03		
Resistivity(Ωm)	Thickness m	Depth m	Resistivity (Ωm)	Thickness m	Depth m	Resistivity (Ωm)	Thickness m	Depth m
6.7174	0.30667	0.30677	1.8293	0.25688	0.25688	5.6512	0.4255	0.42555
9.9083	4.2530	4.5597	7.6442	0.46425	0.72112	6.7818	2.7301	3.1557
3.3174	60.783	65.343	3.0755	4.7907	5.5118	3.2791	11.129	14.285
			1.1900	30.606	36.118	1.9721	27.249	41.534
12.823	131.75	197.09	7.8477	54.867	90.985	12.823	123.00	164.54
46.817	Base not seen		26.559	Base not seen		1.5937	Base not seen	
VES-04			VES-05			VES-06		
Resistivity (Ωm)	Thickness m	Depth m	Resistivity (Ωm)	Thickness m	Depth m	Resistivity (Ωm)	Thickness m	Depth m
14.615	0.70734	070734	3.7740	0.26982	0.26982	2.0931	0.50542	0.5054
9.2215	3.1652	3.8726	5.0656	3.2898	3.5596	2.2732	10.484	10.989
11.760	8.4717	12.344	7.1242	6.3731	9.9327	6.3445	28.267	39.256
3.0875	49.486	61.83	2.1242	72.865	82.79	1.5937	75.488	114.7

		0			8			4
9.9083	42.754	104.5 8	15.937	90.876	173.6 7	12.474	138.55	253.2 9
38.300	Base not seen		24.525	Base not seen		32.689	Base not seen	

Vertical electrical sounding 01 was carried out at the northwest corner of the area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 01 shows a 5 layer geoelectric model (Figure 15, Table 4). The top layer composing of surface soil shows resistivity 6.72 Ωm of about 0.5m thickness. The 2nd layer shows resistivity of 9.90 Ωm with a thickness of 4m and may be composed of silty sandy. 3rd layer shows resistivity of 3.3 Ωm. The lithology is composed of fine sand, silt and clay with a thickness of about 70m. 4th layer shows resistivity around 12 Ωm reflecting lithology as fine sand and silt and the thickness is around 130m. The bottom layer shows resistivity 46.8 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer cannot be determined.

Vertical electrical sounding 02 was carried out east of VES 01 at the northwest corner of the area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 02 shows a 6 layer geoelectric model (Table 4). The top layer composing of surface soil shows resistivity 1.83 Ωm of about 0.25m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 1.19 to 7.87 Ωm with a cumulative thickness of around 90m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom layer shows resistivity 26.55 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer cannot be determined.

Vertical electrical sounding 03 was carried out at the centre of the area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 03 shows a 6 layer geoelectric model (Table 4). The top layer composing of surface soil shows resistivity 5.65 Ωm of about 0.42m thickness. The 2nd, 3rd, and 4th layers show resistivity of 1.97 to 6.78 Ωm with a cumulative thickness of around 41m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The 5th layer shows resistivity 12.82 Ωm indicating the layer as sandy one with fresh water with a thickness of 123 Ωm. The following layer shows low resistivity around 1.6 Ωm indicating layer not suitable for ground water development.

Vertical electrical sounding 04 was carried out at the centre of the area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 02 shows a 6 layer geoelectric model (Table 4). The top layer composing of surface soil shows resistivity 14.61 Ωm of about 0.70m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 3.1 to 11.76 Ωm with a cumulate thickness of around 104m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom layer shows resistivity 38.3 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer cannot be determined.

Vertical electrical sounding 05 was carried out at the north-east corner of the survey area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 02 shows a 6 layer geoelectric model (Table 4). The top layer composing of surface soil shows resistivity 3.77 Ωm of about 0.27m thickness. The 2nd, 3rd, 4th and 5th layers show resistivity of 2.12 to 7.12 Ωm with a cumulative thickness of around 82m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom 5th and 6th layers show resistivity 15.94 to 24.53 Ωm respectively indicating the layer as sandy one with fresh water. Thickness of the layer of the 5th layer is around 90m and thickness of the 6th layer cannot be determined.

Vertical electrical sounding 06 was carried out at the south-east corner of the survey area along northwest-southeast direction. The maximum spreading for the array was taken 500m (AB/2 = 250m). Interpretation of VES 06 shows a 6 layer geoelectric model (Table 4). The top layer composing of surface soil shows resistivity 2.09 Ωm of about 0.51m thickness. The 2nd, 3rd, and 4th layers show resistivity of 1.59 to 6.34 Ωm with a cumulative thickness of around 114m and may be composed of silty sand or clayey sand or sand with brackish to saline water. In other words layers are not suitable as aquifers. The bottom 5th and 6th layers show resistivity 12.47 to 32.68 Ωm respectively indicating the layer as sandy one with fresh water. Thickness of the layer of the 5th layer is around 138m and thickness of the 6th layer cannot be determined.

4.3.2 Resistivity Map of the possible aquifer

Resistivity distribution map of the possible aquifer zone (Fig. 17) shows the lowest resistivity around 14 Ωm at the central part of the investigated BEZA in and around VES 3 and VES 4. Resistivity increases towards all directions from the central part and maximum resistivity (around 40 Ωm) as found from interpretation is in the north-western corner at VES 01. The south-eastern corner shows resistivity around 25 Ωm around VES 05 and VES 06.

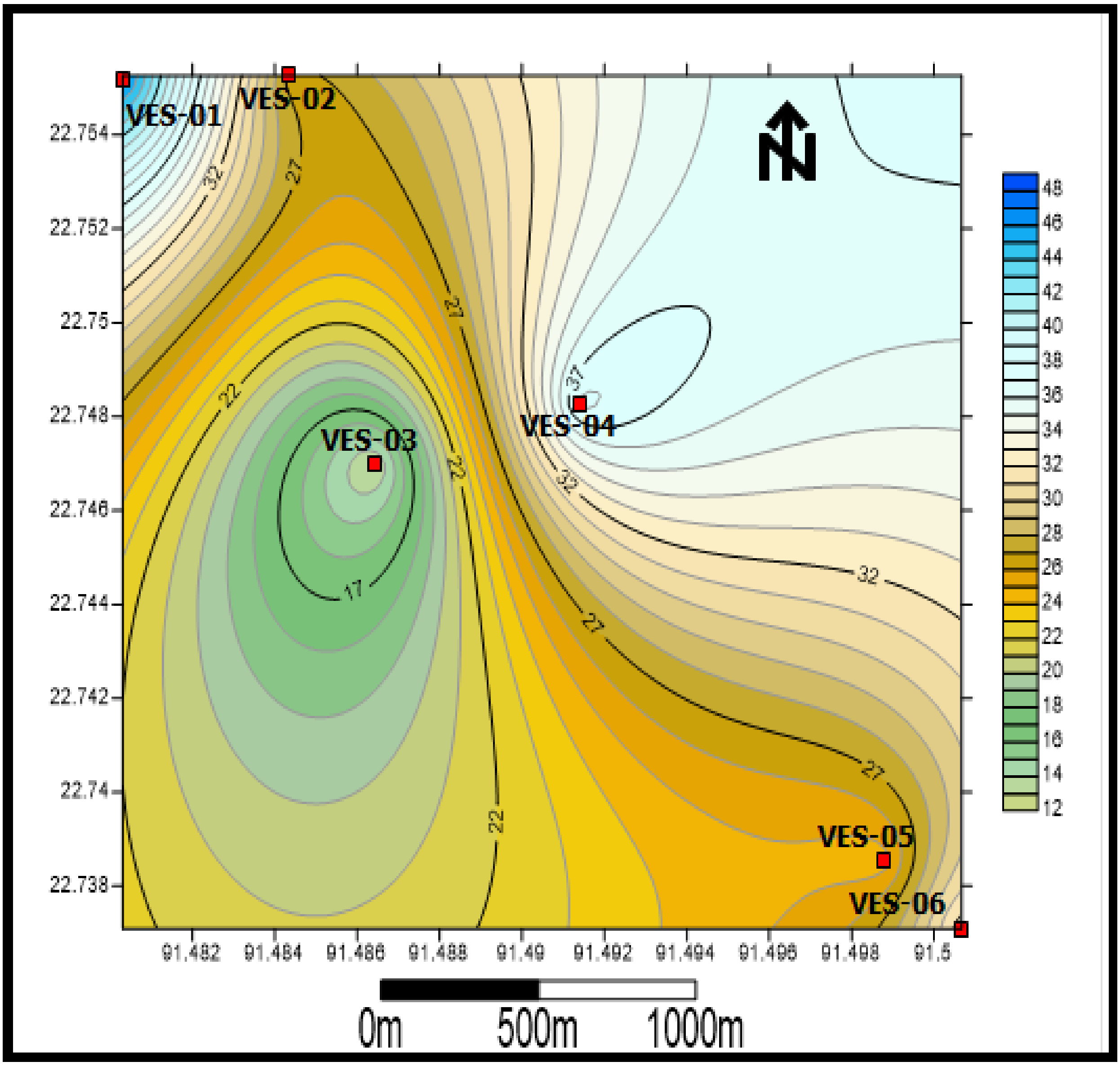


Figure 17: Map showing the resistivity variation of suitable fresh water zone in the BEZA area

4.7.1 4.3.3 Depth Contour along the Top of the Aquifer

The depth contours along the top of the aquifer (Figure 18) show that the depth to the aquifer increases from north northeast to northwest and south southeast with minimum depth around 100m at VES 02. Maximum depth around 200m is found at VES 06.

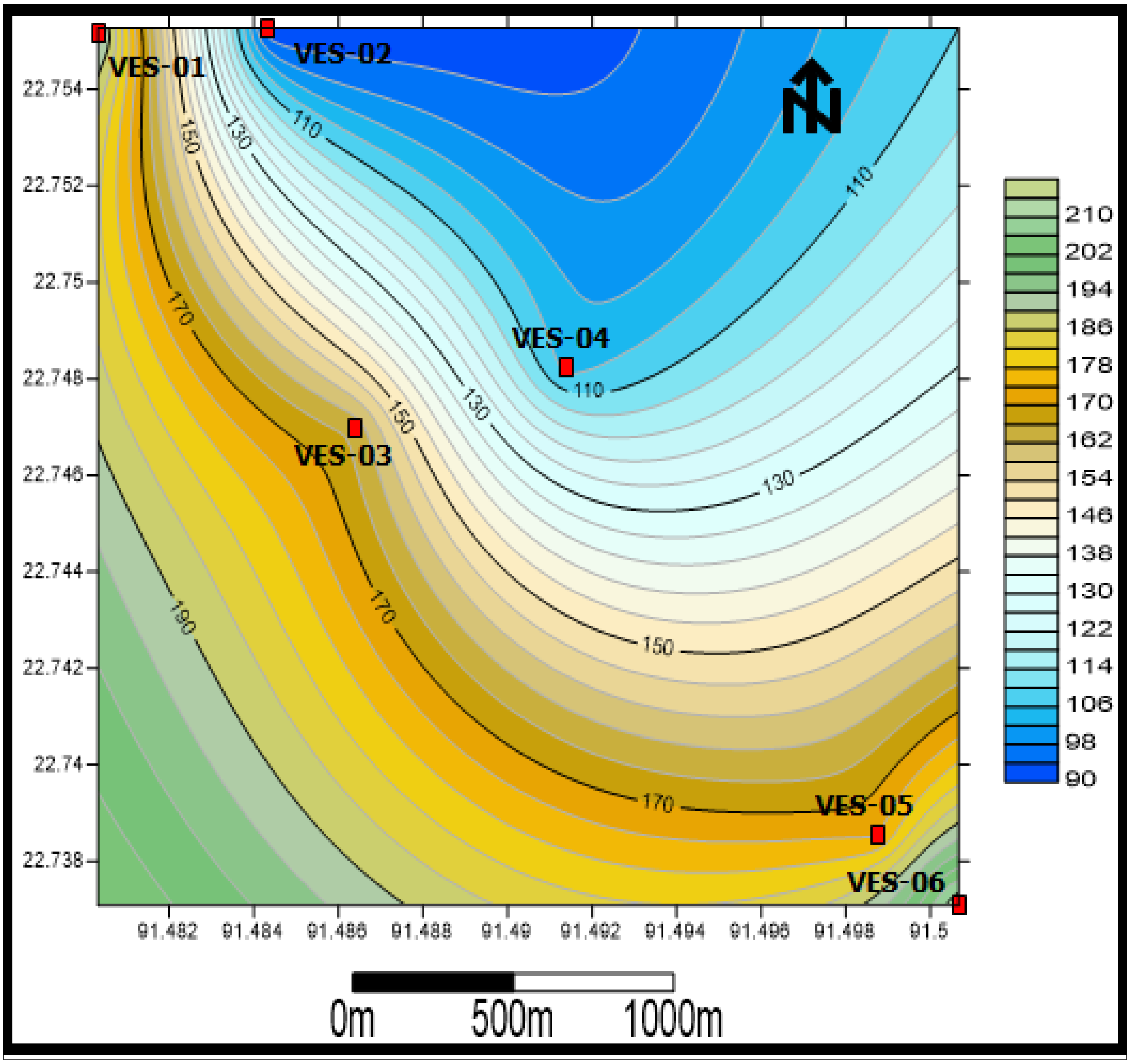


Figure 18: Map showing the depth variation of suitable fresh water zone IN Mirersharai BEZA area

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Electrical Resistivity Sounding survey data obtained from 6 locations of the area has been analyzed for the assessment of subsurface hydro-geological conditions of the study area. Interpretation of VES data shows existence of six geo-electric layers up to a depth of 250m.

vi) The geo-electric layer is the Top soil shows a wide range of resistivity (1.8 to 14.6 ΩM) variation regulated by the composition and the moisture content. Thickness of this unit varies from 0.25 to 0.7m.

vii) Geo-electric layers is II, III, IV and V for VES 02 and VES 04 show resistivity 1.19 to 9.90 Ωm representing either silty clay or sandy clay composition or sand saturated with saline to brackish water. In either case the layers are not suitable for ground water development. The cumulative thickness of these layers vary from around 100m

viii) The depth contours along the top of the aquifer show that the depth to the aquifer increases from north northeast to northwest and south southeast with minimum depth around 100m to 200m.

ix) The bottom layers VI and V for VES 03, VES 05 and VES 06 show resistivity in the range of 12.47 to 46.8 Ωm indicating the layer as sandy one with fresh water. Thickness of the layer of the 5^{th} layer is around 123m, 90m, and 138m respectively for VES 03, VES 05 and VES 06 and thickness of the 6^{th} layer cannot be determined.

x) Interpretation results of VES data (not so consistent) and constructed resistivity and depth maps in the study area suggest the layers showing resistivity above 12 Ωm are suitable for further studies. Depth to this suitable zone increases from north northeast to northwest and south southeast with minimum depth around 100m at VES 02 to 200m at VES 06.

RECOMMENDATION:

As you have asked to suggest Three test drilling locations based on the suitability of encountering good quality ground water following locations are provided based on the Interpretation results of VES data (not so consistent) and constructed resistivity and depth maps:

- VES location 1 may be the first site for test drilling. The site shows high resistivity (46 Ωm) at a depth of around 190m.
- 2nd test drilling site may be the VES location of 5 or 6 in the southeast corner of the area. Interpretation of VES 5, 6 shows resistivity around 24 to 32 Ωm at a depth more than 200m.
- 3rd test drilling site may be the VES location 4 in the central part of the area. Interpretation of VES 4 shows resistivity around 38 Ωm at a depth more than 104m. VES 3 located to the west of VES 4 not very far shows relatively low resistivity (12 Ωm).

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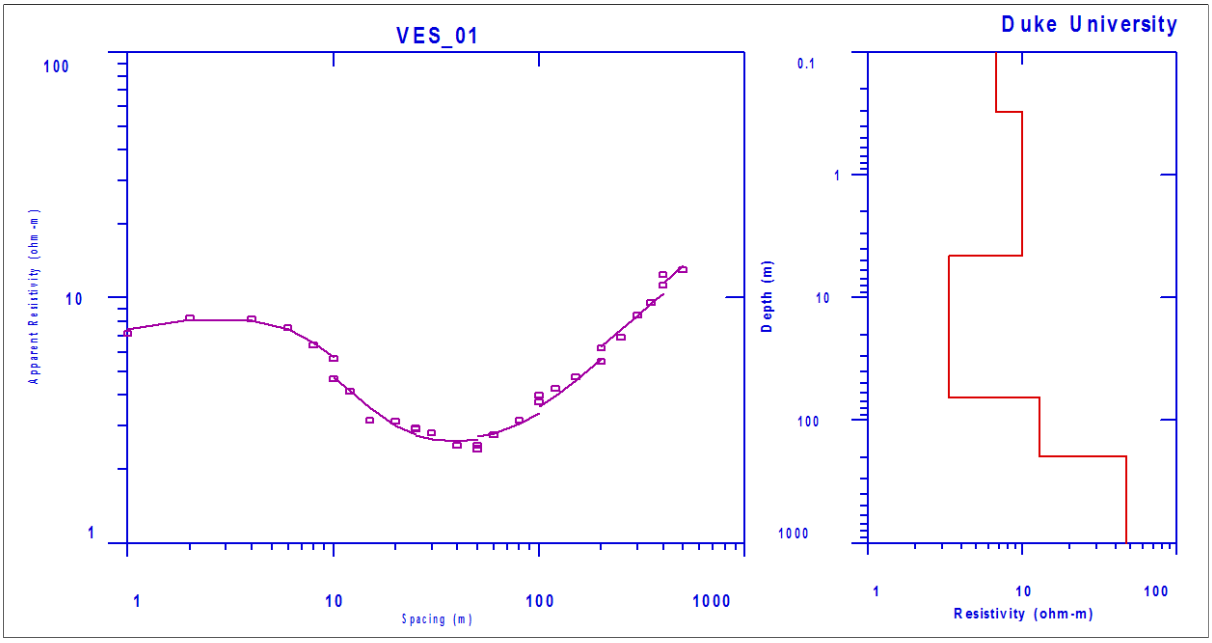
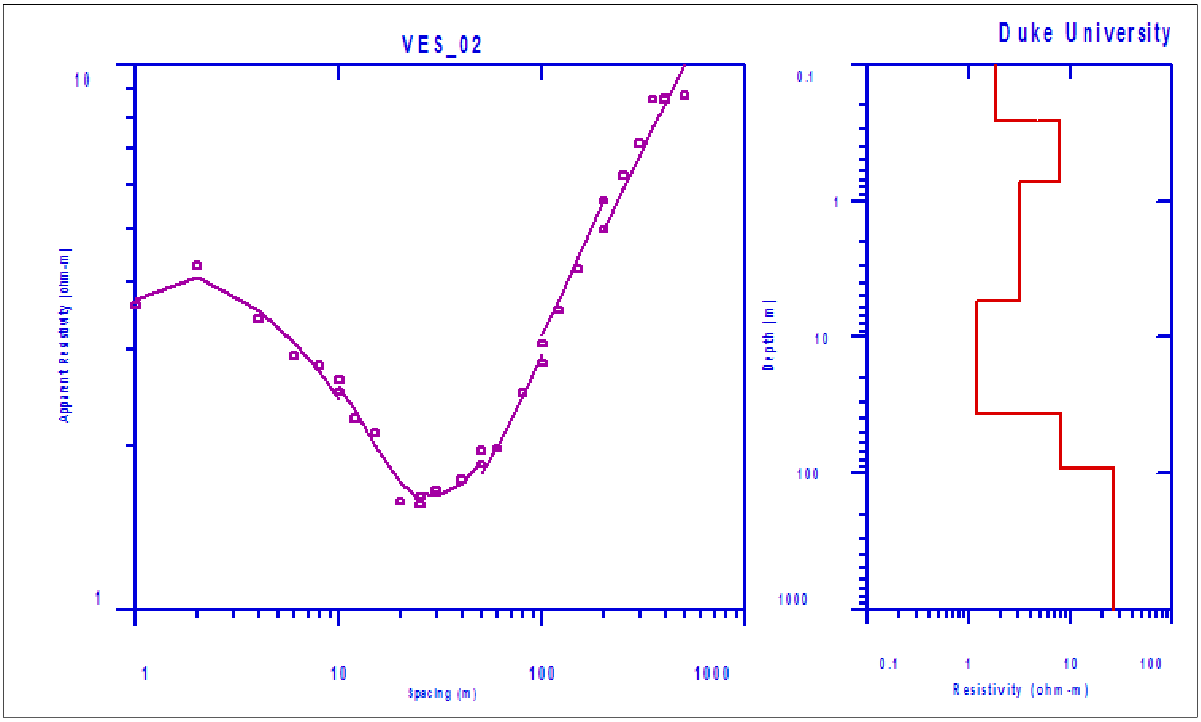
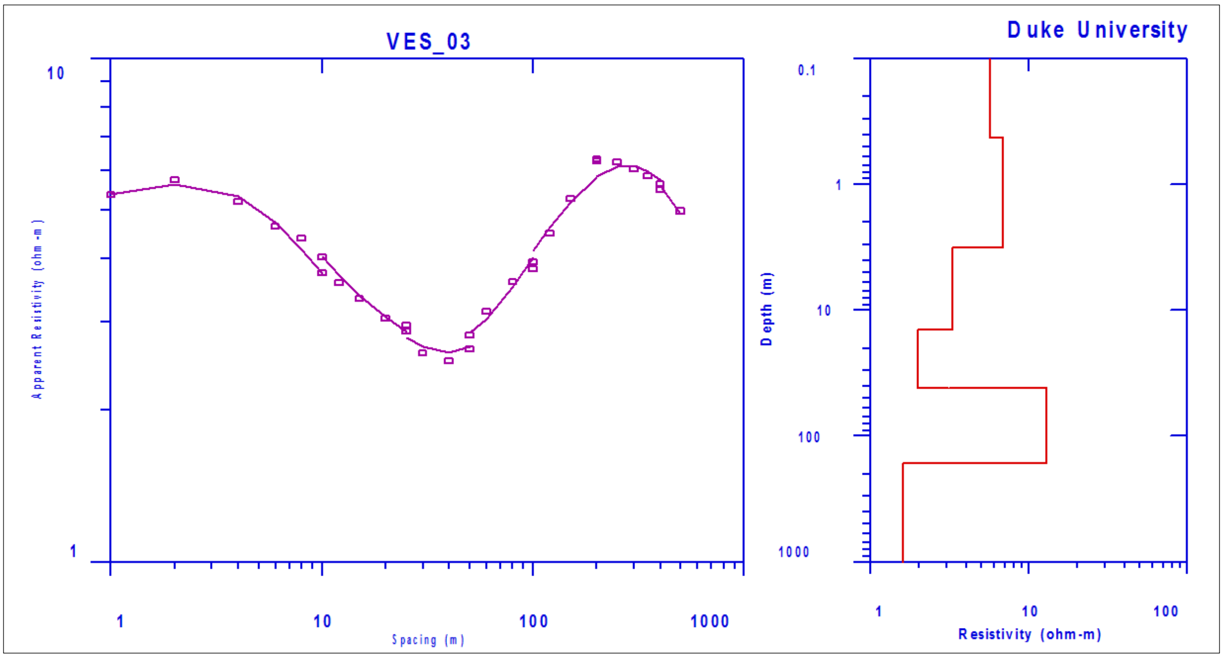
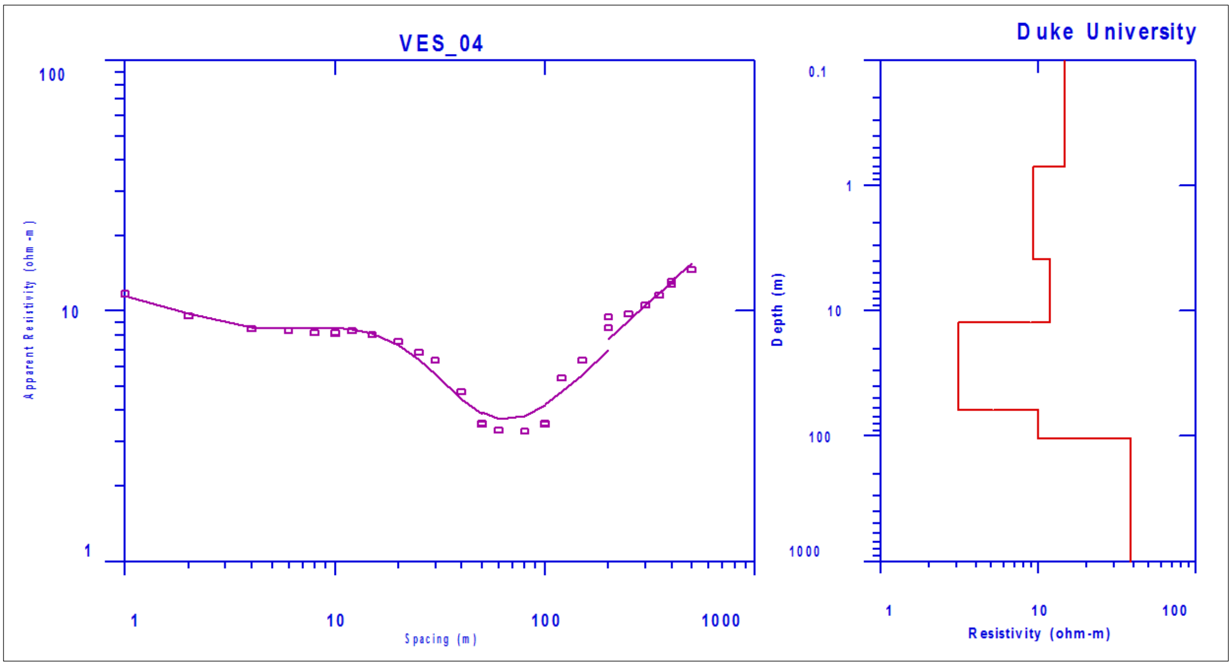
Sounding Curves and their respective models



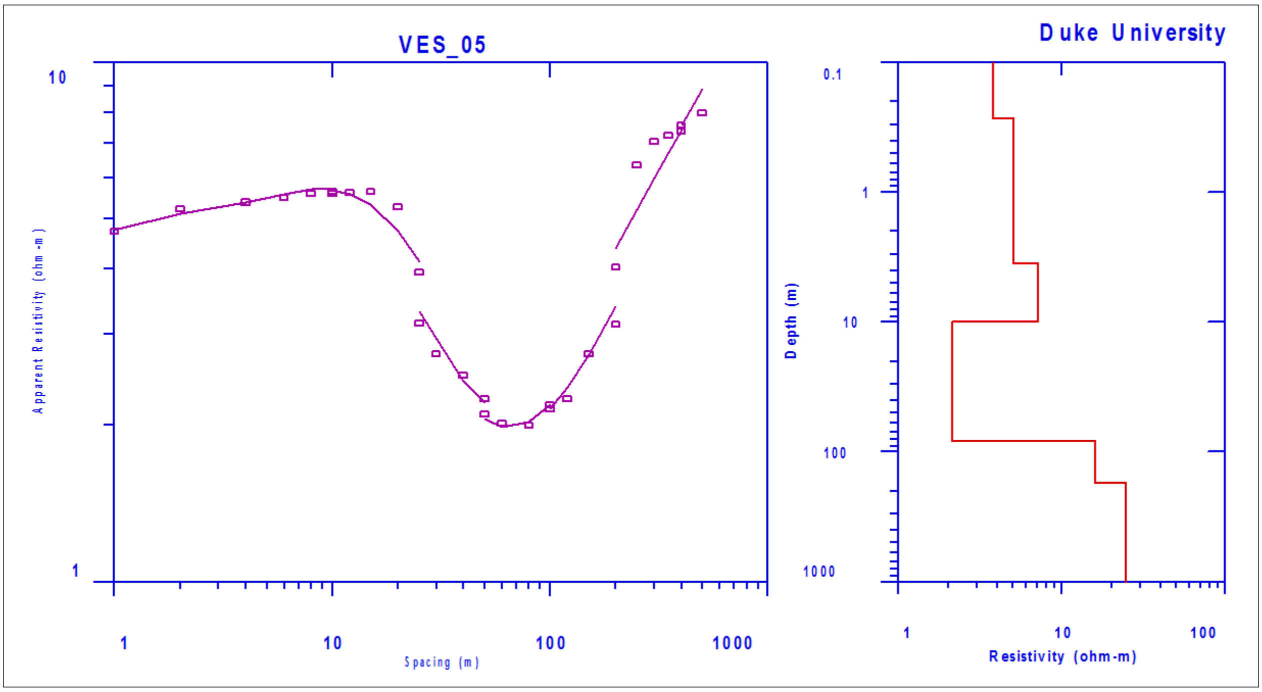




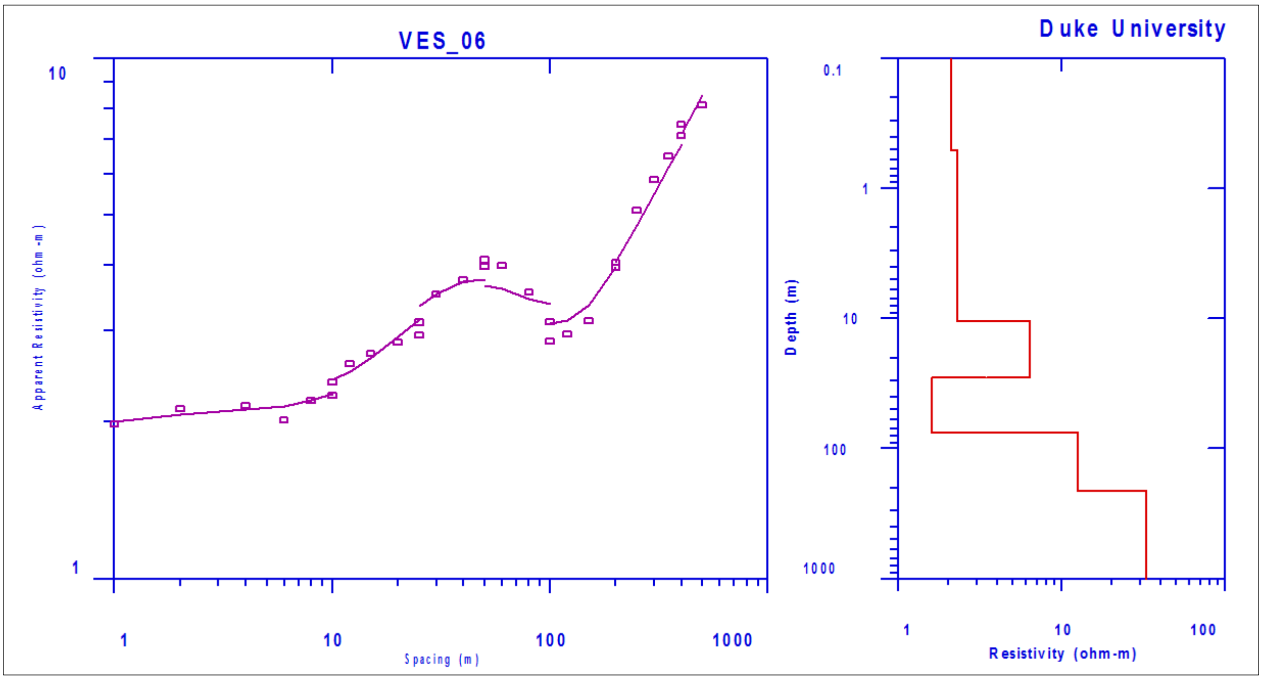
VES_03
Duke University
Apparent Resistivity (ohm-m)
Spacing (m)
Depth (m)
Resistivity (ohm-m)



VES_04
Duke University
Apparent Resistivity (ohm-m)
Spacing (m)
Depth (m)
Resistivity (ohm-m)



VES_05
Duke University
Apparent Resistivity (ohm-m)
10
1
1
10
100
1000
Spacing (m)
Depth (m)
0.1
1
10
100
1000
1
10
100
Resistivity (ohm-m)



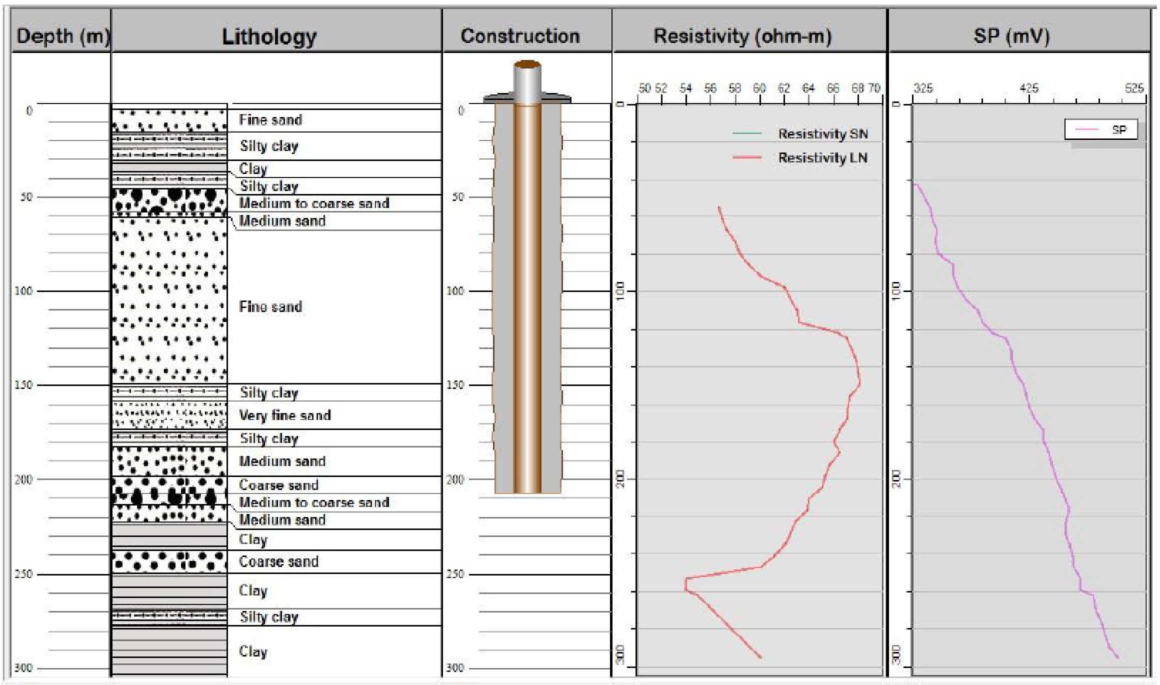
VES_06
Duke University
Apparent Resistivity (ohm-m)
10
1
1
10
100
1000
Spacing (m)
Depth (m)
0.1
1
10
100
1000
1
10
100
Resistivity (ohm-m)

ANNEX-B

ANNEXURE –B: INDIVIDUAL BORING LOG AND CROSS-SECTIONAL VIEW

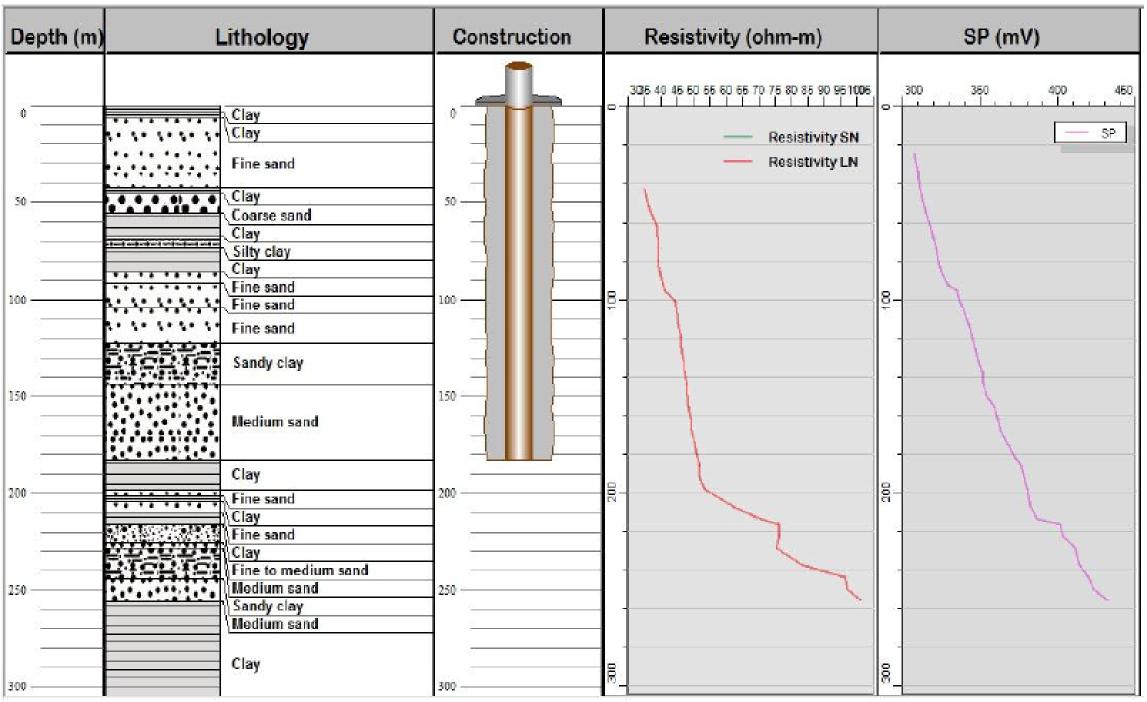
Borehole Log Report

Location: Nilaxmichar, Mirsarai Economic Zone, Mirsharai (TTW-1) Latitude: 22.76384
Depth: 1000ft (300m) Longitude: 91.47594



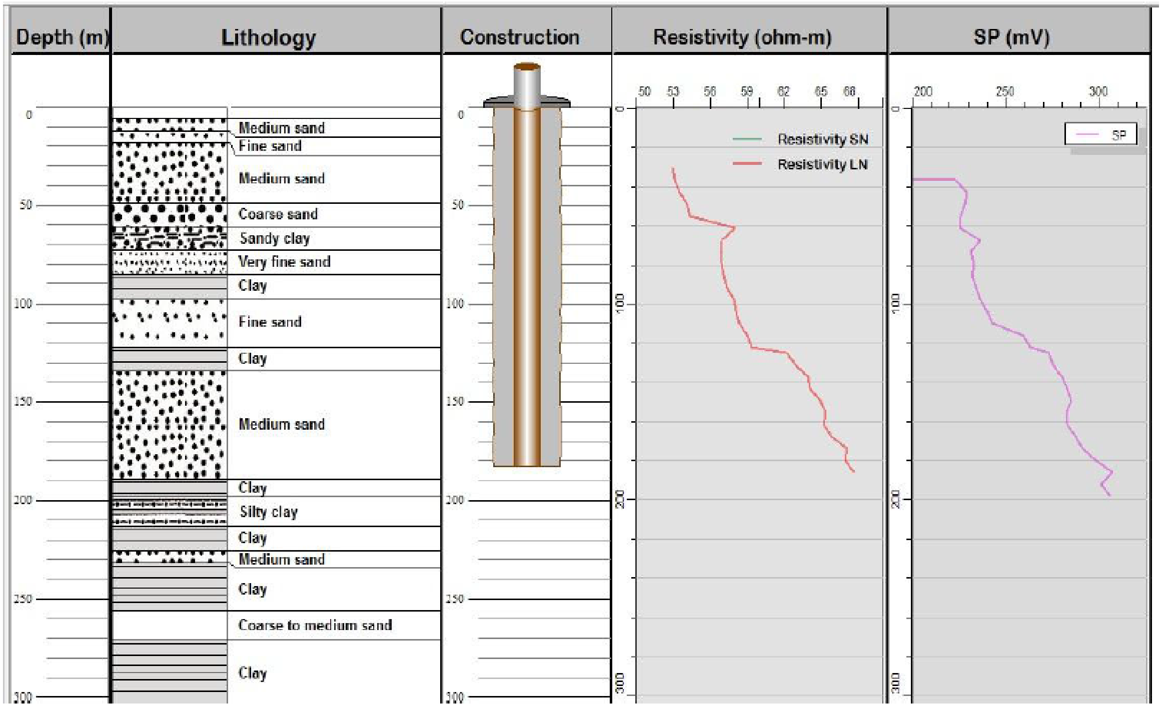
Borehole Log Report

Location: Opposite of Forest office, Mirsharai (TTW-2) Latitude: 22.75749
Depth: 1000ft (300m) Longitude: 91.48215



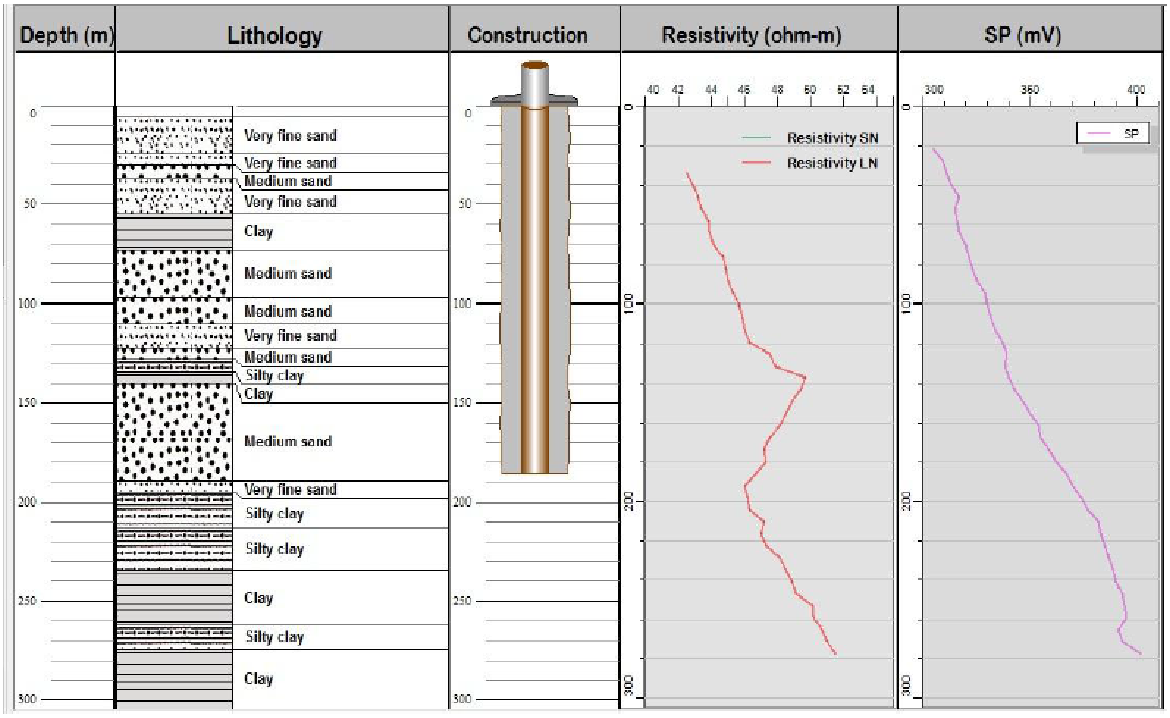
Borehole Log Report

Location: Ichakhali, Mirsharai (TTW-3) Latitude: 22.74888
Depth: 1000ft (300m) Longitude: 91.49224



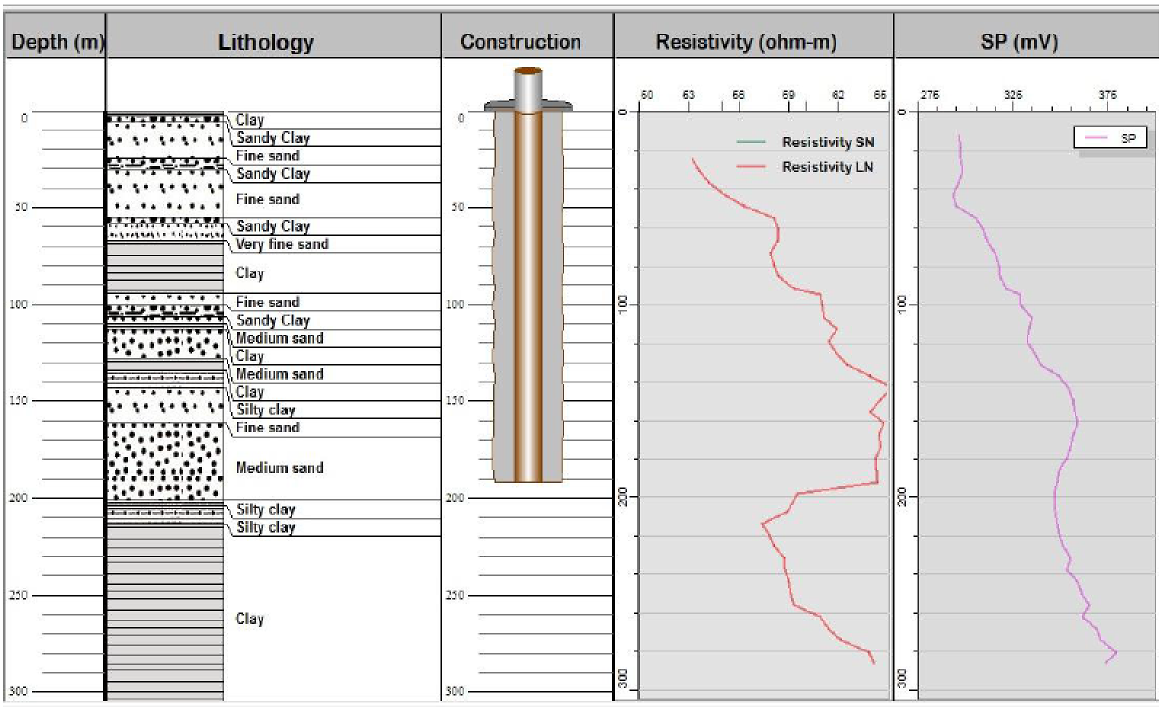
Borehole Log Report

Location: Charsharat, Mirsharai (TTW-4) | Latitude: 22.73699
Depth: 1000ft (300m) | Longitude: 91.49973



Borehole Log Report

Location: Forest office, Mirsharai (TTW-5) | Latitude: 22.73439
Depth: 1000ft (300m) | Longitude: 91.50323



Mirsharai Test Tube Well Lithological Map in HGA