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Subsurface water modeling and structural analysis using VES: A case study of Kumargoan area, Sylhet, Bangladesh

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Abstract

Groundwater zones and subsurface lithology in Kumargoanarea were identified by the Geophysical Electrical Resistivity Survey method. Seven (07) Vertical Electric Sounding (VES) had been conducted using with the Schlumberger array. Pseudo-sections and cross-sections have been generated by IPI2 WIN (version 3.0.1) considering the geology, hydrogeological conditions in the study area. Two major aquifers have been in the study are at different depths. A major discontinuity is detected within the area which causes the main discrepancyin the aquifer distributionbetween west and east of Temukhi-Badaghat road. Eastern part shows good aquifer with fresh water (iron free clean water) at depth ranges from 30 to 52 m. On the other hand, western part, the aquifer with the same lithology startedfrom a depth of 70 m and extended greater depth. The analysis shows that the western part might be an erosional/depositional channel of the Surma River.

Keywords: Resistivity, groundwater, lithology, sand, aquifer, fault

1. Introduction

Electrical resistivity of the soil is considered as a substitution for the spatial and temporal variability of many other soil physical properties (i.e.,Structure, water content, or fluid composition). Since the method is non-destructive and very sensitive, it compromises a very striking tool for telling the subsurface properties without digging.It has been already useful in many contexts likegroundwater exploration, landfill and solute transfer delineation, agronomical management by categorizing areas of excessive compaction or soil horizon thickness and bedrock depth and at least assessing the soil hydrological properties. The surveys, depending on the areas heterogeneities can be performed in one-, two- or three-dimensions and also at the different scales resolution from the centimeter scale to the regional scale[1]. Electrical resistivity is a technique which measures earth resistivity by flowing an electrical current into the ground and measuring the resulting potentials created in the earth. Generally, the geoelectrical resistivity techniqueis used widely in groundwater investigations. In recent times, these studies are also being used to alleviate groundwater quality. It can be best employed to estimate the thickness of overburden and also the thickness of weathered and fractured zones with reasonable accuracy.

However, the surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks. The usual practice in the field is to apply andirect electricalcurrent (DC) between two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Frequently, the potential electrodes are in line between the current electrodes, but in principle, they can be located anywhere. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz).

Vertical Electrical Sounding (VES) is one of the methods to measure the electrical resistivity or conductivity of the soil to any depth when a constant electrical field is artificially created on the surface. This method can be used in both field and laboratory tests [2]. Different studies proved that soil electrical resistivity is affected by its index properties [3] and by the liquid limit and soil plasticity [4]. Regarding soil type and gradation, it was found that clean gravel and sand have relatively high resistivity, while the presence of silt and clay produce low resistivity values that related tothe resistivity and the degree of saturation [5]. An initial spacing's (the distance from the center of the array to either of the current electrodes) is chosen, and the current electrodes are moved outward with the potential electrodes fixedwith an error in apparent resistivity are within 2 to 3 percent if the distance between the potential electrodes does not exceed 2s/5 [6]. Potential electrode spacing is, therefore, determined by the minimum value of s. As spacing is increased, the sensitivity of the potential

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measurement decreases; therefore, at some point, s becomes large enough. In this case, the potential electrode spacing is required. The increments are usually being logarithmic and can be chosen in the same way as described for the Wenner array.

Kumargaon areais facing problem to identify safe and clean aquifer daily need including, drinking purpose. The greedy driller of the area always misleads the people hiding shallow aquifer with fine brownish sand bearing water layer. Often, they drill several hundreds of feet and installed tube well for advising sustainable water finding. However, the water of greater depth using high Fe bearing and not a good aquifer indeed. One problem is that the aquifer of the western side of the area started from 220 m and extend greater depth. Even though, the driller has found the aquifer at the above-mentioned depth but often drill more depth. Sometimes they returned to the shallow depth, which causes more significant loss for the dwellers. In this regard, there needs a good study to solve the problem. In this study, it isaimed to- i) identify the subsurface Lithology ii) Identify the productive zone in this which is finding out theexcellent aquifer zone, and iii) create a subsurface map with our experimented data based on resistivity tool and wellbore data from deep tube well drilling.

2. Study Area and Geologic Setting

Kumargoan area situated in the Surma basin within the Bengal Basin. The Surma basin is an actively subsiding [7]basin, which bounded to the north by the Shillong plateau,east and southeast by the Chittagong-Tripura folds belt of the Indo-Burman ranges due to oblique subsidence of Indian Plate beneath the Burma Plate. The Bouger anomaly map showsprogressive higher values (negative) towards thecenter of the basin. The Aeromagnetic interpretation map[8]shows a slow deepening of the basement towards the center of the basin and also reveals subsurface synclinalfeatures and faults within the basin. Its topography is predominantly flat with some north-south trending ridges of twenty to several hundred meters elevation presents in the north-eastern border. Geographically, the study area lies between the latitudes of 24.91365 to 24.92689°E and longitudes of 91.83214 to 91.83167°N (Fig. 2).The study area is located beside the Surma River. The study area is believed to be deposited in the active river channel or alluvial fan.

The resistivity surveys were conducted at seven (07) locations are given in Table 1.

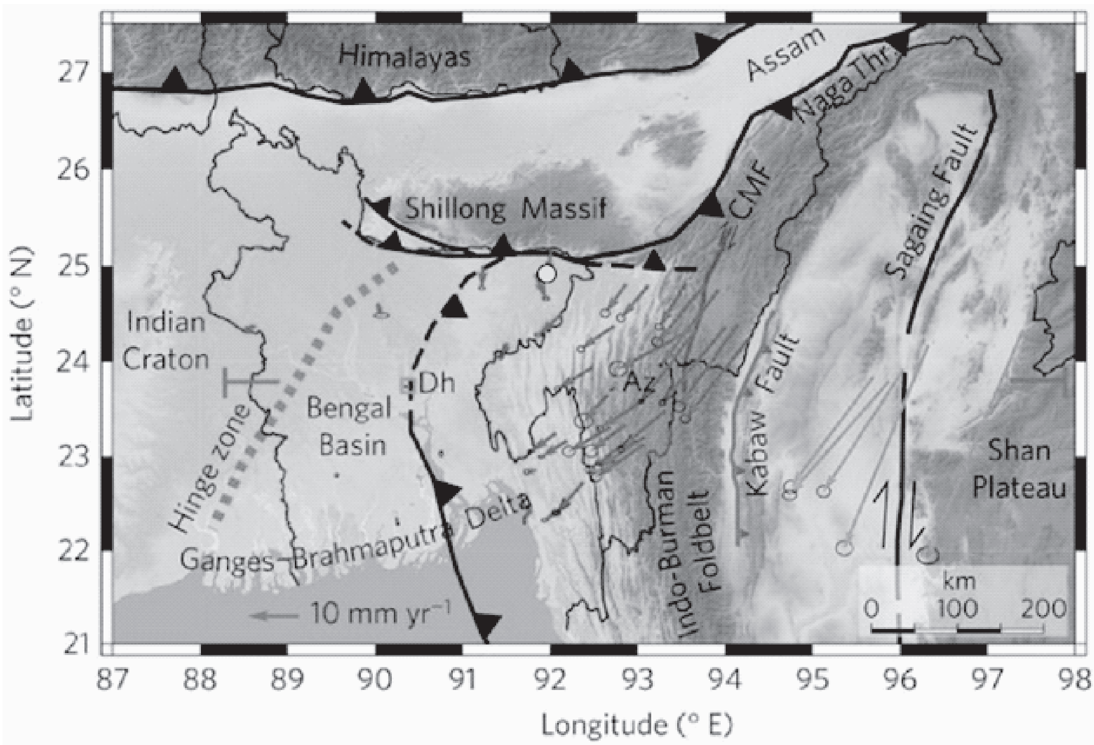


Figure 1: Topographic map of the Ganges-Brahmaputra Delta and Indo-BurmanFoldbelt showing GPS velocities (Modified after [9]. Plate boundaries and major faults are shown in black and gray, respectively. Triangles mark the surface traces of thrusts. Hinge zone indicates the edge of the Indian Craton. Arrows show GPS velocities in an Indian frame of reference. Red, blue and green arrows are new stations from Bangladesh, stations from India, and stations from Myanmar, respectively. Circles at the end of arrows are 2? uncertainties. CMF, Churachandpur-Mao Fault; Thr., Thrust. Boxes labeled Dh and Az indicate Dhaka and Aizawl. The Yellow filled circle indicates the sample locations.

Table 1: Resistivity survey locations

Location	Location Name	Latitude	Longitude
1	Shining City R/A	24.9183	91.81964
2	Shining City R/A	24.91799	91.81909
3	Temukhi-Badagat road north	24.918661	91.819766
4	Kumargoan west	24.91822	91.81792
5	Temukhi-Badagat road south	24.91658	91.82123
6	Al Abrar R/A	24.91612	91.82463
7	Kumargoan R/A	24.91583	91.82285

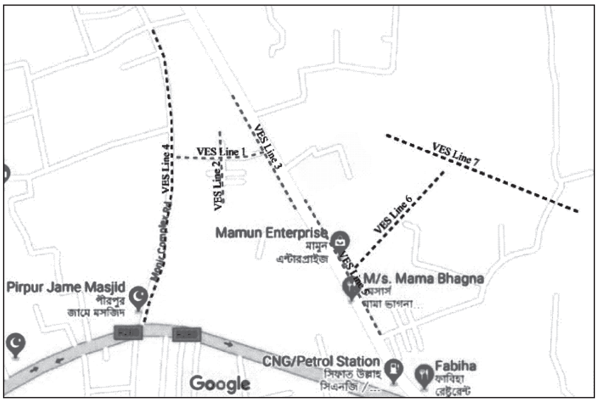


Figure 2: Location map of the study area (downloaded from Google map)

3. Materials and Methods

Vertical Electrical Soundings (VES) were carried out at seven (7) stations (Figure 2). The method based on the estimation of the electrical conductivity or resistivity of the medium. The estimation was performed based on the measurement of voltage of the electrical field induced by the distant grounded current electrodes. A point data gained for each VES station to give the set of apparent resistivity value for the geoelectrical parameters. Schlumberger configuration (Figure 3) using Microprocessor based signal stacking digital resistivity meter of IGIS, Hyderabad (Model - SSR-MP1) was used to deploy. Both the survey procedures resistivity profiling and resistivity sounding (VES) has been carried out. The detailed geological, geomorphological, and hydrogeological properties were evaluated by Interpretation and analysis of VES data by quantitative methods using IPI2 WIN and Surfer 9.0 software. The electrode spacing AB/2 of 250 meters as the maximum was employed to delineate the subsurface lithology and groundwater potentials. The resistivity meter displays resistance R, ?a& strip/true resistivity for each AB/2 setting. The resistivity data are kept as non-volatile memory, and it can be downloaded to the computer through a USB port for further analysis and interpretation. VES has been carried out of seven locations in total, and comparisons of correlation in some borehole data are taken. The resistivity data have been manually also recorded with necessary co-ordinate and elevation measurements by GPS.

3.1 Measurement of Resistivity

This method is used to include the supply of direct current or low-frequency alternating current into the ground through a pair of current electrodes and the measurement of the resulting potential through another pair of electrodes called potential electrodes. Since the current is known and the potential could be measured, an apparent resistivity could be calculated. The resistivity of the subsurface formation four electrodes is essential for measurement. The current of electrical intensity (I) can be identified as A & B, which is introduced between one pair of electrodes called current electrodes. The potential electrodes represented as M & N that results from the current flow is measured with the help of another pair of electrodes. It represents the potential difference (Δv). The apparent resistivity measured by the following equation (1)

$$R = K^* \Delta v / I \quad (1)$$

Where, K represents geometrical constant, which can be calculated if we know the electrode arrangements. The basic needs of the resistivity survey are the power source, meter to measure current and potential, electrodes, and cables.

3.1.1 Schlumberger Array

The Schlumberger array consists of four collinear electrodes (Figure 3). The outer two electrodes are current (source) electrodes, and the inner two electrodes are the potential (receiver) electrodes. The potential electrodes are installed at the center of the electrode array with a small separation, typically less than one-fifth of the spacing between the current electrodes. The current electrodes are increased to a greater separation during the survey, while the potential electrodes remain in the same position to the observed voltage becomes too small to measure. Typically, expanding the current electrodes occurs roughly six times per decade. The advantages of the Schlumberger array are that fewer electrodes need to be moved for each sounding and the cable length of the potential electrodes is shorter than other methods. Schlumberger soundings generally have better resolution, greater probing depth, and less time-consuming field deployment than the Wenner array. The disadvantages are that long current electrode cables are required, the recording instrument needs to be very sensitive, and the array may be difficult or confusing to coordinate amongst the field crew. Substantial lengths of cable energized with the current at high voltage present a safety hazard. The Schlumberger array is a labor-intensive survey because of the cable lengths required and the movement of the electrodes

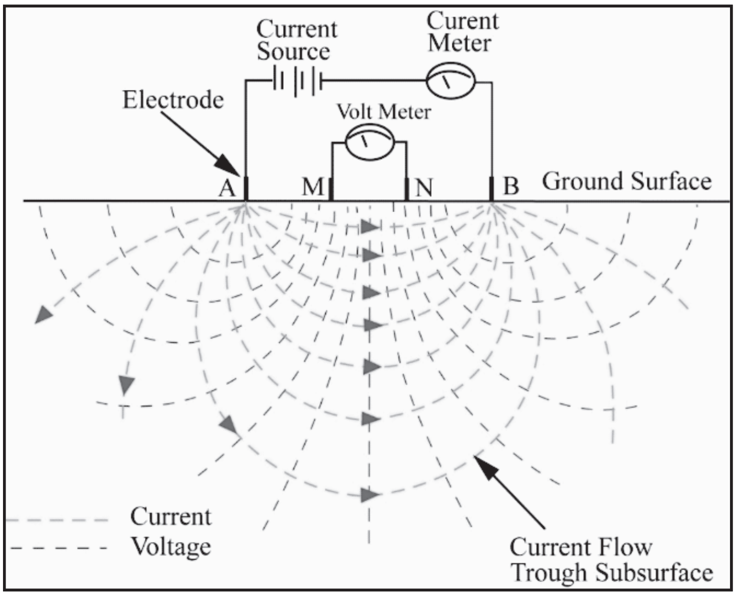


Figure 3: Schematic Schlumberger electricalresistivitysurvey

For each measurement only, the current electrodes are moved only when the signal becomes too weak to be measured. The apparent resistivity for this configuration is computed with the formula (equation 1).

The Schlumberger soundings were carried out with current electrode spacing (AB) ranging from 2 to 300m (AB/2=1m to 150m). The distance used for potential electrode spacing (MN) ranged from 1m to 10m (MN/2=0.5m to 5m). The electrodes were connected through cables to their respective terminals and hammered to make good contact with the earth. The current was sent into the ground, and the potential difference (DV) due to this current was measured and recorded against the electrode spacing. With these values of currents (I) and potential (V) of the electrode configuration, adopted one can get the apparent resistivity (r_a). The apparent resistivity values were plotted against AB/2 on the double - log graph sheets.

4. Result and discussion

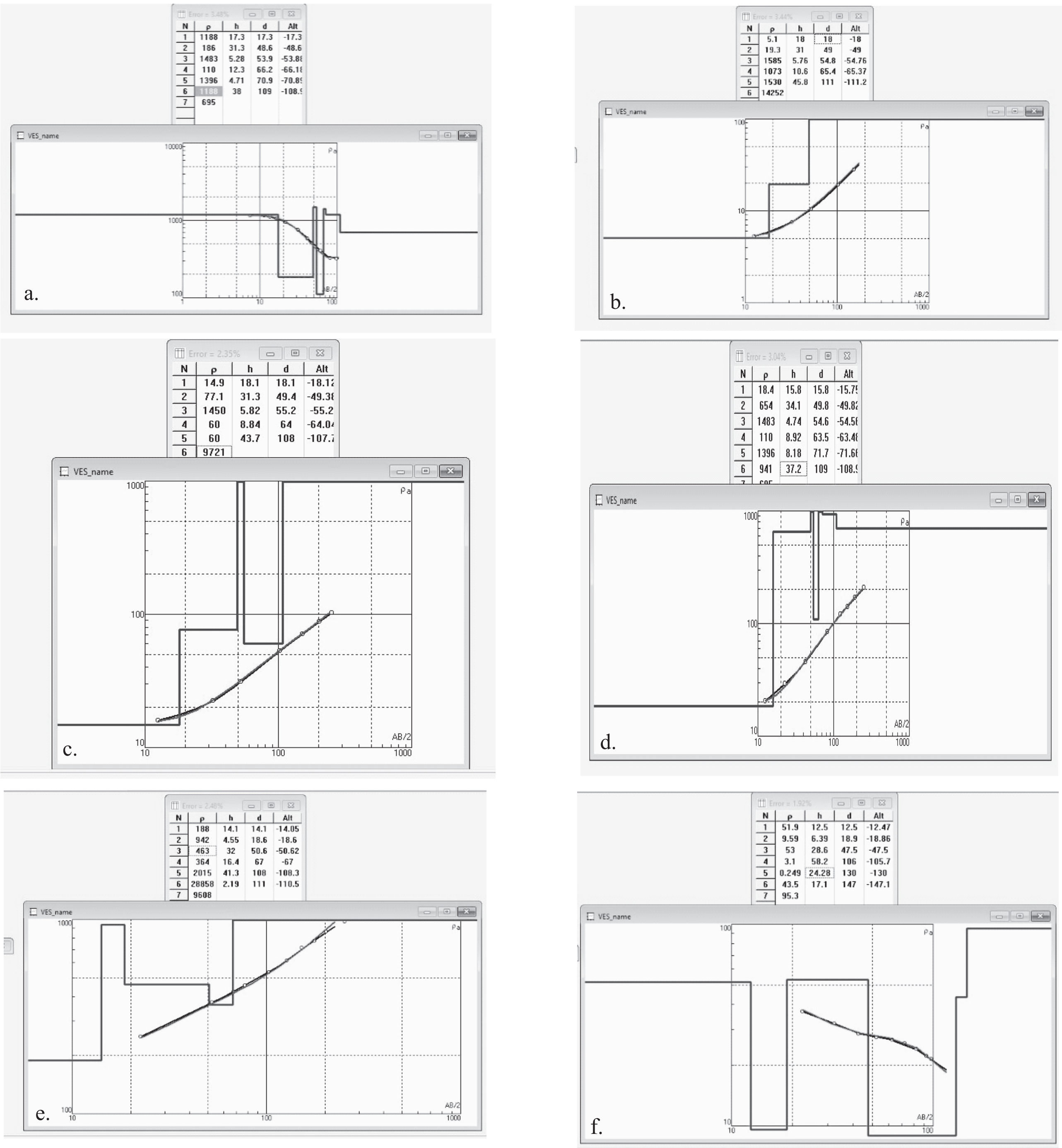
The vertical electrical sounding (VES) data are presented as depth sounding curves, which are obtained by plotting apparent resistivity values against electrode spacing on a graph paper. The depth sounding curves are classified (using IPI2 software) based on layer resistivity combinations (Table 2). From the interpretation of VES curves, the major four subsurface layers were identified within the study area. The curve types are HK, AK, KH, and AA.

The study area consists of 7 locations. The observed inversion curves have been shown the lithologic layer. Both Shining City Residential Area (E-W profile) and Al-Abrar Residential area show the curve type is HK ($\rho1<\rho2>\rho3<\rho4$), suggesting the sites consisting of major four layers. AK curve ($\rho1<\rho2>\rho3<\rho4$), is observed in Shining City R/A (N-S profile), Temukhi-Badaghat Road North (N-S profile) and PirpurJame Masjid Road (N-S profile), suggesting the sites of 4 major layers (Figure 4b-d). KH type curve ($\rho1<\rho2>\rho3<\rho4$), is observed in Temukhi-Badaghat Road South (N-S profile) indicating that major subsurface layers are clay, sand with fresh water, clay and wet sand (Figure 4e). Moreover, AA type curve is ($\rho1<\rho2>\rho3<\rho4$), observed in Kumargoan R/A (E-W profile) also suggesting eight layers of which major four layers are clay, silty sand, sand with fresh water and mud (Figure 4f).From the quantitative assessment of resistivity data indicate that the aquifer 1 in Shining city R/A is situated at a depth of 170-185 feet within the coarse-grained sand. The thickness is only ~15 ft. However, a great aquifer (aquifer 2) have been observed the depth ranges from 235 ft to 380 ft with a resistivity value of 1520 ohm-m. Drill data show that the sand is brownish color and water is clean and drinkable. However, the same sand layer of aquifer 1 is observed between 100 ft to 160 ft in the eastern side of the Temukhi-Badaghat road.

Based on resistivity data interpretation 2D cross-section (Figure 5), fence diagram (Figure 6) 3D lithologic (Figure 7) and 3D stratigraphic model (Figure 8) were generated using Rockwork software which illustrates the subsurface view of the study area. Moreover, developed well cross-section data were compared to the modeling result (Figure 7) shows the consistency and accuracy of our study.

Table 2: Summary of VES data interpretations with positions

VES location	Curve type	Layer No	Apparent Resistivity (©-m)	Thickness	Depth (m)	Lithology
Shining City R/A 1 (E-W profile)	HK	1	1188	17.3	17.3	Silty sand
		2	186	31.3	48.6	Clay
		3	1483	5.28	63.9	Aquifer 1
		4	110	12.3	66.2	Clay
		5	1396	4.71	70.9	Wet sand
		6	1520	145	127.2	Aquifer 2
		7	245	-	193.0	clay
Shining City R/A 2 1 (N-S profile)	AK	1	5.8	18.0	18.0	Silty sand
		2	19.3	31.0	49	Clay
		3	1585	5.76	54.8	Aquifer 1
		4	1073	10.6	65.4	Clay
		5	1530	4.58	76.0	Wet sand
		6	265	-	325.0	Aquifer 2
Temukhi-Badghat Road North (N-S profile)	AK	1	14.9	18.1	18.1	Silty Sand
		2	77.1	31.3	49.4	Clay 1
		3	1450.0	5.82	55.2	Mud
		4	60.0	8.84	64.0	Aquifer 1
		5	60.0	48.0	108.0	Clay 2
		6	234.0	4.0	112.0	Wet Sand
		7	186.0	73.0	185.0	Aquifer 2
		8	18750	-	330.0	Clay 3
Pirpur Jame Masjid Road (N-S profile)	AK	1	18.4	15.8	15.8	Silty Sand
		2	654	34.1	49.8	Clay 1
		3	1483	4.74	54.6	Mud
		4	110	8.92	63.5	Aquifer 1
		5	1396	8.18	71.7	Clay 2
		6	941	37.2	94.1	Wet Sand
		7	265	28.9	123.0	Aquifer 2
		8	2584	-	420.0	Clay 3
Temukhi-Badghat Road South (N-S profile)	KH	1	186	14.1	14.1	Silty Sand
		2	942	4.55	18.6	Clay 1
		3	463	32.0	50.6	Mud
		4	364	16.4	67.0	Aquifer 1
		5	2015	41.3	108.0	Clay 2
		6	564	127.0	233.0	Wet Sand
		7	458	4.0	237.0	Aquifer 2
		8	2548	-	420	Clay 3
Al-Abrar R/A (E-W profile)	HK	1	51.9	12.5	12.5	Silty Sand
		2	9.59	6.39	18.9	Clay 1
		3	53.0	28.6	47.5	Mud
		4	3.1	58.2	106.0	Aquifer 1
		5	0.249	24.28	130.0	Clay 2
		6	43.5	17.8	147.0	Wet Sand
		7	412	17.0	237.0	Aquifer 2
		8	2751	-	250.0	Clay 3
Kumargoan R/A (E-W profile)	AA	1	30.5	12.0	12.0	Silty Sand
		2	46.9	6.34	18.3	Clay 1
		3	167.0	27.2	45.5	Mud
		4	717.0	122	167.0	Aquifer 1
		5	0.249	24.28	130.0	Clay 2
		6	43.5	17.8	147.0	Wet Sand
		7	512	20.0	238.0	Aquifer 2
		8	2655	-	320.0	Clay 3



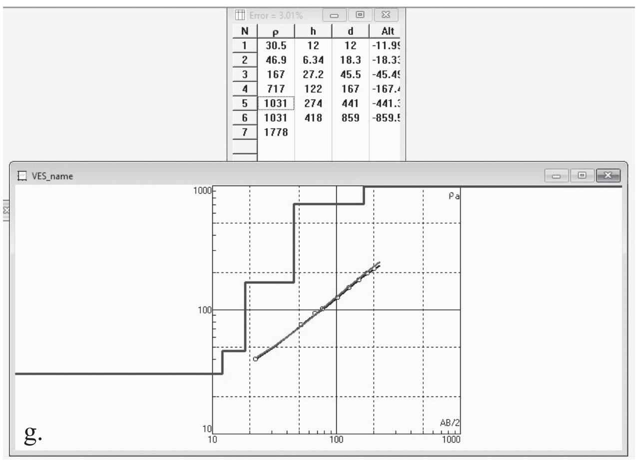
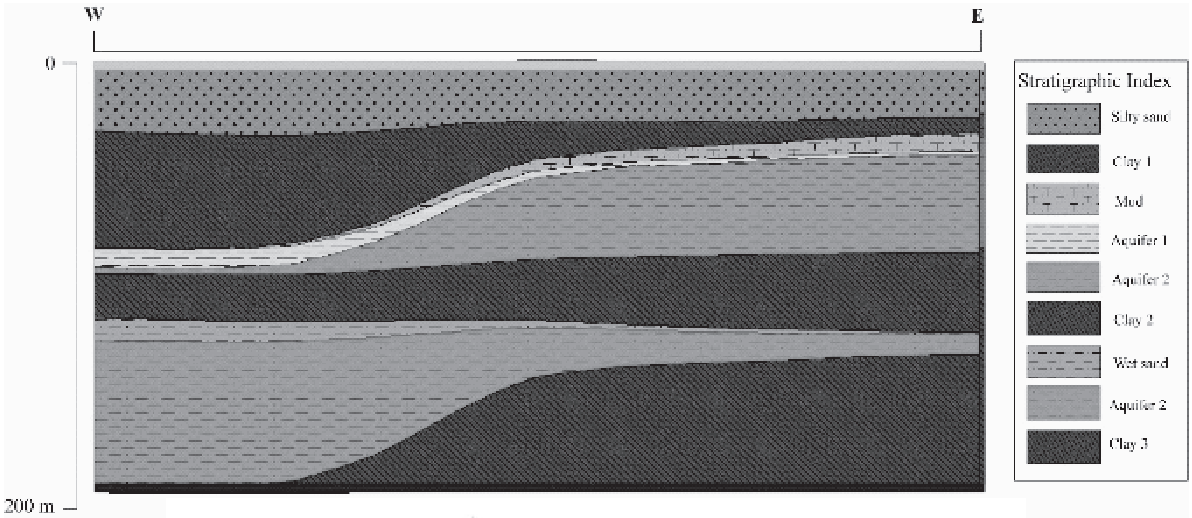
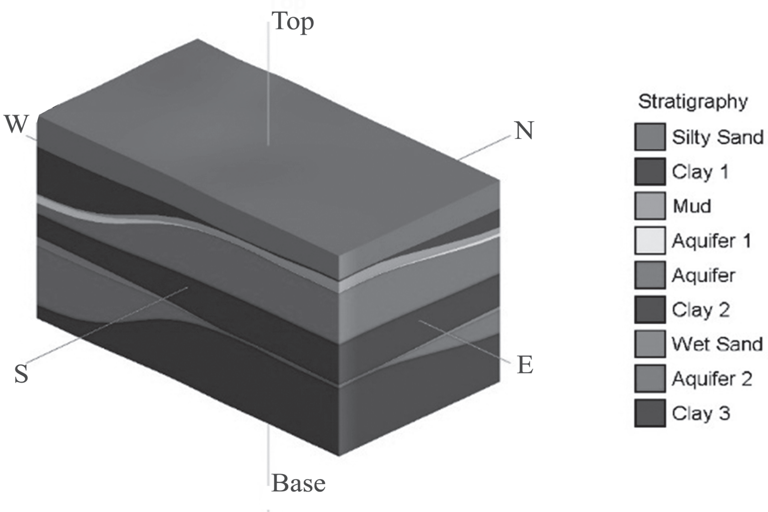


Figure 4: Interpretations of VES field curves for
a) location 1, b) location 2,
c) location 3, d) location 4,
e) location 5, f) location 6,
g) location 7



a.



b

Figure 5: (a) 2D cross-section, (b) 3D subsurface model of the study area

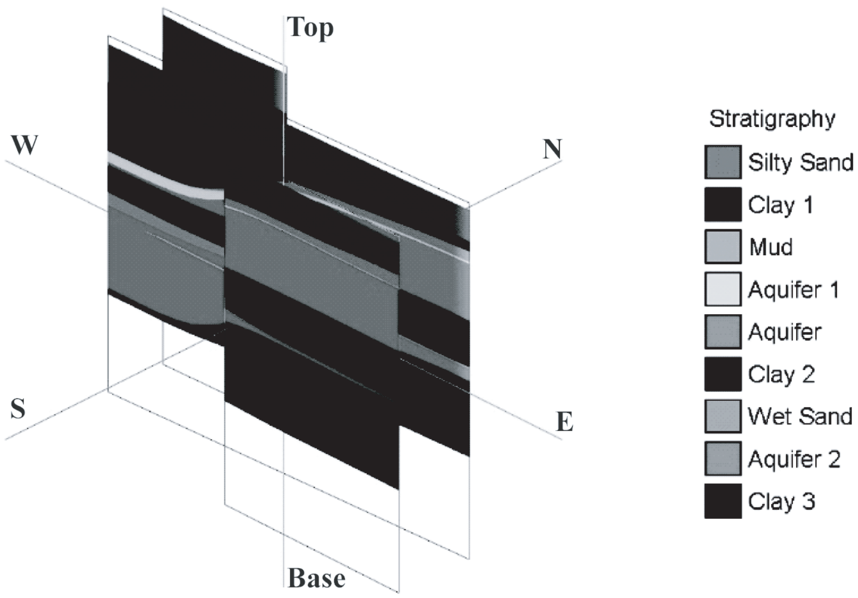


Figure 6: Fence diagram of the stratigraphic unit of the study area.

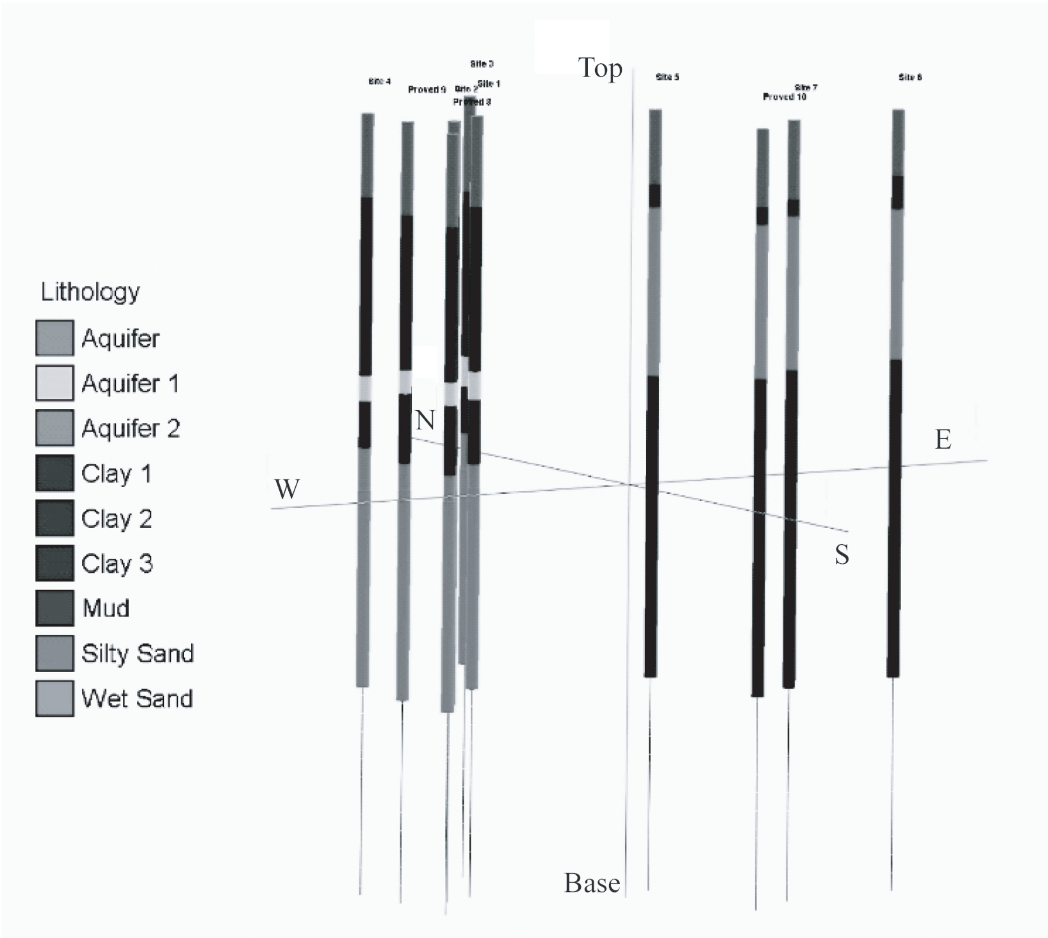


Figure 7. 3D strip log of the lithologic unit of the study area.

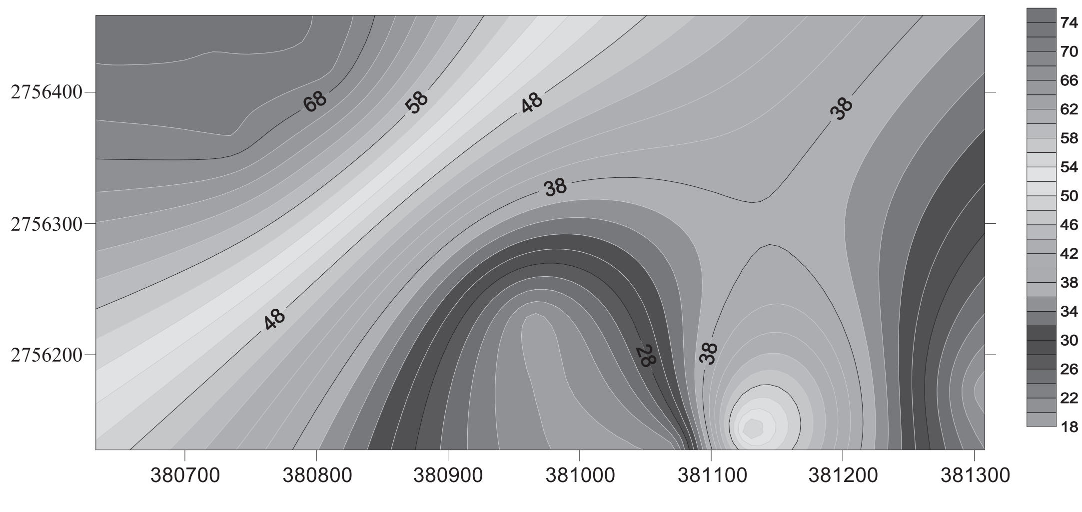


Figure 8: (a) Contour of the subsurface water table of aquifer 2 of the study area

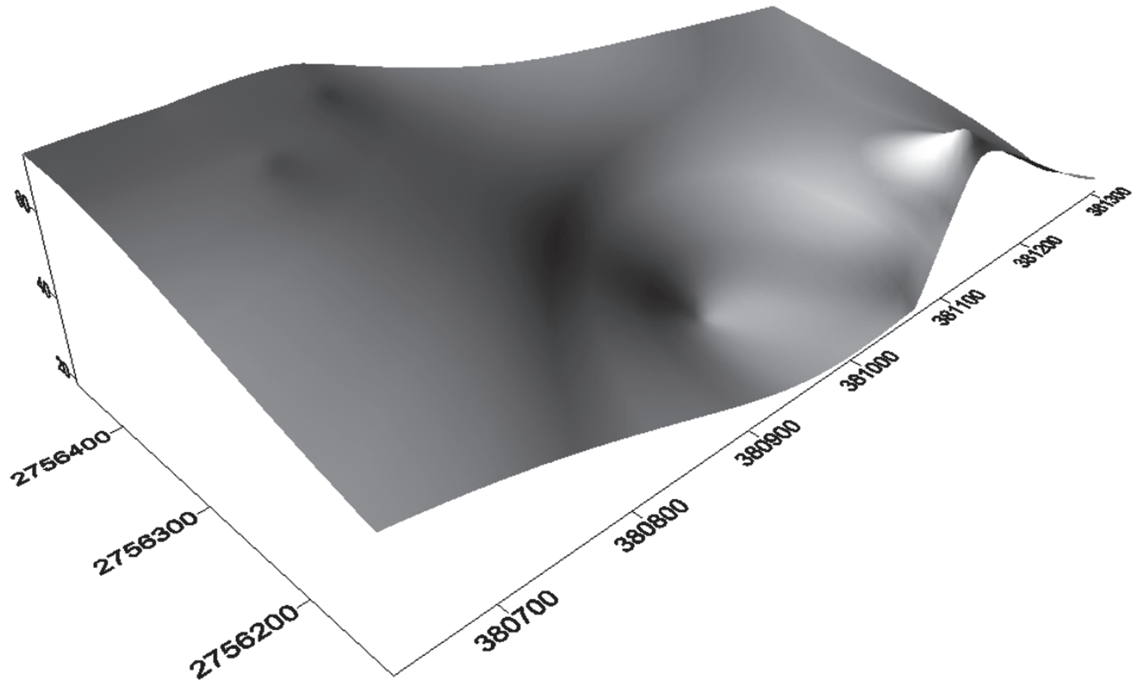


Figure 8: (b) 3D surface map of the subsurface water table of aquifer 2 of the study area

5. Conclusion

VES study with the Schlumberger array yields that the study area consists of four major lithological zones. The qualitative and quantitative analyses show that the aquifer of the study area is situated at different depths. East of the Temukhi-Badaghat road, the aquifer is situated at depth ranges from 33 m to 55 m. The same lithologic unit with fresh water is observed at depth from 70 m. 2D and 3D models show that there might be a discontinuity between east and west zone. The possible thing is that the western part was the paleo-channel of any tributary of the Surma River.

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