GEOPHYSICAL INVESTIGATION OF GROUNDWATER POTENTIALS USING RESISTIVITY METHOD: A CASE STUDY OF ABU PHASE II STUDENTS' HOSTEL

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Abstract: Geophysical survey for groundwater was conducted in two newly built halls of residence (hostels) named Dangote and Shehu Idris at the second phase of Ahmadu Bello University (ABU), Zaria in Nigeria. The vertical electrical sounding (VES) technique of resistivity method was employed with Schlumberger array in seven VES points distributed within the two hostels. Results showed that 4 to 6 geoelectric layers exist within the study area for a spacing of at most 200 m between current electrodes. The resistivity values of the geoelectric layers in all the VES points ranged from 26.6 Ωm – 30342 Ωm while the thickness and depth ranged from 0.263 m – 40.34 m and 0.572 m – 50.66 m respectively. However, four VES points (two in each hostel) were identified to be suitable for borehole drilling though, three out of these four VES points have single aquifer in each with resistivity and thickness ranging from 34.4 Ωm – 40.57 Ωm and 2.02 m – 7.49 m respectively. Conversely, the fourth VES point has two aquifers positioned at the third and fifth layers with resistivity values ranging from 26.6 Ωm – 51.4 Ωm and thickness ranging from 1.93 m – 18.7 m. It was recommended that among the four VES points (two in each hostel) identified to contain aquifers, priority should be given to the ones with larger thickness in each hostel.

Keywords: groundwater, resistivity, schlumberger, terrameter, VES

1. INTRODUCTION

Water is ranked next to air among the essential items for any living being however, only 2.8 % of the global water resources is available as freshwater out of which, 2.2 % is available as surface water and 0.6 % as groundwater. Sources of fresh surface water in arid and semiarid regions are not guaranteed as most streams and rivers in such regions are not perennial hence, groundwater abstraction is vital in arid and semiarid regions of the world. Extracting groundwater is not as easy as that of surface water as the former involves drilling or digging of wells into the ground to certain depths were aquifers are found. This could be very deep in certain locations as adequate groundwater is not easily found at shallow depths in both arid and semiarid regions. Hence, geophysical investigations, which apply the principles of physics to access geological strata existing beneath the earth, are very important in arid and semiarid regions where groundwater are scarcely available. This is because if such investigations are not carried out in advance and the drilling or digging of wells is undertaken, then everything may result futile if sufficient and good quality water is not available. There are different methods of geophysical techniques however, the electrical resistivity method has been successfully used in recent time by numerous authors [1-5] to investigate the groundwater potentials.

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The theory behind the electrical resistivity method is based upon the principle that electrical resistance offered by different types of rocks in the subsurface is different. Electrical resistivity (reciprocal of conductivity) of different rock formations largely depends on the amount of the concentration of dissolved salts (electrolytes) in the pore water present in rocks and also on the volume pore water, since the solid grains are poor conductors of electricity. The concentration of the dissolved electrolytes in pore water of the rock strata, in turns depend on the chemical composition of the rock while the amount of pore water itself depends on the porosity of the rock layer. Hence, a rock layer having more porosity will have more pore water thereby making the said rock layer more conductive for electrical currents. The resistivity of the layer will therefore be low. On the other hand, if the rock layer is composed of some insoluble material (s), it will have low concentrations of dissolved electrolytes in the pores. For such case, the strata will have low electrical conductivity, and hence high resistivity. Thus if the measurement of resistivity is done by passing current through the strata, it can help in the identification of the strata.

Water supply to hostels and staff quarters in Ahmadu Bello University (ABU), Zaria-Nigeria was initially designed to enter through a pipe network system from the university water treatment plant (Figure 1) after treating water from the ABU dam-reservoir. However, due to the increasing number of students and staff, the existing water supply source is not meeting the water requirement of the university community as certain areas receive water at low pressure, causing scarcity of water. Hence, the university management usually drill boreholes in students' hostel to augment the water supply from the treatment plant.

Fig. 1. ABU water treatment plant.

Recently, the management of Ahmadu Bello University (ABU), Zaria has decided to build the second phase of the university known as ABU phase II in order to accommodate more faculties and students. Consequently, two halls of residence named Dangote and Shehu Idris Halls have been designed within the ABU Phase II to serve as hostels. Since the university is located in a semiarid region (Zaria, Nigeria), it is important to conduct geophysical survey within the areas designed for students' hostel in order to identify locations that will yield sufficient water supply through boreholes. This will avoid the danger of drilling boreholes in areas were water may not likely be found in adequate quantity. Hence, this research aimed at identifying suitable locations for siting boreholes within the proposed hostels (Dangote and Shehu Idris Halls) using geophysical technique, for the purpose of supplying water to the hostel residents.

2. MATERIALS AND METHOD

2.1. Description of Study Area

The ABU phase II is an extension of the main campus in Samaru-Zaria, Nigeria. It lies between latitude 11°8'3.392"N to 11°8'23.354"N and longitude 7°37'58.114"E to 7°38'50.466"E as shown in Figure 2. The geology of the study area belongs to the Nigerian basement complex with the upper layer (0–10 m) being lateritic and comprising of reddish-brown silty clay and sandy clay with reddish-brown ferruginous concretions. The middle layer that usually ranged from 10–17 m has a lithology of greyish brown medium-coarse, gravelly, and pebbly sand highly weathered basement materials while the lower layer (17–55 m) consist of quartzite and fresh crystalline rocks [6]. However, a layer with an infinite depth exist with resistivity value varying from 1603 Ωm – 49788 Ωm [7]. Soils at the crest and upper slope are well drained whereas those at the middle slope and valley are poorly drained [8]. The rainy season in the study area and its environ is normally in the period of May to October, with annual mean value of 1000 mm, while the dry season usually accompanied with high evaporation rate is from November to April with a mean annual temperature of 24.5 ºC [9,10]. It has an average altitude of 662 m above mean sea level.

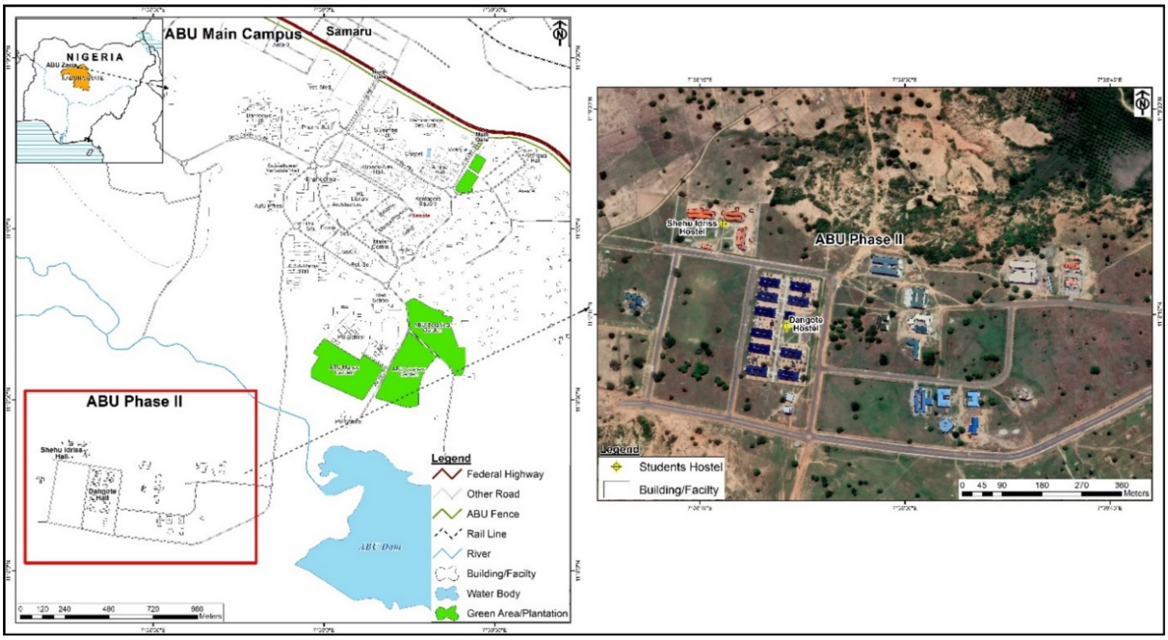

Fig. 2. Map of study area.

2.2. Data Collection and Analysis

The vertical electrical sounding (VES) method of resistivity with Schlumberger array was employed in determining the subsurface strata at seven locations within the hostel (Figure 3), using a terrameter (Ohmega 0134), with a maximum electrode spread (AB) of 200m. The coordinates of the various VES points are 11º8′14.78″N, 7°38'23.187"E for VES 01; 11º8′17.417″N, 7°38'21.241"E for VES 02; 11°8'10.114"N, 7°38'20.749"E for VES 03; 11°8'13.062"N, 7°38'18.778"E for VES 04; 11°8'21.085"N, 7°38'18.932"E for VES 05; 11°8'21.575"N, 7°38'13.058"E for VES 06 and 11°8'23.022"N, 7°38'16.420"E for VES 07. The VES points were selected in areas identified to be free from point source pollutants within the hostel. VES point 01 to 04 are within Dangote Hall while 05 to 07 are within Shehu Idris Hall.

The method involved applying electric current (I) to two outer (current) electrodes C_1 and C_2, equally spaced at a central point and driven into the ground at points A and B respectively. The voltage (V) across two inner (potential) electrodes P_1 and P_2 equally spaced from the same central point and respectively driven into the ground at points M and N as shown in Figure 4 were recorded by a terrameter (Figure 5). The depth of current penetrations was increased by increasing the space between the outer or current electrodes at an equal distance from the center of spread, while maintaining the positions of the inner or potential electrodes [11].

The resistance $\left(R = \frac{V}{I}\right)$ observed from the terrameter at different electrode spacing were multiplied by a geometrical factor (K) to obtain the corresponding apparent resistivity (ρ_a). The geometrical factor (K) depends on the arrangement of the electrodes and in the case of Schlumberger array, the K values at different electrode spacing were calculated using equation (1) as reported in past literatures [11, 12, 13, 14, 15].

$$K = \frac{\pi}{MN}\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right] \quad (1)$$

In equation (1), $\frac{AB}{2}$ is the distance of outer or current electrodes from the center of spread or half of the distance between the outer or current electrodes, measured in meter. Similarly, $\frac{MN}{2}$ is the distance of inner or potential electrodes from the center of spread or half of the distance between the inner or potential electrodes in meter. The resistivity curve for each VES point was plotted on a log-log paper as apparent resistivity (ρ_a) in Ohm-meter (Ωm) versus distance of outer electrodes from center of spread $\left(\frac{AB}{2}\right)$ in meter (m) using IPI2win software (version 3.1).

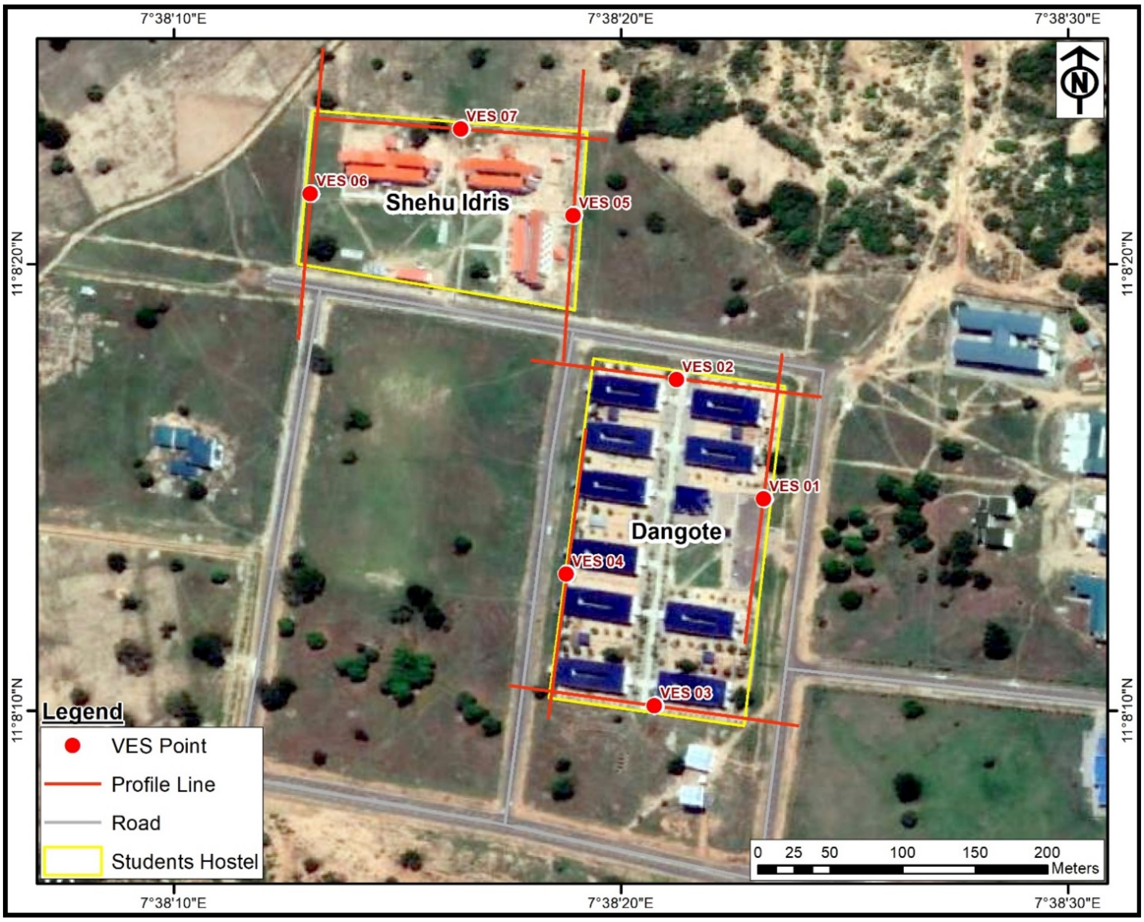

Fig. 3. VES points within hostel.

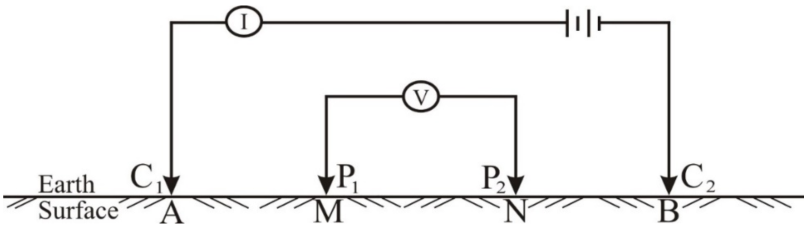

Fig. 4. Schlumberger array.

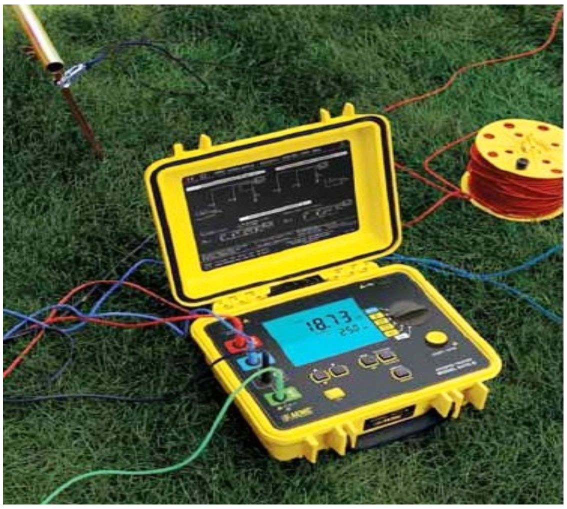

Fig. 5. Terrameter in operation.

The resistivity curves for the various VES points were interpreted by identifying the corresponding lithology of the resistivity values at different layers using standard estimated values for different rocks previously ascertained within the study area as shown in Table 1. The resistivity values and lithology at various layers in each VES point were compared with their corresponding depths and thicknesses before deciding the suitability of a VES point.

Table 1. Resistivity values of common rocks and formations within the study area.

Rock type	Resistivity (Ωm)
Conductive clay	5 – 20
Saturated sand	25 – 45
Wet sand	50 – 80
Silty sand	90 – 160
Weathered basement (fine and coarse)	170 – 450
Fractured basement	500 – 1000
Fresh basement	Greater than 1000

3. RESULTS AND DISCUSSION

The field results and the computed apparent resistivity for the various VES points are presented in Table 2 while the resistivity curves for the various VES points are presented in Figures 6 to 12. However, the symbols N, ρ, h and d in Figures 6 to 12 represent layer number, layer resistivity in Ohm-meter (Ωm), layer thickness in meter (m), and interface depth in meter (m) respectively.

Table 2. Computed apparent resistivity values for various VES points.

$\frac{AB}{2}$, (m)	$\frac{MN}{2}$, (m)	Geometrical factor, k	ρ_a VES 01, (Ωm)	ρ_a VES 02, (Ωm)	ρ_a VES 03 (Ωm)	ρ_a VES 04, (Ωm)	ρ_a VES 05, (Ωm)	ρ_a VES 06, (Ωm)	ρ_a VES 07, (Ωm)
1	0.5	6.284	164.682	93.177	96.390	138.537	160.209	150.633	104.076
2	0.5	11.783	190.098	100.772	114.224	158.946	176.882	142.308	108.938
3	0.5	27.493	197.313	113.135	137.940	156.6125	191.125	124.850	116.490
4.5	0.5	62.840	185.643	121.196	155.361	150.2068	187.615	117.061	113.435
7	0.5	153.173	167.546	120.835	161.4201	107.6645	166.015	119.763	109.655
10	0.5	313.415	169.533	106.859	159.505	107.4859	142.270	130.675	55.780
10	2	75.408	163.467	151.252	162.713	113.854	136.022	130.668	109.255
12	2	109.970	161.531	143.718	160.432	119.1966	123.595	148.116	114.688
14	2	150.816	155.776	133.307	167.991	129.3864	121.696	135.569	120.791
15	2	173.596	154.998	131.740	175.826	133.1282	118.896	154.651	124.797

17	2	223.868	152.435	131.394	188.921	142.1384	112.592	138.557	132.737
20	2	311.058	156.132	135.605	197.1867	150.5337	112.589	144.624	138.093
25	2	487.796	164.853	143.880	221.429	161.9264	103.887	152.172	144.856
30	2	703.808	176.634	150.596	235.746	180.856	103.447	163.967	163.967
45	2	1587.496	211.111	214.286	285.714	241.270	138.095	206.349	184.127
45	10	302.418	217.109	196.245	321.732	227.087	142.119	196.245	96.762
60	10	549.850	251.799	244.652	385.946	296.881	182.527	231.457	153.938
70	10	754.080	275.203	269.171	414.689	340.045	202.821	246.552	196.035
80	10	989.730	319.641	301.828	439.382	369.121	255.317	263.234	203.858
100	10	1555.290	368.556	337.455	485.188	460.307	256.590	295.467	220.823

Note: Column 4 to 10 (i.e. ρ_a) were determined by multiplying the geometric factor *K* (column 3) by the corresponding values of resistance R in Ohm, observed in the terrameter during the field survey, $\frac{AB}{2}$ = Distance of outer (current) electrodes from center of spread, $\frac{MN}{2}$ = Distance of inner (potential) electrodes from the center of spread, *K* = *Geometrical factor for Schlumberger array,* ρ_a = Apparent resistivity, VES = Vertical Electrical Sounding.

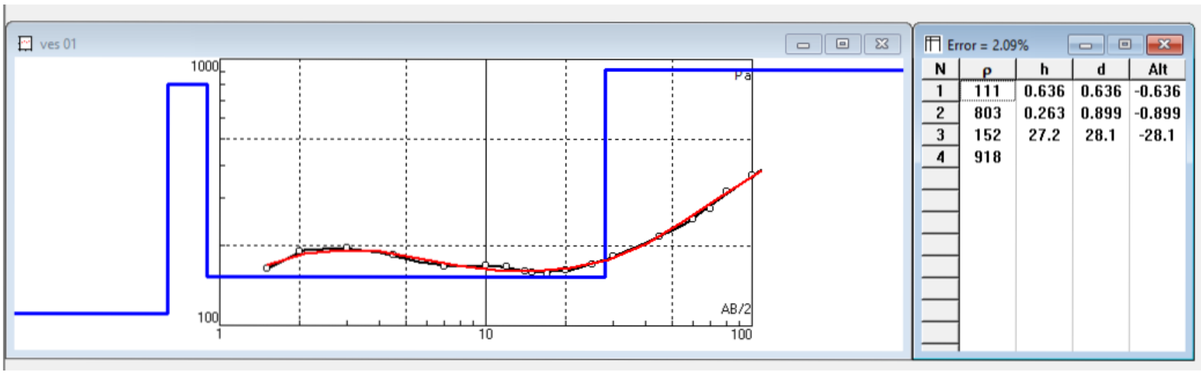

Fig. 6. Resistivity curve for VES 01.

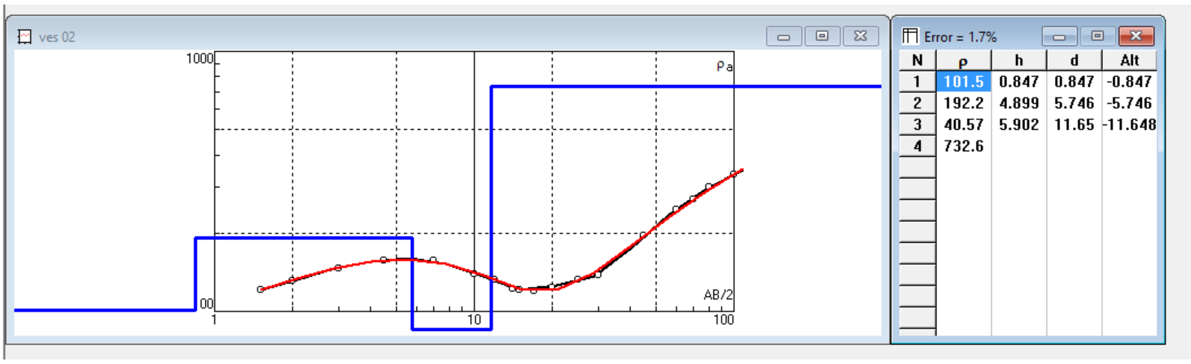

Fig. 7. Resistivity curve for VES 02.

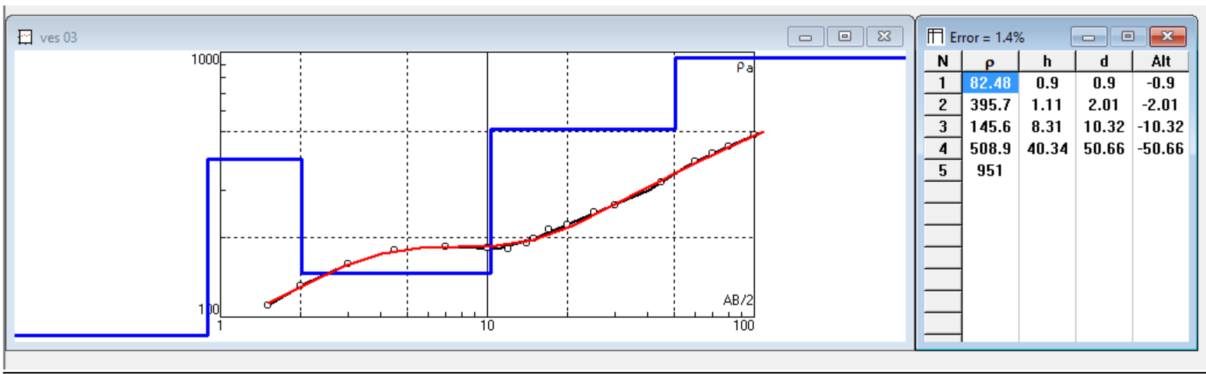

Fig. 8. Resistivity curve for VES 03.

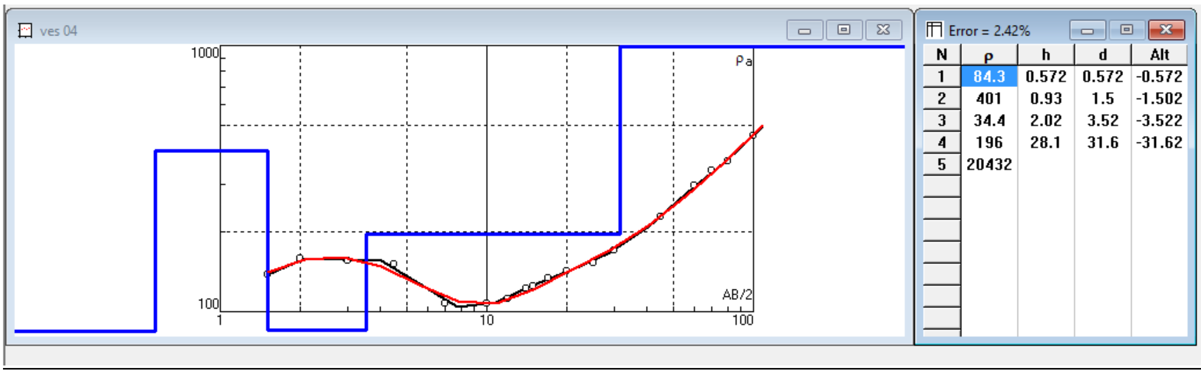

Fig. 9. Resistivity curve for VES 04.

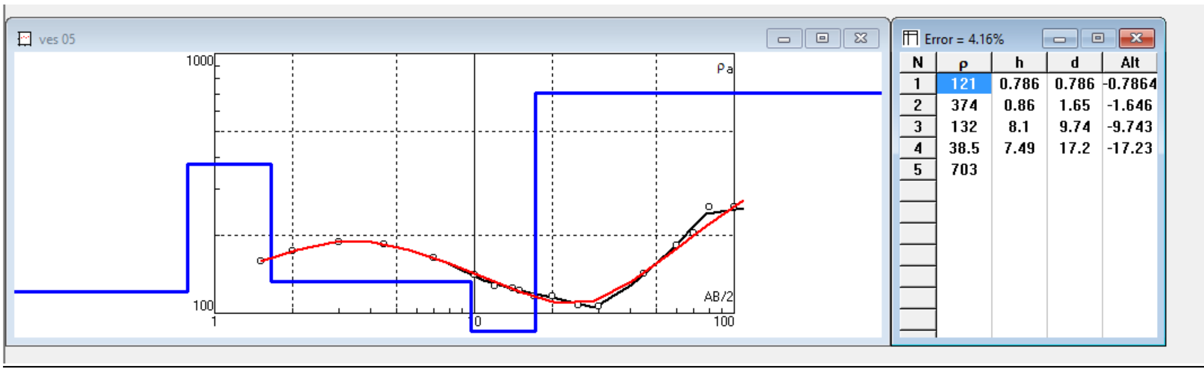

Fig. 10. Resistivity curve for VES 05.

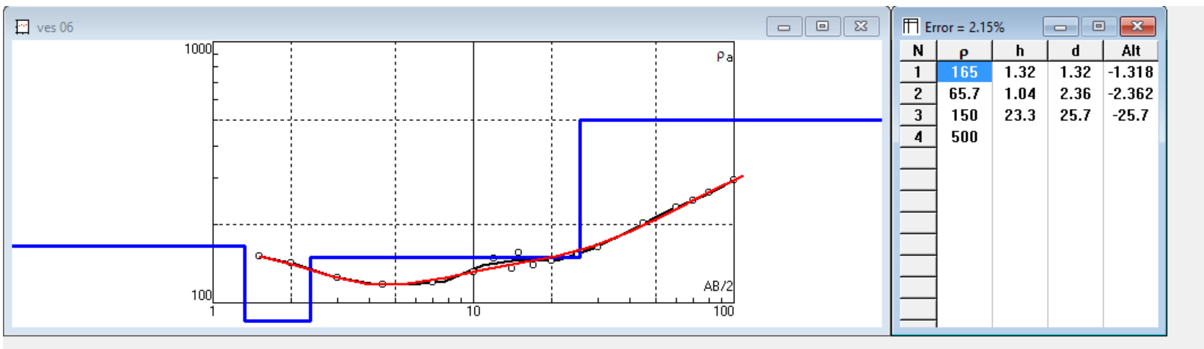

Fig. 11. Resistivity curve for VES 06.

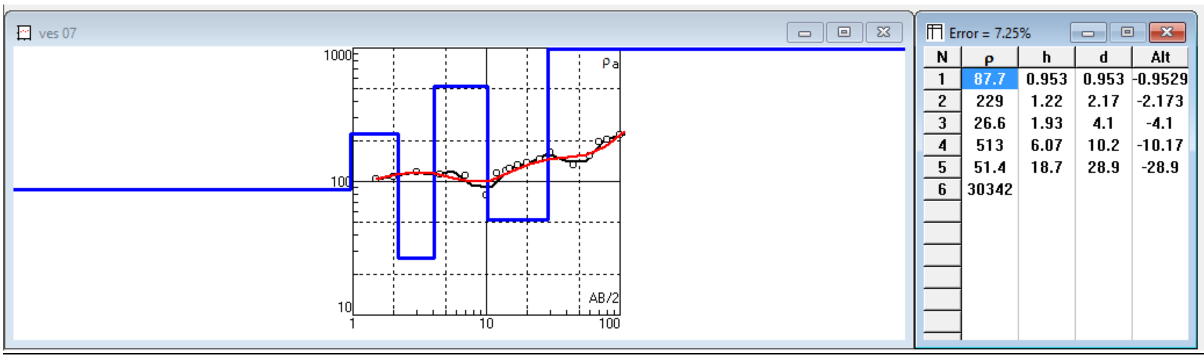

Fig. 12. Resistivity curve for VES 07.

The interpretations of the various resistivity curves are presented in Table 3. The number of geoelectric layers in the various VES points ranged from 4 to 6. The first layers being top soils are usually not considered in other to avoid contamination by leachates. Table 3 revealed that suitable aquifers could not be found at VES points 01, 03 and 06. This is because the resistivity values in all the layers in these VES points were beyond the range for saturated sand. On the other hand, VES points 02, 04, 05 and 07 were found to exhibit the features of a good aquifer (saturated sand). In VES 02, the third layer recorded a resistivity value of 40.57Ωm (saturated sand) with a thickness of 5.902m. This occur in the third geoelectric layer at a depth of 11.65m. Similarly, VES points 04 and 07 recorded low resistivity values of 34.4 Ωm and 26.6 Ωm respectively at their third geoelectric layers as well. The aquifer (saturated sand) in VES 04 has a thickness of 2.02m and occur at a depth of 3.52m while that of VES 07 has a thickness of 1.93m at a depth of 4.1m. On the other hand, the aquifer in VES 05 is situated in the fourth layer. Its resistivity value is 38.5Ωm (saturated sand) and the thickness is 7.49m at a depth of 17.2m. Table 3 also informed that a second aquifer though, wet sand (51.4Ωm) with thickness 18.7 m exists in fifth layer of VES 07 at a depth of 28.9m. Hence, borehole drilling at this point should get to a depth 28.9m and the screens or strainers should be positioned in a way that will permit the inflow of water into the well from the third and fifth layers were these aquifers exist.

Table 3. Interpretation of resistivity curves.

VES Point	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type	Rms error %
01	1	111	0.636	0.636	Top soil	HK	2.09
	2	803	0.263	0.899	Fractured basement		
	3	152	27.2	28.1	Silty sand		
	4	918			Fractured basement		
02	1	101.5	0.847	0.847	Top soil	HK	1.7
	2	192.2	4.899	5.746	Weathered basement		
	3	40.57	5.902	11.65	Saturated sand		
	4	732.6			Fractured basement		
03	1	82.48	0.9	0.9	Top soil	HK	1.4
	2	395.7	1.11	2.01	Weathered basement		
	3	145.6	8.31	10.32	Silty sand		
	4	568.9	40.34	50.66	Fractured basement		
	5	951			Fractured basement		
04	1	84.3	0.572	0.572	Top soil	KA	2.42
	2	401	0.93	1.5	Weathered basement		
	3	34.4	2.02	3.52	Saturated sand		
	4	196	28.1	31.6	Weathered basement		
	5	20432			Fresh basement		
05	1	121	0.786	0.786	Top soil	HK	4.16
	2	374	0.86	1.65	Weathered basement		
	3	132	8.1	9.74	Silty sand		
	4	38.5	7.49	17.2	Saturated sand		
	5	703			Fractured basement		
06	1	165	1.32	1.32	Top soil	HK	2.15
	2	65.7	1.04	2.36	Wet sand		
	3	150	23.3	25.7	Silty sand		
	4	500			Fractured basement		
07	1	87.7	0.953	0.953	Top soil	KH	7.25
	2	229	1.22	2.17	Weathered basement		
	3	26.6	1.93	4.1	Saturated sand		
	4	513	6.07	10.2	Fractured basement		
	5	51.4	18.7	28.9	Wet sand		
	6	30342			Fresh basement		

4. CONCLUSION AND RECOMMENDATIONS

This research has shown that the number of geoelectric layers within the study area ranged from 4 to 6, for Schlumberger electrode spacing (AB) of at most 200 m. Also, most of the aquifers are found within the third geoelectric layer. VES points 02 (11º8′17.417″N, 7°38'21.241"E) and 04 (11°8'13.062"N, 7°38'18.778"E) in Dangote Hall of residence were found to be suitable for drilling boreholes at depths 11.65 m and 3.52 m respectively. However, the well screen or strainer in VES point 02 should lie between depths 5.74 6 m – 11.65 m while that of VES point 04 should be located between depths 1.5 m – 3.52 m in order to maximize the inflow of water into the wells within the entire aquifer's thickness. Similarly, the suitable borehole sites in Shehu Idris Hall of residence were found at VES point 05 (11°8'21.085"N, 7°38'18.932"E) and VES point 07 (11°8'23.022"N, 7°38'16.420"E). Drilling in VES point 05 should get to a depth of 17.2 m and the well screen or strainer should be positioned between depths 9.74 m – 17.2 m. On the other hand, drilling in VES point 07 should get to a depth of 28.9 m but the screen or strainers should be designed between depths 2.17 m – 4.1 m (for first aquifer) and 10.2 m – 28.9 m (for second aquifer).

Based on the analyses given, it is recommended that in Dangote Hall (hostel), priority for selecting borehole site should be given to VES point 02 since its aquifer is much thicker than that of VES point 04. Likewise, in Shehu Idris Hall (hostel), VES point 07 should be considered first since it has two aquifers at the third and fifth geoelectric layers with a considerable thickness in the second aquifer.

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