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A MULTI-TECHNIQUE APPROACH TO AQUIFER CHARACTERIZATION OF BASEMENT COMPLEX TERRAIN: A CASE STUDY OF THE POLYTECHNIC, IBADAN, SOUTHWESTERN NIGERIA

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ABSTRACT

A multi-technique was used to characterize aquifer within the Polytechnic Ibadan, part of the South-Western Nigeria Basement Complex. Electricity resistivity method was employed using the vertical electrical sounding techniques (VES). Nine types of curves were observed in the area and the A-type is most dominant. The resistivity of top soil varies from 40 to 1000 Ω/m with a mean of 294.33 Ω/m. geoelectric section show that a maximum of five units are below the subsurface section which include the top soil, lateritic layer, clay or weathered rock and the fractured/fresh bedrock. The reflection coefficient of the VES points shows that VES 1 and 3-15 are fractured. Five parameters: aquifer thickness, depth to aquifer, hydraulic conductivity, apparent resistivity and transmissivity were used to infer aquifer characteristics in the area. Spatial analyses reveal that aquifer thickness is highest at VES point 15 and lowest at VES point 6. Depth to aquifer is highest at VES point 15 and lowest at VES point 1. Statistical analyses were carried out using factor, hierarchical cluster and bivariate analyses. Factor analysis revealed that all the parameters studied have influence of aquifer in the study area. Cluster analysis grouped the points into five groups of similar properties between the studied aquifer.

Keywords: spatial, electrical-resistivity, statistical analysis, aquifer, basement complex

1. INTRODUCTION

Groundwater is important for human consumption and industrial purposes. Groundwater is a limited resource, which makes it distribution uneven within the subsurface of the Earth. Therefore, the availability of groundwater in every part of the world is impossible. Groundwater is contained in different types of geologic materials. The amount of this resource depends on the ability of different materials to store and transmit it. Appraisal of groundwater resources of Nigeria dated back to as early as 1928 (Offodile, 2002). Groundwater in Nigeria is constrained by the underlying lithology. Within the Basement Complex terrain of Nigeria, groundwater is limited due to the fact that it is not porous and permeable. However, due to intense weathering and fracturing of rocks within this area, secondary porosity were developed which hosts the infiltrating water. In places, the weathered overburden layer overlying crystalline basement can be thick (Alagbe, 2002). Therefore, the aquifers within the Basement Complex area of Nigeria are generally divided into two: the weathered and the fractured basement aquifers. These aquifers may either be perched, shallow or deep depending on the geology and the depth to aquifer. Compared to the sedimentary aquifers, groundwater storage in the crystalline basement is small. The failure rate of new boreholes in the basement has in some cases been as high as 80% (Edet *et al.*, 1998). Many studies have been carried out to determine groundwater potential within the Basement Complex of Nigeria using geophysical methods (Olayinka *et al.*, 1999; Olorunfemi *et al.*, 1999; Ako *et al.*, 2005; Olatunji *et al.*, 2005; Oloruntola and Adeyemi, 2014). Some of the techniques currently being employed internationally for groundwater exploration are remote sensing and geophysical techniques. Of these two techniques geophysical technique is most commonly used, but both can be effectively combined to explore for groundwater. 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. It has been shown that depths of aquifers differ from location to location due to variation in geo-thermal and geo-structural occurrence (Okwueze, 1996). Similar work that has been carried in the study is that of (Akinbiyi and Abudulawal, 2012). Their study focused on geophysical assessment of groundwater potential of part of the Polytechnic Ibadan, South western Nigeria. They concluded that probable aquiferous unit in the geo-environment is the fractured basement rocks (fourth resistivity layer) which occur at a depth of between 17-35 meters from earth surface which is the reason for high yield in the borehole in the area. The aim of this paper is to apply electrical resistivity, statistical and spatial techniques to delineate aquifer characteristics within the northern part of the Polytechnic, Ibadan which is located on the Basement Complex area of south western Nigeria.

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2. STUDY AREA

2.1 Location and accessibility

The study was carried out at the premises of the Polytechnic, Ibadan, Oyo State, Nigeria which is within the south western part of the Basement Complex terrain. It is located on longitude of 4°14´41.24´´Eand latitude of 8°7´31.5´´N. The study area is well drained by river with tributaries jointly forming a dendritic drainage pattern. Accessibility of the area can be best described in terms of its road network (Figure-1). Several roads dissect the area. These include the Rector's road that link the southern part of the institution with staff quarters. With these roads, the accessibility is very easy. The study area is relatively rugged with undulating topography. The elevation varies between 320m and 351m above mean sea level with an average of 345.7m. The area exhibits the typical tropical climate of averagely high temperatures, high relative humidity and generally two rainfall maxima regimes during the rainfall period of March to October. During the rainfall months, average temperatures are between 24°C and 25°C while. Rainfall varies from an average of 1200mm to 1800mm at its peak to an average of between 800mm and 1500mm. The dry season is always characterized by the North-East trade wind in Ibadan. Ibadan is situated along the guinea savanna with the some of its environment covered with grasses. The vegetation consists of rainforest tree species such as oil palm, mango, cashew and food crops like cereals, tubers, etc.

2.2 Geology of the study area

The study area is part of the Basement Complex of south western Nigeria which consists of the following major rocks: quartzite, quartz-biotite schist, biotite schist and banded gneiss (Figure-1) which are generally termed older granite by (Rahaman, 1988) Quartzite is one of the major rocks in Ibadan area. The two type quartzite recognized in the study area include: the massive quartzite and schistose quartzite. The massive quartzite consists mainly of quartz with little or no mica. Structures found on the quartzite include foliation, schist and schistosity. The schistose quartzitealso found in Ibadan area, which consist of micas, chlorite, talc, graphite and quartz. The quartz biotite schist iscoarse-grained and grey to dark in colour. The minerals present in these rocks types include; quartz, biotite and muscovite. Geologic structures found in these rocks are generally fractures. The biotite schist contains quartz and biotite. Structures found in these rocks include foliation and micro folds. The banded gneiss mineralogically contains quartz, muscovite and feldspar. Banding, micro-folds and fractures are the major structures found within this area. Tectonic deformation in the area produced folding that affected the quartz schist in the area.

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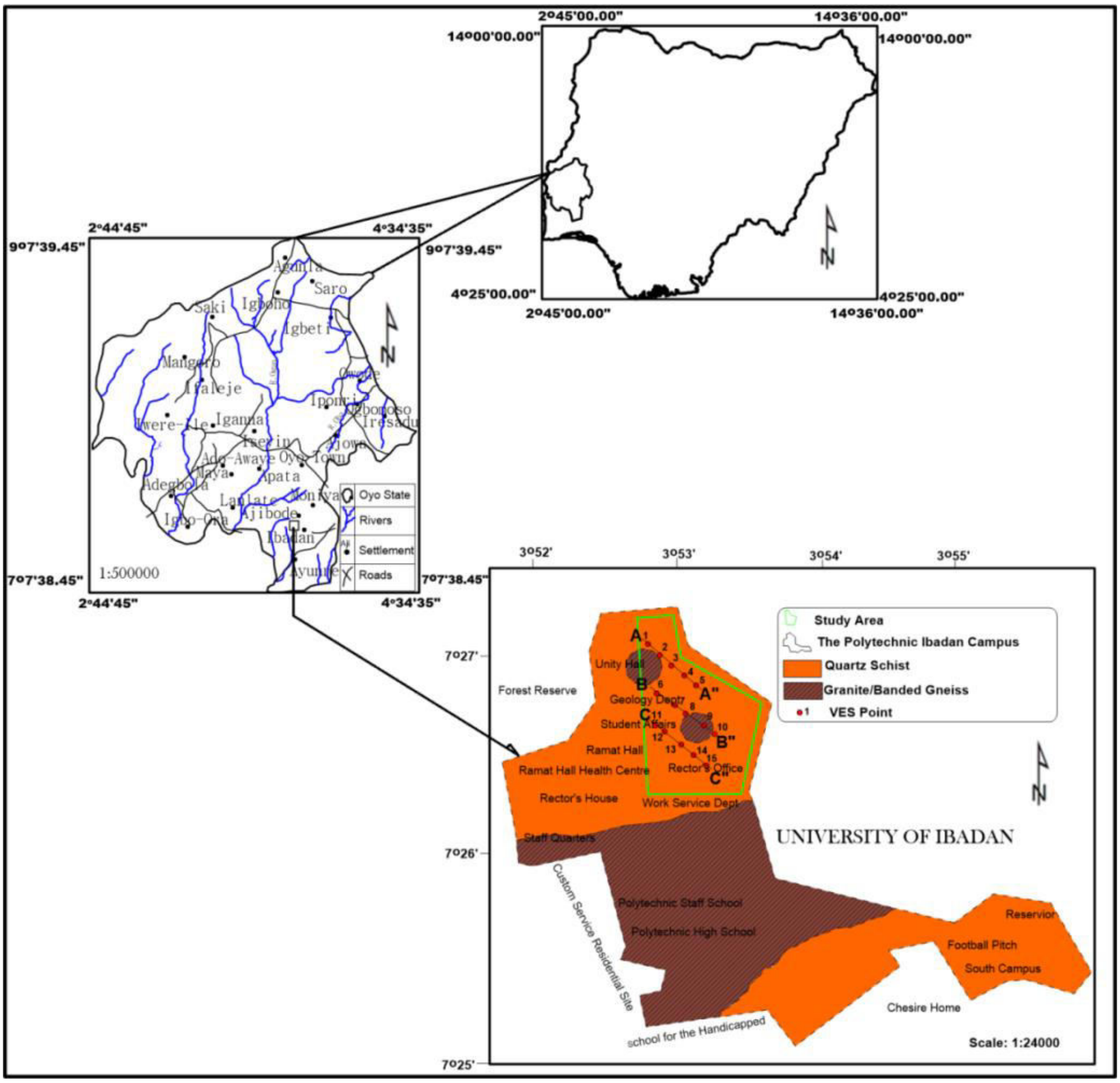

Figure-1. Location, accessibility and Geologic map of the study area (Modified after Akinbiyi and Abudulawal, 2012).

3. RESEARCH METHODS

3.1 Geophysical field mapping technique

The electrical resistivity method was used for this study. Fifteen (15) sounding points were selected. The method involves the passage of electric current (using D.C or low frequency A.C current) into the subsurface, through two electrodes (the current electrodes). Actual resistivity of subsurface layer is determined from ground apparent resistivity, which is computed from the measurement of current and potential difference between the electrodes pair placed on the surface. Vertical Electrical Sounding (VES) technique is based on the fact that the fraction of the electric current put into the ground, penetrating below any particular depth, increases with an increased separation of the current electrodes. Several electrode arrangements are possible for VES but the Schlumberger arrangement was employed (Figure-2) during the course of this study. Schlumberger electrode array also utilizes four electrodes system like Wenner array but they are arranged linearly with different inter-electrode spacing. The electrodes are arranged such that the distance AB between the current electrodes is greater or equal to five times the distance MN, between the potential electrodes. The potential electrodes are fixed about the data station in which the current electrodes are spread until the required maximum separation is attained (Figure-2)

$$C1P1 = C2P2 \neq P1P2 \quad (1)$$

$$\text{Geometric Factor } K = \frac{\pi\left[\left(\frac{C1C2}{2}\right)^2 - \left(\frac{P1P2}{2}\right)^2\right]}{2*\left(\frac{P1P2}{2}\right)} \quad (2)$$

Where C = Current and P = Potential

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Finally, in vertical sounding, the potential electrodes remain fixed while the current electrodes spacing is expanded symmetrically about the centre of the spread. For large value of L_1 it is necessary to increase 'l' also in order to maintain a measurable potential. The assumption is that, the wider the current electrode spacing, the deeper the earth is being probed.

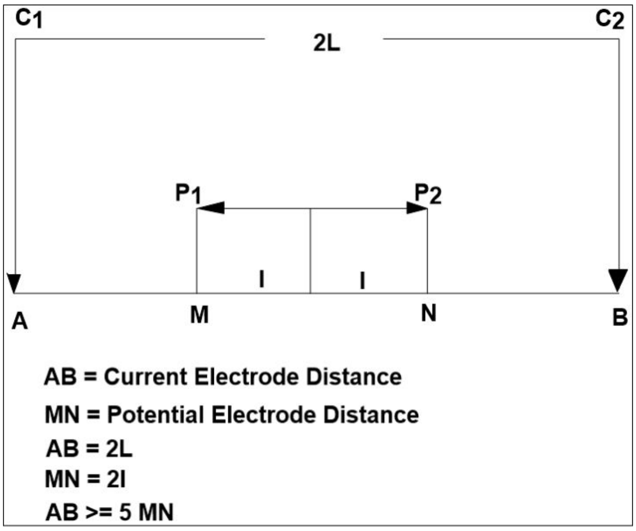

Figure-2. The generalized schlumberger array.

3.2 Data processing

The qualitative interpretation of VES data involves the visual inspection of curve types (Figure-3). Quantitative interpretation of VES data includes the determination of the number of layers represented by the curves, individual layer resistivity and thickness. The procedures for the quantitative interpretation are the partial curve matching (auxiliary point method) and which and direct interpretation. In partial curve matching an empirical method is employed in which a multi-layer problem is progressively reduced to a simple two or more layer case. Two and three layer curves are used in conjunction with one or more of the charts that represent the families of auxiliary curves. However, in direct interpretation of the VES curve in terms of layer thickness and resistivity is carried out with aid of computer programs without an initial approximately geo-electric sections. For this study, partial curve matching method was adopted where sounding curve was superimposed on the master curve. The point of intersection of the master curves was marked on field curve tracing paper as X_1. The coordinate X_1 on the log-log graph paper gave ρ1 and h1, the resistivity and thickness of the first layer. The value K of the master curves, which fitted the first segment of the field curve, is noted as K_1. This is the reflection co-efficient at the interface between the first and the second layers (Keller and Frischknecht, 1996).The auxiliary curve with the reflection coefficient value of K_1 was drawn on the field curve in broken lines with the axes kept parallel; the next segment of the field curve was fitted to a two layer master curve of best fit. When the best fit was obtained, the point of intersection of the master curves was marked as X_2.The coordinates of X_2 on the log-log graph paper gave the replacement resistivity and thickness of the third layer. The actual resistivity and thickness of the second layer was calculated using this relationship:

$$\rho_1 = K_1\rho_1 \tag{3}$$

$$\text{and} h_2 = \frac{D_n}{Dr1} \tag{4}$$

Where D_n/Dr_1 is the depth index read off the auxiliary curve by placing X_1 at the origin of the auxiliary curves and tracing X_2 parallel to the two auxiliaries bordering it. For the four layers, the last segment of the curve was fitted to the master curves and X_3 marked, as done previously K_3:h_3r and are read off. The actual layer resistivity is calculated using the second depth index derived from the auxiliary curve graph using X_2 and X_3 as done previously; thus:

$$H_3 = h_2 r \times \frac{Dn}{Dr_2} \tag{5}$$

Win RESIST Version 1.0 (Vander-Velpen, 2004), based on smoothness constrained optimization technique, was used to refine the geoelectric parameters obtained from manual interpretation of each VES data. A particular model was considered acceptable at 10% error level, as proposed by (Barker *et al.*, 1992).

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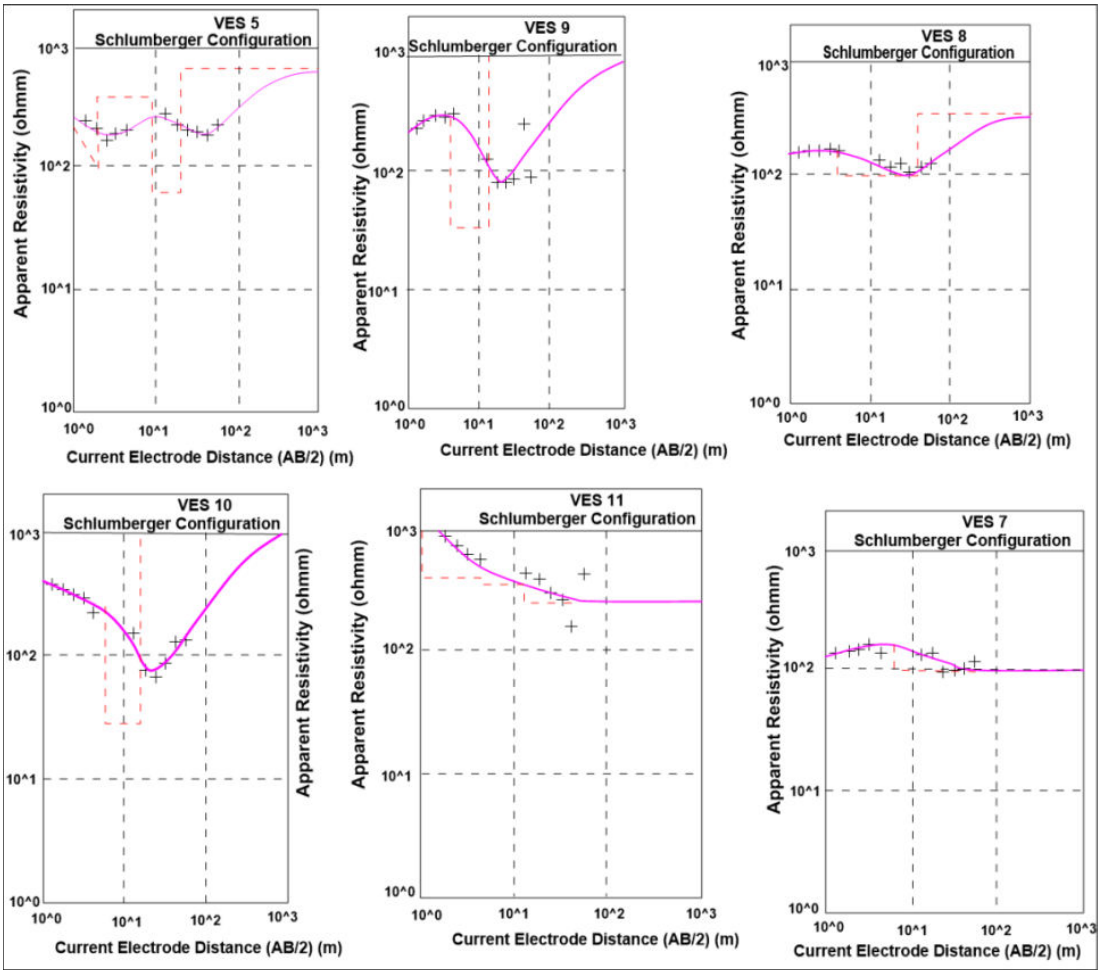

Figure-3. Schlumberger configuration of some VES points in the study area.

4. DISCUSSIONS OF RESULTS

4.1 Geophysical parameters

The sounding curves of the Polytechnic Ibadan vary from 2 to 3. Nine types of curves were observed (Table-1). The A-type is the most dominant curve which is 26.67%. This is followed by HA (20%) and HQ (13.33%). HKA, KA, AQ, K, H, and Q curves corresponds to 6.67% respectively. The H-type curve is a common type of curve in this type of geological terrain (Olorunfemi and Oloruniwo, 1985). The intermediate layer in the H-curve is usually characterized by low resistivity made up of clayey or sandy clay and is often water saturated and highly porous (Oloruntola and Adeyemi, 2014). The HA type consists of the topsoil, clay and sand regolith overlying a weathered fractured rock (Oloruntola and Adeyemi, 2014). Four geologic layers were identified in the study area and they include the topsoil, clay, weathered basement, fractured basement/fresh basement (Figures 4-5).

The resistivity of topsoil (Figures 4-6) varies from 40 to 1000Ω/m with a mean of 294.33Ω/m and a standard deviation 250.35Ω/m. the thickness of topsoil varies from 0.75-1.4m, with an average of 0.99±0.21m. This layer is of least or no significance as a hydrogeological unit because of its low degree of saturation (Olorunfemi and Oloruniwo, 1985; Oloruntola and Adeyemi, 2014).

Table-1. Percentage distribution of curve types.

S/N	Curve types	Percentage
1	HKA	6.67
2	HQ	13.33
3	KA	6.67
4	AQ	6.67
5	HA	20.00
6	K	6.67
7	H	6.67
8	A	26.67
9	Q	6.67
Total		100.02

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4.2 GEOELECTRIC SECTIONS

The results of the interpreted VES curves were used to draw geoelectric sections (Figures 4 - 6; Table-2) along VES 1-5 (A-A"), VES 6-10 (B-B") and VES 11-15 (C-C")to show the vertical distribution of resistivity within the subsurface in the study area. The sections consist of sequence of uniform horizontal (or slightly inclined) layers (horizons). Each layer (horizon) in the geo-electrical section may completely be characterized by its thickness and true resistivity. The strikes for all the traverse is approximately NW-SE. The geoelectric sections show vertical variations in layer resistivity, which is a revelation of the vertical facie changes. A maximum of five subsurface geoelectric units were delineated beneath these sections. These include the topsoil, the lateritic layer, the clay/weathered rock, and the fractured/fresh bedrock.

The topsoil is made up of, sandy clay, sand, or gravel above the water table; hence it's widely of varying resistivity. Layer resistivity and thickness values range respectively from 40 to 1000Ωm and 0.75 to 1.4m. The topsoil is underlain by a second layer of weathered basement in the sounding stations of the investigated area. This layer has resistivity values ranging from 111.7 to 400.1Ωm and thickness values from 1.15 to 12.5m. The second layer is underlain by a third layer of fractured basement. The last layer which forms the bedrock is highly resistive in most places. The bedrock resistivity values vary from 311.6 to 2200Ωm. Study shows that the resistivity value of fresh bedrock often exceeds 1000Ωm, beside, where it is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000Ωm (Olayinka *et al.*, 1999). The depth to this bottom layer varies across the profiles from 1.8 to 18.5m. Reflection coefficient was used to determine if the bedrock in the area is fractured or not. Reflection coefficient defines the nature of the basement rock whether it is fractured or fresh. The formula for two layers case can be expressed as:

$$K = \frac{\rho_3 - \rho_2}{\rho_3 + \rho_2} \qquad (6)$$

The results of the reflection coefficient for all the VES points are presented in Table-3. From the values of reflection coefficient for the VES locations, VES point2 have value greater than 0.8 meaning that the rock is fresh and may be fractured. The situation differs from other VES (1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15) points which have K values less than 0.8 indicating they are fractured. The groundwater is high and has a high yield (Akinbiyi and Abudulawal, 2012).

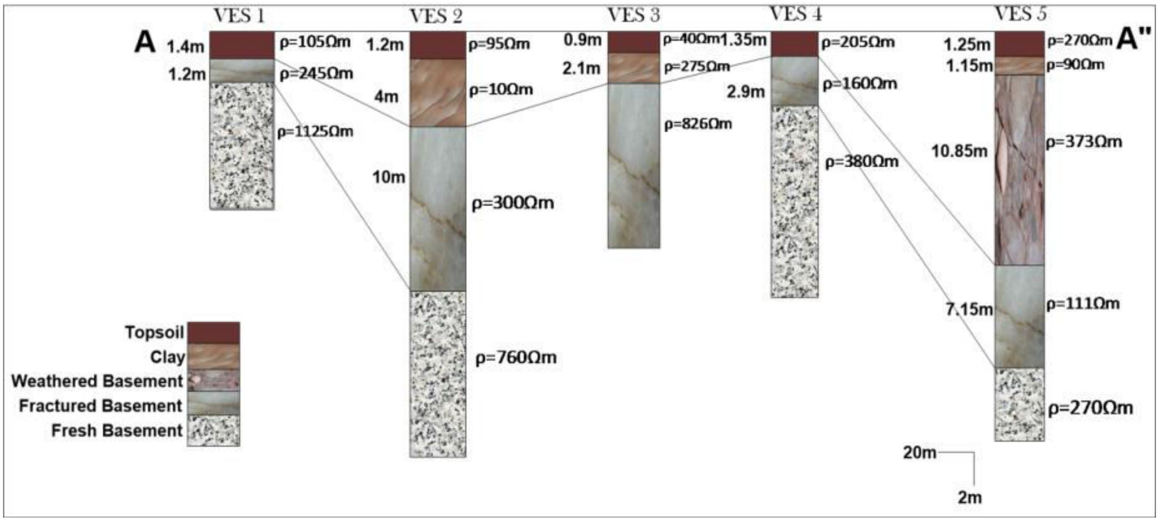

Figure-4. Geo-Electric and inferred geologic sections for VES 1 to 5.

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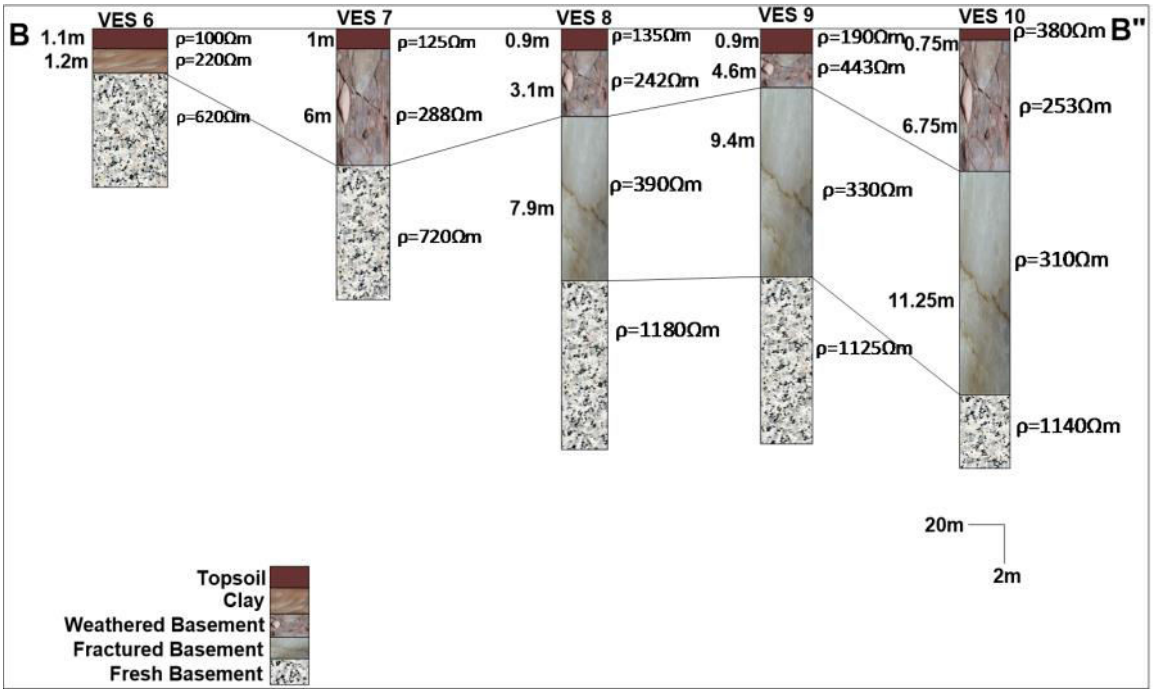

Figure-5. Geo-Electric and inferred geologic sections for VES 6 to 10.

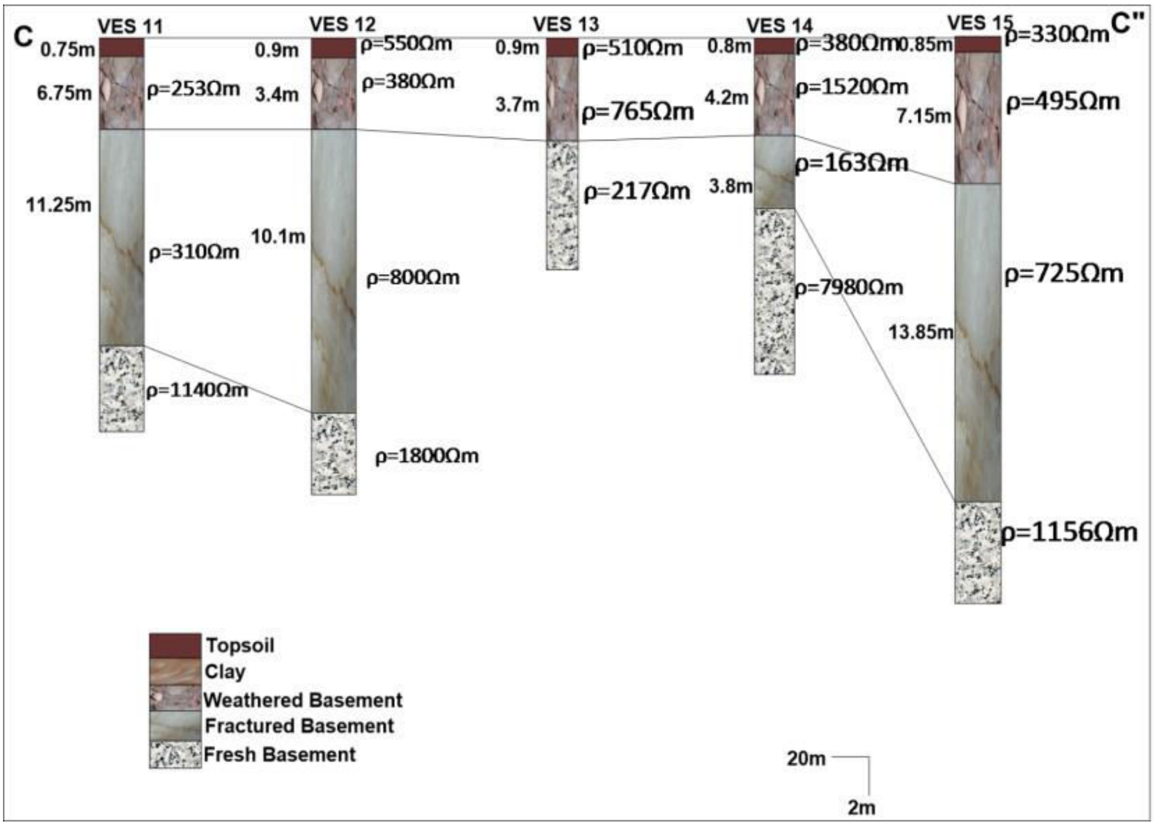

Figure-6. Geo-Electric and inferred geologic sections for VES 11 to 15.

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Table-2. Vertical electrical sounding data from the study area.

S/N	$AB/2$ (m)	$MN/2$ (m)	R (m)	ρ (Ω/m) $VES\ 1$	R (m)	ρ (Ω/m) $VES\ 2$	R (m)	ρ (Ω/m) $VES\ 3$
1	1	0.2	1.914	14.60	5.26	42.48	5.29	40.42
2	2	0.2	0.552	17.17	0.490	15.24	1.38	42.93
3	3	0.2	0.247	17.39	0.183	12.88	0.44	31.12
4	3	0.4	0.523	18.16	0.374	12.99	1.08	37.36
5	5	0.4	0.232	22.63	0.129	12.59	0.24	23.41
6	7	0.4	0.126	24.17	0.092	17.65	0.09	18.03
7	10	0.4	0.063	24.70	0.062	24.31	0.05	19.21
8	10	2.0	0.286	21.60	0.287	21.67	0.29	21.89
9	15	2.0	0.172	29.86	0.150	26.04	0.14	24.48
10	20	2.0	0.083	25.82	0.140	43.86	0.09	30.79
11	30	4.0	0.058	40.82	0.093	65.45	0.06	43.64
12	30	4.0	0.105	36.45	0.168	58.32	0.14	46.87
13	45	4.0	0.038	30.00	0.099	78.11	0.09	74.17
14	50	4.0	0.040	39.02	0.085	82.92	0.08	78.05

Table-3. Reflection coefficients for the VES points in the study area.

VES No.	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	K
1	105	245	1125	-	-	0.64
2	95	10	300	760	-	0.96
3	40	275	826	-	-	0.50
4	205	160	380	930	-	0.41
5	270	90	373	111	720	0.61
6	100	220	620	-	-	0.48
7	125	288	720	-	-	0.43
8	135	242	83	390	-	0.49
9	190	443	330	125	-	0.15
10	380	253	310	1140	-	0.10
11	550	2200	800	180	-	0.47
12	1000	429	275	120	-	0.22
13	510	765	217	-	-	0.56
14	830	1520	163	7980	-	0.81
15	330	496	725	56	-	0.19

4.3 spatial characteristics of aquifer in the study area

Aquifer thickness: Figure-1 and Table-4 show the spatial map for aquifer thickness in the study area. Aquifer thickness decreases in the following order across the VES profiles: 15(21.00m) > 5(18.00m) > 10(18.00m) > 12(16.00m) > 9(14.00m) > 11(13.50m) > 8(11.00m) > 2(10.00m) > 14(8.00m) > 7(6.00m) > 13(3.70m) > 4(2.9m) > 3(2.1m) > 1(1.2m) > 6(1.2m).

Depth to aquifer: Figure-8 and Table-4 show the spatial map for depth to aquifer in the study area. The depth to aquifer decreases in the following order across the VES profiles: 15(21.85m) > 5(20.40m) > 10(18.75m) > 12(17.10m) > 2(15.20m) > 9(14.90m) > 6(12.00m) >

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8(11.90m) > 14(8.80m) > 7(7.00m) > 13(4.6m) > 4(4.25m) > 3(3.00m) > 1(2.6m).

Hydraulic conductivity of aquifer: Figure-9 and Table-4 show the spatial map for hydraulic conductivity in the study area. This is calculated using equation (vii). Hydraulic conductivity of aquifer in the study area decreases in the following order: 12(17.07m/s) > 13(13.27m/s) > 15(9.95m/s) > 8(0.89m/s) > 9(0.59m/s) > 10(0.5m/s) > 11(0.5m/s) > 2(0.47m/s) > 7(0.43m/s) > 3(0.39m/s) > 1(0.31m/s) > 6(0.26m/s) > 14(0.17m/s) > 4(0.17m/s) > 5(0.12m/s).

$K = 0.053e^{-0.0072\rho}$(vii)

Where ρ equals the apparent resistivity of the rock (Abudullahi *et al.*, 2001; Odong, 2013)

Apparent resistivity of aquifer: Figure-10 and Table-4 show the spatial map for apparent resistivity of aquifer in the study area. Apparent resistivity of aquifers in the study area decreases in the following order: 12(800Ω/m) > 13(765Ω/m) > 15(725Ω/m) > 8(390Ω/m) > 9(330Ω/m) > 10(310Ω/m) > 11(310Ω/m) > 2(310Ω/m) > 7(288Ω/m) > 3(275Ω/m) > 1(245Ω/m) > 6(220Ω/m) > 14(163Ω/m) > 4(160Ω/m) > 5(111Ω/m).

Transmissivity of aquifer: Figure-11 and Table 4show the spatial map for aquifer transmissivity in the study area. Transmissivity of an aquifer is calculated using equation (viii) Transmissivity of aquifer in the study area decreases as follows: 12(273.12m/s^2) > 15(208.95m/s^2) > 13(49.10m/s^2) > 8(9.79m/s^2) > 10(9.00m/s^2) > 9(8.26m/s^2) > 11(6.75m/s^2) > 7(2.58m/s^2) > 5(2.16m/s^2) > 14(1.36m/s^2) > 3(0.82m/s^2)> 4(0.49 m/s^2) > 1(0.37 m/s^2) > 6(0.312 m/s^2).

$T = kb$ (viii)

Where T = Transmissivity (m/s^2) and b = aquifer thicknesses [8, 10. The transmissivity of aquifer in the study area shows that groundwater occurrence is moderate to high.

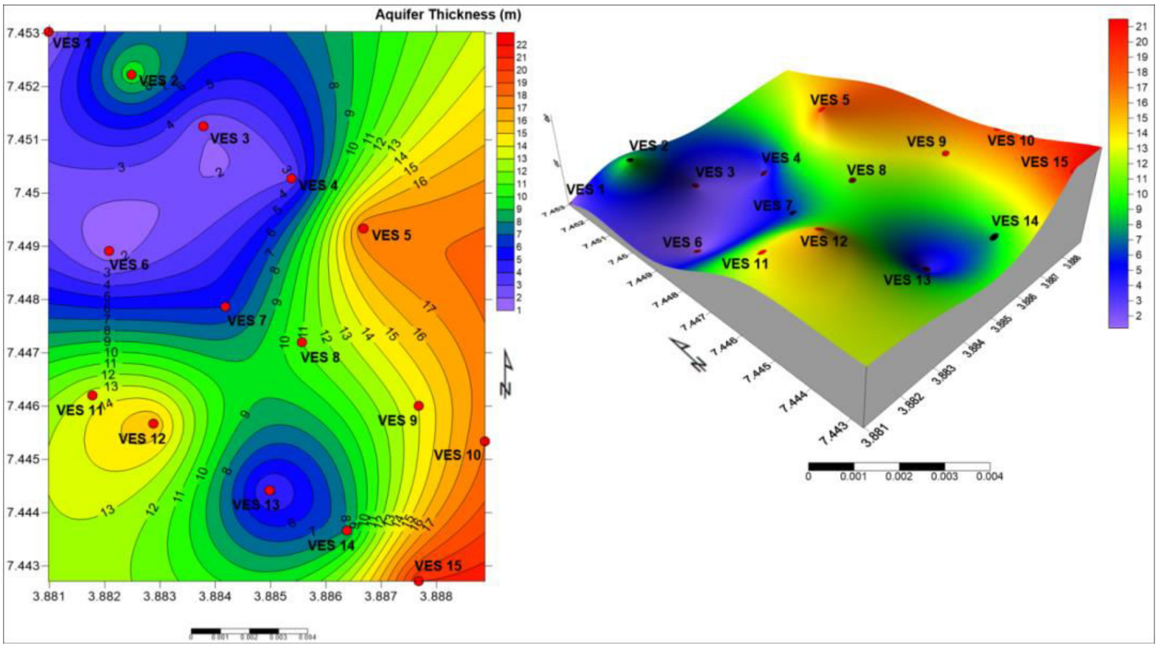

Figure-7. 3-Dimensional spatial map of aquifer thickness in the study area.

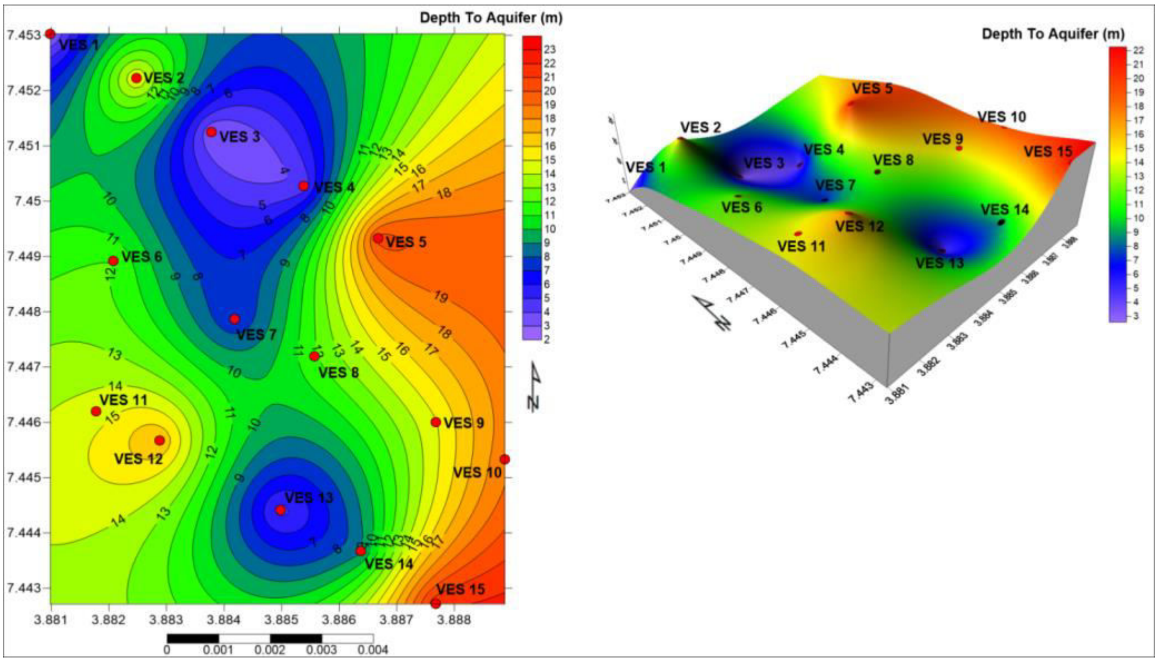

Figure-8. 3-Dimensional spatial map of depth to aquifer in the study area.

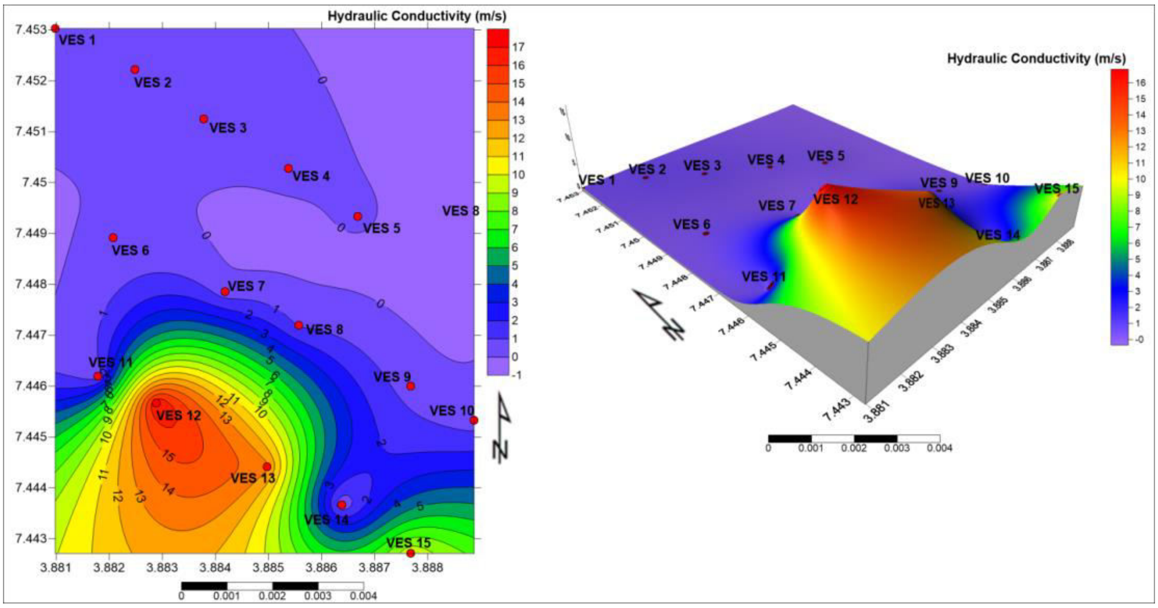

Figure-9. 3-Dimensional spatial map of hydraulic conductivity in the study area.

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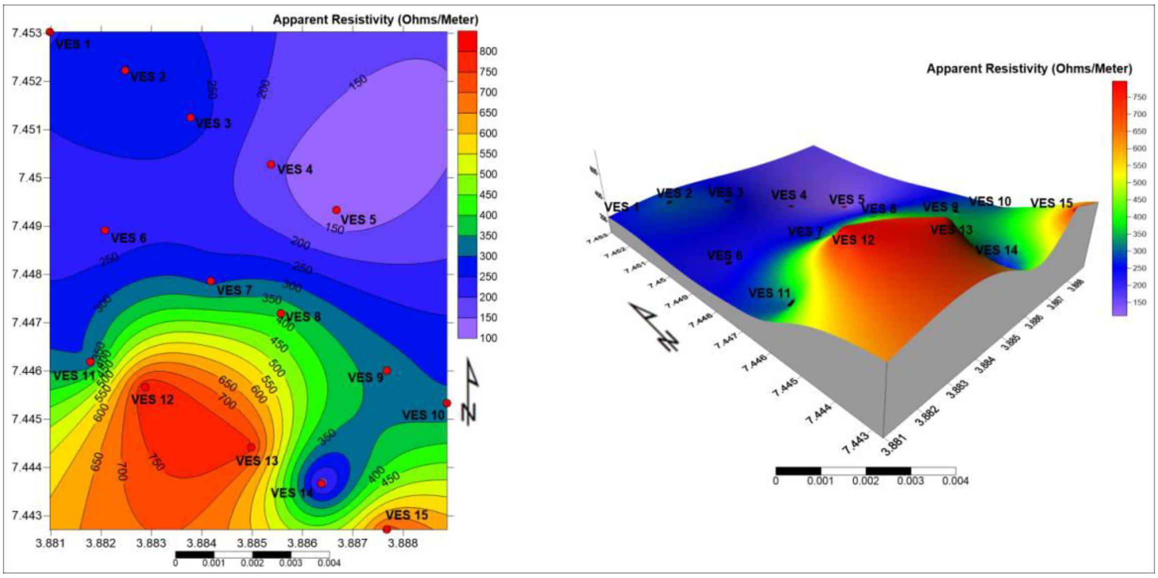

Figure-10. 3-Dimensional spatial map of apparent resistivity in the study area.

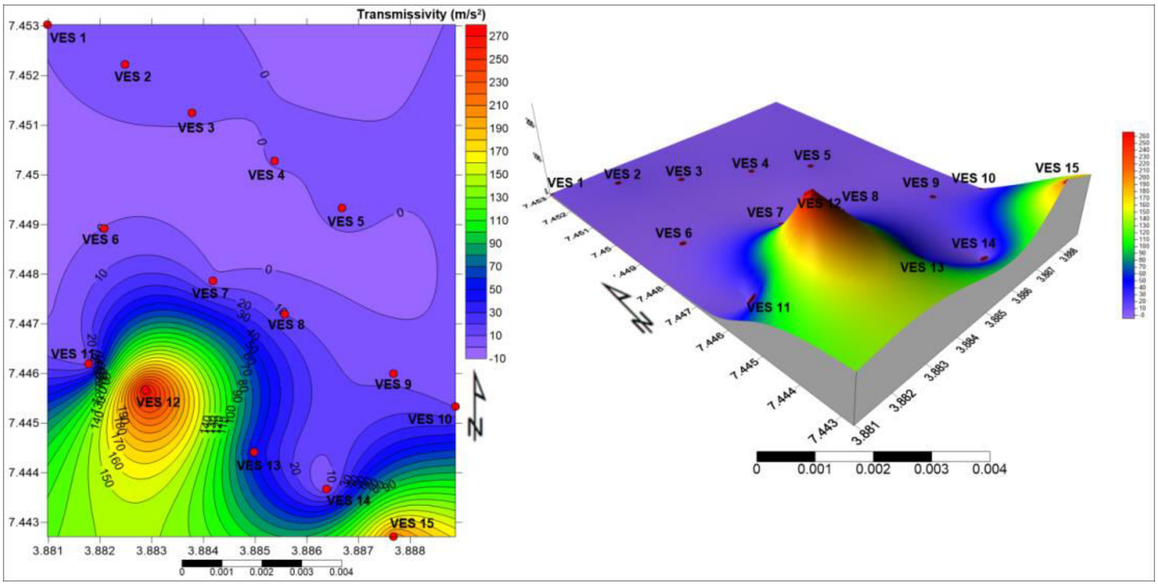

Figure-11. 3-Dimensional map of transmissivity in the study area.

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Table-4. Summary of results of the aquifer parameters inferred from the geo-electric sections in the study area.

VES No.	Easting	Northing	Depth To aquifer (m)	Aquifer thickness (m)	Apparent resistivity (Ω/m)	Hydraulic conductivity (m/s)	Transmissivity (m/s)
1.	3.8809	7.4530	2.60	1.20	245.00	0.31	0.37
2.	3.8830	7.4522	15.20	10.00	300.00	0.47	4.70
3.	3.8838	7.4513	3.00	2.10	275.00	0.39	0.82
4.	3.8854	7.4502	4.25	2.90	160.00	0.17	0.49
5.	3.8867	7.4493	20.40	18.00	111.00	0.12	2.16
6.	3.8821	7.4489	12.00	1.20	220.00	0.26	0.31
7.	3.8842	7.4472	7.00	6.00	288.00	0.43	2.58
8.	3.8856	7.4472	11.90	11.00	390.00	0.89	9.79
9.	3.8877	7.4460	14.90	14.00	330.00	0.59	8.26
10.	3.8888	7.4453	18.75	18.00	310.00	0.50	9.00
11.	3.8818	7.4462	14.45	13.50	310.00	0.50	6.75
12.	3.8829	7.4457	17.10	16.00	800.00	17.07	273.12
13.	3.8849	7.4444	4.60	3.70	765.00	13.27	49.10
14.	3.8864	7.4437	8.80	8.00	163.00	0.17	1.36
15.	3.8877	7.4427	21.85	21.00	725.00	9.95	208.95

4.4 Statistical evaluation of aquifer parameters

Factor analysis: Factor analysis from component matrix analysis reveals that all parameters for used for aquifer characterization in the study area all have a strong but varied influence on groundwater. Two components were extracted using the Principal Component Analysis (PCA) (Table 5). In the first component, transmissivity of the aquifer has the highest influence on aquifers in the area (0.973) followed by the aquifer thickness (0.924). Depth to aquifer is the third most influential factor controlling aquifers in the study area (0.865), which is followed by hydraulic conductivity of the aquiferous units (0.646). The least factor affecting the aquifers in the study area is apparent resistivity. In factor 2, apparent resistivity (0.618) and hydraulic conductivity (0.601) accounts for the most influential parameters. Rotated matrix of these parameters also reveals two components (Table-6). In component 1, depth to aquifer (0.967), aquifer thickness (0.956) and transmissivity (0.851) are the most important factors affecting aquifers in the study area. In component two, hydraulic conductivity (0.854) and apparent resistivity (0.854) are the most influential.

Table-5. Component matrix of aquifer parameters in the study area using principal component analysis.

S/N	Parameters	1	2
1	Depth to Aquifer	0.865	-0.442
2	Aquifer Thickness	0.924	-0.327
3	Apparent Resistivity	0.568	0.618
4	Hydraulic Conductivity	0.646	0.601
5	Transmissivity	0.973	-0.055

Table-6. Rotated matrix of aquifer parameters in the study area using principal component analysis.

S/N	Parameters	1	2
1	Depth to Aquifer	0.967	0.091
2	Aquifer Thickness	0.956	0.220
3	Apparent Resistivity	0.147	0.826
4	Hydraulic Conductivity	0.222	0.854
5	Transmissivity	0.851	0.476

Hierarchical cluster analysis: This was carried out to determine the pattern of relationship between the aquifers in the study area. Five clusters were obtained from the hierarchical analysis (Figure-12). The result (Table-7) shows that VES 1, 2, 3 and 7 are related to one

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another and are in group 1. Group two consist of VES 4, 6, 9, 12 and 13, while group three consist of VES 5, 8, 10 and 15. Group four consist VES 14, while VES 11 is in group five. VES 14 and 15may have be singly grouped because they might have shared possibly relationships with other aquifers that the study area does not cover. The aforementioned implies all VES points in the same group have some unique properties in common.

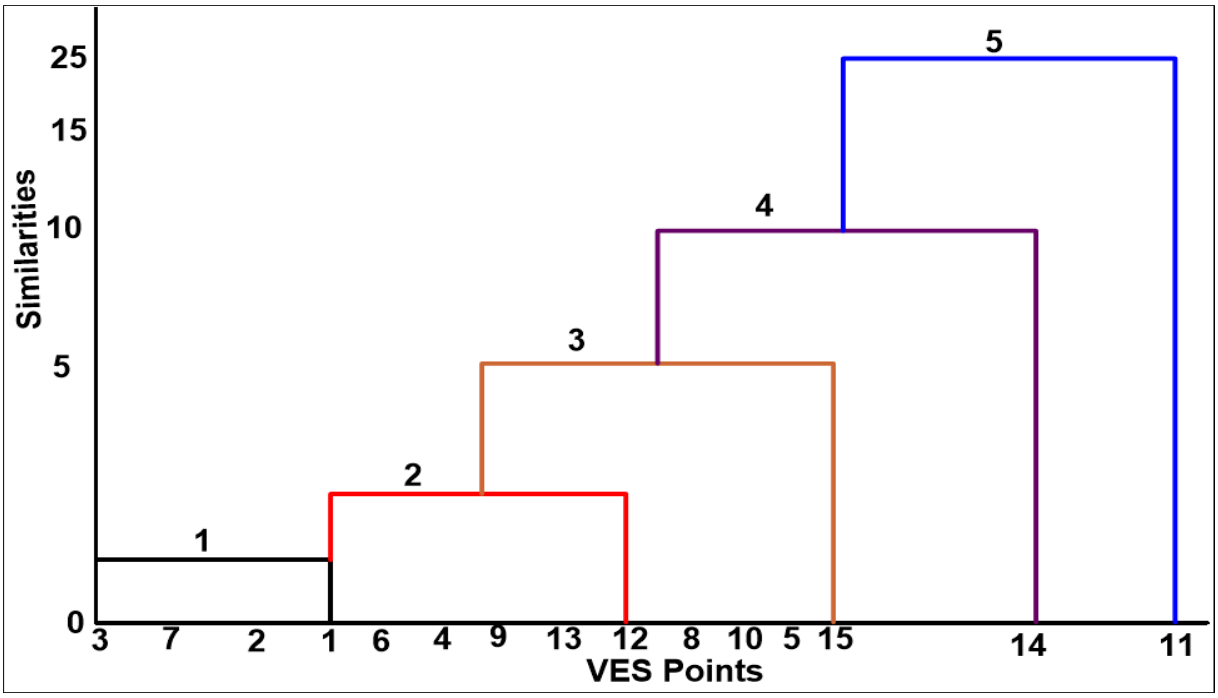

Figure-12. Similarities of VES points in the study area.

Bivariate correlation: Correlation analysis was carried out to determine relationships between aquifer parameters studied. Table VII revealed that there is a very strong and positive relationship between depths to aquifer and the aquifer thicknesses in the area (r = 0.919). It further shows that a very strong and positive relationship also exist between hydraulic conductivity and apparent resistivity of aquifers in the study area (r = 0.944). Finally, it result further shows that there is a strong positive relationship between apparent resistivity and hydraulic conductivity (r = 0.824 and 0.866 respectively).

Table-7. Bivariate correlation factor using Pearson method.

	Depth to aquifer	Aquifer thickness	Apparent resistivity	Hydraulic conductivity	Transmissivity
Depth to Aquifer	1				
Aquifer Thickness	0.919**	1			
Apparent esistivity	0.196	0.300	1		
Hydraulic Conductivity	0.174	0.253	0.944**	1	
Transmissivity	0.428	0.484	0.824**	0.866**	1

**Correlation is significant at the 0.01 level (2-tailed)

5. CONCLUSIONS

A multi-technique approach was used for aquifer characterization of Basement Complex terrain within the Polytechnic, Ibadan, southwestern Nigeria. The study reveals that the fractured basement in the area forms the aquiferous units. Five parameters studied revealed that the groundwater occurs moderately in the area. Statistical analyses further reveal that all these five factors (depth to aquifer, aquifer thickness, apparent resistivity, hydraulic conductivity and transmissivity) have a considerable influence on the aquifer character in the study area. The study shows that if well applied, geophysical, spatial and statistical approach can be combined and used to characterize aquiferous units in an area.

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