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Full Length Research

Geo-electrical investigation for groundwater potential of Kaltungo and environs, North Eastern Nigeria

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ABSTRACT: An investigation of groundwater potential using Vertical Electrical Sounding (VES) and adopting the Schlumberger configuration with a maximum electrode spread of 100 m have been carried out in Kaltungo and environs. This was carried out with the aimed at evaluating geo-electrical parameters for the exploration of groundwater using the Omega Resistivity Meter. Thirty VES points were conducted across the study area. Data collected was analysed using Interpex IX1-D software. The analysed result reveals four distinctive curve types which are H-type 80%; A-type 6.7%; Q-type 10% and K-type 3.3%. Iso - resistivity maps revealed a major anomaly found at the eastern part of the study area which correspond with the 3-D model and indicate hard resistive rocks. Geo-electro stratigraphic section revealed that the area is underlain by three geo-electric layers, top lateritic soil, weathered/fractured and fresh basement. The first layer has a resistivity value of 23 to 1679 Ωm and a thickness that range from 1 to 5m. The second layer is a weathered/fractured basement with a resistivity of 6 to 410 Ωm and thickness of 7 to 28 m which constitute the aquiferous zones and the third layer is a fresh basement with resistivity value of 514 to 34338 Ωm. Maximum hydraulic conductivity value is observed at VES 14 while transmissivity values varies between 23.84 to 964.0 m^2/day. The distribution of aquifer potential in the study area indicates that 75% moderate, 12.5%, high and 12.5% low. Groundwater flow direction is in the NW, SW, SE and E respectively.

Keywords: Groundwater potential, Kaltungo and environs, Vertical Electrical Sounding (VES).

INTRODUCTION

The electrical resistivity method is a geophysical method that has been successfully used by several researchers for groundwater investigations. The electrical resistivity method (non-invasive) is usually preferable because of the resistivity contrasts obtained when the groundwater zone is reached. Research in groundwater geophysics reveals that this technique has been successfully employed for delineating/mapping of geo-materials in the subsurface that guides exploration of groundwater resources (Metwaly et al., 2012; Oyedele et al., 2009). The electrical resistivity method is the most versatile and the most popular method of all the geophysical methods that are used in groundwater investigation in Basement Complex area (Olorunfemi, 2009). It is relevant in the depth to bedrock estimation, aquifer delineation and structural mapping (Ademilua and Eluwole, 2013; Obasi et al., 2013). The occurrence of groundwater in basement rocks is mainly in the weathered/fractured zones of basement. Nur and Ayuni (2004), Nur and Ayuni (2011), Nur and Kujir, (2006), Olasehinde (2010), Ayuni et al. (2017) and Ayuni et al. (2018) have utilized resistivity method as a tool for groundwater exploration in basement area. Resistivity method is the most widely used in groundwater exploration.

The occurrence, storage, and distribution of groundwater in the Precambrian basement complex are influenced by different geological factors (Amadi and Olasehinde, 2010). Groundwater is never chemically pure; dissolution of substances takes place in the course of its percolation through the rocks leading to its acquisition of

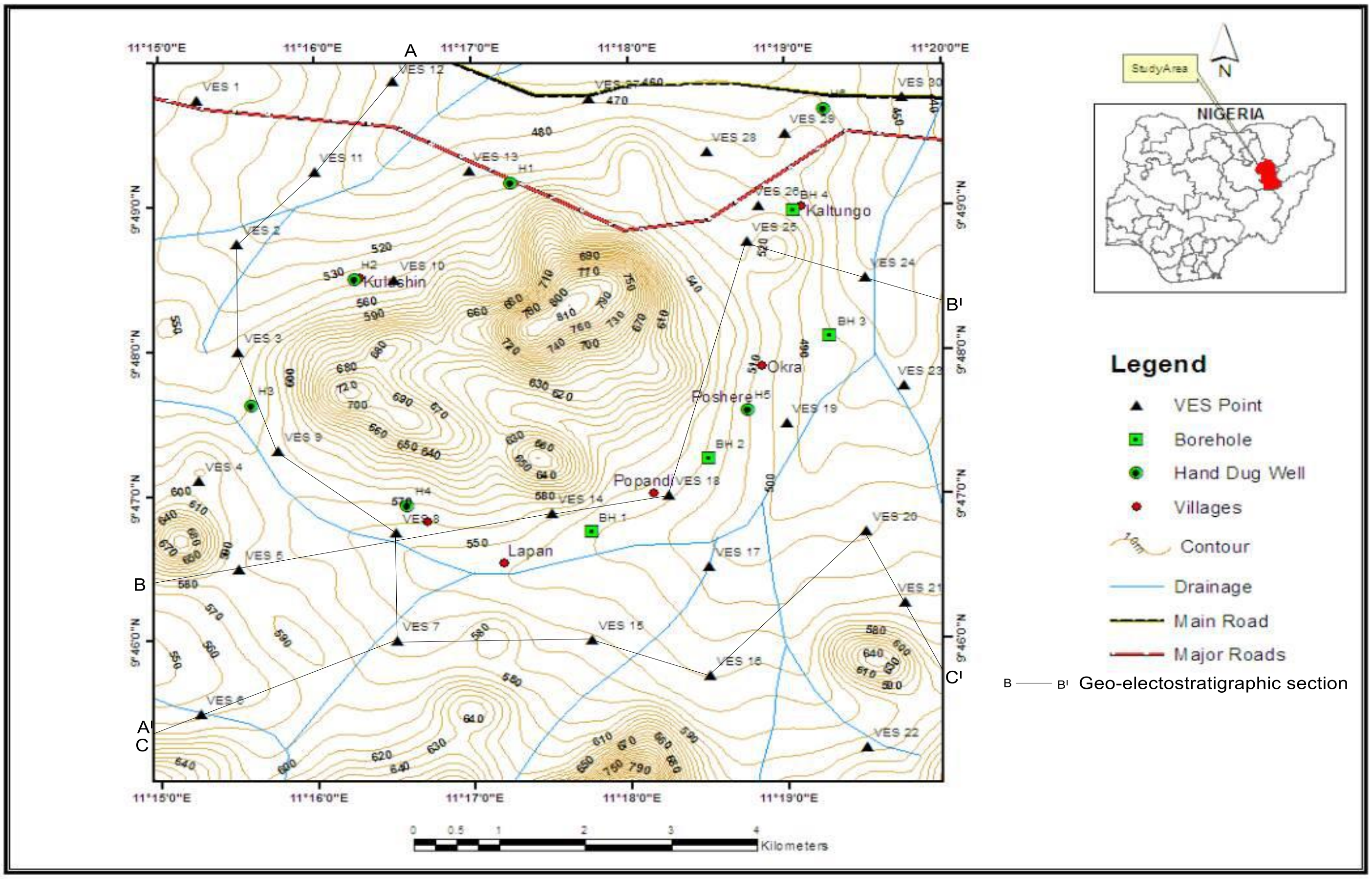


Figure. 1. Topographic Map of the Study Area (Modified After Federal Survey of Nigeria, 1976).

some of their chemical constituents. Most often, the occurrence of groundwater in basement complex terrains is localized and confined to weathered/fracture zones (Adiat et al., 2009). The aquifer parameters calculated from geophysical data such as hydraulic conductivity and transmissivity are important for the management and development of groundwater supply potential.

This work therefore seeks to investigate and to obtain the groundwater potential of Kaltungo and its environs. This will be achieved through the analysis of Vertical Electrical Sounding (VES), determination of depth to bedrock, thickness and to locate possible site for the purpose of groundwater development.

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The study area lies within the Gongola arm of the upper Benue trough of north eastern Nigeria and lies between latitude 9^o 45' and 9^o 50'and longitude 11^o 15'and 11^o 20' (Figure 1). The study area covers an area extent of 84.03 km^2 and is accessible and has good network roads and foot paths. The area is characterized by two distinct seasons, the rainy and the dry season. The rainy season is usually longer and associated with intermitted heavy rainfall in months of July and August, begins around late April to early October. The dry season is relatively shorter and last from November to March in much cases. The area is semi-arid environment characterized with sparse vegetation, stunted trees mostly (Kanje), with shrubs and thorny bushes at the stream banks. The vegetation is described by Sahel Savannah. The relief in the study area is characterized by moderate to high features. It is marked by isolated hills (inliers) and sandstone cliffs towards the southern part.

The area is underlain by the basement complex rocks. Lithological consisting of the older granite, coarse porphyritic granite and biotite granite spread and believe to have been emplaced during the Pan African Orogeny. The area has been described as part of the Nigerian Basement Complex comprising gneisses and migmatites (Precambrian-lower Paleozoic) which were intruded in various places by a relatively younger suit of rocks, the older granite (Falconer, 1911). Bima Formation underlies the southern part of the mapped area (Figure 2). In the

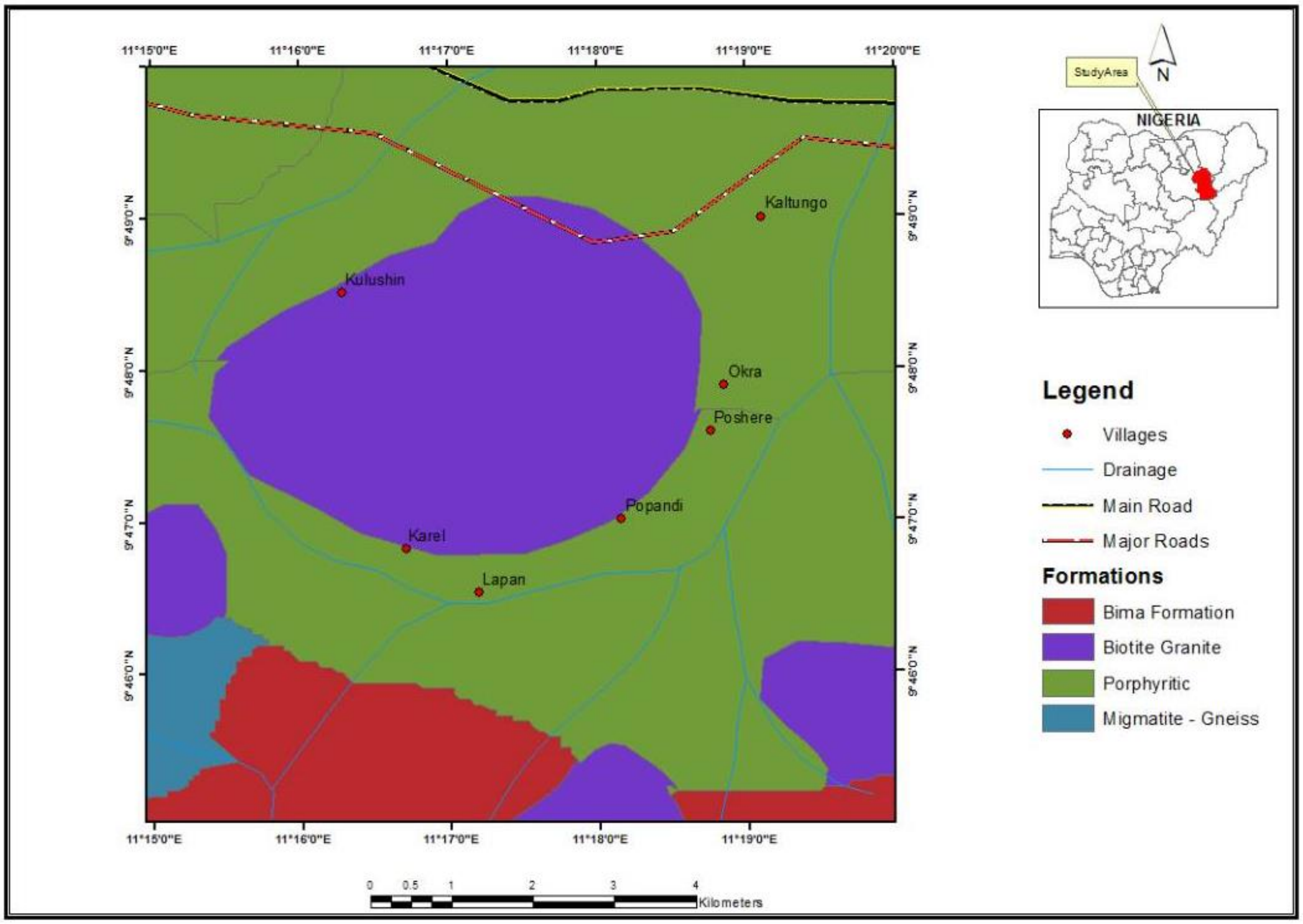


Figure 2. Geologic map of the study area (After Nigerian Geological Survey 2004).

Benue Trough, the oldest rock unit is the Bima Sandstones which lies uncomfortably on the Precambrian basement complex (Allix et al., 1981).

Biotite granite covers the central part of the study area, the colour of the biotite granite ranges from white to grey, which is leucocratic. The biotite is flaky in structure black to grey colour. Some of the biotite granite occurred as boulders. These granites are also found in the western part, southern part and eastern part of the study area respectively.

The porphyritic granite underlies most part of the study area. The porphyritic granite in the study area range from medium to coarse grained with minor variations in texture ranging from granitic to granophyric. The major constituents of the porphyritic granite are K-feldspars, biotite and quartz. The colour of the porphyritic granite ranges mostly from white to grey, which is leucocratic. The porphyritic and biotite granites belong to the older granite of the Nigerian basement complex (Carter et al., 1963). The porphyritic granites are coarse to very coarse grained with large white or pink prismatic phenocysts of microcline.

Migmatite gneiss occupy a small portion of the study area, the outcrop is at the south-western part of the study area. The outcrops were of low relief when compare to biotite granites. Migmatites gneiss is foliated, that is, there is the alignment of light and dark minerals. The leucosome is the lightest coloured part of migmatites gneiss while melanosome is the darker part. The structural features observed on the rock are mostly fracture/joints and foliation.

Hydrogeology is water that filled pores and voids found within a geological formation. The occurrence and distribution of groundwater in an area is controlled by geological factors such as lithology, texture of the rocks and also the structures in the rocks, as well as climatic factors such as rainfall. Surface water in the study area occurs in the form of streams and lakes. They serve as water supply sources for drinking and domestic uses. Most of the streams and lakes are seasonal. The streams and lakes are recharged by direct precipitation during the raining season.

METHODOLOGY

A vertical electrical sounding (VES) of electrical resistivity method was carried out using Omega resistivity meter with Schlumberger configuration. A total of thirty (30) Vertical Electrical Sounding (VES) points were acquired. Electric current is passed into the ground between two outer electrodes while the resultant potential difference is measured by two inner electrodes. The electric field produced is measured by the instrument in the form of resistance which when multiplied by a constant (k) gives the apparent resistivity value for Schlumberger array.

$$\rho_{a} = K\frac{\Delta V}{I} \qquad (1)$$

Where: pa = Apparent resistivity, k = Geometric factor (constant), ΔV= Potential difference and I = Current.

The electrode spacing was progressively increased keeping the centre point of the electrode array fixed. The maximum half current electrode separation $\left(\frac{AB}{2}\right)$ was between 1 and 100 m while the half- potential electrode separation $\left(\frac{MN}{2}\right)$ was maintained between 0.2 and 1.5 m. The apparent resistivity measured at each point was plotted on a log-log paper. The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity (ρ=kR) in ohm-meter. The plots gave a rough idea of subsurface and form of the interface.

The qualitative interpretation of the field data was done using a computer program known as IX1-D software; to identify thickness and resistivity of different layers, so as to give information on deeply weathered and fractured zones.

RESULTS AND DISCUSSION

Thirty Vertical Electrical Soundings (VES) were conducted using the Schlumberger configuration with a maximum current electrode of 100 m using Ohmega Terameter and the results revealed the thickness of layers, resistivity of layers, longitudinal conductivity, transverse resistance, fitting error and curve-types of the 30 VES points in the study area (Table 1). The area is underlain by three geo-electric layers. The first layer represents the top lateritic soil and has an average thickness value of 1.57 m and average resistivity value of 200.13 Ωm. The second layer is a weathered basement with average thickness value of 13.36 m and resistivity value of 50.90 Ωm. The third layer is fresh basement and has an average resistivity value of 2766 Ωm to infinite depth.

Iso–resistivity maps were prepared by plotting the resistivity values obtained from sounding curves at a given electrode spacing common to all the sounding points for $\frac{AB}{2}$ = 60m (Figure 3) and $\frac{AB}{2}$ = 80m (Figure 4) with their corresponding 3-D surfaces. The points of equal resistivity interpretation represents the variation in resistivity at a given electrode spacing and indicates the general lateral changes in the electrical properties within the area. The Iso-resistivity map $\frac{AB}{2}$ = 60m values ranging from 14.30 to 938.17 Ωm (Figure 3) reveals that the high resistivity values were found at the eastern part of the study area as indicated in the 3-D (Figure 3b) and shows a gentle variation in other parts of the map. Figure 4 shows resistivity values of 11.70 to 1100.40 Ωm. The high resistivity values exhibited at the eastern portion of the map is an indication of hard rocks. This can be readily seen in (Figure 4b). Low resistivity indicating clayey materials and/or weathered/fractured basement values are observed along the southwest, northwest and central part of the area. This is consistent with the result of previous studies conducted within the same geologic environment by Uti et al. (2018).

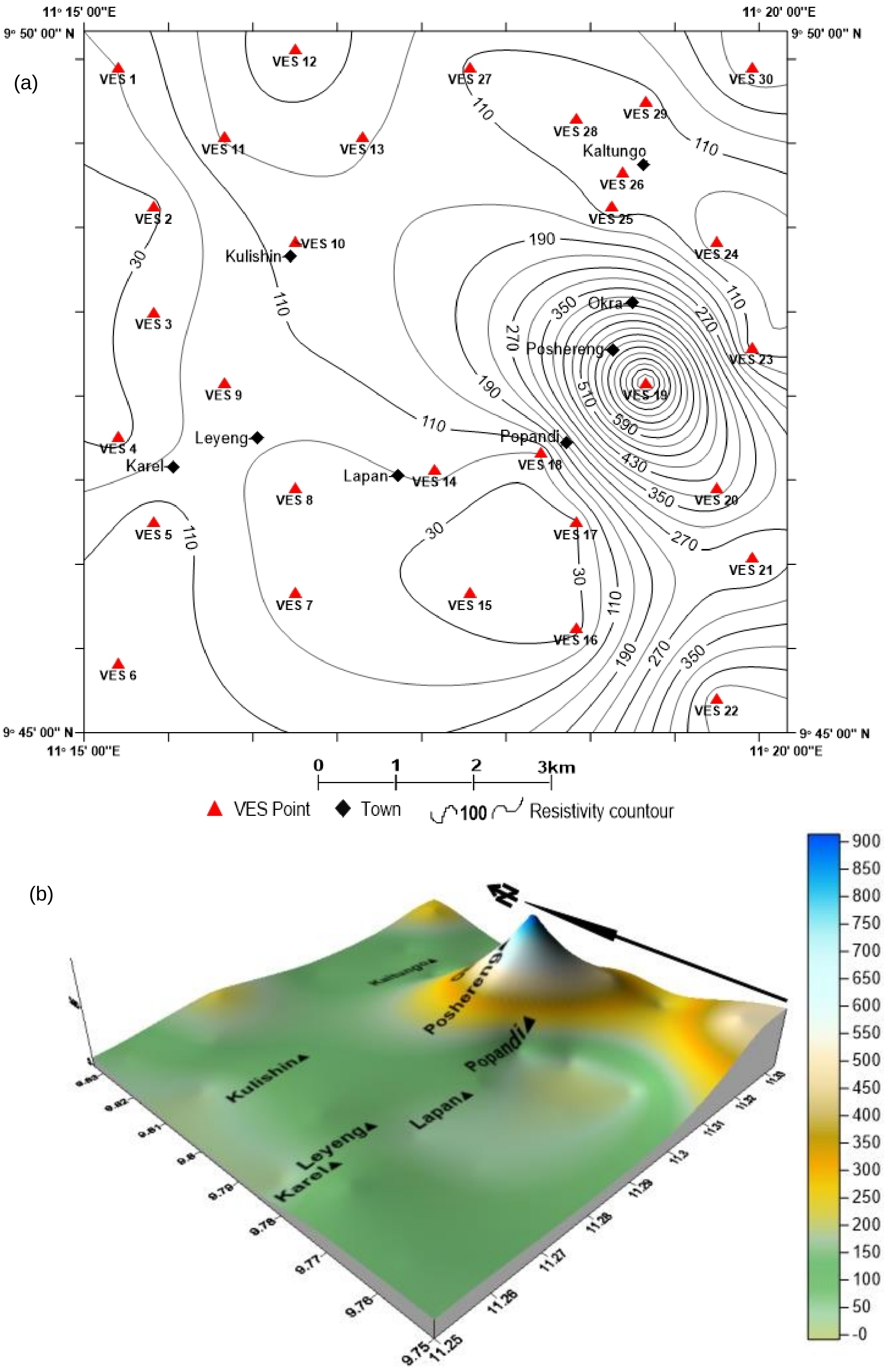
Electro-stratigraphic sections were drawn along profile A-A'. Figure 5 made up of eight (8) vertical electrical sounding points these are VES 6, VES 7, VES 8, VES 9, VES 3, VES 2, VES 11 and VES 12. This section revealed the presences of three geo-electric layers, the top or lateritic soil, weathered/fractured basement and fresh basement. The top soil has resistivity ranging from 75 to 246 Ωm at VES 2 and VES 6 and thickness of about 5 m. The second layer is weathered /fractured basement has resistivity value ranging from 12 to 412 Ωm at VES 7 and VES 9, at VES points 7, 9, 3, and 2, the thickness is about 5 m to infinite depth, suggesting good points for sitting borehole. At VES points 6, 11 and 12, the thickness is between 5 to 19 m suggesting probable high water potential for sitting borehole. The third layer is fresh basement has resistivity value ranging from 514 to 34338 Ωm and infinite thickness. The aquifer thickness of 5 to 19 m falls within the findings made by Onsachi et al. (2016) where an average aquifer thickness of 7 to 40 m was established.

The profile B-B1 (Figure 6) is made up of five vertical electrical sounding points which are VES 5, VES 14, VES 18, VES 25 and VES 24. The first layer which is top soil has resistivity value ranging from 23 to 75 Ωm at VES 14 and VES 18, and thickness of about 2 m. The thickness at VES 18, 24 and 25 increased and thinnest at VES 5 and 14. The second layer is a weathered/fractured basement, has resistivity value ranging from 6 to 160 Ωm at VES 14 and VES 25 and the thickness of about 2 m to infinite depth; all the points are suitable for sitting of borehole which is typical of basement terrain (Mohammed et al., 2007).

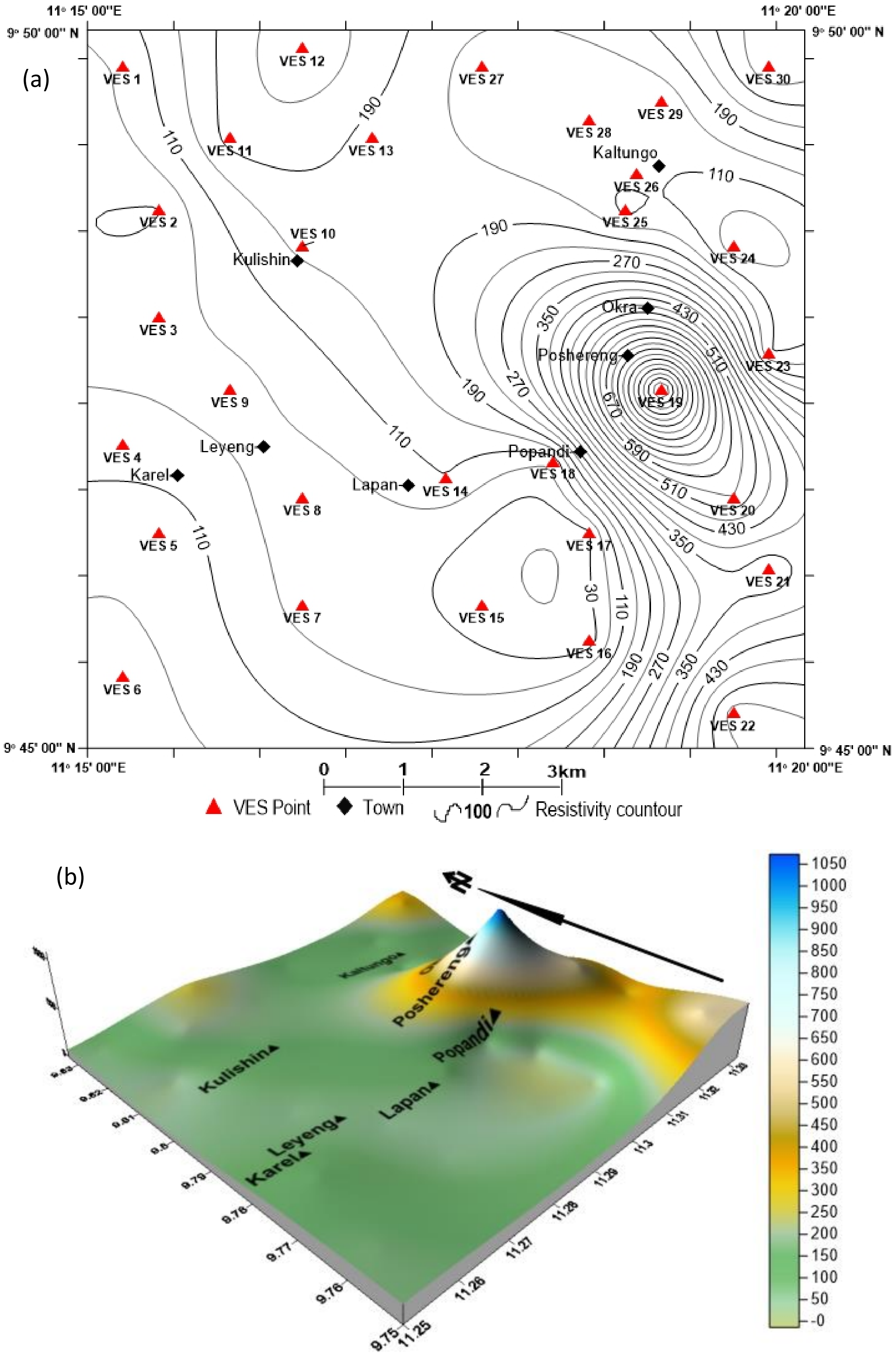
Profile C-C1 (Figure 7) revealed the presence of three geo-electric layers, top lateritic soil, weathered/fractured basement and the fresh basement comprising of six VES points: VES 6, VES 7, VES 15, VES 16, VES 20 and VES 21. The top soil has resistivity range from 72 to 246 Ωm, and thickness of about 2 m. The lateritic soil has resistivity range from 363 to 413 Ωm at VES points 20 and 21 and thickness of about 2 m. The second layer is a weathered/fractured basement with resistivity value ranging from 15 to 240 Ωm at VES points 15 and 16 and the thickness of about 2 m to infinite depth at VES points

Table1. Results Obtained from the analysis of the 30 VES Points in the study area.

S/No	**VES**	**Thickness of Layers (meters)**		**Resistivity of Layers (Ohms-meter)**			**Longitudinal conductivity (Siemens)**		**Transverse resistance (ohms-meter)**		**Fitting Errors (%)**	**Curve Types**
		H1	**H2**	**ρ1**	**ρ2**	**ρ3**	**S1**	**S2**	**T1**	**T2**		
1	VES1	1.47	7.84	179	24	95	0.008	0.326	263.13	188.16	0.89	H
2	VES2	1.54	27.30	75	13	75	0.020	2.100	115.50	354.90	0.98	H
3	VES3	1.61	24.96	77	23	278	0.020	1.085	123.97	574.08	0.83	H
4	VES4	0.68	10.50	128	12	18054	0.005	0.875	87.04	126.00	0.91	H
5	VES5	1.40	1.30	74	14	157	0.019	0.093	103.60	18.20	0.98	H
6	VES6	1.40	15.4	246	46	514	0.006	0.335	344.40	708.40	0.94	H
7	VES7	1.14	8.20	106	12	93	0.011	0.683	120.84	98.40	0.83	H
8	VES8	1.14	27.90	125	22	187	0.009	1.268	142.50	613.80	0.97	H
9	VES9	1.38	12.8	87	410	46	0.016	0.031	120.06	5248.00	0.99	K
10	VES10	1.43	16.17	181	36	1764	0.008	0.449	258.83	582.12	0.92	H
11	VES11	1.84	9.44	128	26	34338	0.014	0.363	235.52	245.44	0.93	H
12	VES12	1.28	13.14	620	78	517	0.021	0.168	793.60	1024.92	0.79	H
13	VES13	2.10	13.3	344	60	294	0.006	0.222	722.40	798.00	0.87	H
14	VES14	1.59	3.30	23	6	650	0.0691	0.550	36.57	19.80	0.87	H
15	VES15	1.85	6.87	72	30	15	0.0257	0.229	133.632	206.10	0.92	Q
16	VES16	4.91	26.59	115	21	240	0.043	1.266	564.65	558.39	0.94	Q
17	VES17	1.52	3.32	241	42	26	0.006	0.079	366.32	139.44	0.93	Q
18	VES18	0.53	5.93	75	15	117	0.007	0.395	39.75	88.95	0.90	H
19	VES19	0.58	17.95	1679	126	1039	0.0003	0.142	973.82	2261.70	0.44	H
20	VES20	1.55	15.57	363	77	200	0.004	0.202	562.65	1198.89	0.39	H
21	VES21	0.71	26.30	413	107	1060	0.002	0.246	293.23	2814.10	0.35	H
22	VES22	1.89	3.42	149	74	837	0.013	0.047	281.61	253.08	0.98	H
23	VES23	3.00	26.1	26	49	774	0.115	0.533	78.00	1278.90	0.95	A
24	VES24	2.38	7.94	27	8	75	0.088	0.993	64.26	63.52	0.85	H
25	VES25	0.87	3.73	34	10	160	0.026	0.373	29.58	37.30	0.83	H
26	VES26	1.61	4.66	51	17	215	0.032	0.274	82.11	79.22	0.94	H
27	VES27	0.89	15.43	88	34	429	0.010	0.454	78.32	524.62	0.79	H
28	VES28	1.32	15.4	164	33	305	0.008	0.647	216.48	508.20	0.95	H
29	VES29	1.66	15.59	23	35	421	0.072	0.445	38.18	545.65	0.93	A
30	VES30	1.96	14.41	194	67	20311	0.012	0.215	315.56	965.47	0.94	H
	Mean	1.57	13.36	200.1	50.90	2766.77	0.023	0.497	252.87	737.46	0.84	



Figures 3a, b. Iso-resistivity contour map for AB/2 = 60m (contour interval 40Ωm).



Figures 4a, b. Iso-resistivity contour map for AB/2 = 80m (contour interval 40Ωm).

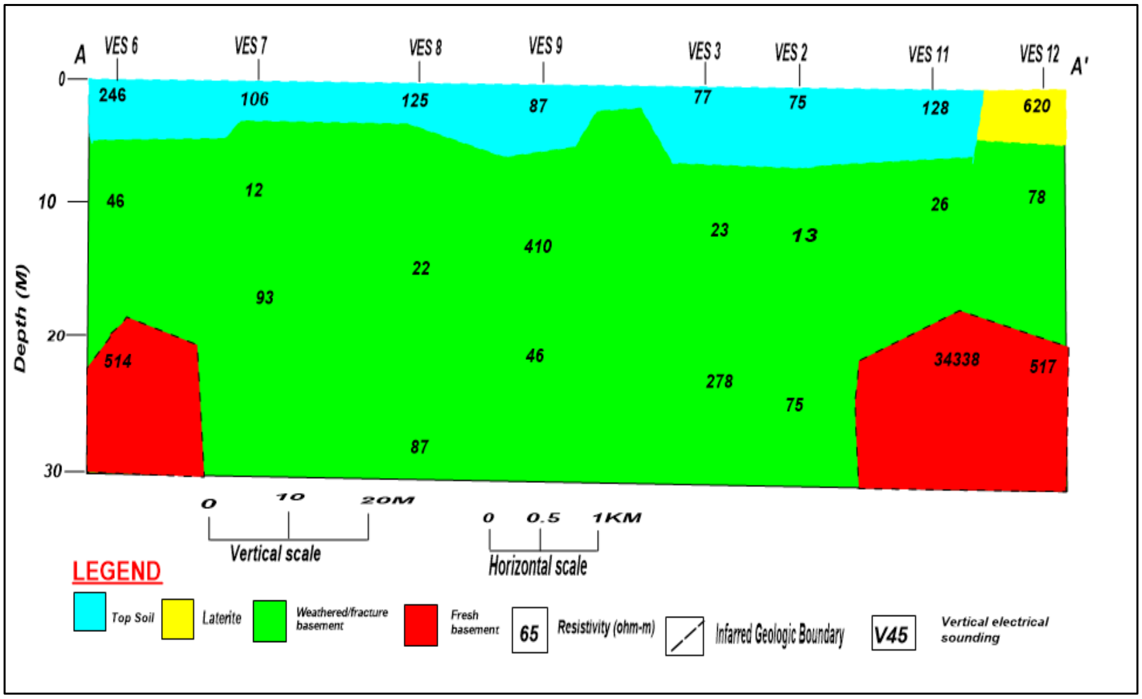


Figure 5. Geo- Electrostratigraphic section A-A^1.

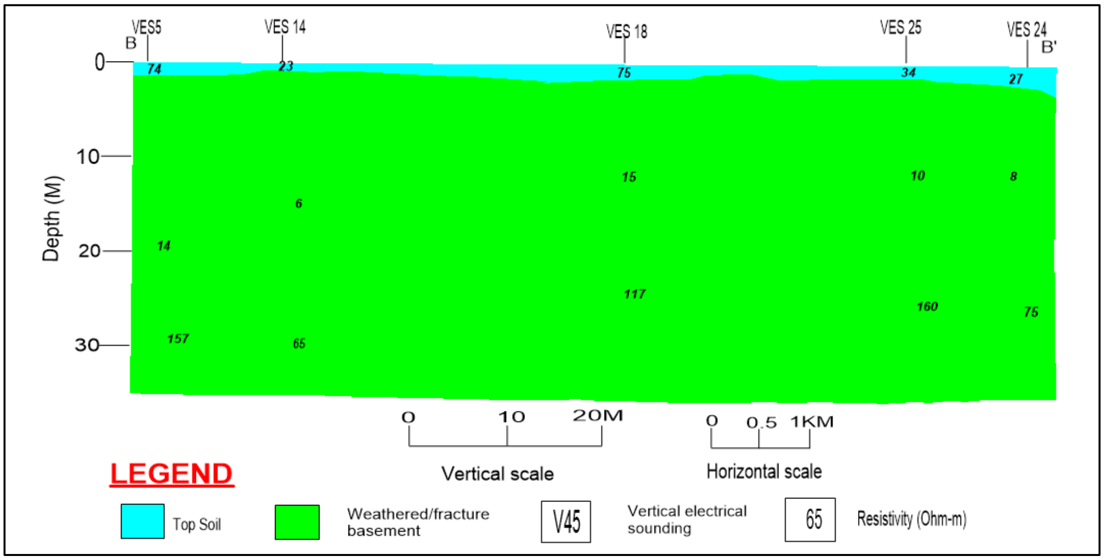


Figure 6. Geo- Electrostratigraphic section B-B^1.

7, 15, 16, and 20 suggesting suitable site for sitting borehole. VES 6 and 21 had the thickness of about 2 to 18 m and can also be good for sitting borehole. The third layer is a fresh basement, has resistivity value of 514 to 1060 Ωm at VES points 6 and 21 and thickness of 19 m to infinite depth. A comparison of values for resistivity range of 514 to 1060 Ωm for fresh basement agrees with the studies carried out by Ayuni et al. (2017), that establish a resistivity of 500 Ωm and above for fresh basement.

Evaluation of hydraulic conductivity (K) and transmissivity (T) value using geoelectrical method

The aquifer parameters calculated from geophysical data like hydraulic conductivity (K) and transmissivity (T) are important for the management and development of groundwater resources. The hydraulic conductivity was estimated using the equation as given by Heigold et al. (1979).

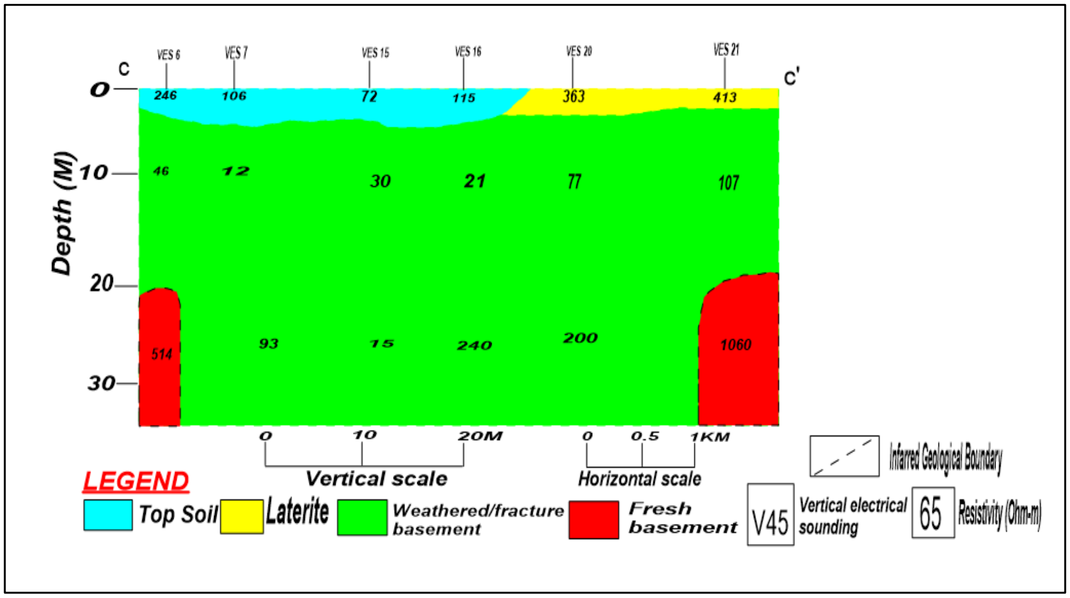


Figure 7. Geo- Electrostratigraphic section C-C^1.

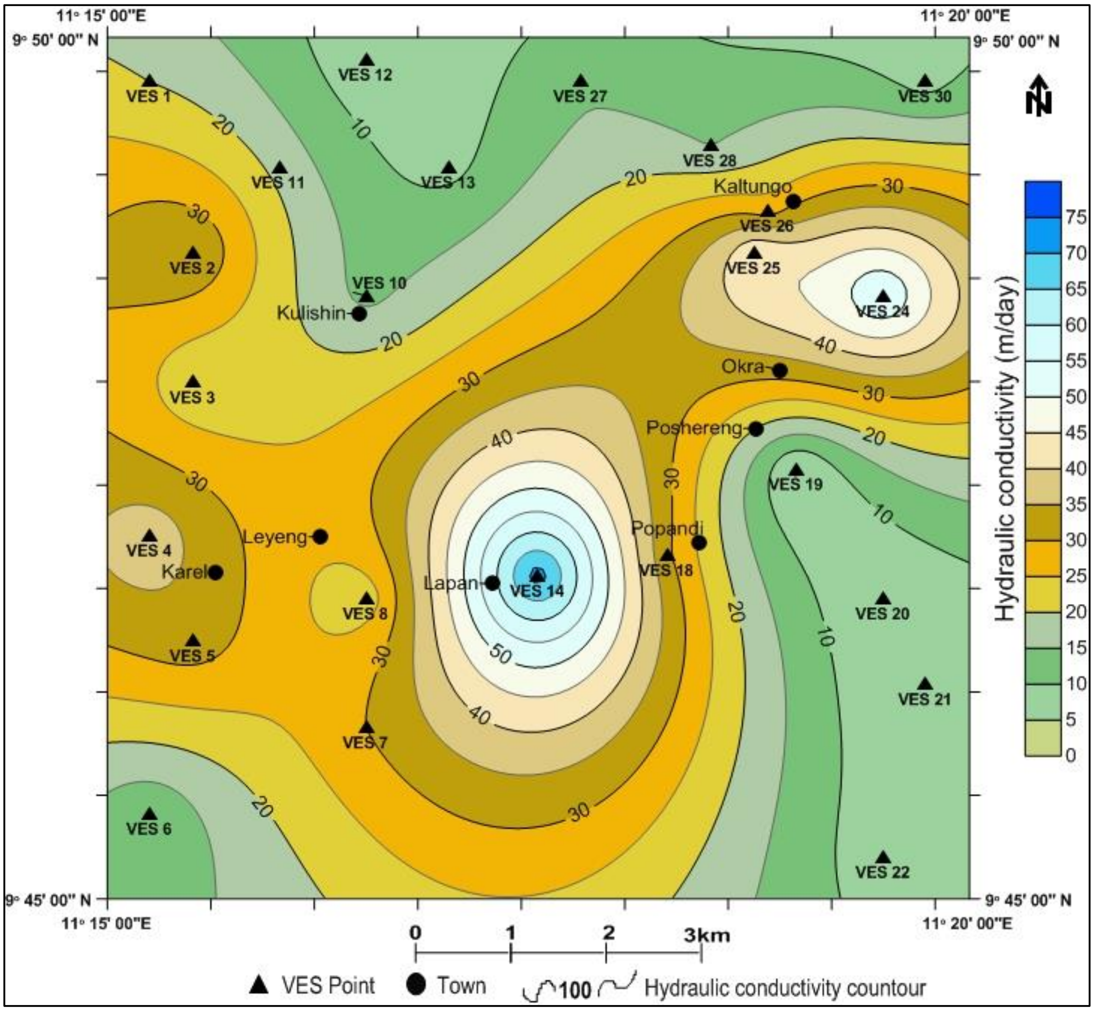


Figure 8. Hydraulic conductivity contour map (contour interval 5 m/day).

Table 2. Aquifer parameters calculated from 24 VES points from geophysical data

S/N	Ves Point	Location	Aquifer thickness	Aquifer resistivity	Transverse resistance (ohm-m^2)	Longitudinal conductance (Siemens)	Kc(m/day)	Tc (m^2/day)	Aquifer Potential
1	VES 1	E11^{0}15’05’’ N9^{0}49’45’’	7.84	24	188.16	0.326	19.9	156.26	Moderate
2	VES 2	E11^{0}15’30’’N 9^{0}48’45’’	27.30	13	354.9	2.1	35.3	964.0	High
3	VES 3	E11^{0}15’30’’N9^{0}48’00’’	24.96	23	574.08	1.085	20.73	517.6	High
4	VES 4	E11^{0}15’15’’N9^{0}47’076’’	10.50	12	126	0.875	38.04	399.5	Moderate
5	VES 5	E11^{0}15’30’’N9^{0}46’30’’	1.30	14	18.2	0.092	32.95	42.83	Low
6	VES 6	E11^{0}15’15’’N9^{0}45’30’’	15.4	46	708.4	0.334	10.86	167.29	Moderate
7	VES 7	E11^{0}16’30’’N9^{0}46’00’’	8.20	12	98.4	0.683	30.04	312.0	Moderate
8	VES 8	E11^{0}16’30’’N9^{0}46’45’’	27.90	22	613.8	1.268	21.61	603.09	High
9	VES 10	E11^{0}16’30’’N9^{0}48’30’’	16.17	36	582.12	0.449	13.65	220.79	Moderate
10	VES 11	E11^{0}16’00’’N9^{0}49’15’’	9.44	26	245.44	0.363	18.49	174.61	Moderate
11	VES 12	E11^{0}16’30’’N9^{0}49’52’’	13.14	78	1024.92	0.168	6.63	87.22	Moderate
12	VES 13	E11^{0}17’00’’N9^{0}49’15’’	13.3	60	798	0.221	8.47	112.7	Moderate
13	VES 14	E11^{0}17’30’’N9^{0}46’53’’	3.30	6	19.8	0.55	72.63	239.7	Moderate
14	VES 18	E11^{0}18’15’’N9^{0}47’00’’	5.93	15	88.95	0.395	30.89	183.23	Moderate
15	VES 19	E11^{0}19’00’’N9^{0}47’30’’	17.95	126	2261.7	0.142	4.24	25.16	Low
16	VES 20	E11^{0}19’30’’N9^{0}47’46’’	15.57	77	1198.89	0.202	6.71	104.60	Moderate
17	VES 21	E11^{0}19’45’’N9^{0}46’15’’	26.30	107	2814.1	0.245	4.94	129.9	Moderate
18	VES 22	E11^{0}19’30’’N9^{0}45’15’’	3.42	74	253.08	0.046	6.97	23.84	Low
19	VES 24	E11^{0}19’30’’N9^{0}48’30’’	7.94	8	63.52	0.992	55.54	440.98	Moderate
20	VES 25	E11^{0}18’45’’N9^{0}48’45’’	3.73	10	37.30	0.373	45.10	168.23	Moderate
21	VES 26	E11^{0}18’50’’N9^{0}49’00’’	4.66	17	79.22	0.274	27.49	128.12	Moderate
22	VES 27	E11^{0}17’45’’N9^{0}49’45’’	15.43	34	524.62	0.453	14.40	222.22	Moderate
23	VES 28	E11^{0}18’30’’N9^{0}49’22’’	15.4	33	508.2	0.646	14.80	228.05	Moderate
24	VES 30	E11^{0}19’45’’N9^{0}49’45’’	14.41	67	965.47	0.215	7.64	110.22	Moderate

Kc = Hydraulic conductivity, Tc = Transmissivity. >500 high potential, 60-500 moderate potential, 6-59 Low potential, 0.5-5 very low potential, <0.5 negligible potential (Offodile, 1983).

$$\mathrm{K} = 386.4\mathrm{R}_{rw}{}^{-0.93283} \text{ (m/day)} \tag{2}$$

Where, R_{rw} is the aquifer resistivity, and K is the hydraulic conductivity.

The transmissivity values were calculated using Offodile (1983).

$$\mathrm{T} = \mathrm{Kb} \text{ (m}^2\text{/day)} \tag{3}$$

Where, T is transmissivity (m^2/day), K is hydraulic conductivity (m/day), and b is aquifer thickness (m).

Generally, the higher the transmissivity value of an aquifer, the better its productivity prospect. Hydraulic conductivity is proportional to permeability. High permeability will be observed in aquifer zone with high hydraulic conductivity and also contaminants will be easily circulated (Kazakis et al. 2016). The hydraulic conductivity calculated from the electrical resistivity sounding data for twenty four (24) potential aquifer resistivity was contoured as shown in Figure 8. The hydraulic conductivity and transmissivity of the aquifer were determined using equation 1 and 2 respectively and presented in Table 2.

The hydraulic conductivity values estimated from the VES results range between 4.24 to 72.63 (Table 2).

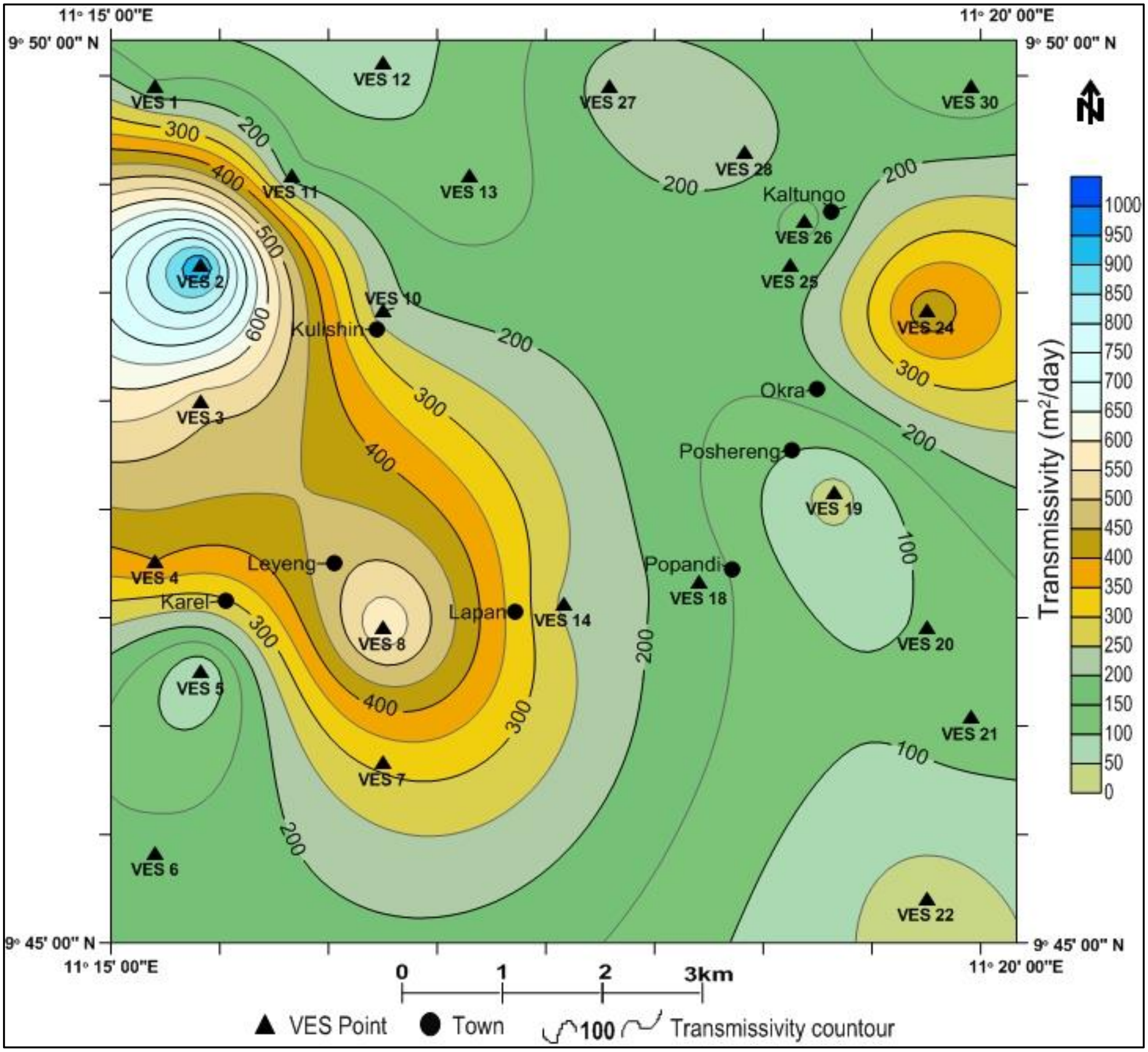


Figure 9. Transmissivity contour map (contour interval 50 m^2/day).

The maximum hydraulic conductivity value is observed at VES 14 toward the southern portion of the study area while the transmissivity values vary between 23.84 and 964.0 m^2/day (Figure 9). VES 2, VES 3, and VES 8 have high transmissivity value which is indicating high groundwater potential zone. The distribution of aquifer potential in the study area is characterized by low which constituting 12.5%, moderate constituting 75% and high constituting 12.5%, groundwater flow potential (Table 2). According to Gabriel et al. 1997, the fractured aquifer has low to moderate hydraulic conductivity and transmissivity values which give rise to low and moderate yield.

Hydraulic head map of the study area was produced by joining points of equal hydraulic heads and piezometrics lines were drawn at a right angle by an arrow drawn perpendicular to the contour line to indicate groundwater flow direction. The contour map showing the groundwater flow direction in the area was produced (Figure 10). Groundwater generally flows from area of high surface elevation, where rocks generally outcrop, to areas of low surface elevation, where rocks are usually buried under more or less thick overburden. The points are contoured with an interval of 5 m. The hydraulic head is the energy available for flow. The hydraulic head map of distribution of the study area indicates groundwater flow from recharge area around Poshereng, Popandi and Lapan. The groundwater flow directions in the study area is in the NW, SW, SE and E respectively.

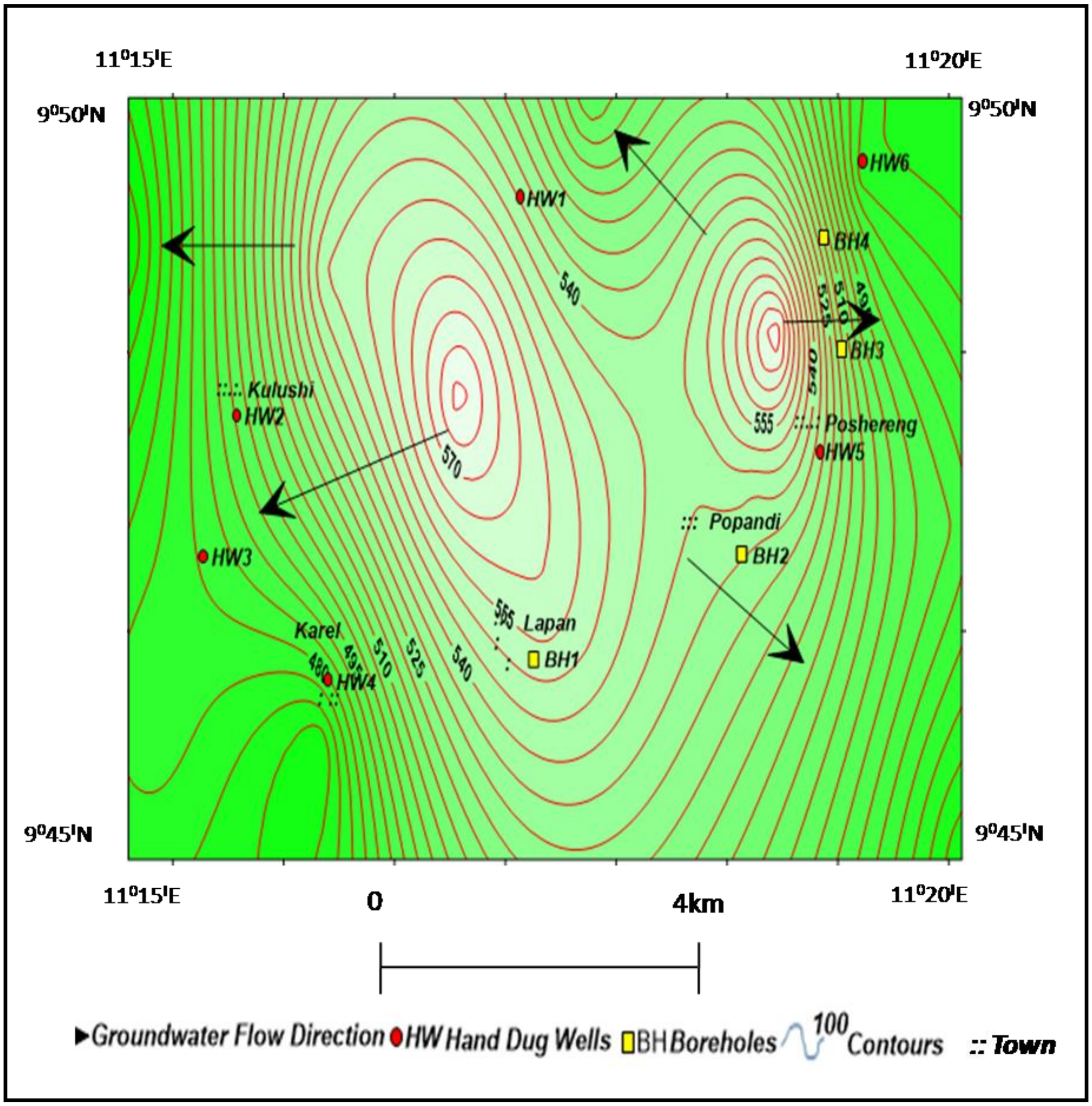


Figure 10. Groundwater flow directions of Kaltungo and environs (contour interval 5 m).

Conclusions

The thirty vertical electrical sounding (VES) were carried out in Kaltungo and environs of Gombe State North-eastern Nigeria. This research has provided useful information on the hydro geological condition of the study area. The curve types obtained in the study area are H, K, Q and A curve types. Three distinctive geo-electric layers were identified. The first layer represents the top lateritic soil with an average thickness value of 1.57m and average resistivity value of 200.13 Ωm. The second layer is a weathered basement with average thickness value of 13.36 m and resistivity value of 50.90 Ωm. The third layer is fresh basement with an average resistivity value of 2766 Ωm to infinite depth. The second layer is considered to be a weathered/fractured basement rocks in the study area and all of these constitute the aquifer zones. The low yield of wells arising from aquifer development and inadequate understanding of the hydrogeology of the crystalline basement aquifer system are perhaps traceable to the lack of concerted efforts to address the problems. The Geo-electrical data guided the estimation of aquifer hydraulic conductivity (Kc) values estimated from the VES results range between 4.24 to 72.63 m/day. The maximum hydraulic conductivity values were observed at VES 14 toward the southern portion of the study area while the transmissivity values vary between 23.84 and 964.0 m^2/day and has helped in determining areas of similar geologic setting and water quality. The distribution of aquifer potential in the study area indicates that 75% moderate, 12.5% high and 12.5% low. The electrical resistivity data therefore gives reasonable accurate results among other methods that can be used to understand the subsurface layers and basement configuration prospecting. The water flow direction from high surface elevation to low surface elevation in the study area is in the NW, SW, SE and E respectively.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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