EVALUATION OF AQUIFER PROTECTIVE CAPACITY OF GROUND WATER RESOURCES IN BOGORO LOCAL GOVERNMENT AREA OF BAUCHI STATE, NORTHEASTERN NIGERIA

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ABSTRACT

The study focuses on the evaluation of aquifer protective capacity of ground water resources in Bogoro area. Forty-four (44) Vertical Electrical Soundings (VES) were carried out using the Schlumberger electrode array configuration, with half-current electrode separation (AB/2) varying from 1 to 125 m using Allied Ohmega terrameter and its accessories. The curve types obtained include: A, H, K, QH, HK, KH and HKH types. The geoelectric sections indicate that the subsurface is characterized into four geoelectric layers namely: topsoil, clayey layer, fractured basement and fresh basement. The longitudinal conductance (S) values ranged from 0.006383 to 1.295251 mhos; hence, the area is classified into poor (< 0.1mhos), weak (0.1-0.19 mhos), moderate (0.2-0.69 mhos) and good (> 0.7 mhos) protective capacity. The total transverse resistance ranges from 259.6 to 24354.6Ω m^2 and the electric anisotropy ranges from 0.557592 to 3.069103. The overburden thickness varies from 1.7 to 41.6 m and the map of the overburden thickness with secondary geoelectric (Dar-Zarrouk) parameters revealed that the delineated areas have productive aquiferous groundwater potentials. The major aquifer delineated in the area is the fractured basement and characterized by thick overburden with high value of longitudinal conductance (S) of moderate to good protective capacity. The aquifers exhibit moderate to relatively low value of coefficients of electrical anisotropy with high value transverse unit resistance. This attests to thick aquifer with thick clay materials above the aquifer that act as seal and high transmissivity's while areas with poor to weak protective capacity are susceptible to infiltrating contaminating fluid.

Keywords: Anisotropy, Dar-Zarrouk, transmissivity, Overburden and Geoelectric

INTRODUCTION

Water is an indispensable commodity for life (Miller, 2006). The geophysical method of water exploration is inexpensive and had been useful for many years in solving numerous problems of groundwater search. This method is also used to determine depth, thickness and boundary of an aquifer. It is also use in the determination of interface between saline water and freshwater boundary within an aquifer, hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer and contamination of groundwater (Adeniji *et al.*, 2004).

Geoelectric method is used for both groundwater resource investigation and water quality evaluations and has increased intensely over the years due to the rapid advances in microprocessors and associated numerical modeling solutions (Baeckmann and Schwenk, 1975). Geoelectric method is also suitable for mapping the thickness and delineating the extent of aquiferous overburden and in the resolve and mapping of groundwater quality (Ajibade and Ogungbesan, 2013).

Searching for viable aquifers for groundwater source has over the years been carried out through numerous means ranging from physical observations to surface and subsurface geophysical procedures (Todd and Mays, 2005). Many investigation techniques are commonly employed with the aim of estimating the spatial distribution of transmissivity and protective capacity of groundwater resources. Unfortunately, the conventional methods for the determination of hydraulic parameters such as pumping tests, parameter measurements and grain size analysis are invasive and relatively expensive.

An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials while groundwater is one of the most precious freely given natural resources and is referred to as the waters found in the subsurface (Bear and Verruijt, 1987). Groundwater is being refilled by rain that infiltrated the soil naturally or through secondary pores of the subsurface rocks (Jaturon *et al*., 2014; Kumar *et al*., 2007). Groundwater resources contribute to meet the water needs for most domestic, municipal and industrial purposes (Nampak *et al*., 2014).

Due to the growing population of Bogoro area, more domestic and industrial wastes were being produced, which are possible groundwater contaminants. The present study focuses on the evaluation of aquifer protective capacity of ground water resources of Bogoro area using a non-invasive and less-expensive geoelectric investigation involving vertical electrical soundings. The specific objectives of this research include the determination of geoelectric layers and overburden thicknesses and as well as the evaluation of aquifer protective capacity zones for groundwater resources

MATERIALS AND METHODS

Study Area

The study area is located within Latitudes 9^{o} 63^{l} 250^{ll} to 9^{o} 71^{l} 654^{ll} N and Longitudes 9^{o} 56^{l} 327^{ll} to 9^{o} 63^{l} 298^{ll} E. It is situated in Bogoro town of Bogoro Local Government Area of Bauchi State, northeastern Nigeria. The topography is slightly undulating surrounded by isolated hills and inselbergs with elevation ranging from 630 to 717 meters above sea level; streams and rivers (Figure 1) drain part of the area.

Geologically, the study area is situated on the Basement Complex of northeastern Nigeria. The rock units of the study area as shown in Figure 2 include the granite gneiss and coarse foliated biotite granite, which according to Oyawoye (1970) and McCurry (1976) are of Birimian in age. The vegetation of the area is of Savanah type, characterized by shrubs and dispersed short trees with rainy season between the months of April to September and long dry season between the months of October to April. The driest month with the lowest rainfall is December (00 mm) while the wettest month with the highest rainfall is August (340 mm). Annual mean temperature is between 12.8^{o}C in December and 36.6^{o}C in April, with relatively low humidity in the month of February (35%) and high humidity (94%) in August (NIMET, 2019).

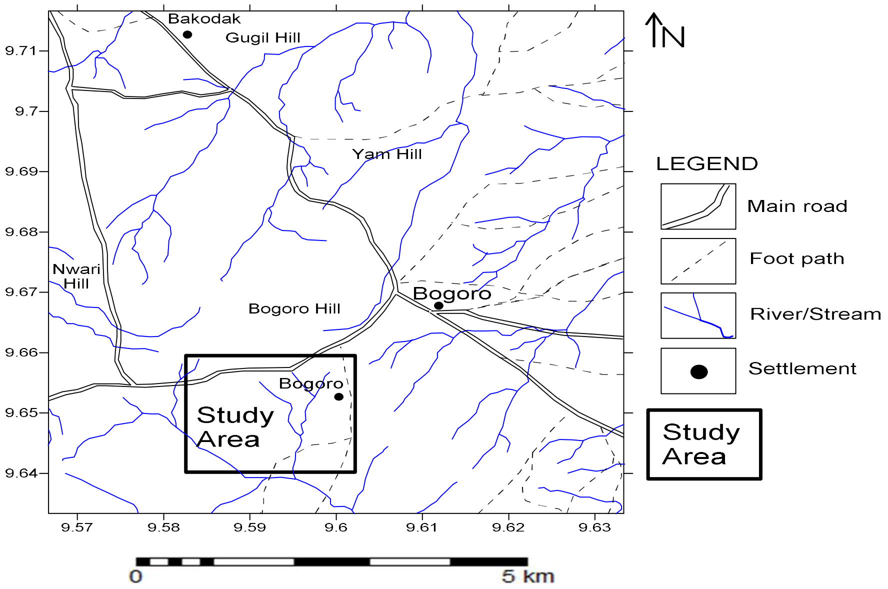

Figure 1: Topographical map of Bogoro showing the study area

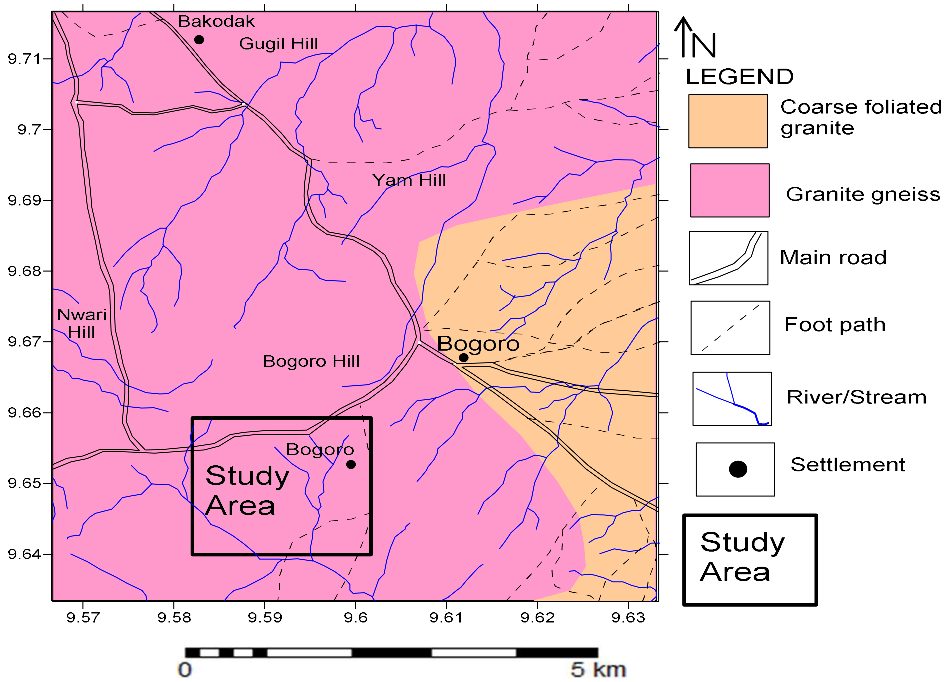

Figure 2: Geological map of Bogoro area showing the study area (Source: NGSA, 2009)

Aquifer Protective Capacity

This present study adopted the use of an electrical resistivity survey method where forty-four (44) Vertical Electrical Soundings (VES) stations were occupied and VES readings were carried out with the used of Allied Ohmega Terameter and its accessories. The conventional Schlumberger array pattern (Figure 3), with half electrode spacing (AB/2) varying from 1 m to a maximum of 125 m was adopted. The apparent resistivity was computed using the equation:

$$\rho a = \pi \left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I}, (1)$$

Where ρa is apparent resistivity,

π is $\frac{22}{7}$,

$G = \pi \left(\frac{a^2}{b} - \frac{b}{4}\right)$ is geometrical factor, and

$\frac{\Delta V}{I} = R$ is the resistance

The apparent resistivity values gotten from equation (1) were plotted on log-log graph against the half current electrode separation spacing (AB/2). From these plots, qualitative deductions, such as the resistivity, thickness and depth of each layer were made with the curve types gotten from the primary electrical parameters. The resistivities and thicknesses of the various layers were enhanced by employing an automatic iterative computer program following the main concepts of Zohdy and Martin (1993). The WINRESIST computer software was employed for carrying out the iteration and inversion processes. The root mean square (RMS) error of lower than 5% was obtained through the iteration process conducted for each sounding station in order to get a goodness of fit for the Computer-generated curves with the corresponding field curves data.

The Dar-Zarrouk parameters (Table 1) were obtained from the first order geoelectric parameters (layer resistivities and thicknesses) and these include the Total longitudinal unit conductance (**S**), Total transverse unit resistance (**T**) and coefficient of anisotropy (**λ**). These secondary geoelectric parameters are mainly significant when they are used to define a geoelectric section comprising of numerous layers (Zhody *et al.,* 1974). For n layers, the total longitudinal unit conductance is:

$$\mathbf{S} = \sum_{i=1}^{n} \left(\frac{hi}{\rho i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mathbf{T} = \sum_{i=1}^{n} \rho i h i \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\lambda = \left(\frac{\rho T}{\rho L}\right)^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ***hi*** is the layer thickness, ***Pi*** is layer resistivity while the number of layers from the surface to the top of aquifer, (*i*) varies from 1 to n. Electrical anisotropy is a measure of the degree of inhomogeneity in a basement terrain; which increases the near surface effects, variable degree of weathering and structural features such as faults, fractures, joints, foliations and beddings (Billings, 1972; Maliek *et al.,* 1973). These in turn are responsible for producing secondary porosity (Φs) and hence effective porosity (Φe).

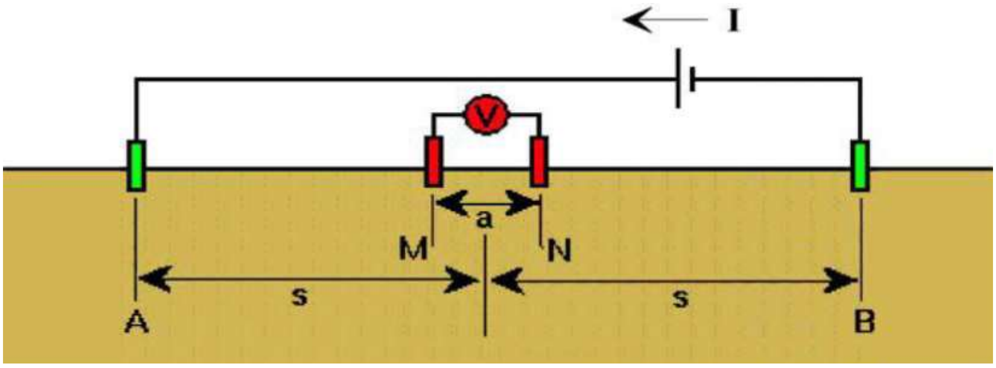

Figure 3: Sketch diagram of Schlumberger array

RESULTS

The true resistivity for each layer (*P*), true thickness for each Layer (h), typical curve types and overburden thickness are presented in Table 1. The summary of the VES interpretations for the forty-four (44) VES stations are presented in Table 1. Total Longitudinal Conductance Unit (S), Total Transverse Resistance Unit (T) and Electric Anisotropy (I) are also presented in Table 1

The resistivity sounding curves obtained from the study area varied from the 3-layer (A, K and H types) to 4-layer (KH, HK and QH) and 5-layer (HKH) with the H type being the predominant.

Table 1: Calculated geoelectric (Dar-Zarrouk) parameters

VES# Station	Resistivity (Ohm-m)					Thickness (m)				Curve Type	Over Burden Thickness	Dar-Zarrouk Parameters		
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h1	h2	h3	h4			S(mhos)	T(Ωm^2)	I
1	84	124	56			3.1	7.5			A	41.6	0.097389	1190.4	0.653494
2	81	163	1177			3.4	5.3			A	8.7	0.074491	1139.3	1.05889
3	183	53	884			1.2	4.6			H	41.6	0.09335	463.4	1.133984
4	197	264	352			2.3	2.9			A	41.6	0.02266	1218.7	1.010589
5	427	788	1119			1.1	3.0			A	4.1	0.006383	2833.7	1.03732
6	90	81	1212			1.2	4.6			H	6.8	0.070123	480.6	0.56134
7	191	98	862			1.2	2.5			H	41.6	0.031793	474.2	1.049408
8	104	93	1185			1.2	4.6			H	5.8	0.061001	552.6	1.001026
9	287	224	517	469	1117	1.2	4	4	8.6	HKH	16.8	0.029775	3308.4	0.557592
10	883	253	578			6.1	9.6			H	41.6	0.044853	7815.1	1.192513
11	1667	926	146	663		1.9	3	6.5		QH	41.6	0.0489	6894.3	1.610627
12	1498	681	72	672		1	3.9	14.1		QH	41.6	0.202228	5169.1	1.701666
13	1399	188	594			1.7	3.6			H	41.6	0.020364	3055.1	1.488228
14	346	81	582			1.7	9.5			H	41.6	0.122197	1357.7	1.150044
15	44	51	246			0.8	4.4			H	41.6	0.104456	259.6	1.00142
16	515	350	1256	945		2.8	4.1	17.1		HK	6.9	0.030766	24354.6	1.140548
17	1046	100	457			1.7	4.9			H	41.6	0.050625	2268.2	1.623605
18	657	335	1193			2.8	8			H	10.8	0.028142	4519.6	1.044255
19	222	422	172	1230		1.7	4.9	12.7		KH	19.3	0.093106	4629.6	1.075731
20	410	97	2060			1.2	1.9			H	3.1	0.022514	676.3	1.523816
21	73	313	2247			2.1	5.8			A	7.9	0.047297	1968.7	1.221467
22	75	314	4110			3.4	5.3			A	8.7	0.062212	1919.2	1.255969
23	126	1652	584			1.7	9.5			K	1.7	0.019243	15908.2	1.562159
24	671	87	1062			0.8	3.1			H	3.9	0.036824	806.5	1.397351
25	92	220	736			3.4	7			A	41.6	0.068775	1852.8	1.377023
26	1042	79	416			1.2	6.5			H	41.6	0.08343	1763.9	1.575461
27	1032	172	217			2.8	10.1			A	41.6	0.061434	4626.8	1.306939
28	277	60	445			2.8	8			H	41.6	0.143442	1255.6	1.242623
29	135	100	154			1.9	15.1			H	41.6	0.165074	1766.5	1.004494
30	648	215	10	1230		2.8	4.5	12.7		QH	20	1.295251	2908.9	3.069103
31	1482	182	172	1230		1.9	7.5	12.7		QH	22.1	0.116328	6365.2	1.231278
32	249	96	127			1.3	14.8			H	41.6	0.159388	1744.5	0.755212
33	104	58	208			0.7	8			H	41.6	0.144662	536.8	1.012894
34	301	97	656			4.1	8.6			H	41.6	0.102281	2068.3	1.145251
35	353	90	500			1.9	7.5			H	41.6	0.088716	1345.7	1.162376
36	380	81	581			1.6	7.6			H	41.6	0.098038	1223.6	1.190497
37	668	84	315			1.7	9.5			H	41.6	0.11564	1933.6	0.95328
38	660	65	363			1.9	10.6			H	41.6	0.165956	1943	1.436556
39	278	29	50	42	66	1.2	2.3	5.9	16.7	HKH	41.6	0.599246	695.3	0.782075
40	165	85	367			0.7	8.1			H	41.6	0.099537	804	0.693478
41	807	87	194			2.5	7.2			H	41.6	0.085857	2643.9	1.553236
42	668	84	214			1.7	9.5			H	41.6	0.11564	1933.6	1.335118
43	656	181	214			1.2	6.5			H	41.6	0.037741	1963.7	1.118028
44	411	134	281	199	394	1.9	3	8.6	20.7	HKH	41.6	0.161636	3599.5	0.705284
Min	44	29	10	42	66	0.7	1.9	4	8.6		1.7	0.006383	259.6	0.557592
Max	1498	1652	4110	1230	1117	6.1	15.1	17.1	20.7		41.6	1.295251	24354.6	3.069103
Mean	493	226	658	742	526	1.9	6.4	10.5	15.3		30.8	0.121108	3096.3	1.197801

P$_1$ = True Resistivity for Each Layer I. h$_1$ = True Thickness for Each Layer.
S = Total Longitudinal Conductance Unit. T = Total Transverse Resistance Unit.
I = Electric Anisotropy (Dimensionless).

DISCUSSION

Aquifer Protective Capacity Evaluation

The values of longitudinal unit conductance (S) obtained from the study area, ranges from 0.006383 to 1.295251mhos (Table 1) with a mean value of 0.121108 mhos. The values obtained from the longitudinal unit conductance of the study area were categorize into poor, weak, moderate and good protective capacity zones according to the classification of Oladapo and Akintorinwa (2007). The longitudinal unit conductance map (Figure 4) was derived from equation 1 above for all the forty-four (44) VES locations and was used for the overburden protective capacity rating of the study area. Where the longitudinal unit conductance is greater than 0.7 mhos, the areas are considered zones of good protective capacity. The section with conductance values ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; and area with values ranging from 0.1 to 0.19 mhos was classified as exhibiting weak protective capacity while the zones where the value of conductance is less than 0.1 mhos were considered to have poor protective capacity.

This research work shows that the overburden materials in the study area around the red and pink colours (Figure 4) have good to moderate protective capacity and consist relatively thick overburden within the range of 20 to 41.6 m as observed in Figure 5. The pink and yellow colour areas as shown in Figure 4 exhibit weak to poor overburden protective capacity with thin overburden thickness in the range of 3 to 20 m (Figure 5). Thus, figure 4 further indicates that about 93% of the area falls within the poor to weak overburden protective capacity, while about 7% constitutes the moderate to good protective capacity rating.
The nature of the overburden materials that overlain the aquifers were estimated using the layer parameters (i.e. resistivity and thickness), the longitudinal unit conductance (S), the transverse unit resistance (T) and the coefficient of anisotropy in order to determine its capacity to prevent the infiltration of fluids contaminant into the aquifer. The geologic materials covering an aquifer might act as a seal in preventing the fluid from percolating into it. The earth materials act as a natural filter to infiltrating fluids; therefore, its ability to retard and filter percolating ground surface fluids pollutant is a measure of its protective capacity (Olorunfemi *et al.,* 1999). The clayey overburden is impervious and is characterized by relatively high longitudinal conductance, which in turn offers protection to the underlying aquifer (Abiola *et al.,* 2009).

Overburden Thickness of the area

The overburden thickness map (Figure 5) shows that the overburden thickness of the area varies from 1.7 to 41.6 m, with a mean value of 30.8 m. The overburden thickness map shows zones of relatively thick overburden with values greater than 20 m and zone of relatively thin overburden with values less than 20 m (figure 5). Appreciable overburden thickness zones are possible groundwater collecting zones; therefore, unconsolidated material could contain reliable aquifer if thick and sandy (Olayinka et al, 2004; Satpathy and Kanungo, 1976).
Geophysical studies in southwestern Basement Complex of Nigeria have recognized thick overburden as regions of high groundwater potentials (Olorunfemi and Okhue, 1992; Oladapo *et al*, 2004; and Oyedele and Olayinka, 2012). This is similar with the present study where the overburden is fairly thick (12 m to 20 m) and occurs in the green colour portions of the study area (figure 5). These zones are indicative of probable groundwater potential zones and cover about 6.8 % of Bogoro area.

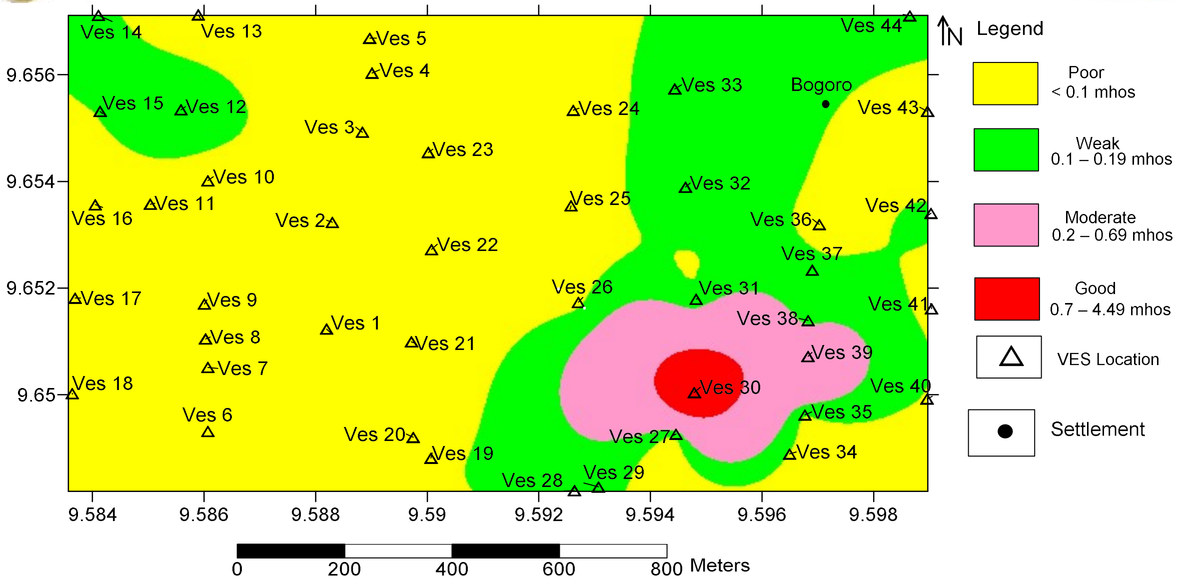

Figure 4: Longitudinal Conductance map of the study area (Present study)

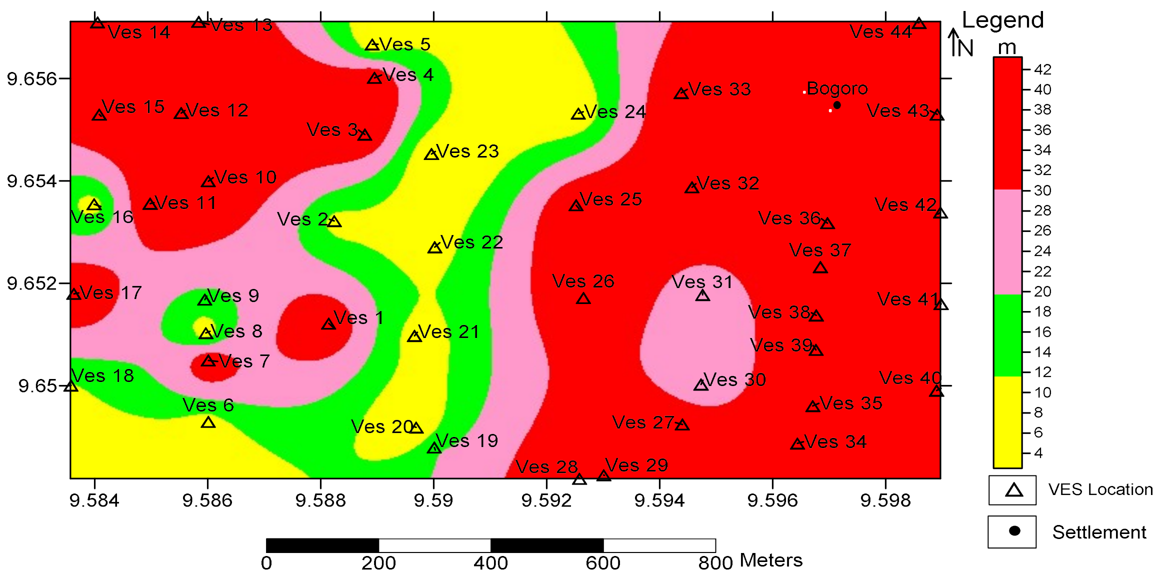

Figure 5: Overburden thickness map of the study area (Present study)

Geo-electric (Dar-Zarrouk) Parameters:

Geoelectric parameters such as total longitudinal conductance (S) and total transverse resistance (T) which were described by Maillet (1947) as Dar-Zarrouk parameters were derived from the fundamental parameters where Resistivity (ρi) and thickness (hi) are the basic parameters that describe the geoelectric layer derived from electrical sounding in an area. The subscript 'i' indicates the position of the layer in the section (Zohdy, *et al*., 1974).

The following parameters are based on the consideration of a column of unit square cross-section area (m^2) cut out of a group of layers of infinite lateral extent (Khalil, 2009). They are mathematically derived as:

Total Longitudinal Conductance (S) = $h1/\rho 1 + h2/\rho 2 + h3/\rho 3 + \ldots\ldots + hn/\rho n$ (Ω-1)
Total Transverse Resistance (T) = $h1*\rho 1 + h2*\rho 2 + h3*\rho 3 + \ldots\ldots + hn*\rho n$ ($\Omega\ m^2$)
Where i = 1, 2, 3 … nth layer.

They are defined for individual layers or as asummation for a multi-layer section (Khalil, 2009).
Average Longitudinal Resistivity (ρL) = H/S = S hi / (S hi/ρi) (Ωm)
Where H = h1 + h2 + h3 + …hn (Ωm)
Average Transverse Resistivity (ρt) = T/H = (S hi*ρi) / S hi (Ωm)
Electric Anisotropy (I) = $(\rho L / \rho t)^{½}$ = $(T*S/H)^{½}$ is a dimensionless entity

These parameters are calculated to the bottom of the last layer of local aquifers made up of clay, weathered and fractured rocks above the basement in the study area. The total longitudinal conductance (S) map (Figure 4) gives information about the variation of the highly resistive fresh basement topography since depth to the basement relates to the total longitudinal conductance (S). Murali and Patangay (2006) noted that in a region where geoelectric conditions are uniform resistivity would not very much. Thus, the total longitudinal conductance (S) is proportional to the total thickness, which means that large total longitudinal conductance (S) values are indicative of deeper basement and vice versa. In Bogoro area, the total longitudinal conductance (S) values ranges from 0.006383 to 1.295251mhos (Table 1) with a mean value of 0.121108 mhos. A marked increase in the total longitudinal conductance (S) value may correspond to a typical increase in the clay content and consequently a decrease in the transmissivity of the aquifer (Oteri, 1981; and Khali, 2009).

In the present study, low values of the total longitudinal conductance (S) correspond with aquifer units made of clay only and were depicted in VES 3, VES 6, VES 7, VES 8, VES 17, VES 20, VES 24, VES 26, VES 35, VES 36, VES 40, and VES 41. This relates to differences in geologic terrain since this study was being carried out in hard rock terrain and is in contrast to the report of Oteri (1981) in sedimentary environment. Meanwhile, the study also reveals that the values around the mean value of the total longitudinal conductance (0.121108 mhos) as shown in Table 1 are associated with good aquifer potential depicted in VES 1, VES 4, VES 10, VES 11, VES 12, VES 13, VES 25, VES 27,VES 30, VES 31 and VES 43, where the aquifer is not clay but rather fractured basement.

The total transverse resistance (*T*) map (Figure 6) of the study area shows *T* value ranges from 259.6 to 24354.6Ω m^2 with a mean value of 3096.3 Ω m^2 (Table 1). Nafez *et al*. (2010) used transverse resistance unit map for the determination of zones with high groundwater potential. According to Braga *et al.* (2006), high values of total transverse resistance (*T)* can be associated with the zones of high transmissivity and an indication of an unconfined aquifer. Hence, the red, pink and green colour zones (figure 6) are suitable for groundwater exploitation.
The coefficient of anisotropy (I) map (figure 7) of the study area is characterized by the transverse and longitudinal resistivities (Maillet, 1947). This parameter is also calculated to the top of basement rock and its value ranges from 0.557592 to 3.069103 (Table 1) with a mean value of 1.197801 in the study area. Singh and Singh (1970) pointed out that lower coefficient of anisotropy (I) value corresponds to high aquifer potential zones. Thus, VES 2, VES 5, VES 6, VES 8 and VES 18 are expected to have higher groundwater potential with thick aquifer but were not observable in the area.

However, the electric anisotropy (I) map (figure 7) reveals that coefficient of anisotropy (I) value cannot be solitarily used to characterize aquifer potential without recourse to the aquifer thickness. VES 2, VES 5, VES 6, VES 8 and VES 18 have low values of coefficient of anisotropy (I) of 1.05889, 1.03732, 0.56134,1.001026, and 1.044255 respectively and they are expected to have higher aquifer thickness but their aquifer thickness are 8.7 m, 4.1 m, 6.8 m, 5.8

m and 10.8 m respectively. This thickness cannot make reasonable yield as we know that aquifer with water column of 7m would be unreasonable to rely on for borehole production.

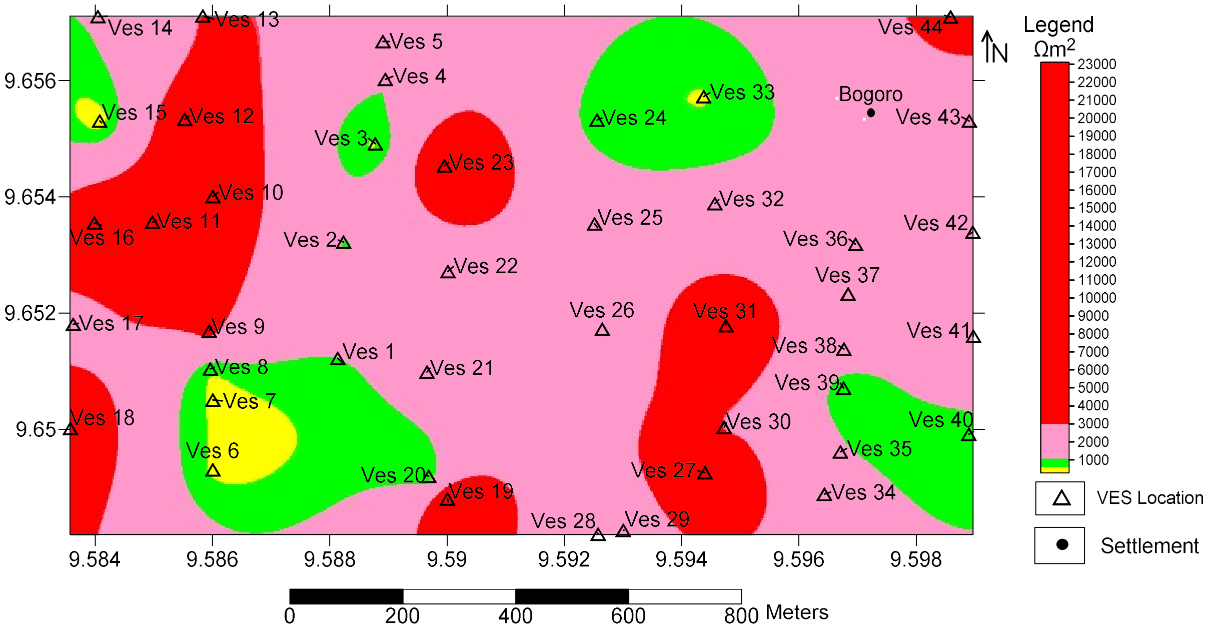

Figure 6: Transverse unit resistance map of the study area (Present study)

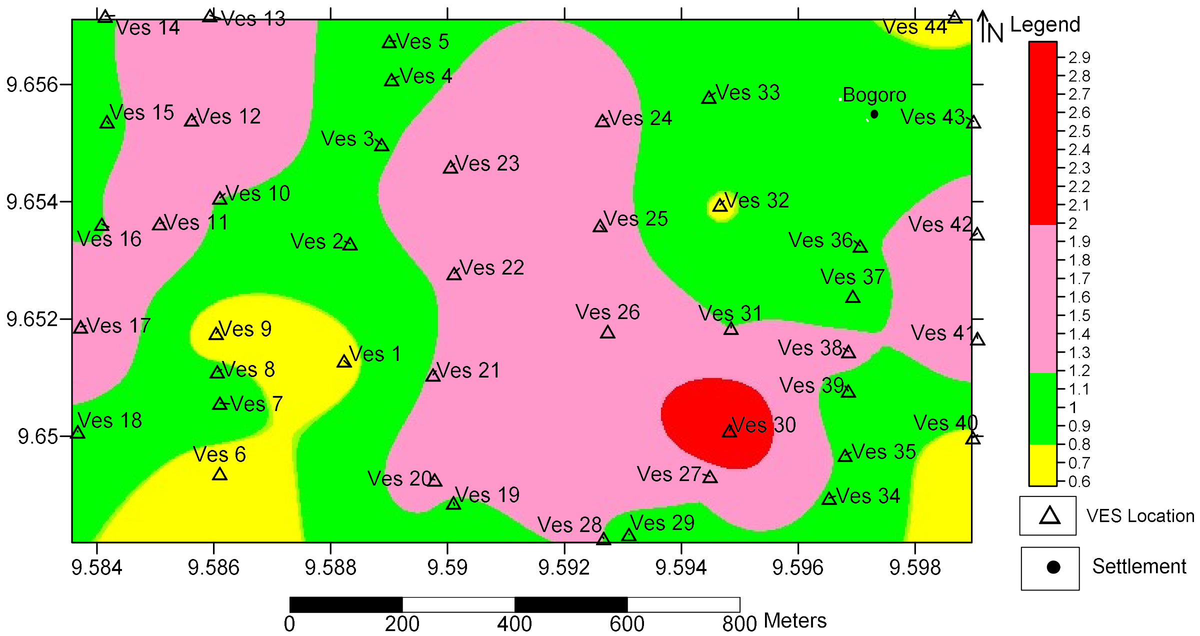

Figure 7: Coefficient of Anisotropy map of the study area (Present study)

Geo-electric Sections

The 2-D geoelectric sections (Figs. 8a - 8c) were drawn in N-S directions. Figure 8a has varying topsoil resistivity values of 81 - 472 ohm-m and thickness of 1.1 to 3.4 m. The second lithologic layer corresponds to clayey layer having resistivity of 53 to 98 ohm-m and thickness of 2.5 to 4.6 m located at VES 3, VES 6, VES 7, and VES 8 and fractured basement sited at VES 2, VES 4, VES 5, and VES 9 with their corresponding resistivity value of 163 - 788 ohm-m and thickness of 2.9 to 5.3 m.

The third layer is the fractured basement having resistivity values of 352 to 884 ohm-m with an infinite thickness. There is also the presence of fresh basement at the third layer with resistivity values of about 1119 to 1212 ohm-m and thicknesses between 4.0 – 8.6 m. The fourth layer is the fresh basement found only at VES 9 having resistivity value of 1117 ohm-m with an infinite thickness. The structural variation showed thickening of the overburden under VES 3, VES 4 and VES 7. The depth to bedrock is deeper which is controlled by structural features relevant for groundwater development.

In Figure 8b, the topsoil resistivities range from 104 to 668 Ω-m with thickness of about 0.7 to 4.1 m. The second layer has resistivities of 29 to 92 Ω-m and thicknesses range of 2.3 to 14.8 m, which correspond to clay materials. The third layer has resistivity value of 42 to 656 Ω-m with an infinite thickness. All the VES in this section has thick aquifer favourable to groundwater accumulation, thick clay layer overlain the aquifer and protect it from fluid contamination with the exception of VES 29

In Figure 8c the topsoil resistivities range from 165 to 807 Ω-m with thickness of about 0.7 to 2.5 m. The second layer, which is the clay/fractured basement, has resistivities of 84 to 134 Ω-m and thickness of 3.0 to 9.5 m. The clayey layer underlain the Topsoil only under VES 40, VES 41 and VES 42 across the section and served as seal for the aquifer under the thick clay layer. There is the presence of fractured basement with resistivities between 134 and 181 Ω-m and thicknesses ranging from 3 to 6.5 m. The third layer has resistivities of 194 to 367 Ω-m with infinite thickness. The entire section has very thick aquifer overburden and is favourable for groundwater accumulation and abstraction. Fresh basement is conspicuously absent. The aquifer unit mapped in the study area is the fractured layer.

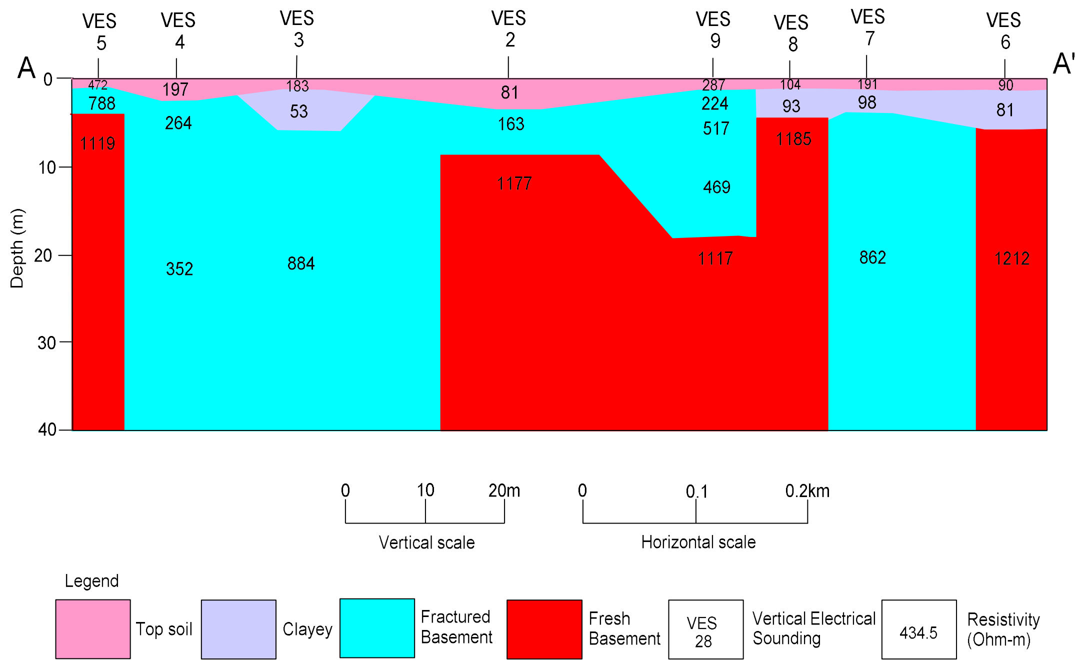

Figure 8a: Geo-electric section across profile AA' (Present study)

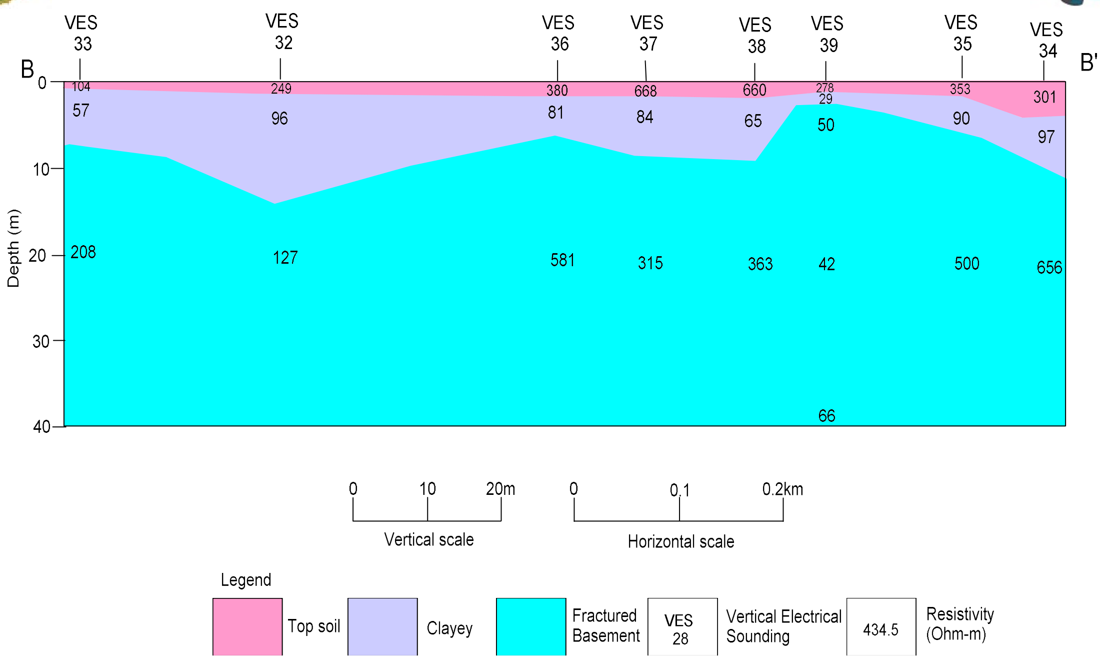

Figure 8b: Geo-electric section across profile BB' (Present study)

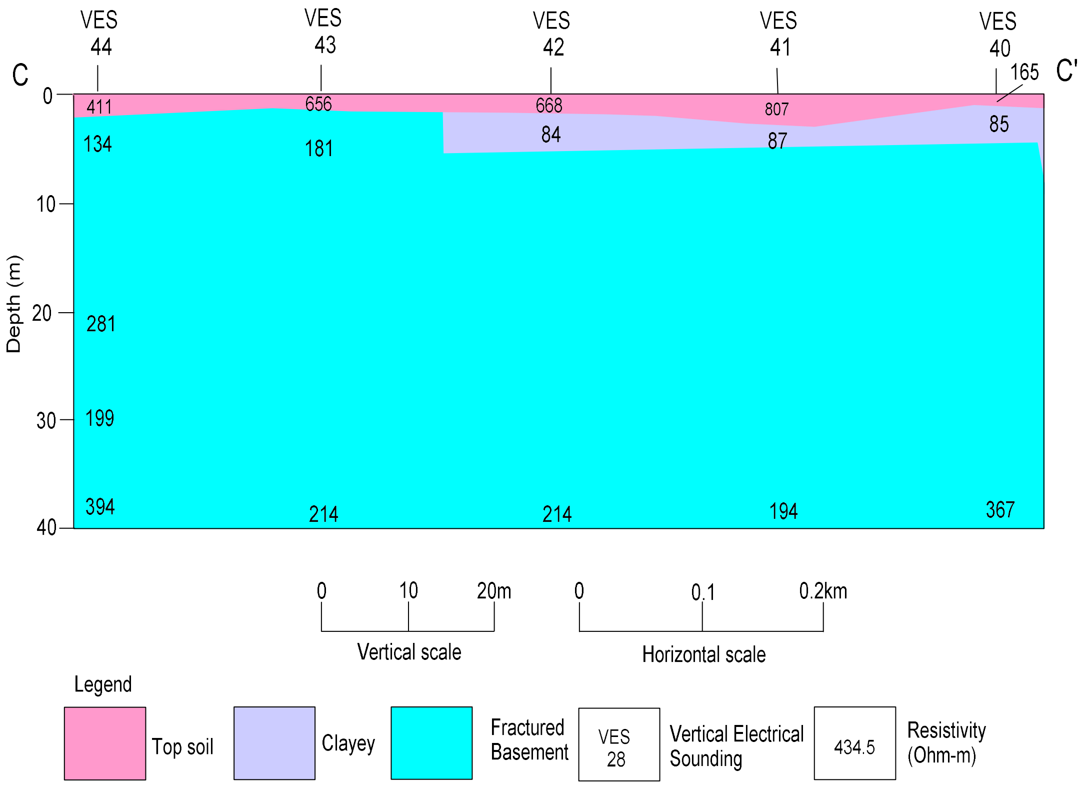

Figure 8c: Geo-electric section across profile CC'(Present study)

CONCLUSION

The geoelectric sections show the variations in resistivity and thickness values of layers within the depth penetrated at the indicated VES stations. All the three profiles indicate three to four subsurface layers and they include the topsoil, clayey layer, fractured basement and the fresh basement. More than 90% of study area is underlain by materials of poor to weak protective capacity while about 7% is underlain by materials of moderate to good protective capacity. The areas with good to moderate protective capacity coincided with zones of appreciable overburden thickness with clayey columns sufficiently thick to protect the aquifer from peculating fluid contaminants. The zones with thin overburden also coincided with weak to poor protective capacity thereby exposing the groundwater to pollution and the area is vulnerable to peculating fluid contaminants. The area with high values of coefficient of anisotropy and low values of transverse unit resistance is a reflection of low transmissivity, which coincide with moderately thin overburden thickness making the groundwater vulnerable to infiltrating fluid contaminants.

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