



Geo-electrical Survey for Groundwater Potential of Biu and Environs, North Eastern Nigeria

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Abstract: Thirty-six Vertical Electrical Sounding (VES) were carried out to evaluate groundwater potential and aquifer protective capacity of the overburden units using Schlumberger configuration with maximum current electrode of 150m using Petrozenith PZ 02b Terrameter. Data was analyzed using Interpex IX1-D, H-curve type dominates the study area with 41%, k-type and Q-type have 17%, KH-type has 14% and A-type has 11%. Iso-resistivity contour map revealed that major anomaly was found at the eastern part of the study area at Biu with length of 6.2km and width of 2.5km. Geo-electro stratigraphic section revealed that the geologic sequence beneath the study area is composed of top soil, partly weathered/fractured basement, highly Weathered/Fracture basement and presumably fresh basement. Topsoil has resistivity of 50Ωm to 1015Ωm with thickness ranging from 1m to 7m. The weathered/fractured horizons constitute the water-bearing zones referred to as aquifer with a thickness value of 10m to 38m and resistivity value of 23Ωm to 237Ωm. Presumably fresh basement has resistivity values of 4617Ωm to 18313Ωm with infinite depth. Total longitudinal conductance for each potential aquifer zone was used to determine its overburden protective capacity. Four zones have good, twelve zones have moderate and one has poor protective capacity. Twenty VES points were used to produce contour maps for transmissivity and hydraulic conductivity. Hydraulic conductivity and transmissivity varied from 3 to 34m/day and 33 to 919m²/day respectively. Correlation coefficient between transmissivity and hydraulic conductivity give positive correlation which signifies a perfect correlation. VES has proved useful in evaluating the groundwater potentials within and around Biu.

Keywords: Biu and Environs, Geoelectrical Survey, Iso-resistivity Contour Map, Geo-electro Stratigraphic Section, Protective Capacity, Hydraulic Conductivity, Transmissivity

1. Introduction

The Biu basalt are usually fractured, jointed and sometimes weathered; these characteristics enable the basalt to attain a secondary form of porosity and permeability thereby making the basalt potential aquifers capable of storing water. Groundwater confined in weathered basalt in the earth crust can be tapped by hand dug well at shallow depths. The yield is usually small and fluctuates at different seasons and climatic condition. The hand-dug wells are commonly sited along drainage lines where the weathered zone is often thick and in the valley areas where there is seepage. Generally, aquifer distribution in Nigeria is categorized into two systems: Basement fluviovolcanic aquifers and Sedimentary aquifers. [1] and [2], found that the availability of

groundwater in areas underlain by crystalline basement rocks depends on the development of thick soil overburden (overburden aquifers) or the presence of fractures that are capable of holding water (fractured crystalline aquifers). [3] Stated that: One of the greatest environmental challenges that confront rural communities in north eastern Nigeria especially Borno state is scarcity of water supply. In most rural communities in northern Nigeria, hand dug wells are the major source of water for both domestic and livestock use. The study area covers some parts of the Biu Plateau, lying between longitude 12° 07' 00"E and 12° 13' 00"E and latitude 10° 34' 00"N and 10° 40' 00"N. it covers an area of about 122km² (Figure 1). The towns bordering the area include Damaturu to the North, Mubi to the South, Damboa to the East and Gombe to the West. The area is fairly accessible and has relatively good network of roads and foot paths. The

vegetation of the study area could be best described as Sudan type. Biu Plateau falls within the Guinea Savannah climatic zones of Nigeria. The present work is aimed at providing basic information about groundwater potential of Biu Volcanic Province using Vertical Electrical Sounding (VES) with the view to fulfil the following objective

1. Compute and analyze aquifer properties in terms of resistivity and thickness of the aquifer units.
2. Delineate the water bearing zone of the area.
3. Evaluate the protective capacity of the overburden materials over the study area.

The study can be used by borehole drilling companies which operate within the study area to aid their drilling activities. Knowledge of the location of the aquifers and their thickness can help eliminate the problem of abortive boreholes within the study areas.

2. Geology and Hydrogeology of the Study Area

The study area is part of the NE basement terrain underlain by basement rocks of Precambrian age. They are mainly basaltic rock. Biu Plateau is situated on the structural and topographic divide between the Benue and Chad sedimentary basins. The structural divide is a broad E-W ridge or swell of basement, which extends to the western edge of the Biu Plateau. They are mostly occurring as "flood Basalts" in a number of flows and in fact cover nearly the area with its center around Biu. According to [4]: The Basalt at some places has built up large number of flows. The dimension of the flows and the marked absence of pyroclastics in and around Biu, Tum, Marama, and Shaffa areas, indicate that the eruption of Basaltic magma in these places was not violent. However, the Basaltic sequence in the North-western part of Biu is surrounded by several youthful scoria, cinder cones, tephra rings etc., the pyroclastics are generally restricted to the area west of Biu- Damaturu road, suggesting that the eruptions in these places are violent in nature. [5] stated that the study area is made up of three types of Basaltic rocks. Massive basalts, slightly vesticulated basalts and vesicular basalts. The age variations between this basalt are due to time of their eruption, nature of their eruption and also the manner into which they solidified. The Biu basalt belongs to the tertiary-Recent volcanic province of Nigeria and Cameroon which is characterized by numerous widely scattered occurrences of alkali olivine basalt together with less important trachyte and phonolite. It consists of intensive flows of basalts which are dense, fine grained and dark in coloured. Some of them contain vesicles which are partially or completely filled with secondary minerals probably calcite or zeolite. The most peculiar thing about the Biu Type of basalt is the degree to which the olivine has been altered. Some olivine crystals are completely altered while some are partially altered along their margins and cracks. The rate of

alteration of the Biu basalt suggests that they are older than the Miringa Type which is Pliocene in age. The massive basalt are dark coloured, fine grained in texture with whitish feldsparitic minerals. It also contains phenocrysts of olivine and secondary minerals such as calcite and iron oxide. It dominated the study area. It occupied the south, northeastern and southwestern part of the study area. The slightly vesicular basalt has smaller number of vesicles and their cavities are smaller in size and scattered. They are light to dark gray in colour. It occurs diagonally from western to northeastern part of the study area. The vesicular basalt has cavities which vary considerably in shapes and sizes. They are spherical, ellipsoidal, cylindrical and irregular in shape. Are found at the northwestern part of the study area.

The lateritic soil formed from the weathering of the basalt are brownish to reddish brown in colour except in some cases where they are found to occur as light gray to dark gray clay. The water resources of the study area can be divided into surface and groundwater resources. The surface water of this area occurs in the form of streams and lakes. They serve as water supply sources for both drinking and domestic uses. Most of the streams are seasonal. The streams and lakes are recharged by direct precipitation during the rainy season.

3. Methodology

A total of thirty six (36) Vertical Electrical Sounding (VES) were carried within the study area using Schlumberger array with Petrozenith PZ 02b terrameter to measure and record the resistance of the subsurface. These stations were chosen at different locations within the study area (Figure 1). The potential electrodes remain fixed and the current electrodes were expanded simultaneously about the center of the spread. The maximum electrode separation used was $AB/2 = 150\text{m}$ and a maximum potential electrode spacing $MN/2 = 5\text{m}$ which are normally arranged in a straight line, with the potential electrode placed in between the current electrodes. This configuration is mostly used as it would provide sub-surface information considering the depth of penetration which ranges between 1/3 and 1/4 of the total separation. The field data were converted to apparent resistivity (ρ_a) in ohm-meter by multiplying with Schlumberger geometric factor (k). The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against half electrode spacing on a bi-logarithmic and edited in the Interpex 1-D software until a smooth layered model with a minimum percentage error of <1 is gotten in which a model graph is plotted for each VES. The curve obtained was then compared to the H, K, Q, and A curve types. The distribution of resistivities of different subsurface layers is described below: H-type, $\rho_1 > \rho_2 < \rho_3$; K-type, $\rho_1 < \rho_2 > \rho_3$; A-type, $\rho_1 < \rho_2 < \rho_3$; Q-type, $\rho_1 > \rho_2 > \rho_3$; KA, HQ-type, and so on, represent four layer curves. Dar-Zarrouk parameters (Longitudinal conductance and Transverse resistance) were used to define target areas of

groundwater potential and also used in aquifer protection studies. The total longitudinal conductance values was utilized in evaluating the overburden protective capacity of the study area. This is because the earth medium acts as a natural filter to percolating fluids. Surfer 12.0 was used to

generate Iso-resistivity contour map, Geo-electro stratigraphic sections, protective capacity contour map, transmissivity and hydraulic conductivity map with the layer data.

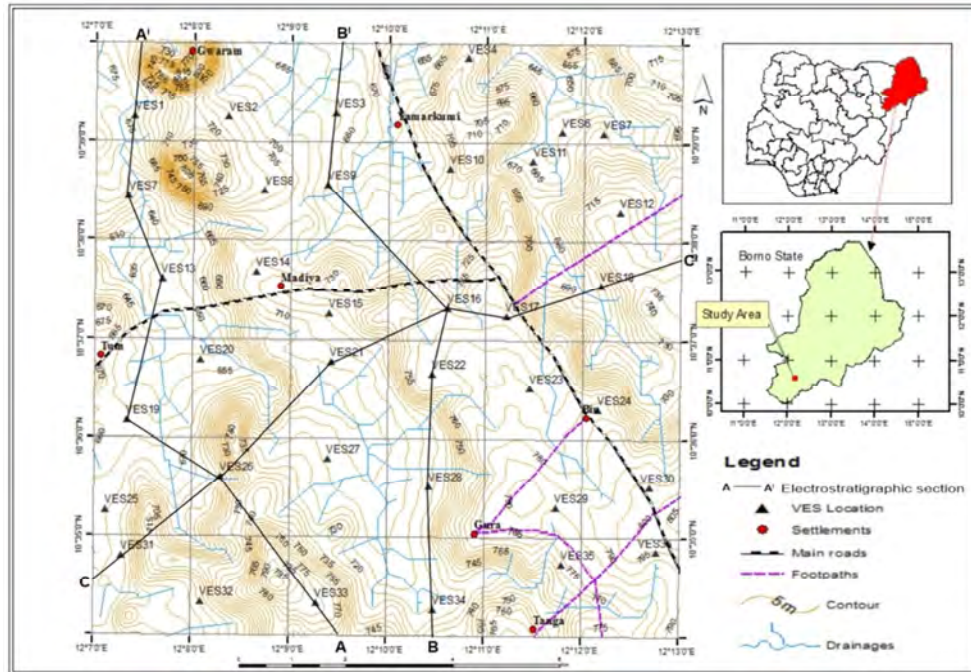


Figure 1. Topographic map of the study area (USA Geological Agency, 2010. Cont inter. 5m).

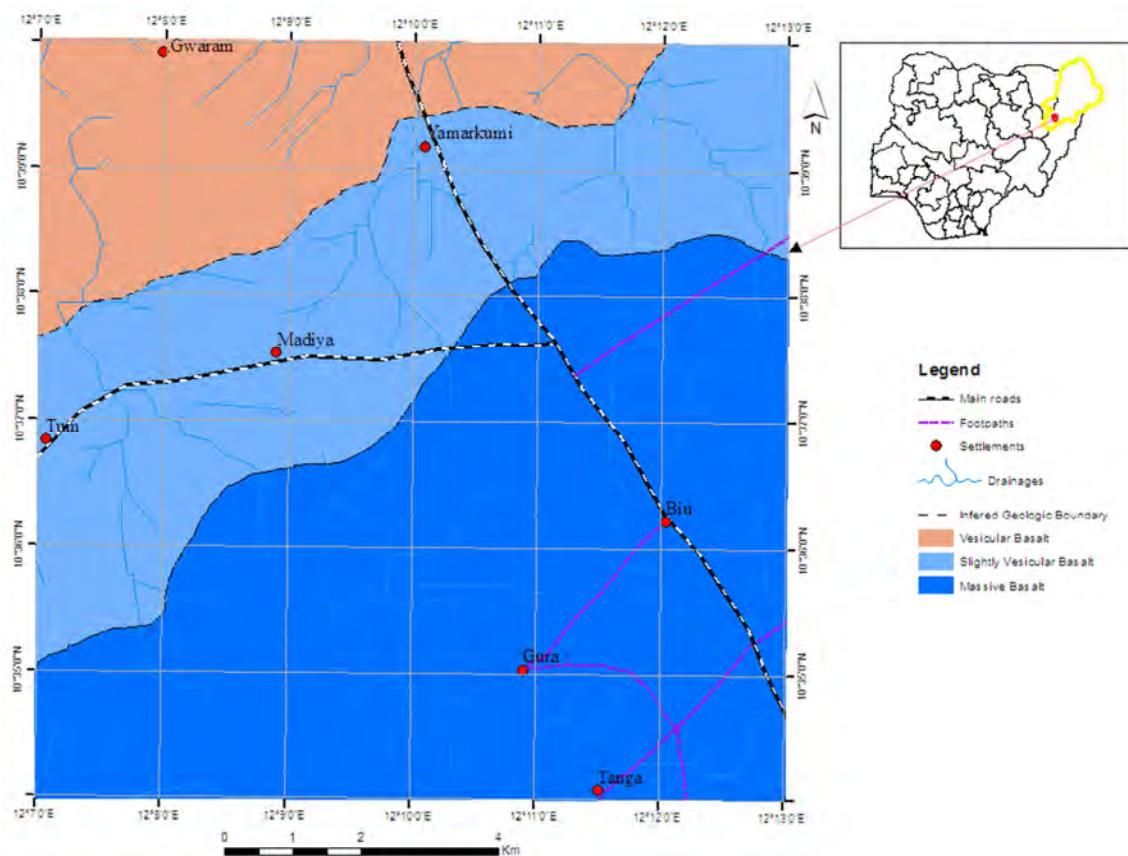


Figure 2. Geologic map of the study area.

4. Results and Discussion

The thirty six (36) Vertical Electrical Soundings (VES) were interpreted qualitatively and quantitatively. The result show details of the measured parameters such as thickness of layers, resistivity of layers, transverse resistance, longitudinal conductance, fitting error and curve-type for all the sounded

points.

From the curve type distribution of the 36 VES in the study area (Table 1). There are about three to four (4) different vertical Electrical Sounding (VES) layers. The qualitative and quantitative interpretation has helped in the delineating aquifer zones in the study area.

Table 1. Summary of Result obtained from the computer output of the 36 VES in the study area.

VES POINT	THICKNESS OF LAYER (m)			RESISTIVITY OF LAYER (ohm-m)			
	h_1	h_2	h_3	ρ_1	ρ_2	ρ_3	ρ_4
VES 1	1.10	2.10	23.79	353.29	502.81	65.49	13131
VES 2	2.54	6.56	—	145.24	1124.8	318.62	—
VES 3	1.11	2.83	24.75	118.62	664.0	132.09	14627
VES 4	1.16	12.01	—	231.0	84.81	6358.0	—
VES 5	4.78	15.26	—	917.0	603.1	299.43	—
VES 6	0.50	1.19	9.88	871.35	6345.2	77.515	18313
VES 7	2.63	24.78	—	49.70	66.24	6078.8	—
VES 8	4.36	27.34	—	696.68	43.34	1054.1	—
VES 9	5.08	14.16	—	536.1	236.97	1171.2	—
VES 10	2.49	19.58	—	530.67	56.017	1323.6	—
VES 11	4.28	38.22	—	514.89	208.32	151.71	—
VES 12	1.30	6.14	—	847.64	627.38	368.52	—
VES 13	3.67	38.10	—	264.5	37.985	6433.4	—
VES 14	6.63	23.80	—	476.69	107.55	76.186	—
VES 15	3.20	5.02	—	325.81	1791.2	252.35	—
VES 16	3.30	11.73	—	142.27	49.80	2324.2	—
VES 17	2.57	21.96	—	672.40	31.07	2729.6	—
VES 18	3.72	6.6	—	82.66	617.2	6657.5	—
VES 19	3.46	14.71	—	226.92	23.178	2367.0	—
VES 20	2.24	9.27	—	163.56	938.48	139.73	—
VES 21	3.50	37.21	—	176.4	88.32	5393.3	—
VES 22	3.52	35.28	—	812.46	35.582	1249.5	—
VES 23	0.47	17.56	—	742.15	2163.3	2870.5	—
VES 24	6.06	31.88	—	257.06	52.42	6477.1	—
VES 25	2.87	8.18	—	119.13	2102.6	163.04	—
VES 26	2.59	11.03	—	190.24	31.983	1004.2	—
VES 27	2.15	14.21	—	1015.3	745.88	144.06	—
VES 28	0.40	1.03	22.11	411.52	649.1	51.73	4818.6
VES 29	1.41	18.41	—	35.02	50.69	5926.0	—
VES 30	2.90	22.97	—	624.1	82.150	2210.0	—
VES 31	2.02	11.05	—	583.5	73.780	1354.50	—
VES 32	0.31	4.09	—	197.11	7770.4	340.21	—
VES 33	2.67	16.11	—	788.4	244.74	42.875	—
VES 34	0.40	8.31	—	141.10	703.2	118.41	—
VES 35	6.12	15.46	—	276.39	35.148	12063	—
VES 36	1.50	3.35	27.360	114.66	1250.5	35.796	4616.5
MEAN	2.75	15.48	21.57	406.99	839.98	2161.7	11101.2

Table 1. Continue.

VES POINT	LONGITUDINAL CONDUCTIVITY (Seimens)			TRANSVERS RESISTIVITY (ohm-m ²)			FITTING ERROR (%)	CURVE TYPE
	S_1	S_2	S_3	T_1	T_2	T_3		
VES 1	0.0031	0.0042	0.3662	388.3	1054.2	1547.0	0.97	KH
VES 2	0.0175	0.0058	—	369.51	7383.4	—	0.51	K
VES 3	0.0093	0.0042	0.1879	129.81	1859.2	3273.6	0.92	KH
VES 4	0.0051	0.1417	—	269.81	1019.1	—	0.99	H
VES 5	0.0052	0.0253	—	4392.1	9204.5	—	0.92	Q
VES 6	0.0006	0.0002	0.1275	439.77	7577.7	766.05	0.59	KH

VES POINT	LONGITUDINAL CONDUCTIVITY (Seimens)			TRANSVERS RESISTIVITY (ohm-m ²)			FITTING ERROR (%)	CURVE TYPE
	S ₁	S ₂	S ₃	T ₁	T ₂	T ₃		
VES 7	0.0531	0.3742	—	127.4	1630.2	—	0.87	A
VES 8	0.0063	0.6310	—	3039.1	1185.3	—	0.80	H
VES 9	0.0095	0.0598	—	2727.7	3356.7	—	0.42	H
VES 10	0.0047	0.3496	—	1323.2	1097.1	—	0.89	H
VES 11	0.0083	0.1835	—	2207.5	7963.4	—	0.84	Q
VES 12	0.0015	0.0098	—	1108.1	3854.6	—	0.57	Q
VES 13	0.0139	1.0033	—	972.30	1447.3	—	0.89	H
VES 14	0.0139	0.2213	—	3163.8	2559.8	—	0.33	Q
VES 15	0.0098	0.0028	—	1045.3	9007.0	—	0.20	K
VES 16	0.0232	0.2357	—	469.53	584.66	—	0.62	H
VES 17	0.0038	0.7069	—	1733.4	682.36	—	0.65	H
VES 18	0.0451	0.0106	—	303.4	4073.5	—	0.38	A
VES 19	0.0152	0.6347	—	785.25	340.95	—	0.75	H
VES 20	0.0137	0.0099	—	367.70	8699.7	—	0.36	K
VES 21	0.0198	0.4212	—	616.0	3284.7	—	0.87	H
VES 22	0.0043	0.9918	—	2860.5	1255.7	—	0.84	H
VES 23	0.0006	0.0081	—	351.33	37989.7	—	0.54	A
VES 24	0.0236	0.6081	—	1560.0	1671.6	—	0.78	H
VES 25	0.0242	0.0039	—	342.95	17218.6	—	0.43	K
VES 26	0.0136	0.3450	—	493.88	352.93	—	0.61	H
VES 27	0.0021	0.0191	—	2185.9	10601.1	—	0.84	Q
VES 28	0.0010	0.0015	0.4333	164.4	649.0	1127.1	0.97	KH
VES 29	0.04	0.368	—	49.0	920.0	—	0.24	A
VES 30	0.0046	0.2797	—	1809.9	1886.9	—	0.95	H
VES 31	0.0035	0.1497	—	1179.3	815.27	—	0.30	H
VES 32	0.0016	0.0005	—	61.518	31828.3	—	0.16	K
VES 33	0.0034	0.0658	—	2105.0	3942.8	—	0.97	Q
VES 34	0.0099	0.0118	—	197.4	5834.9	—	0.92	K
VES 35	0.0222	0.4399	—	1692.9	543.49	—	0.50	H
VES 36	0.0132	0.0027	0.7643	173.03	4192.6	979.38	0.97	KH
MEAN	0.0125	0.2314	0.3758	1144.6	5488.0	1538.6	0.68	

Table 2. Curve Type Distribution of the 36 VES in the Study Area.

S/N	VES NUMBER	Curve Type	Number of Layers	%
1	4, 8, 9, 10, 13, 16, 17, 19, 21, 22, 24, 26, 30, 31 and 35	H	3	41
2	2, 15, 20, 25, 32 and 34	K	3	17
3	5, 11, 12, 14, 27 and 33	Q	3	17
4	7, 18, 23, and 29	A	3	11
5	1, 3, 6, 28 and 36	KH	4	14

Iso-resistivity contour map were produced for better understanding of the subsurface groundwater occurrence with surfer twelve (12) software for AB/2 = 150m which reveal the situation of the subsurface at a depth of 38-50m which is depth of penetration. It has resistivity values ranging from 45 - 2799Ωm. The Southwestern and Northwestern part of the study area has the low resistivity values, while the Northeastern parts of the study area has high resistivity values. The anomalous zone were seen at Tum with length of

4.3km and width of 1.5km. At the central part of the study area close to Madiya the anomaly has length of 3.3km and width of 1.5km another anomaly has length of 2.5km and width of 1.5km. Two minor anomalies are found at the western part of Tanga with length of 0.9km and 1.5km with width of 0.7 and 0.9km respectively. The major anomaly was found at the eastern part of the study area at Biu with length of 6.2km and width of 2.5km (Figure 3).

Geo-electro stratigraphic sections were taken along profile A-A' comprises of VES 33, VES 26, VES 19, VES 13, VES 7, and VES 1. Profile B-B' comprises of VES 34, VES 28, VES 22, VES 16, VES 9, and VES 3 and profile C - C' comprises of VES 31, VES 26, VES 21, VES 16, VES 17 and VES 18. Which revealed that there are mostly three and four geologic layers beneath each VES point composed of top soil, partly weathered/fractured basement, highly weathered/fractured basement and presumably fresh basement.

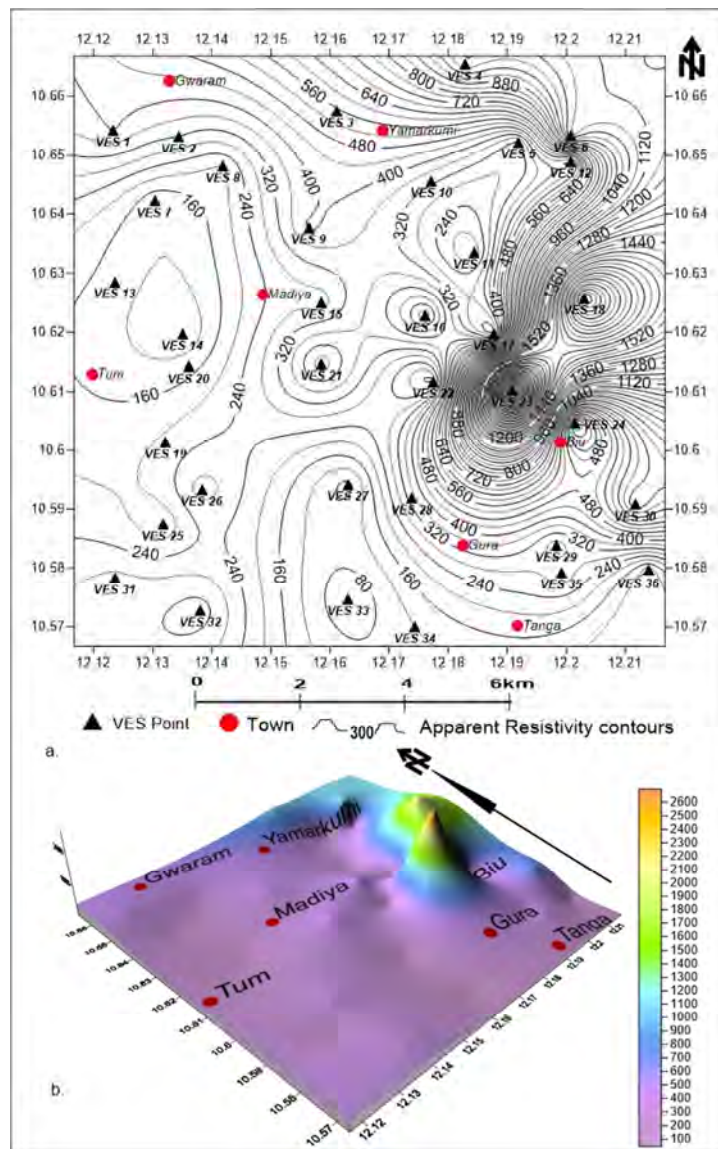


Figure 3. a: Iso-resistivity contour map for $AB/2 = 150m$ (Contour interval = $40\Omega m$). b: 3D surface map.

Profile A-A': the first layer is the top soil which is composed of clayed and sandy-lateritic hard pan with resistivity value ranging from $49\Omega m$ to $788\Omega m$ and thickness varying from 1.1m – 3.7m with thinnest at VES 1 and thickness at VES 13. It is however, observed from the geoelectric section that VES 7 is characterize with low resistivity value of $49\Omega m$ suggesting that the top soil in these area are possibly high moisture content. The second layer at VES 33 and VES 1 are partly weathered/fractured basement with resistivity value of $788\Omega m$ and $507\Omega m$ and thickness value of 16.1m and 2.1m respectively, while the third layer at VES 33 and VES 1 are highly weathered/fractured basement with resistivity value of $42\Omega m$ and $65\Omega m$ and thickness of 23.8m at VES 1 which is good for sitting borehole. At VES 26, VES 19, VES 13 and VES 7 the second layer is highly weathered/fractured basement with resistivity value ranging from $23\Omega m$ to $66\Omega m$ and thickness value of 11m to 38.1m. With thickness value of 38.0m at VES 13, suggesting this point

for sitting borehole. Other point with probable high water potential suitable for sitting borehole includes VES 26, 19 and 7 with appreciable thickness of weathered/fractured rock also known as aquiferous zone. The third layer is presumably fresh basement whose resistivity vary from $1004\Omega m$ to $13131\Omega m$ with an infinite depth (figure 4a).

Profile B - B': the first layer is the top soil with resistivity value ranging from 188 to $812\Omega m$ and thickness value of 0.4 to 5.1m, thickness at VES 9 and thinnest at VES 28. At VES 34, 28 and VES 3; the second layer is partly weathered/fracture basement with resistivity value of $703\Omega m$, $694\Omega m$, and $663\Omega m$ and thickness value of 8.3m, 1.0m and 2.8m respectively. Third layer at this VES point is highly weathered/fractured basement with resistivity value of $118\Omega m$, $51\Omega m$ and $132\Omega m$ respectively. The layer thickness of 22.1m for VES 28 and 24.8m for VES 3 which are both good for borehole development. The second layer for VES 22, 16 and 9 are highly weathered/fractured basement with resistivity value

of $35\Omega\text{m}$, $49\Omega\text{m}$, $236\Omega\text{m}$ and layer thickness of 35.3m, 11.7m, and 14.2m respectively. With the resistivity value and considering the thickness of the layer VES 22 and VES 16 point are probable high water potential suitable for sitting borehole. The third layer is presumably the fresh basement whose resistivity values varies from $1171\Omega\text{m}$ - $14627\Omega\text{m}$ with an infinite depth (figure 4b).

Profile C - C': the resistivity of the top soil vary from $82\Omega\text{m}$ - $672\Omega\text{m}$ and thickness ranges from 2.0m - 3.7m, thickness at VES 18 and thinnest at VES 31, it is observed that VES 18 has low resistivity value of $82\Omega\text{m}$ suggesting that the top soil possibly has high moisture content. The second layer is highly weathered/fractured basement except

for VES 18 which is partly weathered/fractured basement with resistivity value of $617\Omega\text{m}$ and thickness of 6.6m. The resistivity value for the highly weathered/fractured basement ranges from $31\Omega\text{m}$ - $88\Omega\text{m}$ and thickness of layer from 11m - 37m which are all suitable for sitting of borehole. The third layer is presumably fresh basement whose resistivity vary from $1004\Omega\text{m}$ - $6657\Omega\text{m}$ with an infinite depth (figure 4c). From the geoelectro stratigraphic section profile taking, based on the interpretation, it is deduced that VES point 1, 3, 7, 13, 16, 17, 18, 21, 22, 26 and 31 are viable point for sitting boreholes with appreciable thickness of weathered/fractured basement (aquiferous zone).

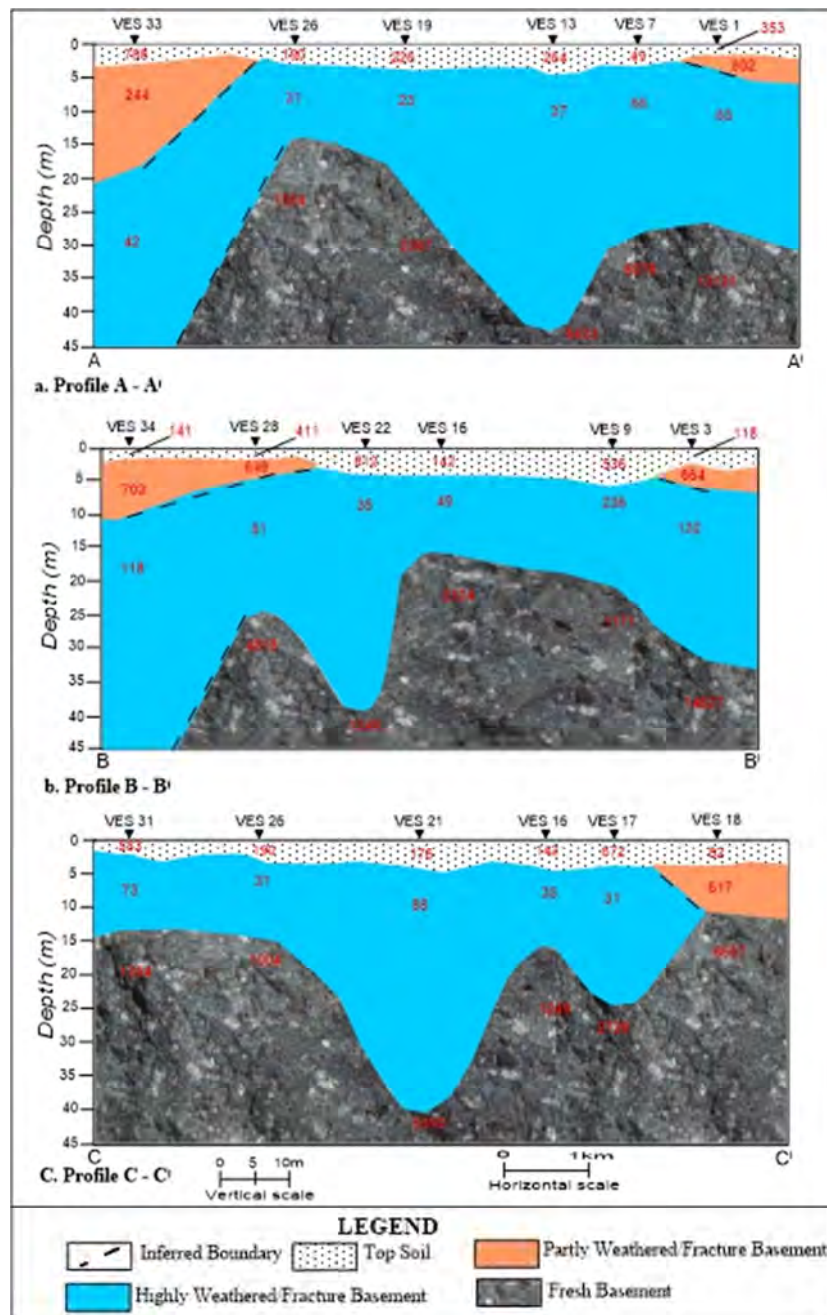


Figure 4. (a), Geoelectro-stratigraphic section profile A-A'. (b), Profile B-B'. (c), Profile C-C'.

The total longitudinal conductance (Dar-Zarrouk) values can be utilized in evaluating overburden protective capacity in an area, because the earth medium acts as a natural filter to percolating fluids. Its ability to retard and filter percolating fluid is a measure of its protective capacity. According [6] "an aquifer protection capacity rating can be classified on the basis of the total longitudinal unit conductance (ΣS) as excellent ($S > 10$), very good ($5 \leq S \leq 10$), good ($0.7 \leq S < 5$), moderate ($0.2 \leq S < 0.7$), weak ($0.1 \leq S < 0.2$) and poor ($S < 0.1$) protective capacity". From the results obtained, twenty (20) potential aquifer zones were observed. Four (4) VES Points, the layers overlying the aquifer zone have a good

capability in terms of aquifer protection. The total overburden thickness provides protection from the overlying materials. Moreover, the second overburden layer will also impede fluid movement through it. Twelve (12) potential aquifer zones showed moderate protective capacity of the overburden materials. This in-turn decreases the infiltration time of contaminant fluids moving from the ground surface into the aquifer. Three (3) VES points showed weak and one (1) VES point has poor capability in terms of aquifer protection. Areas that are classified as poor and weak are indicative areas are thus vulnerable to infiltration of leachate and other surface contaminations (figure 5).

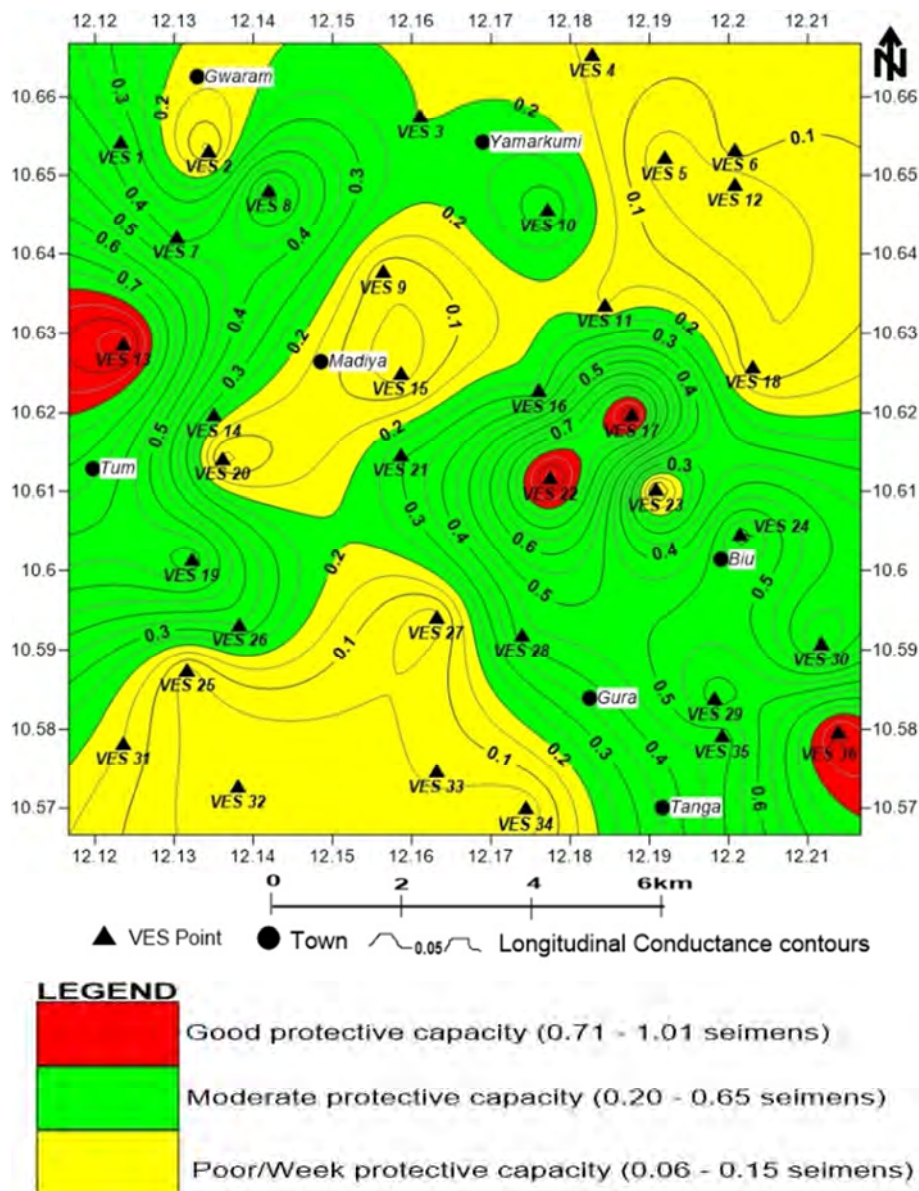


Figure 5. Protective capacity contour map of the study area (contour interval 0.05 Seimens).

EVALUATION OF HYDRAULIC CONDUCTIVITY (K) AND TRANSMISSIVITY (T) VALUE USING GEOELECTRICAL METHOD

The aquifer parameters like hydraulic conductivity (K) and

transmissivity (T) are extremely important for the management and development of groundwater resources. The values of transmissivity and hydraulic conductivity were calculated from geophysical data.

$$K = 386.4\rho^{-0.93283} \text{ (m/day)} \quad (1)$$

$$T = Kb \text{ (m}^2\text{/day)} \quad (2)$$

Where ρ is resistivity of aquifer layer, b = Aquifer thickness (m).

Generally the higher the transmissivity value of an aquifer, the better its productivity prospect. The hydraulic conductivity and transmissivity of the aquifer were quantitatively determined using equation (1 and 2) respectively and presented in table (3). 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. The hydraulic conductivity estimated from the electrical resistivity sounding data for twenty (20) potential aquifer resistivity was contoured as shown in (Figure 6). Hydraulic conductivity values for the potential aquifers determined from geoelectrical technique range between 2.35 to 33.6m/day with average value of 11.22m/day. Its shows low hydraulic conductivity observed at northern parts of the study area at Yamarkumi and high values of hydraulic conductivity observed in the extreme southwest and northwest of the map, it can be inferred that high permeability is dominant in the study area and seems to be a good aquifer zone.

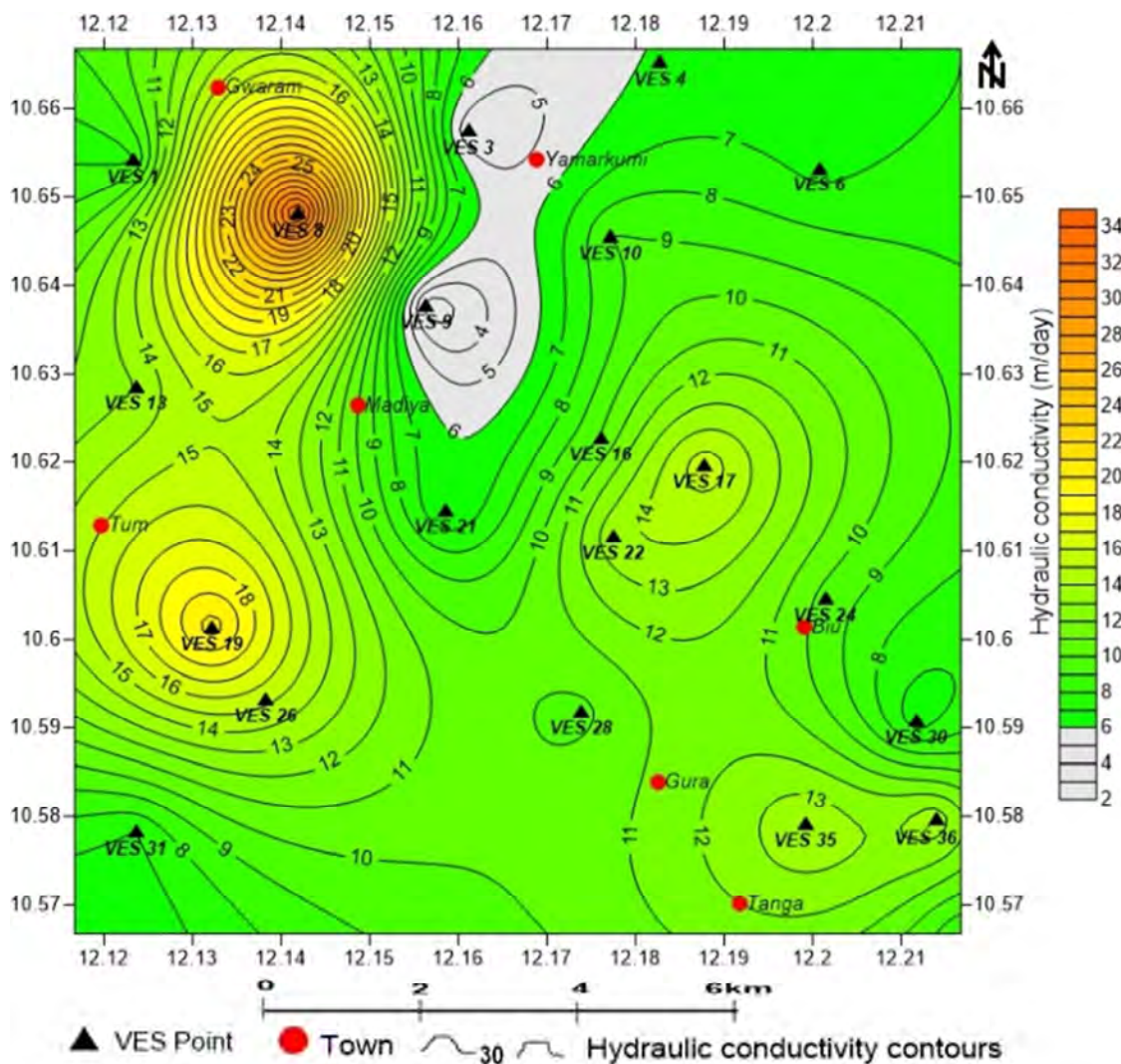


Figure 6. Hydraulic conductivity contour map (contour interval 1 m/day).

For characterization of rocks as a water conducting media, transmissivity is a major property. Transmissivity values obtained from VES method for potential aquifers range between 33.19 to 918.54m²/day with average of 251.32m²/day. VES 8 has high transmissivity value which indicating the large amount of groundwater in this zone. Transmissivity value are low in northeast and southwest part of the study area which suggest that the chance of

groundwater is low in this part of the study area. (Figure 7). The study area is characterised by low, moderate and high groundwater flow potential. According to [7], the fractured aquifer in the basement complex areas has low to moderate hydraulic conductivity and transmissivity values, which give rise to low and moderate yields and specific capacities in boreholes tapping these aquifer systems.

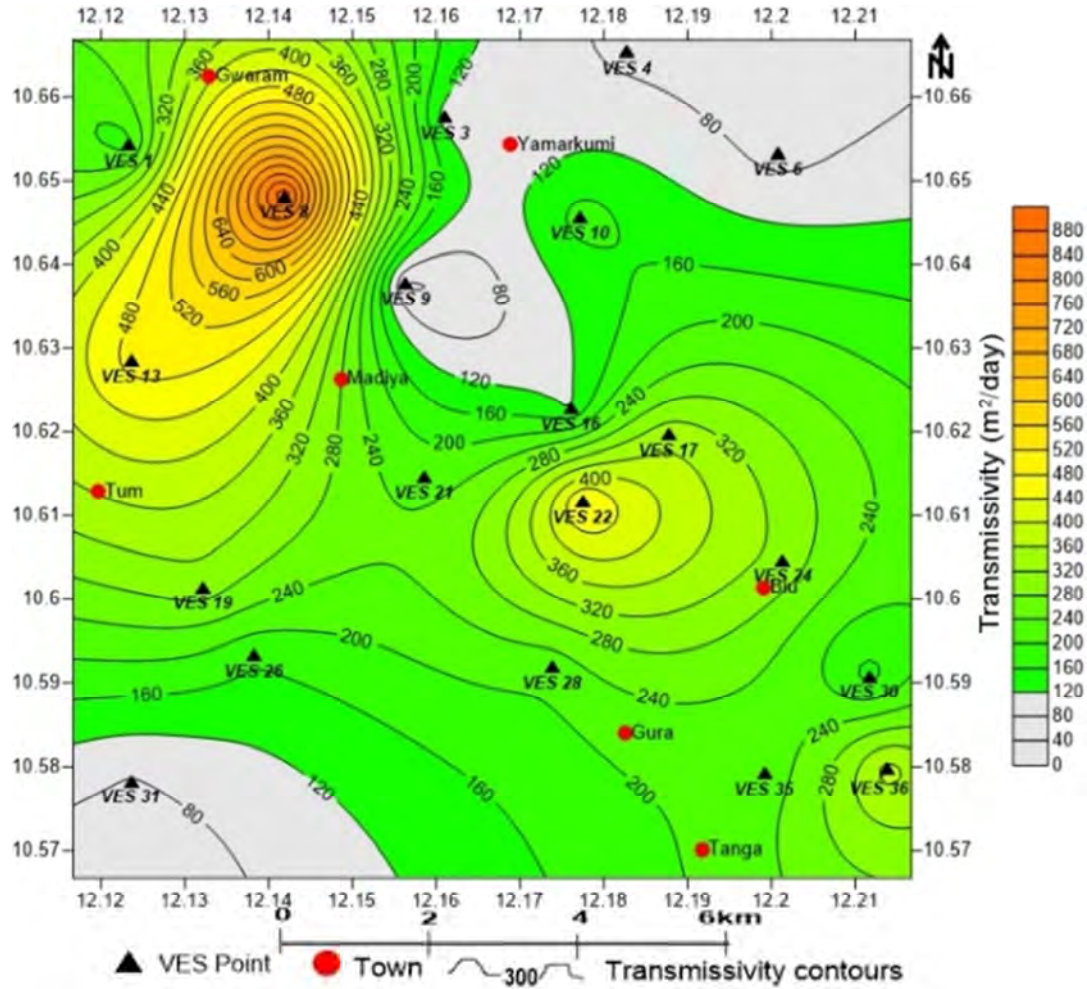


Figure 7. Aquifer transmissivity contour map (contour interval 40 m²/day).

Table 3. Aquifer Parameters Estimated from Geophysical Data.

S/N	VES POINT	COORDINATE	AQUIFER THICKNESS (m)	AQUIFER RESISTIVITY (Ωm)	TRANSVERSE RESISTANCE (ohm-m ²)
1	VES 1	N10° 39' 15" E12° 07' 24"	23.8	65.50	1558.3
2	VES 3	N10° 39' 27" E12° 09' 40"	24.8	132.09	3270.0
3	VES 4	N10° 39' 55" E12° 10' 58"	12.0	84.81	1019.1
4	VES 6	N10° 39' 12" E12° 12' 03"	9.8	77.52	766.05
5	VES 8	N10° 38' 53" E12° 08' 31"	27.3	43.34	1185.3
6	VES 9	N10° 38' 16" E12° 09' 23"	14.1	236.97	3356.7
7	VES 10	N10° 38' 44" E12° 10' 38"	19.6	56.02	1097.1
8	VES 13	N10° 37' 43" E12° 07' 25"	38.1	37.99	1447.5
9	VES 16	N10° 37' 22" E12° 10' 34"	11.7	49.80	584.66
10	VES 17	N10° 37' 11" E12° 11' 16"	22.0	31.07	682.36
11	VES 19	N10° 36' 05" E12° 07' 56"	14.7	23.18	340.95
12	VES 21	N10° 36' 53" E12° 09' 31"	37.21	88.32	3286.4
13	VES 22	N10° 36' 42" E12° 10' 39"	35.3	35.58	1255.7
14	VES 24	N10° 36' 17" E12° 12' 05"	31.9	52.43	1671.6
15	VES 26	N10° 35' 36" E12° 08' 18"	11.0	31.98	353.93
16	VES 28	N10° 35' 31" E12° 10' 26"	22.1	51.74	1144.1
17	VES 30	N10° 35' 27" E12° 12' 42"	23.0	82.15	1887.6
18	VES 31	N10° 34' 42" E12° 07' 25"	11.0	73.78	811.95
19	VES 35	N10° 34' 45" E12° 11' 57"	15.5	35.15	543.49
20	VES 36	N10° 34' 47" E12° 12' 50"	27.4	35.80	979.38

Table 3. Continue.

S/N	VES POINT	LONGITUDINAL CONDUCTANCE (Seimens)	K_c (m/day)	T_c (m ² /day)	GROUNDWATER POTENTIAL
1	VES 1	0.3632	7.813	185.94	Moderately potential
2	VES 3	0.1878	4.060	100.71	Moderately potential
3	VES 4	0.1417	6.139	73.67	Moderately potential
4	VES 6	0.1275	6.676	65.42	Moderately potential
5	VES 8	0.6310	33.646	918.54	High Potential
6	VES 9	0.0598	2.354	33.19	Low potential
7	VES 10	0.3496	9.039	177.16	Moderately potential
8	VES 13	1.0032	12.986	494.77	Moderately potential
9	VES 16	0.2357	10.088	118.03	Moderately potential
10	VES 17	0.7069	15.665	344.63	Moderately potential
11	VES 19	0.6347	20.588	302.65	Moderately potential
12	VES 21	0.4213	5.911	219.97	Moderately potential
13	VES 22	0.9918	13.804	487.30	Moderately potential
14	VES 24	0.6081	9.615	306.73	Moderately potential
15	VES 26	0.3450	15.289	167.74	Moderately potential
16	VES 28	0.4274	9.735	215.14	Moderately potential
17	VES 30	0.2797	6.325	145.47	Moderately potential
18	VES 31	0.1492	6.991	76.91	Moderately potential
19	VES 35	0.4399	13.962	216.41	Moderately potential
20	VES 36	0.7643	13.726	376.08	Moderately potential

K_c = Hydraulic conductivity. T_c = Transmissivity.

>500 High potential, 60 – 500 Moderate potential, 6 – 59 Low potential, 0.5 - 5 Very low potential, <0.5 Negligible potential [8].

The high groundwater flow potential is favourable for sustainable groundwater development. Transmissivity values are suitable for sustainable groundwater development and zones with high yield have been determined for future development and for choosing the drilling sites. A good

correlation between hydraulic conductivity and transmissivity given the correlation coefficient of $R^2 = 0.86$. This signifies that hydraulic conductivity is directly proportional to transmissivity (Figure 8).

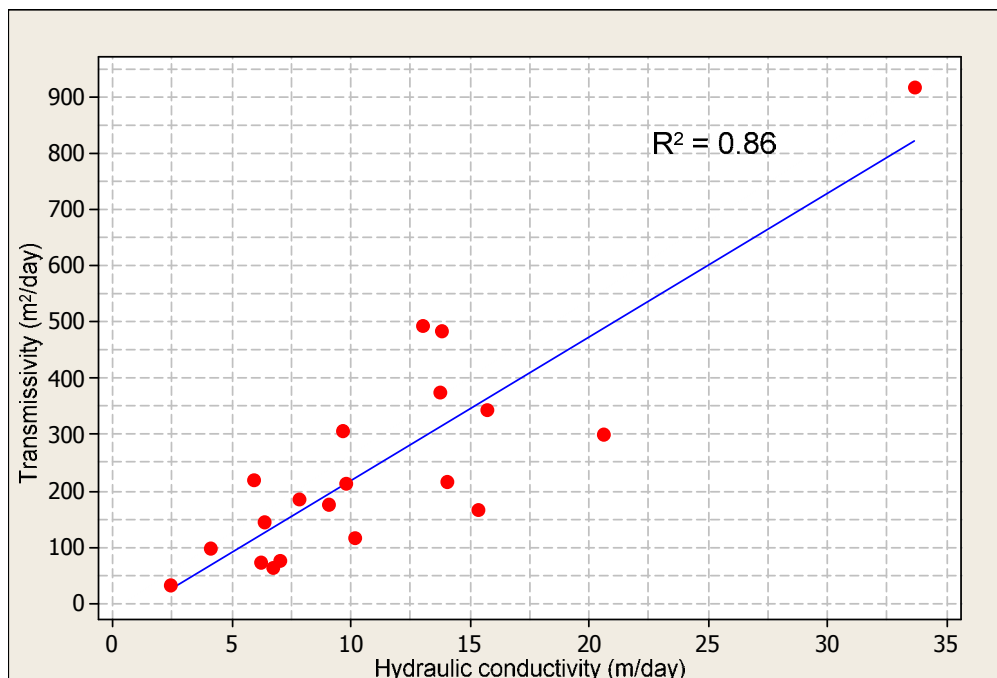


Figure 8. Correlation between transmissivity and hydraulic conductivity.

5. Conclusions

The geophysical methods used in this study have greatly assisted in evaluating groundwater potential of Biu and its environs. Groundwater potential aquifers

producing zones have been delineated through investigation conducted by the geo-electrical survey. Weathered and fractured horizons have been identified in the study area underlying VES stations, and all of these constitute the aquifer zones. Results obtained from the

area showed three to four geoelectrical layers, which has been interpreted as: top soil, fracture/weather basement and fresh basement. The electrical resistivity data therefore gives reasonably accurate results among other methods that can be used to understand the subsurface layers and basement configuration in groundwater prospecting. Viable point for sitting boreholes with appreciable thickness of highly weathered/fractured basement (aquiferous zone) were identify.

Based on the results from the Dar-Zarrouk parameters calculated, the potential groundwater zones in the study area have a moderate aquifer protection capacity. VES 8 has high transmissivity value which indicating the large amount of groundwater in this zone. Transmissivity value are low in northeast and southwest part of the study area which suggest that the chance of groundwater is low in this part of the study area. We hereby conclude that the data presented here are representative and can be of significant value as a guide to groundwater resource development in the study area. This study should therefore serve as useful guide for future groundwater development and citing of productive boreholes in the area.

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