# HYDRO-GEOPHYSICAL INVESTIGATION OF GROUNDWATER RESOURCES WITHIN ABAKALIKI, LOWER BENUE TROUGH, NIGERIA

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***ABSTRACT***

*Hydro-geophysical investigation of groundwater resources within Abakaliki, lower Benue Trough was evaluated with the view of determining the groundwater potentials and the aquifer variation in the area. Eight (8) vertical electrical soundings (VES) were carried out using ABEM 4000 SAS Terrameter. Two (2) VES were conducted around area that has existing borehole to enable us check the efficacy of the method. VES data was analyzed and processed using the computer iteration techniques using 1D interpex software. The modeled interpretation from the analysis shows five to six geo-electric layers. The shape of the geo-electric curves in a particular location of the surveyed area depicts characteristics of the subsurface geologic layers. The fractured shale serves as the geologic material that can contain and discharge water. Result reveals that the depth to water table in the study area varies between 11m and 21m and the aquifer thickness is highest in the eastern part of the surveyed area with a thickness value of 7.6meter. The depth to watertable is deepest around staff quarter axis of Onu Ebonyi. Results also reveal a little variation in hydraulic conductivity which ranged between 0.03m/day and 0.19m/day. The wide range of variation in the transmissivity values of the study area could be attributed to the difference to the depth to the fractured shale in the study area and aquifer systems. This area has transmissivity values ranging from 0.0311m2/day to 1.056 m2/day. The result correlates well with the borehole history from the study area.*

**Keywords**: Hydro-geophysics, Aquifer parameters, Correlation, Fractured Shale, Geo-electric Models

## 1.0 Introduction

Abakaliki area of Ebonyi state has witnessed an increase in infrastructural growth and increase in human population. However, a number of failed boreholes have also been recorded in the area thereby; the quest for potable groundwater for human and agriculture consumption has grown immensely over the years. Therefore the evaluation of groundwater recourses from geophysical parameters and boreholes within the study area is necessary so as to determine the domestic and agricultural usability of water. Groundwater quality is as important as groundwater (Igbokwe et al., 2011). Substantial efforts are required in some area to site. In order to achieve this, the knowledge about the geology and stratigraphy of the survey area is very important, as well as to apply the basic geophysical technique(s). Although some boreholes have been drilled without prior knowledge of the subsurface geology in the study area and this has led to many failed borehole. However, because of some many failed boreholes, researchers attention is now drawn to proper geophysical survey to reduce the risk of well failure (Adetola, and Igbedi, 2000). Marvelous breakthroughs have been documented in the use resistivity method in the exploration of groundwater (Selemo et al., 1995). Also, notable authors such as Keller and Frischknecht, 1966, Onwuemesi and Olaniyan, 1996; Anizoba et al., 2015 has proven the efficacy of the method.

Vertical Electrical Sounding (VES) technique is normally used to measure vertical variations in resistivity of rock with respect to depth. Several researcher have efficaciously used the resistivity method in groundwater study (Nfor et al., 2007, Alile et al.,2008, Anakwuba et al., (2014), Oseji and Ujuanbi, 2009; Akpoborie et al., 2011, Ibrahim et al., 2012, Osele et al., 2016). The method has been known to be very appropriate for groundwater survey in mostly a sedimentary environment (Keller and Frischnechk, 1979; Onwuemesi and Olaniyan, 1996; Obasi et al., 2013, Anizoba et al., 2015). Okoro et al., (2010) applied VES techniques to study the groundwater potential of parts of southeastern Nigeria. Correlation of Geoelectric information with borehole information has proven to be highly efficacy in hydro-geophysical studies (Obasi et al., 2013).

Aquifer parameter estimation is very vital in re-evaluating of the aquifer geometry. Aquifer hydraulic parameters are calculated in order to ascertain quantitative information of the groundwater flow system, Resistivity method have been employed to investigate groundwater potential and it has provided information about fluid electrical conductivity, bulk density and fracture conductance. The technique has been proven to be more efficient for hydro-geological investigation in a sedimentary environment (Keller and Frischknecht 1979).

**2.0. Location and Accessibility of the study Area**

The surveyed area lies between longitude 8° 05 - 8° 10E and latitude 6° 15 - 6° 20N and covers an area of about 2km within Abakaliki. The area is can be access by networks of road; whereas the area sample points were accessible through major roads, minor roads, and foot paths while long distance was covered with the aid of motor bikes.

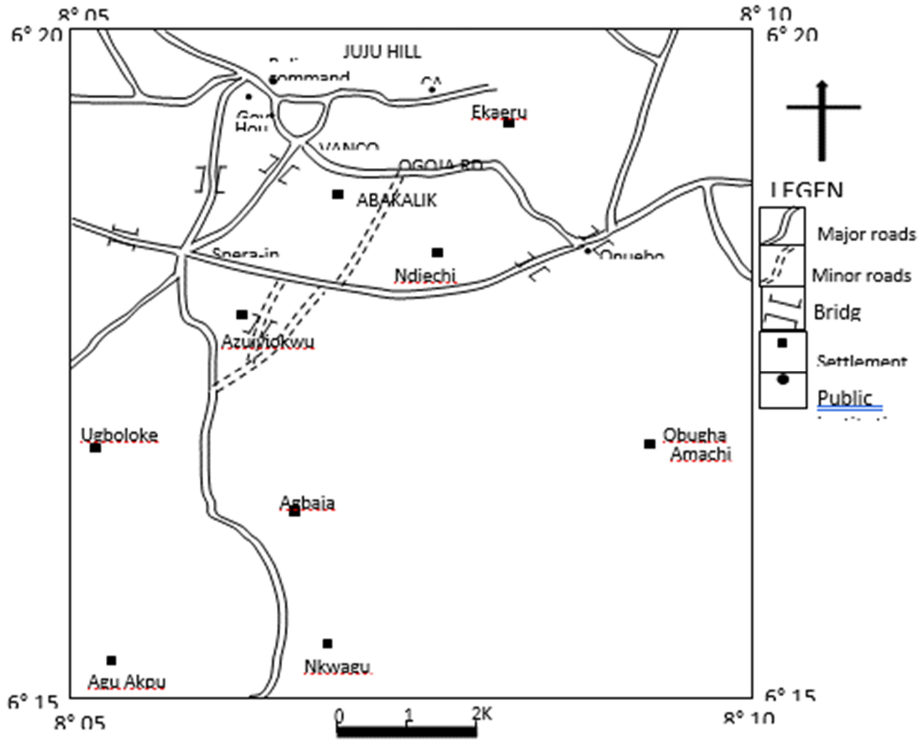


Fig.1: Map of Abakaliki showing the location and accessibility of the area

## 2.1. Geological Framework Of The Study Area

Geologically, the Abakaliki area is underlain by the Abakaliki Shale of the Asu River Group (Umeh et al, 2014). The Asu River Group sediments are mainly shales, and little amounts of siltstone, sandstone and limestone Intercalations (Murat, 1972). The deposition was believed to have started in mid-Albian and the sediment was deposited in the lower Benue Trough in the southeastern Nigeria. Fig 2 x-rays the stratigraphy as well as the geology of the study area existing with the sediment of Asu River Group is occurrence of intrusive and extrusive pyroclastic rocks. Murat, 1972; Okoro et al, 2010; Todd., 1980 Benkhelil et al.,1989 reported that the average thickness of the group is about 2000m and it unconformably underlined by the Precambrian Basement. The shale unit of the Abakaliki Formation has an average thickness of about 500m and it is dark grey in colour,blocky and non-micaceous in most locations. The shale is intensely faulted, folded and fractured by sequence of tectonic events which has reworked the rocks (Egboka, 1986).

The geologic structures from the tectonic activities gave the shale the ability to house groundwater at economic magnitude in certain areas, while its nature as aquiclude still occur were fracturing is not prominent. The area is calcareous (calcite-cemented) and extremely weathered to brownish clay in the larger part of the Abakaliki Formation. Most part of the Abakaliki megalopolis is underlain by aquiclude; except places where secondary aquiferous settings were made possible by syn and post depositional conditions. The syn-depositional condition is the existence of lenses of sandstone or siltstone beds, while the post depositional conditions include; faulting, fracturing, weathering, shearing, and volcanic intrusions. The areas are recharged mostly in the uttermost of rainy season and by surface waters in the area. The main river that drains the research area is mainly the Ebonyi River and its tributaries: (Udene and Iyiokwu Rivers).

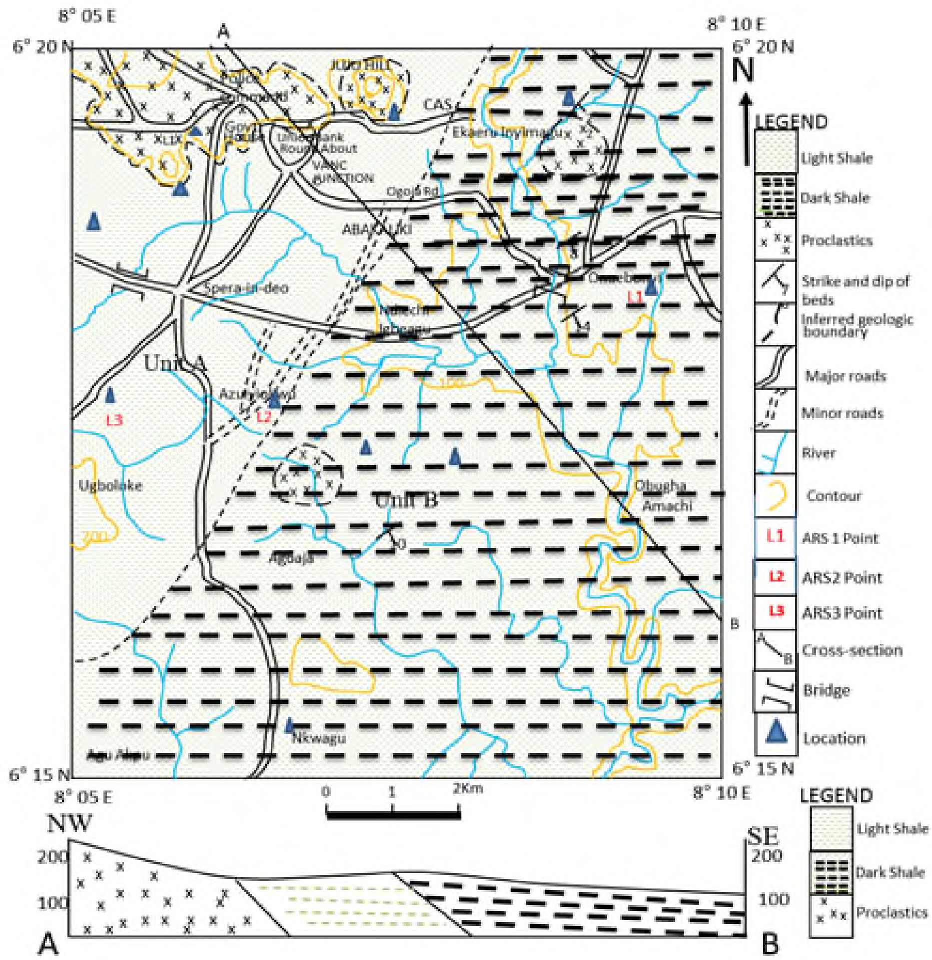

Fig. 2: Geologic map of the study area

## 2.2 LITHOSTRATIGRAPHY OF THE STUDY AREA

The lithostratighy shows the lithofacies relationship and the geologic framework of the Albian – Coniacian sequences in southeastern Nigeria (Fig. 3). Previous researches by Okoro et al (2010), Eburue (1977), Ezeigbo (1998), Ibe and Uzoukwu, 2004 and others along with the revealing excavations by the mining companies operating in Ameka have significantly improved the geologic knowledge of the area. Lower Benue Trough is underlain and it has the following geological sequence.

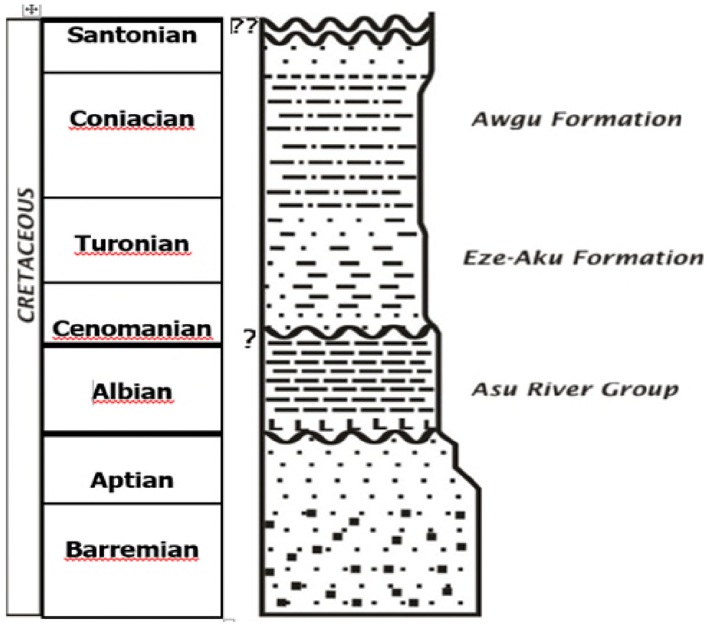


Fig. 3: Stratigraphic Section of the Abakaliki Basin through Late Cretaceous. (Modified from Burke, 1996).

## 3.0. Materials and Methods

The method adopted in this research was in stages and it include; desk studies, reconnaissance survey, geophysical survey, collection of borehole samples for analysis, data interpretation. The desk study was done by studying available literature. A preliminary survey was carried out to identify important geological spots and to know the feasibility of the designed hydro-geophysical techniques and to have a good geologic appraisal of the research area.

### 3.1 Geophysical survey

Eight (8) Vertical Electrical Sounding (VES) was done. Four electrode and ABEM 4000 SAS Tetrameter was used in the survey with Schlumberger configuration. The subsurface resistivity with respect to depth was measured and potential generated recorded by sending an electrical current into the subsurface.

The VES survey was carried out by making the sounding point and increasing the current electrode spacing which consequently implies increase in the depth of probe (Fig.4). The resistance and the electrical current (I) were measured and recorded for each electrode spacing and the apparent resistivity ($\rho_a$) was computed using equation 1.

$$\rho_a = G\frac{\Delta v}{I}(ohm - m) \quad (1)$$

Where, $\rho_a$= Apparent resistivity of the aquiferous layer;
G = the geometric factor; I = current

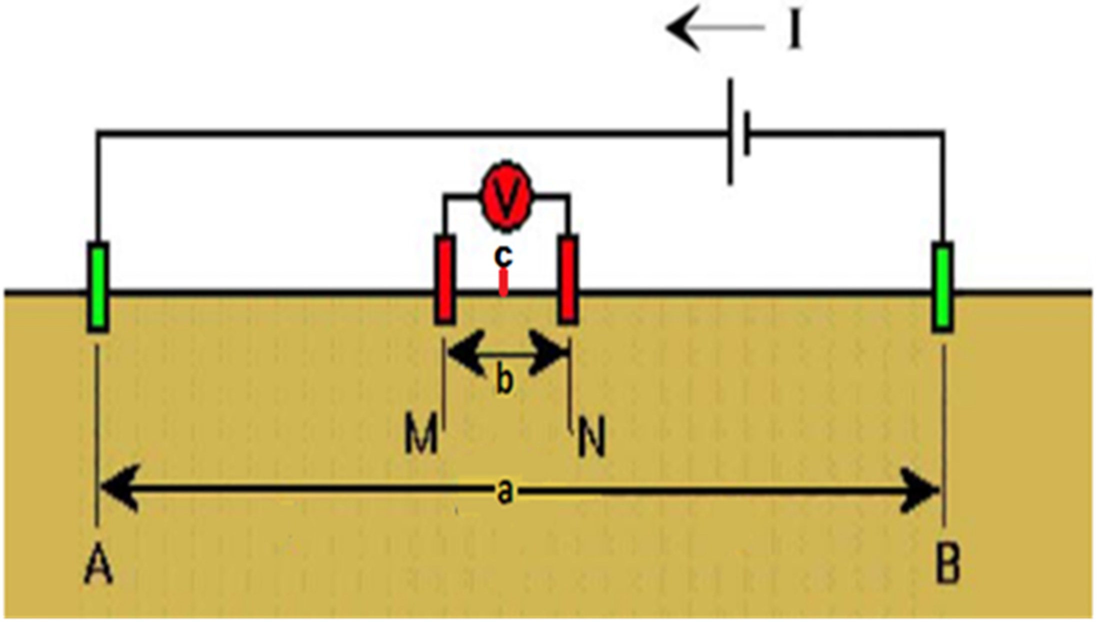

Fig. 4: Electrode arrangement for Schlumberger configuration

In case of Schlumberger electrode configuration 'G' is given by the equation:

$$G = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right) \quad 2$$

Where, a = half current electrode spacing;
b = potential electrode spacing

The setup is repeated by increasing the spacing of the current electrode, the VES were performed unceasingly and apparent resistivities of the subsurface layers were measured. Apparent resistivity ($\rho_a$) against current electrodes spacing plot contains vital information like, aquifer depth, thickness of aquifer, resistivity of each layer etc.

## 4.0 Results and Discussion

In this study, eight (8) VES measurements were done in such a way that the study area should be well covered. VES one, two and four were ruined along a defined profile for correlation analysis and to check the efficacy of this method.

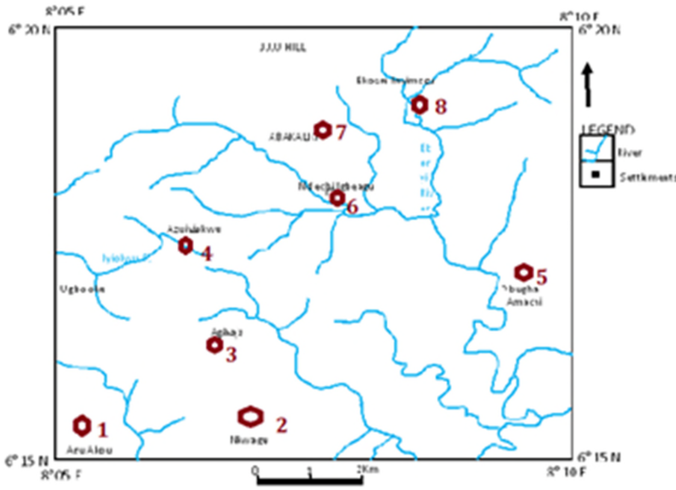


Fig. 5: Map showing VES Locations

### 4.1 QUALITATIVE INTERPRETATION

This involves analyzing the various curve types gotten based on the characteristics of their shapes which is a function of resistivity variation with respect to depth of different layers.

### 4.2 QUANTITATIVE INTERPRETATION

The quantitative interpretation of the depth sounding curves involves generating a computer modeled curve using a computer program. The resulting modeled layers are then interpreted in terms of geology depending on their resistivity value. For instance, shale and clay have a very low resistivity value whereas sand/sandstone has a very high resistivity.

#### 4.2.1 VES 1 Result (RCCG AREA AZU-UGWU 6019' 40.2"N, 08007'33.1"E)

Vertical Electric Sounding VES one (Fig. 6 and Table 1), the subsurface model revealed six geo-electric layers with the resistivity value ranging from 20Ω to 161Ω. The first layer was delineated as the top soil and it has apparent resistivity of 161Ω, it thickness and depth is about of 1m respectively. The apparent resistivity of the second layer is 149Ω and is inferred as shale with minor facture which has a depth of 2m as well as thickness of 1m. The third layer has apparent resistivity of 99Ω, a thickness of 1m and a depth of about 3m, which inferred as fractured shale. The fourth layer has an apparent resistivity of 52Ω, thickness of 3m and a depth of 6m which is inferred as partial fractured shale. The fifth layer has an apparent resistivity of 30Ω, thickness of 24m and a depth of about 30m which is interpreted as saturated fractured shale. The base of the underlying unit is not reach and was interpreted as clay because it has high conductivity.

#### 4.2.2 VES 2 Result (Onu Ebonyi area)

Vertical Electric Sounding VES two (Fig 7and Table 2) was carried out at Onu Ebonyi area, the subsurface model revealed six geo-electric layers with the resistivity value ranging from 30Ω to 680Ω. The first layer inferred as the top soil has an apparent resistivity of 680Ω and thickness of 1m and depth of 1m. The second layer has an apparent resistivity of 99Ω and is inferred as shale which has a depth of 2m as well as thickness of 1m. The third layer has apparent resistivity of 81Ω, a thickness of 1m and a depth of about 3m, which interpreted as siltstone. The fourth layer has an apparent resistivity of 33Ω, thickness of 11m and a depth of 12m which is inferred as fractured shale. The fifth layer has an apparent resistivity of 30Ω, thickness of 5m and a depth of about 18m which is inferred as saturated fractured shale. The sixth layer has an apparent resistivity of 30Ω, thickness of 10m and depth of 27m which is inferred as partially fractured shale which could be the aquifer zone. The base was not reached.

**4.2.3 VES 3 Result**

Vertical Electric Sounding VES three (Fig. 8 and Table.3), the subsurface model revealed six geo-electric layers with the resistivity value ranging from 5Ω to 102Ω. The first layer interpreted as the top lateritic soil has an apparent resistivity of 102Ω and thickness of 1m and depth of 1m. The second layer has an apparent resistivity of 60Ω and is inferred as shale which has a depth of 2m as well as thickness of 1m. The third layer has apparent resistivity of 20Ω, a thickness of 1m and a depth of about 3m, which inferred as siltstone. The fourth layer has an apparent resistivity of 10Ω, thickness of 8m and a depth of 9m which is delineated as fractured shale. The fifth layer has an apparent resistivity of 9Ω, thickness of 9m and a depth of about 12m which is inferred as partially fractured shale. Lastly the sixth layer has an apparent resistivity of 5Ω, thickness of 10m and depth of 17m which is inferred as saturated fractured shale which could be the aquifer zone.

**4.2.4 VES 8 Result**

Vertical Electric Sounding VES eight (Fig.9 and Table 4) model revealed six geo-electric layers with the resistivity value ranging from 20Ω to 679Ω. The first layer inferred as the top lateritic soil has an apparent resistivity of 679Ω and thickness of 2m and depth of 1m. The second layer has an apparent resistivity of 186Ω and is inferred as dry shale which has a depth of 3m as well as thickness of 2m. The third layer has apparent resistivity of 101Ω, a thickness of 3m and a depth of about 4m, which inferred as mudstone. The fourth layer has an apparent resistivity of 60Ω, thickness of 4m and a depth of 10m which is inferred as partially fractured shale. The fifth layer has an apparent resistivity of 31Ω, thickness of 5m and a depth of about 14m which is inferred as saturated fractured shale. Lastly the sixth layer has an apparent resistivity of 20Ω, thickness of 7m and depth of 16m which is inferred as clay whose was not reached.

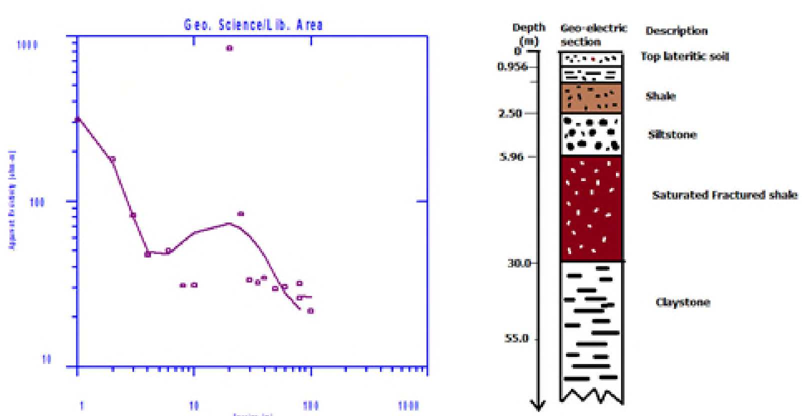

Fig.6: 1D inversion of apparent resistivity data of VES curve and (VES 1) and Geo-electric section model around RCCG Area Azu-Ugwu

Table. 1: Resistivity model of VES One

| RCCG Area Azu-Ugwu VES 1 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a(\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 161.437 | 0.953 | 0.956 | Top lateritic soil |
| 2 | 149.442 | 0.758 | 1.711 | Shale |
| 3 | 98.656 | 0.801 | 2.512 | Siltstone |
| 4 | 52.104 | 3.424 | 5.960 | Saturated Fractured shale |
| 5 | 30.414 | 24.125 | 30.061 | Claystone |
| 6 | 20.198 | Base not | Reached | Clay |

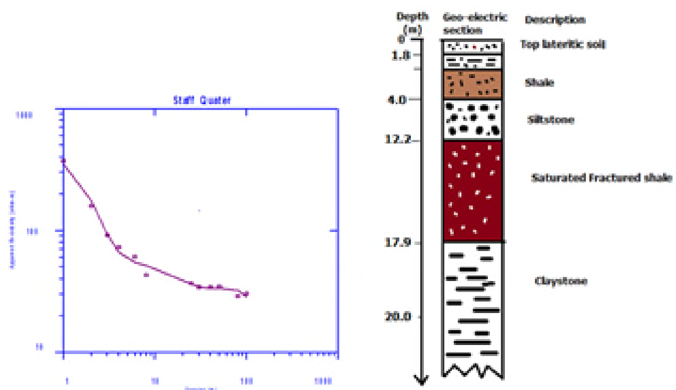


Fig. 7: 1D inversion of apparent resistivity curve and Geo-electric section of VES Two at (Onu-Ebonyi Junction 6018'32.9"N, 08008'34.4"E)

Table. 2: Resistivity model of VES TWO

| Onu-Ebonyi Junction VES 8 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a(\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 680.340 | 0.812 | 0.812 | Top lateritic soil |
| 2 | 98.597 | 0.854 | 1.821 | Shale |
| 3 | 80.854 | 0.883 | 2.829 | siltstone |
| 4 | 32.814 | 11.371 | 12.207 | Partial Fractured shale |
| 5 | 30.115 | 5.393 | 17.594 | Saturated Fractured shale |
| 6 | 30.149 | Base not | Reached | Clay |

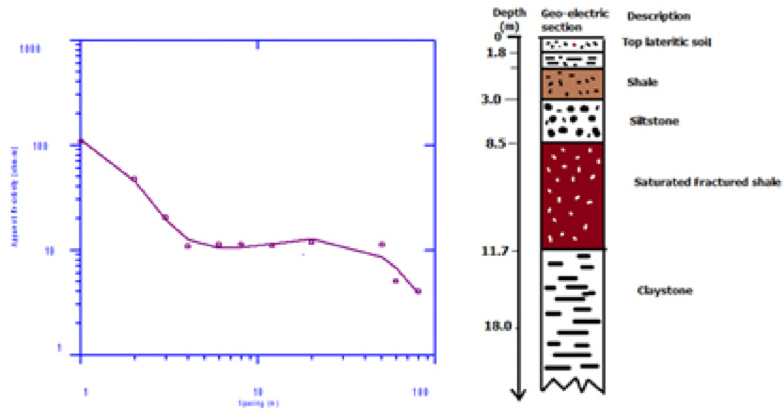


Fig. 8: 1D inversion of apparent resistivity curve and Geo-electric section of VES Three (Obubra Junction Area 60 18’35.0”N, 08009’42.7”N)

Table. 3: Resistivity model of VES Three

| Obubra Junction Area VES 3 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a(\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 102.16 | 0.747 | 0.747 | Top lateritic soil |
| 2 | 60.472 | 0.862 | 1.755 | Shale |
| 3 | 20.087 | 0.894 | 2.764 | siltstone |
| 4 | 10.049 | 7.798 | 8.562 | Partial Fractured shale |
| 5 | 81.690 | 9.180 | 11.742 | Saturated Fractured shale |
| 6 | 5.209 | Base not | Reached | Clay |

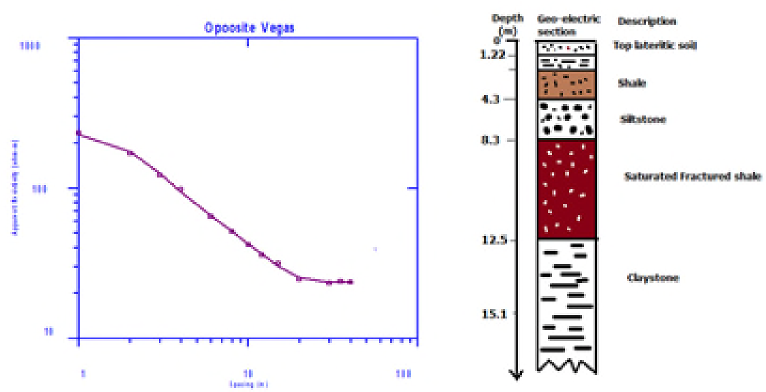


Fig. 9: 1D inversion of apparent resistivity curve and Geo-electric section of VES Four (OCHUDO CITY 6017’36.2”N, 08006’42.8”E)

Table. 4: Resistivity model of VES Four

| OCHUDO CITY VES 4 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a(\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 243.420 | 1.227 | 1.227 | Top lateritic soil |
| 2 | 120.430 | 2.128 | 4.239 | Shale |
| 3 | 80.107 | 3.712 | 6.247 | siltstone |
| 4 | 70.251 | 6.122 | 8.369 | Partial Fractured shale |
| 5 | 60.403 | 8.098 | 12.466 | Saturated Fractured shale |
| 6 | 20.643 | Base not | Reached | Clay |

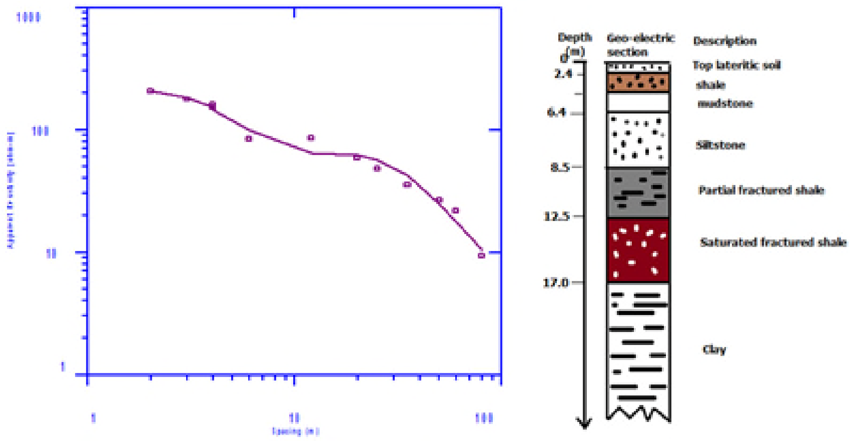


Fig. 10: 1D inversion of apparent resistivity curve and Geo-electric section of VES Five (Nkwagu area 6015’22.3”N, 08006’30.6”E)

Table. 5: Resistivity model of VES Five

| Nkwagu Area VES 5 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a(\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 210.960 | 2.406 | 2.406 | Top lateritic soil |
| 2 | 111.028 | 1.152 | 4.421 | Shale |
| 3 | 77.444 | 2.859 | 6.429 | siltstone |
| 4 | 46.827 | 4.122 | 7.552 | Partial Fractured shale |
| 5 | 35.638 | 4.088 | 8.089 | Saturated Fractured shale |
| 6 | 9.651 | Base not | Reached | Clay |

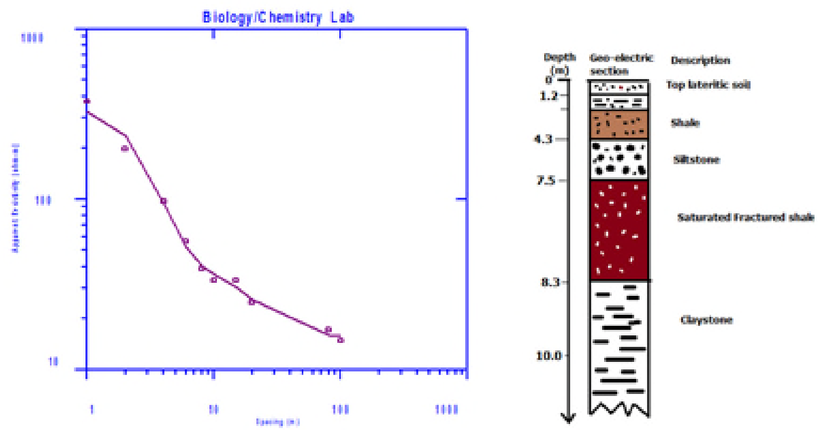


Fig. 11: 1D inversion of apparent resistivity curve and Geo-electric section of VES Six (Nkaliki area 6018’08.3”N, 08005’53.7”E)

Table. 6: Resistivity model of VES Six

| Nkaliki area VES 6 | | | | |
|---|---|---|---|---|
| **Layer** | $\rho_a(\Omega m)$ | **Thickness(m)** | **Depth(m)** | **Remarks** |
| 1 | 348.620 | 1.282 | 1.282 | Top lateritic soil |
| 2 | 100.430 | 2.193 | 2.301 | Shale |
| 3 | 60.257 | 4.128 | 4.314 | siltstone |
| 4 | 40.017 | 6.184 | 7.497 | Partial Fractured shale |
| 5 | 42.409 | 6.858 | 8.335 | Saturated Fractured shale |
| 6 | 11.869 | Base not | Reached | Clay |

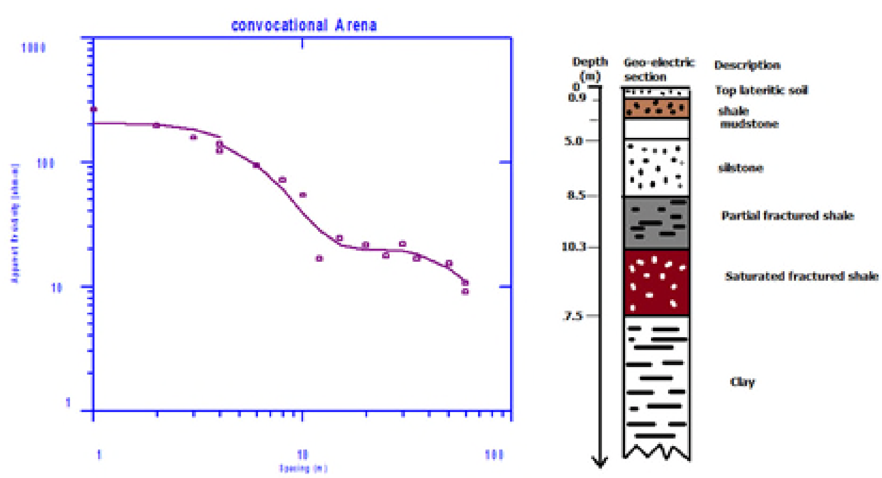


Fig. 12: 1D inversion of apparent resistivity curve and Geo-electric section of VES Three 6019’06.6”N, 08005’45.4”E

Table: 7 Resistivity model of VES Seven

| 6°19'06.6"N, 08°05'45.4"E VES 7 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a (\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 156.650 | 2.880 | 0.880 | Top lateritic soil |
| 2 | 108.040 | 0.509 | 3.931 | Shale |
| 3 | 95.470 | 0.796 | 4.961 | Siltstone |
| 4 | 78.930 | 0.542 | 8.403 | Partial Fractured shale |
| 5 | 67.254 | 2.089 | 10.290 | Saturated Fractured shale |
| 6 | 50.300 | Base not | Reached | Clay |

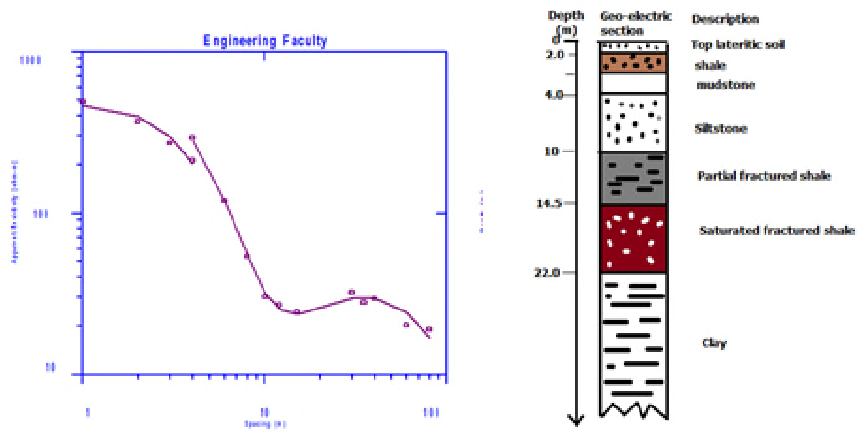


Fig. 13: 1D inversion of apparent resistivity curve and Geo-electric section of VES Eight (Nsugbe Street 6019'43.1"N, 08006'44.6"E)

Table 8: Resistivity model of VES Eight

| Nsugbe Street VES 8 | | | | |
|---|---|---|---|---|
| Layer | $\rho_a (\Omega m)$ | Thickness(m) | Depth(m) | Remarks |
| 1 | 679.070 | 1.919 | 1.919 | Top lateritic soil |
| 2 | 187.039 | 2.104 | 3.023 | Shale |
| 3 | 100.927 | 3.430 | 4.066 | Siltstone |
| 4 | 60.186 | 4.641 | 9.701 | Partial Fractured shale |
| 5 | 30.535 | 5.769 | 14.48 | Saturated Fractured shale |
| 6 | 20.192 | Base not | Reached | Clay |

### 4.3. COMPARISON OF VES 4, 6 and 5 along a horizontal area

The relationship of interpreted geo-electric section at VES 4, 6 and 5 (Fig.14) showed that the top layer thicknesses in the three geo-electric sections, along the profile are 0.956, 1.217 and 1.919 meters respectively. The underlying unit is delineated as shale and this occurs in the three geo-electric section, although there are variations in there depths and thickness. Furthermore, the saturated fractured zone shows varying thickness and depths. The depth to the saturated fractured shale in VES four is 5.96meter with thickness of 3.424meter while the depth to the saturated fractured shale in VES 6 is 29.81meter and thickness of 23,625meter. That of VES five has thickness of 4.779meter and at a depth of 14.48meter. The depth of the saturated fractured depth along the profile is not a horizontal level, it is undulating. The depth to the base was not reached in the VES but they are interpreted as clay because of their high conductivity value.

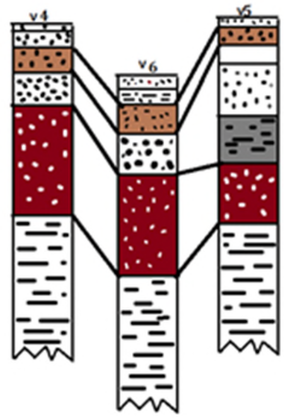

Fig. 14: COMPARISON VES 4, VES 6 AND VES 5

**4.3.1 COMPARISON OF BOREHOLE AT OCHUDO CITY WITH VES 4**

The correlation of lithologic section from the borehole located near a sounding station at Ochudo City and its interpreted geo-electric units at VES 4 (Fig.15) showed that the overburden thickness in the lithologic section is 3.2 meters while in geo-electric section, it is 2.0 meters. In the underlining unit, the geo-electric section reveals destruction and integration of some lithologic units from the borehole; this is because a geologic section is more detail than a Geoelectric section. Thus Lithologic unit with differences in resistivity values will give rise to several geo-electric units. Also, different Lithologic layer with similar resistivities would be fused as one geo-electric layer. Hence, there is little variation in the depth from the geo-electric unit with value of depth being 5.0 meters and 7.0 meters in geologic section. There is a high correlation with the borehole section at Ochudo City (Fig. 15) and this supports the depth to aquifer in the study area. The aquiferous layer is underlain by shale unit with apparent resistivity of 1,125Ω.

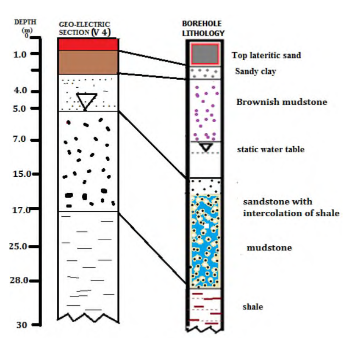


Fig. 15: Comparison of Borehole at Ochudo City with VES within the area (VES 4)

**4.4 CALCULATION OF AQUIFER HYDRAULIC PARAMETERS FROM SURFACE GEOPHYISCAL METHOD**

In order to obtain quantitative and qualitative information in ground water flow and its potentials in the area of study an alternative cheap and quick approaches have been applied in this work by utilizing non-invasive surface geophysical method.

Geophysicists have realized that a relationship exists between hydraulic parameters and electrical properties of aquifers, as both properties are related to the pore space structure and heterogeneity of subsurface layers (Keller and Frischknecht, 1966, Mandel and Shiftan; 1991. Hence, it is a standard practice to estimate aquifer hydraulic properties from established empirical and semi-empirical relationship (Fig. 16).

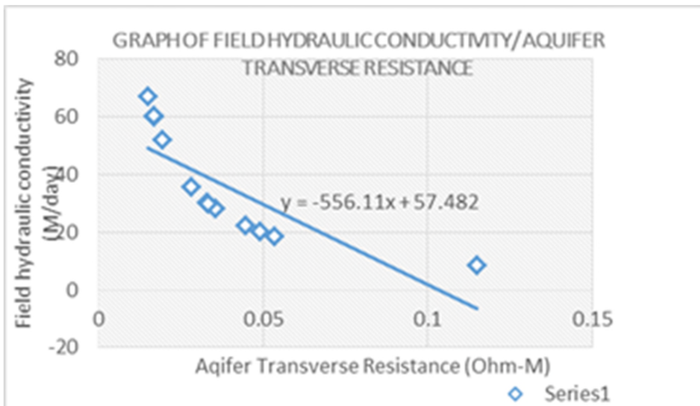


Fig.16: The Relation between Hydraulic (K) Conductivity and Resistance(R)

The above relationship gave rise to equation 4.1 given thus;

$$K = 556.11x + 57.482 \quad 3$$

Darcy equation for discharging fluid (Q) is given by;

$$Q = KIA \quad 4$$

The flow of electric current (J) is governed Ohm's law as stated;

$$J = \sigma E \quad 5$$

Niwas and Singhal 1981 solve the combine (3) and (4) and arrived at,

$$T = K\sigma R = \frac{KS}{\sigma} = Kh \quad 6$$

K is hydraulic conductivity, I is hydraulic gradient, A is cross sectional area, J is current density, E is electric filed intensity, $\sigma$ is electrical conductivity, T is aquifer transmissivity, h is Aquifer thickness, R is aquifer transverse, S is longitudinal conductance.

S and R are referred to as the Dar- Zarrouk parameters and are designated by

$$\boldsymbol{S = h/\rho_a} \quad 7$$

And

$$\boldsymbol{R = h\rho_a} \quad 8$$

Where, h and $\rho_a$ are thickness and apparent resistivities of various geo-electric layers respectively.

TABLE 9: AQUIFER PARAMETER CALCULATION

| VES NO | TOWN | ELEVATION (m) | LATITUDE | LONG | THICKNESS (m) | Aqiufer depth (m) | Aqifer resistance | Hydraulic conductivity | Transmissivity (L/s) | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **RCCG Area Azu-Uguu** | 56 | 8.2138 | 6.4276 | 3.424 | 5.96 | 52.104 | 0.019192384 | 0.065714724 | 0.114387 |
| 2 | **Onu-Ebonyi Junction** | 54 | 8.227 | 6.338 | 5.39 | 17.594 | 30.115 | 0.033206043 | 0.178980574 | 0.584227 |
| 3 | **Obubra Junction** | 59 | 8.26 | 6.3972 | 9.18 | 11.742 | 81.69 | 0.0122414 | 0.112376056 | 0.143739 |
| 4 | **OCHUDO CITY** | 48 | 8.216 | 6.383 | 8.098 | 12.468 | 60.403 | 0.016555469 | 0.134066189 | 0.206414 |
| 5 | **Nkwagu** | 50 | 8.183 | 6.31 | 4.088 | 8.089 | 35.638 | 0.028059936 | 0.114709018 | 0.226977 |
| 6 | **Nkaliki** | 53 | 8.2305 | 6.3222 | 6.855 | 8.355 | 42.409 | 0.0235799 | 0.161640218 | 0.19701 |
| 7 | **Army base** | 61 | 8.2083 | 6.3327 | 2.089 | 10.29 | 67.254 | 0.014869004 | 0.03106135 | 0.153002 |
| 8 | **Nsugbe** | 63 | 8.2 | 6.436 | 5.769 | 14.48 | 30.535 | 0.032749304 | 0.188930735 | 0.47421 |

### 4.4.1 Aquifer Parameter maps

**(A) Watertable map with respect to mean sea level (MSL)**

Depth to the water table map produced suggests that the depth to watertable with respect to MSL is higher in eastern part of the studied area, (Fig. 17 and Fig 18). Whereas western part of the studied areas the depth to water table with respect to MSL is shallower.

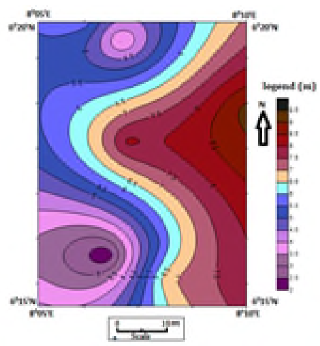


Fig. 17: Aquifer Thickness map of the area

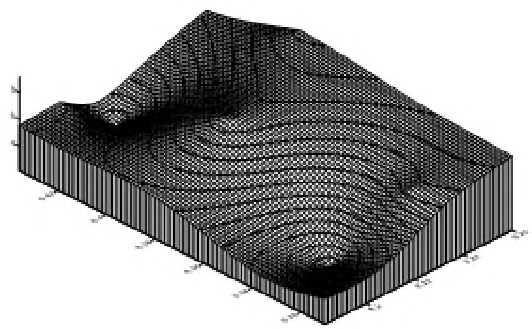

Fig. 18: 3D map of the Aquifer thickness map

**(B)The Aquifer hydraulic characteristics maps**

From the hydraulic conductivity and transmissivity maps (Fig 19 and 20), communities around Onu Ebonyi and Nkaliki area have high values of transmisivity as an indication of high hydraulic conductivity and thick aquiferous unit. Fig 19 and fig. 20 show that around Nkwage Nsuge, the aquifer transmissivity values are high (1,484m2 /day-1,132m2) where as they are low (369.68m2/day-667.9m2/day) around Obubra Junction

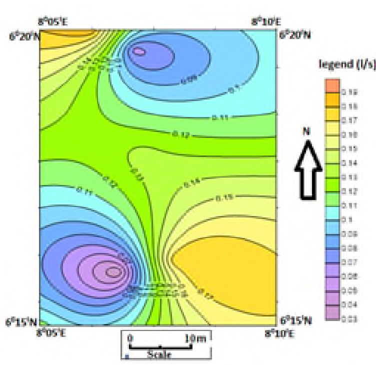


Fig. 19: Aquifer Transmissivity map of the area

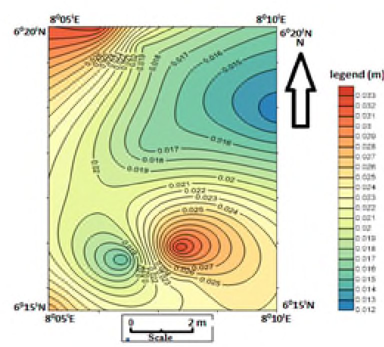


Fig. 20: Hydraulic conductivity map of the area

**Conclusion and Recommendation**

The research evaluated the groundwater potential, hydro-geophysical and groundwater hydraulic parameter of some parts of the Abakaliki Formation lower Benue Tough. The result correlates well with the borehole history from the study area. The modeled interpretation from computer iteration showed the presence of five to six geo-electric layers. The lithology cut across reveals similarity in the geology of the VESs sounding. The shape of the geo-electric curves in a particular location of the study area depicts characteristics of the subsurface geologic layers. The unit resistivity is dependent on fracture zone, present of moisture in the pore spaces and the rock matrix.

The water table depth in the survey area varies between 11m and 21m and the aquifer thickness was interpreted to be highest in the eastern part of the survey area with a thickness value of 7.6meter. The depth to Watertable is deepest around staff quarts axis of Onu Ebonyi.

Similarly, the survey areas have a little variation in hydraulic conductivity which ranged between 0.03m/day and 0.19m/day. The wide range of variation in the transmissivity values of the surveyed area could be accredited to the difference to the depth to the fractured shale in the study area and aquifer systems. The research area has transmissivity values ranging between 0.0311m2/day and 1.056 m2/day. These high values of hydraulic conductivity and transmissivity of the aquifer system is an indication high prospectivity for drilling of productive boreholes and groundwater development. The estimated hydraulic characteristics of the aquifer and computed Da-Zarrouk parameters in the surveyed area are in conformity with the studies done by previous researchers (Nfor, et al., 2007)

The aquiferous zone of the surveyed area is mainly fractured basement and the depth is not entirely a horizontal level, it is undulating as such an integrated geophysical method is recommended for a better understanding.

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