



# Hydrogeophysical Investigation of Fractured Shale Aquifers in Ikwo and Environs, South-Eastern Nigeria

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## Abstract

Results obtained from the interpretation of vertical electrical sounding (VES) were combined with geological data to determine the groundwater potential of the study area. The dominant lithology in the area is the shales of the Asu River group of Albian age. The tectonic activities that took place in Santonian times resulted in folding, uplift, and intense fracturing of the shales of the study area. The challenge lies on how to map the fracture zones in the shales in order to optimally exploit the groundwater resources in the area. Ten (10) vertical electrical soundings (VESs) with maximum current electrode (AB) spread of 300 m were acquired using the Schlumberger configuration. Four (4) of the soundings were carried out near existing boreholes for comparative purposes between the geological and geoelectric sections. Layer parameters (aquifer thickness, depth to water, transverse resistance, etc.) were obtained after data processing with the IP12 Win™ software. The derived layer parameters were combined with borehole logs and pumping test data from existing boreholes to estimate aquifer hydraulic parameters in other locations without boreholes. Results show that the depth to the fractured shale aquifer ranges from 22.1 to 54.9 m at Ekpelu (VES 9) and Ndufu Alike II (VES 2), respectively, while aquifer thicknesses vary from 19 m at Ndufu Alike I and II (VES 1 and VES 2) to 56.4 m at Amainyima (VES 10). Hydraulic conductivity varies between 0.0047 m/day at Ndufu Alike I (VES 1) and 0.300 m/day at Onyikwa playground (VES 5), while

transmissivity varies between 0.0893 m<sup>2</sup>/day at Ndufu Alike I (VES 1) and 9.780 m<sup>2</sup>/day at Onyikwa Playground (VES 5).

## Keywords

Aquifer parameters • Vertical electrical sounding • Fractures • Groundwater

## 1 Introduction

Shales are defined as non-aquifers on hydrogeology maps and often overlooked as a source of sustainable source of groundwater supply in poor communities not underlain by conventional aquifer materials like sandstones (Struckmier and Margarat 1995). MacDonald and Davies (2000) have shown that approximately 70 million people in Sub-Saharan Africa live in rural communities underlain by shales and mudstones. Many of such communities are located within Ikwo and environs, and the areas have continued to witness a surge in population following the establishment of a Federal University in the area. The entire area is underlain by consolidated shales of the Asu River group. It is a well-known fact that shales are classified as low permeability formations because of little or no interconnectivity between individual pores within the rock matrix. The permeability of the shales can be greatly enhanced when fractured. Fractured shale aquifers can yield significant volumes of water because of their enhanced porosity and permeability. Several workers have used the electrical resistivity method to characterize aquifer types and geometry (Onuoha & Mbazi, 1988; Ekwe et al., 2006; Ekwe & Opara, 2012; Opara et al., 2012). Some more recent works have been done by employing the electrical resistivity to prospect for water in low permeability formations (e.g., shales) and hard rock terrains (Ekwe et al., 2010; Omeje et al., 2015; Loke et al., 2013; Okonkwo & Ezeh, 2013; Okonkwo et al., 2017). MacDonald et al. (2001)

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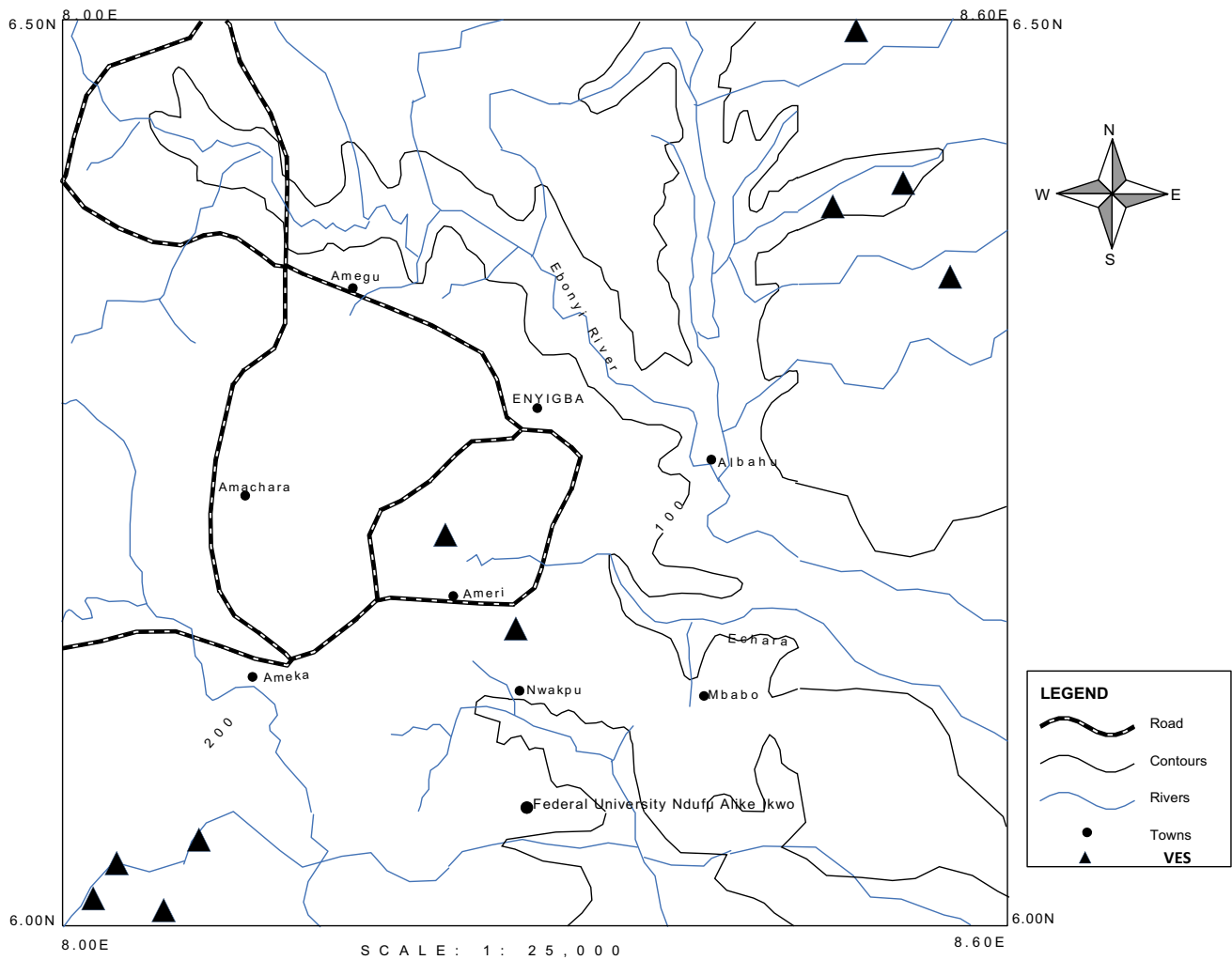
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applied geophysical techniques to locate groundwater in low permeability sedimentary rocks in southeast Nigeria. The present study would involve the integration of geophysics, geology, and geographic information system (GIS) to map and characterize the fractured shale aquifers of Ikwo and environs to guide water resource planners and developers in the area.

## 2 Location of the Study Area

The study area (Fig. 1) falls within Ikwo local government area of Ebonyi state and has an elevation profile of about 100 m above the mean sea level. Some important towns within the study area include Amegu, Nwakpu, Enyigba, and Ndufu Alike. The area is situated within the tropical rain

forest of Nigeria. Two seasons are prominent in the area—dry and rainy seasons. It has a humid tropical climate with high temperature, with a mean daily maximum and minimum annual temperatures of 32.2 and 23 °C, respectively. The annual rainfall rate is about 1820 mm, while mean daily temperature ranges from 30 °C during the rainy season to about 34 °C in the dry season. The annual mean of the relative humidity in the area is 71%, while the rate of evaporation is about 3.4 mm/yr. Soil temperature measurements at depths of 5, 10, 20, 30, 50, and 100 cm gave values of 32, 31, 30, 30.5, 27, and 30 °C, respectively, while the average monthly sunshine hours for the months of February–June 2014 are about 6.6 h (Federal University Ndufu Alike Ikwo Weather Station data, 2014). The study area is drained by the Ebonyi River and its numerous tributaries. The pattern is dendritic.



**Fig. 1** Topographic map of the study area showing VES points, important towns, and drainage pattern

### 3 Geology of the Study Area

The study area lies within the Lower Benue Trough. The Benue Trough is a SW-NE trending elongate structure with a sedimentary fill ranging from over 2000 m in the northern limit to 7000 m in the southern region. The lithologic unit underling the study area is mainly the shales of the Asu River group (Fig. 2) and the Abakaliki shale formation (Reyment, 1965). The shales are fissile, thinly laminated, highly fractured, and weathered. The shales have been classified based on their lithologic characteristics, structures, and stratigraphic positions by Obarezi and Nwosu (2013) into two units with colors ranging from dark to black to grayish brown, reddish, and pinkish.

### 4 Methodology

A detailed literature review was carried out before actual field work and subsequent acquisition of ten (10) vertical soundings (VESs) with the Schlumberger configuration. The method involves the injection of direct current (5 mA) from a 12 V battery source into the ground through a pair of current electrodes and measuring the resulting potentials through another pair of potential electrodes. The geoelectrical data was acquired using ABEM SAS 1000, with a maximum current electrode spacing (AB) of 300 m. Few of the soundings were carried out near existing boreholes for comparative purposes. The data obtained was plotted as a graph of apparent resistivity against half current electrode

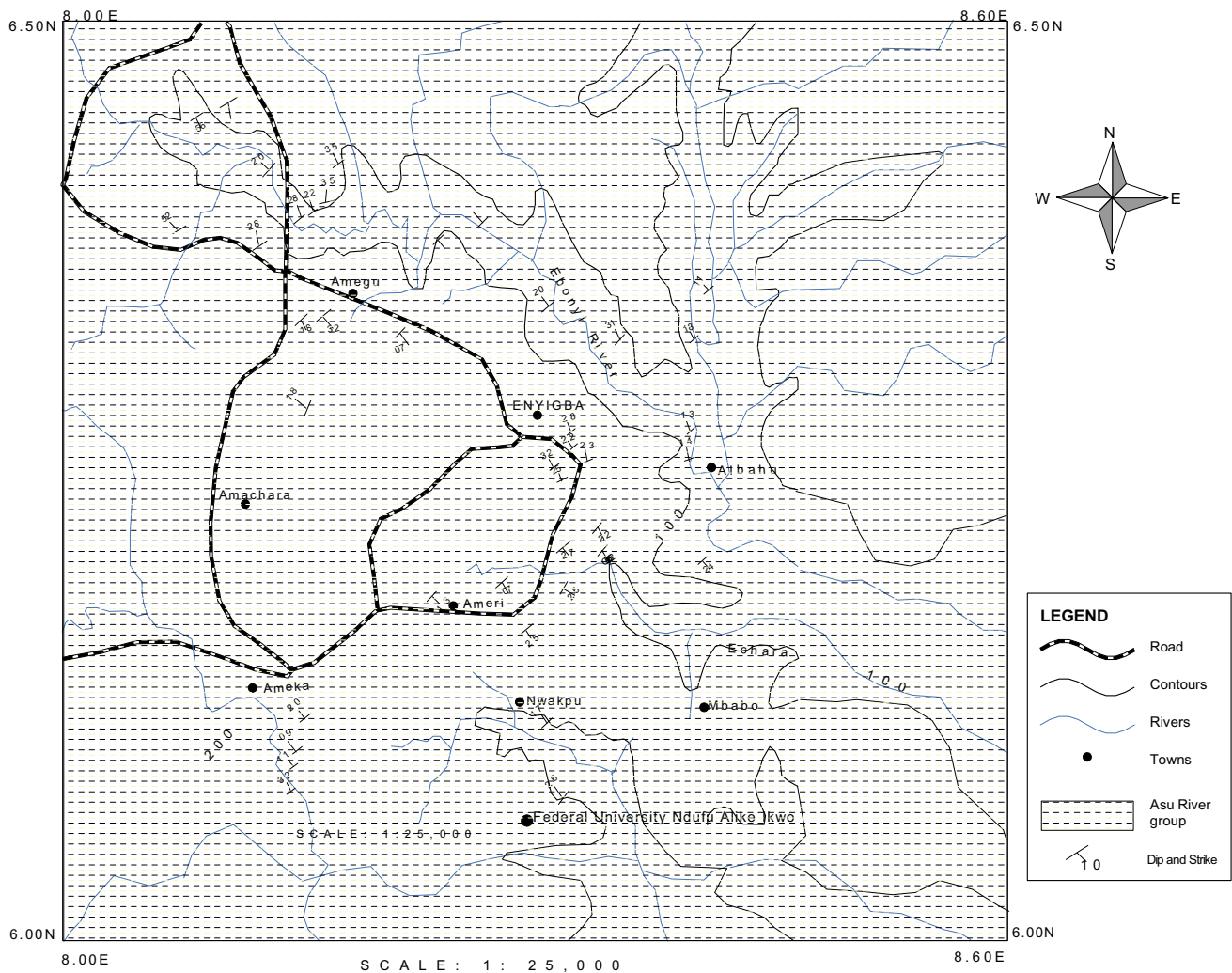


Fig. 2 Geologic map of the study area

spacing and the electrode spacing at which inflection occurs on the graph provides an idea of the depth to the interface. The apparent resistivity ( $\rho_a$ ) for the Schlumberger array is given by Eq. 1.

$$\rho_a = \pi R \left( \frac{a^2}{b} - \frac{b}{4} \right) \quad (\text{Keller \& Frischknecht, 1979; Ekwe et al., 2006}) \quad (1)$$

where  $a$  = half current electrode spacing,  $b$  = potential electrode spacing,  $R$  = resistance, while  $\pi \left( \frac{a^2}{b} - \frac{b}{4} \right)$  is the geometric factor. The geometric factor depends on the electrode configuration in use. The apparent resistivity ( $\rho_a$ ) is usually obtained by multiplying the measured resistance with the geometric factor.

## 5 Determination of Aquifer Hydraulic Parameters from Geoelectrical Data

Previous researchers have shown that in areas of similar geology and water quality, the product of hydraulic conductivity ( $K$ ) and electrical conductivity ( $\sigma$ ) remains fairly constant (Niwas & Singhal, 1981; Onuoha & Mbazi, 1988; Ekwe et al. 2006; Okonkwo & Ezech, 2013). An empirical relation exists between aquifer transmissivity and transverse resistance on the one hand, and aquifer transmissivity and longitudinal conductance on the other hand (Niwas & Singhal, 1981). It is given by:

$$T = K\sigma R = KS/\sigma \quad (2)$$

where  $T$  = aquifer transmissivity,  $h$  = aquifer thickness,  $\rho$  = aquifer resistivity,  $K$  = hydraulic conductivity,  $R = h\rho$  = transverse resistance of the aquifer, and  $S = \frac{h}{\rho}$  = longitudinal conductance.

One of the problems we encountered in the study area was the paucity of pumping test data at all the VES locations. The pumping test data can be used to generate aquifer parameters at known borehole locations, but the cost is usually high. To overcome this challenge, we applied the empirical relation developed by Niwas and Singhal (1981) to estimate various aquifer parameters at all the sounding locations, including areas where no boreholes exist. In these instances, we extracted  $K$  values from pumping tests at sites with boreholes and used those values to estimate  $K$  for other areas without boreholes.

## 6 Results and Interpretation

### 6.1 Comparison of Geoelectrical Section with Lithology Log at Eke Ettem Market Square, Ikwo

The first geoelectric layer (Fig. 3) with an apparent resistivity of 135  $\Omega\text{m}$  correlates well with a moist reddish clayey overburden on the lithology log. The second geoelectric layer has a resistivity of 265  $\Omega\text{m}$  and corresponds to a hard dark grayish shale. The third geoelectric layer has a resistivity of 59.7  $\Omega\text{m}$  and correlates with a semi-hard shale layer on the lithology log. The fourth geoelectric layer with a resistivity of 17.2  $\Omega\text{m}$  correlates with a moist grayish shaley layer on the lithology log. The fifth geoelectric layer with a resistivity of 12.6  $\Omega\text{m}$  correlates with a fractured shale aquifer at a depth of 38.4 m. The aquiferous layer is underlain by a hard shale layer with a resistivity of 797  $\Omega\text{m}$ . The processed curve is shown in Fig. 4.

### 6.2 Comparison of Geoelectrical Section with Lithology Log at Ekpelu

The first geoelectric layer with an apparent resistivity of 733  $\Omega\text{m}$  coincides with the reddish brown lateritic overburden. The second (340  $\Omega\text{m}$ ) and third (32.1  $\Omega\text{m}$ ) geoelectric layers correlates with yellowish and moderately soft shale layers, respectively. The fourth geoelectric layer with an apparent resistivity of 46.9  $\Omega\text{m}$  correlates with the fractured dark shale layer, which serves as the aquifer, while the last geoelectric layer has an apparent resistivity value of 458  $\Omega\text{m}$  and corresponds with the hard grayish shale layer in the lithology log (Fig. 5). The processed curve is shown in Fig. 6.

### 6.3 Comparison of Geoelectrical Section with Lithology Log at Elugu Ettem, Ikwo

The first geoelectric layer has an apparent resistivity of value of 875.9  $\Omega\text{m}$  and correlates with a reddish brown lateritic overburden on the lithologic log. The second and third layers have resistivity values of 136.8 and 48.15  $\Omega\text{m}$ , respectively. These layers correspond to a light grayish hard shale and mottled shale layers on the lithology log. The fractured shale

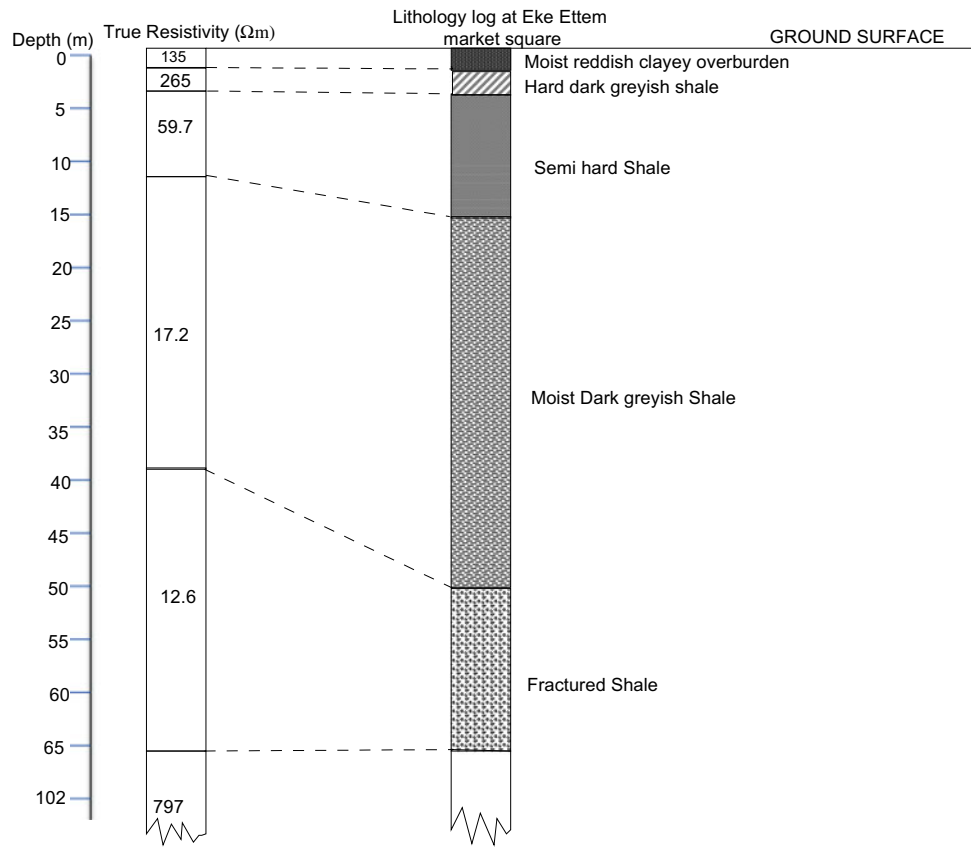


Fig. 3 Comparison of geoelectrical section with lithology log at Eke Ettem market square, Ikwo

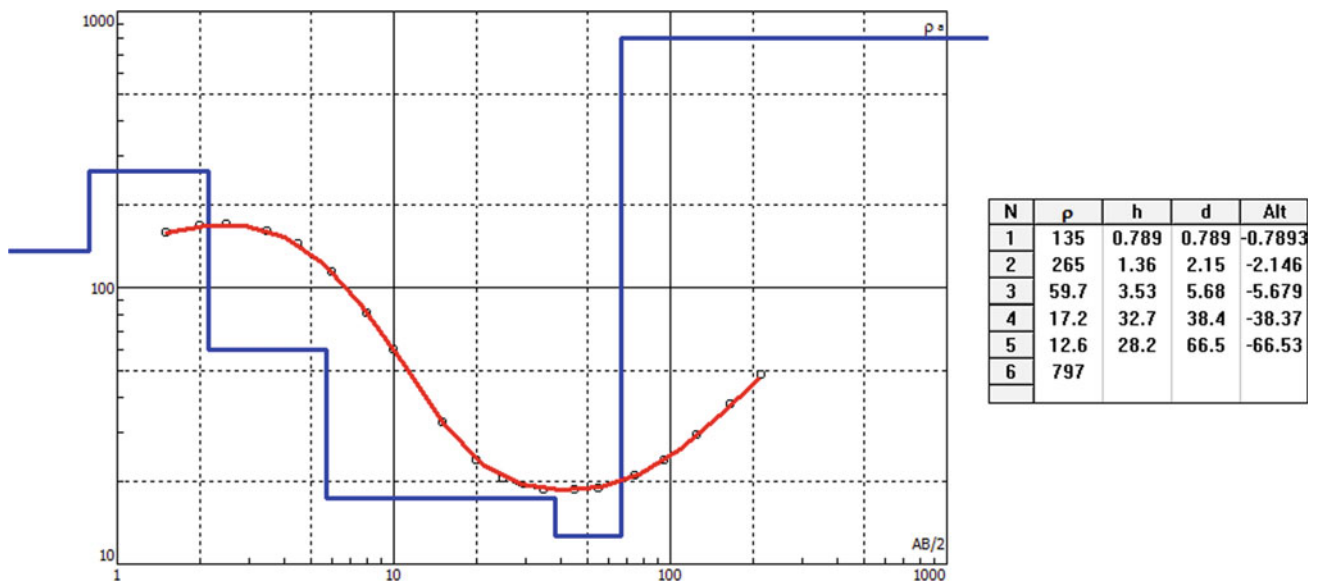


Fig. 4 Processed vertical electrical sounding result at Eke Ettem market square, Ikwo

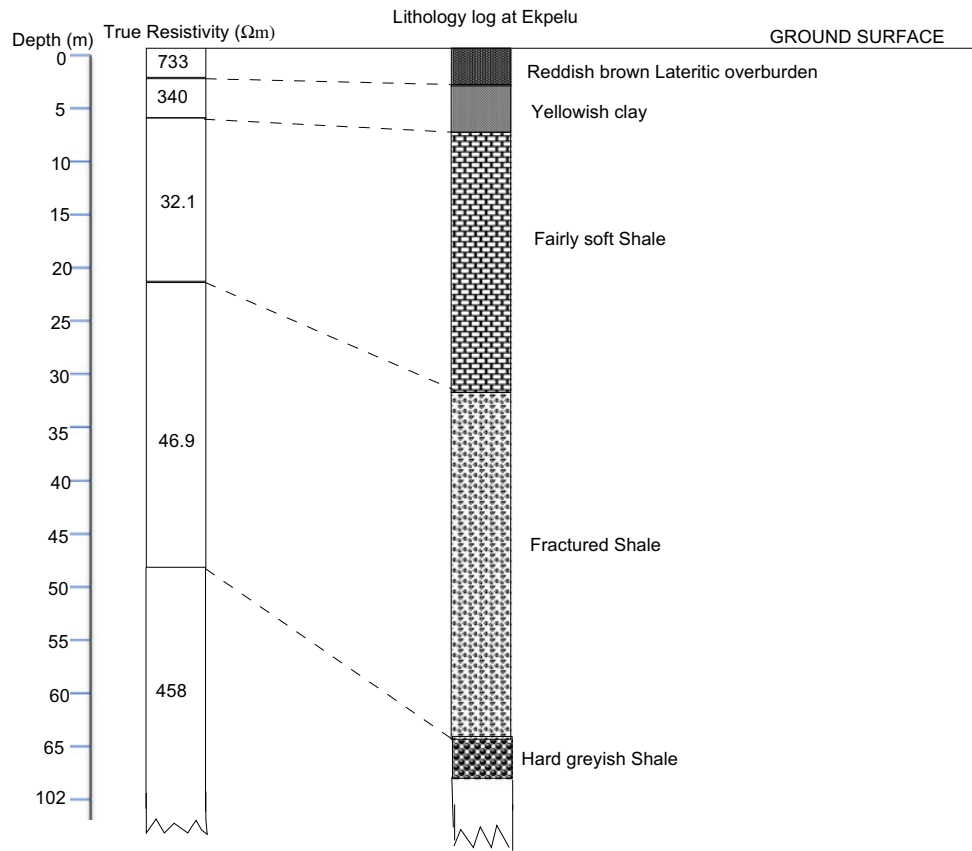


Fig. 5 Comparison of geoelectrical section with lithology log at Ekpelu, Ikwo

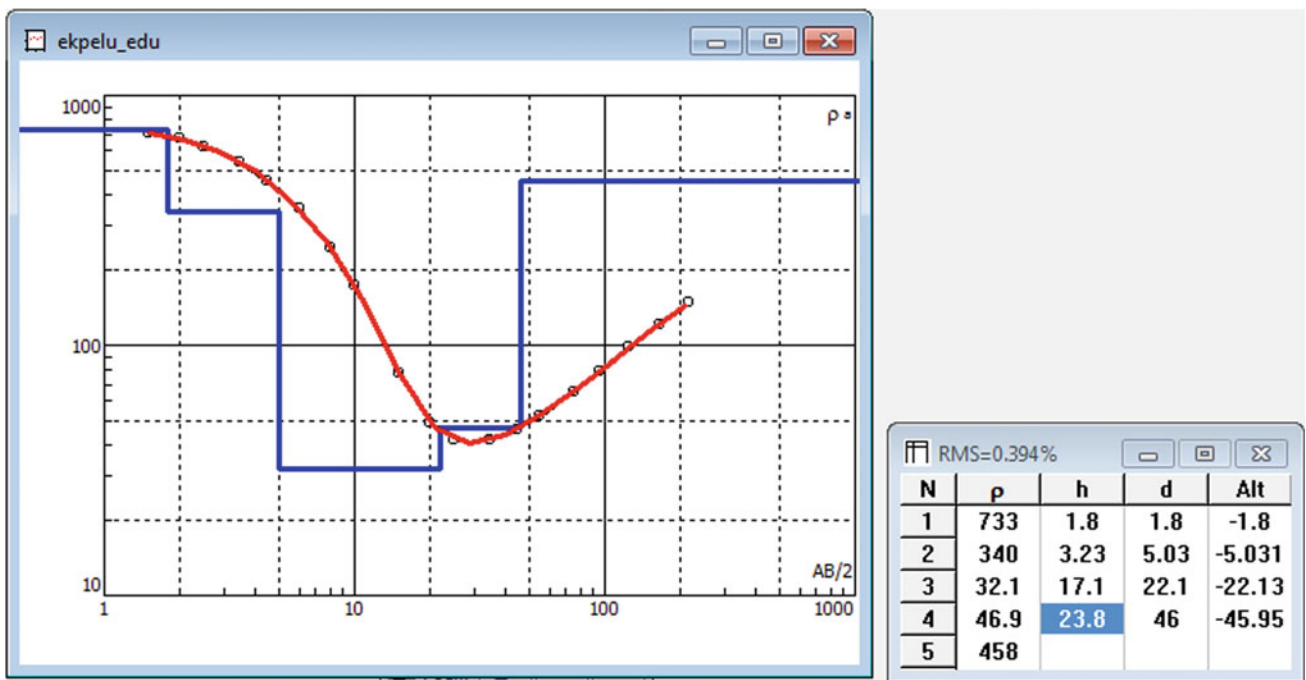


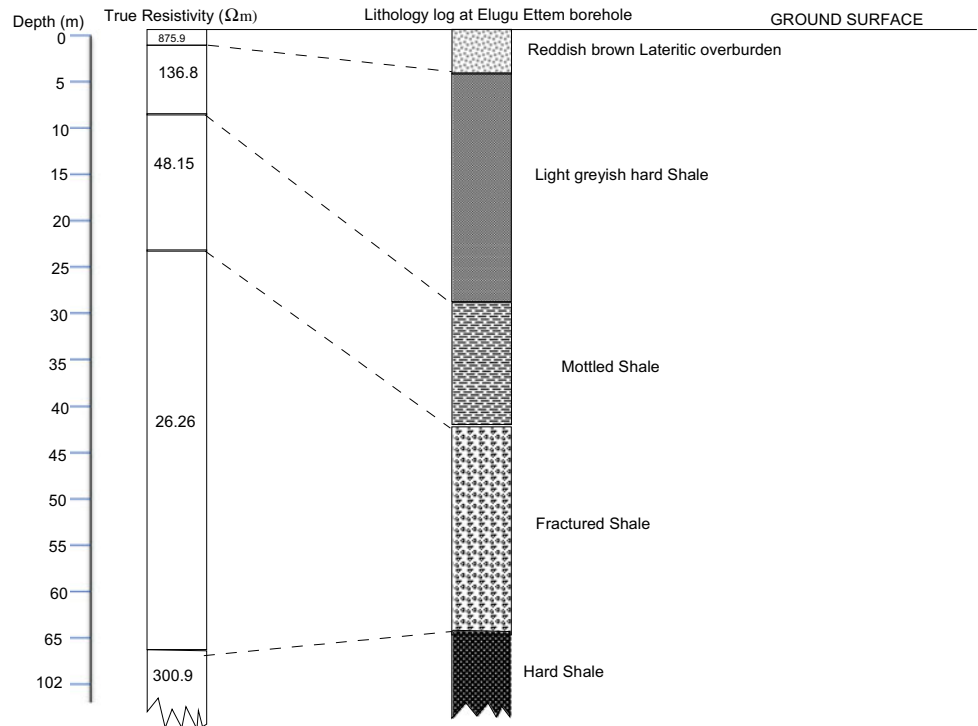
Fig. 6 Processed vertical electrical sounding result at Ekpelu, Ikwo

layer which serves as the aquifer has an apparent resistivity value of 26.26  $\Omega\text{m}$ . The aquiferous layer is underlain by a dark hard shale layer of indeterminate thickness and a resistivity of 300.9  $\Omega\text{m}$  (Fig. 7). The processed curve is shown in Fig. 8.

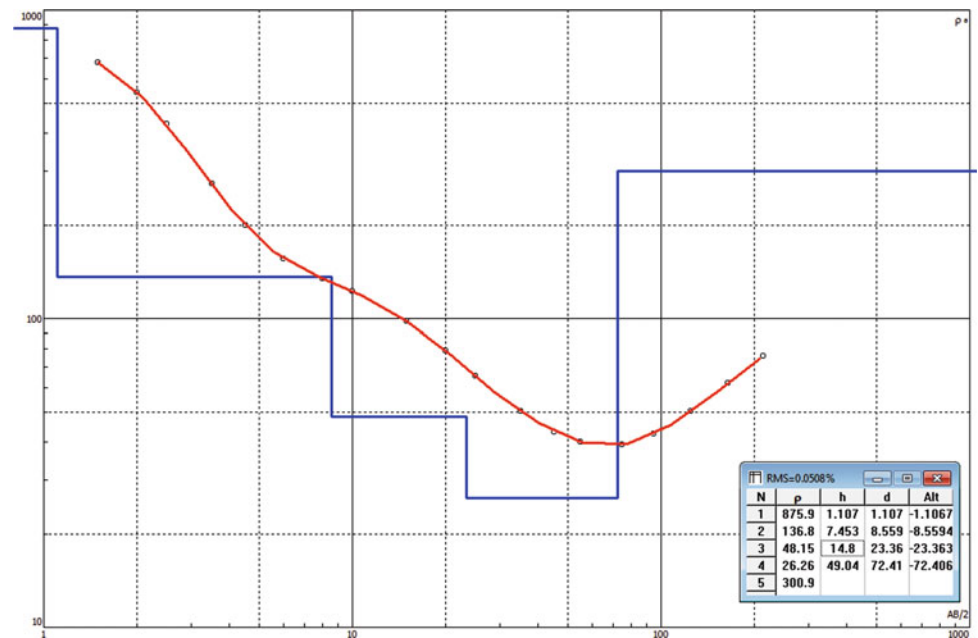
### 6.4 Comparison of Geoelectrical Section with Lithology Log at Amainyima, Ikwo

Five geoelectrical layers (Fig. 9) were delineated with the first two layers correlating with a reddish brown lateritic

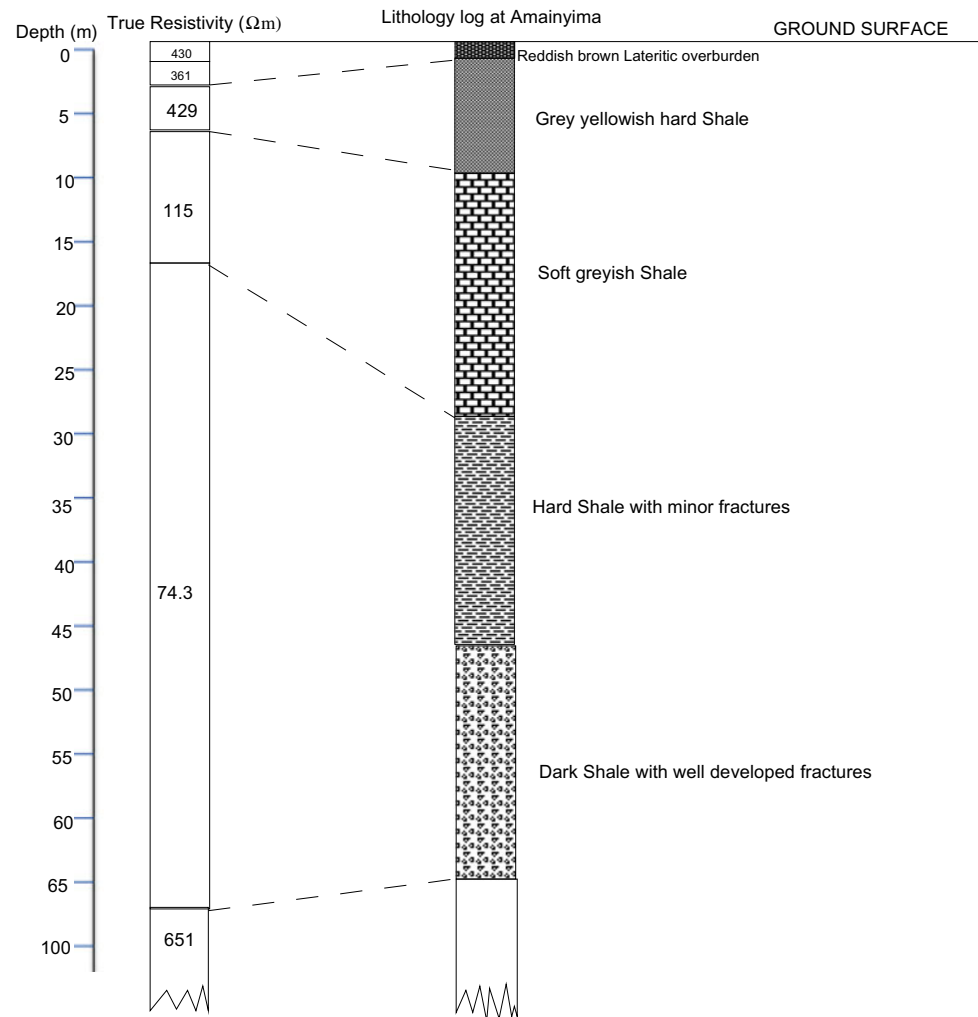
**Fig. 7** Comparison of geoelectrical section with lithology log at Elugu Ettem borehole, Ikwo



**Fig. 8** Processed vertical electrical sounding result at Elugu Ettem, Ikwo



**Fig. 9** Comparison of geoelectrical section with lithology log at Elugu Ettem borehole, Ikwo



overburden with a resistivity of 430  $\Omega\text{m}$ . The third geoelectric layer with a resistivity of 429  $\Omega\text{m}$  correlates with a yellowish gray hard shale on the lithology log. The resistivity value dropped to 115  $\Omega\text{m}$  in the fourth layer which corresponds to a soft grayish shale layer. The aquiferous layer has a resistivity of 74.3  $\Omega\text{m}$  with an upper layer corresponding to a hard dark shale with minor fractures which is underlain by a dark shale layer with well-developed fracture framework. The aquiferous layer is underlain by a hard dark shale layer of undefined thickness and a resistivity of 651  $\Omega\text{m}$ . The processed curve is shown in Fig. 10.

## 7 Aquifer Parameters from Geosounding Data

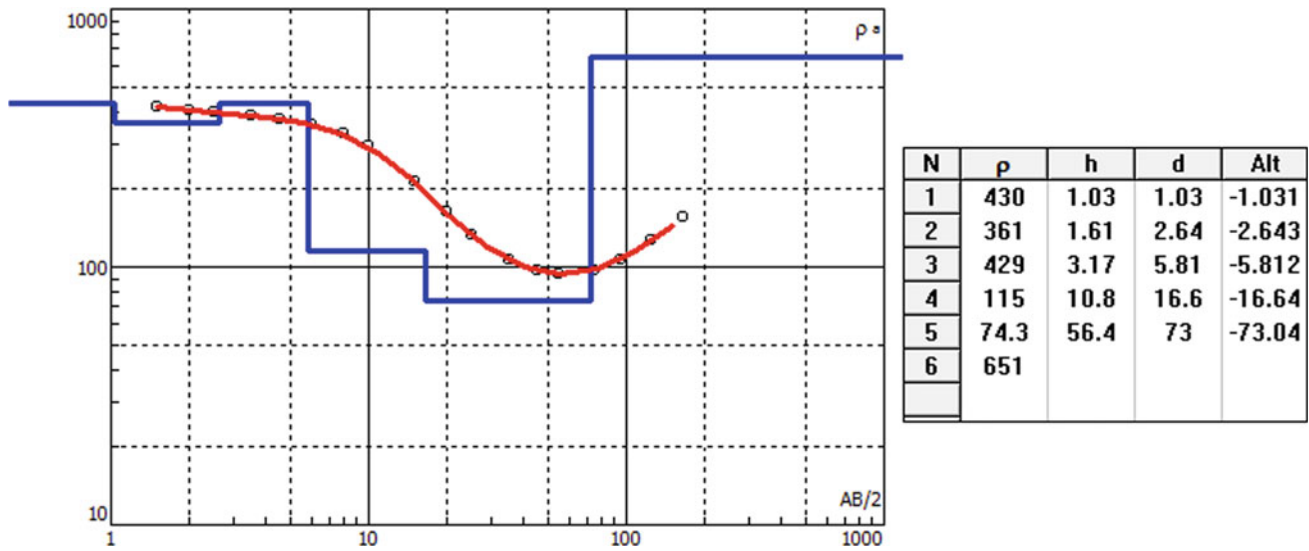
The depth to the fractured shale aquifer ranges from 22.1 to 54.9 m at Ekpelu and Ndufu Alike, respectively, while aquifer thicknesses varies from 19 m at Ndufu Alike to 56.4 m at Amainyima. Hydraulic conductivity varies

between 0.0047 m/day at Ndufu Alike I and 0.3 m/day at Onyikwa Playground, while transmissivity varies between 0.0893  $\text{m}^2/\text{day}$  at Ndufu Alike Ikwo and 9.78  $\text{m}^2/\text{day}$  at Onyikwa Playground (Table 1).

## 8 Discussion and Conclusion

The results compare well with those obtained from pumping tests and other statistical analysis methods from other research works in Abakaliki area and environs (Ozoko, 2012; Ozoko, 2014; Onwe et al., 2020). The obtained aquifer parameters are compared well with earlier results by MacDonald et al. (2005). This shows that electrical resistivity survey is a useful technique for understanding the hydraulic characteristics of the aquifer system within the study area. Computer-modeled interpretation techniques were used to resolve the true thicknesses, resistivities, and depths to the fractured shale aquifers. The depth to the fractured shale aquifer ranges from 22.1 to 54.9 m at Ekpelu





**Fig. 10** Comparison of geoelectrical section with lithology log at Elugu Ettem borehole, Ikwo

**Table 1** Derived aquifer parameters of the study area

VES No.	Location	Depth to water (m)	Aquifer thickness b (m)	Aquifer resistivity, ρ (Ωm)	Transverse resistance, ρb (Ωm <sup>2</sup> )	K from wells m/day	Kσ	Kσ_AVE	K from geosounding data_m/day	T/m <sup>2</sup> /day
1	Ndufu Alike 1	48.4	19.0	14.6	277.4			0.0032	0.0047	0.0893
2	Enyim Ogidiga road (Ndufu Alike II)	54.9	19.0	22.6	429.4			0.0032	0.0723	1.3737
3	Ekpa Omaka	34.8	23.7	13.4	317.58			0.0032	0.0429	1.0167
4	Comm. Prim. school Ohatekwe	38.8	27.5	10.3	283.25			0.0032	0.0330	0.9075
5	Onyikwa playground	54.1	32.6	93.9	3061.14			0.0032	0.3000	9.7800
6	Comm. Pri. school Igweledoha	33.2	26.3	38.9	1023.07			0.0032	0.1245	3.2744
7	Eke Ettem market square	38.4	28.2	12.6	355.32	0.0564	0.0045	0.0032	0.0403	1.1365
8	Elugu Ettem playground	23.36	49.04	23.26	1140.67	0.0542	0.0023	0.0032	0.0744	3.6486
9	Ekpelu	22.1	23.8	32.1	763.98	0.1282	0.0040	0.0032	0.1027	2.4440
10	Amainyima	25.8	56.4	25.8	1795.68	0.0484	0.0019	0.0032	0.0826	4.6586

(VES 9) and Ndufu Alike II (VES 2), respectively, while aquifer thicknesses vary from 19 m at Ndufu Alike I and II (VES 1 and 2) to 56.4 m at Amainyima (VES 10). Hydraulic conductivity varies between 0.0047 m/day at Ndufu Alike I (VES 1) and 0.300 m/day at Onyikwa playground (VES 5),

while transmissivity varies between 0.0893 m<sup>2</sup>/day at Ndufu Alike I (VES I) and 9.780 m<sup>2</sup>/day at Onyikwa playground (VES 5). We recommend that a hydrochemical study be carried out to determine the potability of the water for both industrial and domestic uses.

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