HYDROGEOPHYSICAL AND AQUIFER PROTECTIVE CAPACITY OF ABAKALIKI/AFIKPO AREA AND ENVIRONS, SOUTHEASTERN NIGERIA USING GEO-SOUNDING DATA

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Abstract

This work was carried out to evaluate the hydrogeological and geophysical properties of Abakaliki and Afikpo environs. Forty-seven (47) Vertical Electrical Sounding data were acquired with electrode spacing (AB/2) of 500m using Schlumberger electrode configuration. Conventional curve matching techniques were used to interpret the data and obtain initial model parameters. Results of the study showed 3-7 electric layers which indicate multiple aquifer system. QQH, QHK, KHK and QQHK models were the Vertical Sounding curves obtained. The aquiferous layers make up the third and fourth layers. The resistivity of the aquifer varies from 10.74Ωm to 13201Ωm with an average of 1013.58 Ωm. Aquifer depth ranges from 6.2m to 92.5m with an average aquifer depth of 27.07m, while the aquifer thickness varies from 2.3m to 55.87m with an average of 15.61m. Transverse resistance varies from 65.34Ωm² to 7079.14 Ωm² with an average of 9966.29 Ωm²; and the longitudinal conductance varies from 0.00018Ω⁻¹ to 1.65 Ω⁻¹ with an average of 0.026 Ω⁻¹. From the study, 49% of the study area falls under the poor protective rating while 21% falls under the weak rating with 25% and 5% which makes up the moderate and good ratings respectively. Using the average longitudinal conductance, it is observed that the study area is moderately protected.

Key words: Resistivity; Vertical Electrical Sounding; Longitudinal conductance; Transverse resistance; Vulnerability.

Introduction

Access to fresh and potable water for domestic and industrial use is a major challenge in Abakaliki/Afikpo areas due to the collapse of the public water supply schemes. Most public water schemes that provide pipe-borne water in the area have been abandoned by the government whose duty, it is to provide this all important resource. Most households do not have access to pipe borne water consistently. With population explosion in towns like Abakaliki, Afikpo, Izzi and Ishiagu occasioned by the presence of several mining and quarrying companies such as Crushed Rock Industries Limited, Setraco Nigeria Limited etc., a greater need for potable water has become obvious. More so, the need to assess the protective capacity of the aquifer in the area cannot be overemphasized as there is the danger of its contamination from surface industrial effluents and pollutants emanating from mining and quarrying activities in the area. An alternative means water includes surface water, hand dug wells and boreholes. Surface water is usually associated with diseases like typhoid, cholera etc. it has been estimated that roughly five to ten million people die annually to water related diseases and most of them are little children (Snyder and Merson, 1982). This means that groundwater is the safest and best source of potable water for Ebonyi state inhabitants. On the other hand, the availability and use of the groundwater is also becoming troublesome. Although some of the drilled boreholes yield water at economic quantities all year round, some are productive only at the height of the rainy season, and the rest are totally unproductive, and are referred to locally as 'abortive' boreholes. The characteristics mentioned above can be related to the existence of fractures and the complete absence of weathered areas within the investigated area.

Geometric, geo-hydraulic and protective capabilities of aquifers are some of the fundamental properties defining the hydrogeology of any given area. In general, these properties are calculated using geological details, which are typically derived from drilled wells. In case of non-disponibility of well data, however, from existing boreholes within the study area, data from surficial electrical resistivity measurements may be used to predict aquifer properties. Vertical Electrical Sounding (VES) is very effective in determining the fundamental aquifer properties and protective capacities. It is well known that the electrical resistivity data of the subsurface can be used to provide important information for detailed aquifer delineation and characterization (Opara et al. 2012). Surficial electrical resistivity techniques have therefore been used extensively in delineating groundwater resources in various parts of the world (Niwas and Singhal 1981). Similarly, several scholars have previously established a strong relationship between aquifer geohydraulic properties and aquifer resistivity indicating an inverse relationship (Niwas and Singhal 1981). Researchers have applied this relationship to estimate hydraulic aquifer characteristics, geometric capacity, and susceptibility using data on electrical resistivity (Obiora et al. 2016a, b; Ugada et al. 2013).

Resistivity techniques are well established and widely used to solve a variety of engineering, geological, hydrogeological and environmental challenges because they are non-evasive and cost effective (Ward, 1990). The primary aim of the resistivity method is to quantify the possible surface variations due to the current flow within the field. The hydraulic and electrical conductivities are mutually dependent because the mechanism that controls fluid flow and electrical current and conduction is generally regulated by the same physical parameters and lithological properties. The current flow and conduction in the soil are extremely variable, therefore, the measured resistivity values are not absolute but relative. Several authors have therefore delineated shallow aquifers and estimated aquifer hydraulic

parameters using surface geophysical methods in different parts of the world (Ugada et al., 2012, Ejiogu et al., 2019). Vertical electrical sounding (VES) investigations have been widely employed in aquifer investigations across the world, both in basement and sedimentary terrains (Zorhy et al., 1974; El - Hussaini et al., 1995; Ayers, 1989; Vchery and Hobbs, 2003; Akaolisa, 2006; Tizro et al., 2010; Arabi et al., 2010; Oni et al, 2017 and Eyankware et al., 2020).

Aquifer protective capacity is the aquifer's ability to protect itself from damage from anthropogenic surface sources. Protective capacity or vulnerability of aquifers is an essential feature necessary for the sustainable use and management of groundwater. Protecting groundwater from contamination is a function of the layers above it. However, the degree of pollution depends on certain intrinsic properties of aquifer systems that may include topography, porosity / permeability, and climate influences. The protective ability of groundwater is a feature not only of the properties of the groundwater flow system but also of its proximity to contaminant sources, the existence of the contaminant and other factors that may trigger the potential contaminants to reach the groundwater resources as quickly as possible (Michael et al. 2005). Usually, geological techniques that use parameters such as depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity, etc. are used to estimate aquifer protective capacities. Such techniques which include DRASTIC, GOD, SINTACS, etc. have been used by several scholars to study issues related to aquifer protective capacity over the years (Aller et al. 1987; Navulur and Engel 1996). In very recent times, because of the paucity of data needed for the estimation of aquifer protective capacity, several empirical equations based on electrical resistivity have been used with great success to predict aquifer protective capacity (Obiora et al. 2016).

A study was carried out by Uma (1989) on the groundwater potential of the Imo River basin and shallow and deep aquifers were discovered using pump test and borehole data. Similarly, numerous researchers have previously studied parts of the study region (Imo River Basin) using parameters from Dar-Zarrouk (Ugada et al., 2013, 2014; Eke et al. 2015). Therefore, the present study is a detailed hydrogeophysical study of the area intended to delineate the shallow aquifer units in the area of study. In addition, the longitudinal conductance values produced from this analysis were used to assess the study area's aquifer protective capacity. Geophysical sounding data has also been correlated with lithological logs from boreholes and the electrical logs available for comparative purposes. It is hoped that results of this research will resolve the study area's groundwater problems. Therefore, it is important the aquifer potentials and groundwater quality be assessed as a reliable and safe source of potable water supply. This study seeks to appraise the aquifer potential in the area and assess the protective capacity of the aquifers.

1.1 Location, Geomorphology, Drainage and Geology of the Study Area

The study area is located within Latitude 6° 26' 49''N of the equator and Longitude 8° 01' 37''E (Figure 1) and covers 412.55 sq. km. and located in the southeast Nigeria. The area experiences an average annual rainfall ranges from over 1500mm to over 2000mm per annum, with temperatures rarely exceeding 38° C. The Ebonyi formation soils are mainly hydromorphic with lesser soils in the uplands. This established land use which is mainly for the production of rice. The region is marked by undulating topography, and there is no place above sea level 400m.

The Abakaliki region is underpinned by the Asu River Group (Reyment, 1965) Abakaliki Shale Formation. Sediments of the Asu River System are mainly shale, with scattered occurrences of intercalations of sandstone, siltstone with calcareous (Ofoegbu and Amajor, 1987). In the mid-Albian period, it was generally believed to have started depositing and was deposited within the lower (or southern) Benue Trough, southeastern Nigeria. Sediments in these Asu River Groups are intermediates to simple invasive, extrusive, and pyroclastic substances (Murat, 1972; Nwachukwu, 1972; Ofoegbu and Amajor, 1987; Tijani et al., 1996). The group has an average thickness of about 2000 m and rests on the Precambrian Basement (Benkhelil et al. 1989). Abakaliki shale formation, has an average thickness of approximately 500 m, shale is dominant, dark grey in color, blocky and non-micaceous in most areas. It is deeply folded and broken by the sequence of tectonic activities that have been taking place on the rocks (Ezeh and Anike, 2009). This has provided the shales the opportunity to house groundwater in economic quantities in some regions, while other sections still exist as aquiclude and fractures not pronounced.

The Afikpo area is underlain by Ezeaku and Nkporo Formations (Reyment, 1965, 1967) (Figure 2). Low productivity of many boreholes already drilled in the area supports the difficulty to find sustainable water supplies. The geology of the study area has been described in details by various authors (Nwankwoala, 2015; Adelana et al, 2008; Reyment, 1965) and these formations consist of thin shallow but extensive unconfined aquifer, and deep and perched aquifer (Adelana et al, 2008). The formations have variable saturated thickness and generally less than 50m and 78m in aquifers found in its lower and middle hydrogeological groups respectively (Reyment, 1965).

Figure 1. Geology map of the study area

2.0 Data Acquisition and Processing

Resistivity data was obtained using vertical electrical sounding (VES). Schlumberger electrode configuration was adopted with an electrode spacing of 150m. In theory, the resistivity of a material has a direct relationship with the resistance of a material.

$$\rho_a = \pi \left[\frac{\left(\frac{AB}{2} \right)^2 - \left(\frac{MN}{2} \right)^2}{MN} \right] \frac{\Delta V}{I} \quad \dots \dots \dots (1)$$

IP2WIN software aided the data processing and generated sounding curves. The data from these curves were used to determine aquifer thickness.

Dar Zarrouk parameters are parameters related to the combination of resistivity of electric layer and thickness, these are vital for understanding and analyzing geologic model (Zohdy et al. 1976). These parameters are transverse (T) and Longitudinal (S), given by:

$$S = h/p \quad \dots \dots \dots (2)$$

$$T = hp \quad \dots \dots \dots (3)$$

h represents the thickness of the layer in meters while p is the layer resistivity in ohmmeters.

3.0 Result Presentation and Interpretation

3.1 Interpretation of the Layer Parameters

The acquired field resistance data were used to produce geo-electric curves representative of the underlying geology of the study area. The arrangement of the curves for each location of the sound typically provides an understanding of the physical characteristics of the layers within that location. The curve types for the soundings gave clues to the nature of the nature of the layers between the surface and maximum depth of penetration. The curve types identified ranges from simple QQ to QH, KHK, HKK, to complex AKHH, HKHK types, reflecting different facies or lithological variations in the area. Previous work by (Ngwoke, 2016) revealed that, the occurrence of many curve forms indicates minimal uniformity of resistance patterns over the study area and the lack of uniformity of layering and alteration of layer properties due to weathering, fracturing and other geological phenomenon across study area are elements that can cause alternations in resistance patterns across the study region. The typical curve types from the study area are shown in figure 2.

Figure 2. Sample Geo-electrical Curve Types in the study area: (a) NNPC filling Station Amasiri, Ebonyi State (b) Federal Medical Centre, Abakaliki, Ebonyi state.

Three, four, five, six and seven layers were discovered from the data after analysis. The six layer models were the most prominent occurring 19 times, followed by five layers occurring 12 times

3.2 Aquifer Resistivity

Aquifer resistivity across the study area was estimated from the geo-electric curves generated from the Vertical Electrical Sounding data. The aquifer resistivity varied spatially across the study area in agreement with the geological complexity of the study area as shown in (figure 3).

Aquifer resistivity in Afikpo varies from as low as 24.1 Ωm at VES 11 to as high as 13203 Ωm at VES 1 with a mean value of 4644 Ωm . The aquiferous zones are found in the 3rd and 4th layers. The Abakaliki study area varies from lows of 18 Ωm at VES 8 to highs of 105 Ωm at VES 16 with an average of 62.94 Ωm . The third layer is the aquiferous zone, the weathered and fractured areas are zones where flow of water is most favorable. Izzi aquiferous zones are found in the third and fourth layer and has values ranging from as low as 30.2 Ωm at VES 23 to 330 Ωm at VES 27 with an average of 151.3 Ωm while the Ishiagu aquiferous zones are found in the third, fourth and fifth layers and have values as low as 10.74 and high as 2338 Ωm with an average of 644.67 Ωm .

Figure 3: Aquifer resistivity map of the study area

3.3 Iso-resistivity of the Study Area

Iso-resistivity maps obtained at depth intervals of $AB/2 = 10\text{ m}$ to $AB/2 = 150\text{ m}$, this showed the resistivity varied vertically with depth. Below are iso-maps derived from resistivity data. After analyzing the maps, it can be observed there is a multi-aquifer system in the study area hydraulically separated by band of clay, shale and sand.

Figure 4: Iso-resistivity maps of the study area: (a) $AB/2 = 5$ (b) $AB/2 = 10$ (c) $AB/2 = 20$ (d) $AB/2 = 50$ (e) $AB/2 = 100$, (f) $AB/2 = 150$

3.3.1 Isoresistivity ($AB/2 = 5$ m)

The isoresistivity map shown in (figure 4a) revealed most sections asides the western areas are underlain by low resistivity materials. The magenta and deep blue colors indicate areas of low resistivity (figure 4a) and have values ranging from 0- 1000Ωm. The Isomodel with a penetration of 10.57ft showed that the resistance values rose from 200m to 38,000 m (red) throughout the study area. The magenta color shows the area is underlain by clay zone or shales.

3.3.2 Isoresistivity Map ($^{AB}/2 = 10\text{m}$)

Iso-map at 10 m in (Figure 4b) shows that low resistive materials are found in the research area except the region of Afikpo region. Resistivity of the study area was observed in the south, east, central and northern parts of the study area with an appropriate depth of penetration of 13.33m, with low to medium resistivity varying from 0 to 150 Ωm (in magenta and bluish). The resistivities have ranges of 450 to 950 Ωm and were found to be restricted to the West of this area, while the medium resistivity values were found for green areas between 150 and 400 Ωm . The crimson and bluish colors is a sign that the area is underlain by shaley or clay units, while other colors are underlain by fractured shale units.

3.3.3 Isoresistivity Map ($^{AB}/2 = 20\text{m}$)

This iso map shows high resistivity materials such as sandstone to support the Afikpo area. The crimson and bluish colors may in general indicate shale and clay formations, the rest are made up of fractured variations of shale and sandstone.

3.3.4 Isoresistivity Map ($^{AB}/2 = 50\text{m}$)

Most sections of the study area in the North, East, West and South-Eastern areas are highlighted by relative low resistive materials in the $^{AB}/2 = 50\text{m}$ iso map in (Figure 4d). The resistivity of the field showed that the shale coverage rose throughout the region as crimson and bluish areas rose. Resistance levels range from 1 and 200 Ωm in crimson and bluish colored areas. High resistivities between 250 and 700 percent are mostly found within the south-west axis of the study region, with pockets located in its north-west and north-eastern regions. In general, the crimson and bluish colors of resistivity is an indicator of clay or silt formations while the remaining colors on the map usually represent the areas above fractured shale or shallow and sandstone alternations.

3.3.5 Isoresistivity Map ($^{AB}/2 = 100\text{m}$)

The iso-map (Figure 4e) below highlights how most parts of the study area are underlain by low resistance materials. The resistivity of the study area revealed that the resistivity values at the sounding points increase from 0 to as high as 1900 Ωm . This depth led to the area becoming shaly as Abakaliki, Izzi and Ishiagu study areas are made of low and medium resistivity materials (magenta color) the range are 0-500 Ωm while the high resistivity values are found in the western study area.

3.3.6 Isoresistivity Map ($^{AB}/2 = 150\text{m}$)

The iso-resistivity for $AB/2 = 150\text{m}$ (Figure 4f) indicated that relatively low resistive materials are used to underlay majority of the study area along the Northern, Eastern and Southwest axes. Penetration depth is given at 100 m (to 326 ft.) the resistivity of the study area showed that the shale units were the across the region with magenta colored areas increasing across the region. Resistivity levels vary from 0 to 700 Ωm for the magenta colored areas. In general, the west axis is limited to high resistivity values ranging from 700 to 2900 Ωm .

3.4 Aquifer Depth

This was calculated from the Vertical Electrical Sounding data and the map is shown in (Figure 7). The depth to water table in Abakaliki area ranges from 8.11m at Ochi Udo city to 89.9m at Presco Campus Abakaliki with a mean value of 30.214m, Afikpo ranges from 6.2m at NYSC orientation camp to 24.3m at Government college Afikpo with a mean value of 15.63m, Izzi area ranges from 13.6m at Nduna Market square to 45.8m at Assembles of God church with a mean value of 21m and Ishiagu area ranges from 7.28 at VES 41 to 92.25 at Amalokpa Amonyne with a mean value of 31.56m.

Figure 5: Contour map of aquifer depth of the study area

3.5 Aquifer Thickness

Aquifer thickness in Abakaliki ranges from 2.7m in Akam street to 55.2m at Federal Hospital with a mean value of 17.44m, Afikpo thickness ranges from 2.67m at Nysc orientation camp to 16.06m at Ukpa by Oko Ogenyi road with an average thickness of 8.77m, Izzi area aquifer thickness ranges from 2.6m to Nkumanyi Mbalukwu to 37.6m at Assembles of God Umuogodo with an average value of 13.96m and Ishiagu area thickness ranges from 55.87m at Ekengwu Amaonyi to 2.33m at Federal college of agriculture with an average of 18.67m. The aquifer thickness map is shown in figure 6.

Figure 6: Aquifer thickness maps of the study area

3.6 Dar-Zarrouk Parameters of the Study Area

3.6.1 Transverse Resistance

The parameter known as the Dar-zarrouk Parameter has also been measured (Table 1). Transverse resistance is the product of aquifer resistivity and aquifer thickness. This is estimated as low as $3999.54 \Omega\text{m}^2$ in Afikpo region and as high as $388964.52 \Omega\text{m}^2$ and an average of $31503.10 \Omega\text{m}^2$. Abakaliki area varies from $65.34 \Omega\text{m}^2$ up to $2073.99 \Omega\text{m}^2$ on average from $1000.50 \Omega\text{m}^2$; the Izzi area is as low as $78.52 \Omega\text{m}^2$ and as high as $7079.12 \Omega\text{m}^2$ with an average of $1983 \Omega\text{m}^2$ and Ishiagu varies from $26.28 \Omega\text{m}^2$ to $40587.68 \Omega\text{m}^2$ with average values of $10852 \Omega\text{m}^2$. The Afikpo study area has the highest transverse resistance (Figure 7) and is believed to have high transmissibility and aquifer unit output (Agbasi and Edet, 2016).

Table 1: Aquifer properties from resistivity data

S/N	LOCATION	Aquifer Resistivity (ohm-m) ρ_a	Aquifer Depth (m)	Aquifer Thickness (m)	Aquifer Conductivity $\sigma = 1/\rho_a$	Transverse Resistance $R = (\rho_a \times l)$	Longitudinal Conductance $S = \text{Thickness}/\rho_a$
1	Akani Ibiam Federal Polytechnic Uwana	13203.00	19.2	10.67	7.57404E-05	140876.01	0.00080815
2	NNPC FILLING STATION AMASIRI	2638	11.4	4.05	0.000379075	10683.9	0.001535254
3	GOVERNMENT COLLEGE AFIKPO	556.00	24.3	13.4	0.001798561	7450.4	0.024100719
4	NYSC ORIENTATION CAMP AFIKPO	14556.00	6.2	2.67	6.87002E-05	38864.52	0.00018343
5	UKPA BY OKO OGENYI ROAD AFIKPO	1155.00	23.6	16.06	0.000865801	18549.3	0.013904762
6	FEDERAL HOSPITAL ABAKALIKI	74.13	32.03	26.82	0.013489815	1988.1666	0.361796843
7	ABAKALIKI LOCAL GOVERNMENT	80.70	34.7	9.5	0.012391574	766.65	0.11771995
8	OCHI UDO CITY ABAKALIKI	18	8.11	3.63	0.055555556	65.34	0.201666667
9	INTERNATIONAL MARKET ABAKALIKI	80.7	79.40	25.7	0.012391574	2073.99	0.318463445
10	EZI NWACHI NDIBE, AFIKPO NORTH	382	16.50	10.47	0.002617801	3999.54	0.027408377
11	EZI-EGWU UBANA UGWU-EGU, AFIKPO NORTH	24.1	8.23	4.07	0.041493776	98.087	0.168879668
12	PRESCO CAMPUS EBSU ABAKALIKI	50	89.9	55.2	0.02	2760	1.104
13	ABOFFA VILLAGE SQUARE ABAKALIKI	45	12	7.5	0.022222222	337.5	0.166666667
14	OROEQUHA ABAKALIKI	28	13	8.5	0.035714286	238	0.303571429
15	NKALIKI EBONYI STATE HOUSE OF ASSEMBLY	85	12	6	0.011764706	510	0.070588235
16	AKAM STREET ABAKALIKI	105	4.5	2.7	0.00952381	283.5	0.025714286
17	NWANU VILLAGE SQUARE, IZZI	86.7	12	6.5	0.011534025	563.55	0.074971165
18	ASSEMBLES OF GOD UMUOGODO OSHA OHAUKWU	102.0	45.8	37.6	0.009803922	3835.2	0.368627451
19	EDUKWU ACHI, AGBAJA, IZZI	104.7	18.2	8.8	0.009551098	921.36	0.084049666
20	AMAECCHARA VILLAGE SQAURE, IZZI	86.3	18.2	25.1	0.011587486	2166.13	0.290845886
21	NDIAKPARA PRIMARY SCHOOL, NWAEZENYI, IZZI	124.8	26.5	17.4	0.008012821	2171.52	0.139423077
22	OFIA NKWU NWAEZENYI, IZZI	574.7	27.8	4.3	0.001740038	2471.21	0.007482165
23	NKWUMANYI MBALUKWU IZZI	30.2	17.8	2.6	0.033112583	78.52	0.086092715
24	OKWARAKA, EZZA-INYIMAGU, IZZI	132.0	22.3	13.3	0.007575758	1755.6	0.100757576
25	NDUNA MARKET SQAURE, AGBAJA IZZI	41.5	13.6	6.7	0.024096386	278.05	0.161445783
26	ALIBARU VILLAGE SQUARE AGBOJA IZZI,	50.6	17.2	9.9	0.019762846	500.94	0.195652174
27	NWOMILLA VILLAGE SQUARE, MGBAUKWU IZZI	330.8	15	21.4	0.003022975	7079.12	0.064691657
28	Civic Centre Amaeze	82.33	35.71	20.37	0.012146241	1677.0621	0.247418924
29	Onovo Ukwu Amaeze	1957	23.09	9.7	0.000510986	18982.9	0.004956566
30	Imuhuebe Amaeze	3240	29.32	14.21	0.000308642	46040.4	0.004385802
31	AGM Primary School	737.2	31.04	19.27	0.001356484	14205.844	0.026139447
32	Assemblies of God Church	1337	36.18	22.25	0.000747943	29748.25	0.016641735
33	Ekengwu Amaonye	90.63	65.55	55.87	0.011033874	5063.4981	0.61646254
34	GMSS Ihietutu Ishiagu	33.13	31.92	15.73	0.030184123	521.1349	0.474796257
35	Amabor Amaonye Ishiagu	79.65	81.15	49.75	0.012554928	3962.5875	0.624607659
36	Amalokpa Amaonye Ishiagu	137.6	92.25	51.94	0.007267442	7146.944	0.37747093
37	Near Echiele Development Center, Amokwe Ishiagu	41.13	12.1	5.28	0.024313153	217.1664	0.12837345
38	General Hospital Amaokwe Ishiagu	1242	31.62	23.12	0.000805153	28715.04	0.018615137
39	Near Christ Embassy, Amaokwe Ishiagu	2338	23.25	17.36	0.000427716	40587.68	0.00742515
40	Ngwogwo Primary School, Ngwogwo Ishiagu	17.87	12.31	6.92	0.055959709	123.6604	0.387241186
41	HighnigHonfen Primary School, Amaokwe Ishiagu	14.85	7.28	3.61	0.067340067	53.6085	0.243097643
42	Aguena Primary School, Okue Ishiagu	431.7	10.61	3.74	0.002316423	1614.558	0.008663424
43	Federal College of Agriculture Ishiagu	11.28	13.14	2.33	0.088652482	26.2824	0.206560284
44	Ivo Divisional Police Headquarters, Ishiagu	873.8	19.8	18.2	0.001144427	15903.16	0.020828565
45	Ishiagu high school, Ishiagu	48.11	11.09	3.84	0.020785699	184.7424	0.079817086
46	Obioha Primary School, Amagu Ishiagu	10.74	30.92	17.74	0.09310987	190.5276	1.651769088
47	sir G.C. Ajah residence, Amagu Ishiagu	169.5	32.87	12.3	0.005899705	2084.85	0.072566372

Figure 7. Spatial variation of transverse resistance (Ωm^2) across the study area

3.6.2 Longitudinal conductance

The dissemination of aquifer longitudinal conductance (S) is shown in Table 5. Afikpo values range from 0.0018343 to 0.027 with an average of 0.033, Abakaliki varies from 0.0257 to 1.104 with an average of 0.29, and Izzi has values from 0.0074 to 0.36862 with an average of 0.143 while Ishiagu varies from 0.0043 to 1.65 with an average of 0.260. In the assessment of aquifer protective capacity, longitudinal conductance values are usually used. The aquifer protective capacity basically measures the natural ability of overburden layers to filter or slow percolating pollutants [Olorunfemi et al, 1999]. The longitudinal conductance values of the study area have been categorized to low, medium, moderate and strong aquifer protection capacity as shown in Table 2 (Oladapo and Akintorinwo, 2007).

Table 2: Aquifer protective capacity rating of the study area using Longitude Conductance (Oladapo and Akintorinwo, 2007).

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
10	Very Good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

Figure 8: Aquifer protective capacity map of the study area

In comparison with other regions, the Afikpo region of the study shows a relatively lower aquifer protective capacity, since it consists of sands which are alternating, rendering it vulnerable to pollution due to the high permeability of sand compared to Abakaliki and Ishiagu which is dominated by shale, except when fractured or weathered. Eyankware et al. (2020) carried out an estimation on aquifers in Abakaliki and discovered their study area was underlain by clay/shale and fractured shale and most parts are underlain by materials of poor to excellent protective capacity.

4.0 Summary, Conclusion and Recommendation

The hydro-geophysical study of the study area using surficial resistivity data have been carried out with the objective of appraising the groundwater potentials of the area.

Results of the study revealed that the geoelectric curves interpreted from the study area are QH, QQ, HHK, etc. with the dominant curve type being the HKHK type. The aquifer resistivity varies from 10.74Ωm at VES 46 to 13201Ωm at VES1 with an average of 1013.58 Ωm, Aquifer depth ranges from 6.2m at VES 4 to 92.5m at VES 36 with an average aquifer depth of 27.07m, The layer resistivity varies across the study area thus reflecting the geological complexity area of study with the aquifer resistivity values across the area varying from as low as 18Ωm to as high as 14,556Ωm. Transverse resistance varies from 65.34Ωm² at VES 10 to 7079.14 Ωm² at VES 29 with an average of 9966.29 Ωm² and the longitudinal conductance varies from 0.00018Ω⁻¹ at VES 6 to 1.65 Ω⁻¹ at VES 46 with an average of 0.026 Ω⁻¹.

The findings of this study revealed that the aquifer potentials of the study areas were revealed to be variable with the aquifer type, nature and characteristics generally controlled by the underlying geology. The areas with the highest transverse resistance values are expected to give the highest groundwater yield. Areas for future groundwater development have been suggested on the ground of high transverse resistance values. It was there concluded that the

southern study area has a high aquifer potential when compared to the northern part. The Longitudinal conductance revealed the Afikpo area has low aquifer protection compared to the other areas that offer weak to moderate aquifer protection

In addition, the Eze Aku formation was delineated as the formation with the greatest aquifer potentials in the study area. It is therefore recommended that a detailed groundwater exploration should be carried out before siting a borehole in the study area.

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6.0 References

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DECLARATIONS

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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