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Research Paper

An Investigation of Groundwater Potential and Aquifer Protective Capacity at Aguleri and Nando, Anambra State

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Abstract— A geophysical survey using electrical resistivity method was conducted at Aguleri and Nando town in Anambra East LGA, Anambra State, Nigeria to investigate the groundwater potential and aquifer protective capacity. The project area lies within Latitude: 06°17'N - 06°20'N and Longitude: 006°51'E - 006°54'E. Vertical Electrical Sounding (VES) was carried out with a digital readout resistivity meter (ABEM SAS 1000). The VES data interpretations were done using INTERPEX software and the VES results were presented in terms of resistivity, thickness, depth and lithology. The lithology was inferred to the layers by correlating the lithology log of one of the boreholes drilled in each of the study areas and the geology of the study area. The VES result shows lithologic layers varying from 4 - 6 with the subsurface sequence varying as follows: red earth, shaly sand, shale, sandstone and water saturated sand. The water saturated sand layers constituted the aquifer unit in the area.
The aquifer protective capacity was determined by calculating for longitudinal conductance and matching the values to known standards ranging from poor (< 0.1 mhos) to excellent (>10 mhos). The longitudinal conductance was computed to be ranging from 0.1889 – 6.293 mhos. The interpreted VES result also shows that VES 1 – 3 has good, weak and very good aquifer protective capacity of the overburden layers respectively.

Keywords— aquifer, aquiferous zone, geoelectric section, vertical electrical sounding, Nando, Aguleri

1. Introduction

The term "groundwater" refers to subterranean water that is present beneath a geological formation that can produce water. An aquifer is an underground layer of water-bearing permeable rock. Sediments that tend to make the best aquifers include sandstone, limestone, gravel and in some cases, fractured volcanic rocks such as columnar basalts make good aquifers while rocks such as granite are poor aquifers because they have low porosity. Highly fractured rocks are good aquifers. Through the water cycle, groundwater is always in motion throughout the hydrosphere (Amadi, 2010). Water is becoming more and more necessary on a daily basis, and humanity may certainly profit from it. Water is a necessary food and a fundamental part of life. High percentage of water users in the world rely substantially on groundwater (Reilly *et al.*, 2008). In addition, and most importantly, very minor water treatment is often required to make it potable. As a result, it's essential to consider not only the groundwater's source but also its protection from contamination by materials that are close to the surface. Groundwater is largely protected from pollution by natural barriers. However, in areas with thin weathered layers and where aquifers are in hydraulic continuity with the ground surface, groundwater could be vulnerable to pollution from surface sources.

Environmental pollution is a problem in 85% of the world as water related diseases are mostly responsible for about 80% of illnesses or deaths in the developing countries and kill infants more (UNESCO, 2007). Nigeria as a country faces a waste management challenge as a result of both her growing population and her rapid industrialization (Odewumi, 2013). Epidemic and disease outbreaks have been linked to specific garbage disposal practices. A high quantity of nickel (Ni), cadmium (Cd), and suspended particulates in the water from the decomposition of household and industrial waste has also been connected to surface and shallow groundwater pollution in the Aguleri and Nando area. Diseases are more likely to spread in Aguleri and Nando town respectively since some areas have open waste disposal facilities but the geological setting of the study area tends to be favorable in reducing the tendency of leachate penetration as shale is a good filter.

Aquifer protective capacity has been defined as the capacity of the overburden unit to impede and filter percolating ground surface polluting liquid into the aquiferous unit, it is a measure of the ability of an earth medium to retard and filter percolating fluid. The protective capacity of an overburden is directly proportional to its thickness and inversely proportional to its hydraulic conductivity. Permeable materials such as sand and gravels have high resistivity, high hydraulic conductivity, and low longitudinal conductance, while impermeable material such as clay and shale have high longitudinal conductance values due to their low resistivity values. The preservation of basement aquifers is just as crucial as their use, although its delineation receives far more attention than putting safeguards in place to guarantee its safety from potential pollutants (Sullivan *et al.* 2003).

Combination of the resistivity and thickness of the overburden layers can be used to compute the longitudinal conductance of the layers which is the way for assessing groundwater/aquifer protective capacity. As part of groundwater exploration programme, the need to assess the protective capacity of groundwater becomes very important. Geophysical studies have proven to be one of the effective ways of evaluating an environment without interfering with the hydro geologic system Oladapo and Akintorinwa (2009). Geophysical techniques have been used for the delineation of waste that are hazardous and groundwater contaminated areas and have been proven to be rapid and cost effective. The observation derived from a geophysical exploration can be used to infer the conditions of subsurface at, and in the locality of an investigated area. Many researchers have used different geophysical methods to evaluate aquifer protective capacity and groundwater potential of an area using parameters such as the geo-electric parameters.

These areas of study are rural and semi – urban areas where access to other sources of water is limited. However, these areas are faced with increased pressure from population growth, urbanization, improper waste water channels, climate change and also limited information and understanding of the hydrogeological conditions, and the impact of human activities on groundwater resources in these areas. In addition, groundwater extraction and use are often uncontrolled and unsustainable, leading to depletion and degradation of aquifers, increased risk of contamination. Hence, this study will identify areas good groundwater potential and aquifer protective capacity of the study area and hence this study is of great importance because it will give the populace an idea on the actual depth where good water table can be harnessed and will warn the inhabitants on areas with high risk of groundwater pollution from solid waste and waste water pollutants.

This study will also provide an overview of some of the approaches used to assess the aquifer potential using Vertical Electrical Sounding (Schlumberger array) in different locations within the Aguleri and Nando towns. The method was used for this study in order to provide a geophysical database for exploration of the study area's groundwater resources and also it's less expensive and less time consuming. VES has proved to be effective in solving groundwater problems in most places in Nigeria (Ezeh and Ugwu 2010; Ugwu and Ezeh, 2012; Nzemeka et al., 2023).

1.1 Location and Accessibility of Study Area

Aguleri and Nando are medium-sized towns, located within the Anambra valley in the southeastern quadrant of the Federal Republic of Nigeria, which is a country on the west coast of Africa. Both towns are located in Anambra East Local Government Area of Anambra State, in the Southeastern region of Nigeria with Latitude: 06°17'N - 06°20'N and Longitude: 006°51'E - 006°54'E and can be accessed through the Enugu – Onitsha Expressway by Awkuzu and Igbariam junctions respectively.

Aguleri and Nando are bordered by the following towns and villages: Umueri, Mmiata Anam, Anaku, Awkuzu, Igbariam, Nteje, Nsugbe, Achalla and Umunya (Figure 1)

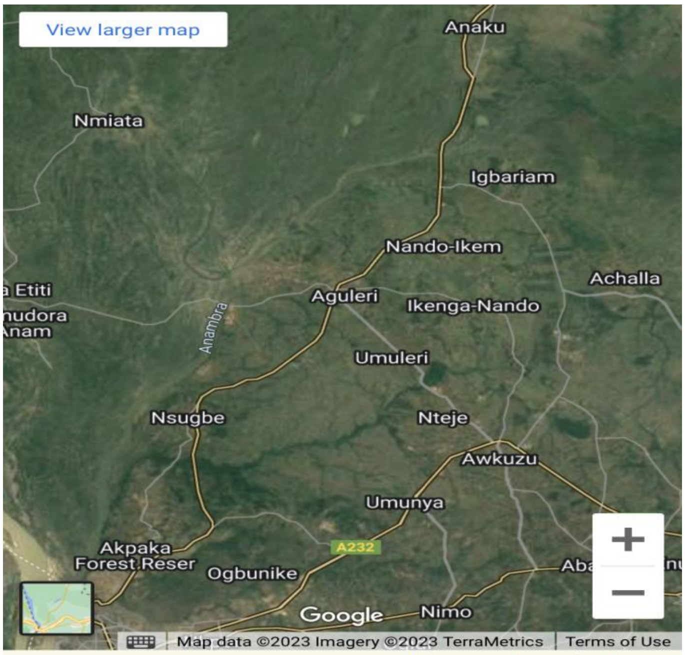

Figure 1. Google map of Anambra State showing the Location of the study areas (www.google.com)

2. Related Work

Various researchers have studied the effect of aquifer protective capacity on the groundwater in Nigeria and all over the world. Tahama *et. al., (*2019) evaluated the groundwater potential and aquifer protective capacity of the overburden units in trap Covered Dhule District, Maharashtra using Vertical Electrical Sounding and concluded that about 92% of the study area is characterized by moderate to good protective capacity, 4% reveals excellent and 4% poor ratings which shows that the study area is less vulnerable to aquifer pollution and contamination.

Obiora *et. al*., (2015) evaluated the aquifer protective capacity of overburden unit and soil corrosivity in Makurdi, Benue state, Nigeria, using electrical resistivity method and concluded that areas of thick overburden units and low resistivity values constitute zones of high longitudinal conductance. Regions with poor protective capacity are vulnerable to pollution and contamination if there is oil spillage, leakage in buried storage tank, petroleum pipelines, and infiltration of leachate from decomposed dump or waste site. Regions of weak protective capacity are less vulnerable to groundwater pollutant or contaminant but can be more vulnerable with time as pollutant persists.

Atakpo (2013) employed the resistivity survey in parts of Sapele Local Government Area, Delta State to study the aquifer protective capacity of the area and found out that the study area showed poor protective capacity (< 0.1 mhos) and concluded that the area is vulnerable to pollution. He also recommended that any form of sewage disposal should be discouraged and waste water disposal channeled properly.

In order to assess the aquifer vulnerability at Igbanke, Orhionmwon Local Government area of Edo State, Nigeria, Egbai et al. (2015) employed the geo-electric approach. They found that practically every section of the research area had a poor or weak protection capacity rating and caution should be taken in indiscriminate disposal and in citing a municipal dumpsite.

Tsepav and Umar (2016) evaluated the aquifer protective capacity and soil corrosivity using geoelectrical method in some parts of Angwan - Gwari, an outskirt of Lapai Local Government area, Niger State and concluded that the overburden unit is of poor aquifer protective capacity and aquifers are highly permeable to fluid movement within, leading to the possibility of enhanced migration and circulation of contaminants in the groundwater system and that the area is generally corrosive.

Olaniyan (2020) estimates the aquifer protective capacity, soil corrosivity and Dar-Zarrouk Parameters in Kaura Area of Kaduna State using Vertical Electrical Sounding and borehole pumping test data and concluded that moderate to good aquifer protective capacity was obtained, which showed that the overburden thicknesses are sufficiently thick enough to protect the aquifer from surface polluting fluids.

Olajide *et. al*.,(2020) evaluated the aquifer protective capacity and groundwater potential in Part of Iju, Akure-North, Ondo State, Nigeria using integrated geophysical methods involving Very Low Frequency Electromagnetic (VLF-EM) profiling and Vertical Electrical Sounding (VES) and concluded that the larger part of the area of study (about 70%) is situated within low groundwater potential zones, 25 % falls within medium potential zones while only 5 % constitute the high potential zones. Also the aquifer protective capacity assessment shows that < 25 % of the study area aquifer have moderate to good protective capacity, while the weak to poor protective capacity occupied about 75 % of the study area.

Aderemi and Bamiro (2021) estimated the aquifer protective capacity using electrical resistivity method in Odo Ona Elewe, Ibadan and concluded that the depths of the aquifers ranges from 6.5 to 14.0m.

Abiola *et. al.*,(2009) studied groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, Ekiti State, using Vertical Electrical Sounding and concluded that high variability of the thickness of the top soil appeared responsible for the observed overlapping resistivities across the study area. The weathered layer constituted the sole aquifer unit in the area; the yield being dependent on degree of the clay content. The higher the clay content, the lower the groundwater yield.

Olateju *et. al*.,(2018) assessed the groundwater prospect and aquifer protective capacity in Olabisi Onabanjo University campus, Ago-Iwoye using resistivity method and concluded that the north, north-eastern and south-western parts of the study area are characterized to yield more water than the other part of the study area. The study area is overlain mostly by materials of weak protective capacity and only a small area of the south- western part is of moderate protective capacity. It is therefore evident that groundwater in most parts of the area is vulnerable to pollution.

Osi-Okeke *et al.,* (2021) evaluated the hydrogeological and aquifer protective capacity of Abakaliki/Afikpo area and environs, using Vertical Electrical Sounding and concluded that the southern part of the 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.

Oladunjoye et al (2011), used geochemical analysis in environmental impact assessment of waste disposal site in Ibadan, Southwestern Nigeria. The resistivity survey yielded low resistivity values at locations close to the septic tank and higher values further from it which revealed that the environment is impacted by the septic system.

Abdullahi *et. al.,* (2014) used geo-electrical method in the evaluation of groundwater potential and aquifer protective capacity of overburden units around Opi area in Nsukka, Southeastern Nigeria and their results revealed a heterogeneous nature of the subsurface geological sequence.
Oghenero *et. al.,* (2018) assessed the Protective Capacity of Aquifers using Very-Low-Frequency Electromagnetic Survey at Burutu, Delta State and concluded that the clay materials produced the high positive peak values associated with the filtered real components, while the non-anomalous zones are less positive and negative for filtered real components, which were caused by sand. The non-anomalous zones and the corresponding high resistivity values are areas associated with the freshwater discharge, and they also specify the presence of shallow aquifers that are not being intruded by saltwater.

In Anambra State, Eugene *et. al.,* (2020) carried out the geoelectrical investigation of groundwater potential and vulnerability at Oraifite, Anambra state and revealed that 90% of the study area has poor aquifer protective capacity. Therefore, these areas are vulnerable to contamination.

Onyenweife *et. al*., (2020) estimated aquifer protective capacity at Awka and its environs using Vertical Electrical Sounding and concluded that the aquifers in the study area have better protective capacity of groundwater in comparison to the geological formations. Nine (9) locations, representing 50% of the surveyed area have aquifer protective capacity rated good while four (4) of the locations representing 22.2%

of the surveyed area have moderate protective capacity rating.

Nzemeka *et. al.,* (2023) estimated the groundwater potential and aquifer protective capacity of the overburden units within Agricultural Farm Estate Nkwelle - Ezunaka, Anambra State using Vertical Electrical Sounding and concluded that all parts of the area are underlain by materials of poor protective capacity and therefore the area is vulnerable to pollution that may arise from runoff water, sewage and indiscriminate waste disposal in the study area.

3. Experimental Method/Procedure/Design

This study involved the use of electrical resistivity method. The technique adopted was Vertical Electrical Sounding (VES). A total of three Vertical Electrical Sounding (VES) using Schlumberger array (figure 1) was conducted at Abube Agu Nando and Igboezenu Aguleri.

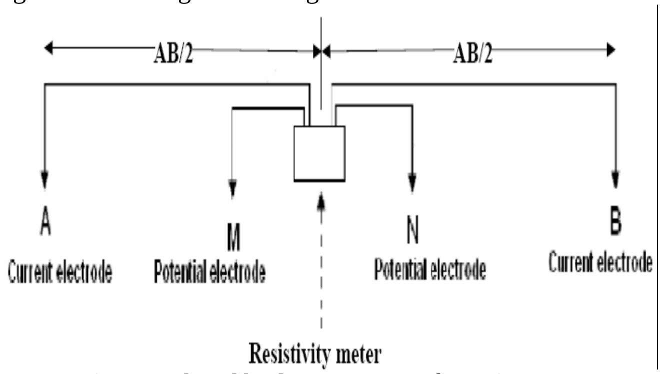

Figure 2: The Schlumberger array configuration

In this survey, current is passed between the A and B electrodes, while the potential difference is monitored between the M and N electrodes. By varying the electrode spacing, the survey aims to characterize different lithologic units and determine the depth to the water table.

The Schlumberger array configuration involves increasing the distance between the current electrodes (A and B) to probe deeper horizons. The distance between the current and potential electrodes at the center of the array is crucial for depth probing. The reasonable distance between the M and N electrodes should be equal to or less than one-fifth of the distance between the A and B electrodes at the beginning, and this ratio can increase to one-tenth or one-fifteenth depending on the signal strength.

In this specific survey, the maximum current electrode spread is 400 meters, with 200 meters on both sides. The current electrode spacing starts at 2 meters and extends up to 200 meters, while the potential electrode spacing starts at 0.5 meters and extends up to 20 meters. The $\frac{AB}{2}$ or half current electrode spacing was increased to a maximum of 200 meters

In the majority of cases, the $\frac{MN}{2}$ or half potential electrode spacing resulted in overlapping two readings. This indicates that the potential electrodes spacing were only increased when the potential difference decreased to a level where accurate measurements could no longer be obtained. During the survey, there was no need to increase the potential electrodes spacing until reaching the current electrodes spacing of 9 and 75 meters. At these specific points, measurements were taken for both the previous and new values of the electrode spacing. This particular procedure enables the identification of near-surface inhomogeneities.

Table 1. Sample of VES data sheet

VES 1 DATA SHEET

LOCATION: Igboezunu Aguleri

CO-ORDINATE **N: $06^{0}19^{'}12.2^{''}$**

E: $006^{0}54^{'}10.0^{''}$

ELEVATION: 130m

STATION NO: VES 1

READING NO:	$\frac{AB}{2}$	$\frac{MN}{2}$	Ka	R(Ω)	ρ_a(Ωm)
1	2		11.78	40.42	476.148
2	3	0.5	27.50	20.50	563.75
3	6		112.36	8.937	1004.161
4	9		253.79	5.411	1373.257
5	9	2.0	60.50	11.02	666.71
6	15		173.64	7.125	1237.185
7	25		487.93	2.539	1238.854
8	40		1254.00	1.492	1870.968
9	50		1961.14	0.5699	1117.653
10	75		4416.50	0.5321	2350.019
11	75	10.0	868.21	1.401	1216.362
12	100		1555.71	1.924	2993.186
13	150		3520.00	1.186	4174.72
14	200		6270.00	0.6227	3931.29

The VES field results was recorded as shown in Table 1**.**

where

$\frac{AB}{2}$ is the half current electrode spacing which extends from 2m to 200m on both sides

$\frac{MN}{2}$ is the half potential electrode spacing which extends from 0.5m to 10m

Ka is the geometric factor (K) calculated using eqn 1 which is

$$K=\pi\left\{\frac{\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2}{MN}\right\} \quad (1)$$

R (Ω) is the Resistance values collected from the field using ABEM SAS 1000 resistivity meter

ρ_a is the apparent resistivity values calculated using eqn 2 which is

$$\rho_a=\pi\left\{\frac{\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2}{MN}\right\} x\ R \quad (2)$$

The VES field data were processed using the Schlumberger automatic INTERPEX analysis software, which generates model curves using initial layer parameters. The Dar-

Zarrouk parameters were obtained from the first order geoelectric parameters (layer resistivities and thicknesses).These include the total longitudinal unit conductance (S). These secondary geoelectric parameters are particularly important when they are used to describe a geoelectric section consisting of several layers (Zhody *et al.* 1974). For n layers, the total longitudinal unit coductance is

$$S = \sum_{i=1}^{n} \left(\frac{h_i}{\rho_i}\right) \quad (3)$$

where h_i is the thickness of the ith layer and ρi is the resistivity of the ith layer. Using Ogungbemi (2013) classification, the results of longitudinal conductance was used to classify areas into good, moderate, weak and poor protective capacity as shown in Table 2. The lithology was inferred to the layers from the correlation between the one of the borehole drilled in the study area and geology of the study area (Ugwu and Ezeh, 2012; Nzemeka *et. al.*, 2023).

Table 2: Longitudinal Conductance/Protective Capacity Rating Ogungbemi (2013)

Longitudinal Conductance (mhos)	Protective Capacity Rating
>10	Excellent
5 – 10	Very good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
< 0.1	Poor

4. Results and Discussion

The Qualitative Interpretation of VES Results

Sounding curve analysis aims to obtain the equivalent subsurface layering of the apparent resistivity curve. The qualitative interpretation of the profiles and depth sounding curve were carried out based on distinctive geoelectric parameters on the number of layers represented by the four types of auxiliary curves (A, H, K and Q). VES 1 curve type is QH (Fig 3) with four geoelectric layers, VES 2 curve type is HH (Fig 4) which has five geoelectric layers while VES 3 curve type is QHK (Fig 5) which also has six geoelectric layers. The summary of qualitative interpretation of VES curves is shown in Table 3.

Table 3: summary of qualitative interpretation of ves curves

VES	CURVE TYPE	RESISTIVITY PROFILE	NUMBER OF LAYERS
1	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	4
2	HH	$\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$	5
3	QHK	$\rho_1 > \rho_2 > \rho_3 > \rho_4 < \rho_5 > \rho_6$	6

VES 1 carried out at Abube Agu, Nando showed four (4) geoelectric layers while VES 2 and 3 were both conducted at Igboezenu, Aguleri had five (5) and six (6) geoelectric layers respectively (Table 3).

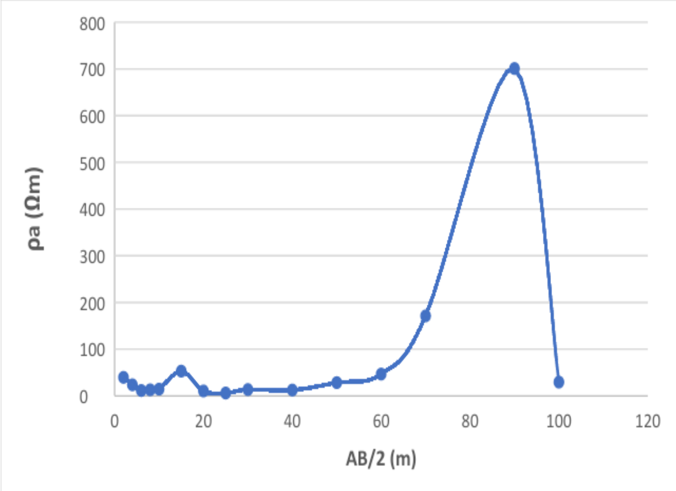

Fig. 3: Interpretation result of VES 1 curve of Abube Agu, Nando

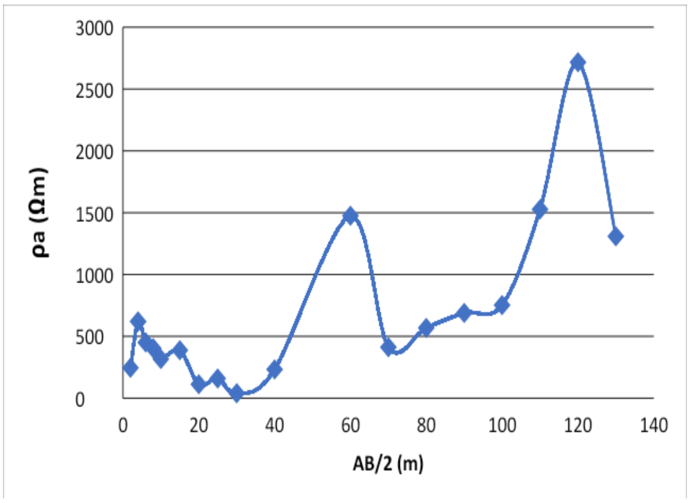

Fig. 4: Interpretation result of VES 2 curve of Igboezunu, Aguleri I.

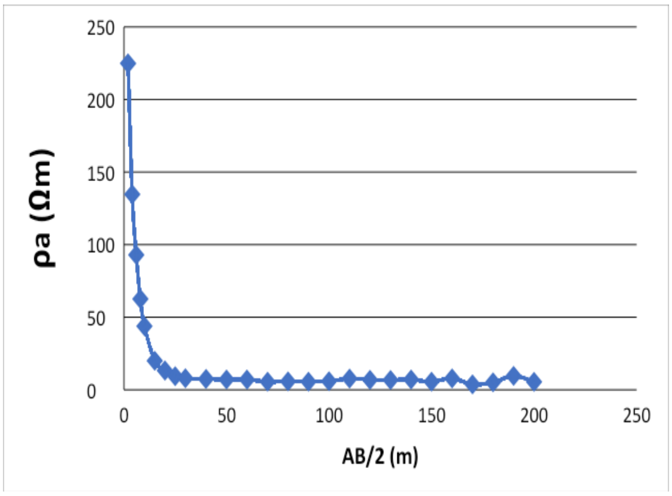

Fig. 5: Interpretation result of VES 3 curve of Igboezunu, Aguleri II

Quantitative Interpretation

Three geoelectric soundings were carried out in the study area. The stations were represented with VES 1 – 3 in Table 4:

Table 4: summary of ves interpretation results

VES	Layers	RESISTIVITY (Ωm)	Thickness (m)	Depth (m)	Lithology	Longitudinal conductance (S) (mhos)	Aquifer Protective Capacity
1	1	31.655	5.33	5.33	Red Earth	0.168	3.867 (Good)
	2	23.0025	14.67	20.00	Shaly Sand	0.638	
	3	19.6017	60.00	80.00	Shale	3.061	
	4	300.557	53.33	133.33	Water Saturated Sand	0.177	
2	1	433.35	5.33	5.33	Red Earth	0.0122	0.1889 (Weak)
	2	267.024	34.67	40.00	Shaly Sand	0.1298	
	3	853.375	40.00	80.00	Sandstone	0.0469	
	4	605.652	53.33	133.33	Water Saturated Sand	0.0881	
	5	1850.803	40.00	173.33	Shaly Sand	0.0216	
3	1	179.76	4.00	4.00	Red Earth	0.0223	6.293 (Very Good)
	2	66.45	6.00	10.00	Shaly Sand	0.0903	
	3	9.7075	60.00	70.00	Shale	6.1808	
	4	5.71	30.00	100.00	Water Saturated Sand	5.2539	
	5	6.9667	60.00	160.00	Water Saturated Sand	8.6124	
	6	5.9725	40.00	200.00	Shaly Sand	6.6974	

5.3 Discussion of VES results

A correlation between the borehole logs of Igboezunu town square Aguleri and Abube Agu Nando drilled 40m, 45m and 50m away from the study areas (VES 2, 3 and 1) respectively obtained from the State Ministry of Water Resources and the interpretation results of VES 1, 2 and 3 showed the occurrence of four to six lithologic layers respectively. These lithologic layers are as follows: Red Earth, Shaly Sand, Shale, Sandstone and water saturated sand as shown in Table 4. The first layer has resistivity values ranging from 31.655 – 433.35Ωm, inferred to be Red Earth with thickness ranging from 4.0 – 5.33m. The second layer inferred as Shaly sand has resistivity range of 23.0025 - 267.024 Ωm with the thickness varying from 10.0 – 40.0m. The resistivity of the third layer varies from 9.7075 – 853.375Ωm with the thickness varying from 40.0 – 60.0m. This layer was inferred to be shale for VES 1 and 3; sandstone for VES 2. The aquifer layer is water saturated sand which is located at the fourth and fifth layers, it is at these layers that the aquifer are located in agreement with the result of Oyeku and Eludoyin (2010) and Nzemeka *et al.*, 2023). The resistivity of the aquifer layers varies from 5.71 – 605.652 Ωm with thickness ranging from 53.33 – 60.00m. VES 1 – 3 have high aquifer thickness which is a favourable condition for productive and sustainable borehole yield (Ugwu *et al*. 2013; Nzemeka *et. al.*, 2023) The aquifer protective capacity was determined by calculating for longitudinal conductance and matching the values to the standard set by Ogungbemi *et al.,* (2013) (Table 2). The longitudinal unit conductance (S) values of the overburden unit obtained from VES 1 - 3 are 3.867, 0.1889, 6.293 mhos respectively which indicates a good, weak and very good aquifer protective capacities respectively.

6. Conclusion and Recommendation

In this study, the groundwater potential and aquifer protective capacity evaluation of the rock units around Aguleri and Nando environs in Anambra State were undertaken using three Vertical Electrical Soundings. The results showed that VES 1 - 3 has a total of 4 - 6 lithologic layers respectively. The subsurface sequence comprises of the red earth, shaly sand, shale, sandstone and water saturated sand. The water saturated sand layers constituted the aquifer unit in the area and its thickness varies from 30m to a maximum of 60m. All the areas of study are areas of productive and sustainable borehole yield because of their high aquifer thicknesses.

This study also revealed that all areas of study are underlain by materials of good, weak and very good protective capacity. It is therefore seen that VES 2 (Igboezunu Aguleri I) area is vulnerable to pollution that may arise from runoff water, sewage and indiscriminate waste disposal in the area because of its weak protective capacity. Thus these information obtained from results can be used for pre – drilling estimation of the yield of a prospective borehole in the area. For effective groundwater development programmes in the study area, we therefore recommend that pre-drilling geophysical investigations such as to assess the extent of contaminant infilteration be carefully conducted in Igboezunu Aguleri I area because of weak protective capacity for economic and environmental purposes. Any form of sewage and indiscriminate waste disposal should be discouraged and drainages channeled properly away from residential areas.

Authors' Contributions

Olisah Nzemeka C. is a geophysicist who has carried out various research work especially on groundwater potential and vulnerability in Enugu and Anambra State. I contributed to the analysis by collecting data at these towns and creating the map and figures depiciting terrain, surface water and groundwater.

Modu Franklyn C. is a student of geophysics who carried out all the interpretation and analyzing existing water resources data.

Nwobodo Anthonia N. is a lecturer and a geophysicist who has mentor various students in research work in solid earth geophysics in Enugu. She contributed in the equipment used in acquiring the data and also in data interpretation and processing.

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