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Hydrogeophysical assessment of aquifer vulnerability in some parts of Amawbia and its environs, south east, Nigeria

Obichukwu Obiemeka Obiajulu and Ezenwa Gabriel Nneji
Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Anambra State Nigeria
***Corresponding Author's E-mail**: o.obiajulu@unizik.edu.ng

Abstract
The rapid increase in the population of Amawbia has led to a growing demand for groundwater resources. This increase has necessitated the evaluation of aquifer protective capacity in order to protect it from contamination. The electrical resistivity measurements were used to assess the aquifer protective capacity of Amawbia. Vertical electrical sounding data were collected at four locations and the interpretation was done using Winresist software. The result revealed that the lithology of the area comprised mainly of laterite, clayey sand, shale, dry sand and saturated sand. The longitudinal conductance was computed using the resistivity and thickness values obtained from the interpreted data to evaluate the protective capacity. The protective capacity values ranged from 0.0081 to 1.3486 mhos. The results further revealed that most of the areas investigated are vulnerable to groundwater contamination.

Keywords: Groundwater, Electrical resistivity, vulnerability, Longitudinal conductance and Aquifer protection

1. Introduction

Amawbia is one of the fastest growing towns in Southeastern, Nigeria. The town has experienced significant development in both human and infrastructure. It is estimated that by next ten years, the population will double. The increasing population growth has led to rise in groundwater demand since over 90% of the population depend on groundwater. However, the quality and sustainability of groundwater largely depends on the protective capacity. Aquifers that lack adequate protection are highly vulnerable to contamination. Aquifer Vulnerability is a term used to describe how groundwater can be contaminated. This occurs when harmful substances enter into groundwater and reduces water quality. Some of the factors that can contribute to aquifer vulnerability include discharge of poorly treated industrial waste, leakage of chemicals like heavy metals, leakage from septic tanks and soak-away pits, open dumping of refuse and leachate, fertilizers and animal waste from livestock.

In recognition of the need to protect groundwater resources from contamination, geophysicts have developed methods for predicting areas that are vulnerable to contamination. These methods used for aquifer vulnerability assessment include DRASTIC method, GOD method, Aquifer vulnerability index (AVI) and Electrical resistivity method. Electrical method is widely used geophysical technique and is very suitable tools in exploration and has been widely applied in groundwater investigation (Obiajulu, 2021). The use of electrical resistivity method in investigating aquifer vulnerability is increasing becoming popular all over the world as it provides cost effective and an efficient means of collecting information about the subsurface of an area.

Researchers have applied this method to investigate aquifer vulnerability among them are Olisah et al., (2023) that investigated groundwater potential and aquifer protective capacity at Aguleri and Nando in Anambra State and found that some areas exhibited poor aquifer protective capacity. Akana et al., (2016) used the method to assess aquifer vulnerability to pollution in Yenagoa, Bayelsa State, Nigeria and reported that more than 50% of the area had a weak protective capacity, about 33% had poor protective capacity and 13% had good and moderate protective capacity. Atakpo (2013) applied the method to evaluate the vulnerability in Amukpe of Delta State, Nigeria and found all areas surveyed had poor protective capacity. Similarly, Oni et al., (2017) also the electrical method to evaluate groundwater vulnerability in Igbara Oke, Southwestern Nigeria and concluded that the area had poor to moderate aquifer protective capacity. The present study aims at using electrical resistivity method to evaluate aquifer vulnerability in Amawbia and its environs.

2.0 Materials and methods

The study area Amawbia is located in Awka South Local Government of Anambra State, Nigeria. The area lies 96 m above sea level and is situated along the old Enugu- Onitsha express road. The climate of the study area is tropical with its temperature averaging about 28^0c between April and October riseing to 33^0c between November and March (Nimet, 2012; Obiajulu and Okpoko, 2014). The study area lies within the Anambra basin in the lower Benue trough tectonic unit and are mainly underlain by the Imo shale formation. Figure 1 is the topographic map of Awka South showing the study area.

Figure 1: Topographic map of the study area

2.1 Materials

The materials used for this research work include two current electrodes through which currents are passed, potential electrodes which are used to measure the resulting voltage, Mc Ohm resistivity meter which was used to record apparent resistivity values. Others materials used are 12v battery used to power Mc Ohm resistivity meter, cables, hammers and measuring tapes etc.

2.2 Method

In the electrical resistivity method, an electric current is passed into the ground through current electrodes, the resulting potentials are measured at the surface using potential electrodes. Variations in the resistivity of materials beneath the ground affect how the electrical potential is distributed at the surface. The extent of this effect depends on the shape, size and resistivity of the underground materials. (Obiajulu and Nneji, 2026). For Schlumberger configuration, apparent resistivity according to Olisah et al., 2023 is given by:

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

Where $\frac{AB}{2}$ = half current electrode separation and $\frac{MN}{2}$ = half potential electrode separation.

3.0 Result and Discussion

3.1 Data Collection and Interpretation

Electrical resistivity data were acquired at four different locations. The instrument used was Mc Ohm resistivity meter which was used to obtain resistivity values which was later multiplied by the geometric factor to obtain apparent resistivity. The interpretation was done using Winresist software in order to obtain resistivity, thickness and depth values of various layers while the lithological sections were obtained by comparing the results with established geological information of the Anambra Basin and relevant previous studies. Fig 2 and Table 1 is a typical example of the interpreted VES data

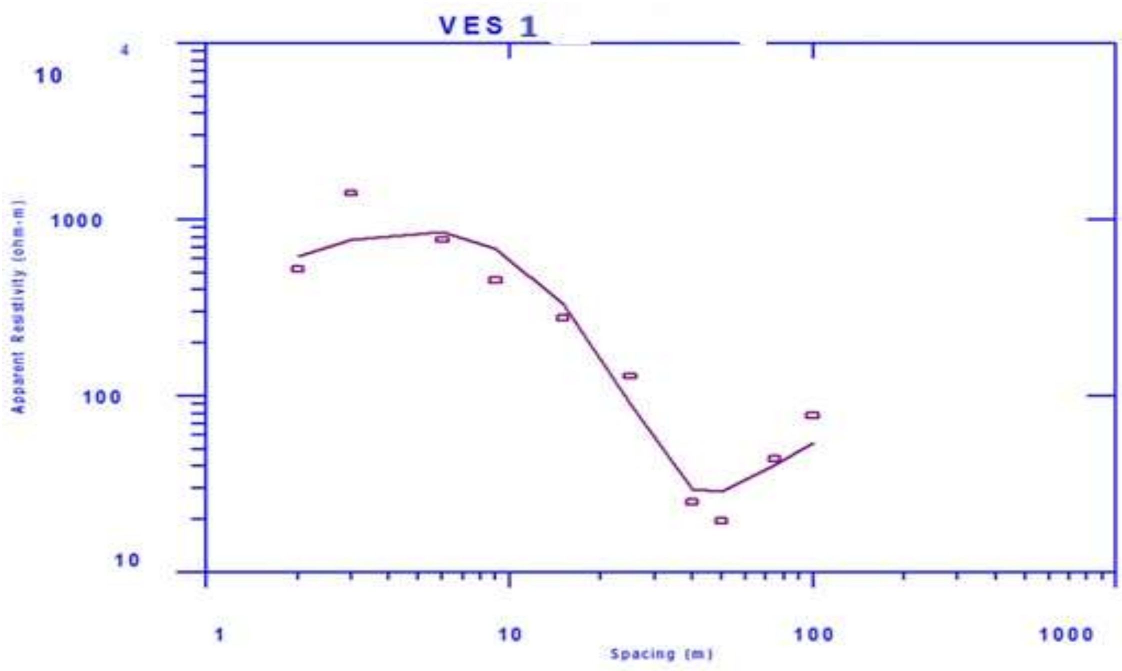

Figure 2: Sounding curve for VES 1

Table 1: Interpretation for VES 1

VES No. & Name	Layer	Res. (Ohm-m)	Thickness (m)	Depth (m)	Description
	1	744.83	2.52	2.52	Top soil/laterite
VES 1	2	1726.81	8.17	10.69	Dry sand
	3	892.35	26.05	36.74	Saturated sand
	4	8.13	13.89	50.63	Shale
	5	1591.62	Base not reached		Dry sand

3.2 Mathematical Formulation

The resistivity and thickness values obtained from the interpretation of VES data were combined to produce longitudinal conductance Lc (Dar-Zarrouk parameters). Longitudinal conductance is defined as the ratio of layer thickness (h) to resistivity (ρ), $L_C = h/\boldsymbol{\rho}$ (Ω^{-1}). (Ekwe et al.,2006; Obiadi *et al., 2022*)

This parameter is very important in evaluating the properties of an aquifer in an area. Since the protective capacity of the overlying materials is directly proportional to longitudinal conductance.

Conductance (S)	**Protective Capacity**	**Vulnerability**
High	Good	Low
Moderate	Moderate	moderate
Low	Poor	High

The total longitudinal conductance at each geoelectric sounding station was calculated using the formula

$$S=\Sigma\left(\frac{hi}{\rho i}\right)=\frac{h1}{\rho 1}+\frac{h2}{\rho 2}+\ldots\ldots+\frac{hn}{\rho n}$$ (Akana *et al., 2016*)

Where S is the total longitudinal conductance, h_i and $\boldsymbol{\rho}_i$ are the thickness and resistivity of the ith layer respectively. The resistivity and thickness values obtained from the interpretation of VES data were used to compute the longitudinal conductance L_C. Using Henriet (1976) classification table 2, the results of the longitudinal conductance were used to classify areas into good, moderate, weak and poor protective capacity while table 3 is the summary of the results obtained from VES.

Table 2 : Protective Capacity Rating (Henriet, 1976)

Sum of longitudinal conductance (mhos)	Overburden protective capacity classification
<0.1	Poor
0.1-0.19	Weak
0.2-0.69	Moderate
0.70-4.9	Good
5-10	very Good
>10	Excellent

Table 3: Calculated Values of VES Data and Aquifer Protective Capacities

VES	Layers	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Lithology	Longitudinal conductance (mho)	Protective capacity	Classification
1	1	744.83	2.52	2.52	Laterite Sand	0.0034	0.0081	Poor
	2	1726.81	8.17	10.69	Dry Sand	0.0047		
	3	892.35	26.05	36.74	Saturated Sand			
	4	8.13	13.89	50.63	Shale Sand			
	5	1591.62			Dry Sand			
2	1	4765.19	2.12	2.12	Laterite Sand	0.0004	0.0260	Poor
	2	245.97	4.04	6.16	Clayey Sand	0.0164		
	3	1598.66	14.71	20.87	Dry Sand	0.0092		
	4	869.04	23.14	44.01	Saturated Sand			
	5	12.74						
3	1	1313.57	2.40	2.40	Laterite Sand	0.0018	0.0517	Poor
	2	101.08	1.57	3.97	Shale Sand	0.0155		
	3	468.04	12.28	16.25	Clayey Sand	0.0262		
	4	3548.41	29.16	45.41	Dry Sand	0.0082		
	5	1528.17	27.18	72.59	Saturated Sand			
	6	15.95						
4	1	284.30	2.54	2.54	Laterite Sand	0.0089	1.3486	Good
	2	132.52	4.59	7.13	Clayey Sand	0.0346		
	3	15.57	19.96	27.09	Shale Sand	1.2820		
	4	943.09	21.82	48.91	Dry Sand	0.0231		
	5	663.39	22.11	71.02	Saturated Sand			
	6	8065.97			Dry Sand			

3.3 Discussion of Results

VES 1

There are five geoelectric sections in this location with the first layer having resistivity of 744.83 Ωm, thickness of 2.52 m and longitudinal conductance of 0.0034 mho and is interpreted as laterite. The second layer with resistivity of 1726.81 Ωm, thickness of 8.17 m and longitudinal conductance of 0.0047 mho is interpreted as dry sand. The third layer is interpreted as saturated sandstone (layer of interest) with resistivity of 892.35 Ωm and thickness of 26.05 m. The fourth layer has low resistivity of 8.13 Ωm, thickness of 13.89 m and is interpreted as shale. The last layer whose depth could not be reached is interpreted as dry sand with resistivity of 1591.62 Ωm. The aquifer protective capacity in this area is found to be poor with a value of 0.0081 mho.

VES 2

Five geoelectric layers were encountered in this location with the first layer interpreted as laterite having resistivity of 4765.19 Ωm, thickness of 2.12 m and longitudinal conductance of 0.0004 mho. The second layer has a resistivity of 245.97 Ωm, thickness of 4.04 m and longitudinal conductance of 0.0164 mho. Based on these parameters, it is interpreted as clayey sand. Beneath this layer lies the third which has resistivity of 1598.66 Ωm, thickness of 14.71 m and longitudinal conductance of 0.0092 mho. The fourth layer is the aquiferous layer of interest it has resistivity of 869.04 Ωm, thickness of 23.14 m and it's interpreted as saturated sandstone. The last layer is interpreted as shale with low resistivity of 12.74 Ωm. Based on the computed total longitudinal conductance of 0.0260 mho, aquifer in this location has a poor protective capacity.

VES 3

This area has six geoelectric layers with the first layer having a resistivity of 1313.57 Ωm, thickness of 2.40 m and longitudinal conductance of 0.0018 and as expected is interpreted as laterite. The second layer is interpreted as shale with low resistivity value of 101.08 Ωm, longitudinal conductance of 0.0155 mho. The third layer has a thickness of 12.28 m, longitudinal conductance of 0.0262 mho and is interpreted as clay. The fourth layer has resistivity value of 3548.41 Ωm, thickness of 29.16 and longitudinal conductance of 0.0082 mho. The fifth layer is the layer of interest with resistivity of 1528.17 Ωm, depth and thickness of 72.59m and 27.18 m. The last layer whose depth could not be reached is interpreted as shale with a low resistivity of 15.95 Ωm. Based on the total computed longitudinal conductance of this area. The area is classified as poor with protective capacity value of 0.0517 mho.

VES 4

Six geoelectric sections were encountered in this area with the first layer having resistivity value of 284.30 Ωm, thickness of 2.54 m and longitudinal conductance of 0.0089 mho. The second with resistivity of 132.52 Ωm and longitudinal conductance of 0.0346 mho is interpreted as clayey sand. Beneath this layer lies the third layer with a very low resistivity of 15.57 Ωm, thickness of 19.96 m and longitudinal conductance of 1.2820 mho and is interpreted as shale. The fourth layer is interpreted as dry sand with resistivity of 943.09 Ωm and longitudinal conductance of 0.0231 mho. The layer that follows it is the layer of interest (aquifer), it has resistivity of 663.39 Ωm and thickness of 22.11 m. The last layer whose depth could not be found is interpreted as dry sand with resistivity of 8065.97 Ωm. The total computed longitudinal conductance of this area is 1.3486 and so the aquifer in this area has a good protective capacity.

3.4 Quantitative and Comparative Analysis

The longitudinal conductance values obtained from the study area which ranged from 0.0081 to 1.3486 mhos with a mean value of 0.3586 mhos were statistically evaluated. The standard deviation shows spatial variation in the overburden protective capacity across the area. The result shows that 75% of the area surveyed had poor aquifer protective capacity while 25% had good protective capacity.

Geologically speaking, shale and clay have high longitudinal conductance (as a result of low resistivity values) provide good protection to the underlying aquifer whereas sandy materials have low protective capacity as a result of high resistivity values (low longitudinal conductance) does not really offer protection. (Obiajulu, 2021). This shows that the study area is predominately vulnerable to contamination due to low clay or shale content. The observed low protective capacity in most locations is consistent with dominance of sandy lithology which generally exhibits high permeability and low attenuation capacity

4.0 Summary and Conclusion

The increase in the population of Amawbia, Awka South Local Government Area of Anambra State have increased the demand for groundwater resources with majority of the population depending on groundwater for domestic and agricultural use. This has necessitated the evaluation of aquifer protective capacity to safeguard groundwater from being contaminated. This research was carried out with the aim to assess the vulnerability of aquifer in the area using electrical resistivity method.

Four vertical electrical sounding (VES) were conducted using Mc Ohm resistivity meter. The acquired data were interpreted with Winresist software to determine the resistivity, thickness and depth of the various layers. The longitudinal conductance was computed using the interpreted parameters (resistivity and thickness) to evaluate the protective capacity. Using Henriet (1976) classification, the results of the protective capacity across the study area revealed that VES 1, 2 and 3 had poor protective capacity accounting to 75% of the area surveyed with longitudinal conductance ranging from 0.0081 to 0.0517 mhos while VES 4 showed good protective capacity. The results showed that some areas in Amawbia are vulnerable to groundwater contamination.

The results obtained from this study are consistent with the works of Akana *et al*., (2016) and Atakpo (2013) which are in the same Anambra Basin with the study area. They reported that areas dominated by sandy formations exhibit low aquifer protective capacity due to high permeability and minimal shale and clay intercalations. However, the slightly better protective capacity observed at VES 4 (1.3486 mhos) may be attributed to the presence of shale layers which act as confining units thereby reducing contaminant from entering into the aquifer

This research has shown that electrical resistivity method is a cost effective and efficient way to investigate groundwater vulnerability assessment.

5.0 Recommendation

It is therefore recommended that open dumping site be replaced with engineered sanitary landfills, construction of properly lined and sealed septic systems and also maintain safe distances between septic tanks and boreholes and also taking the direction of groundwater flow into consideration

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