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Aquifer Vulnerability Assessment in Some Parts of Awka, South Eastern Nigeria.

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Abstract
A geophysical survey using electrical resistivity method was conducted to assess the vulnerability of aquifer in some parts of Awka, South Eastern, Nigeria. The Schlumberger array was adopted, vertical electrical sounding (VES) data were collected at twelve (12) locations with maximum current electrode spacing (AB) of 600m. The instrument used was Mc Ohm resistivity meter, a digital instrument for direct current resistivity work. The interpretation was done using software called IP2win. The results revealed that depth to aquifer ranged between 23.08 and 81.41m, resistivity of aquifer ranged between 452.9 and 2249.71Ωm. The interpreted parameters (resistivity and thickness) were used to compute the longitudinal conductance. The longitudinal conductance was considered to be directly proportional to protective capacity. Using Henriet (1976) classification, the longitudinal conductance values obtained ranged between 0.0044 and 2.157mho with the majority of the area having a poor aquifer protective capacity.

Keywords: *Aquifer, Vertical Electrical Sounding, Resistivity method, Longitudinal Conductance.*

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I. Introduction

Since Awka was made the capital of Anambra State, it has witnessed rapid increase in population. This increase in the population has led to an increased pressure on underground water which is the major source of water supply in the area. Groundwater is typically not easily contaminated, yet once this occurs, water quality is difficult to restore (Jang *et al 2017*). Groundwater quality has been affected by a number of factors such as movement of leachate to the aquifer from dumpsites, leakage of surface and underground storage and septic tanks and improper use and disposal of pesticides etc. The importance of quality water to human cannot be over-emphasized, therefore the need to protect the resource becomes imperative. Several groundwater (boreholes) in the area have been abandoned as a result of contamination after a lot of money have been spent. Huge financial and serious health hazards would have been averted if a well planned vulnerability assessment had been carried out. The vulnerability is the sensitivity of an aquifer to be adversely affected by an imposed contaminant load (Oni *et al, 2017*). Meanwhile the earth materials act as natural filter to percolating fluids, therefore its ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity (Akpan *et al, 2018*). In order to guarantee a continuous supply of safe and potable water in the area, there is need to assess the vulnerability of the aquifers to contamination. There are modern approaches to assess groundwater vulnerability, these include DRASTIC, Electrical resistivity and GOD method etc but because of some factors like availability of the instruments, cost effectiveness, DC electrical resistivity was used in this research to assess the aquifer vulnerability of the study area.

II. Description and Geological setting of the study area

The study area, Awka is the capital of Anambra state, South Eastern Nigeria. The area has a topography that slopes gently towards Mamu River with Major cuestas lying in the North South direction. The study area, Awka is located on latitude 6^{o} 25N, and longitude 7^{o} E. The city is along Enugu - Onitsha express road. The climate of the study area is tropical with an average yearly rainfall of 1500mm while daily temperature ranges from 22^{o}C to 32^{o}C. Relative humidity for the wet months is 90% while for the dry months; it is 65% (Egboka and Okpoko, 1999; NIMET, 2012). Two climatic seasons exists, the wet season which is experienced from the months of April to October and the dry season which is felt from November to March. During the dry season, the influence of the Sahara air mass affects 75% of the country. The air is dry and dusty. The rainy season is characterized by heavy flooding, groundwater infiltration and percolation. The study area lies within the Anambra basin in the lower Benue trough tectonic unit. The geology and regional stratigrapy of the trough has been studied and described in details by many researchers including (Ehirim and Ebeniro, 2010;

Ezeigwe,2015). The study area are mainly underlain by the Imo Shale Formation (fig 1). This consists of thick clayey shale, fine-textured, dark-grey to bluish-grey with occasional admixture of clay ironstone and thin sandstone bands. The Formation becomes sandier towards the top where it may consist of alternating bands of sandstone and shale (Ehirim and Ebeniro,2010).The Imo Shale Formation is an aquiclude, but contains some thin lenses of sand bodies which when saturated and probably encountered, could yield productive boreholes under confined and unconfined conditions. The shales are hydrogeologically important since they form the confining impermeable layers.

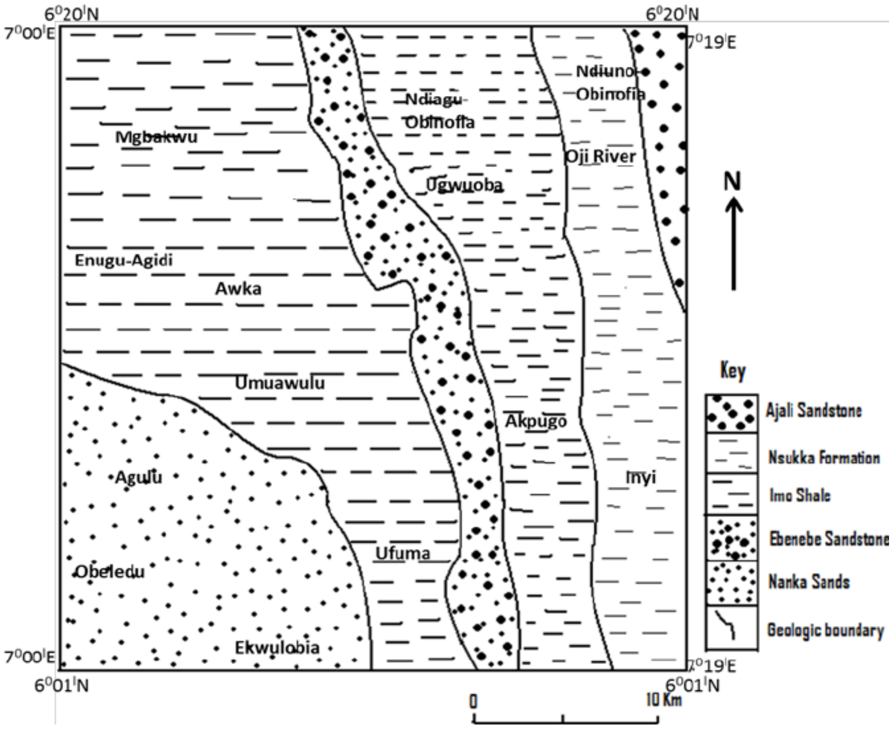

Fig 1: Geologic map of some parts of Anambra basin showing the study area.
Source: (Anakwuba *et al*.,2014

III. Materials and Methods

The materials used for this research consist of the followings:

MC Ohm resistivity meter used to record the resistance values, 12V battery used to power resistivity meter, two current electrodes through which current is passed and two potential electrodes used to measure the voltage caused by the current. Other materials include cables, hammers, measuring tapes, writing materials, GPS and handsets.

In this research work, the Schlumberger array of electrical resistivity survey was adopted. The four electrodes are positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside. Current is sent through the outer electrodes A and B and the potential is measured across inner electrodes M and N. To change the depth range of the measurement, the current electrodes are displaced outwards while the potential electrodes in general are left at the same position. When the ratio of the distance between the current electrodes to that between the potential electrodes become too large, the potential electrodes will be displaced outwards otherwise, the potential difference becomes too small to be measured with sufficient accuracy. (Koefoed, 1979; Obiajulu, 2018).

For Schlumberger configuration, apparent resistivity according to Dobrin (1983) is given by:

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

Where $\frac{AB}{2}$ = half current electrode separation

$\frac{MN}{2}$ = half potential electrode separation.

Vertical electrical sounding (VES) data were collected at twelve (12) locations with maximum current electrode spacing (AB) of 600m (fig 2). The instrument used was MC Ohm resistivity meter, a digital instrument for direct current resistivity work. The current electrodes and the potential electrodes were driven into the ground at marked points. A good contact between the ground and the electrode was ensured by hammering the electrodes deep into the ground. Current was injected into the ground through the current electrodes and the potential electrodes are measured across the potential electrodes which displayed on the resistivity meter.

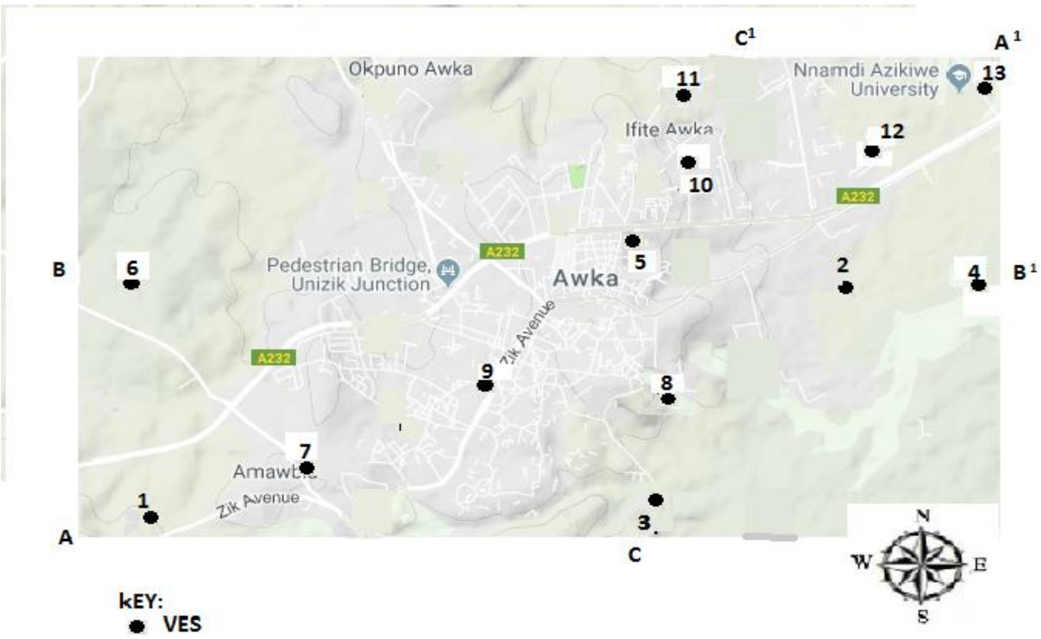

Fig 2: Topographic map of the study area showing the sounding points.

The interpretation was done using software known as IP2win, this was to determine the subsurface layer resistivities and their thicknesses.

The combination of resistivity and thickness obtained from the interpretation of VES data into single variables known as Dar Zarrouk parameter (longitudinal conductance L_C) which is defined thus

Longitudinal conductance $L_C = h / \boldsymbol{\rho}$ (Ω^{-1})

Is one of the most important parameters often used in the evaluation of aquifer properties.

Knowledge of the longitudinal conductance L_c is of importance in assessing the vulnerability of the aquifer in an area. The protective capacity is considered to be proportional to the longitudinal conductance in mhos (Oladapo *et al, 2004*). The total longitudinal conductance (S) for each of geoelectric sounding stations was computed from the relation

$$S = \Sigma \left(\frac{hi}{\rho i}\right) = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \ldots\ldots + \frac{hn}{\rho n}$$ (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 1 , the results of the longitudinal conductance were used to classify areas into good, moderate, weak and poor protective capacity and table 2 shows the aquifer protective capacity values obtained from the study area.

Table 1: 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
0.70-1.0	Good

IV. Results and Discussions

Table 5: Summary of the Results obtained from VES data.

VES	Location	GPS Coordinates	Layers	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Lithology	Transvers Resistance (Ωm)	Longitudinal Conductance (mho)	Protective Capacity	Classification
1	Comm. Pri. Sch.	$06^{0}11^{1}427^{11}N$	1	309.21	2.28	2.28	Laterite	705	0.0074	0.0237	Poor
		$07^{0}2^{1}729^{11}E$	2	190.72	1.29	3.57	Clayey sand	246	0.0068		
			3	2643.08	25.15	28.72	Dry sand	66473	0.0095		
			4	940.54			Saturated sand				
2	Behind Awka Sports Club	$06^{0}10^{1}727^{11}N$	1	2478.52	2.43	2.43	Laterite	6023	0.00098	0.0162	Poor
		$07^{0}03^{1}838^{11}E$	2	299.46	1.88	4.31	Clayey Sand	563	0.0063		
			3	2525.61	22.63	26.94	Dry sand	57155	0.0089		
			4	1019.08			Saturated Sand				
3	Amenyi, Awka	$06^{0}13^{1}512^{11}N$	1	699.14	2.28	2.28	Laterite	1594	0.0033	0.0065	Poor
		$07^{0}05^{1}174^{11}E$	2	4418.28	14.25	16.53	Dry Sand	62960	0.0032		
			3	1643.08	30.58	47.11	Saturated sa	50245			
			4	36.03	13.18	60.29	Shale	475			
			5	1976.31			Dry sand				
4	Esther Obiakor	$06^{0}14^{1}411^{11}N$	1	1372.04	2.34	2.34	Laterite	3211	0.0017	0.0403	Poor
		$07^{0}05^{1}896^{11}E$	2	82.19	1.31	3.65	Clayey Sand	108	0.0159		
			3	1421.56	32.38	36.03	Dry Sand	46030	0.0227		
			4	719.08	11.48	47.51	Saturated san	8255			
			5	32.11	10.66	58.17	Shale	342			
			6	1836.69			Dry sand				
5	Behind Hausa Quarters	$06^{0}10^{1}132^{11}N$	1	522.81	2.36	2.36	Laterite	1234	0.0045	0.072	Poor
		$07^{0}03^{1}518^{11}E$	2	107.28	1.63	3.99	Clay	175	0.0152		
			3	398.74	12.06	16.05	Clayey Sand	4809	0.0302		
			4	1295.63	28.58	44.63	Dry sand	37029	0.0221		
			5	841.35	17.91	62.54	Saturated sand	15069			
			6	1277.25			Shale				
6	Nwakpad olu Estate	$06^{0}14^{1}219^{11}N$	1	88.23	2.29	2.29	Laterite	202	0.0259	0.0712	Poor
		$07^{0}04^{1}114^{11}E$	2	477.09	9.72	12.01	Clayey Sand	4637	0.0204		
			3	1396.33	34.73	46.74	Dry Sand	48495	0.0249		
			4	857.28	27.88	74.62	Saturated sand	23901			
			5	52.84	28.57	103.19	Shale	1510			
			6	4732.44			Dry sand				
7	Abuja Estate	$06^{0}13^{1}219^{11}N$	1	187.29	2.37	2.37	Laterite	444	0.0127	0.0272	Poor
		$07^{0}04^{1}098^{11}E$	2	591.33	4.34	6.71	Clayey Sand	2566	0.0073		
			3	2264.72	16.38	23.09	Dry Sand	37096	0.0072		
			4	1579.01	51.02	74.11	Saturated	80561			

							sand				
			5	40.05	76.22	150.33	Shale	3053			
			6	7664.42			Dry sand				
8	Close to Unizik	$06^0 15^1 137^{11}$N	1	38.91	1.07	1.07	Laterite	42	0.0275	0.4154	Moderate
		$07^0 06^1 891^{11}$E	2	20.09	4.15	5.22	Shale	83	0.2066		
			3	83.45	15.13	20.35	Clay	1263	0.1813		
			4	572.5	8.3	28.65	Saturated san	4752			
			5	877.7			Dry sand				
9	Amansea 1, Awka	$06^0 15^1 421^{11}$N	1	1170.28	2.36	2.36	Laterite	2762	0.002	0.0044	Poor
		$07^0 06^1 329^{11}$E	2	2422.71	5.85	8.21	Dry sand	14173	0.0024		
			3	1160.56	14.87	23.08	Saturated sand	17258			
			4	46.47	27.06	50.14	Shale	1257			
			5	5974.72			Dry sand				
10	Dumpsite, Aguawka	$06^0 13^1 914^{11}$N	1	507.06	2.72	2.72	Laterite	1379	0.0054	0.0323	Poor
		$07^0 06^1 291^{11}$E									
			2	757.01	13.61	16.33	Clayey Sand	10303	0.0179		
			3	3558.92	31.72	48.05	Dry Sand	112889	0.009		
			4	1209.43	26.86	74.91	Saturated sand	32485			
			5	20.49			Shale				
11	Opp Udoka	$06^0 11^1 903^{11}$N	1	559.8	2.32	2.32	Laterite	1299	0.0041	2.157	Good
	Estate										
		$07^0 03^1 017^{11}$E	2	390.46	4.87	7.19	Clayey sand	1902	0.0125		
			3	17.03	36.28	43.47	Shale	618	2.1304		
			4	1357.67	13.64	57.11	Dry sand	18519	0.0100		
			5	914.06	18.91	76.02	Saturated sand	17285			
			6	22.34			Shale				
12	Dike Street	$06^0 12^1 091^{11}$ N $07^0 03^1 171^{11}$E	1	724.5	1.05	1.05	Laterite	761	0.0014	0.3142	Moderate
			2	3126	3.94	4.99	Dry sand	12316	0.0013		
			3	238.6	15.08	20.07	Clayey Sand	3598	0.0632		
			4	45.26	11.24	31.31	Shale	509	0.2483		
			5	452.9			Saturated sand				

Twelve (12) vertical electrical soundings were carried out, the VES were grouped into three profiles AA^1, BB^1 and CC^1 (fig 2), the discussion of the results are presented below.

Profile AA^I

This profile was drawn along NE-SW direction of the study area. The VES along this profile are VES 1, VES 7, VES 9 and VES 12 (fig 2). The first layer with resistivity ranged between 309.21 and 1170.28Ωm and thickness between 1.05 and 2.36m is interpreted as laterite . The second layer has resistivity and thickness ranged between 190.72 and 3126.0Ωm and between 1.29 and 5.86m respectively. The aquifer bearing layer is identified at the fourth layer except in VES 9 and VES 12 where they are seated at the third and fifth layer respectively, their resistivity values varies from place to place but falls within the range of 452.90- 1579.01Ωm. Depth to aquifer in this profile ranged between 23.08 and 74.11m. The aquifer protective capacity in this profile is classified as poor expect VES 12 which is classified as moderate (table 2).

PROFILE BB^1

There are four sounding points along this profile VES 2, VES 4, VES 5 and VES 6 (fig 2) . The first layer has resistivity ranged between 88.23 and 2478.52Ωm and thickness ranged between 2.29 and 2.43m and is interpreted as laterite . The second layer with resistivity and thickness ranged between 82.19 and 477.09Ωm and between 1.31 and 9.72m is interpreted as clay. The third layer has resistivity ranged between 398.74 and 2525.61Ωm and thickness ranged between 12.06 and 34.73m is interpreted as dry sand except in VES 5 where it is interpreted as clayey sand. The layer of interest (aquifer) is located at the fourth layer except in VES 5 where it is seated at the fifth layer, it has its lowest resistivity at VES 4 with resistivity of 719.08Ωm and highest resistivity at VES 2 with resistivity of 1019.08Ωm, the depth of aquifer varies from place to place but falls within the range of 26.94 to 46.74m (fig). Aquifers in this profile are vulnerable to contamination as can be seen in table 2 . The aquifer protective capacity of this profile ranged between 0.0162 and 0.0720mhos and is classified as poor.

Profile CC[1]

There are four sounding points drawn along this profile VES 3, VES 8, VES 10 and VES 11 respectively (fig 2). The first layer as expected is interpreted as laterite with resistivity ranged between 38.91 and 699.14Ωm and thickness ranged between 1.07 and 2.72m. The second layer with resistivity ranged between 20.09 and 4418.28Ωm and thickness ranged between 4.15 and 14.25m. The layer of interest which is interpreted as saturated sand varies from place to place, it has resistivity ranged from 572.5 and 1643.08Ωmand thickness ranged from 8.3 and 30.58m respectively (fig). The protective capacity values of the aquifer in this profile are 0.0065 (poor), 0.4154 (moderate), 0.0323 (poor) and 2.157 (good) respectively as can be seen in table 2.

V. Summary and Conclusion

Electrical resistivity method was used to carry out this research in the study area (Awka) with the aim to assess the vulnerability of aquifer. Thirteen vertical electrical soundings were conducted. The computer interpretation techniques have helped to resolve the resistivities, thicknesses and the depths to the various layers. Data analysis showed that the area under investigation was a four to six layered. The top layer resistivity and thickness ranged between 38.91 and 2478.52Ωm and between 1.05 and 2.72m respectively and consisted of laterite. The second layer has a resistivity and thickness ranged between 20.09 and 4418.28Ωm and between 1.29 and 14.25m respectively and are consisted mainly of clayey/ dry sand except in VES 8 where it contained shale. The third layer has a resistivity ranged between 17.03 and 9945.26Ωm and thickness ranged between 12.06 and 45.27m. The fourth layer is mainly where the aquifer is located and it is interpreted as saturated sand except in VES 5, VES 11 and VES 12 where it is seated at the fifth layer and VES 3 and 9 where it is seated at the third layer, the resistivity of the aquifer bearing layers has its lowest value at VES 12 with resistivity of 452.9Ωm and its highest value at VES 13 with resistivity of 2249.71Ωm, its lowest thickness value is found at VES 8 with value of 8.3m and highest value of 51.02m at VES 7 respectively. The results obtained have shown a very close semblance with those obtained from borehole drillers log. This shows that dc electrical resistivity method is a very useful method to investigate the lithology/aquifer systems within the area.The modeled geoelectric parameters (layer resistivity and layer thickness) at each station were used to compute the longitudinal conductance L_c. The total longitudinal conductance of the study area was observed to be low with its value ranging between 0.0044 and 2.1570 mho. Geologically speaking, shale and clay which have high longitudinal conductance (as a result of low resistivities values) provide protection to the underlying aquifer whereas sand that has a very low protective capacity as a result of high resistivity value (low longitudinal conductance) does not really offer protection. The high value of the protective capacity as was observed in VES 11 was due to the presence of shale and clay underlying the aquifer and the low value of the protective capacity (poor and moderate) observed in VES 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12 and 13 were due to the absence of shale and clay which expose aquifer hence becomes vulnerable to contamination. The low protective capacity of the study area has helped us to conclude that the aquifer in the study area may be vulnerable to some factors such as leakage of underground septic facilities, over abstraction and leachate to the aquifer from the dumpsite etc.

Conclusively if Government, Estate developers, Individuals and those involved in underground water should take the results obtained from this research into consideration, cases of loss of lives and health hazards arising from boreholes will be minimized.

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