International Journal of Innovative Environmental Studies Research 8(4):1-17, Oct.-Dec., 2020

© SEAHI PUBLICATIONS, 2020 www.seahipaj.org ISSN: 2354-2918

Application of Electrical Resistivity Method in Estimating Aquifer Protective Capacity of Awka and its Environs, Anambra State, Nigeria

Onyenweife, G. I[1*]., Nwozor, K.K[1]., Nwike, I.S[1]., Onuba, L.N[1]., Egbunike, M.E[1]., and Anakor, S.N[1].

[1]Department of Geology,
Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria
***Email of corresponding author: onyenweifegeraldine@gmail.com**

ABSTRACT

The unlawful discharge of pollutants from the industries and anthropogenic factors has an alarming danger to groundwater potential. Groundwater is a vital natural resource that plays a significant function in sustainability of living things on earth. This research helped to unveil the rate of aquifer protective capacity of the study area against the effects of pollutants. The measured resistivity data were interpreted with computer software packages, which gave the resistivity, depth, and thickness for each layer within the maximum current electrodes separation. Aquifer parameters useful for this analysis were determined and highlighted through vertical electrical sounding data of nine (9) communities at two locations each in the study area. The geoelectric sections of zone A and zone B revealed aquifer thickness ranges from 30 m – 140 m and 20 m – 140 m respectively following with aquifer depths of 40 m – 90 m and 40 m – 100 m respectively. The result of aquifer resistivity of the study area ranges from 108.92 Ωm – 1214.04 Ωm in zone A and 147.23 Ωm – 1235 Ωm in zone B while aquifer longitudinal conductance of the study area ranges from 0.00819 Ohm^{-1} – 0.45879 Ohm^{-1} in zone A and 0.04855 Ohm^{-1} - 1.03950 Ohm^{-1} in zone B. The estimated values of overburden longitudinal conductance of the aquifer in the study area ranged from 0.009 Ohm^{-1} – 3.484 Ohm^{-1} in zone A and 0.075 Ohm^{-1} – 2.340 Ohm^{-1} in zone B. The interpreted results of overburden layer show 50% good, 22.2% moderate, 11.1% weak and 16.7% poor aquifer protective capacity. These foretell that aquifers in Awka and environs have been distinguished geologically/geophysically to have predominantly moderately good aquifer protective capacity with lenses of weak – poor protective capacity. The results of this study also help in groundwater resource exploration and management.

Keywords: - VES, Aquifer Resistivity, Longitudinal Conductance and Aquifer Protective Capacity.

1.0 INTRODUCTION

Groundwater forms a major source of drinking water and mostly used in the maintenance of plants and animals' life. Groundwater is reserved for the subsurface water that occurs beneath the geological formation capable of yielding water. Groundwater is constantly in motion in the hydrosphere through the process of water cycle (Amadi, 2010). Despite its usefulness, the uncontrollable increase in human populaces, anthropogenic pollution and industrial discharges trigger contamination of the groundwater thereby shortening groundwater potential of Awka and environs. The presence of these pollutants deteriorate the quality of environmental media; air, water and land, thus releasing water and other environmental related diseases thereby threatening human health and balance of aquatic ecosystems (Ogbonna, 2006).

Furthermore, poor drilling techniques by the local or unprofessional drillers stand great chances of contaminating the groundwater in study area. Groundwater contamination is an impairment of water quality by chemicals, heat or bacteria to a degree that does not only create public hazard rather does adversely affect such water for domestic, farm, municipal or industrial use (Akhilesh et al., 2009). Heavy metal contamination in addition to reducing the quality of groundwater in the study area poses great risk to the health of the increasing populace. Nwozor et al. (2015) linked the source of these metals to the result of the weathering and leaching of volcanic aggregates that are mostly used in places of river gravels as borehole completion materials.

Water related diseases are mostly responsible for about 80% of illnesses or deaths in the developing countries and kill infants more (UNESCO, 2007). These suggest that the groundwater is susceptible to contamination. The geological setting of the study area tends to be favorable in reducing the tendency of groundwater contamination as shale being a good filter. Combination of the resistivity and thickness of the overburden layers was used to compute the longitudinal conductance of the layers which is the way for assessing groundwater/aquifer protective capacity. Therefore, the study considered it necessary to delineate the vulnerability of the underlying aquifer to contamination and educate the populaces on the proper disposal of wastes.

2.0 LOCATION OF THE STUDY AREA

The study area is located in Awka South Local Government Area, Anambra State, Nigeria. Awka South Local Government Area is made up of nine towns namely; Amawbia, Awka, Ezinato and Awka, Okpuno, Isiagu, Mbaukwu, Nibo, Nise and Umuawulu. Awka and environs lie within the latitudes: 06° 06'N and 06° 15'N and longitudes: 07° 05'E and 07° 15'E and covers a land extent of about 120 km². Two climatic conditions exist in Nigeria and the study area, namely the dry season and the rainy season. The rainy season occur between April – July, followed by a short dry period in August lasting two to three weeks with the rain starting in September to October. The dry season is about five months (November – March) marked by a Harmattan wind that enters in late December to early part of January as it leads to extreme dry heat later in February and March. The temperature of Awka is about 27-30 degree Celsius between June and December and rises to 32-34 degree Celsius in last few months of dry season resulting to intense heat. The study area is reasonably accessible. The Enugu – Onitsha express way is the major route that facilitates the mobility within the study area. Fig. 1 below shows the communities of the study area aligned in the befitted coordinates as subdivided into zone A and zone B for easy access and workflow.

2.1 Geological Setting of the Study Area

Awka area is located within the Anambra Basin in southeastern Nigeria which formed from the lower Benue Trough**.** Petters (1978) documented the main stages of tectonic evolution of the Benue Trough in stratigraphic succession. These include three depositional sequences; an Albian-Cenomanian pyroclastic, paralic shallow marine and fluviatile sequence corresponding to the graben and transitional tectonic stages. The subsequent stages include a Turonian–Coniacian paralic, marine and fluviatile sequence that gave rise to down-warping and resulting widespread marine transgression (Burke, 1972). Anambra Basin is one of the Cretaceous Sedimentary Basin of Nigeria which is bounded on the southwestern Benin flank by the Niger Delta, northwest by the Benue Trough and Southeast by the Abakaliki Anticlinorium. The formation of Anambra Basin was as a result of tectonic activities that accompanied with the Africa and South American plates in the Early Cretaceous (Murat 1972). During the evolution, Abakaliki Trough was uplifted to Abakaliki Anticlinorium while the Anambra platform was downwarped to form the Anambra Basin (Weber and Daukora, 1975), which resulted in the westward displacement of the trough's depositional axis. Its sedimentation trend is said to be a platform by the drifting of depocentres. In Anambra Basin, the strongly folded Albian – Coniacian succession (Pre – Santonian Sediments) is overlain by nearly flat – lying Campanian – Eocene Succession. Anambra Basin consists of Nkporo Group which is the oldest sediment; Nkporo Group is overlain by Mamu Formation which was deposited in Early Maastrichtian (Obi, 2000). It comprises succession of siltstone, shale, sand and coal seam. Mamu Formation which is mostly unconsolidated coarse-fine grained, poorly cemented, mudstone and siltstone is overlain by Ajali Sandstone (Reyment, 1965). Ajali Sandstone (Maastrichtian) is overlain by Nsukka Formation (Maastrichtian - Danian) which is also known as the upper coal measure. Imo Shale (Paleocene) overlies the Nsukka Formation (Nwajide, 1990). The study area is underlain by Paleocene Imo Shale and Eocene Ameki Formation. Imo Shale comprises clayey Shale with lenses of ironstone and sandstone in which carbonized plants remains may occur (Kogbe, 1989). The sandstone members of Imo Shale consist of Ebenebe, Umuna and Igaku sandstone members. The Eocene Ameki Formation which is underlain by Imo Formation consists of calcareous sandstone, grey – dark shale, argillaceous sandstone and pebbly sandstone. Nwajide and Reijers (1996) interpreted the Imo Shale to reflect product of shallow marine shelf in which foreshore and shoreface are occasionally preserved. Its depositional environment is mainly shallow marine with littoral environments. Hydrologically, Awka lies about 300m above sea level in a plain of the Mamu River. The two ridges lying in both directions of Awka and environs made the major topographic features which reach the highest point at Agulu Lake and also at about 6 km east, the minor cuesta peaks lie at about 150 m above sea level at Ifite – Awka (Ezenwaji, 2013).

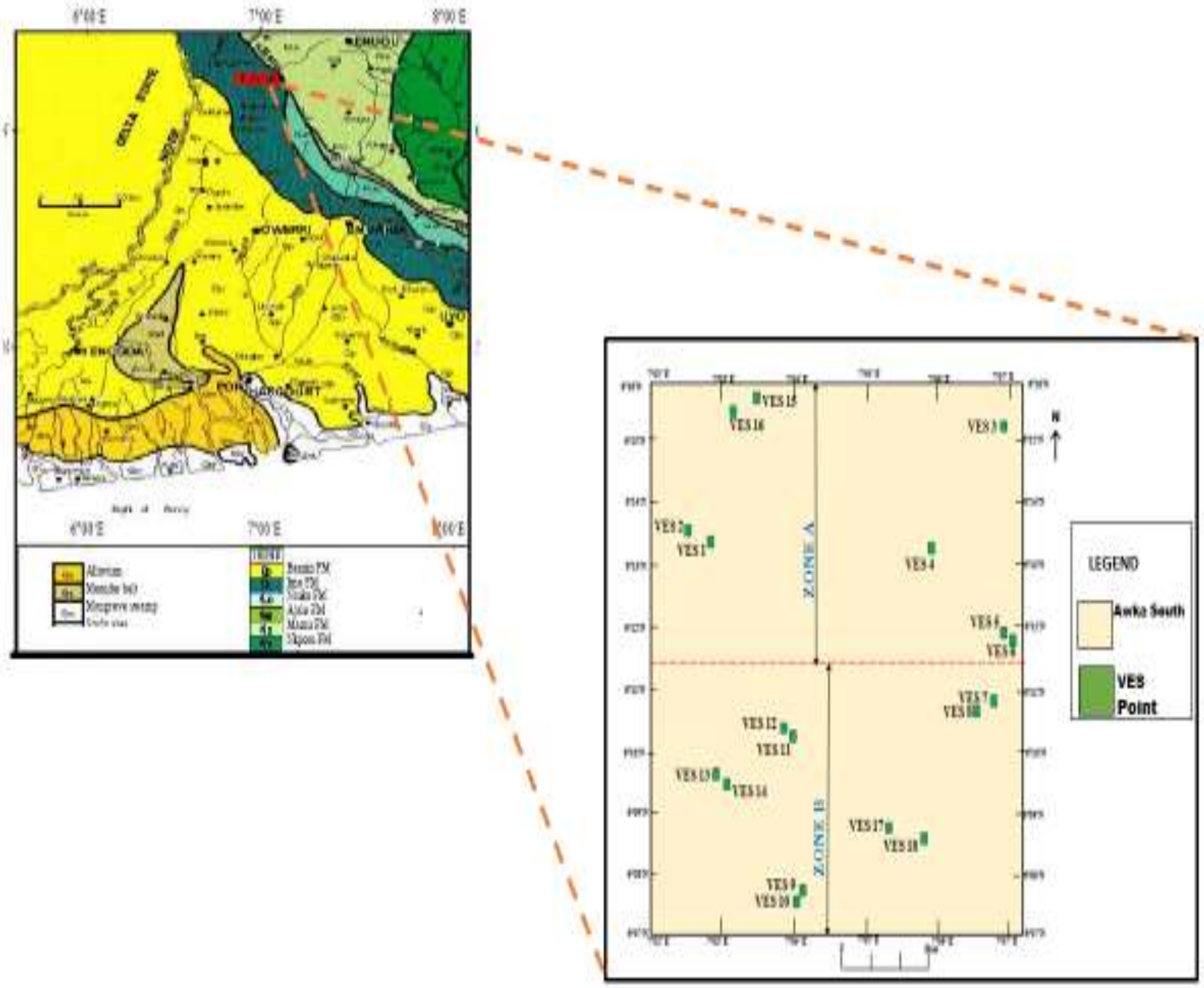


Figure 1: Modified Geological Map of Nigeria showing the study area (Modified after Nwozor et al., 2015).

3.0 METHODOLOGY

The study involved electrical resistivity method with the use of ABEM SAS 300 Terrameter, Global Positioning System (GPS), metal electrodes, measuring tape, labelled tag and hammer for taking accurate geophysical readings.

3.1Data Collection and Interpretation

The electrical resistivity method adopted is the vertical electrical sounding (VES) using Schlumberger Configuration Array (Fig. 3). The procedures include the injection of current into the subsurface to measure the potential between two electrodes resulting from the applied current through two other electrodes in coaxial with the potential electrodes. In this study, total of eighteen (18) vertical electrical sounding were conducted in nine (9) communities of Awka South Local Government Area. Two traverses each were run in the communities; Amawbia, Awka, Ezinato, Okpuno, Isiagu Mbaukwu, Nibo, Nise and Umuawulu in order to get their true resistivity in the subsurface which depends on the spatial configuration of the measuring systems. The vertical electrical sounding (VES) field data acquired in the study area were converted to apparent resistivity values by multiply the resistance with the appropriated Schlumberger geometric factors (K). The formula of geometric factors (K) is given below.

$K = \pi\,(L^2 - b^2)R/2$ ………………………………… …………………….. (1)

Whereas, $\rho a = K \times R\alpha$ ……………………………………………………..…. (2)

(i.e. apparent resistivity is the product of geometric factor and resistance)

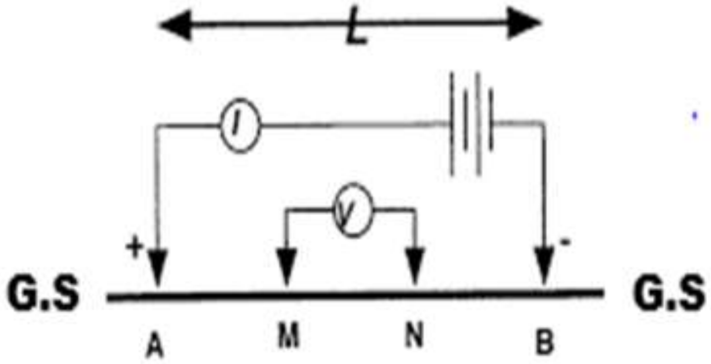
Where;

ρa = apparent resistivity in ohm-m

$R\alpha$ = resistance reading in ohm

L = current electrode spacing (AB/2)

b = potential electrode spacing (MN/2)



Where;

- A and B = Current Electrodes
- M and N = Potential electrodes
- V = potential difference (volt)
- I = Electric current (ampere)
- L = Profile length (m)
- G.S = Ground Surface

Figure 2: Illustration of the Schlumberger Array (Milson, 2003).

3.2 Aquifer Protective Capacity

Longitudinal conductance has been used to estimate the protective capacity of the overburden units. In this study the overburden layers were computed as thickness of the layers divided by resistivity of the layers whereas the longitudinal conductance of the water saturated sand being the aquifer is its thickness over its resistivity. Aquifer Protective Capacity (APC) simply means the ability of the overburden unit to retard and filter penetrating ground polluting fluid into the aquiferous unit. According to Abiola et al., (2009) and Oladapo and Akintorinwa (2007), the protective capacity of an aquifer is compared directly with the sum of the longitudinal conductance of all the layers above the aquifer. The protective capacities of identified aquifers in the study area were determined from the longitudinal conductance of the geoelectric layers above the aquifer. This evaluation creates awareness on the state of the aquifers' possibilities to contamination regarding to human activities and industrial discharge. Therefore, the study considered it essential to evaluate the protective capacity of the saturated zone in each location. Aquifer protective capacity estimates the vulnerability of the underlying aquifer to contamination. The aquifer protective capacity was compared favorably with the standard rating given by Ogungbemi et al. (2013) (Table 1).

Table 1: Longitudinal Conductance/Protective Capacity Rating (Ogungbemi et al. 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

The longitudinal conductance of a unit or layer is given by Niwas and Singhal (1981) as:

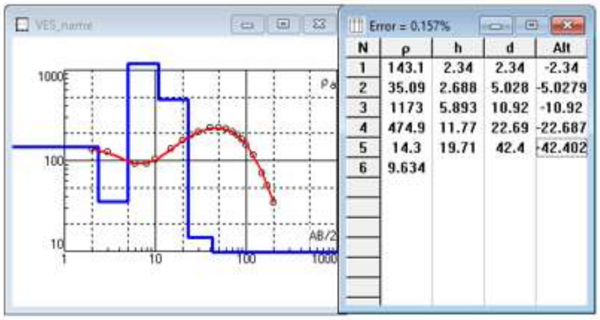
$$S = b/p \quad (3)$$

Where,
S = longitudinal unit conductance
b = layer thickness
p = layer resistivity.

4.0 RESULTS AND DISCUSSION

IPI2WIN Software was used to plot the AB/2 against apparent resistivity on the horizontal and vertical axis respectively for Awka and Umuawulu locations (Figure 3 - 4). The VES curves for Awka and Umuawulu locations were used as samples for VES curves of other locations. The field data were interpreted geologically and geophysical as summarized in table 2 – 3. The interpretation revealed total apparent resistivity prior to the number of occurrence at the profiling points of the current electrode AB/2 of each layers. The VES curves show 4 – 6 layers from the curve distribution and the types. The curve types generated from the VES curves and the aquifer potential information of the study area are shown in Table 3. The H- type curves have a definite minimum type, indicating beds of anomalously low resistivity at intermediate depth. Figure 5 showed the resistivity curve distribution chart of the study area.

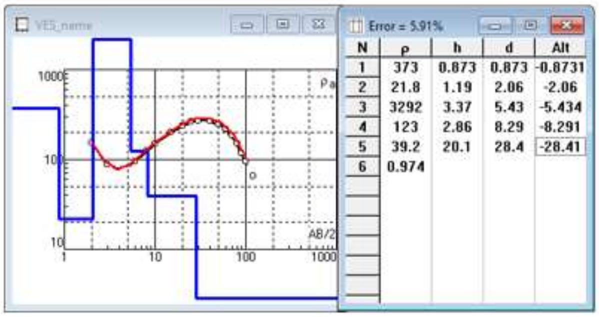
VES Curve B1 Awka



Error = 0.157%

N	ρ	h	d	Alt
1	143.1	2.34	2.34	-2.34
2	35.09	2.688	5.028	-5.0279
3	1173	5.893	10.92	-10.92
4	474.9	11.77	22.69	-22.687
5	14.3	19.71	42.4	-42.402
6	9.634			

VES Curve B2 Awka

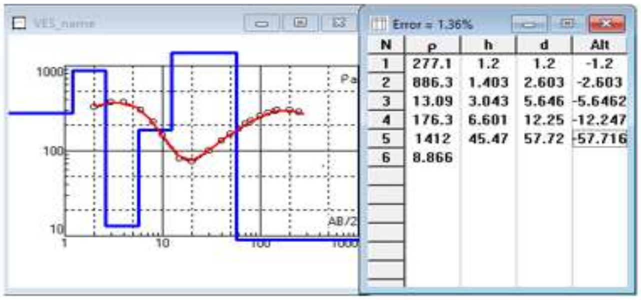


Error = 5.91%

N	ρ	h	d	Alt
1	373	0.873	0.873	-0.8731
2	21.8	1.19	2.06	-2.06
3	3292	3.37	5.43	-5.434
4	123	2.86	8.29	-8.291
5	39.2	20.1	28.4	-28.41
6	0.974			

Figure 3: VES Curves of B_1 and B_2 Sites

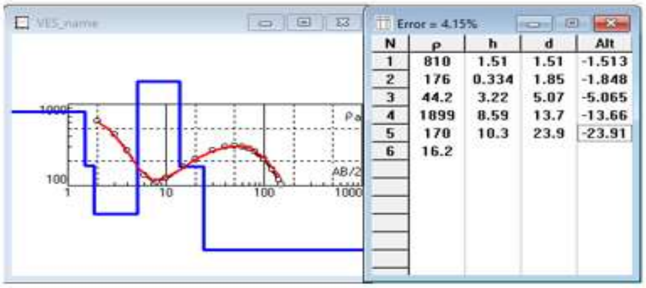
VES Curve I1 Umuawulu



Error = 1.36%

N	ρ	h	d	Alt
1	277.1	1.2	1.2	-1.2
2	886.3	1.403	2.603	-2.603
3	13.09	3.043	5.646	-5.6462
4	176.3	6.601	12.25	-12.247
5	1412	45.47	57.72	-57.716
6	8.866			

VES Curve I2 Umuawulu



Error = 4.15%

N	ρ	h	d	Alt
1	810	1.51	1.51	-1.513
2	176	0.334	1.85	-1.848
3	44.2	3.22	5.07	-5.065
4	1899	8.59	13.7	-13.66
5	170	10.3	23.9	-23.91
6	16.2			

Figure 4: VES Curves of I_1 and I_2 Sites

Table 2: Comprehensive Summary of Interpreted Geoelectric Results of the Study Area

ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	h_6	d_1	d_2	d_3	d_4	d_5	d_6			
91.75	461.68	120.21	8191.50	1235.96	167.85	3	17	40	30	30	80	3	20	60	90	120	200	N06° 13' 16.2"	E007° 02' 53.6"	109
425.23	38.14	3.41	532.52	183.21	19.87	2	18	10	40	50	80	2	20	30	70	120	200	N06° 13' 30.3"	E007° 02' 35.2"	113
128.39	48.66	776.37	265.31	24.83	-	3	12	25	80	80	-	3	15	40	120	200	-	N06° 15' 77.1"	E007° 06' 78.1"	60
151.47	128.9	481.35	165.09	42.47	-	2	23	35	30	30	-	2	25	60	90	120	-	N06° 13' 15.9"	E006° 05' 51.9"	94
212.92	777.04	60.27.	4290.13	1214.04	-	2	8	5	35	100	-	2	10	15	50	150	-	N06° 11' 55.7"	E007° 06' 59.4"	88
543.02	878.21	12.26	239.76	-	-	2	18	20	110	-	-	2	20	40	150	-	-	N06° 11' 50.1"	E007° 07' 08.6"	97
91.75	461.68	120.21	8191.50	1235.96	167.85	3	22	35	40	60	40	3	25	60	60	100	160	N06° 10' 55.2"	E007° 06' 40.1"	20
399.15	999.52	247.81	46.86	830.85	81.86	3	17	20	40	60	60	3	20	40	80	140	200	N06° 10' 47.4"	E007° 06' 38.4"	46
703.93	153.41	1924.43	248.76	-	-	3	7	70	120	-	-	3	10	80	200	-	-	N06° 07' 57.4"	E007° 04' 54.2"	127
5175.12	258.75	2962.71	362.23	-	-	2	13	75	110	-	-	2	15	90	200	-	-	N06° 07' 52.9"	E007° 04' 36.7"	121
191.75	682.44	12.98	134.98	564.66	-	2	8	5	45	40	-	2	10	15	60	100	-	N06° 10' 10.7"	E007° 03' 59.2"	124
166.53	498.00	15.68	695.90	206.37	-	4	11	5	60	20	-	4	15	20	80	100	-	N06° 10' 15.4"	E007° 03' 49.8"	102
379.12	468.06	13.67	147.23	-	-	2	6	32	80	-	-	2	8	40	120	-	-	N06° 09' 32.2"	E007° 02' 58.9"	112
282.92	718.37	43.09	347.31	-	-	3	7	40	70	-	-	3	10	50	120	-	-	N06° 09' 21.3"	E007° 03' 04"	109
273.97	117.35	5454.50	378.53	-	-	2	8	50	140	-	-	2	10	60.	200	-	-	N06° 15' 52.5"	E007° 03' 30.6"	65
277.23	90.08	1176.34	295.22	-	-	2	13	55	130	-	-	2	15	70	200	-	-	N06° 15' 23.4"	E007° 03' 10.2"	45
109.58	696.87	65.46	878.93	222.17	-	3	3	32	30	180	-	3	6	40	70	150	-	N06° 08' 43.5"	E007° 06' 22.5"	99
324.62	630.77	82.01	995.76	134.68	-	2.	2.	16	40	140	-	2	4	20	60	250	-	N06° 08' 33.4"	E007° 06' 52.8"	103

Table 3: Potential Results of Integrated Analysis of Geophysical and Geological Aquifer Parameters of Awka and Environs.

VES 1	A_1	$p_1 > p_2 < p_3 > p_4 < p_5$	HKH	30.0	108.92	0.27543
VES 2	A_2	$p_1 > p_2 < p_3 > p_4$	HK	50.0	183.21	0.27291
VES 3	B_1	$p_1 > p_2 < p_3 > p_4$	HK	80.0	265.31	0.30153
VES 4	B_2	$p_1 > p_2 < p_3 > p_4$	HK	30.0	165.09	0.18172
VES 5	C_1	$p_1 < p_2 < p_3 > p_4$	AK	100.0	1214.04	0.00819
VES 6	C_2	$p_1 < p_2 > p_3 < p_4$	KH	110.0	239.76	0.45879
VES 15	H_1	$p_1 > p_2 < p_3 > p_4$	HK	140.0	378.53	0.36985
VES 16	H_2	$p_1 > p_2 < p_3 > p_4$	HK	130.0	295.22	0.44035
VES 7	D_1	$p_1 < p_2 < p_3 > p_4$	AK	60.0	1235.96	0.04855
VES 8	D_2	$p_1 < p_2 > p_3 < p_4$	KH	60.0	830.85	0.07222
VES 9	E_1	$p_1 > p_2 < p_3 > p_4$	HK	120.0	248.76	0.48239
VES 10	E_2	$p_1 > p_2 < p_3 > p_4$	HK	110	362.23	0.30367
VES 11	F_1	$p_1 > p_2 < p_3$	H	40.0	564.66	0.07084
VES 12	F_2	$p_1 < p_2 > p_3 < p_4$	KH	20.0	206.37	0.09691
VES 13	G_1	$p_1 > p_2 < p_3$	H	80.0	147.23	0.54337
VES 14	G_2	$p_1 < p_2 > p_3 < p_4$	KH	70.0	347.31	0.20155
VES 17	I_1	$p_1 > p_2 < p_3$	H	180	222.17	0.81019
VES 18	I_2	$p_1 > p_2 < p_3 > p_4$	HK	140.0	134.68	1.03950

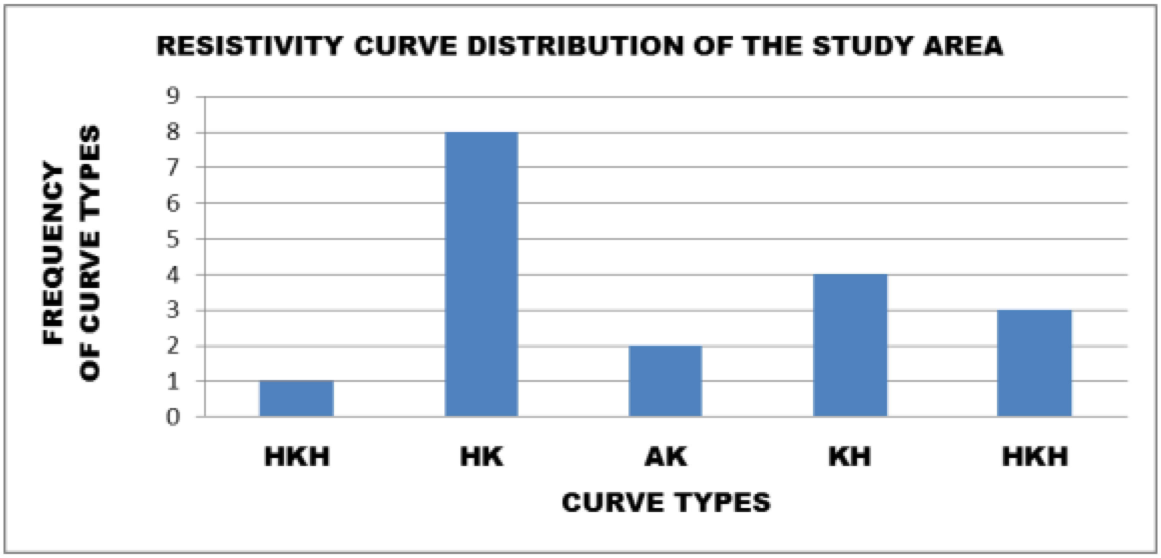


Figure 5: Frequency of the Resistivity Curve Distribution of the Study Area

The average depths and thicknesses of the locations were empirically estimated to the basis of simplified order of the lithological characteristics of the study area (Table 2). This was achieved from the current electrode of profiling points in variation to apparent resistivities of the subsurface lithologies. From the geoelectrical sections, the thickness was estimated as the layer terminal electrode distance whilst the depths were calculated as the end of the layer minus the beginning. Thus, the lithological distribution of VES in the geoelectric sections of zone A and zone B revealed aquifer thickness ranges from 30 m – 140 m and 20 m – 140 m respectively and aquifer depths of 40 m – 90 m and 40 m – 100 m respectively. The average resistivity values of VES locations were calculated as summation of apparent resistivities divided by its number of inferred lithological layer occurrence. Hence, the aquifer resistivity of the study area ranges from 108.92 Ωm – 1214.04 Ωm in zone A and 147.23 Ωm – 1235 Ωm in zone B (Figure 6). The aquifer longitudinal conductance of the study area which is also a parameter used to define target areas of good and portable groundwater was calculated as aquifer thickness divided by resistivity value of the aquifer which ranged from 0.00819 Ohm^{-1} – 0.45879 Ohm^{-1} in zone A and 0.04855 Ohm^{-1} - 1.03950 Ohm^{-1} in zone B (Figure 7).

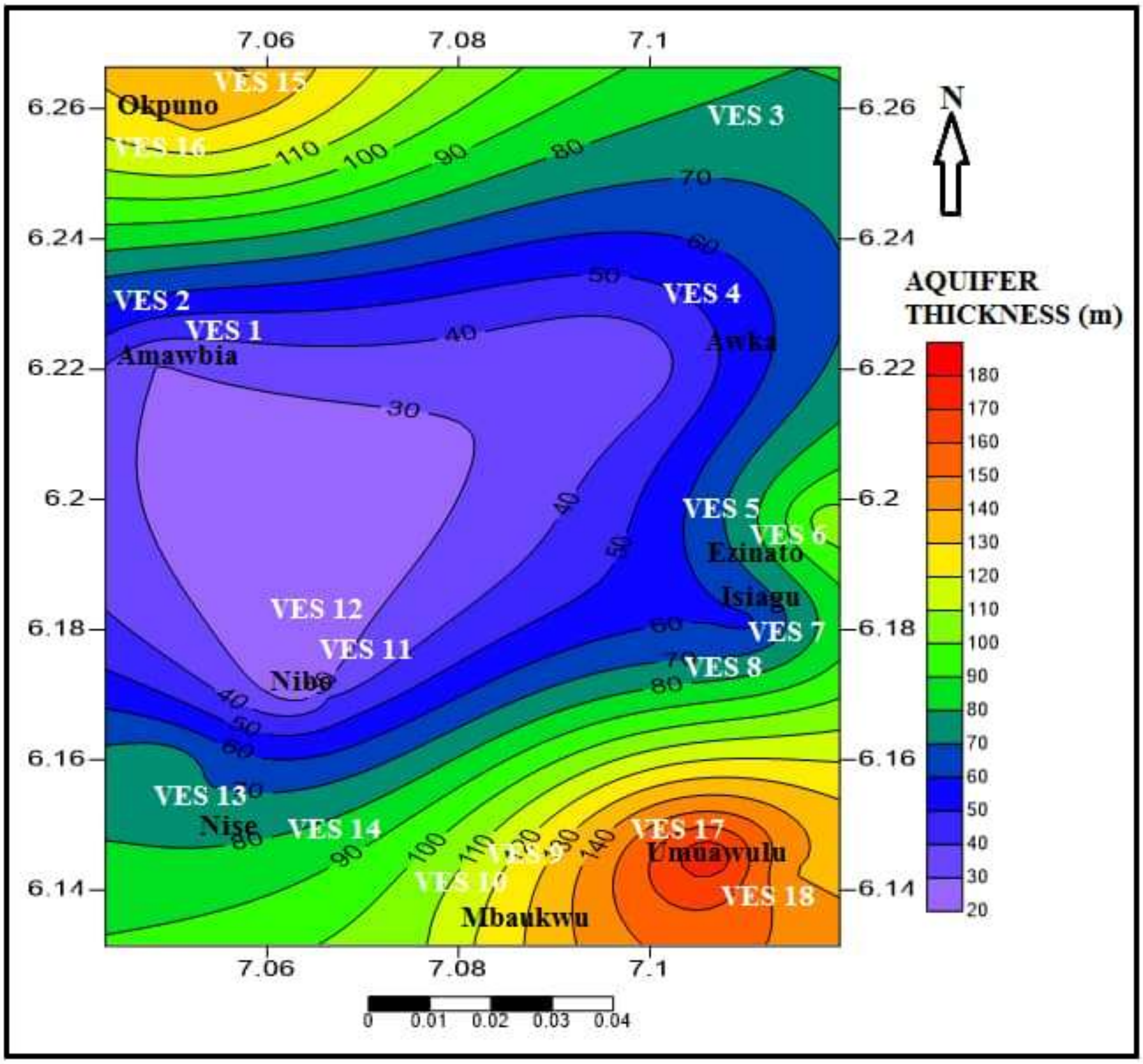


Figure 6: Aquifer Thickness Contour Map of the Study Area.

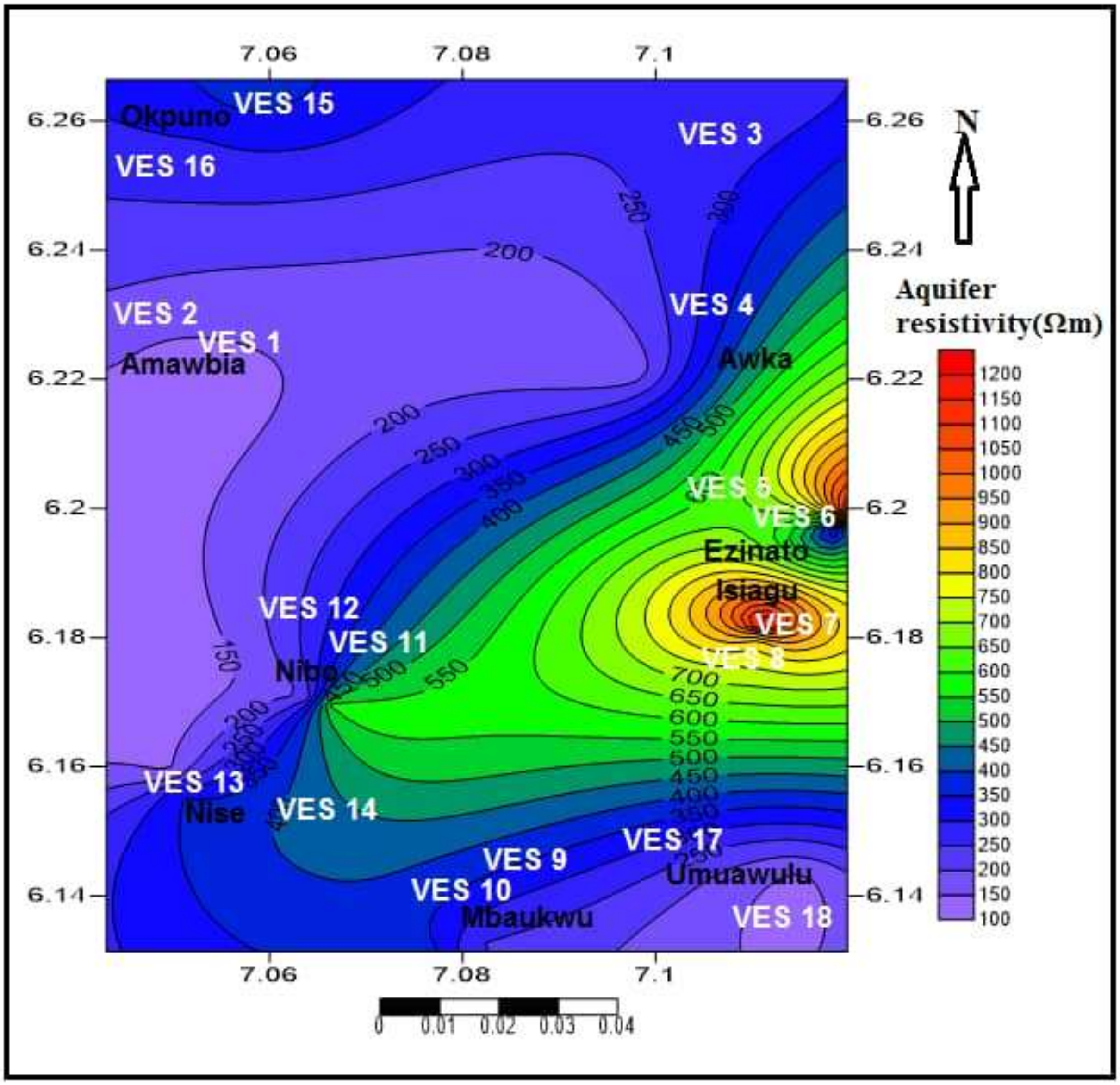


Figure 7: Aquifer Resistivity Map of the Study Area

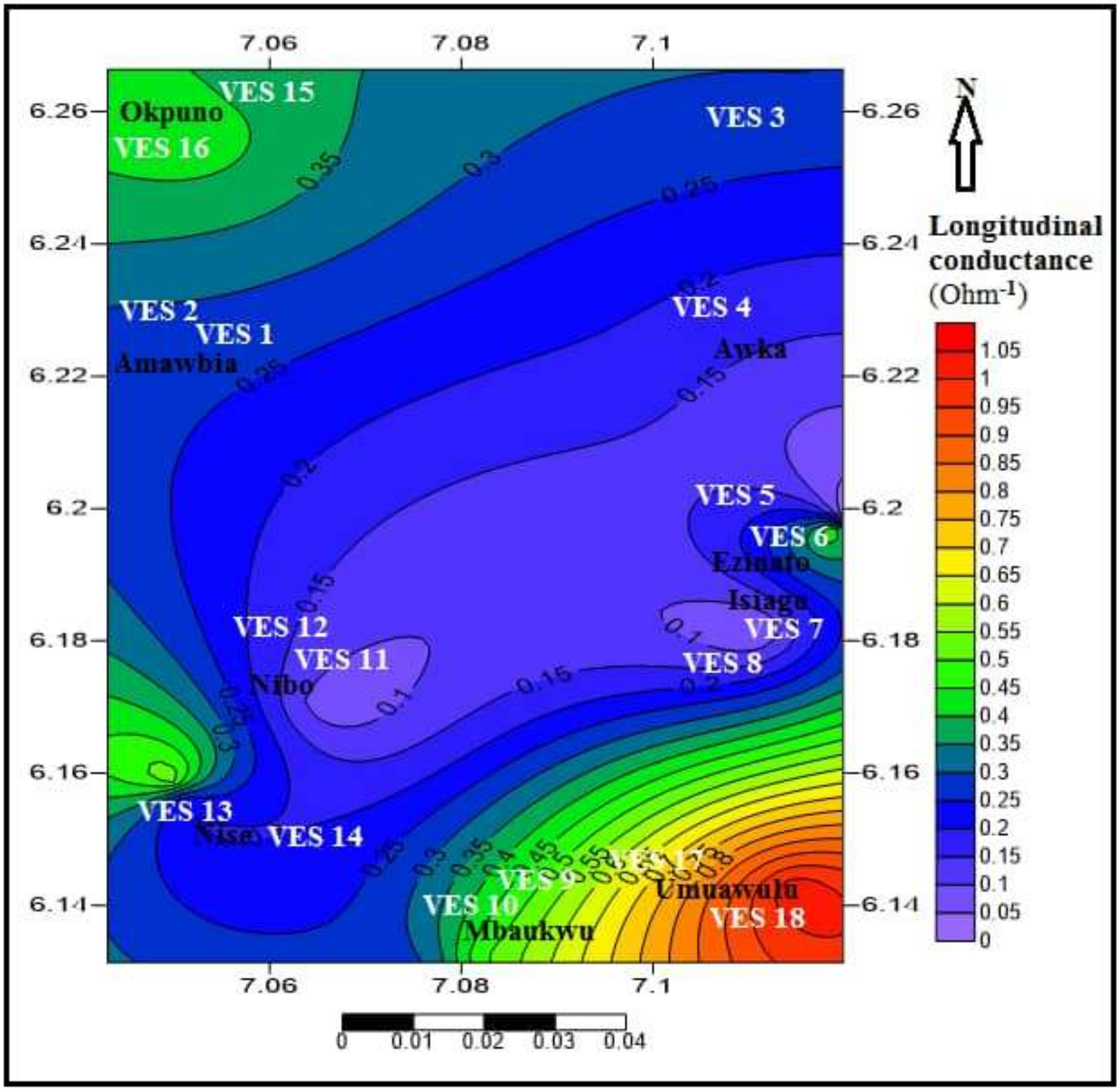


Figure 8: Map of Longitudinal Conductance of the Study Area

4.1 AQUIFER PROTECTIVE CAPACITY OF THE STUDY AREA

The vulnerability/susceptibility of the aquifer to contamination, the longitudinal conductance of overburden layers was evaluated using its resistivity and the thickness of overburden layers from electrical sounding results (Adeniji et al., 2017). In zone A the overburden longitudinal conductance ranges from 0.009 Ohm^{-1} – 3.484 Ohm^{-1} in zone A while in zone B the overburden longitudinal conductance ranges from 0.075 Ohm^{-1} – 2.340 Ohm^{-1} (Table 4). According to the APC rating of Ogungbemi et al. (2013), the frequency and percentage of aquifer protective capacity are ranged as follows; 9 VES locations of 50% have good aquifer protective capacity, 4 VES locations of 22.2% have moderate APC, 2 VES location of 11.1% have weak APC and 3 VES locations of 16.7% have poor APC (Table 5). These show that 5 VES locations out of 18 VES locations in the study area revealed poor-weak aquifer protective capacity (Figure 9). Thus, a clear reflection of geological formation of the study area also ascertained as predominantly Imo Shale (Paleocene) and partly Eocene Ameki Formation. The results proved that the groundwater potential of Awka and environs has moderately good aquifer protective capacity; hence the aquifers of the study area constitute definite overburden thickness with shale which serves as natural filter to percolating fluids. An effective groundwater protection is provided by protective layers with sufficient thickness and low hydraulic conductivity leading to high rate of percolating water (Mosuro et al., 2017). Areas with high longitudinal conductance (thick overburden and low resistivity) constitute regions of excellent – good aquifer protective capacity in which such locations have sufficient seal from groundwater contamination. Locations with moderate aquifer protective capacity are less susceptible or rare to contamination while areas with weak – poor APC are susceptible to contamination (Atakpo and Ayolabi 2009). These results show that the groundwater potential of the study area is moderately good and indefinite locations of poor – weak aquifer protective capacity of the overburden layers.

Table 4: Comprehensive Summary of Interpreted APC Results of the Study Area

ρ_1, ρ_2, ρ_3, ρ_4, ρ_5, ρ_6	**h_1, h_2, h_3, h_4, h_5, h_6**	**d_1, d_2, d_3, d_4, d_5, d_6**	**Lc_1, Lc_2, Lc_3, Lc_4,**	
91.75, 461.68, 120.21, 8191.50, 1235.96, 167.85	3, 17, 40, 30, 30, 80	3, 20, 60, 90, 120, 200	0.0368, 0.3551, 2.2714, 0.132544,	2.7959 (Good)
425.23, 38.14, 3.41, 532.52, 183.21, 19.87	2, 18, 10, 40, 50, 80	2, 20, 30, 70, 120, 200	0.004703, 0.471945, 2.93251, 0.075115	3.4843 (Good)
128.39, 48.66, 776.37, 265.31, 24.83, -	3, 12, 25, 80, 80 -	3, 15, 40, 120, 200 -	0.023366, 0.246609, 0.032201	0.3022 (Moderate)
151.47, 128.9, 481.35, 165.09, 42.47 -	2, 23, 35, 30, 30 -	2, 25, 60, 90, 120 -	0.013204, 0.178419, 0.072712	0.2643 (Moderate)
212.92, 777.04, 60.27. 4290.13, 1214.04 -	2, 8, 5, 35, 100 -	2, 10, 15, 50, 150 -	0.009393, 0.010295, 0.082960, 0.008158	0.1108 (Weak)
543.02, 878.21, 12.26, 239.76 - -	2, 18, 20, 110 - -	2, 20, 40, 150, - -	0.003683, 0.020496, 1.631321	1.6555 (Good)
91.75, 461.68, 120.21, 8191.50, 1235.96, 167.85	3, 22, 35, 40, 60, 40	3, 25, 60, 60, 100, 160	0.032698, 0.047652, 1.731816, 0.004883	1.8170 (Good)
399.15, 999.52, 247.81, 46.86, 830.85, 81.86	3, 17, 20, 40, 60, 60	3, 20, 40, 80, 140, 200	0.007509, 0.017008, 0.080707, 0.853606	0.9588 (Good)
703.93, 153.41, 1924.43, 248.76 - -	3, 7, 70, 120 - -	3, 10, 80, 200 - -	0.004262, 0.045629, 0.036374	0.0863 (Poor)
5175.12, 258.75, 2962.71, 362.23 - -	2, 13, 75, 110 - -	2, 15, 90, 200 - -	0.000386, 0.050242, 0.025315	0.0759 (Poor)
191.75, 682.44, 12.98, 134.98, 564.66 -	2, 8, 5, 45, 40 -	2, 10, 15, 60, 100 -	0.010430, 0.011723, 0.385208, 0.333383	0.7407 (Good)
166.53, 498.00, 15.68, 695.90, 206.37 -	4, 11, 5, 60, 20 -	4, 15, 20, 80, 100 -	0.024020, 0.022088, 1.318878, 0.086219	1.4512 (Good)
379.12, 468.06, 13.67, 147.23 - -	2, 6, 32, 80 - -	2, 8, 40, 120 - -	0.005275, 0.012819, 2.340892	2.3409 (Good)
282.92, 718.37, 43.09, 347.31 - -	3, 7, 40, 70 - -	3, 10, 50, 120 - -	0.010604, 0.009744, 0.928290	0.9486 (Good)
273.97, 117.35, 5454.50, 378.53 - -	2, 8, 50, 140 - -	2, 10, 60. 200 - -	0.007300, 0.068172, 0.009167	0.0092 (Poor)
277.23, 90.08, 1176.34, 295.22 - -	2, 13, 55, 130 - -	2, 15, 70, 200 - -	0.007214, 0.144316, 0.046755	0.1983 (Weak)
109.58, 696.87, 65.46, 878.93, 222.17 -	3, 3, 32, 30, 180 -	3, 6, 40, 70, 150 -	0.027392, 0.004305, 0.488848, 0.034132	0.5547 (Moderate)
324.62, 630.77, 82.01, 995.76, 134.68 -	2. 2. 16, 40, 140 -	2, 4, 20, 60, 250 -	0.006161, 0.003171, 0.195098, 0.040170	0.2446 (Moderate)

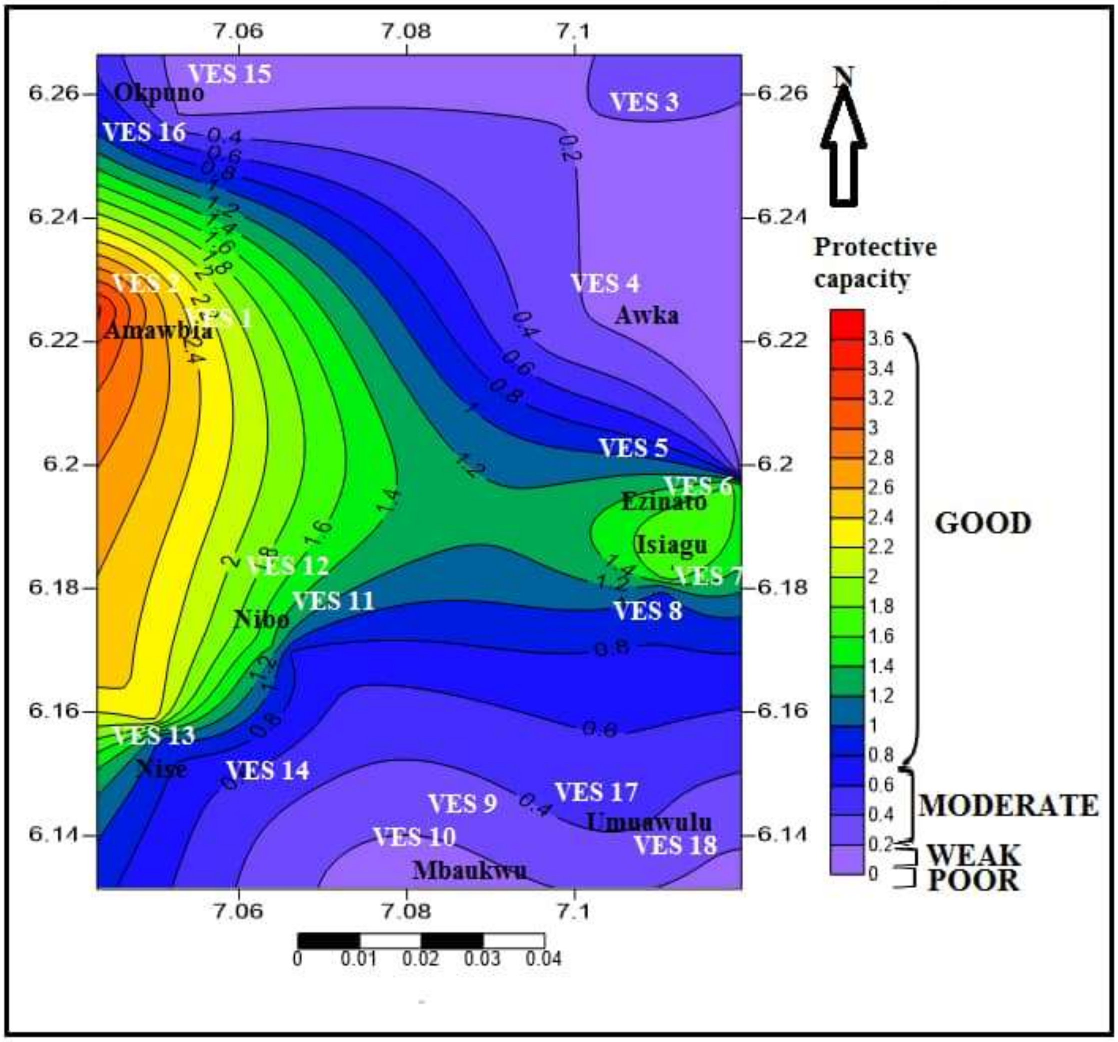


Figure 9: Contour Map of Aquifer Protective Capacity of the Study Area

Table 5: Summary of Aquifer Protective Capacity in the Study Area.

Zone A / North	Zone B / South		
VES 1, VES 2, VES 6, VES 13, VES 14	VES 7, VES 8, VES 11, VES 12	9	50%
VES 3, VES 4	VES 17, VES 18	4	22.2%
VES 5, VES 16	-	2	11.1%
VES 15	VES 9, VES 10	3	16.7%

5.0 CONCLUSION AND RECOMMENDATION

Electrical resistivity method which is most efficient in groundwater studies was successfully employed in this analysis of groundwater contamination and protective capacity in Awka and environs. This research shows the influence of the geological setting of the study area to contaminants. Shale being a good filter generally in this study provided higher longitudinal conductance hence constrained the high spread of contaminants to the water saturated layer. From the geoelectric sections of zone A and zone B, the aquifer thickness ranges from 30 m – 140 m and 20 m – 140 m respectively with aquifer depths of 40 m – 90 m and 40 m – 100 m respectively. Aquifer resistivity values of the study area ranges from 108.92 Ωm – 1214.04 Ωm in zone A and 147.23 Ωm – 1235 Ωm in zone B respectively while aquifer longitudinal conductance ranges from 0.00819 Ohm^{-1} – 0.45879 Ohm^{-1} in zone A and 0.04855 Ohm^{-1} - 1.03950 Ohm^{-1} respectively. The estimated values of overburden longitudinal conductance of the aquifer of zone A revealed 0.009 Ohm^{-1} – 3.484 Ohm^{-1} and 0.075 Ohm^{-1} – 2.340 Ohm^{-1} in zone B respectively. The overburden longitudinal conductance aids in analyzing aquifer protective capacities in this research which revealed that 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 locations have aquifer protective capacity rated good while four (4) of the locations representing 22.2% of the surveyed locations have moderate protective capacity rating. From the analysis, two (2) locations which represent 11.1% of the surveyed locations have weak protective capacity rating and also three (3) sounding locations representing 16.7% of the surveyed locations have aquifer protective capacity rated poor. More than 72% of the study locations including Amawbia, Awka, Isiagu, Nibo, Nise, Umuawulu and parts of Ezinato have groundwater potentials of good to moderate aquifer protective capacity. This research will ensure safety among the populaces and the aquiferious zones of those locations of weak-poor protective capacity. Therefore, it is recommended that a detailed groundwater exploration should be carried out before siting a borehole in the study area. Thus, Ministry of Environment should provide adequate policy towards proper disposal of waste.

6.0 ACKNOWLEDGEMENTS

The authors are grateful to Akwuba, G.K., Udezek, K.E. and Rural Water Supply and Sanitation Agency (RUWASSA) Anambra State, Nigeria for providing the data used for this research work.

7.0 REFERENCES

Amadi, A.N. (2010). Effects of Urbanization on groundwater quality. A case study of Portharcourt Southern Nigeria. Natural Applied Science ISSN: 1119-9296: www.naasjournal.ng.org, 11(2) 43-152

Akhilesh, J. Weiss, A. and Ogbonna, D.N. (2009). Groundwater contamination, an impairment of water quality by chemicals, heat or bacteria. Journal of Applied Sci. Environ. Manage, 13 (4): 47 – 50.

Abiola, O., Oladapo, M.I. and Akintorinwa, O.J. (2009). Protective capacity of an aquifer and longitudinal unit conductance of layers above the aquifer. International Journal of Physical Sciences Vol. 4 (3): 120 – 132.

Adeniji, A.E., Obiora, N.D. and Mosuro, I.O. (2017). Estimation APC from longitudinal Conductance. Journal of Geophysical Prospecting (24): 59 – 68.

Abiola, O., Enikanselu, P.A. and Oladapo, M.I. (2009). Groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, southwestern Nigeria. Int J Phys Sci 4 (3):120–132.

Atakpo, E.A. and Ayolabi, E.A. (2009). Evaluation of Aquifer vulnerability and the protective capacity in some oil producing communities of western Niger Delta. Environmentalist, 29 (3): 318 – 322.

Burke, K.C. (1972). Geological history of Benue Trough and adjacent area. In Dessauvagie, T.F.J. and Whiteman, A.J. (eds.), African Geology. Univ. of Ibadan Press Nigeria.P. 187 – 218.

Emberga, T.T., Opara, A.I., Onyekuru, S.O., Ibe, I.A., Nkpuma, O.R. and Eluwa, N.N. (2019). Regional Hydro-geophysical Study of the Groundwater potentials of the Imo River Basin Southeastern Nigeria using Surficial Resistivity Data. Australian Journal of Basic and Applied Sciences, 13(8): 76-94.DOI: 10.22587/ajbas.2019.13.8.12.

Ezenwaji, E.E. (2013). The relative contributions of climatic elements and environmental factors to flooding in Awka urban area. Afr. J. Environ. Sci. Technol. 7 (8): 666 – 766.

Kogbe, C.A. (1989). The Cretaceous and Paleogene Sediments of Southern Nigeria. Kogbe C.A.(Ed.), Geology of Nigeria. Elizabethan Publ., Lagos, Nigeria. 273 – 286.

Milsom, J. (2003). Field Geophysics. 3rd Edition, John Wiley and Son, New York, 244.

Mosuro, G.O., Omosanya, K.O., Bayewu, O.O., and Oloruntola, M.O. (2017). Assessment of groundwater vulnerability to leachate infiltration using electrical resistivity method. Appl Water Sci 7:2195–2207. https ://doi.org/10.1007/s1320 1-016-0393-4.

Murat, R.C. (1972). Stratigraphy and Pale geography of lower Tertiary, Southern Nigeria, in Dessavagie, T.P.J. and Whiteman (Eds.), Afri – geol. University of Ibadan, Nigeria. 425.

Nwozor, K.K., Chiaghanam, O.I. and Onuorah, L.O. (2015). Borehole Annulus- Filling Materials and Enrichment of Heavy Metals in Eocene Palaeocene Aquifer Systems in Awka, Southeast Nigeria. British Journal of Applied Science (BJAST), 8(3):206,277-285.

Nwajide, C.S. and Reijers, T.J.A. (1996). Geology of the Southern Anambra Basin. International Journal of Geoscience. Vol. 7, No. 2, 197 – 223.

Niwas, S. and Singhal, D.C. (1981). The longitudinal conductance of a unit or layer. Journal of Hydrology (50): 393 399.

Obi, G.C. (2000). Depositional Model for the Campanian – Maastrichtaian Success, Anambra Basin, Southeastern Nigeria. Ph.D Thesis, University of Nigeria, Nsukka, Nigeria.

Oladapo, M.I. and Akintorinwa, O.J. (2007). Hydrogeophysical study of Ogbese Southwestern, Nigeria. Global J. Pure and Applied Sci. vol 131:55-61.

Ogumgbemi, S.O. (2013). Longitudinal Conductance/Protective Capacity Rating. Journal of Applied Geology and Geophysics 1 (5): 1 – 7.

Ogbonna, D.N. (2006). Microbiological and Physico-chemical characteristics of the soils of waste collection sites in Port Harcourt City, Nigeria. Nigeria Journal of Soil Science (16): 243 - 250.

Petters, S.W. (1978). Stratigraphic evolution of the Benue trough and its Implication for the Upper Cretaceous paleogeography of West Africa. Journ, Geol., 86: 311 – 322.

Reyment, R.A. (1965). Aspect of the Geology of Nigeria. Ibadan University Press. 145.

UNESCO, (2007). Record of illness and death from Water related diseases in the developing countries. Journal of Medical Ethics 33 (3): 150 – 154.

Weber, K.J. and Daukora, E.M. (1975). Petroleum Geology of the Niger Delta. Proceedings of the Ninth World Petroleum Congress, volume 2, Geology. London, Applied Science Publishers, Ltd., 210 – 221.