GEO-ELECTRIC GROUNDWATER VULNERABILITY ASSESSMENT OF OVERBURDEN AQUIFERS AT AWKA IN ANAMBRA STATE,

BY
OGBUEKWE MARTIN IFEANYI
Email: matinekwe@yahoo.com

AND
Prof. M. N. UMEGO

DEPARTMENT OF INDUSTRIAL PHYSICS, CHUKWUEMEKA ODUMEGWU OJUKWU UNIVERSITY, ULI

A RESEARCH PAPER PRESENTED AT THE 2 ND INTERNATIONAL CONFERENCE OF THE FACULTY OF PHYSICAL SCIENCES, CHUKWUEMEKA ODUMEGWU OJUKWU UNIVERSITY.

OCTOBER 2019.

ABSTRACT
Geoelectrical measurements were carried out in Awka to delineate various aquifers and to recommend areas that has high protective geological formation to contamination. Physical properties of geologic materials that over and underlie aquifers are expected to show reasonable contrast such that a carefully organized electrical resistivity investigation can be used to map their spatial distribution. From the analysis and interpretation of such data constrained with geologic and lithologic information, the distribution of such materials can be inferred from the discontinuities in the electrical signatures. Vertical electrical sounding (Schlumberger configuration) data were collected at sixteen (16) stations with minimum current electrode spacing (AB) was 2m while maximum current electrode spacing vary between 500 and 600m. The geoelectrical curves obtained vary considerably throughout the study area. Data analysis showed that the area under investigation was a five layered. The study area could be considered averagely protective from surface contamination. Seven (7) VES stations were covered moderate longitudinal conductance (S > 0.2), which represents 43.75% of the study area is considered relatively protective. However, VES station 3 is found with longitudinal conductance (S < 0.2) is considered weak and vulnerable to contamination. While four (4) VES stations which represent 25% of the study area areconsidered poor likewise 25% of the VES stations are considered with a good protective capacity. The research has presented a guide to both the Government and individuals especially those involved in groundwater development on the depth to aquifers, thecomposition and the vulnerability of the aquifers in the study area.

Keywords: Vertical electrical sounding, vulnerability assessment, longitudinal conductance, protective capacity.

1. INTRODUCTION

Fresh water makes up only 2-5% of all the water on earth but not all of this water is available for human use. The water in polar ice caps, other forms of ice and snow, soil moisture, marshes, biological system and the atmosphere are not readily available. As a result, only the 10,530,000km3 of groundwater, 91,000km3 of freshwater in lakes and the 2,120km3 of water in rivers are considered available for use. Consequently, groundwater comprises 99% of the earth's available freshwater (Delleur, 1999). Groundwater is typically not easily contaminated, yet once this occurs water quality is difficult to restore (Jang et al., 2017).

All people irrespective of their development, economies and social condition are entitled to have access to drinking water in good quality and quantities (NWRI 2011). In any environment, there is a strong relationship between human activities and water pollution of that environment due to anthropogenic activities resulting from the growth of waste disposals, agrochemicals, industries and technological advancement. While environmental pollution is one of the worlds known disaster that occurs on earth surface, groundwater is one of our most important sources of water for domestic and industrial purposes. Unfortunately, groundwater is susceptible to pollutants. Groundwater contamination occurs when man-made products such as gasoline, oil, road salts and chemicals get into the groundwater and cause it to become unsafe and unfit for human use. The potential sources of pollution in Awka are open pits, careless waste disposal, haulage roads, degradable materials such as animal remains and agrochemicals. Groundwater and environmental pollution can also result from poor drainage system. Sustainable drainage systems are approaches put in place to manage the water quantity (flooding), water quality (pollution) and amenity issues in the environment. Good drainage system provides opportunities to reduce the causes and impacts of flooding, remove pollutants from urban runoff at source, and combine water management with recreation and wildlife. The concept of aquifer vulnerability derives from the assumption that the physical geomaterials may provide some level of protection to groundwater, especially with regard to pollutants entering the subsurface (Robins et al., 2007). Consequently, the lithologic variations and the thickness of the unsaturated zone (Vadose zone) which determine the accessibility of the underlying aquifer units (Wilson, 1983) constitute the focus in aquifer vulnerability assessment. Although the general concept of vulnerability has been in use for years, strict definition of the term and the conventional vulnerability assessment methodology are still evolving (Robins et al., 2007).

Inexpensive, simple guides to intrinsic hydrogeological contamination potential are important in groundwater/source water protection and remediation decisions, especially because public health is at risk. Often, the creators and users of vulnerability assessments come from diverse scientific backgrounds, thus the intentions and limitations of these tools must be made very clear. Final aquifer vulnerability assessments are meant for use as a communication tool to bridge the gap between hydrogeological science and environmental management (Foster, 2002). In bridging this gap, there is a definite threat of misinterpretation or disagreements. Vulnerability assessment maps can be dangerous if used in the wrong context or misunderstood.

Location and Geology

The study area (Awka in Anambra State of Nigeria) has a topography that slopes gently towards Mamu River with major cuestas lying in the North-South direction. The first ridge peaks at 300 m above sea level at Agulu (outside Awka) while the minor cuesta peaks at 150m at Ifite-Awka. A major part of Awka is underlain by a thick sequence of shale and sandstone formed in the Paleolene age. Major soil types which exist within this region are loamy, clay and fine white sands, and lateritic soils. The study area is located between Latitude 6º12'- 6º16' N and Longitude 7º04' - 7º07' E and lies within the tropical wet climate zone having two distinct seasons: wet season (April- October) and dry season (November - March). The mean temperature which prevails over this region varies between 27 ºC - 28 ºC which most times peak to 35 ºC between January and April. This region also witnesses amean annual rainfall of about 2000 mm with maximum monthly rainfall during the peaks ranging from 270 mm - 360 mm (Odumodu and Ekenta, 2012). The map of the area is shown in the figure below:

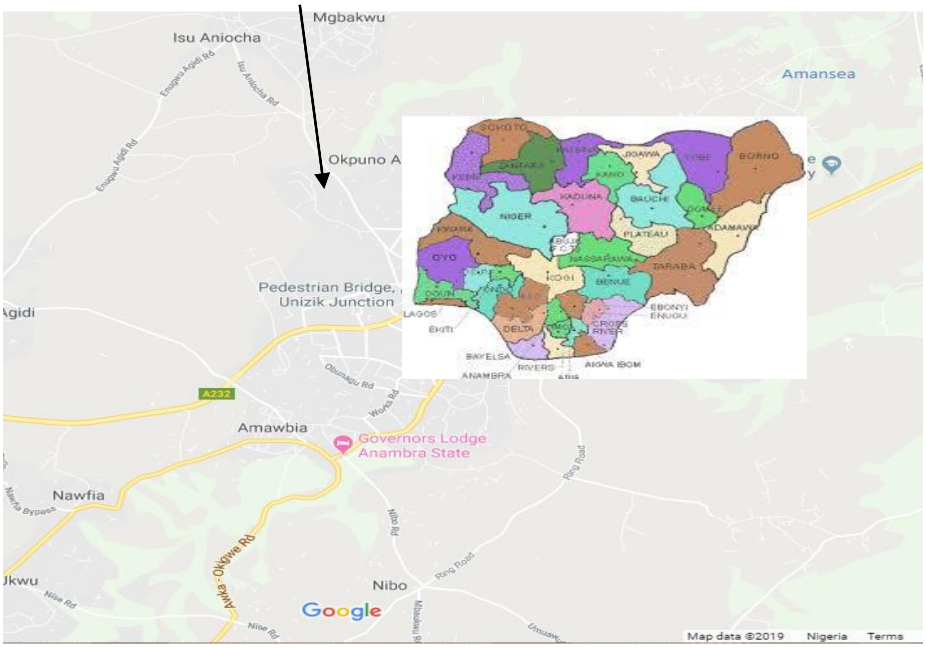


Figure 1: Map showing the study area in Anambra state of Nigeria

Materials and Methods

Geoelectric sounding (VES) surveys in the area were conducted using ABEM Terrameter Self Averaging System (SAS) 1000 which displays apparent resistivity values digitally as computed from Ohm's law. The ABEM Terrameter SAS 1000 performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it (Dobrin and King, 1976). From the field data, the apparent resistivity, which is a function of AB/2 (half the current electrode spacing) was calculated and interpreted with computer software (One dimentional IPWIN2). An electrode made of stainless steel was driven into the soil at each end of the spread A and B. Both electrodes were then connected to the current sender of the Terrameter. The electrodes M and N were also driven into the soil and connected to the voltage receiver. At each position of A and B, the current was sent, and the potential difference between M and N was measured. Also, the distances AB and MN were measured. Following the placing and connection of all electrodes, resistance measurements were made Beginning with the small spacing and progressing outward. When the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes must also be displaced outwards otherwise the potential difference becomes too small to be measured with sufficient accuracy (Koefoed, 1979). The Root Mean Square error was less than 10%. The apparent resistivity values obtained in the field was plotted against half current electrode spacing in a bi-logarithmic graph. The curves of best fit were traced and the data obtained from the smooth curve was noted. Qualitative and quantitative interpretations of the field curves were carried out by inspection to obtain the type of curves.

Sixteen (16) vertical electrical sounding (VES) points were conducted at various locations within the study area in order to study the variations in the resistivity distribution of the soil with depth. GPS device was used for measuring the spatial location (latitude and longitude) for the VES points (Table 2).

Aquifer Parameter Estimation

The resistivity parameters of the upper most geoelectric layer in the study area have been used to assess the vulnerability of the underlying aquifer. The combination of the resistivity and thickness in the Dar Zarrouk parameter (longitudinal conductance) have been used by various researchers in groundwater potential and aquifer vulnerability studies (Golam *et al*. 2014; Oborie and Udom, 2014) High longitudinal conductance values usually indicate relatively high protective capacity and should be accorded the highest priority in terms of groundwater vulnerability assessment. The total longitudinal conductance (S) for each of geoelectric sounding (VES) stations was computed from the relation:

$S = \Sigma (hi / \rho i) = h1 / \rho 1 + h2 / \rho 2 + \ldots + hn / \rho n$ (1)

Where S is the total longitudinal conductance, Σ is summation sign, hi is the thickness of the ith Layer and ρi is the resistivity of the ith layer.

Results and Discussions

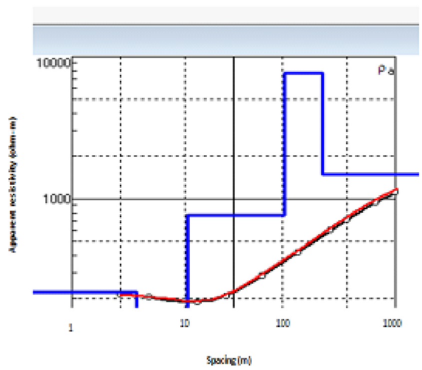
3.1 Geo-electric Sections

The most important parameter in quantitative interpretation is the depth of the aquiferous units. Depth to water information is contained in the interpretation of the geo-electric curves. In VES 1 the sounding encountered five geo-electric units: top soil, sand, shale, water saturated sand and sand. Furthermore, Fig. 2 is a typical interpretation results of geo-electric sounding data acquired in the area (VES 1 - 6).

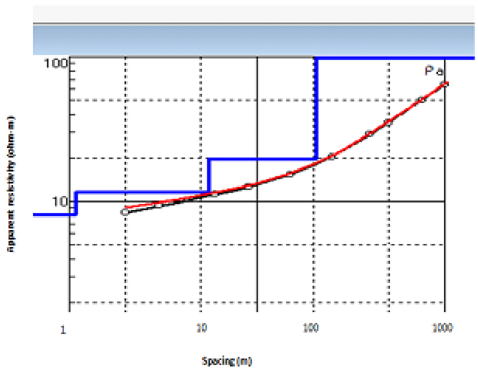
The geoelectrical curves obtained vary considerably throughout the study area. Data analysis showed that the area under investigation was generally five layered. Typical forms of the curves obtained were QH, HA, H, HQ, HK, QK and QA respectively.

The computer interpretation techniques have helped to resolve the resistivities , thicknesses and the depths to the aquiferous layers. The results obtained show that the depth of water in the area is above 100m. The result revealed that the top layer thickness and resistivity ranged between 0.634 and 2.58m and between 8.08 and 4770 Ωm. The second layer thickness and resistivity ranged between 3.10 and 78.02m and between 11.6 and 5194 Ωm. The third layer thickness and resistivity ranged between 7.89 and 83.63m and between 11.9 and 8125 Ωm. The fourth layer thickness and resistivity ranged between 9.57 and 136.6m and between11.4 and 8544 Ωm. The last layer resistivity ranged between 9.81and 9605 Ωm.

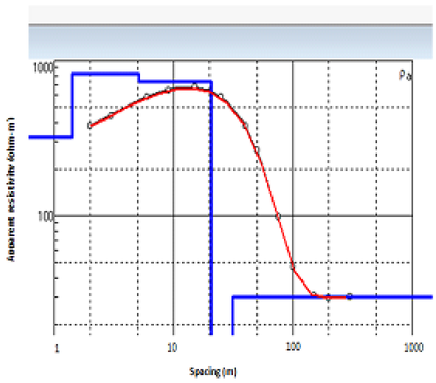
The total longitudinal conductance values were used in evaluating the protective capacity/ vulnerability of the aquifer. The protective capacity rating (table 1) enables the classification of the study area into poor, weak, moderate and good protective capacity zones. Areas that are classified as poor are indicative of areas of high infiltration rates from. Such areas are vulnerable to infiltration of leachate and other surface contaminants. Aquifer protective capacity was evaluated from the aquifer layer parameters using the Dar-zarrouk parameters, (longitudinal conductance (S)). Equation (1) was used to compute Longitudinal conductance shown in Table 2 which was used to determine the overburden protective capacity of the aquifer in the study area. Since table 1 has already established that the higher the longitudinal conductance, the higher the aquifer protective capacity. The higher the resistivity of a material, the lower its conductivity and vice versa. Since the earth subsurface acts as a natural filter to percolating fluid, its ability to retard is a measure of its protective capacity. For instance, Clayey soil is known to be relatively impermeable, but sandy soil which is relatively permeable can provide an infiltration path for the pollutants to enter the aquifers (Loke, 1999). The study area is characterized by average values of longitudinal conductance ranging from 0.004 to 0.987 Ω. Olorufemi, et al., (1999), observed that the highly impervious clayey overburden that is characterized with relatively high longitudinal conductance, offers protection to the underling aquifer. Considering Table 1, the study area could be



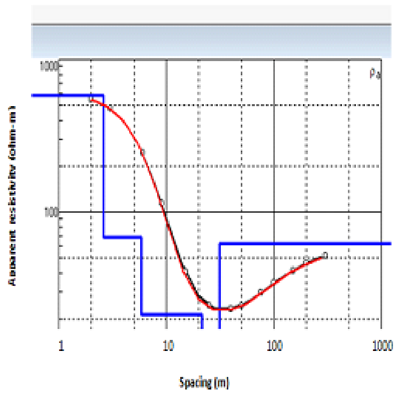
VES 1



VES 2



VES 3



VES 4

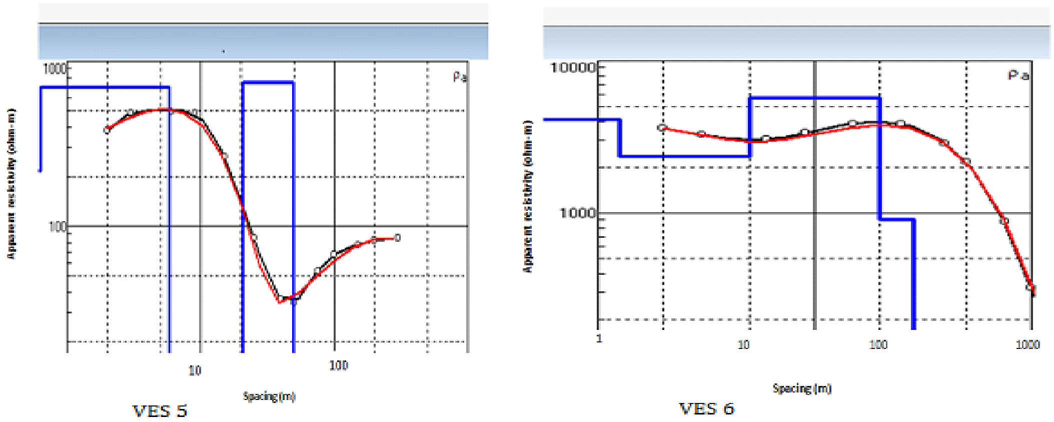


Fig 2: Typical interpretation results of geo-electric sounding data acquired in the study area

Table 1: Protective capacity classification (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 – 1.00	Good

Table 2: VES Coordinates points, Geoelectric parameters, lithological delineation and protective capacity of the study area

VES	VES Location Coordinates		Layer	Layer resistivity ρ (Ω. m)	Thickness (m)	Estimated depth to bottom (m)	Aquiter resistivity (ΩM)	Aquiter Thickness (M)	Curve Type	Lithology	Protective capacity
1	6°25.442' N	7°13.086' E	1	218	0.634	0.634	749	136.6	QH	Top soil	0.6733 Moderate
			2	702	5.18	5.81				Sand	
			3	11.9	7.89	13.7				Shale	
			4	749	136.6	150.3				Water saturated sand	
			5	9.81						Sharp sand	
2	6°23.899'	7°12.369'	1	582	2.58	2.58	11.4	10	HA	Laterite	0.7795 Good
			2	68.2	3.23	30.81				Sandy Sand	
			3	21.3	15.5	42.3				Shale	
			4	11.4	10	92.3				Saturated	
			5	61.7						Sharp Sand	
3	6°22.897'	7°09.718'	1	319.2	1.41	1.41	11.62	40.56	KH	Top Soil	0.1264 Weak
			2	819.1	3.68	5.09				Shale sand	
			3	726.6	15.43	20.53				Sand	
			4	11.62	40.56	6.09				Saturated	
			5	30.02						Sharp sand	
4	6°23.939'	7°10.679'	1	8.08	1.08	1.08	225	57.5	HQ	Laterite	0.9760 Good
			2	11.6	4.41	5.49				Sandy Sand	
			3	19.5	9.01	14.5				Shale	
			4	225	57.5	70				Saturated	
			5	391						Sharp Sand	

5	6°21.554' N	7°06.046' E	1	220	22.69	2.51	7693	25.1	HA	Laterite	0.5181 Moderate
			2	102	2.69	25.2				Shally Sand	
			3	765	65.4	90.6				Sand	
			4	7693	15.1	105.7				Water Saturated	
			5	1493						Shale	
6	6°22.099'	7°05.941'	1	4110	1.26	1.26	901	38.1	HK	Top soil	0.0114 Poor
			2	2367	3.75	5.01				Sand	
			3	5759	59.99	60				Shanly Sand	
			4	901	38.9	98.9				Saturated	
			5	41.7						Shale	
7	6°19.369'	7°05.675'	1	759	1.2	1.2	15.5	27.3	QK	Top Soil	0.2716 Moderate
			2	429	4.08	5.28				Shale sand	
			3	288	75.02	80.3				Sand	
			4	15.5	27.3	107.6				Saturated	
			5	12.3						Sharp sand	
8	6°19.477'	7°05.759'	1	504.5	1.28	1.28	5125	11.09	HA	Top Soil	0.9873 Good
			2	155	3.83	5.1				Shale sand	
			3	46.91	45.04	50.14				Sand	
			4	5125	11.09	61.23				Saturated	
			5	7430						Sharp sand	
9	6°19.991'	7°09.919'	1	464	1.39	1.39	48.7	24.7	KH	Top Soil	0.4297 Moderate
			2	1857	3.66	5.05				Shale sand	
			3	177	75.25	80.3				Sand	
			4	48.7	24.7	105.3				Saturated	
			5	3599						Sharp sand	
10	6°20.777'	7°05.605'	1	1594	1.05	1.05	85.1	38.5	QH	Top soil	0.9205 Good

			2	773	4.08	5.13				Sandy Sand	
			3	60	54.87	60				Shale	
			4	85.1	38.5	98.5				Saturated	
			5	7293						Shale	
11	6°20.491'	7°07.907'	1	540.9	1.05	1.05	126	29.95	HA	Lateritre	0.3432 Moderate
			2	248.7	4	5.05				Shale	
			3	508.8	73.63	78.68				Sand	
			4	126	79.95	18.63				Water saturated	
			5	3353						Shale	
12	6°24.043'	7°05.294'	1	116	1.19	1.19	5541	18.89	QA	Lateritre	0.3549 Moderate
			2	240.6	4.02	5.21				Shale	
			3	1190	15.41	20.62				Sand	
			4	5541	9.89	30.51				Saturated Sand	
			5	9605						Shale	
13	6°21.871' N	7°09.929' E	1	231.5	1.01	1.01	2732	10.98	QA	Top Soil	0.0162 Poor
			2	419.8	4.18	5.19				Shale sand	
			3	8125	15.1	20.29				Sand	
			4	2732	10.98	31.27				Saturated Sand	
			5	8228						Sharp sand	
14	6°23.648' N	7°08.115' E	1	481.8	1.41	1.41	8544	26.84	QA	Lateritre	0.0917 Poor
			2	471.4	3.82	5.23				Sandy Sand	
			3	908.3	73.32	78.55				Shaly Sand	
			4	8544	26.84	105.39				Water saturated	

										Sand	
			5	9327						Shale	
15	6°19.873' N	7°06.418' E	1	4770	1.99	1.99	4443	9.57	QK	Top soil	0.0043 Poor
			2	5194	3.1	5.09				Sand	
			3	4708	15.53	20.63				Sandy Sand	
			4	4443	9.57	30.19				Saturated water	
			5	178						Shale	
16	6°20.088' N	7°05.251' E	1	520.9	1.12	1.12	489.7	71.57	HA	Lateritre	0.299 Moderate
			2	325.5	3.89	5.01				Shaly Sand	
			3	627.6	73.75	78.06				Sand	
			4	489.7	71.57	419.63				Saturated Sand	
			5	2369						Shale	

considered averagely protective from surface contamination. Seven (7) VES stations is found to have moderate longitudinal conductance (S > 0.2), which represents 43.75% of the study area. However, VES station 3 is found with longitudinal conductance (S < 0.2) is considered weak and vulnerable to contamination. While four (4) VES stations which represent 25% of the study area are considered poor protective capacity (S < 0.1) likewise 25% of the VES stations are considered to have a good protective capacity (S > 0.7).

3.2 Assessment of Aquifer Vulnerability

The earth medium acts as a natural filter to percolating fluid, the ability of the earth to filter fluid is dependent on the aquifer thickness, the covering materials and the protective capacity of the overlying overburden of the aquifer. Silts and clays are suitable aquitards which often constitute protective geologic barriers and when they are found above an aquifer they constitute a protective cover (Lenkey *et al*. 2005), they thus protect the aquifer from surface and near-surface contamination, because their low hydraulic conductivity leads to high residence time of percolating water. Clayey overburden has been reported by Golam *et al*. (2014) to be characterized by relatively high longitudinal conductance, which offers protection to the underlying aquifer. Table 2 shows the soil layers, geo-electrical resistivity, aquifer thickness, lithology and the protective capacity of the VES points. The study area lithology is characterised with sand, shaly-sand and shale. Shale layer in this study seems to offer higher longitudinal conductance in the absence of clay. The longitudinal unit conductance (S) values obtained from the study area, ranges from 0.001 to 0.9 mhos. , the study area could be considered averagely protective from surface contamination. Seven (7) VES stations is found to have moderate longitudinal conductance (S > 0.2), which represents 43.75% of the study area. However, VES station 3 is found with longitudinal conductance (S < 0.2) is considered weak and vulnerable to contamination. While four (4) VES stations which represent 25% of the study area are considered poor protective capacity (S < 0.1) likewise 25% of the VES stations are considered to have a good protective capacity (S > 0.7).Consequent upon these observations it can be inferred from this study that a minimum shale thickness of 10m is required to provide good protective capacity for groundwater using the longitudinal conductance aquifer assessment criteria. By using the resistivity values measured from the geo-electric survey, longitudinal unit conductance of the overlying overburden was evaluated. gives detailed information on the pattern of the protective capacity of the natural overburden over the aquifer in the study area.

Conclusion

This study was embarked upon to quantitatively rate the level of protection that will be of advantage or otherwise to the sandy aquifers, which are the major sources of potable water for the people in Awka. Awka area was selected because it is an area where inorganic wastes resulting from household, soil productivity enhancement techniques and micro-industrial activities are prevalent. The geophysical data used were the electrical resistivity data generated from sixteen VES sounding. The geological data used include the generalised geological, borehole lithologic information of the area. Both manual and computer modelling techniques were adopted in converting the measured field data to their geologic equivalents using borehole lithologic data as constraints. Interpreted layer resistivities and thicknesses were used in computing the longitudinal conductance for lithologies that overlie the aquifers.

The geoelectrical investigation revealed lithologic sequence which consists of shale and sand. The study delineated an aquifer each along the 16 VES locations and further showed that the depth of water in the area is above 100m. The result revealed that the top layer thickness and resistivity ranged between 0.634 and 2.58m and between 8.08 and 4770 Ωm. The second layer thickness and resistivity ranged between 3.10 and 78.02m and between 11.6 and 5194 Ωm. The third layer thickness and resistivity ranged between 7.89 and 83.63m and between 11.9 and 8125 Ωm. The fourth layer thickness and resistivity ranged between 9.57 and 136.6m and between11.4 and 8544 Ωm.

The study area is characterized by average values of longitudinal conductance ranging from 0.004 to 0.987 Ω. The aquifer protective capacity was evaluated from computing the longitudinal conductance.

Finally, this research hence is a communication tool to bridge the gap between hydrogeological science and environmental management agencies in Awka as it has points out the various overburden protective capacities for effective management and planning.

References

Anomohanran, O. (2013). Geoelectrical investigation of groundwater condition in Oleh, Nigeria.13 www.arpapress.com. IJRRAS; 15(1)1:5.

Delleur, J. (1999). *The handbook of groundwater engineering*. CRC press LLC, USA.

Dobrin, M .D., Ring, R. F., (1976). *Introduction to Geophysical Prospecting.* New York, McGraw-Hill Brook.

Foster, S. (2002). *Groundwater Quality protection- a guide for water utilities, municipal a authorities and environmental agencies*. The international Bank for Reconstruction and Development/The World Bank, Washington DC available at e searchgate. Net / publication / 280493781

Golam, S. S., Keramat, M., & Shahid, M. (2014). Deciphering transmissivity and hydraulic conductivity of the aquifer by vertical electrical sounding (VES) experiments in Northwest Bangladesh, Appl Water Sci.

Henriet, J. P. (1976). *Direct application of the dar zarrouk parameters in groundwater surveys.* Geophysical prospecting (24) 345-353

Jang, D. (2017). *Aquifer vulnerability Assesment for sustainable groundwater management using DRASTIC.* Water (9)792

Koefoed, O. (1979). Geo-sounding Principles: Resistivity Sounding Measurements. Armsterdam: Elsevier Scientific Publishing Company.

Lenkey, L., Hamori Z., & Mihalffy, P. (2005). Investigating the hydrogeology of a water supply area using direct-current vertical electrical soundings. Geophy; 70(4):1-19.

Loke, M. H. (1997). *Electrical imaging surveys for environmental and engineering studies.* Unpublished report: www.heritagegeophysics.com.

NWRI, (National Water Resource Institute, Kaduna, (2011). National Assessment of Drinking Water Quality Project Report: Federal Ministry of Water Resource.

Oborie, E. 1., & Udom G. J. (2014). Determination of aquifer transmissivity using geoelectrical sounding and pumping test in parts of Bayelsa State, Nigeria. Peak Journal of Physical and Environmental Science Research; 2(2):32-40.

Odumodu, O. I., & Ekenta, E. O. (2012). Modelling Operation and Maintenance, Management of Water Supply in Awka, Anambra State, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*; 3(5):868-873.

Olorufemi M. O. (1999). Hydrogeophysical evaluation of the groundwater potential of Akure metropolis, Southwestern Nigeria. J. Min. Geol. 35(2): 207-228.

Robins, N. S. (2007). Adapting existing experience with aquifer vulnerability and groundwater protection. African Journal of Earth Sciences 4(7)30-38.

Wilson, L. G. (1983). Monitoring in the vadose zone part 3 groundwater monitoring review 3(1)155-166.