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Aquifer Vulnerability Assessment in Some Towns of Yenagoa, South-South Nigeria

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Abstract An assessment of aquifer protective capacity was investigated in some towns of Yenagoa. Fifteen (15) Vertical Electrical Soundings (VES) stations were occupied using the Schlumberger electrode configuration. The VES data interpretation involved quantitative modelling and the curve types obtained were HA, KHK, HK, AK, HKQ and KH. The modelled geoelectric parameters (layer resistivity and layer thickness) at each station were used to compute the Dar-zarrouk parameter (i.e. longitudinal conductance L_C). Longitudinal conductance values showed areas with poor (less than 0.1 mho), weak (0.1 mho – 0.19 mho), moderate (0.2 mho – 0.69 mho) and good protective capacity (0.7 mho– 4.9 mho). Results showed that 53.3% of the area had a weak aquifer protective capacity, 33.3% had poor protective capacity and 13.3% had good and moderate aquifer protective capacity. The longitudinal unit conductance indicated that the Southern Yenagoa had good to moderate aquifer protective capacity rating, while the Northern area had poor to weak aquifer protective capacity.

Keywords Aquifer Vulnerability, Resistivity, Dar-zarrouk parameters, Yenagoa

1. Introduction

The rapid increase in population in Yenagoa owing to urbanization has led to an increased pressure on underground water which is the major water resource in the area. Groundwater quality has been affected by a number of factors such as over abstraction, movement of leachate to the aquifer from dumpsites, leakage of surface and underground storage and septic facilities e.t.c. The importance of potable water supply to human health cannot be over-emphasized, as such; one must take into consideration the quality of the geologic material overlying the aquifer. Henrit (1976) showed that the combination of layer resistivity and thickness can be used to compute the Dar Zarrouk parameters L_C (longitudinal conductance) and R_T (transverse resistance), which may be of direct use in aquifer protection studies and evaluation of hydrologic properties of aquifers. The protective capacity is considered to be proportional to the longitudinal unit conductance in mhos (Olorunfemi et al., 1998; Oladapo et al., 2004).

A detailed geoelectric survey covering parts of Yenagoa was carried out to determine the geoelectric parameters of subsurface layers and their hydrogeological properties for the evaluation of the protective capacity of the aquifer overburden materials in the area.

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2. Physiography and Geology of Study Area

The study area is Yenagoa the capital of Bayelsa state. It lies within latitude 04° 4N and 05° 02N and longitude 006° 15E and 006° 24E (fig 1) and situated in southern part of the Niger Delta of Nigeria. The city lies within the tropical Equitorial climate with an annual mean rainfall of 3000 mm (Amajor and Ofoegbu, 1988). It is accessible by a good road network and tributaries of the river Nun. The average elevation of the study area is 10m above sea level. The area under study falls within the Niger Delta which is characterized by nearly flat topography sloping slightly seawards (Etu-Efeotor and Akpokodje, 1990). This area lies in the sedimentary basin of the Niger Delta and is devoid of any outcrop. During the rainy season, the area is flooded while it is dry during the dry season.

The geologic sequence of the Niger Delta consists of three main tertiary subsurface lithostratigraphic units which are overlain by various types of quaternary deposits (Short and Stauble, 1965). The base of the unit is the Akata formation; it is comprised mainly of marine shales with some sand beds. The formation ranges in thickness from about 550 m to over 6,000 m. Very little hydrocarbon has been associated with the formation. The Agbada formation is the overlying paralic sequence which consists of interbedded sands and shale with a thickness of 300 m to about 4,500 m, thinning both seawards and towards the Delta margin. The topmost unit is the Benin formation; it is comprised of over 90% sandstone with shale intercalations. It is coarse grained, gravely, locally fine grained, poorly sorted, sub angular to well-rounded and bears lignite streaks and wood fragments (Allen, 1965). The unit is thickest in the central area of the Delta. The contact with the underlying Agbada formation is defined by the base of sandstones which also corresponds to the base of the fresh water bearing strata.

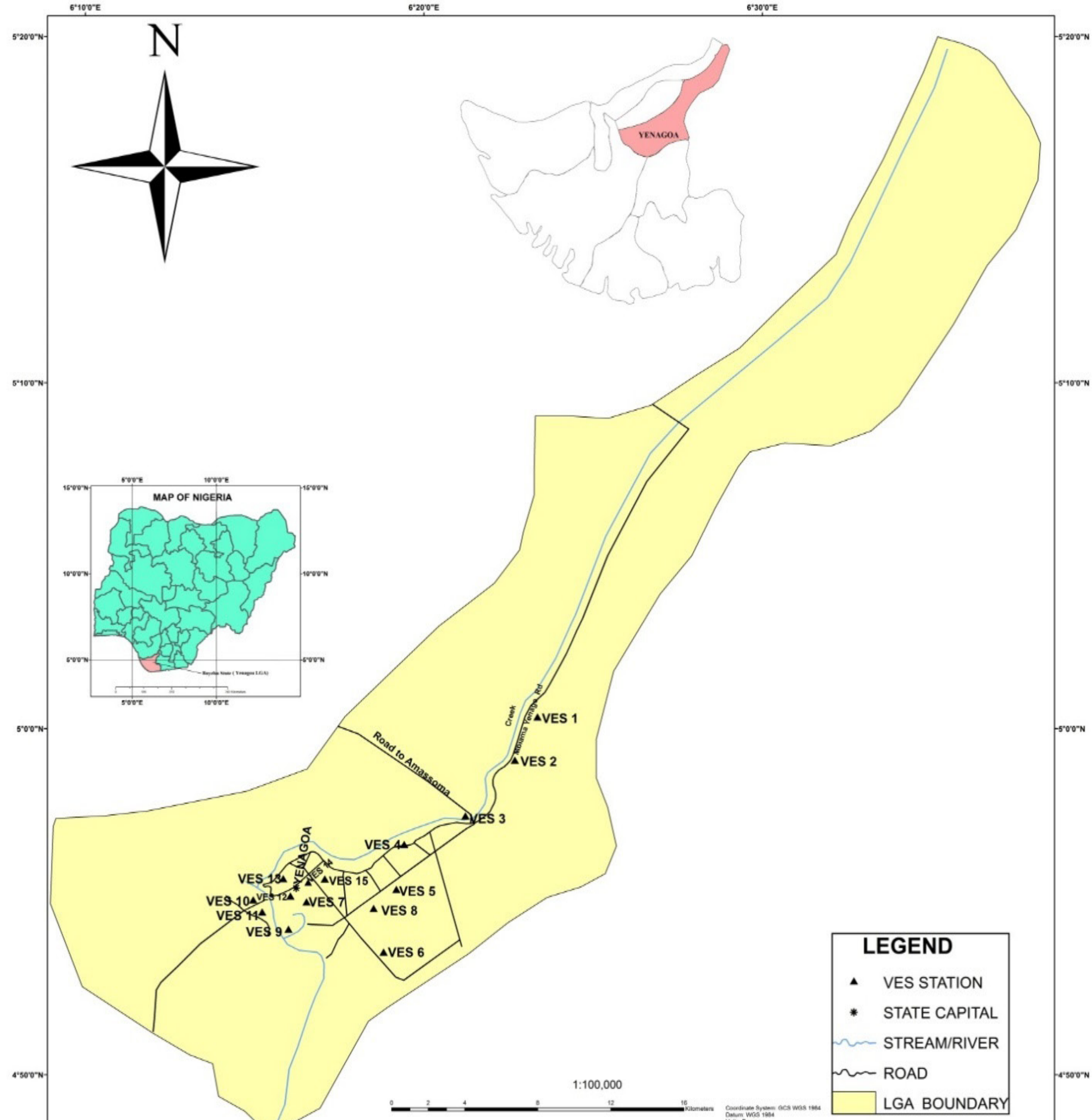


Figure 1. Map of Yenagoa LGA showing the location of VES stations

3. Materials and Method

Investigation was done using the Vertical Electrical Sounding method (Schlumberger configuration) with a maximum current electrode (AB) spread of 200m – 266m. A total of Fifteen (15) VES stations were occupied (Fig 1). The ABEM terrameter SAS 1000 was used for data acquisition. The field procedure was carried out by applying current to the ground through two electrodes (A and B) and then measuring the resultant potential difference (ΔV) between the potential electrodes (M and N). The centre point of the electrode array remained fixed but the spacing of the electrodes was increased so as to obtain information about the stratification of the ground (Koefoed, 1977). The interpretation was computer assisted; some of these soundings were done at the sites of existing boreholes. Lithology and thickness of layers from these boreholes were used to constrain models. The combination of the resistivity and layer thickness was used to compute the Longitudinal conductance of layers (Golam et al., 2014; Oborie and Udom, 2014). High longitudinal conductance indicated relatively high protective capacity. The total longitudinal conductance (S) for each of geoelectric sounding (VES) stations was computed from the relation:

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

Where S is the Total Longitudinal Conductance, hi is the thickness of the ith Layer and ρi is the resistivity of the ith layer.

Using Henriet (1976) classification, the results of longitudinal conductance was used to classify areas into good, moderate, weak and poor protective capacity (Table 1).

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

4. Results and Discussion

The geoelectrical curves obtained (fig 2) vary considerably throughout the study area. Data analysis showed that the area under investigation was a four to five layered. Typical forms of the curves obtained are HA, HK, KH, AK, KHK and HKQ (Fig. 2). The top layer thickness and resistivity ranged between 0.42 m - 1.5 m and 15 Ωm – 48.8 Ωm respectively and consisted of weathered/dry organic rich peaty clay. The second layer thickness and resistivity ranged between 0.9 m - 15.0 m and 2.4 Ωm – 615 Ωm respectively. It consisted mainly of silty clay but on VES's 6, 9 and 11 this layer consisted of medium-coarse grained sands. The third layer was chiefly medium - coarse grained sands with few clay lenses. This layer was observed to be the main water-bearing layer, resistivity ranged between 77 Ωm - 1960 Ωm with an average of 460 Ωm, its thickness ranged between 23.9 m – 48.7 m. The fourth layer in this study is mainly the half-space, it had an average resistivity of 3000 Ωm. VES 2 and 13 were five layer cases, they had a thickness that ranged between 32 m – 48 m, with resistivity range of 13 Ωm – 51 Ωm, typical of a clay/ silty clay formation.

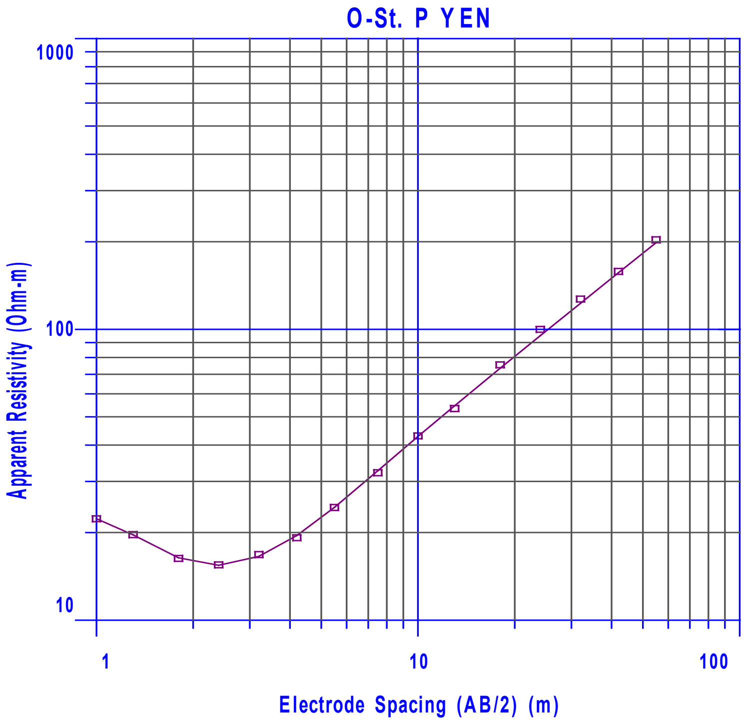
The total longitudinal conductance values were used in evaluating the protective capacity/vulnerability of the aquifer. Henriet (1976) suggested that high clay content with a potential to impede fluid movement is generally characterized by low resistivity values, low hydraulic conductivities, and consequently high longitudinal conductance. The protective capacity rating table (Table 2) enables the classification of the study area into poor, weak, moderate and good protective capacity zones. Areas that are classified as poor and weak are indicative of zones of high infiltration rates from precipitation. Such areas are vulnerable to infiltration of leachate and other surface contaminants. In addition to high transmissivity and low protective capacity ratings in most of the VES stations, the aquifers tapped by most of the boreholes drilled in the study area are relatively close to the surface and thus susceptible to contamination over large areas. However, groundwater potential in terms of availability is high in the study area as evident in the high transverse resistance (R_T) and dominantly low longitudinal conductance values of the subsurface formations which are characteristics of productive aquifers.

Table 2. Showing Overburden Thickness

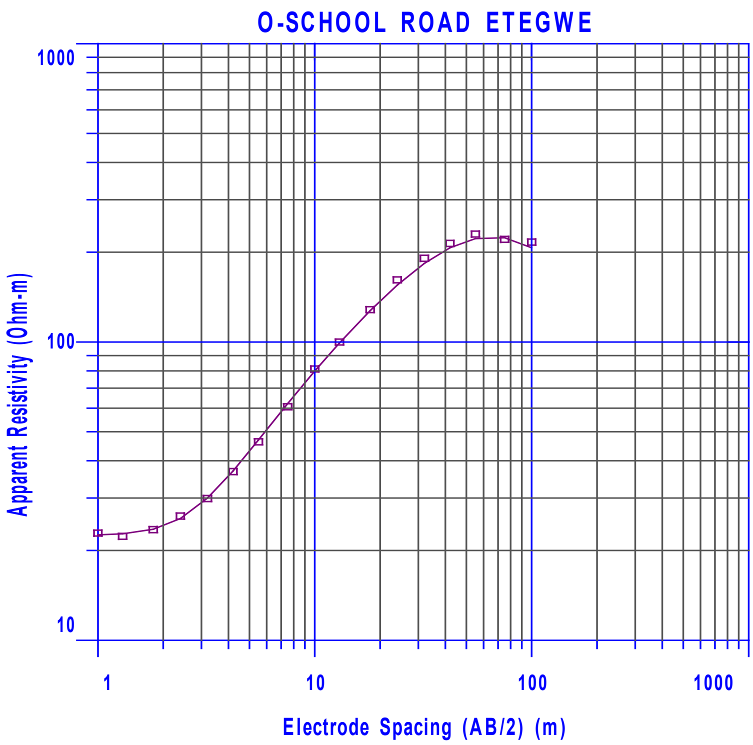
VES LOCATION	OVERBURDEN THICKNESS (m)
VES 1	3.3
VES 2	0.8
VES 3	2.2
VES 4	2.8
VES 5	1.5
VES 6	0.8
VES 7	2.7
VES 8	3.3
VES 9	0.9
VES 10	2.9
VES 11	0.7
VES 12	2.5
VES 13	2.6
VES 14	2.9
VES 15	3.6

Aquifer

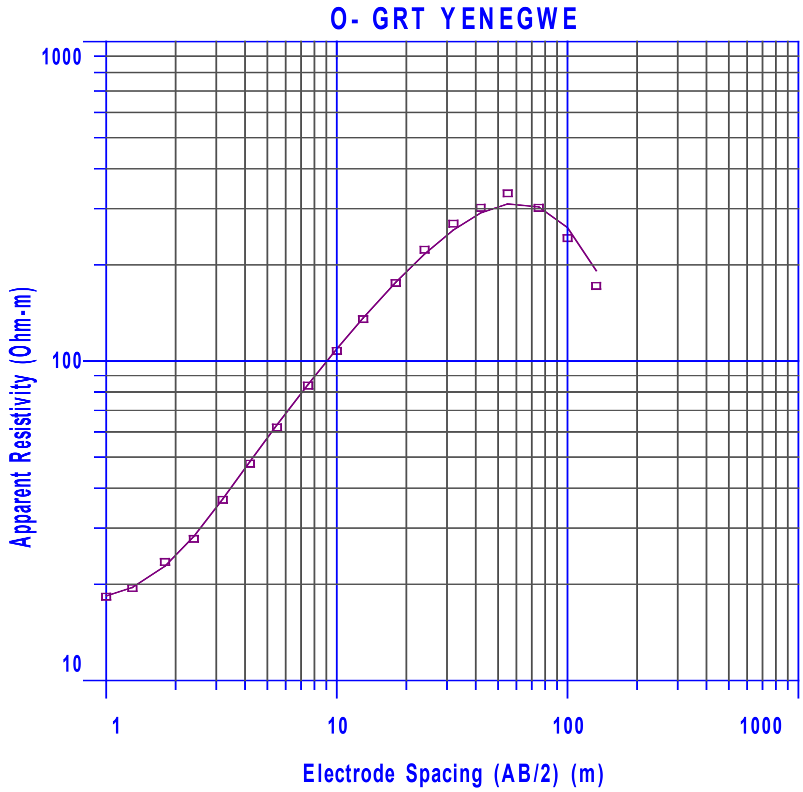
Longitudinal conductance ranged between 0.0172 mhos to 0.8904 mhos in the study area. The weak protective capacity is observed at VES's 1, 3, 7, 8, 10, 12, 13 and 14. All other locations showed poor aquifer protective capacity. VES 4 and 15 showed moderate and good aquifer protective capacity respectively. The overburden thickness of aquifer ranged from 0.7 m to 3.6 m, (Table 3). Thicknesses showed shallow water bearing formation. It can be correlated to results of areas having poor protective capacity, which is as result of the thin layer of impervious material protecting the aquifer.



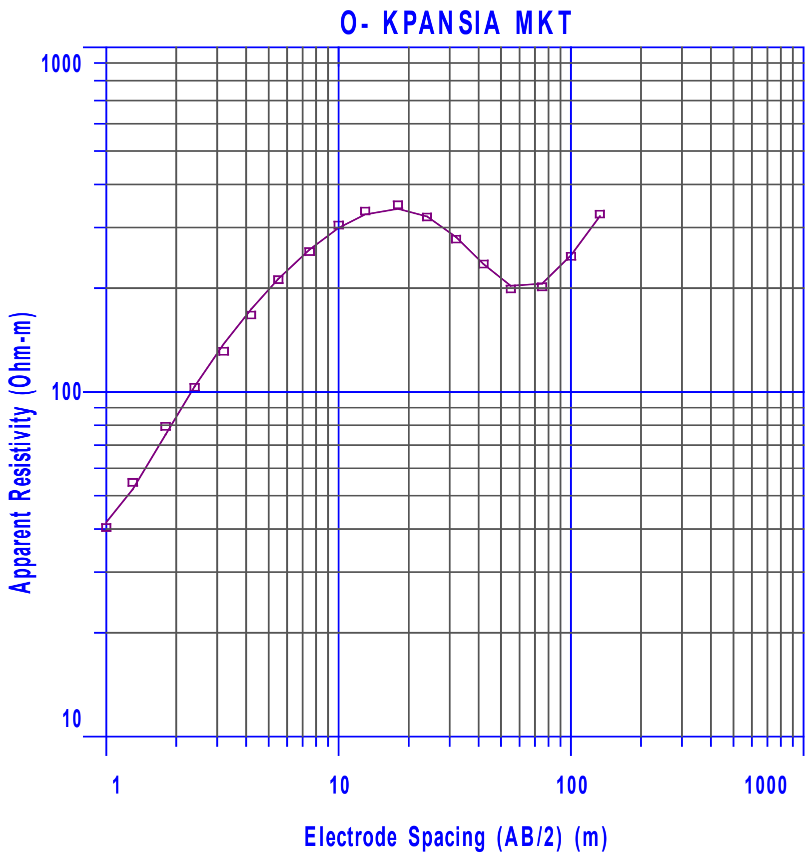
HA –CURVE



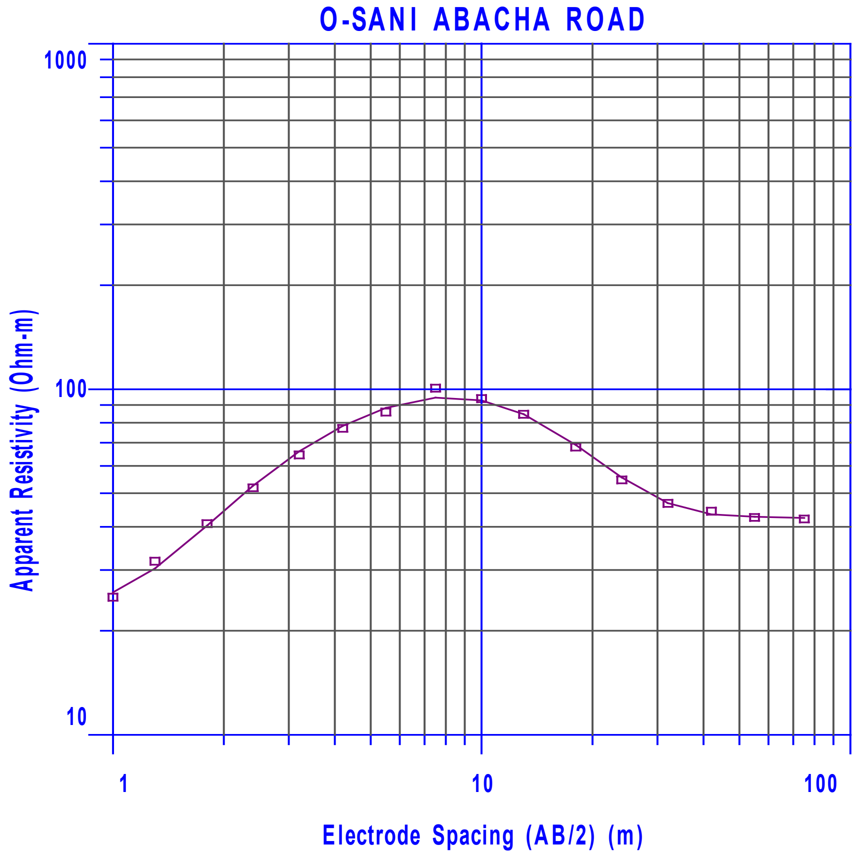
HK-CURVE



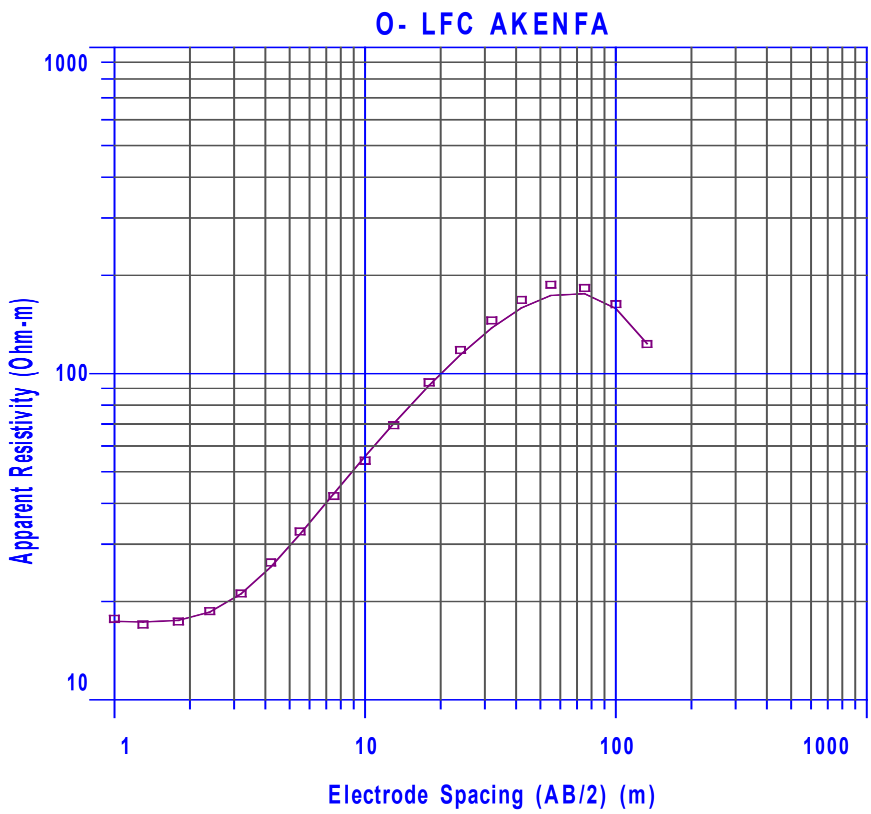
AK-CURVE



KH-CURVE



KHK-CURVE



HKQ-CURVE

Figure 2. showing Predominant VES curves

Table 3. VES Coordinates Points, Geoelectric Parameters, Lithological Delineation and Protective Capacity

VES No and co-ordinate points.	LOCATION	Layers	Resistivity (Ωm)	Thickness (m)	Curve Types	Lithology	Longitudinal conductance	Protective capacity
VES 1 N04054'13.4" E006016'59.1"	OX-BOW LAKE, SWALI	Layer 1	44.020	0.6583	HA	Top Soil	0.0150	0.1366 Weak
		Layer 2	21.485	2.6126		Clay	0.1216	
		Layer 3	1960.9	25.850		Sand	0.0132	
		Layer 4	24366.					
VES 2 N04^{O}54'38.9" E006^{0}17'34.6"	SANI ABACHA ROAD	Layer 1	25.847	0.7817	KHK	Top Soil	0.0302	0.0302 Poor
		Layer 2	188.41	3.6144		Sandy Clay	0.0192	
		Layer 3	32.597	14.642		Clay	0.4492	
		Layer 4	51.186	32.931		Clay	0.6434	
		Layer 5	31.936					
VES 3 N04^{0}57'26.7" E006^{0}21'13.5"	SCHOOL ROAD, ETEGWE	Layer 1	22.568	0.7195	HK	Top Soil	0.0319	0.1052 Weak
		Layer 2	20.541	1.5052		Clay	0.0733	
		Layer 3	475.93	26.918		Clayey Sand	0.0566	
		Layer 4	87.399					
VES 4 N04^{0}55'33.1" E006^{0}16'32.1"	St. PATRICK, YENEGOA	Layer 1	22.326	0.4280	HA	Top Soil	0.0192	0.2140 Moderate
		Layer 2	12.339	2.4037		Clay	0.1948	
		Layer 3	457.18	21.604		Clayey Sand	0.0473	
		Layer 4	2255.7					
VES5 N05^{0}01'11.1" E006^{0}23'53.4"	YENEGWE	Layer 1	18.389	0.5780	AK	Top Soil	0.0314	0.0787 Poor
		Layer 2	19.320	0.9139		Clay	0.0473	
		Layer 3	767.87	29.069		Clayey Sand	0.0379	
		Layer 4	8.9239					
VES 6 N04^{0}59'03.3" E006^{0}22'38.6"	AGUDAMA	Layer 1	25.605	0.7795	KQ	Top Soil	0.0304	0.0304 Poor
		Layer 2	337.33	11.697		Sandy Clay	0.0347	
		Layer 3	77.001	38.842		Clay	0.5044	
		Layer 4	14.220					
VES 7 N04^{0}56'15.6" E006^{0}16'56.9"	AMARATTA	Layer 1	34.457	1.2113	HK	Top Soil	0.0352	0.1628 Weak
		Layer 2	11.397	1.4549		Clay	0.1277	
		Layer 3	605.27	25.488		Clayey Sand	0.0421	
		Layer 4	35.092					

VES No and co-ordinate points.	LOCATION	Layers	Resistivity (Ωm)	Thickness (m)	Curve Types	Lithology	Longitudinal conductance	Protective capacity
VES 8 N04^{0}56’35.7” E006^{0}19’29.3”	BIOGBOLO	Layer 1	23.487	0.7307	AK	Top Soil	0.0311	0.1380 Weak
		Layer 2	23.904	2.5559		Clay	0.1069	
		Layer 3	736.93	31.217		Clayey Sand	0.0424	
		Layer 4	16.615					
VES 9 N04^{0}55’01.3” E006^{0}15’04.4”	FAMGBE	Layer 1	48.855	0.8762	KH	Top Soil	0.0179	0.0179 Poor
		Layer 2	359.97	19.854		Clayey Sand	0.0552	
		Layer 3	88.364	32.946		Clay	0.3728	
		Layer 4	2494.2					
VES 10 N04^{0}53’30.6” E006^{0}18’48.4”	HOUSE OF ASSEMBLY	Layer 1	15.195	1.0444	AA	Top Soil	0.0687	0.1047 Weak
		Layer 2	52.224	1.8776		Clay	0.0360	
		Layer 3	198.36	48.700		Sandy Clay	0.2455	
		Layer 4	3336.0					
VES 11 N04^{0}55’03.8” E006^{0}19’03.3”	KPANSIA	Layer 1	41.879	0.7234	KH	Top Soil	0.0173	0.0173 Poor
		Layer 2	615.75	9.4800		Clayey Sand	0.0154	
		Layer 3	81.549	29.995		Clay	0.3678	
		Layer 4	11334.					
VES 12	LAW FACULTY	Layer 1	36.735	0.6125	HK	Top Soil	0.0167	0.1651 Weak
		Layer 2	12.647	1.8775		Clay	0.1485	
		Layer 3	207.44	23.922		Sandy Clay	0.1153	
		Layer 4	7.0535					
VES 13 N05^{0}011’11.0” E006^{0}23’12.0”	AKENFA	Layer 1	17.405	0.5043	HKQ	Top Soil	0.0290	0.1601 Weak
		Layer 2	15.888	2.0837		Clay	0.1311	
		Layer 3	535.75	25.027		Clayey Sand	0.0467	
		Layer 4	13.163	48.564		Clay	3.6894	
		Layer 5	7.0261					
VES 14 N04^{0}54’08.3” E006^{0}15’54.0”	OGU	Layer 1	23.587	0.4617	HK	Top Soil	0.0196	0.1651 Weak
		Layer 2	16.432	2.3906		Clay	0.1455	
		Layer 3	195.55	48.275		Sandy Clay	0.2469	
		Layer 4	123.96					
VES 15 N04^{0}54’42.3” E006^{0}18’21.5”	OKAKA	Layer 1	40.727	1.5726	HA	Top Soil	0.0386	0.8904 Good
		Layer 2	2.4354	2.0745		Clay	0.8518	
		Layer 3	489.60	32.849		Clayey Sand	0.0671	
		Layer 4	3992.9					

5. Conclusions

About 53.3% of the area showed weak aquifer protective capacity, 33.3% had poor protective capacity and 13.3% possessed moderate to good aquifer protective capacity. Geoelectric investigation by the analysis of the longitudinal unit conductance suggested that sections of the aquifer underlying the Northern parts of the area studied had poor to weak protective capacity, while, good to moderate protective capacity was observed in the Southern parts of the study area. It is thus recommended that sanitary landfill sites, underground storage and septic facilities be sited on the Southern parts of Yenagoa with better aquifer protective capacity, taking the direction of underground water flow into consideration.

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