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Research Paper

HYDRO-GEOELECTRIC STUDY OF AQUIFER POTENTIAL IN PARTS OF IKOT ABASI LOCAL GOVERNMENT AREA, AKWA IBOM STATE USING ELECTRICAL RESISTIVITY SOUNDINGS

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Geoelectric survey employing Vertical Electrical Sounding (VES) was carried out in parts of Ikot Abasi Local Government Area, Akwa Ibom state, Nigeria. In this area there is no borehole that has been drilled until now, the main objectives of this study is to be a guide for the suitable position of borehole in order to avoid wild cat drilling and also to avoid salt intrusions using the VES geophysical techniques. Schlumberger electrode configuration was used in acquiring the data. Four to five geoelectric layers were delineated from the interpreted results. It shows the topsoil having resistivity range of 80.64-2810.23 Ωm, with a thickness and depth ranging from 0.13-2.26 m. The second layer has resistivity range of 12.48-2802.61 Ωm, the third layer shows a resistivity range of 9.08-2534.06 Ωm, whereas the fourth layer with a resistivity of 0.53-1483.27 Ωm, harbours most of the aquifers in the study area and is highly resistive. The geoelectric parameters obtained were also used to estimate the longitudinal conductance and transverse resistance. This result shows that most parts of the study area have aquifer with poor protecting capacity (<0.1 mhos) resulting in high salt intrusion. The groundwater potential is high in VES 3 and 4, and moderate in others. Curve types: HAA, KHKH, KHK and HKH, were obtained.

Keywords: Groundwater hydraulic, Coastal aquifers, Longitudinal conductance, Transverse resistance

INTRODUCTION

The variation of factors such as dissolved ions, soil composition, thickness and water contents affects the groundwater/aquifer potential of an area. A lot of pressure is put on subsurface structure (groundwater) by the increase in population growth and urbanization. In a settlement, potable water plays a major role in determining the growth and development of that settlement. Ikot Abasi has witnessed an increase in population which has signalled an increase in local economy, the inhabitants being farmers, civil servants, students, etc. They rely mostly on boreholes as a major renewable fresh water source thus increasing the demand for portable water supply. According to Oseiji and Ofomata

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(2010), groundwater exists below the earth surface within saturated layers of sand, gravel and pore spaces in sedimentary as well as crystalline rocks. In order to pursue large scale development of groundwater, it is essential to have a reliable estimate of groundwater potential (Singh, 1985).

The widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses the potential for widely distributed groundwater contamination (Obiora *et al.*, 2015). Environment can be evaluated without interfering with the hydrogeological system through the use of geophysical studies (Yahaya *et al.*, 2009). The geophysical studies will help in solving the problems of fail boreholes; since it will give a wide knowledge of the subsurface. It will also delineate the subsurface lithology and prolific aquifers in the study area. Electrical resistivity method involving VES has proved to be useful in groundwater study (Niwas and Singhal, 1981; Singh, 2005; Soupious *et al.*, 2007; Ibuot *et al.*, 2013; and George *et al.*, 2014).

This method has been widely used in groundwater exploration to determine depth to water table, aquifer geometry and groundwater quality by analysing measured apparent resistivity field data. The nature of the subsurface materials is a great factor in designing of appropriate groundwater management strategies in any geologic environment, whose properties (physical and chemical) and spatial distribution constitutes the goal of all hydrogeological and hydro geophysical investigations (George *et al.*, 2014). This study is aimed at stratifying the subsurface and also determine the distribution of aquifer repositories through the use of Schlumberger electrode configuration.

Ikot Abasi, in Akwa Ibom state located in the Niger Delta, Nigeria is characterized by wetlands and water bodies with creeks and rivers criss-crossing the entire region. The higher-lying plains experience 5, 7 months of flooding in the year, resulting from the overflowing waters of the lower Niger River in which whole communities and farm lands are invariably submerged. Flooding and river-bank or coastal erosion are the bane of the people. The Niger Delta is, no doubt, a difficult if not an out rightly inclement terrain. However, the region is endowed with enormous natural resources. It has the world's third largest mangrove forest with the most extensive freshwater swamp forest and tropical rainforest characterized by great biological diversity. Alongside the immense potential for agricultural revolution, the Niger Delta region also has vast reserves of non-renewable natural resources, particularly hydrocarbon deposits in oil and gas. Other non-renewable natural resources include clay pits for burnt brick making in the construction industry, and silica sand for the glass manufacturing industry which have however, remained largely untapped.

STUDY AREA DESCRIPTION

Ikot Abasi Local Government Area is located on the south-western part of Akwa Ibom State. Its geographical coordinate is Latitude: 4°34'56.71" and Longitude: 7°48'56.74".The study area is that of humid tropic with the temperature range of 26 °C and 28 °C, while the mean annual rainfall lies between 2,000-4,000 mm. The rainy season lasts from April to November and is characterized by high relative humidity and heavy cloud covers.

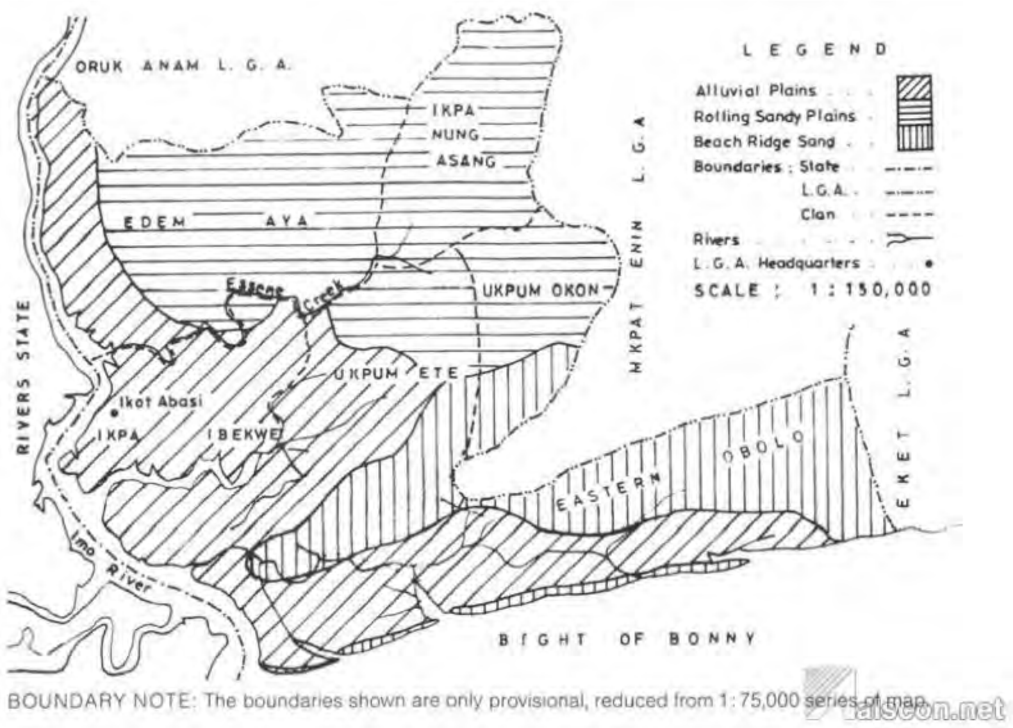
It is bordered by OrukAnam Local Government Area in the north, MkpatEnin Local Government Area in the west and the Eastern Obolo Local

Government Area and the Atlantic Ocean in the south. The Imo River forms the natural boundary in the east separating it from Rivers State (Figure 1). It covers an area of approximately, 451.73 sq. km.The region is flat and low-lying, but three major physiographic units can be identified from the terrain, the alluvial plains (mangrove and flood plains), the beach ridge sands and the rolling sandy plains.

The alluvial plains comprise mangrove swamps and fresh water flood plains. The mangrove swamps, which are drained by tidal brackish water, are found in the estuaries of Imo River, UtaEwa (Jaja), Shooter and Qua Iboe Creeks and along the coastal fringes, separating the beach ridge sands from the upland coastal sandy plains. The fresh water flood plains are formed by the upper reaches of Imo River and a large network of creeks, the major ones being Essene, UtaEwa (Jaja), Shooter and Qua Iboe Creeks. The area of alluvial plains is quite extensive, forming about 40% of the total land mass of the LGA (http://alscon.net/tradition-and-culture/).

The beach ridge sand zone reaches from themangrove mudflats towards the shoreline. The zone with its beautiful scenery is quite extensive around Okoroete, creating an attractive tourist resort. In the forties and early fifties, it used to attract a good number of Europeans from the upland areas to Ikot Abasi (Opobo). The tourist potential of the beautiful scenery of the beach sands needs to be explored. The rolling sandy plains are located in the upland areas of the local government area, the topography is gently undulating plains, being part of the coastal plain sands of Calabar Formation (http://en.wikipedia.org/wiki/Ikot-Abasi). It occupies about 50 % of the

Figure 1: Map of Ikot Abasi



land mass of the LGA. The area is drained by the Imo River and its tributaries, principally Essene Creek and numerous streams and rivulets. The Essene Creek is the most important physical feature in the area. It comes from the northern part, passing through MkpatEnin LGA and moving southwards. Another creek (Ete Creek), which passes through UkpumEte and Okon territory, joins it near Urua Essen, at a confluence, usually referred to as MkpatEte - MkpatAya. The creek then flows into the Imo River at a point near Ikot Abasi (http://en.wikipedia.org/wiki/Ikot-Abasi). The tidal creek is navigable by launch at high tides and was a major transport route for the early European trade into the hinterland.

The geological formations in the area consist of the Quaternary sedimentary deposits, and the Tertiary Coastal Plain Sands, generally referred to as Calabar Formation. The Quaternary sediments give rise to alluvial plains as well as the beach ridge sands. The alluvial plains include the mangrove mudflats, which are under the influence of tidal brackish waters along the coast and in the estuaries of rivers and creeks, and the fresh water flood plains and swamps which form the wetland environments found along the upper reaches of rivers, creeks, tributaries and meander belts. The beach ridge sands form some raised portion of land between the mangrove swamps and the shoreline. The mangrove mudflats contain strata of mixed inorganic matters and plant debris. The soils are deep, have loamy sand to sandy loam surface over clay loam to sandy clay subsoil (http://en.wikipedia.org/wiki/Ikot-Abasi). They have good physical attributes for seedbed preparation, but because of their sandy nature, they are fragile and highly susceptible to erosion. The study area is that of humid tropic with the temperature range of 26 °C and 28 °C, while the mean annual rainfall lies between 2,000-4,000 mm. The rainy season lasts from April to November and is characterized by high relative humidity and heavy cloud covers.

Data Acquisition

Data from six Vertical Electrical Soundings (VES) were acquired on the study area using the ABEM Terrameter employing the Schlumberger array with electrode spread varying between 1-600 m. Six Vertical Electrical Sounding (VES) were carried out within the maximum current electrode separation. Using equation 1, the apparent resistivity (ρ_a) was measured. According to Ibuot *et al.* (2013).

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

where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and R_a is the apparent electrical resistance measured from the equipment. The equation can be simplified to

$$\rho_a = K.R_a \quad ...(2)$$

where K is the geometric factor:

$$K = \pi.\left[\frac{\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2}{MN}\right]$$

The Global Positioning System (GPS) was used in measuring the coordinates of the sounding points. The apparent resistivity obtained was plotted using bi-logarithm graph and the curves were smoothened and quantitatively interpreted in terms of true resistivity and thickness by a conventional manual curves and auxiliary charts (Orellana and Moony, 1996). The manually interpreted data was improved upon using a Zond IP 2 and geological curves were

Figure 2: Interpreted Data for VES 3

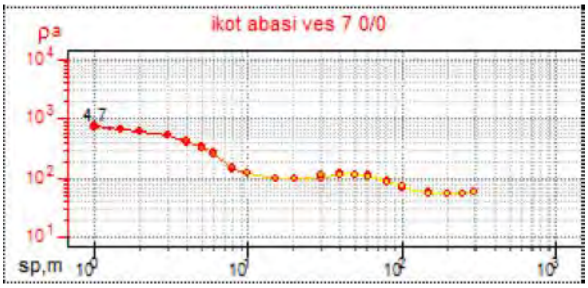
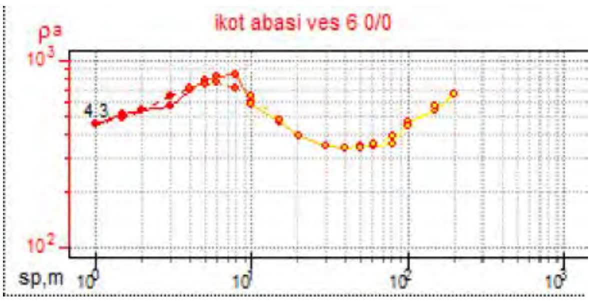


Figure 3: Interpreted Data for VES 6



obtained from this (Figures 2-3). The interpretation of the resistivity curves was based on a number of layers depicted on the observed curves and models that are geologically reasonable and produce acceptable fit. The geoelectric parameters of different layers are obtained after a number of iterations with minimal RMS error.

To avoid drilling abortive wells, geophysical investigation is imperative because it helps to delineate aquifer (or potential water bearing geological units) while on the other hand, assessment of Water yielding capacity of aquifer are traditionally determined from parameters obtained from well pump tests and well log data (Singh, 2005), which is time consuming and expensive. A faster and less cost effective means of determining these parameters involves the calculation of the following; hydraulic conductivity and transmissivity, is with resistivity data (Kelly, 1977; Niwas and Singhal, 1981; and Singh, 2005), particularly where bore wells are not sufficient or not available (Dhakate and Singh, 2005)

According to Niwas and Singhal (1981), the analytical relationship between aquifer transmissivity (T), hydraulic conductivity (K) and aquifer thickness (h) is given by:

$$T = K\,h \qquad ...(3)$$

And in accordance with Singh (2005)

$$K = 8 \times 10^{-6} e^{-0.0013\rho} \qquad ...(4)$$

where ρ is resistivity of the aquifer the relation (Equation 3) was used to estimate hydraulic conductivity (K) because the water bearing unit of the study area is a hard rock aquifer and the unit is sandwiched by resistive layers (Singh, 2005). The hydraulic conductivities were multiplied with the aquifer thickness of interpreted VES stations to determine aquifer transmissivity

RESULT AND DISCUSSION

Figures 2 and 3 shows the bi-log for VES stations 3 and 6 respectively. The resistivity, thickness and depth values of each of the electro-stratigraphy layers are presented in Table 1. The study area is characterised by heterogeneous lithology with four to five geoelectric layers with resistivity values varying from low to high values and made of the following curve types: HAA, KHKH, KHK and HKH. The first geoelectric layer which is the top soil varies in resistivity from between 80.64 to 2810.23 Ωm, while the thickness and depth ranges from 0.13 to 2.26 m. This shows that the soil is made of sand and clay or intercalation of clay with sand, but having a very high resistivity value at VES 4 which may be as a result of near surface weathered rock and stones as well as human activities on the top soil. The second layer has resistivity values varying from 12.48-2802.61 Ωm. This layer is more resistive than the first layer

Table 1: Results of Geo-Electric Survey

VES	Layer	Longitude (degreeN)	Latitude (degreeE)	Resistivity (?m)	Thickness (m)	Depth (m)	Curve Type	Soil Corrosivity
1	1	7.5606	4.5654	210.68	1.11	1.11	HAA	PNC
	2			12.48	0.68	1.79		MC
	3			2109.73	6.68	8.47		PNC
	4			1483.27	4.1	12.57		PNC
	5			-	-	-		
2	1	7.5615	4.5664	80.64	0.5	0.5	KHKH	SC
	2			2802.61	0.36	0.86		VSC
	3			9.08	1.05	1.91		VSC
	4			782.76	2.39	4.3		PNC
	5			-	-	-		PNC
3	1		4.5657	105.38	0.13	0.13	KHK	SC
	2	7.5599		1166.03	0.8	0.93		PNC
	3			36.78	6.03	6.96		MC
	4			1411.22	31.52	31.6		PNC
	5			-	-	-		
4	1	7.5607	4.5666	2810.23	0.37	0.37	HKH	PNC
	2			167.29	0.14	0.52		SC
	3			2534.06	1.6	2.11		PNC
	4			166.06	28.78	30.09		SC
	5			-	-	-		PNC
5	1	7.5608	4.5643	442.77	1.6	1.6	KHK	PNC
	2			2270.15	0.12	1.73		PNC
	3			10.6	0.38	2.11		MC
	4			1007.02	0.4	2.51		PNC
	5			1171.51	0.4	2.91		PNC
6	1	7.5598	4.5657	695.63	2.26	2.26	HKH	PNC
	2			77.14	12.63	14.89		SC
	3			5233.96	0.77	15.67		PNC
	4			0.53	0.88	16.55		VSC
	5			-	-	-		SC

Note: VSC = Very Strongly Corrosive, MC = Moderately Corrosive, SC = Slightly Corrosive, PNC = Practically Corrosive.

in locations like VES 2, 3 and 5. It is less resistive in those locations where the lithologic composition may be intercalated with argillaceous materials. The resistivity of the third geoelectric layer ranges from 9.08-2534.06 Ωm with thickness of 0.38 to 6.68m. The fourth layer which harbours most of the aquifers in the study area has a resistivity range of 0.53-1483.27 Ωm while the thickness ranges from 0.44 to 31.52 m. This layer is highly resistive except at VES 6. The lithology of this layer can be said to compose of fine to gravelly sand, with sand and clay intercalation. It can be inferred that this layer is less conductive. The fifth layer is not defined at VES 1 and 3, but varies from 75.32 to 19196.68 Ωm across the remaining locations within the maximum current penetration. The high resistivity values across most of the geoelectric layers can be attributed to conductive argillaceous geomaterials. The most prolific aquifers in the area will be observed at VES 3 and 4; this is due to the high thickness of these layers. The spatial distribution of the topsoil geomaterials is shown in a 2-D contour map (Figures 4 and 5).

Figure 4: 2-D Contour Showing the Variation of Top Layer Resistivity

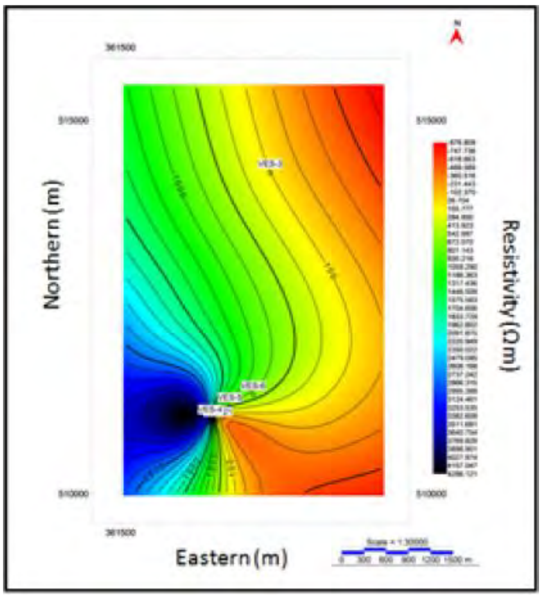
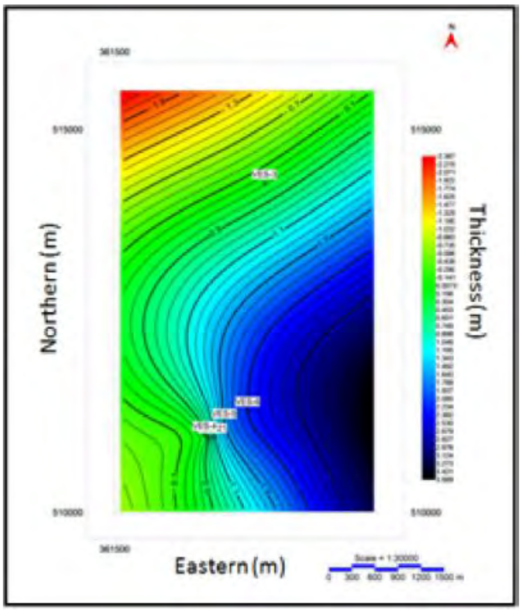


Figure 5: 2-D Contour Showing the Variation of Top Layer Thickness



The distribution of resistivity values indicates that resistivity of the geomaterials decreases from northern part of the study area down to the south. The southern part will have high conductive materials, while lowly conductive materials will be obtained in the northern part of the study area. From Figure 5, it is observed that the thickness of the topsoil increases from the northeast to the south-western part of the study area. Generally, it can be inferred that the underlying aquiferous layer is unprotected from the surface contamination flow due to the fact that the protective capacity of most part of the study area is poor. The resistivity and thickness of theaquiferous layers varies between 77.14 to 2109.78 Ωm and 0.40 to 31.52 m respectively (Table 2).

Figure 6 show the distribution of aquifer resistivity, VES 1 has the highest aquifer

Table 2: Aquifer resistivity and thickness in the study area

VES Stations	Aquifer Resistivity (t m)	Aquifer Thickness (m)	Longitudinal Conductance (t^{-1})	Protective Capacity Rating	Transverse Resistance (t m)	Curve Types
1	2109.78	6.68	0.0032	Poor	14093.33	HAA
2	784.76	2.39	0.0031	Poor	1870.8	KHKH
3	1411.22	31.52	0.0223	Poor	44475.35	KHK
4	166.06	28.78	0.1733	Weak	4779.21	HKH
5	1007.02	0.4	0.0004	Poor	402.81	KHK
6	77.14	12.63	0.1637	Weak	974.28	HKH

resistivity value of 2109.78 Ωm. It is observed that the central part of the study area has the highest aquifer resistivity with the least observed in the north-western part of the study area. High and moderate groundwater potential can be obtained from the area based on the aquifer thickness. VES 3 and 4, have aquifer thickness greater than 25 m can be delineated as zones with low and intermediate groundwater potential respectively, while others with thickness less than 10 m are considered as zones with low, very low and impermeable groundwater potential. The distribution of aquifer thickness is shown in Figures 7a and 7b, the north-western zone of the study area has the highest aquifer thickness and high groundwater potential can be inferred in this part of the study area. The greater part of the study area have between low and very low groundwater potential.

Figure 6: Contour Map Showing the Distribution of Aquifer Resistivity in the Study Area

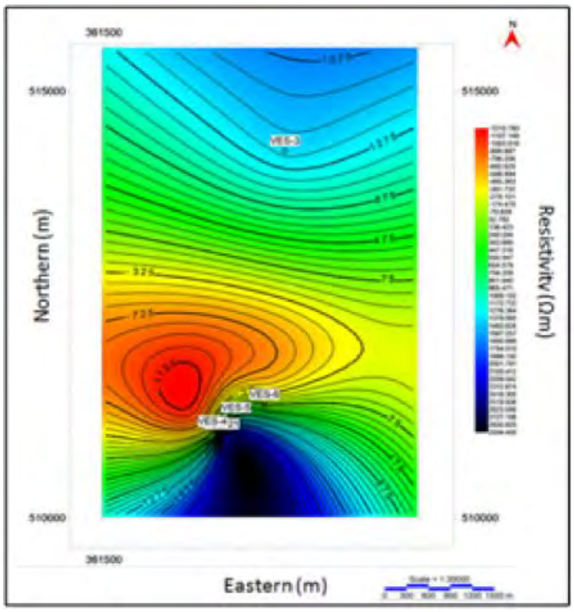


Figure 7a: 2-D Contour Map Showing the Distribution of Aquifer Thickness in the Study Area

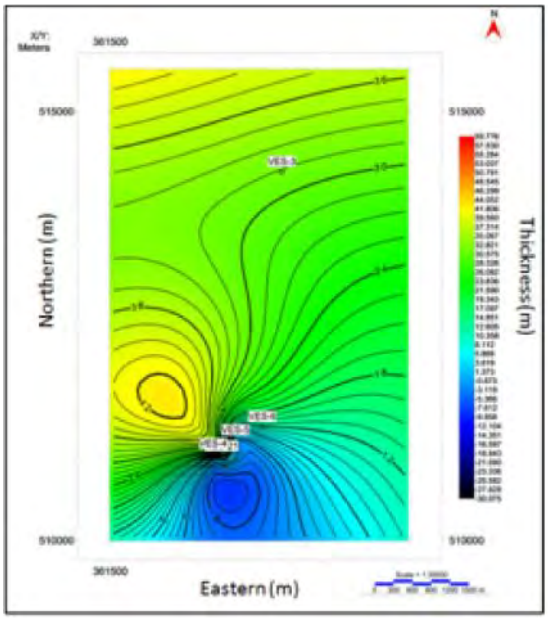
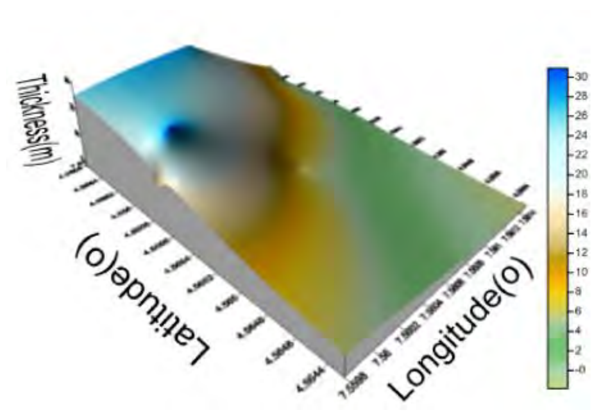


Figure7b: 3-D Contour Map Showing the Distribution of Aquifer Thickness in the Study Area



The aquifer properties from the results in Table 3 revealed an average hydraulic conductivity value of 0.30 m day^{-1} and a mean transmissivity of 4.73 m^{2} day^{-1}. By the standard set by Krasny (1993) (Table 4), the aquifer has low transmissivity capacity that offers withdrawal that meets local water supply.

Longitudinal conductance and transverse resistance of the study area were also computed using the aquifer geoelectric parameters (Table 2). The result shows that most parts of the study area have unprotected aquifer as shown by the poor longitudinal conductance values of less than

Table 3: Summary of Results of Aquifer Properties of VES Stations

VES Stations	Hydraulic Conductivity (m/s) x 10^{-6}	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Designation	Groundwater Supply Potential
1	0.51	0.04	0.3	Very Low	Withdrawal for local water supply (private consumption)
2	2.88	0.25	0.6	Very Low	Withdrawal for local water supply (private consumption)
3	1.28	0.11	3.48	Low	Smaller withdrawal for local water supply (private consumption
4	6.45	0.56	16.03	Intermediate	Withdrawal of local water supply (small community, plants, etc.)
5	2.16	0.19	0.07	Impermeable	Sources for local water supply are difficult
6	7.24	0.63	7.9	Low	Smaller withdrawal for local water supply (private consumption

Table 4: Standards for Transmissivity

Transmissivity (mday^{-2})	Designation	Groundwater Supply Potential
1000	Very high	Withdrawal of great regional importance
100– 1000	High	Withdrawal of lesser regional importance
10– 100	Intermediate	Withdrawal of local water supply (small community, plants, etc.)
1– 10	Low	Smaller withdrawal for local water supply (private consumption)
0.1– 1	Very low	Withdrawal for local water supply (private consumption
< 0.1	Impermeable	Sources for local water supply are difficult

Source: Krasny (1993)

0.1 Ω^{-1}. The low longitudinal conductance across the study area is an indicative that the study area is characterised with high permeability, hydraulic conductivity and low clay volume. From Figure 8, the longitudinal conductance is observed to decrease from northwest to southeast. The extreme northwest of the area has good protective capacity. The high transverse resistance values indicate high transmissivity and high yield of the aquifer units. From Table 5 all the aquifer in the study area are practically noncorrosive except in VES 6.

Figure 8: Distribution of Longitudinal Conductance

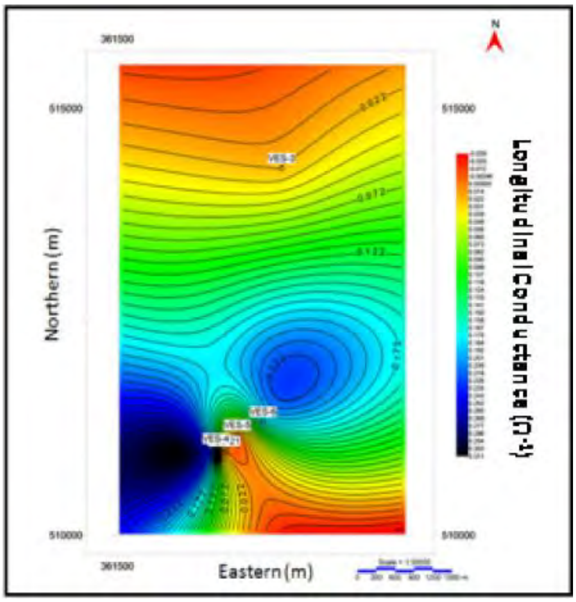


Table 5: Classification of Soil Resistivity in Terms of Corrosivity

Soil Resistivity (t -m)	Soil Corrosivity
<10	Very strongly corrosive (VSC)
10–60	Moderately corrosive (MC)
60–180	Slightly corrosive (SC)
≥180	Practically noncorrosive (PNC)

Source: Baeckmann and Schwenk (1975) Agunloye (1984) and Oladapo et al. (2004)

Table 6: Modified Longitudinal Conductance / Protective Capacity Rating

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

Source: Henriet (1976) and Oladapo et al. (2004)

CONCLUSION

The study successfully revealed the subsurface lithology of the study area. Subsurface resistivity, thickness and depth values were obtained from the computer modelling. The varying lithology shows the following curve types: HAA, KHKH, KHK and HKH. Groundwater potential of the area is high to moderate from estimation of longitudinal conductance (0.0004 – 0.1733) and transverse resistanceof geoelectric parameters. The longitudinal conductance shows that the area is vulnerable to contamination due to high permeability in the aquiferous layer, while the transverse resistance indicates high transmissivity and yield (14093.33). This study emphasizes the applicability of geophysical methods in the determination and distribution of aquifer repositories, especially within the Nigeria Coastal areas. It provides a database for water sourcing, assessment and management.

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