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A survey of the repository of groundwater potential and distribution using geoelectrical resistivity method in Itu Local Government Area (L.G.A), Akwa Ibom State, southern Nigeria

Research Article

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Abstract: Vertical electrical sounding (VES), employing a Schlumberger electrode configuration, was used to investigate the sediments and aquifer repositories in Itu Local Government Area of Akwa Ibom state, southern Nigeria. This was done in sixteen (16) locations/communities with the maximum current electrode spread ranging between 800-1000m. The field data were interpreted using forward and iterative least square inversion modeling, which gives a resolution with 3-5 geoelectric layers. The observed frequencies in curve types include 31.25% of AKH, 18.8% of AAK and HK and 6.25% of K, QHK, AKH, KA and KHQ, respectively. These sets of curves show a wide range of variabilities in resistivities between and within the layers penetrated by current. The presence of K and H curve types in the study area indicates the alteration of the geomaterials with limited hydrologic significance to the prolific groundwater repository. A correlation of the constrained nearby borehole lithology logs with the VES results shows that the layers were all sandy formations (fine and well sorted sands to gravelly sands or medium to coarse-grained sands as described by nearby lithology logs) with some wide ranges of electrical resistivity values and thicknesses caused by electrostratigraphic inhomogeneity. The geologic topsoil (motley topsoil) is generally porous and permeable and as such the longitudinal conductance (S) values for the covering/protective layer is generally less than unity of Siemens ($S < 1\Omega^{-1}$), the value considered for efficient protection of the underlying aquifers by the topmost and overlying layer. The spatial orientations and the leveling patterns of the most economically viable potential groundwater repository within the maximum current electrode separations has been delineated in 2-D and 3-D contoured maps. The estimated depth range for the desired groundwater repository is 32.6-113.1m and its average depth value is 74.30m. The thickness of this layer ranges from 27.9-103m while its average depth has been evaluated to be 63.02m. Also, its resistivity range and average value have been estimated to be 507-5612Ωm and 3365.125Ωm

Keywords: Groundwater repository • groundwater potential • VES and Itu L.G.A

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1. Introduction

Groundwater is a basic necessity which nature has endowed. It is becoming an increasing important georesource. Access to clean water is a human right and basic requirement for economic development. The worldwide development of past civilisations as well as recent socio-economic evolution of nations are based and strongly controlled by the availability of water which can be obtained either as surface or subsurface water. Surface water is frequently found to be grossly degraded in quality because of its exposure to physical, biological or chemical contaminants [1]. Groundwater on its own has less of a degree of contamination when compared with surface water. Inadequate public water supply has led to increased demand for alternative sources of water supply in Itu Local Government Area (L.G.A) in recent times [2]. Today, we are witnessing an increasing number of boreholes drilled by the Government, non-governmental organizations and individuals. This clearly shows that groundwater is increasingly complementing other sources of water supply in the area, due to the rate of contamination of surface water. Some of the boreholes drilled in the area have either partially or entirely failed because of wildcat exploitation of groundwater which was not supported by any professional prospecting for the location of water bearing sediments. The consequence of of these actions often manifests in outbreaks of water borne diseases like diarrhoea, cholera, guinea worm, schistosomiasis, typhoid, etc. Despite this, the efforts of government and other intervention agencies like the United Nations International Children Emergency Fund (UNICEF), the European Union (EU), the Niger Delta Development Commission (NDDC), the Cross River Basin and Rural Development Authority (CRBDA) and many others have recorded significant success in making safe drinking water available to some communities and, therefore, curbing (and in some cases eradicating) the menace of some of these diseases through definition of aquifer geometry for potable water. This is because in spite of the huge amount of money made available by many donor agencies, motorized boreholes and even hand pumped wells are still unsuccessful in many communities due to wildcat drilling, and some of the boreholes have poor yield particularly in the dry season when rainfall, the primary source of recharge, stops [4?]. Desperation compels the people living and doing business in this area to resort to traditional methods of getting water from any of the available surface water sources during crisis periods without paying any attention to the water quality [5]. After several years of suffering, this research and general consultancy services involving hydrogeological, and geophysical investigations and analyses of results have helped in the identification of the vertical and horizontal distributions of the most economically potential, safe and near surface groundwater repository and it depth range in the study area. It is expected that our findings which include spatial distribution of the economic and near surface groundwater repository and groundwater potential, will be found useful in giving the precise direction of accessing safe drinking water and managing the groundwater problems of the area and other places with similar geologic settings and problems.

2. Physiographic, geological and hydrogeological settings of the study area

Itu Local Government Area, shown in Fig.1 is located between latitudes 50001N and 50201N of the Equator and longitudes $7^{0}49^{1}$E and $8^{0}10^{1}$E of the Greenwich Meridian. It spreads over an area of about 34km2 [6].The region has guinea savanna vegetation which consists basically of shrubs, trees and grasses. Itu area is generally dominated by farmlands and forests with hot and humid climatic conditions that are controlled by two seasons, wet (March-October) and dry (November-April) [6]. Annual precipitation is usually over 2,200 mm, while annual temperatures range between 23 and 32^{0}C. Average relative humidity for the area is about 88 %. Recently, significant shifts in both the upper and lower boundaries of these two climatic conditions have been observed [7–10] The area is drained directly by the Cross River and Itu River and some of their tributaries that collectively form a dendritic drainage pattern within the area. The large expanse of the study area occupies the valleys associated with the Niger Delta Basin. The area which is subjected to constant inundation by the water of coastal flank is geologically characterized by the Miocene Akata Formation (shales, intercalated sands and silstone), Miocene-Pliocene Agbada Formation (sands and sandstones, intercalated with shales) and the Pliocene Benin Formation (coarse-grained, gravelly sands with intercalation of clays and shales) from top to bottom respectively [11] Fig.2. The middle and the Upper sand units of the Benin Formation constitute the major aquiferous units in the area [?]. Typical boreholes in the adjoining areas have 42-172m depths, 1-55m static water level (SWL) and 39-100m saturated thickness. Other hydrological data are 216- 5304m^2/day transmissivity, 1.2-42.5m drawdown and storage coefficient of 0.10-0.30 [13]. The water table in the area also varies from 1.3m to 52m according to [13].

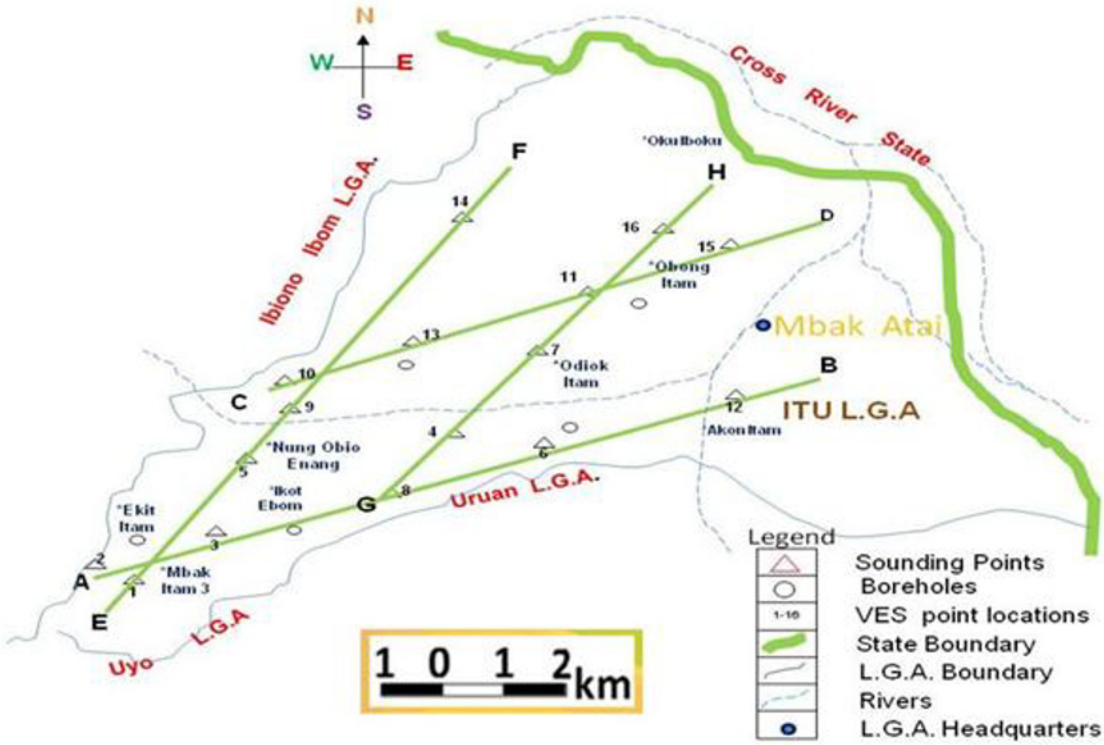

Figure 1. Map showing the VES transects, VES points and the borehole locations.

3. Surface-geophysical method and data collection

Geophysical methods provide an efficient tool for characterizing subsurface geology and hydrology. The geophysical method used in this study measured the electrical resistivity using the Vertical Electrical Sounding (VES), employing the Schlumberger electrode configuration Fig.3 [14]. This was performed by using SAS 4000 ABEM Terrameter and its accessories. The apparent resistivity (ρ_a) was measured in 16 locations using Eq. 1

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

The equation can be simplified as in Eq. 2

$$(\rho_a) = K \times R_a \qquad (2)$$

Where the geometric factor $K = \pi \times \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right]$; AB *and* MN
are the current and potential electrode separations respectively and R is the resistance measured by the equipment. The potential and current electrode separations ranged between 1-40m ($\frac{MN}{2}$ *=0.5 to 20m*) and 2-1000m ($\frac{AB}{2}$ *=1.0 to 500m*) respectively. Since the area has good access with avoidable obstructions, the cable spread was extended up to 1km in order to ensure that depths greater than 150m were sampled assuming that the penetration depth varies between 0.25AB to 0.5AB [15, 16]. The co-ordinates and elevations of the locations were taken using the Global Positioning System (GPS). The processing of apparent resistivity values with Resist Software constrained by drilled borehole lithologic information led to the determination of the model curves used in this work. Depth, thickness and resistivity values of different layers that the current penetrated were determined from the curves as shown in Table 1. The measured VES data in the entire area were characterized by spatial variability due to inhomogeneity of the subsurface [17, 18].The smoothing process involved either averaging of the observed electrical resistivity data at crossover points or outright deleting of one of the two data sets at crossover points and other outliers that fall significantly outside the dominant trend of the curve. Any discontinuity observed in the smoothened curve was attributed to vertical varia-

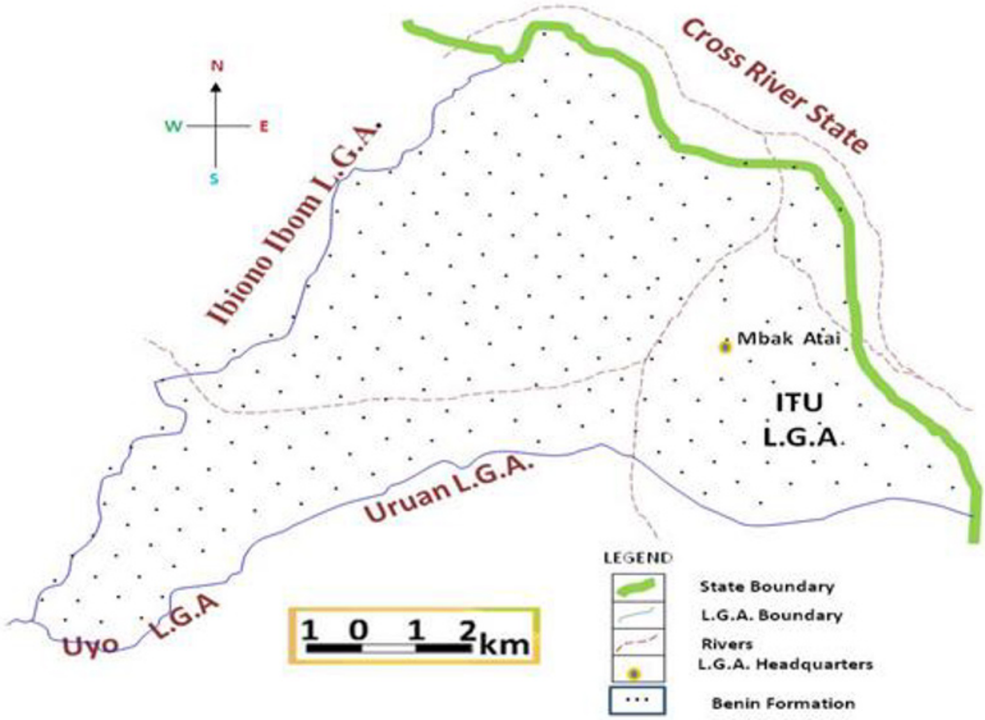

Figure 2. Map showing the general geology of the study area.

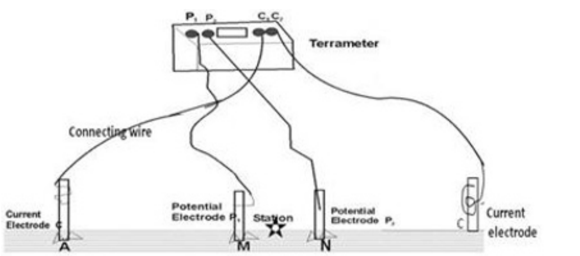

Figure 3. Schlumberger electrode configuration used in collecting the VES data.

tion of electrical resistivity which is a function of geologic formation with depth. The smoothened curves were quantitatively interpreted in terms of true resistivity and thickness by a conventional manual curve matching procedure using master curves and auxiliary charts [19]. Software programs were later used to improve the manually interpreted results. Since the data were acquired different times, several VES modeling software programs including Resist [20], Ato [21] and Res1D [22] were used in modeling the data and the results were later transformed to their equivalent geological models. The primary layer parameters comprising thicknesses and depths obtained from the manual interpretation stage were fed as inputs into some of the computer modeling software programs (Resist and Res1D only). The computer software programs used these parameters to generate data for the estimated model and compared the computed data with their measured counterpart. The extent of fit between the calculated and the measured data sets was assessed using the root mean square error (RMSE) technique in which 10 % was set as the maximum accepted value. After the smoothening and modeling exercises, typical modeled VES representative curves chosen on the basis of proximity to boreholes are as shown in Figs.4a and 4b. A good correlation was observed between the 1-D subsurface model derived from electrical resistivity data and the geologic model as shown in Fig.4a and 4b. Depth cross sections were constructed for topsoil and the desired aquifer unit in order to see their lateral and vertical positions along the three transects comprising the sixteen VES points with the aid of Surfer from Golden Software Inc., USA by combining the inverted results of the depth of burial of the desired aquifer repository and the coordinates of the sounding points de-

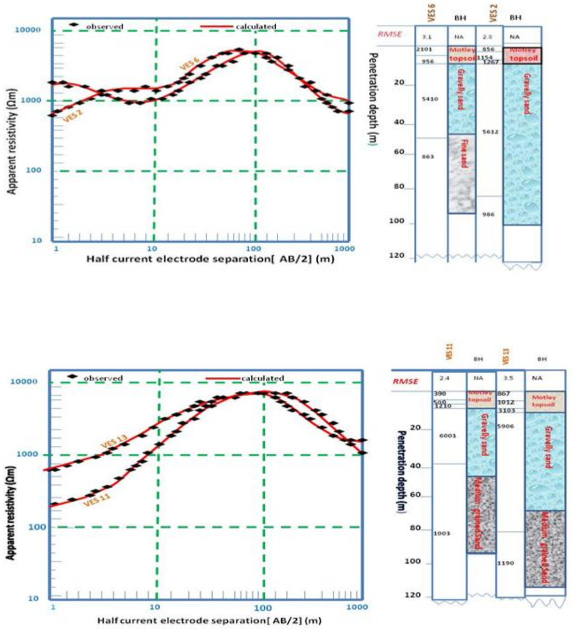

Figure 4. a) Typical VES curves along AB transect and their correlations with the nearby boreholes from top to bottom; b) Typical VES curves along CD transect and their correlations with the nearby boreholes from top to bottom

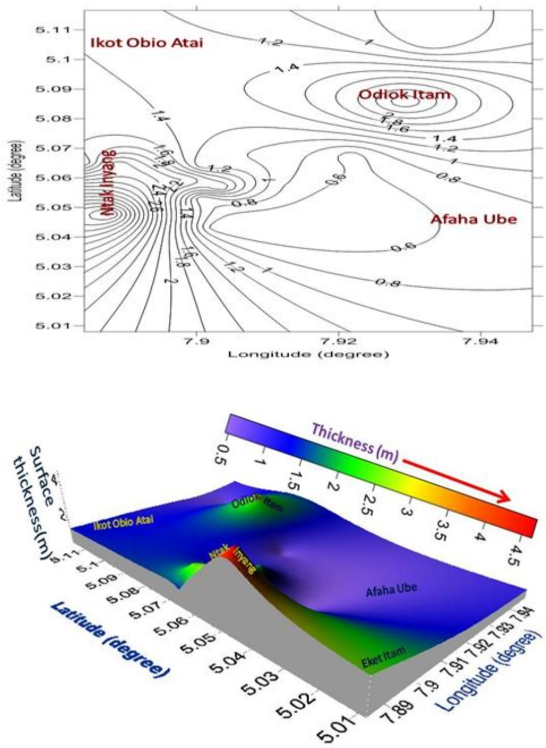

Figure 5. a) 2-D contour map showing the distribution of the topsoil thickness of unsaturated geomaterials; b) 3-D image map showing the distribution of the topsoil thickness of unsaturated geomaterials

termined from GPS (see Table 1). The vertical variation in depth at the mapped coordinates was gridded using the Kriging gridding technique available in the Surfer package [23]. The interpolated depth for the topsoil (motley topsoil with limited hydrologic significance) and the desired safe aquifer repository were respectively contoured for the entire mapped area in order to see the lateral and the vertical geometrical boundaries (see Figs. 5 and 6).

4. Results and discussion

Sixteen VES points located on the three transects (see Fig. 1) which cut across the study area have been carefully selected and used to determine the spatial distribution of the groundwater repositories in the study area. The curves are generally 3-5 layered sounding curves that are characterized by low to moderately high electrical resistivity values. The frequency of the observed curve types are grouped into eight types which are 31.25% of HKH covering VES 1,3,9,10 and 15; 18.8% of AAK (VES 2,11 and 13) and HK (5,6 and 8). Other curve types are 6.25% of K (VES 4), QHK (VES 7), AKH (VES 12), KA (VES 14) and KHQ (VES 16). The dominant curve type is HKH with 31.25% and this followed by HK and AAK with 18.8%. QHK, AKH, KA and KHQ with 6.25% have the least percentage of dominance (see Fig.7). The first layer with limited hydrologic significance is extensively exposed at the surface. It has a resistivity range of 112-2157Ωm, which averages to 825.875Ωm. This layer is characterized by electrical resistivity values that are generally less than 2160Ωm (that is r<2160Ωm) and with a thickness that rarely exceeds 4.7m in vertical extent. The average thickness of this layer is 1.8125m. Representative lithological logs from the dominant Itu hydrogeological province are shown in the Figs.4a and 4b. Higher electrical resistivity values were observed in locations where poorly cemented high grain size materials like gravels, pebbles, coarse sands, breccias and other detrital materials dominate the lithostrata of this layer. Materials with low electrical resistivity were prevalent in locations where surface outcrops of clayey and other argillaceous materials were observed. The second geoelectric layer, though gravelly sand dominated in composition, is unsaturated and variable. In locations where the lithologic composition was intercalated with argillaceous materials, the electrical resistivity values were observed to be generally less resistive than the over- and underlying lithologic

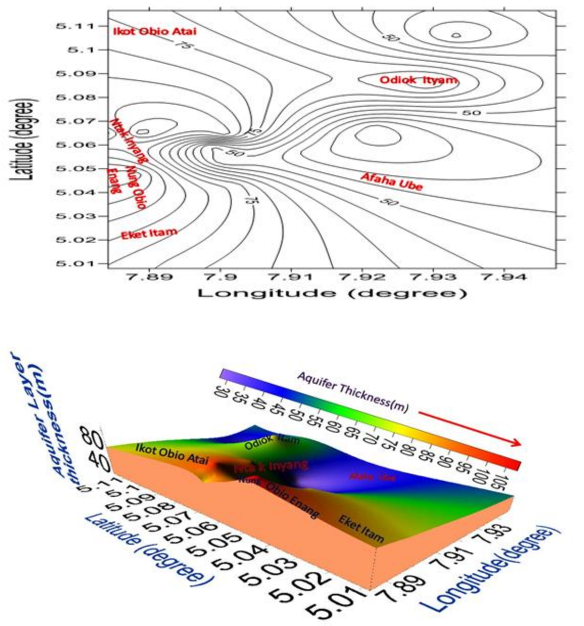

Figure 6. a) 2-D contour map showing the vertical and horizontal distribution of aquifer thickness; b) : 2-D image map showing the vertical and horizontal distribution of aquifer thickness

units. In some few VES points, where coarse sand and other detrital and/or conglomeritic materials like gravels, pebbles, breccias dominate the lithostrata, the electrical resistivity values exceeded 5000Ωm. Generally, comparatively low resistivity values suspected to be due to the conductive argillaceous materials which have no distinctive layers in any of the VES points but their interactions within the near surface layers can be noticed in the geoelectric layers around Odiok Itam and Ntak Inyang communities, where road construction works which involve piling, tunneling, filling, excavation and burying of geomaterials from other geological provinces are dominant. The observed high and thick gravelly content of the overburden layers suggest that the primary porosity will be very high and, consequently, water transmission and percolation into the underlying geologic repository will be at high rate [24]. This condition implies that the underlying aquifer repository is vulnerable to surface contamination due to the seemingly low values of the aquifer longitudinal conductance which will be far less than unity. In some VES values, the vertical extent of the gravelly materials is transitional at variable depths by fissures, weathering, joints, fractures, doming, baking and lineaments which impact the sand-clay intra-lithologic sequence secondary porosity [25–27]. The development of these structures, which are known to be pathways for the circulation of water in the previously impervious hardened materials, is an indicator of the post-depositional processes that the intra-lithologic argillaceous materials have undergone [24, 27, 28] .Gowd [27] has also discussed the importance of these secondary structures on the ground water yield in a compacted limestone environment. These structures also serve as important channels for the flow of electrical current if they are filled with conducting fluid like ground water [29]. The electrical resistivity values of the third layer were observed to be highly variable, with resistivity values ranging from 154 to 5442Ωm.The average thickness and resistivity values in this layer are respectively 24.593m and 2031.938Ωm. These variations capture the variability in the lithological composition of this layer. Electrical resistivity values of less than 200Ωm in this layer were inferred to be responses from zones of intra-lithologic composition of the sand and clay sequence (sandy clay), while electrical resistivity values of 300?m and above were attributed to fine to gravelly sands (Table 1). These observations show good correlation with lithology logs from nearby boreholes. The layer is saturated with water and has a sizeable thickness for groundwater storage. In the fourth layer, the defined thickness and resistivity ranges are 27.9-103.0m and 507-5612Ωm respectively. The average depth and resistivity are respectively 63.019m and 3365.125Ωm. In VES 2, 6, 11 and 13, which have nearby boreholes, this layer overlays the fine - gravelly sand and medium grained sand defined by the respective lithology logs of the aquifer repository. The high thickness of this layer makes it a prolific and desirable main aquifer when compared with the saturated geomaterials above it. Below layer four lies layer five, which has an undefined thickness at the maximum electrode current separation. This layer shows resistivity inversion with range and average values of 332-4747Ωm and 1495.875Ωm respectively. In some locations where the observed electrical resistivity values were lower than the immediate overlying layer, this layer in combination with the third layer help in confining the fourth layer thereby making the fluid content of the fourth layer to exist in a partially confined state. The fifth layer is saturated due to its moderately high electrical resistivity values at its depth of burial. The vertical and lateral extents of the topsoil were determined in order to see the electrical, geometrical and the spatial distributions of the protective aquifer repository in 2-D and 3-D maps (Figs.5a and 5b). The maps display the spatial distribution of the topsoil. The VES at Ntak Inyang shows it is the greatest thickness while the VES at Afaha Ube is the thinnest. This layer has a high range of resistivity (112-2157Ωm) due to its plastic nature. It is moderately resistive with an average resistivity value of 825.875Ωm. The observed longitudinal conductance (S) (thickness- resistivity ratio) is much

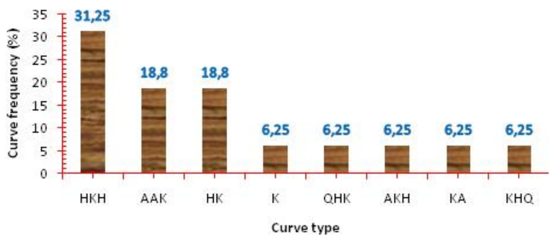

Figure 7. Bar chart showing frequency of curve type in the study area

less than unity of Siemens ($S < 1\Omega^{-1}$). This condition of the topsoil reveals that the underlying layer is practically unprotected from the surface contamination flow, even though most of the covering layer in some locations is quite thick[30]. The immediate underlying aquifer repositories (layers 1, 2 and 3) receive the dissolved contaminant plume from the surface flow due to their high porosities and permeabilities. Using Table 1, the desired aquifer repository was also contoured in 2-D and 3-D as shown in Figs. 6a and 6b. The desired aquifer repository has a resistivity range of 507-5612Ωm and a thickness range of 27.9-103m, with an average thickness of 63.019m and an average depth of 74.30m. The average thickness of the fourth layer (fine and well sorted sands to gravelly sands or medium to coarse-grained sands as described by various lithology logs) and the geoelectric characteristics of the aquifer repository which reflect high groundwater potential make it more prolific than the overlying aquifer repositories. Also, the overlying saturated geomaterials (layers 2 and 3) are more likely prone to contamination by surface flow since the covering/protective layer (layer 1) has less protective capacity based on its low values of longitudinal conductance. The contoured 2-D and 3-D maps of Figs. 6a and 6b display the leveling and spatial distributions of the lithostrata of the economically viable aquifer repository. From the figures, Ntak Inyang has the highest leveling thickness while Afaha Ube has the least among the communities shown on the maps. Table 1 also displays the comprehensive electrical properties, thicknesses and depths of the aquifer repository in discrete form while the geometry of the groundwater repository is displayed in a continuum in Figs.6a and 6b. The ensemble gives the leveling pattern of distribution of the aquifer. The maps and the table serve as guides to the locations of aquifers, aquifer capacity and their distributions throughout the entire study area.

5. Conclusion

Wildcat drilling is rampant in the study area because there is no previous information regarding the hydrogeology of the study area. This fact has provoked the drilling of boreholes that partially or entirely failed. To curb the problem, information generated from vertical electrical sounding, constrained by lithology logs of the nearby boreholes, have been used in mapping shallow subsurface electrostratigraphy; identifying the capacity of the covering/protective layers of the underlying aquifer repository and assessing the various aquifers within the maximum current electrode separations in order to recommend the most efficient and prolific aquifer thickness and its depth in Itu Local Government Area of Akwa Ibom State, southern Nigeria. The aquifer repositories are unconfined. The aquifers are anisotropic and localized in both lateral and vertical extents in the entire study area. The topsoil (covering/protective layer) has been found to be deficient from the study results because of its high porosity and permeability and the observed thickness-resistivity ratios (longitudinal conductance values) which are all less than unity, the benchmark for efficient protection of the underlying aquifer repositories. The electrostratigraphic variations between and within the layers penetrated by electric current is responsible for the anisotropic nature of the aquifers. This is also responsible for the wide ranges of resistivities and thicknesses in the layers assessed. The geometry and the leveling patterns of the motley topsoil (covering layer) and the economically viable aquifer repository (fine and well sorted sands to gravelly sands or medium to coarse-grained sands as described by various lithology logs) have been delineated for use and this will reduce seasonal borehole failures and its attendant contaminant plumes caused by wildcat drilling . The frequency of the curve types indicates regular presence of K and H curves. This indicates the translation of layers with limited hydrologic significance into prolific units in which the selecting of the best near surface and economic groundwater aquifer repository is based on aquifer thickness and its degree of exposure to surface contamination. The average depth and thickness of the most economically potential aquifer repository has been estimated to be 74.30m and 63.02m respectively. During drilling, use of this average depth should yield a reliable and safe borehole in any of the locations/communities in the study area. The correlation of our results and findings with the borehole drilled near VES 11 (*Ikot Obio Atai*) based on the authors' recommendation is proof of the workability of the method employed in this work.

Table 1. Summary of Results of Geo-electric Survey from Computer Modeling.

VES	Location	Coordinate	Layer no	Resistivity (Ωm)					Layer thickness (M)				Layer depth (m)				Curve type
		Lat. Long		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	T_1	T_2	T_3	T_4	D_1	D_2	D_3	D_4	
1	Mbak Itam 3	5.06490N 7.88420E	5	1474	3355	1151	4220	1454	1.4	4.5	9.2	78.1	1.4	5.9	15.1	93.2	KHK
2	Ekit Itam	5.00800N 7.89610E	5	856	1154	1267	5612	988	2.0	2.9	6.5	75.8	2.0	4.9	11.4	87.2	AAK
3	Ikot Ebom Itam	5.06520N 7.88870E	5	554	897	690	5494	2123	2.5	2.9	5.0	103	2.5	5.4	10.4	113.1	KHK
4	Ikot Ekwere Itam	5.06420N 7.90090E	3	587	5358	1723	-	-	1.0	92.1	-	-	1.0	93.1	-	-	K
5	Nung Obio Enang	5.04780N 7.88800E	4	838	446	4390	2713	-	4.7	7.9	108.2	-	4.7	12.7	120.9	-	HK
6	Afaha Itam	5.05950N 7.89880E	4	2101	956	5410	863	-	2.2	2.1	48.6	-	2.2	4.3	52.9	-	HK
7	Odiok Itam	5.08580N 7.92930E	5	217	213	154	4229	2150	2.6	2.3	2.7	80.0	2.6	4.9	7.6	87.6	QHK
8	Ikot Ekpuk	5.05660N 7.90350E	4	2157	524	1682	507	-	2.0	3.3	55.3	-	2.0	5.3	60.7	-	HK
9	Ibiaku Itam	5.05330N 7.90070E	5	379	2147	600	5139	337	0.8	4.3	6.3	44.0	0.8	5.1	11.4	55.4	KHK
10	Ikot Ekang	5.05700N 7.91210E	5	1484	3703	861	2993	1579	0.8	1.6	1.5	38.1	0.8	2.3	3.9	42.0	KHK
11	Ikot Obio Atai	5.06440N 7.91830E	5	390	500	1210	6001	1003	0.7	1.6	2.4	65.9	0.7	2.3	4.7	70.6	AAK
12	Akon Itam	5.10580N 7.93310E	5	692	1056	5442	1006	4747	0.6	4.1	14.1	33.7	0.6	4.7	18.8	91.2	AKH
13	Afaha Ube	5.04330N 7.90210E	5	867	1012	3103	5906	1190	0.5	0.8	2.4	77.3	0.5	1.3	3.8	81.1	AAK
14	Ntak Inyang	5.08580N 7.92930E	4	112	5820	2204	1200	-	5.8	9.5	30.0	-	5.8	15.3	45.3	-	KA
15	Obong Itam	5.11660N 7.94730E	5	245	3215	654	5432	1025	0.9	2.5	6.2	52.3	0.9	3.4	9.6	61.9	KHK
16	Ikot Obong	5.06770N 7.92170E	5	261	1483	1970	804	332	0.5	1.2	3.0	27.9	0.5	1.7	4.7	32.6	KHQ

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