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Hydrogeophysical Delineation of Prolific Groundwater Aquifer Around Students' Hostels in FUPRE Campus, Nigeria

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Abstract
Electrical Resistivity survey was conducted around Students' Hostels, FUPRE to delineate prolific aquifer for potable water to serve the teeming population of staff and students. Five vertical electrical soundings (VES) using Schlumberger electrode configuration with a maximum current electrode spread of 300m were employed for data acquisition. WINRESIST software was employed to execute the iteration and inversion processes of computing resistivities, depths and thicknesses of the various layers and the curve types. Results indicate that the area is characterized by 4 distinct geoelectric layers inferred differently at the VES locations. Two potential groundwater aquifer zones are delineated. The unconfined shallow aquifer zones found at VES 1, 3, 4 and 5 locations have shallow overburden depth ranging between 3.7-19.3m and coarse-grained sand columns with thicknesses ranging between 2.8-17.7m while the confined deep aquifer zone found at VES 2 location coincides with deep overburden layer at a depth of 42.6m and coarse-grained sand column with appreciable thickness of 19.1m. These results suggest that boreholes for sustainable groundwater supply around the Students' Hostels should be sited at VES 2 location and screened at a depth ≥40.0m. However, aquifers at VES 1, 3, 4 and 5 have potentials for groundwater but are vulnerable to contamination. It is recommenced that electrical resistivity survey and hydrogeological surveys should be conducted at all times and locations in FUPRE to delineate the appropriate aquifer before any borehole(s) are drilled for potable groundwater supply to avoid possible contamination.

Keywords: VES, Aquifer, Coarse-grained Sand, Groundwater, Students' Hostels, FUPRE Campus

1. Introduction
Delineating the depth to a prolific groundwater aquifer to meet the growing demands for potable water by staff and students in Federal University of Petroleum Resources Effurun (FUPRE) Campus is very essential in the absence of public water utility system. FUPRE is witnessing rapid expansion in infrastructure and increase in population of staff and students. Its proximity to two host communities is also leading to high demands for potable water to serve the teeming populace.

The availability of potable water basically depends on the soil composition, depth and thickness of aquifer and environmental factors such as content of dissolved salts, mineralization of rocks, organic matter content, recharge rate, and pH value. These factors control the groundwater potential and quality in any area. Electrical resistivity survey remains one simple method for easy and cheap access to good quality groundwater in aquifers because the instrumentation is simple, field logistics are easy to implement and data analysis is less tedious and economical. Vertical electrical sounding (VES) is an electrical resistivity method for measuring vertical variations of electrical resistance. The method has been recognized to be more suitable for hydrogeological surveys in sedimentary basin (Iserhien-Emekeme et. al., 2017; Anomohanran, 2015; Atako, 2013; Oseji, 2009; Okolie, et. al., 2005; Olobaniyi and Owoyemi, 2004).

The water table regime in FUPRE Campus and its environs is very shallow as it is a relatively low terrain with porous and permeable sand that supports groundwater percolation and retention. Most groundwater boreholes in this vicinity are bottomed at shallow depth (less than 40m deep) and assumed to be very suitable for domestic and industrial uses but the mineralization level and dissolved salts reduce the quality as observed by Amadi, 2009 and Akpoborie, et. al. (2014). Consequently, this research is focused on properly delineating prolific aquifer suitable for the location of groundwater boreholes to serve as sources of potable water for the University Community and its environs. The thicknesses, depths, resistivities and lithologies of different soil layers have been determined using the VES method.

1.1 Location, Geography, Geology AND Hydrogeology of the Study Area

Location

The study area is located around the Students' Hostels within the campus of Federal university of Petroleum Resources Effurun, Nigeria (Figure 1).

Geography

FUPRE is located between Ugbomro and Iteregbi Communities in Uvwie local Government Area of Delta State. These communities are surrounded by Okuatata, Okuokoko, Okorikpere and Agbarho communities. The area is a lowland with elevation not greater than 15m above sea level. It is a relatively flat terrain and the area is drained by the Agbarho and Ugbomro Rivers.

The area is a hot/wet equatorial climate region made of two main seasons: the wet and dry seasons. The climate is tropical equatorial type with mean annual rainfall greater than 300m and mean temperature of about 28°C (Iloeje, 1981). The wet season begins from April and ends in September while dry season begins from October and ends in March. The study area has a direct recharge from rainfall, the rate of infiltration and percolation is very high. The area belongs to the fresh water vegetation belt of rainforest and swamp forest which is thickly vegetated with grass, trees and creeping plants.

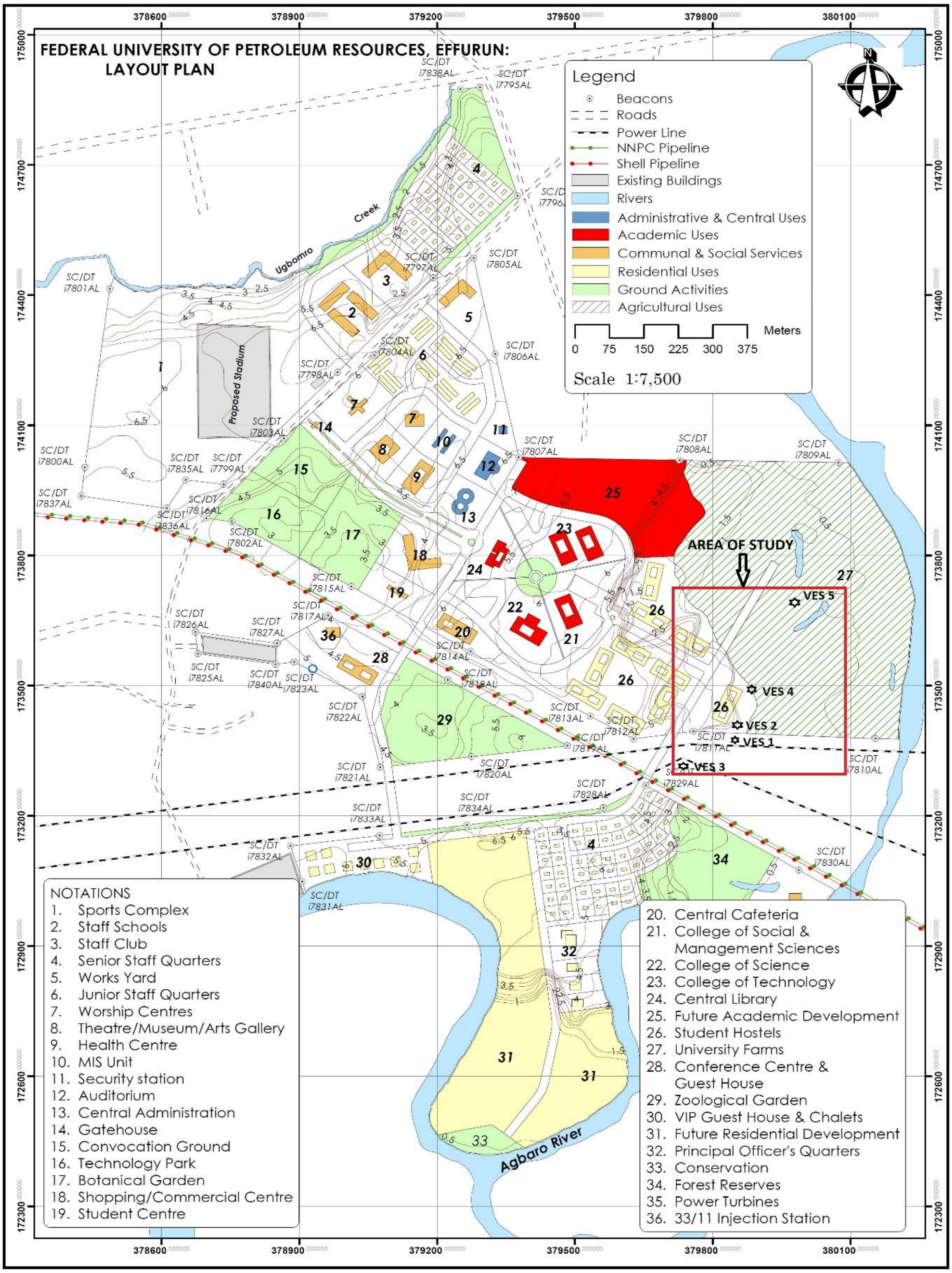

Fig. 1: Map of FUPRE Campus showing the Study Area

Geology

The area of study is located within the Niger Delta which is the largest Basin in West Africa and the most prolific delta in Africa. The Niger Delta is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 4°N to 7°N and longitude 5°E to 8°E covering an area of about 108900km^2 (Whiteman, 1982). It extends from the Calabar flank and the Abakaliki Trough in eastern Nigeria to the Benin flank in the west and it opens to the Atlantic Ocean in the south. The development of the Niger Delta resulted from the formation of the Benue trough as a failed arm of a triple junction associated with the separation of the Africa and South American Plates and subsequent opening of the South Atlantic (Whiteman, 1982). The Benue-Abakaliki trough was filled with sediments during the early Cretaceous time, which later underwent folding, faulting and uplift with subsidence of the adjacent Anambra basin to the west and Afikpo syncline to the east during the Santonian. The Niger Delta consists of three diachronous units, namely from bottom, Akata, Agbada and Benin Formations (Weber and Daukoru, l975).

Hydrogeology

The study area is underlain by the Quaternary Warri deltaic sand (Etu-Efeotor and Akpokodje, 1990). The sediment overlies the Coastal Plain sand. It is characterized by yellowish colour and consists of silt, sand and clay. The sands are generally loose, porous, poorly sorted and lateritic. Small proportions of gravels and limited number of thin clay horizons are sometimes present at greater depths (Avbovbo, 1978). According to Amadi (2009), two main aquiferous units have been identified in the study area. The shallowest aquifer of 2-5m depth occurs within the unconfined superficial alluvium comprising of sandy/silty layers. Hand dug wells exploit water from this aquifer. Deeper, confined and prolific aquifers are encountered at about 55rn. This aquifer consists of medium-to-coarse grained sand and gravel. Industrial and public boreholes derive their source from the second aquifer. Water level in this area fluctuates in response to climatic conditions, Average water level in the dry season is 3.0m while it rises to the ground level during the rainy season (Amadi, 2009).

2. Methodology

2.1 Field Data Acquisition

Ohmega 1000 Resistivity Meter was employed in acquiring the Vertical Electrical Sounding data along 5 traverses. The Schlumberger configuration (Figure 3) with a maximum half current electrodes separation of 150m was employed. Two current electrodes were placed linearly at the same mid-point with two potential electrodes but at different distances from one another. The current electrodes were placed at equal distance, ***s*** from the mid-point of the array while the potential electrodes were similarly placed at equal distance but at a distance, *a/2* < ***s.*** Different spreads of current electrodes, AB were achieved, thereby resulting in different probe depths (Table 1). A total of 4 cycles were taken for each point and the average was recorded.

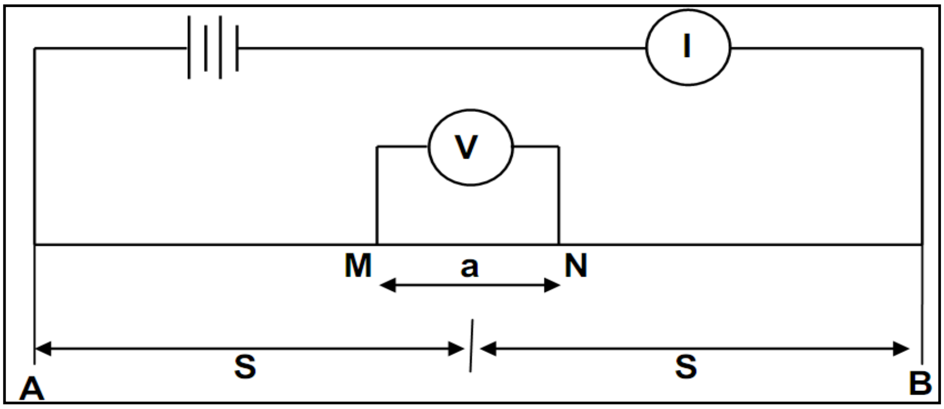

Fig. 3: Schlumberger Array for Data Acquisition

2.2 Computation of Soil Apparent Resistivity, ρ_a

Apparent resistivities were obtained from field resistance values using the equation:

$$\rho_a = \frac{2\pi R}{\left[\frac{1}{A_M} - \frac{1}{A_N} - \frac{1}{B_M} + \frac{1}{B_N}\right]} \qquad (1)$$

Where ρ_a is apparent resistivity, R is the measured resistance, AB= Distance between current electrodes, MN=Distance between potential electrodes and $\left[\frac{1}{A_M} - \frac{1}{A_N} - \frac{1}{B_M} + \frac{1}{B_N}\right]$ is the geometric factor, K.

3. Results and Discussions

3.1 Data Interpretation

The apparent resistivity, ρ_a values were plotted against half current electrode spread, AB/2 employing WINRESIST software. For each VES station, the iteration process was conducted until the root mean square (RMS) error of $\leq$ 3.7% was obtained. The resistivities, thicknesses and depth of the various layers were computed and the curve types were determined.

Table 1: Vertical Electrical Sounding Data Acquired around Students' Hostels

ELECTRODE CONFIGURATION		GEOELECTRIC FACTOR, K	TRAVERSES									
			VES 1 Lat. 05°34'05.1" N; Long. 005°50'30.6" E; Elevation 13m		VES 2 Lat. 05°34'07.7" N; Long. 005°50'35.7" E; Elevation 12m		VES 3 Lat. 05°34'04.3" N; Long. 005°50'38.2" E; Elevation 12m		VES 4 Lat. 05°34'09.1" N; Long. 005°50'38.6" E; Elevation 14m		VES 5 Lat. 05°34'22.2" N; Long. 005°50'35.2" E; Elevation 11m	
AB/2 (m)	MN/2 (m)		R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)	R (Ω)	ρ_a (Ωm)
2	0.5	11.78	68.09	802.1	46.87	552.129	109.6	1291.1	116.7	1374.7	90.62	1067.5
3	0.5	27.5	37.51	1031.53	24.64	677.6	60.24	1656.6	55.01	1512.8	52.2	1435.5
6	0.5	112.36	12.77	1434.84	6.758	759.329	18.7	2101.1	18.2	2045	17.09	1920.2
9	0.5	253.79	6.143	1559.03	2.72	690.309	8.327	2113.3	7.667	1945.8	8.358	2121.2
9	2	60.5	28.36	1715.78	13.47	814.935	35.3	2135.7	30.37	1837.4	31.07	1879.7
15	2	173.64	11.67	2026.38	4.854	842.849	8.987	1560.5	8.966	1556.9	7.231	1255.6
25	2	487.93	3.980	1941.96	2.102	1025.63	2.741	1337.4	2.538	1238.4	2.264	1104.7
40	2	1250	1.350	1687.5	0.8845	1105.63	0.9362	1170.3	0.8256	1032	0.8083	1010.4
50	2	1961.14	0.787	1543.42	0.53	1039.4	0.53	1039.4	0.4884	957.82	0.505	990.38
75	2	4416.5	0.251	1108.54	0.1878	829.419	0.1787	789.23	0.1604	708.41	0.1878	829.42
75	10	868.21	1.167	1013.2	1.117	969.791	0.9616	834.87	0.7839	680.59	0.9068	787.29
100	10	1555.71	0.451	701.625	0.4285	666.622	0.4315	671.29	0.3401	529.1	0.3747	582.92
150	10	3520	0.2152	757.504	0.07462	262.662	0.1096	385.79	0.07941	279.52	0.07599	267.50

Figures 4 - 8 show the geoelectric sections for the five VES stations. Generally, the KQ type curve except VES 1 with AQ type curve were observed in the study area. Figure 9 shows the lithologic cross section for the study area.

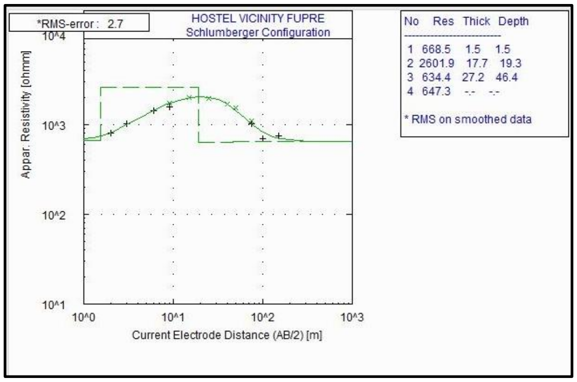

Fig. 4: Geoelectric Section for VES 1

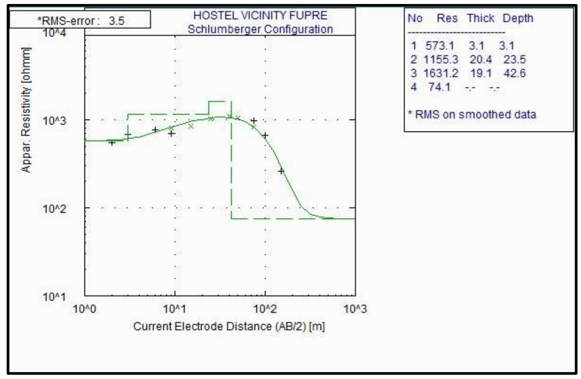

Fig. 5: Geoelectric Section for VES 2

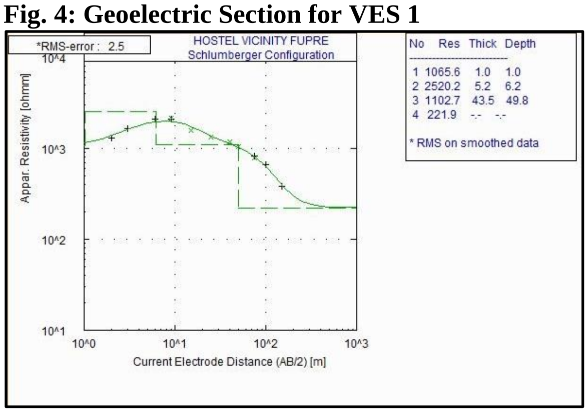

Fig. 6: Geoelectric Section for VES 3

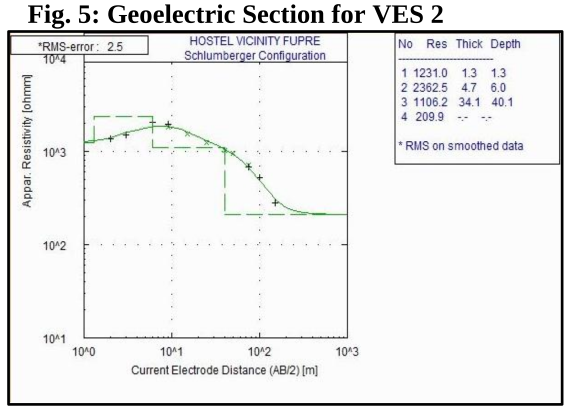

Fig. 7: Geoelectric Section for VES 4

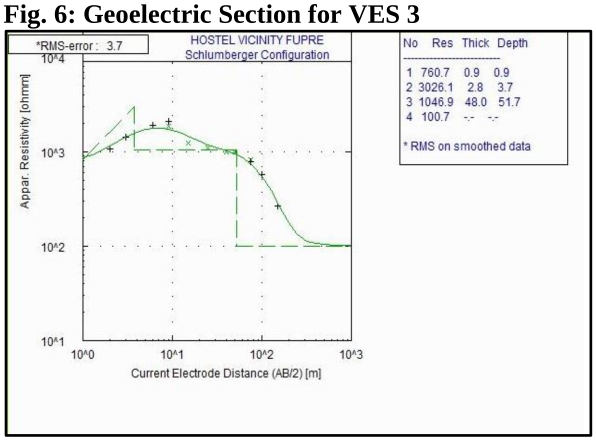

Fig. 8: Geoelectric Section for VES 5

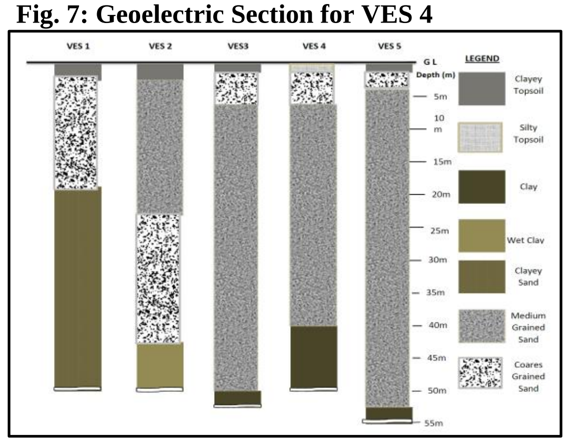

Fig. 9: Lithologic Cross Section for the Area

Table 4 is a summary of the interpretation of the results of the Vertical Electrical Sounding in the study area. The results show that the area is characterized by four geoelectric subsurface layers.

Table 4: VES Data Interpretation Results in the Study Area

Sounding Locations	Geoelectric Layers	Resistivity, ρ(Ωm)	Thickness, *h*(m)	Depth, D(m)	Inferred Lithology	Curve Type
VES 1	**I**	668.5	1.5	1.5	Clayey Topsoil	AQ
	II	2601.9	17.7	19.3	Coarse-grained sand	
	III	634.4	27.2	46.4	Clayey sand	
	IV	647.3	-	-	Clayey sand	
VES 2	**I**	573.1	3.1	3.1	Clayey Topsoil	KQ
	II	1155.3	20.4	23.4	Medium-grained sand	
	III	1631.2	19.1	42.6	Coarse-grained sand	
	IV	74.1	-	-	Wet clay	
VES 3	I	1065.6	1.0	1.0	Silty Topsoil	KQ
	II	2520.2	5.2	6.2	Coarse-grained sand	
	III	1102.7	43.5	49.8	Medium-grained sand	
	IV	221.9	-	-	Clay	
VES 4	**I**	1231.0	1.3	1.3	Silty Topsoil	KQ
	II	2362.5	4.7	6.0	Coarse-grained sand	
	III	1106.2	34.1	40.1	Medium-grained sand	
	IV	209.9	-	-	Clay	
VES 5	**I**	760.7	0.9	0.9	Clayey Topsoil	KQ
	II	3026.1	2.8	3.7	Coarse-grained sand	
	III	1046.9	48.0	51.7	Medium-grained sand	
	IV	100.7	-	-	Clay	

VES 1: Four geoelectric layers of AQ curve type are delineated at this location. Inferred lithologies are characterized by a 1.5m thick topsoil that is composed of clayey sand with resistivity of 668.5 Ωm to a depth of 1.5m. Below this formation is a 17.7m thick coarse-grained sand to a depth of 19.3m. This is a ***shallow aquifer zone*** with resistivity value of 2601.9Ωm. This is followed by two layers of clayey sand formations with resistivity values of 634.4Ωm and 647.3 Ωm respectively with undetermined thicknesses and depths since they make up the last layers.

VES 2: Four geoelectric layers of KQ curve type are delineated at this location. The 3.1m thick topmost sediment to a depth of 3.1m is characterized by clayey topsoil materials with resistivity of 573.1 Ωm. Underlying this layer are a 20.4m thick medium-grained sand to a depth of 23.4m with resistivity of 1155.3 Ωm and a 19.1m thick coarse-grained sand to a depth of 42.6m with resistivity of 1631.2Ωm. The third layer constitutes the ***deep aquifer zone***. Below this zone is a layer of wet clay with resistivity of 74.1Ωm and undetermined thickness and depth.

VES 3: Four geoelectric layers of KQ curve type are delineated at this location. Soil layers here are characterized by a porous and permeable 1.0m thick silty topsoil with resistivity of 1065.6 Ωm and depth of 1.0m. Below this layer is a 4.7m thick coarse-grained sand to a depth of 6.0m. This is a ***shallow aquifer zone*** with resistivity value of 2520.2Ωm. However, this is followed by a 43.5m thick aquiferous medium-grained sand formation with resistivity values of 1102.7Ωm to a depth of 49.8m. Below this zone is a layer of clay with resistivity of 221.9Ωm and undetermined thickness and depth.

VES 4: Four geoelectric layers of KQ curve type are delineated at this location. Similar to VES 3, lithologies here are also characterized by a porous and permeable 1.3m thick silty topsoil with resistivity of 1231.0 Ωm to a depth of 1.3m. Underlying this layer is a 5.2m thick coarse-grained sand to a depth of 6.2m. This is a ***shallow aquifer zone*** with resistivity value of 2362.5Ωm. However, this is followed by a 34.1m thick aquiferous medium-grained sand formation with resistivity value of 1106.2Ωm to a depth of 40.1m. Beneath this zone is a layer of clay with resistivity of 209.9Ωm and undetermined thickness and depth.

VES 5: Four geoelectric layers of KQ curve type are delineated at this location. The 0.9m thick uppermost layer to a depth of 0.9m is characterized by clayey topsoil materials with resistivity of 760.7Ωm. Underlying this layer are a 2.8m thick coarse-grained sand to a depth of 3.7m with resistivity of 3026.1Ωm and a 48.0m thick medium-grained sand to a depth of 51.7m with resistivity of 1046.9Ωm. The second layer constitutes the ***shallow aquifer zone***. Below the third layer is a layer of clay with resistivity of 100.7Ωm and undetermined thickness and depth.

Conclusion and Recommendation

The study reveals that resistivity varies within different soil layers and lithology also varies from one VES location to another in FUPRE. This implies non-uniform lithological composition. So, assuming that groundwater will be found at the same depth at different parts of FUPRE will not suffice. Lithology varies laterally and vertically due to the mineralogical composition of the different rock types which weathered to constitute the soil. Low resistivity values are observed to be prevalent in zones with high clay rock-forming minerals which bound the aquifer top and bottom while high resistivities are observed to be dominant in zones with medium-grained and especially coarse-grained sands which constitute the potential aquifer materials.

Two potential groundwater aquifer zones are delineated. The ***unconfined shallow aquifer zones*** found at VES 1, 3, 4 and 5 locations have shallow overburden depth ranging between 3.7-19.3m and coarse-grained sand columns with thicknesses ranging between 2.8-17.7m and the ***confined deep aquifer zone*** found at VES 2 location coinciding with deep overburden layer at a depth of 42.6m and coarse-grained sand column with appreciable thickness of 19.1m. These results suggest that boreholes for sustainable groundwater supply around the Students' Hostels should be drilled at VES 2 location and screened at a depth ≥40.0m. However, aquifers at VES 1, 3, 4 and 5 have potentials for groundwater but are vulnerable to contamination. Shallow aquifer zones have higher tendency of allowing the permeation of contaminant fluids into the groundwater such that in any event of contamination such water becomes unsafe for both domestic and industrial uses.

Sequel to the findings of this study, it is recommenced that electrical resistivity survey and hydrogeological surveys should be conducted at all times and locations in FUPRE to delineate the appropriate deep aquifer zones before any borehole(s) are drilled for potable groundwater supply to avoid possible contamination.

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