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Evaluation of Groundwater Potentials for Borehole Drilling by Integrated Geophysical Mapping of Auchi-South Western Nigeria Using Very Low Frequency Electromagnetic Profiling (VLF-EM) and Vertical Electrical Sounding (VES)

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ABSTRACT: An integrated geophysical survey involving Very Low Frequency Electromagnetic (VLF-EM) and electrical resistivity sounding was conducted at Auchi-Southwestern Nigeria, in order to delineate the fissured zones and associated groundwater-bearing media for borehole drilling in the study area. The area is underlain by the Precambrian Basement Complex rocks and in some places sedimentary rocks. The VLF-EM traverses were established along two traverses using ABEM-WADI equipment, with a station interval of 10 m and with lengths ranging from 200 to 240 m. Linear fissures presumed to be geologic fissures inferred from the filtered real and filtered imaginary assisted in selecting seven VES points that were further probed using ABEM SAS 1000 Resistivity meter. The spreading were conducted using the convectional Schlumberger electrode configuration with half-current electrode separation (AB/2) that ranged from 1 to 225 m,was used for the sounding. The VES data were presented as depth sounding curves and were suitably iterated using Schlumberger O'Neil software. The VLF filtered real profile showed a high peak trend signifying a fracture signature. The delineated weathered and basement column constituted the aquifer units for borehole drilling. Six lithologic formations were delineated which included the top soil, clay/shale, fine grained sand, coarse grained sand, fractured bedrock and fresh bedrock. Four Model field curves were delineated which included HAKQ, HKQQ, KHAA and KHKH. There are two main targets for groundwater exploration in the study area. These included the weathered zone (fine and medium grained sand) and the fractured zone. The thickness of these zones varied between 15.2 to 50.1 m. Based on the geophysical parameters such as thin overburden thickness, clayey weathered layer and low fractured basement characterized by the study area, it is therefore inferred that the groundwater potential of the area is low. Nevertheless, the study has justified the use of integrated geophysical mapping as a better tool in evaluating the groundwater potential in crystalline terrains. ©JASEM

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Groundwater consists of all subsurface water trapped in the pores and other open spaces in rocks, sediment and soil (Monroe and Wicander, 2005). It is a significant part of the hydrologic cycle containing about 21% of the world's supply of freshwater (Adepelumi et al., 2013). Groundwater occurs in a highly permeable and porous geological formation known as aquifers which have the properties that allow storage and movement off water (Eduvie, 2006; Taiwo *et al*., 2016).Groundwater can be abstracted by drilling boreholes and hand-dug wells within the permeable geological formation. Nevertheless, the study area is underlain by Precambrian Basement Complex rocks where groundwater is usually contained in the weathered and/or fractured basement rocks (Jayeoba and Oladunjoye, 2013). The highest groundwater yield in basement terrain is found in areas where thick overburden overlies fractured zones (Olorunniwo and Olurunfemi, 1987; Taiwo *et a*l., 2016). These zones are often characterized by relatively low resistivity. But, the indiscriminate drilling of boreholes without employing pragmatic and scientific approach, that is pre-drilling geophysical investigation, has led to the unsuccessful boreholes with low yield (Bayode *et al*; 2007). It is against this background that the evaluation of groundwater potential in the area was carried out.

Thus, geophysical methods especially electromagnetic and resistivity methods are commonly used in groundwater exploration, mainly due to the close relationship between electrical and some hydrological parameters. The Very Low Frequency Electromagnetic (VLF-EM) is an effective tool in mapping conductive fault and fracture zones, while resistivity method is used for detecting groundwater presence and differentiating sub surface layers. Electromagnetic and electrical methods have been widely used in groundwater investigations because of good correlation between electrical properties, geological (composition) and fluid content (Olayinka *et al*; 2004, Khali, 2009; Jayeoba and Oladunjoye, 2013; Chinyem et al; 2014; Taiwo *et al*; 2016). In this present study, Very Low

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FrequencyElectromagnetic (VLF-EM) and Vertical Electrical Sounding (VES) methods were employed with the aim of evaluating the groundwater potentials of Auchi area for borehole drilling.

MATERIALS AND METHODS

*Description of study area with maps and Locations:*The study area lies within latitude $7^0 3^1 00^{11}$ to $7^0 4^1 30^{11}$ N and longitude $6^0 15^1 0^{11}$ to $6^0 18^1 0^{11}$ E (Figure 1). The climate is classified as a tropical savanna with a tropical dry forest biozone. The area has an annual rainfall of about 1,300 mm and annual temperature range of between 18^0 to 33 ^{0}C. The landscape is mostly covered with mosaic forest – shrub land and grass land. The study area falls within the localities where the lithofacies of the Niger Delta grade gradually into that of the Anambra Basin. The geologic setting of the area is typical of the intrusive granites and migmatite gneiss complex of Southwestern Nigeria (Rahaman, 1976). The area is underlain by a sequence of sedimentary formations which consists of laterite, clay/shale, clayey sand, fine and coarse sandstones and the basement complex rocks.

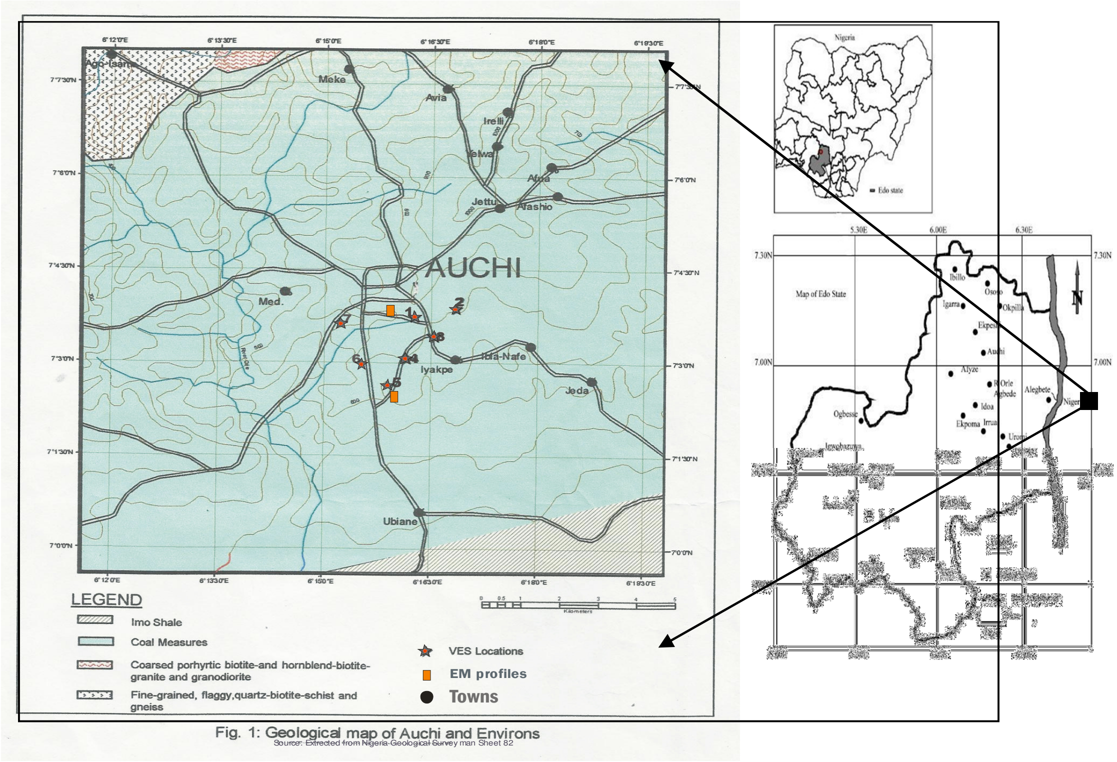

Fig 1: Location map of the study area showing EM profiles and VES locations.

DataSampling: The integrated geophysical field investigation involved application of both Very Low Frequency Electromagnetic (VLF-EM) measurement and Vertical Electrical Sounding (VES) for mapping fractures in the bedrock and delineating geoelectric layers in the overburden materials. The VLF-EM data were acquired with the aid of ABEM WADI equipment. Two profiles were measured with each profile trending approximately N-S and E-W directions respectively to effectively monitor the subsurface inhomogeneity. The VLF-EM data were sampled at 10m intervals along two profiles ranging 200to 240m. A Global Positioning System (GPS) was used for exact spatial positioning of the sampled data. Seven Vertical Electrical Sounding (VES) data were subsequently acquired at the locations of the anomaly identified in the VLF-EM profiles (Figures 2 and 3) with the aid of ABEM signal Averaging System (SAS) 1000 Tetrameter Resistivity Meter. The VES utilized the Schlumberger electrode array with half – current electrode Separation (AB/2) ranging from 1 to 225 m. The co-ordinates of each VES station were taken with the GPS device to ensure accurate future geo-referencing.

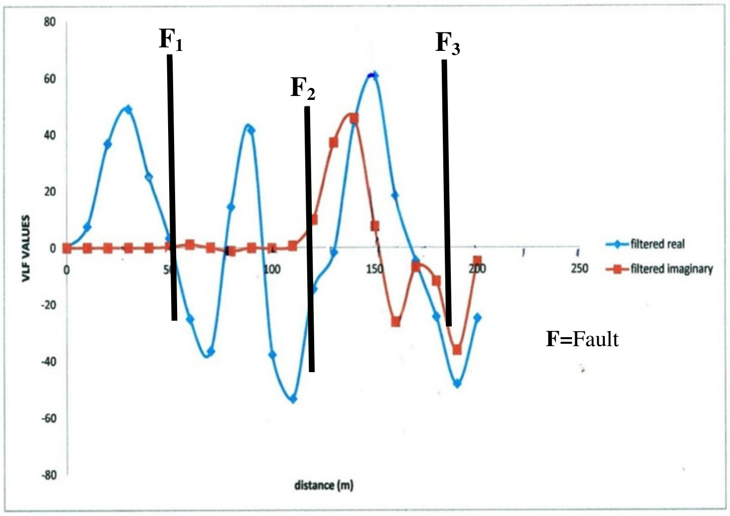

Fig 2: VLF-EM Profile along Traverse 1

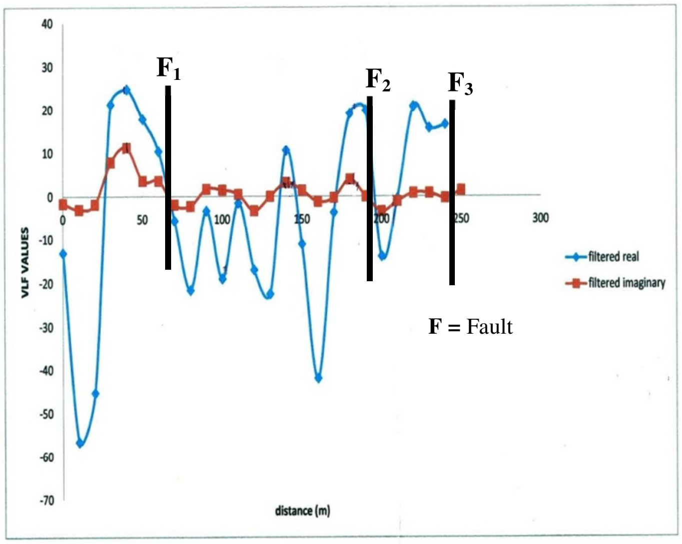

Fig 3: VLF-EM Profile along Traverse 3

Data Processing and Data Interpretation: The VLF-EM data in addition to the VES measurements were subjected to data processing as the basis for interpretation. For VLF-EM, the acquired field data were processed to simplify the obtained complex information into a profile in which the displayed function is directly related to physical properly of the underlying rock. Hence, measured raw real and imaginary components were subjected to Fraser (Fraser, 1969) and Karous-Hjeit (Karous and Hjeilt, 1983) filtering operations in order to suppress noise and enhance the signal. The raw real (in phase) and the raw imaginary (quadrature) components acquired in the field were subjected to filtering process to generate the filter real and the filter imaginary part data. The raw real as well as the raw imaginary data were converted with the aid of an in-built filtering program provided in the ABEM WADI equipment. Freely available MATLAB-based software (Sundarajan et al; 2011) was used to process the measured components of the VLF-EM data. The filtered real data anomaly inflections appear as peak positive anomalies and false VLF anomaly inflections as negative anomalies of the profiles (Adiat et al; 2009). Subsequently the filtered real in addition to the filtered imaginary data was plotted against distance to generate the VLF-EM profiles. Thus, this formed the basis for the overall interpretation and delineation of potential fracture zones.

The VES data presented as depth sounding curves (Figures 4 and 5) were inverted with the aid of computer aided iteration curve matching techniques. The apparent resistivity obtained was plotted on a log-log graph paper with the electrode separation (AB/2) on the abscissa and apparent resistivity (ρ_a) values as the ordinate. The true resistivity and thickness of the subsurface layers were interpreted by partial curve matching with the two layer model master curves and the corresponding auxiliary curves. The thickness and resistivity values obtained from the partial curve matching were then used for a quantitative computer iteration using the Schlumberger O'Neil software package (Schlumberger, 1986). The results obtained from the computer modeling are presented in Table 1. The iterated geoelectric parameters (Table 1) were used to generate geo-electric sections for the study area (Figures 6 and 7) in accordance with the analysis of the geo-electrical data

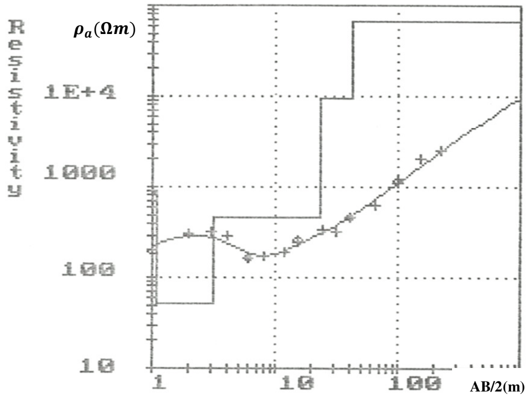

Fig 4: Typical VES curve for Auchi (VES 4)

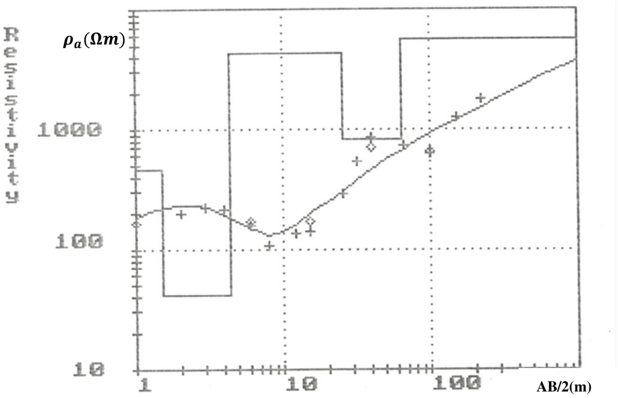

Fig 5: Typical VES curve for Auchi (VES 5)

Table 1: Geoelectric layers' parameters deduced from computer iterationand modeling of the VES curves from Auchi area

VES Location	Layer	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Inferred Lithology	Model Curve
VES 1	1	297	0.6	0.6	Top soil	HAKQ
	2	101	0.8	1.4	Clay/shale	
	3	960	7.2	8.6	Medium grained sand Medium grain sand Fine	
	4	1080	32.7	41.3	grained sand	
	5	370	49.7	91.0	Fine grained sand	
	6	299	-	-		
VES 2	1	245	0.8	0.8	Top soil	HKQQ
	2	94	0.8	1.6	Clay/shale	
	3	2400	1.8	3.4	Medium grained sand Medium grain sand Fine	
	4	1100	23.3	26.7	grained sand	
	5	655	50.1	76.8	Fine grained sand	
	6	254	-	-		
VES 3	1	165	0.3	0.3	Top soil	KHAA
	2	1190	0.6	0.9	Medium grained sand Clay/shale	
	3	69.1	2.0	2.9	Fine grained sand	
	4	529	15.2	18.1	Fractured bedrock	
	5	11400	16.2	34.3	Fresh bedrock	
	6	56800	-	-		
VES 4	1	112	0.4	04	Top soil	KHAA
	2	860	0.7	1.1	Medium grained sand Clay/shale	
	3	51	2.0	3.1	Fine grained sand	
	4	473	20.7	23.8	Fractured bedrock	
	5	9400	18.1	41.9	Fresh bedrock	
	6	65200	-	-		
VES 5	1	116	0.4	0.4	Top soil	KHKH
	2	472	1.1	1.5	Fine grained sand	
	3	41	2.8	4.3	Clay/shale	
	4	4380	20.7	25.0	Fractured bedrock	
	5	810	37.9	62.7	Medium grained sand	
	6	5530	-	-	Fracture bedrock	
VES 6	1	158	0.4	0.4	Top soil	KHAA
	2	726	0.9	1.3	Fine grained sand	
	3	94	2.2	3.5	Clay/shale	
	4	527	19.2	22.7	Fine grained sand	
	5	14400	21.5	44.2	Fractured bedrock	
	6	60500	-	-	Fresh bedrock	
VES 7	1	123	0.4	0.4	Top soil	KHAA
	2	203	0.8	1.2	Fine grained sand	
	3	85	2.3	3.5	Clay/shale	
	4	388	12.6	16.1	Fine grained sand	
	5	19200	20.5	36.6	Fractured bedrock	
	6	83000	-	-	Fresh bedrock	

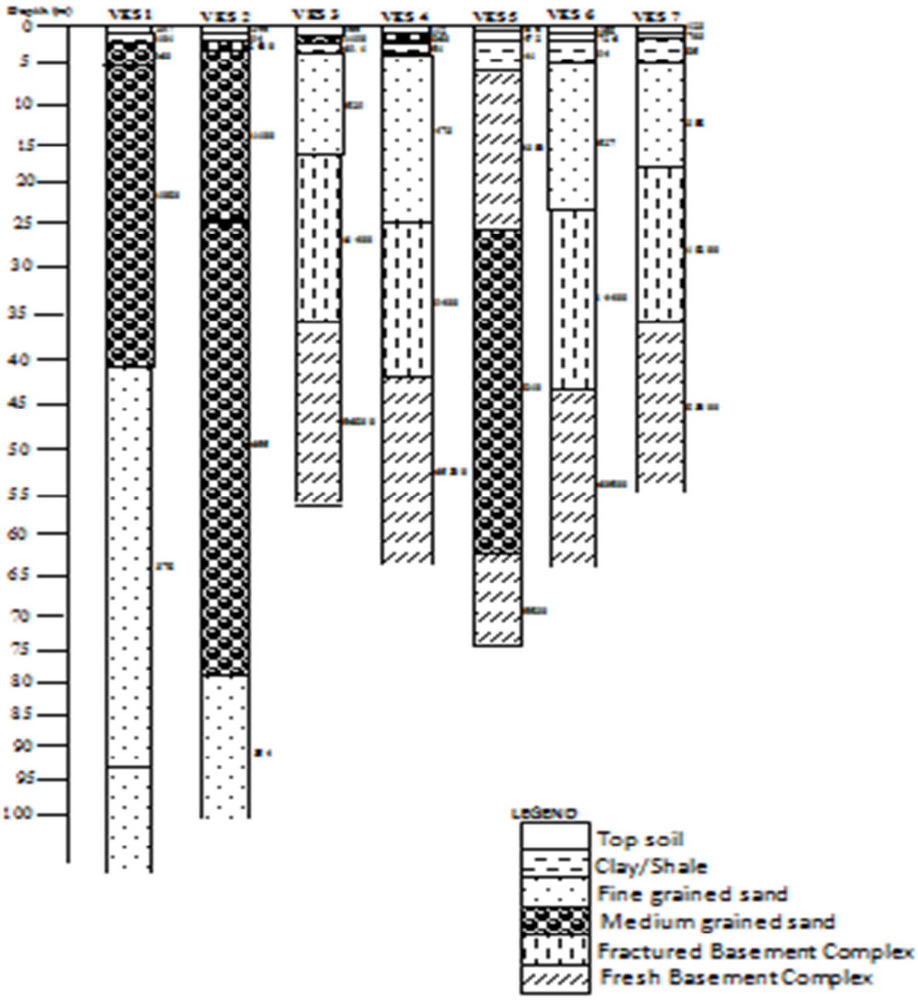

Fig 6: Geolectric section of VES 1 – 7 showing lithologic distribution.

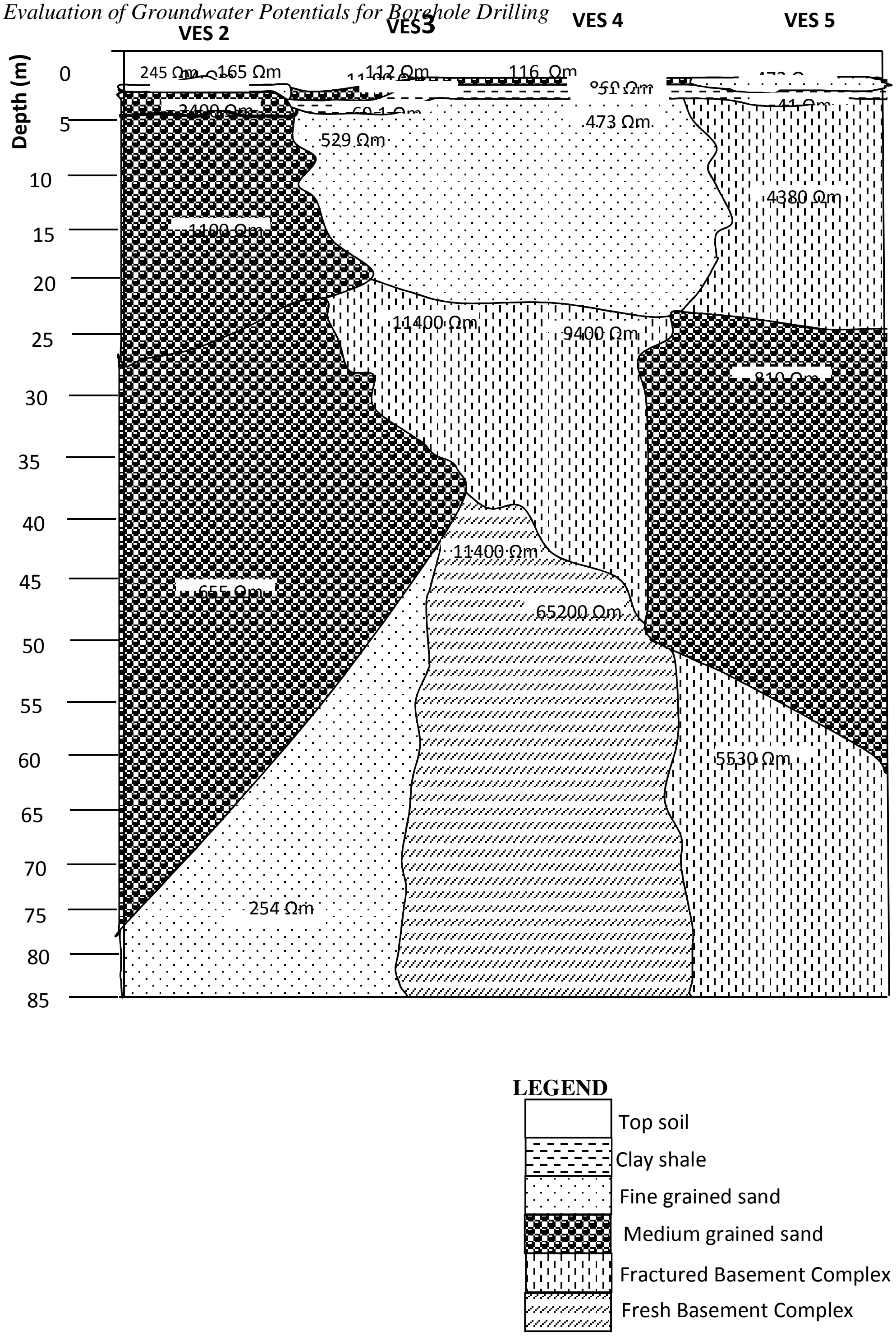

Fig 7: Geoelectric Section of the study area showing near surface lithologic distribution across VES 2, 3, 4 and 5.

RESULTS AND DISCUSSION

The results, which evolved from the VLF-EM and VES data interpretation are presented as profile and geoelectric sections. The results are aimed at explaining the subsurface conducting and or resistivity in the study area. Conductive features, which are characterized by significant positive filtered VLF-EM peaks (Figures 2 and 3), were interpreted as probable geologic fissures capable of holding appreciable quantity of water. The VLE-EM anomalies varied greatly. The values of the filtered real ranged from – 42.0 to 65.6 while those of the filtered imaginary ranged from – 3.4 to 11.2 across the study area. The profiles of the VLF-EM sections (Figures 2 and 3) contained significant maxima in the filtered real part and only a small anomaly is the imaginary part. Zones with peak positive filtered real anomalies were considered areas for electrical soundings since they often correspond to zones of high conductivity. Figure 2 shows the VLF-EM profile along traverse1. Several positive peaks were delineated as fractures (F_1, F_2 and F_3) at distances between 10 and 40m; 80 and 90m; and 140m respectively on the filtered real as shown in Figure 2. Figure 3 also shows VLF-EM profile along traverse 2. Different features of varying degree of conductivity (fractures) were delineated. For example, between stations 10 and 30m; 140 and 150 m; and 170 m and 200m respectively, the in-phase profiles show positive peaks of varying intensities and sharpness, suggesting the presence of a shallow and deep conductors. These points are zones of interest in groundwater abstraction in hard rock terrains.

The VES data obtained were interpreted by partial curve matching and computer iteration techniques. From the interpretation, the geoelectric parameters of the subsurface layers were deduced as presented in Table 1. The resistivity sounding curves obtained from the study area consist of 6-layers (HAKQ, KKQQ, KHKH and KHAA with the KHAA type being the predominant).The typical VES curve types are shown in figures 4 and 5 and they correspond to the VES data from the study area. Figure 4 is characteristic of typical KHAA model curve and it consists of top soil, medium sand, clay/shale, fine sand, fractured bedrock while figure 5 represents KHKH curve type and it consists of top soil, fine sand, clay/shale, medium sand and fractured bedrock. Figures 6 and 7 show the geoelectric cross sections generated from VES interpretation results. The sections show the subsurface variation in electrical resistivity along the profiles and an attempt to correlate the geoelectric sequence across the profiles (Figure 7).

The two dimensional view of the geoelectric parameters (resistivity and depth) obtained from the inversion of the electrical resistivity sounding data are represented as geoelectric sections. The geoelectric section obtained from the sounding curves revealed a six layer earth model of the subsurface categorized into the top soil, clay / shale, fine grained sand, coarse grained sand, fractured and fresh basement. The top soil which is relatively thin has resistivity values between 112 to 245 Ωm and thickness values between 0.3 to 0.8 m, characteristic of lateritic soil. Beneath the top soil layer is a layer characterized by medium grained sand at VES 1 and VES 4 which terminates at VES 5 and this composed of fine grained sand. VES 2 is composed of clay and this does not extend to VES 3. This layer is characterized by resistivity values that ranged from 94 to 1190 Ωm with thickness which ranged from 0.6 to 1.1 m at a depth which varied from 0.9 to 1.6 m. The third layer has resistivity values that ranged from 41 to 2400 Ωm. This clearly depicts a clayey layer at VES 3, 4 and 5 except at VES 2 where it is medium grained sand. It has a varying thickness of 2.0 to 2.8 m and a depth range of 2.9 to 4.3 m. The aquiferous units are located in layers 4, 5 and 6 of VES 2 and VES 5; and layers 4 and 5 of VES 3 and VES 4. These aquiferous units are characterized by resistivity values ranging from 473 to 11400 Ωm with thickness values ranged between 15.2 and 50.1 m and at depths between 18.1 and 76.8 m. These aquiferous layers are presumed to have resulted from highly fractured and weathered bedrock. The bedrock is observed to be fractured which appears as vertical conductors on the VLF – EM profiles at VES 5. This indicates that the location (VES 5) is most suitable for sitting most borehole in the area. The fresh bedrock is characterized by resistivity values that ranged from 56800 to 83000 Ωm. In general, the study revealed the groundwater potential of the area to be generally low with limited hydrogeological importance.

Conclusion: The integrated geophysical methods used in this study have immensely assisted in evaluating groundwater potential of Auchi-Southwestern Nigeria, as it has enhanced the knowledge of the hydrogeology of area and this will assist groundwater development and management activities. Furthermore, the study has provided knowledge on the capabilities of integrated geophysical methods in delineating areas of groundwater occurrence in the area. Hence, an integrated geophysical mapping is highly recommended before borehole drilling in areas with similar geologic framework across Nigeria so as to avoid loses caused by drilling abortive or unproductive boreholes.

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