Investigation of Groundwater Prospect Using Electromagnetic and Geoelectric Sounding at Afunbiowo, near Akure, Southwestern Nigeria

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ABSTRACT

Electromagnetic (EM) profiling and geoelectric sounding were conducted to locate fissured zones and associated groundwater containing media at Afunbiowo, near Akure, Nigeria.

The EM data was collected at 20m intervals along seven profiles, ranging from 250 to 350m, while the soundings were conducted at locations of anomaly identified on the EM profiles. Points of positive EM filtered real anomalies are considered priority areas for resistivity sounding and groundwater development, since they often suggest lithological variations within the unconsolidated overburden, and/or water-filled fissures in the bedrock.

The VES interpretation delineated three groundwater target areas within EM localized zones: (i) the overburden, with thickness varying from 1.1 to 39.1m (ii) the weathered zone, with thickness ranging from 0.9 to 38.2m and layer resistivity of 29 to 1136 ohm-m (iii) the fractured zone. This study has provided information on the hydrogeologic framework and subsurface disposition of main aquifer units in the area.

(Keywords: electromagnetic profiling, vertical electrical sounding, VES, fissured zones, aquifers, hydrogeological framework)

INTRODUCTION

Abrupt changes in lithology, electrical properties and variable thicknesses of weathered bedrock materials often make the interpretation of vertical electrical sounding (VES) data from basement terrain very difficult.

Electromagnetic (EM) profiling and VES are the two complementary, widely used geophysical methods in the delineation of basement regolith and location of fissured media and associated zones of deep weathering in crystalline terrains (Beeson and Jones, 1988; Hazel et al., 1988; Olayinka, 1990; Olayinka et al., 2004). In many instances, reconnaissance EM surveys are used to locate aquiferous zones such as fractures, faults and joints (Palacky et al., 1981; Bernard and Villa, 1991), subsequently detailed using conventional resistivity sounding. Consequently, such combination can greatly assist the successful location of productive water wells in crystalline rock terrains.

The vertical electrical sounding on the other hand provides information on the vertical variation in electrical resistivity with depth. It is commonly used to assess the reliability of the features delineated from EM survey.

Afunbiowo is a new residential estate in the outskirt of Akure metropolis (Figure 1). The area requires a mini groundwater supply scheme pending the realisation of municipal water supply. Water resources development on any scale requires careful planning for appropriate delivery. However, previous studies (Beeson and Jones, 1988; Palacky et al., 1981; Olayinka, 1990; Olayinka et al., 2004) have shown that an approach through integrated EM profiling and depth sounding would enhance the reliability of data interpretation and the success rate of water well location.

This study is focused on assessing the groundwater prospect of the area, and more importantly, providing information on the hydrogeologic framework of major aquifer units, and delineation of areas suitable for water wells.

PHYSIOGRAPHY, GEOLOGY AND HYDROGEOLOGY

The study area is located along the Akure-Idanre roadway. It lies between longitudes $5^0$10'29"E and $5^0$10'57"E and latitudes $7^0$12'11.2"N and $7^0$12'53.6"N. It occupies about 2.17km^2 of land area (Figure 1).

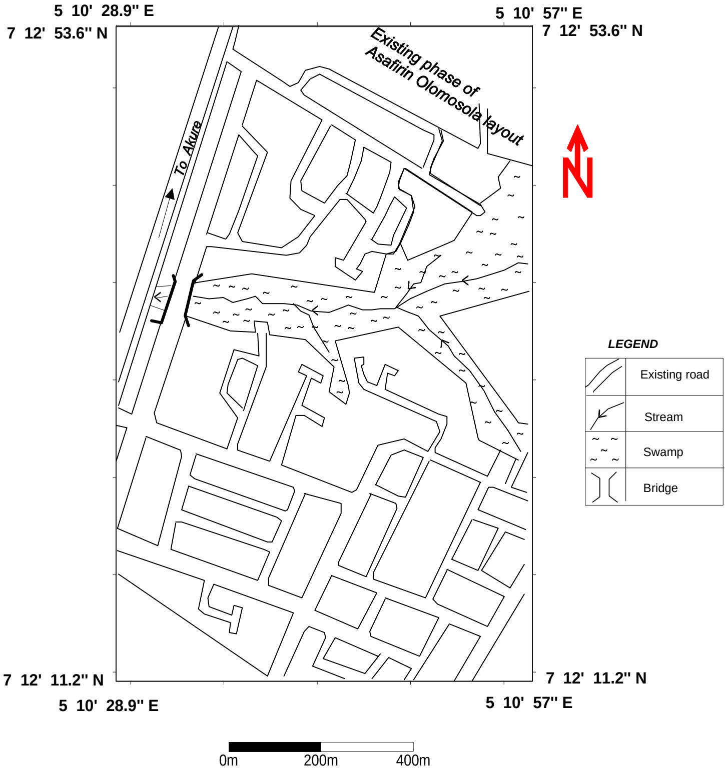

Figure 1: Layout of Afunbiowo (Ondo State Housing Corporation, Akure, 2004).

The terrain in the study area is moderately undulating, with topographic elevation ranging from 340m to 377m above sea level. The area is traversed by the Ogburugburu stream which flows approximately in the east-west direction.

The area is situated within the tropical rain forest region, with a climate characterized by dry and wet seasons. Annual rainfall ranges between 100 and 1500 mm, with average wet days of about 100. The annual temperature varies between 18^0C to 34^0C (Iloeje, 1980).

The study area is underlain by the Precambrian Basement complex rocks of Southwestern Nigeria (Rahaman, 1978). The local lithologic units identified in the study area the migmatite – gneiss, biotite gneiss and granites (Figure 2). The migmatite-gneiss is the most wide spread rock unit on the estate, covering more than half of the area and occurring in north-eastern and south eastern parts of the area. The biotite-granite occurs in several locations, mostly in the central part of the study area. They are porhyritic and of medium-coarse-grained texture. Granites occur as intrusive in low-lying outcrops within the biotite gneiss and occur mostly in the south-western part of the estate.

In the basement terrain, groundwater occurs in the weathered mantle and the joints, fractures or faults within the bedrock (Odusanya and Amadi, 1990; Ademilua and Olorunfemi, 2000). The concealed basement rock may contain faulted areas, incipient joints and fracture systems derived from tectonic events earlier experienced. The detection and delineation of these hydrogeologic structures may facilitate the location of groundwater prospect zones in a typical basement setting (Omosuyi et al., 2003).

DATA ACQUISITION AND ANALYSIS

The ABEM WADI VLF-EM Instrument used to measure the EM response is a portable instrument which measures the electrical properties of the subsurface, using EM induction as detailed in McNeil (1980a). In this work, seven EM profiles were made (Figure 3 and Figure 4) using a 20m coil spacing, with an expected maximum depth of investigation of about 15m for the horizontal dipole (HD) mode (McNeil, 1983). The EM data were collected at 20m interval along seven profiles with lengths ranging from 250 to 350m. The VLF-EM data were presented as profiles by plotting filtered real and filtered imaginary values against their station positions. The EM profiles were interpreted quantitatively by matching with geophysical models (McNeil, 1980a and Palacky et al., 1981)

The VES was conducted using the Schlumberger electrode array (Zohdy et al., 1974). The R-50 Soil Test Conductivity Meter was used for resistance measurements. In all, thirty (30) soundings were conducted, with maximum half-current electrode spacing (AB/2) of 100m. The field curves were interpreted through partial curve matching (Koefoed, 1979) with the help of master curves (Orellana and Mooney, 1966) and auxiliary point charts (Zohdy, 1965; Keller and Frischnecht, 1966). From the preliminary interpretation, initial estimates of the resistivity and thickness of the various geoelectric layers at each VES location were obtained. These geoelectric parameters (Table 1) were later used as a starting model for a fast computer-assisted interpretation (Vander Velpen, 1988). The algorithm takes the manually derived parameters as the starting geoelectric model, successively improved on it until the error is minimized to an acceptable level.

Table 1: Summary of Layer Model Interpretation of the Sounding Data from the Afunbiowo Area.

	LAYER THICKNESS					LAYER RESISTIVITY							LAYER THICKNESS					LAYER RESISTIVITY				
VES No	h_1	h_2	h_3	h_4	h_5	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	VES No	h_1	h_2	h_3	h_4		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5
1	4.1	1.9				104	29	8367				16	0.8	1.8				114	73	1358		
2	1.0	3.3				76	187	3769				17	1.2	3.0				119	58	10993		
3	0.9	2.9				729	1046	9700				18	0.7	2.8				312	64	2358		
4	1.0	0.9				107	120	3581				19	0.6	1.9	31.0			274	152	241	12245	
5	0.8	1.4				150	57	1743				20	0.9	11.8				167	159	5115		
6	1.0	1.0	6.3	8.4		408	163	435	191	800		21	0.9	38.2				423	262	4582		
7	0.9	7.6				235	103	1005				22	1.1	4.8				702	249	1211		
8	0.9	12.8				330	179	8540				23	1.9	13.8				624	198	1401		
9	1.6	7.4				271	92	4906				24	0.7	1.0	1.5	5.6		293	216	625	150	1354
10	0.7	1.6	2.5	10.		349	60	316	96	6082		25	0.5	3.7				757	175	1434		
11	0.8	2.1	0.7	1		156	137	680	554			26	0.7	3.7				324	181	1061		
12	1.1	2.7	5.2		14.5	388	1136	204	996	355	5266	27	0.7	3.9	8.4			1400	702	161	24453	
13	0.6	1.2	4.2	6.9		532	157	434	139	481		28	1.0	3.3				336	365	3056		
14	1.8	8.0		6.5		749	275	489				29	0.9	3.5	5.6			336	558	122	24729	
15	0.6	1.1	13.4	2.1		460	72	290	179	1226		30	3.0	3.0				329	378	114		

h-Layer thickness
ρ- Layer resistivity

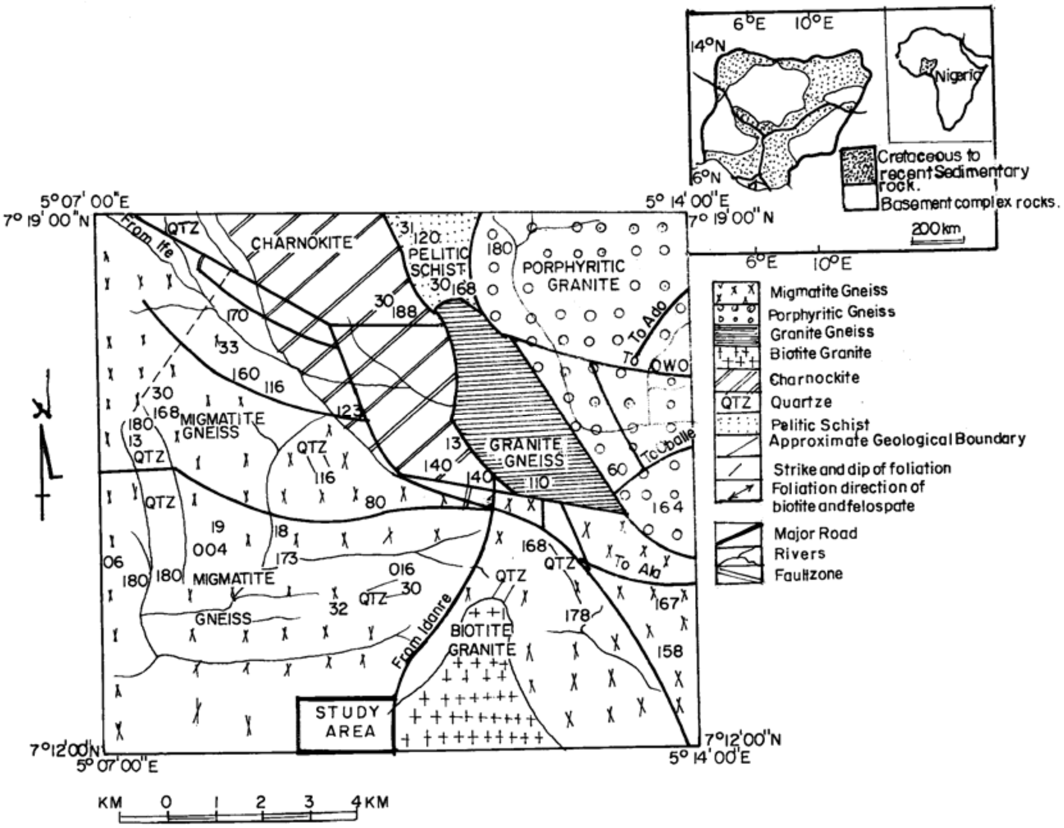

Figure 2: Geological Map of Akure Area (after Owoyemi, 1996)

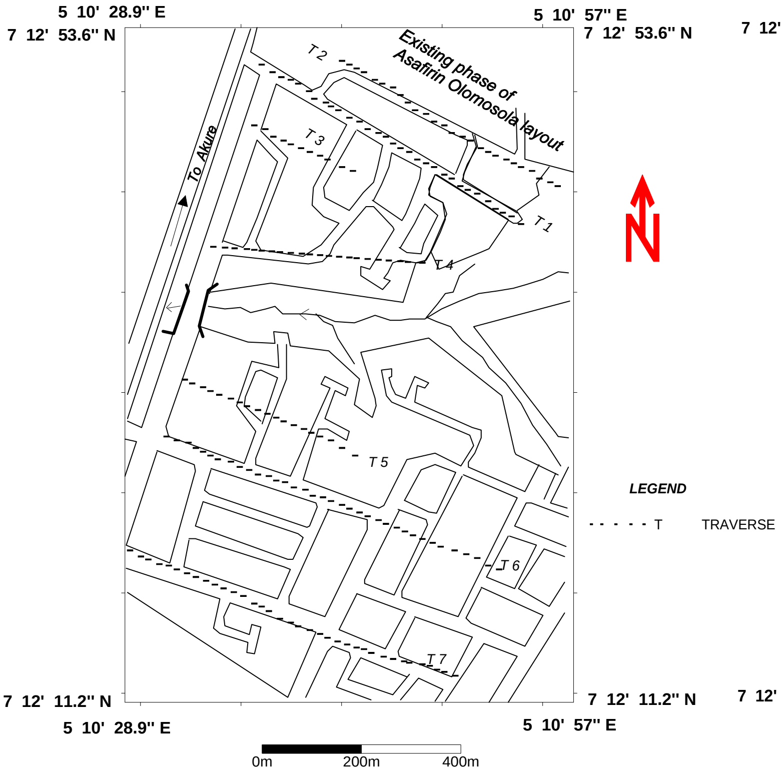

Figure 3: Map Showing the VLF – EM Traverses at Afunbiowo.

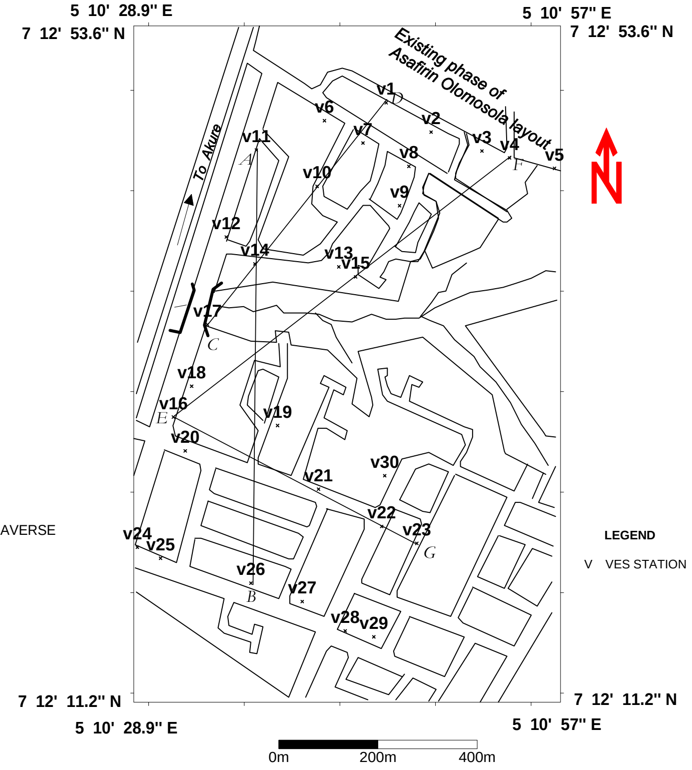

Figure 4: Map Showing the VES Locations in the Area.

RESULTS AND DISCUSSION

The results, which evolved from the EM and VES data interpretation, are presented as profiles, geoelectric sections and maps.

Figure 5 shows typical EM profiles from the study area. The EM anomalies vary greatly. Some of the anomaly peaks are narrow, sharp while others are broad with varying width extent.

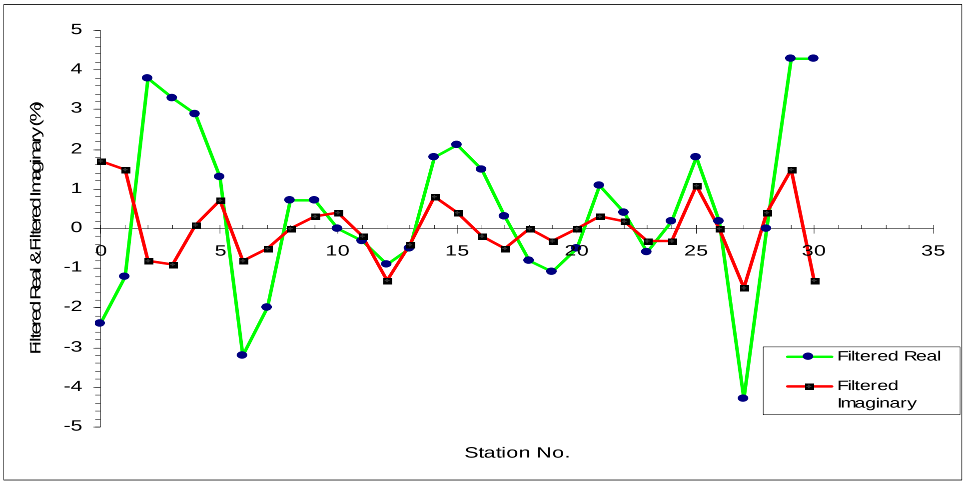

Figure 5(a): Filtered Real and Filtered Imaginary Profiles of Afunbiowo (Traverse 01)

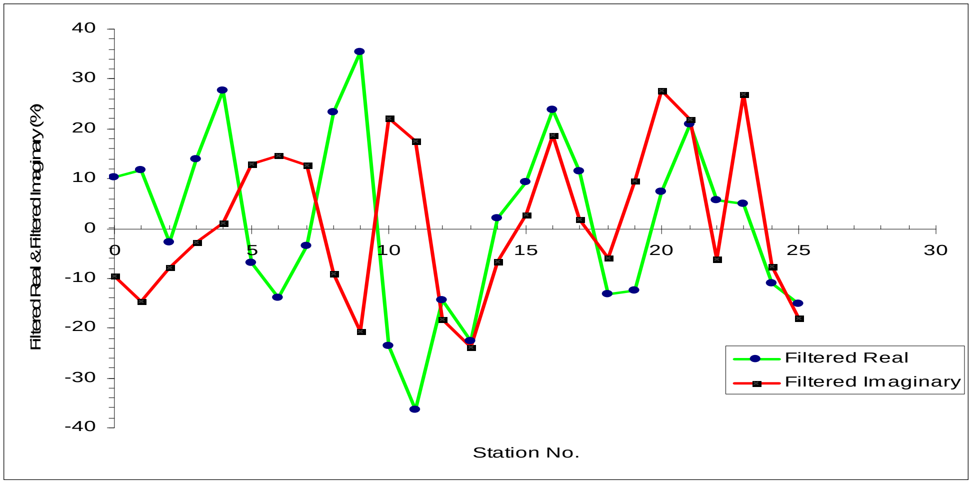

Figure 5(b): Filtered Real and Filtered Imaginary Profiles of Afunbiowo (Traverse 02)

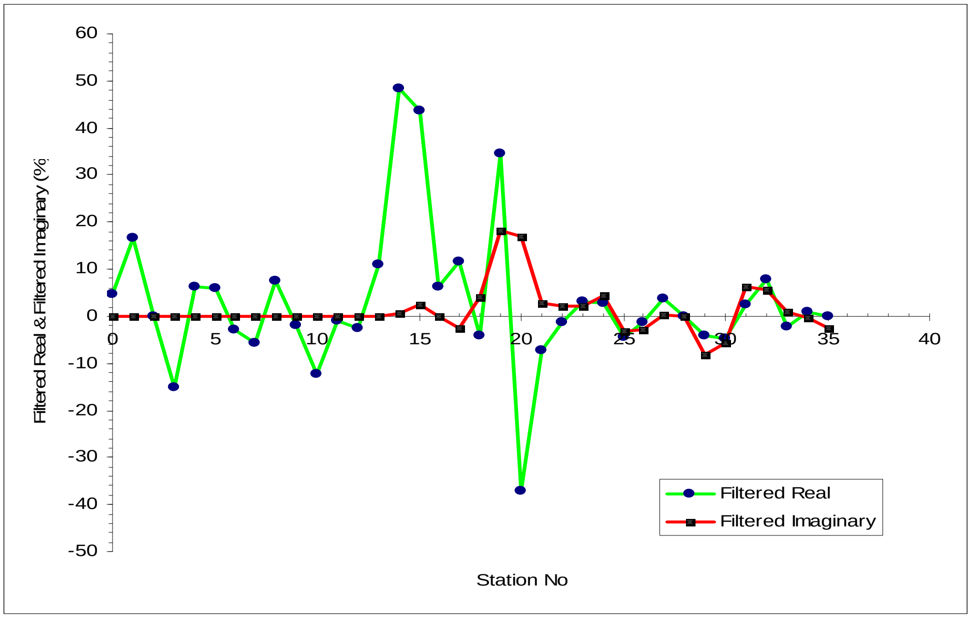

Figure 5(c): Filtered Real and Filtered Imaginary Profiles of Afunbiowo (Traverse 07)

The values of the filtered real range from -43.8 to 48.5, while those of the filtered imaginary vary from -43.8 to 35.0 across the study area. The profiles for the EM sections (Figure 5) contain significant maxima in the filtered real part and only small anomaly in the imaginary part. Zones with peak positive filtered real anomalies are considered priority areas for electrical sounding, since they often correspond to zones with high conductivity, characteristic of water-filled fractures or faults (Alvin et. al., 1997), or effect of appreciable depth to bedrock or lithological variations within the unconsolidated regolith (White et al., 1988).

Geoelectric/Lithologic Characteristics and Aquifer Delineation

Figure 6 shows typical geoelectric curves corresponding to VES data from the study area.

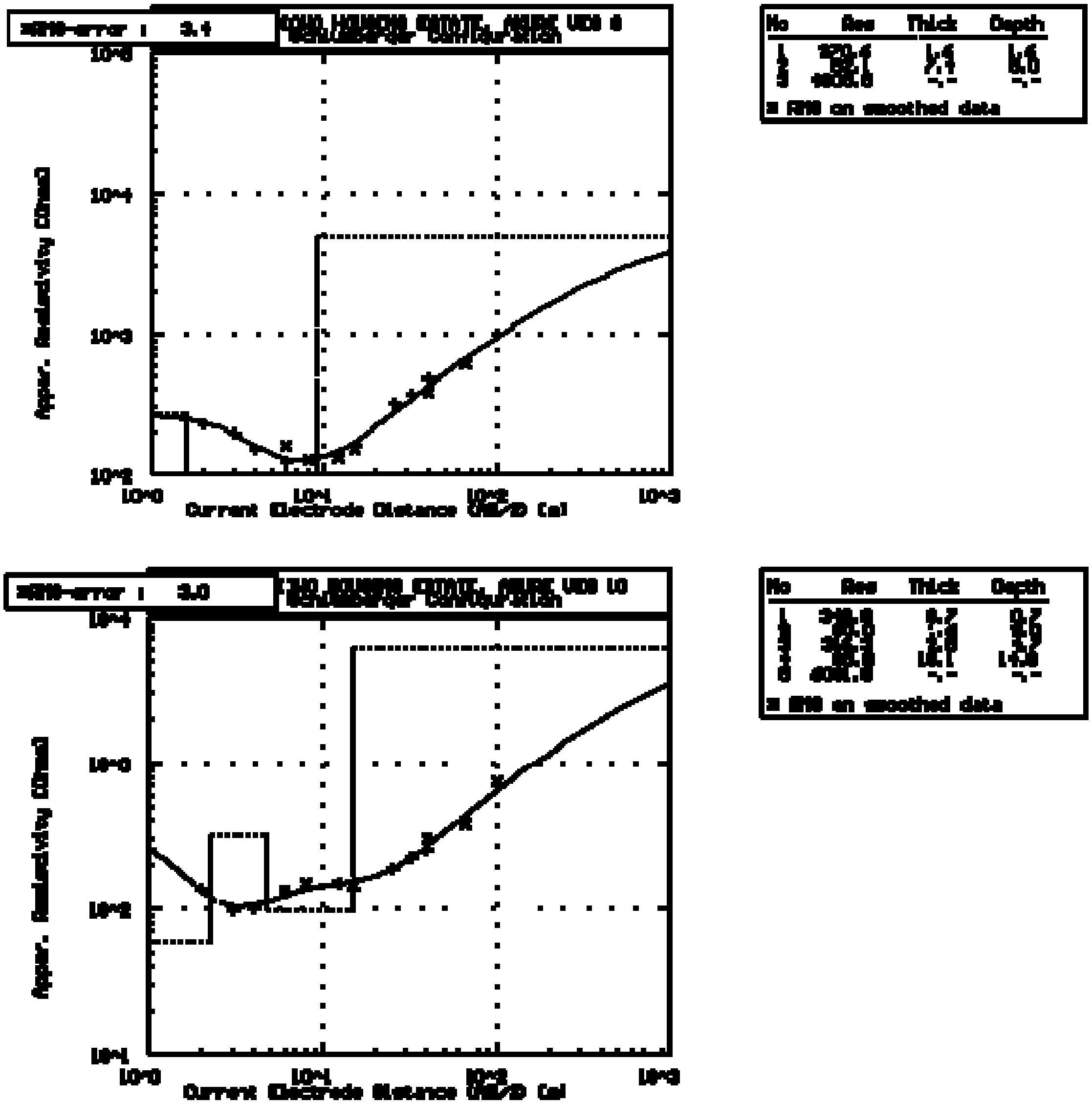

Fig 6: Typical VES curves from Afunbiowo (VES 9 and 10).

The curve types include A, H, QH, HK, KH, HKH, and KHKH. Typical curves from the area are shown in Figure 7. The H type is the most preponderant, constituting 50% while each of A and HKH types constitute 16.7%. It is often possible to make qualitative hydrogeologic deductions from curve types (Worthington, 1978). The KH, HKH and KHKH curves thus suggest subsurface geoelectric configurations apparently favorable for groundwater occurrence.

Electrical methods primarily reflect variations in ground resistivity. The electrical resistivity contrasts existing between lithological sequences (Dodds and Ivic, 1998; Lashkaripour, 2003) in the subsurface are often adequate to enable the delineation of geoelectric layers and identification of aquiferous or non-aquiferous layers (Schwarz, 1988).

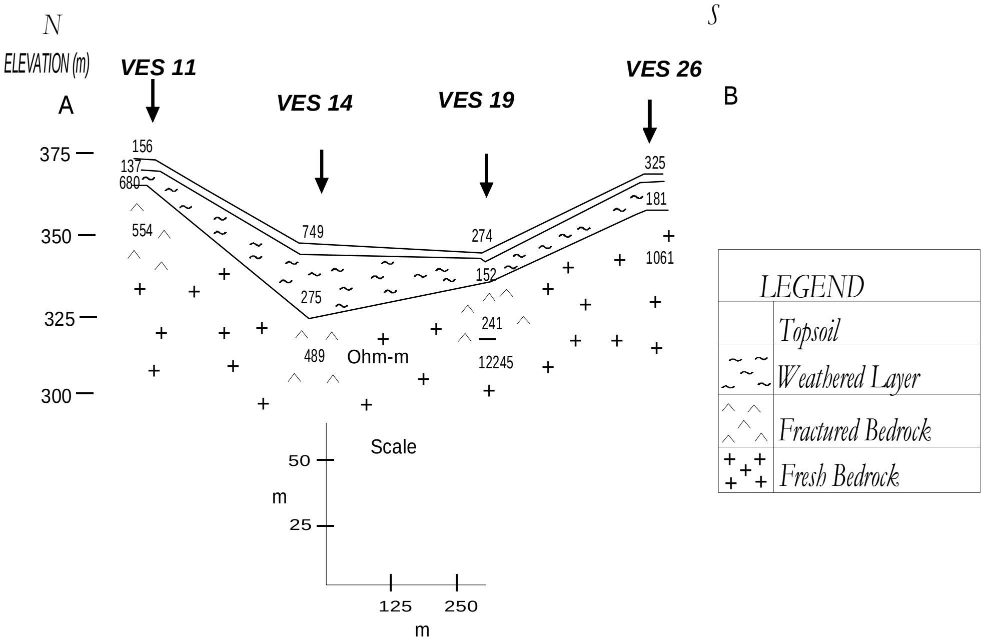

Figure 7(a): A N-S Geoelectric Section Embracing VES 11, 14, 19 and 26 along Profile AB.

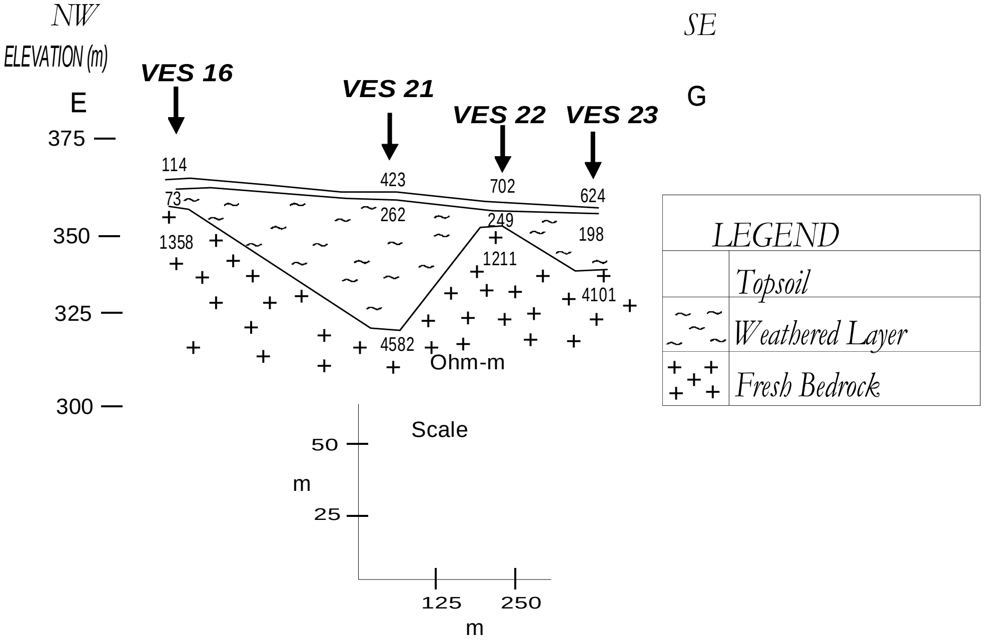

Figure 7(b): A NW-SE Geoelectric Section Embracing VES 16, 21, 22 and 23 along Profile EG.

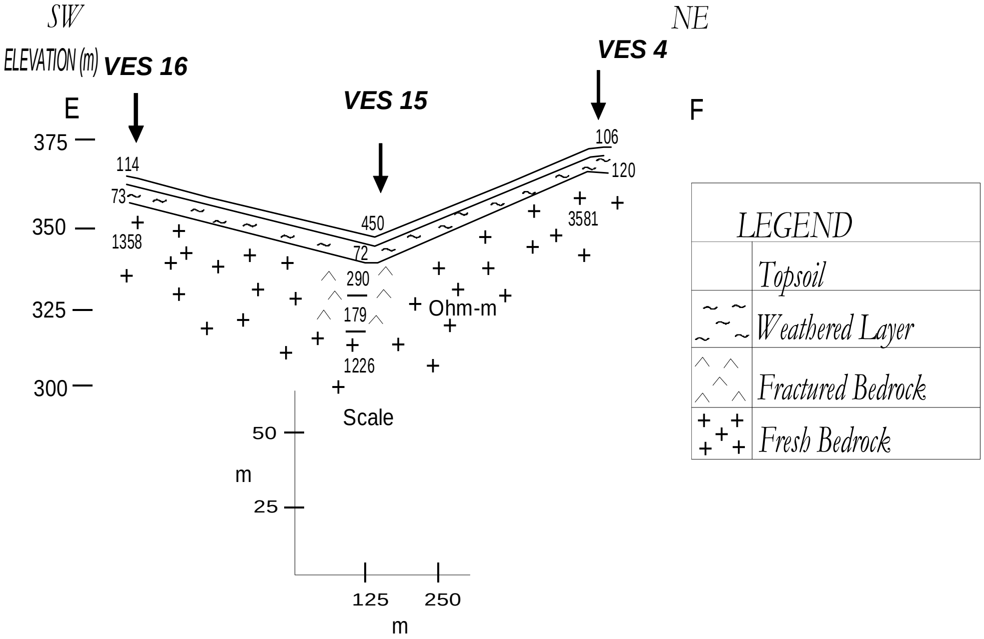

Figure 7(c): A SW-NE Geoelectric Section Embracing VES 16, 15 and 4 along Profile EF.

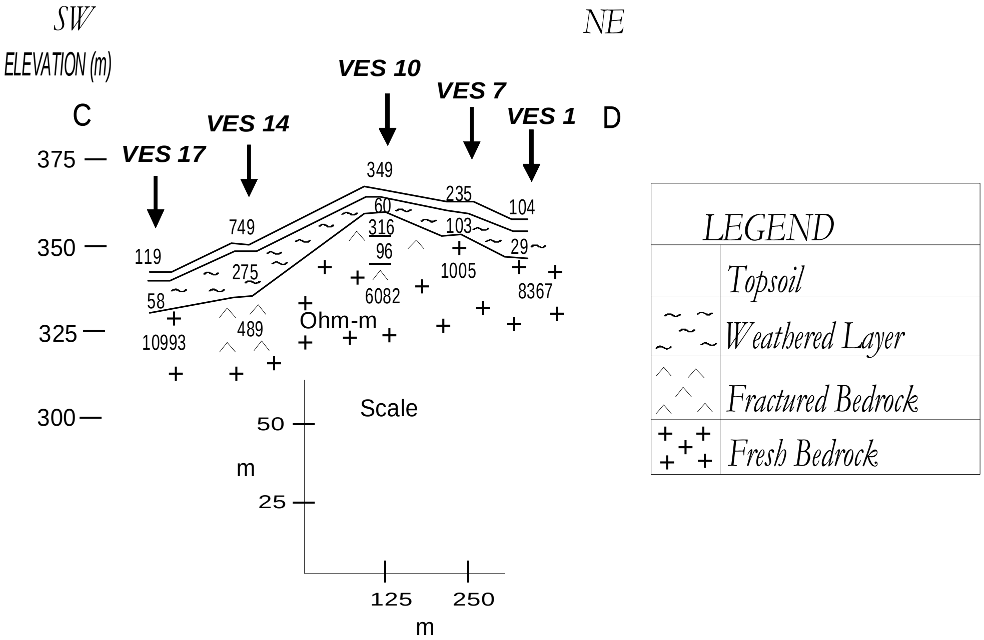

Figure 7(d): A SW-NE Geoelectric Section Embracing VES 17, 14, 10, 7 and 1 along Profile CD.

Figure 7 shows four interpretive geoelectric sections AB, CD, EF and GH taken in the N-S, NW-SE, SW-NE and SW-NE directions respectively. The sections show the subsurface variation in electrical resistivity along the profiles and attempts to correlate the geoelectric sequence across the profiles. The VES interpretation, summarized in the table inserts, reveals three to six geoelectric layers across the study area: the topsoil, the weathered layer (clay/sandy clay/clay sand/lateritic layer) and the bedrock (fractured/fresh bedrock).

In the first layer (topsoil), resistivity varies from 76 to 1400 ohm-m, while in the second layer (weathered layer), resistivity values range from 29 to 1136 ohm-m. The resistivity values in the third layer (fractured/fresh bedrock) vary from 96 to 24,729 ohm-m. Layer thicknesses also vary from 0.5 to 4.1m and 0.9 to 38.2m in the first and second layers respectively. Depth to the bedrock ranges from 1.9m to 39.1m across the study area.

The interpreted depths to the bedrock beneath all the VES stations were plotted and contoured as isopach or overburden thickness map (Figure 8). The overburden thickness in the study area varies from 1.1 to 39.1m. The isopach map shows zones of relatively thick overburden (greater than 15m) and zones of relatively thin overburden (less than 15m).

Studies in similar basement terrain (Bala and Ike, 2001; Omosuyi et. al., 2003) have identified areas with thick overburden cover as high groundwater potential zones. Consequently, areas with overburden thickness of 15m and above are priority areas for groundwater development.

The bedrock topography has a lot of hydrogeologic significance in a basement setting (Olorunfemi et al, 1999). Depressions are noted for thick overburden, in addition to serving as groundwater collecting troughs for water displaced from the ridges. These features, delineated and identified as D1-D4 in Figure 9, often constitute priority areas for groundwater development in a basement setting.

Groundwater Potential Evaluation

The groundwater potential map (Firgure 10) was generated based on the aquifer thicknesses delineated across the VES locations. These thicknesses were plotted and contoured. The map reveals that aquifer thickness varies from 2 to 38.2m (where delineated). The groundwater potential map enabled the identification of groundwater potential zones in the area.

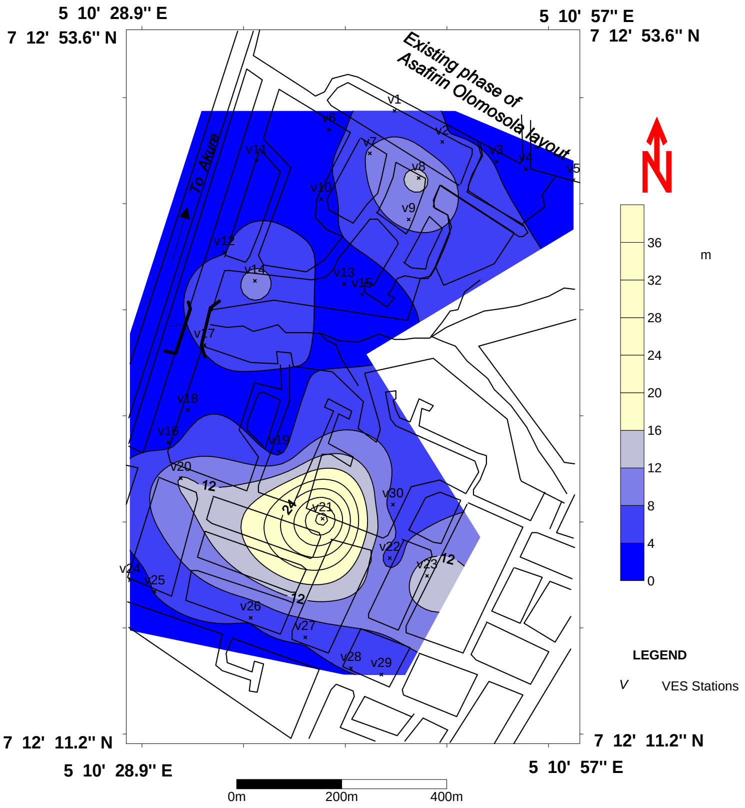

Figure 8: Overburden Thickness Map of Afunbiowo.

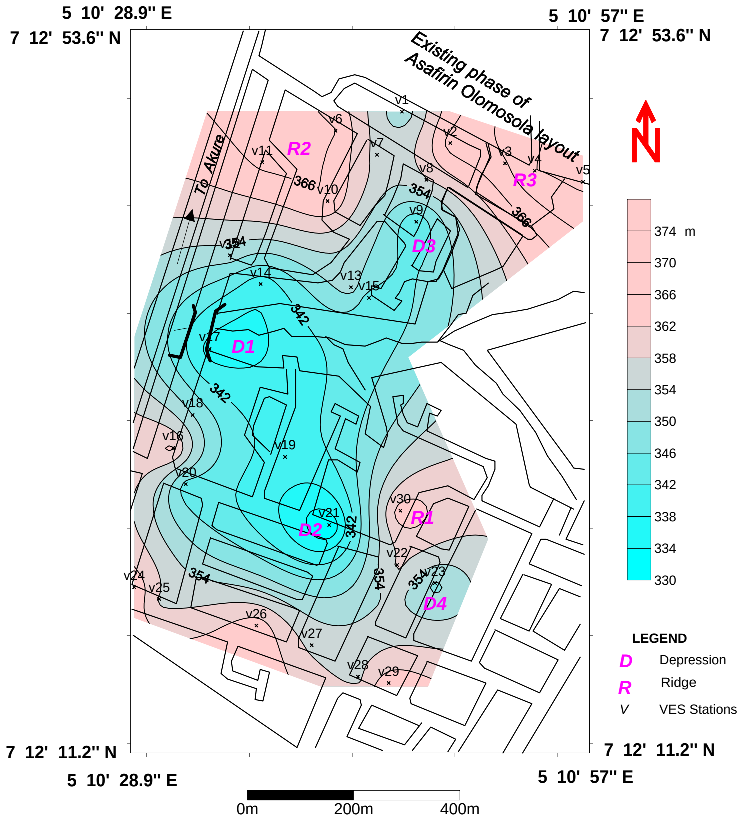

Figure 9: Bedrock relief map of Afunbiowo.

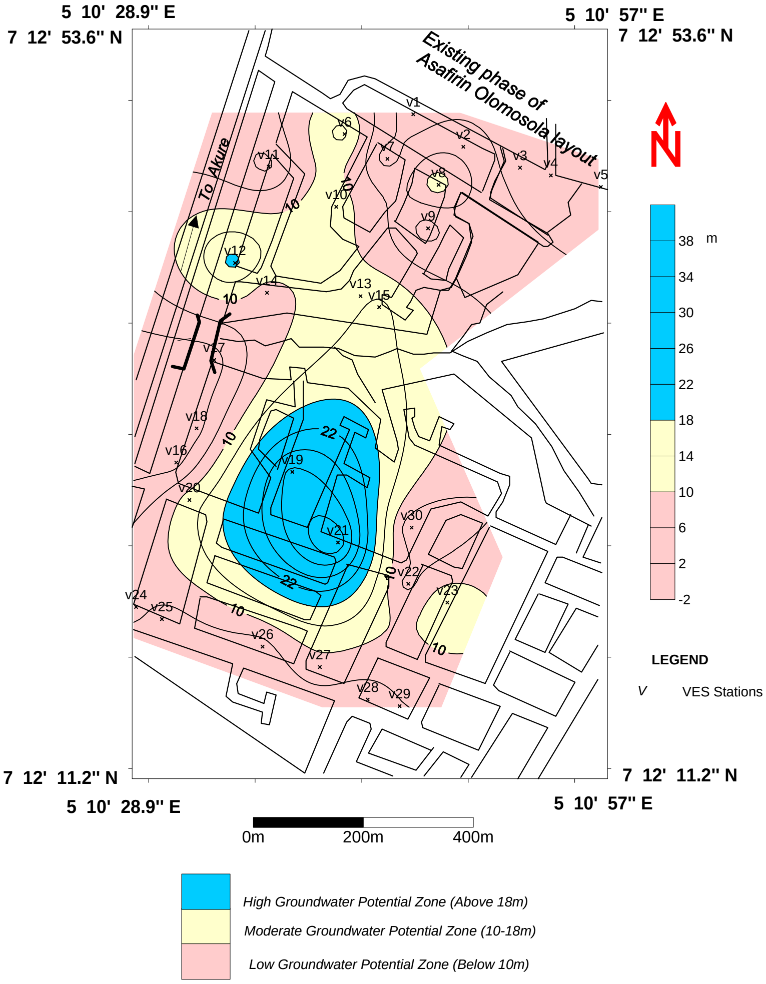

Figure 10: Groundwater Potential Map of Afunbiowo.

Zones where aquifer thickness ranges over 18m are classified as high groundwater prospect zones, while areas where aquifer thickness falls between 10 and 18m, and below 10m are considered medium and low groundwater potential zones respectively.

CONCLUSION

The electromagnetic profiling and vertical electrical resistivity surveys in the Afunbiowo area have contributed to a better understanding of the basement complex of Southwestern Nigeria. Sites with high electromagnetic anomaly (high positive filtered real anomaly) can be expected to be aquifers, implying locations suitable for the development of groundwater resources. However, air-filled, altered or fissured bedrock, or predominantly clayey regolith may exhibit such anomalies. Vertical electrical sounding should therefore be conducted at locations selected for EM profiling in order to resolve possible ambiguities.

Based on the results obtained from this survey, it can be concluded that the integration of electromagnetic profiling and DC electrical methods are efficient tools for borehole sitting in groundwater exploration in a typical crystalline terrain.

In this study, data from the combined disciplinary sources has provided information on the hydrogeologic framework and subsurface disposition of major aquifer units in the study area.

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