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GEOELECTRIC INVESTIGATION FOR GROUNDWATER AQUIFER IN A SEDIMENTARY ENVIRONMENT, A CASE STUDY OF IRRUA SPECIALIST TEACHING HOSPITAL, ESAN CENTRAL LOCAL GOVERNMENT AREA OF EDO STATE, NIGERIA.

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ABSTRACT
A Geophysical investigation involving the Very-Low Frequency Electromagnetic (VLF-EM) profiling method and Vertical Electrical Sounding (VES) method with the Schlumberger configuration were carried out at Irrua Specialist Teaching Hospital (I.S.T.H) and environ in Esan Central Local Government area of Edo State, Nigeria. The study was carried out with the aim of gleaning the subsurface layer information and/or parameter (conductivity, resistivity, and thickness) and thereby ascertains the underground water potential thereof.
A total of three (3) VLF-EM profiles were transverse at different directions using the Abbem wadi Electromagnetic equipment used in the study as a reconnaissance tool. With the Omega resistivity meter a total of two (2) VES (Ves 1 and Ves 2) study was done with AB/2 covering a predetermined distance of 500meter.
The VLF-EM result reveals that the filter real and the filter imaginary amplitude vary between 31.2% to -41.6% and -30.5% to 53.2% respectively. From the quantitative interpretation of the VES data(with computer iterative method) enabled the characterization of eight(8) geo-electric layers made up of dry top sand, sandy clay, sandstone and a high resistive dry sand, covering a total depth of (178.30 - 178.71) m.
From the study, it is evident that ground water in the study area is in the upper aquifer which is shallow and may not be too prolific in terms of accumulation and yield.

KEY WORDS: Anomaly, conductivity signature, Fracture Zone, Geoelectric sections, groundwater, resistivity

1 INTRODUCTION

Throughout ages, groundwater (which is water underground) has form a substantial source of portable water supply to man for domestic, industrial and agricultural purposes in most part of the world. The application of geophysical techniques to determining the quality and quantity of groundwater has being pursued worldwide, by individuals', cooperate bodies, government agency, involved in groundwater resource development (Dobrin, 1976).With financial limitation inherent with the developing nations of the World, groundwater development and exploitation had witness much setback in meeting with the day to day water requirement of man. In line with the adage "a stitch in time, save nine" it's therefore imperative to using geophysics in the most appropriate time, as well as appropriate manner for finding and abstracting groundwater, to ensuring a high success rate of its exploitation (MacDonald and Davies 2000).

Potable and adequate supply of water is central to life and civilization.Portable water supply has become a real challenge particularly in Irrua specialist hospital,the area of study. Groundwater is the water that occurs beneath the ground. It occurs in aquifers-which are layers of water bearing permeable rock or an unconsolidated deposit that can yield economic quantity of water (Udensi,2005).
Geophysical techniques of investigating the earth subsurface composition and structure had reach a high degree of sophistication with the convergence of the need to investigating the earth for both scientific and societal challenges (GreenHouse and Slaine, 1983). The availability of groundwater depends primarily on the geological features of the area. As pointed out by MacDonald and Davis (2000), where groundwater is readily available wells and boreholes can be sited using mainly social criteria qualified by simple hydro geological considerations. However, if an area is underlain by difficult geological conditions, where groundwater resources are limited and hard to find, simple 'rule of thumb' criteria are not sufficient to sitting sustainable boreholes and following exclusively social approach, with minimal technical input can lead to many dry boreholes. Generally, the success rate of geophysical application to groundwater investigation relies on careful interpretation and integration of result with other geologic and hydro geologic information of the study area (Dobrin, 1976; Ujuanbi and Asokhia, 1999).
Deep saturated fractures in bedrocks are potential target for groundwater accumulation mostly in sedimentary terrain. To mapping this fracture, the Electrical resistivity sounding using the Schlumberger electrode array are widely useful for this purpose (Ujuanbi and Asokhia, 1999; Egwebe and Aigbedion, 2004) offering both qualitative and quantitative interpretations.
The geo-hydrological properties like porosity, the clay content, mineralization of groundwater including the degree of saturation make this method's of study very effective method of underground water studies (Ward, et al, 1983; Benson, et al, 1997).

2 THEORETICAL BACKGROUND INFORMATION OF THE STUDY

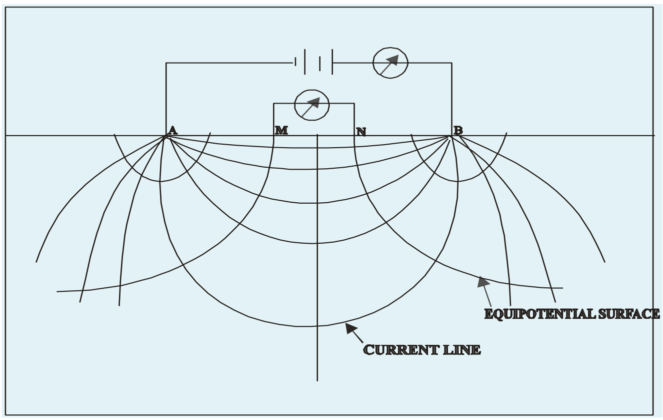

Figure 1.1: Showing the pattern of current distribution between two current electrodes (AB) implanted on a homogenous isotopic earth.

Ohm's law provides the relationship between electric field and current density, given by the equation,

$$J = \sigma \bar{E} \quad (1.1)$$

where,

σ is the conductivity (a constant for a given medium). For an isotropic medium, the conductivity will be a scalar quantity, so that J and $\bar{E}$ will be in the same direction. For anisotropic medium, the conductivity is a tensor of second rank, so that

$$J = \sigma_{ij} \bar{E} \quad (1.2)$$

The subscript i and j may be any of the X, Y, and Z spatial directory.

The basis of all resistivity prospecting with direct current is given by,

$$\nabla \sigma_{ij} \nabla V = 0 \quad (1.3)$$

In the isotropic case, equation (1.3) reduces to Laplace equation,

$$\nabla^2 V = 0 \quad (1.4)$$

For the horizontal Earth model the solution to equation (1.4) according to **Stefanesco et al**, (1930) becomes

$$V(r) = \left[\frac{I\rho_1}{2\pi} \frac{1}{r} + 2\int_o^{\infty} \theta_n(\lambda) J_o(\lambda_r)\, dr \right] \quad (1.5)$$

where,

$J_o = \bar{E}$ is the zero order Bessel function of first kind and θ_n is called the **kernel function** which is a function of the thickness and reflection coefficient for an assumed earth model. By differentiating equation (1.5) the Schlumberger apparent resistivity over an n – layer earth becomes,

$$\rho_a(r) = \left[\rho_1 \quad 1 + 2r^2 \int_o^{\infty} \lambda \theta_n(\lambda) J_1(\lambda_r) d\lambda \right] \quad (1.6)$$

where,

J_1 = first order Bessel function of first kind.

The evaluation of this integral of equation (1.6) has been done in a number of ways. However in this study we have adopted Ghosh (1971) in which is possible to determine a linear digital filter, which converts resistivity transform samples into apparent resistivity values for theoretical models.

3. GEOLOGY OF THE LOCATION OF STUDY AREA.

The geophysical study was carried out at Esan Central Local Government Area of Edo State, with case study of Irrua Specialist Teaching Hospital (I.S.T.H), Edo State, Nigeria. It lies at a latitude of $06^0 43^1$ north and longitude $006^0\ 11^1$ east. It is located at the east boundary with Esan West local government area, Ekpoma, Edo state, Nigeria. The location of study is accessible through the

Ekpoma- Irrua, express road, and through the Benin –Auchi express way (see the base map for the study) in figure 1.2

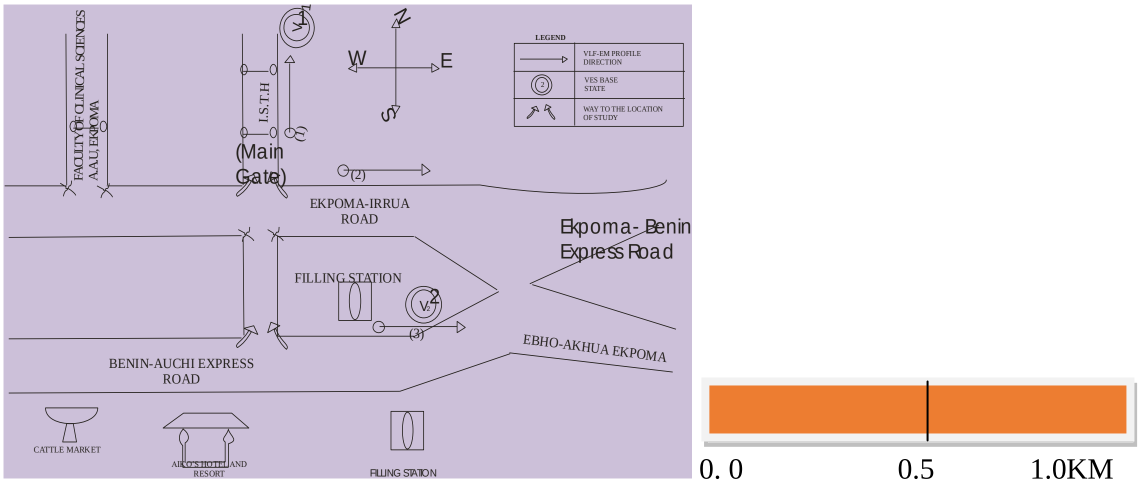

Figure 1.2: Base Map of the Study Area

The local geology of the location of study falls within the Anambra sedimentary Basin, in the Agbede sedimentary formation. This formation is characterized by laterites , underlain by sandy clay and clay. The area lies in the tropical rainforest with mean annual rainfall of 1300mm and an annual mean temperature between 18^0 C and 35^0 C. The area is situated on a gently undulating terrain with an elevation of 377m. Towards the administrative headquarter of the area of study, Esan central local government area of Edo state, underground water is found in coarse sandstone region. The depth to groundwater in this study area vary, depending on the thickness of overlying sediment and the topography (that is the elevation/depression) of the site.

4. **MATERIALS AND METHODS.**

The Vertical Electrical Sounding (VES), adopting the Schlumberger Electrode configuration which entails sending in artificially generated current (usually direct current or low frequency alternating current) source was introduced into the ground through two current electrodes (A and B) and the resulting potential difference measured by another two potential Electrode (M and N). A direct current introduced through the electrode ‘AB’ induces a voltage across the two inner potential electrodes ‘CD’. The *ohmmeter resistivity meter* converts the voltage and current into the electrical resistance which is displayed on its screen and recorded. The arrangement of the electrode at each predetermined distance was done in such a way as to make a straight line and the orientation maintain throughout the spread of AB/2. The current electrode spacing (AB/2) is directly proportional to the depth of penetration (that is, the greater the electrode separation, the greater the depth of penetration). However, this process yield a rapidly decreasing potential difference across the potential electrode, which will eventually exceed the measuring capacity of the instrument, at this instant a new value of potential electrode separation was established (Asokhia, et al, 1994; Dobrin, 1976). The apparent resistivity (ρ_a) value is calculated from the known parameters using the relation,

$$\rho_a = KR$$

$$k = \frac{\pi(AB/2)^2 - (MN/2)^2}{MN},$$

where,
K=Geoelectric factor
R = Obtained resistivity value.

The sounding data obtained are presented as depth sounding curve by plotting apparent resistivity against the current electrode spacing (AB/2) on a transparent tracing paper superimposed on the ABEM Bi- log graph. The field data and the model parameters obtained from the curve matching above was used as input data for computer modeling and iteration using software (Resist1Diverse) which automatically plot the field curve, the model curve; with the field data adjusted to have an error tolerance within (0-10) %. The resistivities, the geo electrical layer, the thickness, the cumulative thickness, the soil litho logy and the depth to the area probed are displayed. The obtained VLF-EM data in table 1.0, 1.1 and 1.2 below are presented as plots of filter real (%) and filter imaginary (%) on the ordinate and the station spacing (meter) on the abscissa, given in figure 1.4a, 1.4b and 1.4c. The EM anomaly vary significantly, some are sharp, while some are broad with varying width extent. However, zones with peak positive filtered real cross-over filter imaginary are inferred as weak (or conductive) zones typical character of geological formation like fault and fracture, favorable for groundwater accumulation.

Table 1.0: Vlf-Em data for profile one (1)

STATION SPACING(M)	RAW-REAL(%)	RAW-IMAGINARY(%)	FILTER REAL(%)	FILTER IMAGINARY(%)
0.00	0.00	-4.50	-6.50	-4.90
20.00	-9.20	12.40	0.20	-2.40
40.00	5.80	6.20	-4.90	8.00
60.00	-12.20	-18.20	3.70	0.30
80.00	8.30	4.30	41.60	-4.90
100.00	-1.60	0.00	-12.10	21.40
120.00	-4.40	-99.90	-4.40	4.10
140.00	-2.80	-99.90	-1.60	-28.40
160.00	0.00	71.00	20.90	52.60
180.00	-31.40	-15.10	16.70	38.60
200.00	-3.50	4.00	4.30	-2.20
220.00	1.20	-1.60	4.00	1.20
240.00	0.40	-2.80	2.20	0.90
260.00	4.50	-4.10	-4.50	-1.50
280.00	-8.40	-2.00	-0.70	2.60
300.00	5.40	-15.30	4.50	-1.10
320.00	2.80	-11.10	-3.20	7.70
340.00	-0.70	-14.50	-5.00	3.70
360.00	-5.00	-26.30	-6.90	-2.70
380.00	-8.50	-4.10	-3.10	1.60
400.00	-3.20	-29.20	-2.80	0.40
420.00	-4.00	-9.40	-4.10	-7.00
440.00	0.30	3.10	-4.20	-0.10
460.00	-5.90	-11.50	-0.20	1.60
480.00	4.80	-6.30	3.30	-0.70

Table 1.1: VLF-EM data for profile two

STATION(M)	RAW REAL(%)	RAW IMAGINARY(%)	FILTER REAL(%)	FILTER IMAGINARY(%)
0.00	0.00	7.20	18.60	7.00
20.00	4.20	14.30	-2.60	-5.70
40.00	20.80	-4.10	-6.70	-4.60
60.00	-14.60	35.90	6.40	-12.10
80.00	-3.30	-0.70	-8.10	-2.90
100.00	3.20	8.90	2.60	-2.30
120.00	-6.30	1.20	0.80	0.30
140.00	-0.30	-2.57	-2.70	1.10
160.00	-4.60	-0.20	-3.57	0.70
180.00	23.10	3.30	7.60	1.60
200.00	-4.30	-4.20	-3.20	-0.70
220.00	-3.00	-3.20	3.70	1.60
240.00	0.10	-5.00	-2.50	-0.40
260.00	-5.90	-1.60	-0.2	-3.70
280.00	4.80	79.00	3.80	-30.40

Table 1.2: VLF-EM data for profile three

STATION SPACING(M)	RAW REAL(%)	RAW IMAGINARY(%)	FILTER REAL(%)	FILTER IMAGINARY (%)
0.00	0.00	-35.90	9.90	-12.10
20.00	9.70	-0.70	10.00	-13.90
40.00	3.00	8.90	5.00	-2.70
60.00	3.80	0.30	0.70	1.20
80.00	0.30	-2.50	-12.30	1.10
100.00	-12.30	-2.70	-12.30	0.70
120.00	0.00	-23.10	3.20	2.40
140.00	14.60	-1.80	64.60	-33.20
160.00	-30.50	66.40	47.50	-23.20
180.00	13.50	68.30	53.20	-2.40
200.00	7.80	49.30	13.50	-1.90
220.00	0.00	62.70	7.80	-3.10
240.00	-10.40	15.10	-10.10	-0.70
260.00	-2.40	-24.40	-1.30	7.40
280.00	-0.30	-14.10	-1.70	1.20
300.00	-1.10	-25.40	-1.10	4.80
320.00	-0.10	-26.00	-0.10	-0.60
340.00	-0.30	-22.00	-0.30	0.80

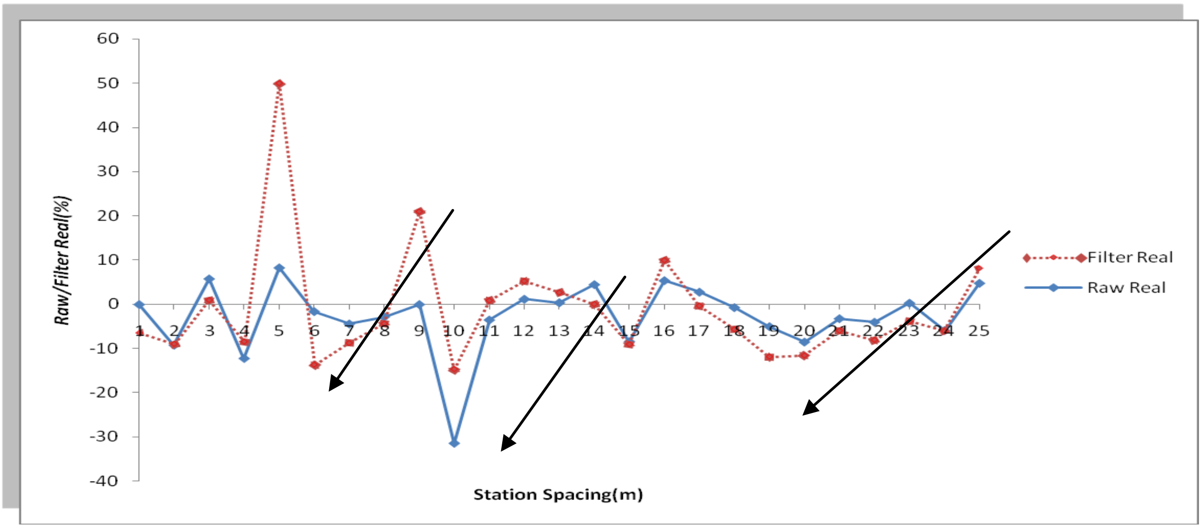

Figure 1.4a: Graph of Filter real and imaginary (%) Versus Station spacing (m) for profile one (1).

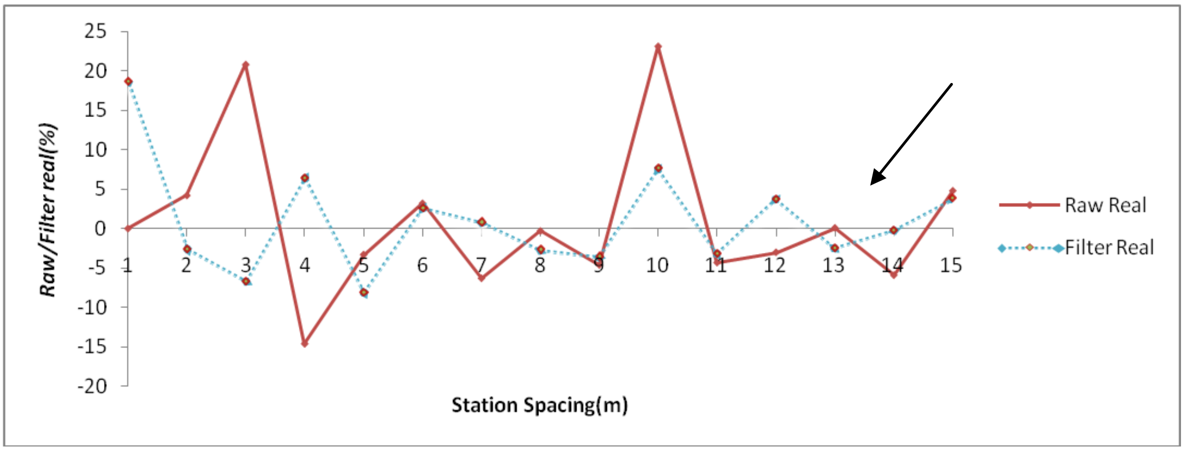

Figure 1.4b: A Graph of Filter Real and imaginary (%) Versus Station Spacing (m) for Profile two (2).

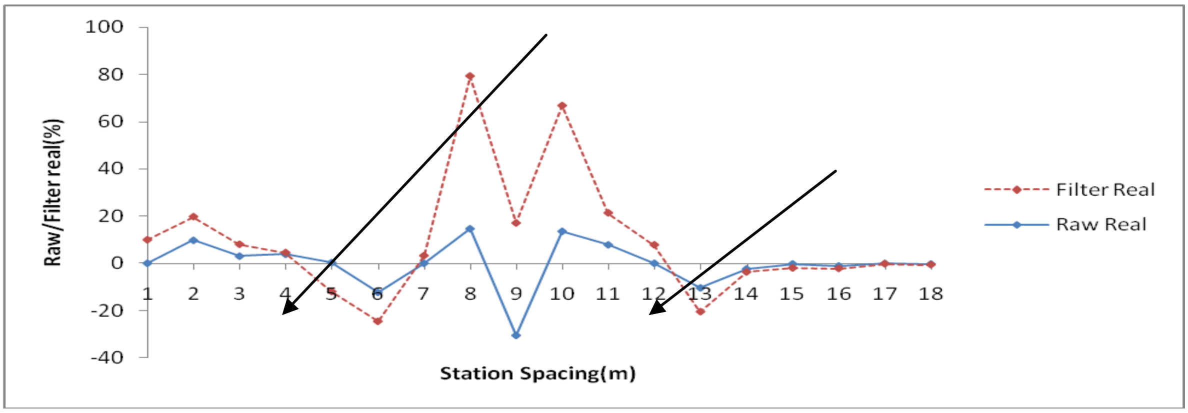

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Figure 1.4c: A Graph of Filter Real and imaginary (%) Versus Station Spacing (m) for profile three (3).

Station spacing (220-280) meter in profile one (1) (figure 1.4a) and (20-80) meter in profile three (3) (figure 1.4c) having longest width cross-over between the filter real and filter imaginary, were earmarked for further geophysical studies. The Vertical Electrical Sounding was used in detailing the groundwater aquifer conditions in profile one and profile three (which acted as a control part of the study). The obtained data in profile one (1) are presented in table 2.0 below and the bi-log sounding curve is presented in figure 1.5a and 1.5b

Table 2.0: VES data in profile one (1)

Electrode position	*(AB/2)m*	*(MN/2)meters*	*Current(A)*	*Resistance(Ω)*	*Geometric factor(k)*	*App. Resist. In ohm-meter*
1	1	0.500	1	46.970	2.400	111
2	2	0.500	1	11.480	11.780	135
3	3	0.500	2	6.405	27.480	176
4	4	0.500	5	4.005	49.460	198
5	6	0.500	5	1.931	112.260	217
6	8	1.000	10	2.581	98.910	255
7	12	1.000	10	1.026	224.510	230
8	15	2.000	10	1.778	173.490	309
9	25	2.000	20	0.837	487.480	408
10	32	2.000	20	0.629	800.700	504
11	40	2.000	20	0.491	1252.860	615
12	65	5.000	20	0.614	1318.800	810
13	100	10.000	50	0.724	1555.250	1126
14	150	10.000	50	0.327	3522.936	1152
15	225	10.000	50	0.210	7937.478	1670
16	325	20.000	50	0.255	8270.588	2109
17	500	40.000	50	0.284	9742.958	2767

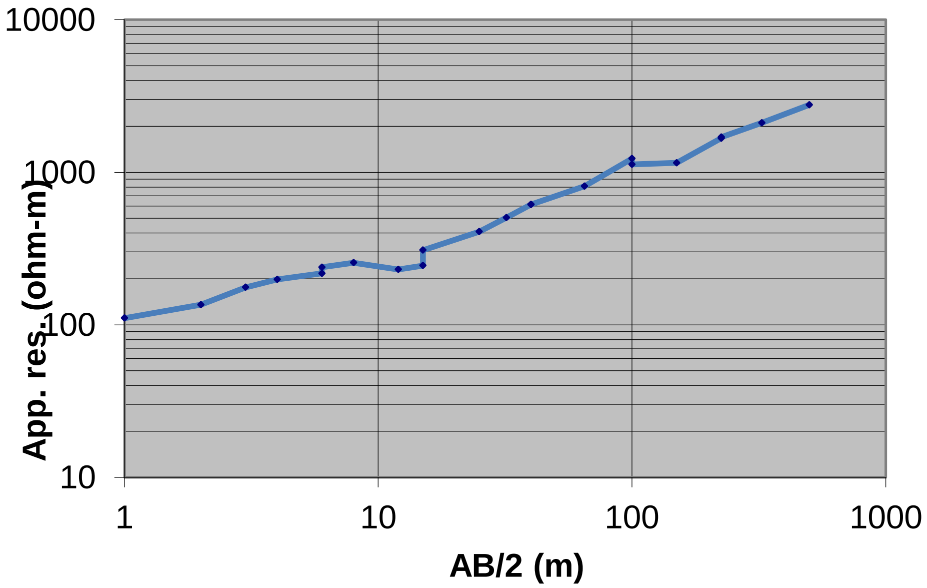
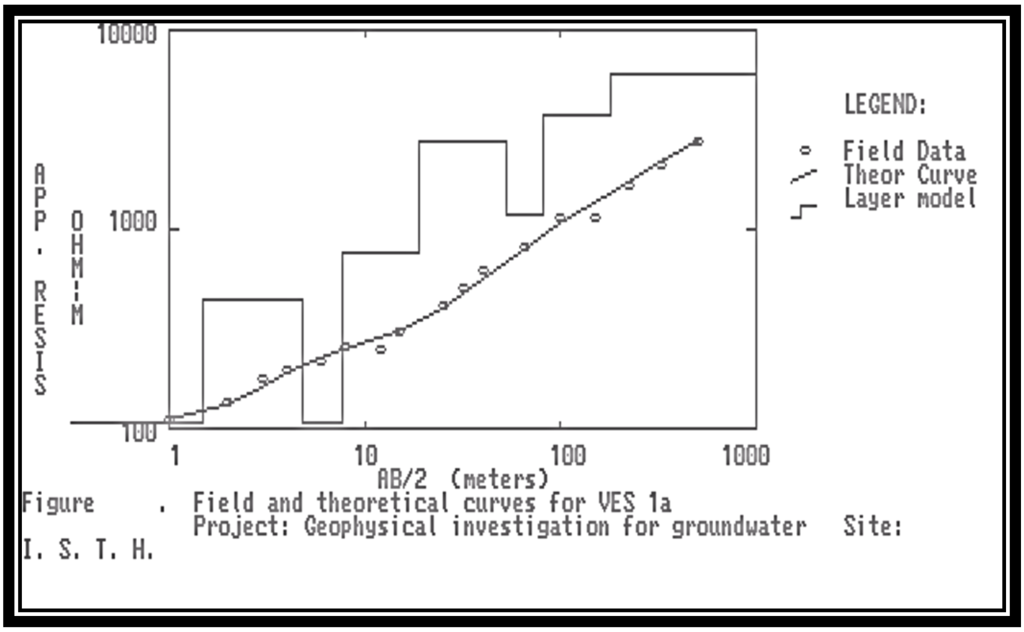


Figure 1.5a: Log- Log graph of apparent resistivity versus current electrode spacing for VES1 (one)



From the curve presented in figure 1.5b using the ResistDinverse computer software aided interpretation, eight (8) geologic layers where delineated; which is a typical trend of Agbede/Ekpoma sedimentary formation. Table 1.1 shows the derived layer model parameters for VES1 (one).

GEOELECTRIC LAYER	RESISTIVITY(ohm-meter)	THICKNESS(m)	CUMMULATIVE THICKNESS(m)	SOIL LITHOLOGY
1	105.00	1.49	1.49	Top soil
2	449.26	3.34	4.83	Sandy clay
3	105.84	2.85	7.68	Sand
4	762.09	11.15	18.83	Sandy clay
5	2767.09	34.33	53.16	Dry sand
6	1173.25	27.90	81.06	Sandstone
7	3759.15	97.65	178.71	Dry sand
8	6107.00	Infinity	Infinity	Dry sand

Table 1.1: Layer Parameter for VES one (1)
RMS error = 3.09%

The trend of the apparent resistivity for **VES1 ($\rho_1<\rho_2>\rho_3<\rho_4<\rho_5>\rho_6<\rho_7<\rho_8$)** represent the **KHAKHA** curve type in this sedimentary terrain of study. The first layer has a resistivity of 105.00 Ω-m representing top soil layer with thickness of 1.49m. The second layer has a resistivity of 449.26Ω-m representing a sandy clay layer with thickness of 3.34m. The third layer has a resistivity of 105.84Ω-m representing a sand layer with thickness of 2.85m. The fourth layer has resistivity 762.09 Ω-m representing sandstone with thickness of 11.15m. The fifth to the eight layers are made up of high resistive dry sand with thickness between 34.33m to infinity.
The Ves data for profile three (3) is presented in table 2.1 and the Bi-log curve is shown in figure 1.6,

Table 2.1: VES data for profile three (3)

STATION POINT	AB/2(M)	MN/2(M)	RESISTIVITY (Ω)	CURRENT(A)	GEOMETRIC FACTOR	APPARENT RESISTIVITY(Ω-M)
1	1.00	0.50	22.360	1	2.3565	52.70
2	2.00	0.50	5.205	1	11.7825	61.30
3	3.00	0.50	3.131	2	27.4925	86.10
4	4.00	0.50	2.257	5	49.4865	112.00
5	6.00	0.50	1.281	5	112.3265	144.00
6	8.00	1.00	1.748	10	98.9730	173.00
7	12.00	1.00	1.047	10	224.6530	235
8	15.00	1.00	0.8164	10	351.9040	287
9	25.00	2.00	0.7585	20	487.7955	370
10	32.00	2.00	0.5754	20	801.2100	461
11	40.00	2.00	0.4299	20	1253.658	539
12	65.00	5.00	1.1890	20	1319.640	767
13	100.00	10.00	0.7664	20	1555.29	1192
14	150.00	10.00	0.5303	20	3519.04	1866
15	225.00	20.00	0.6489	20	3945.17	2560
16	325.00	20.00	0.3713	50	8265.42	3069
17	500.00	40.00	0.3677	50	9755.91	3587

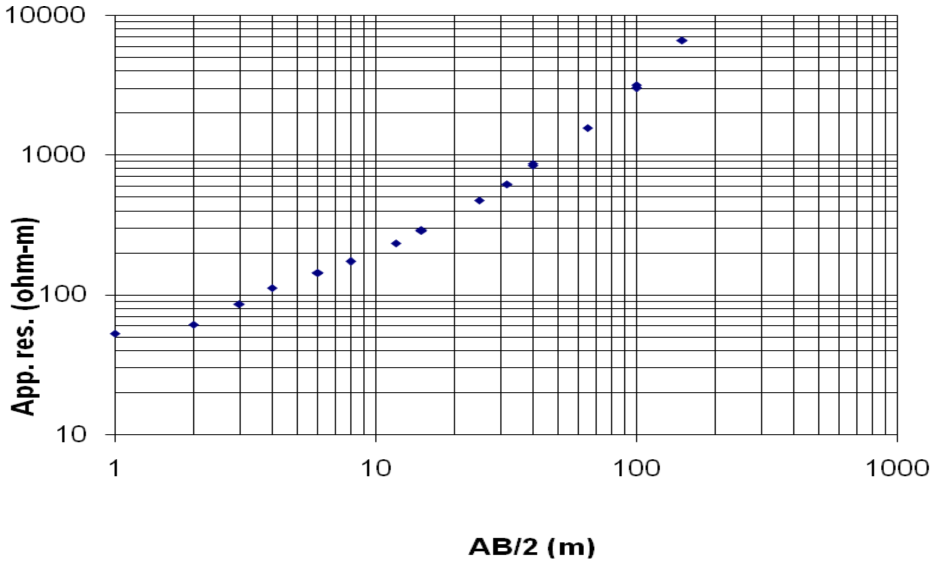
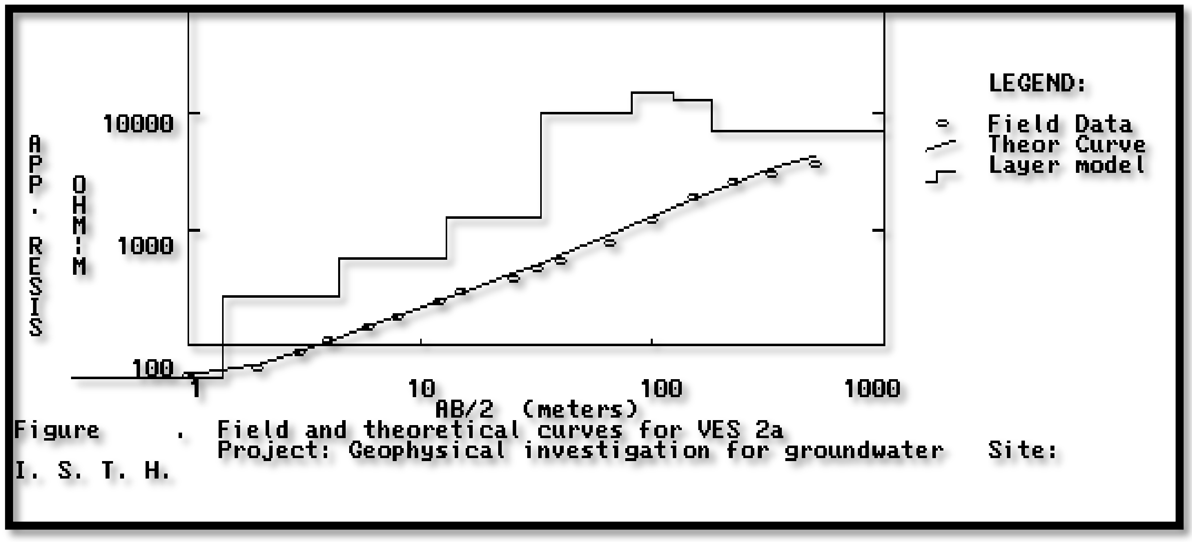


Figure 1.6a: Log-Log graph of Apparent Resistivity (ohm-meter) versus Current Electrode Separation (AB/2) in meter for VES2a



From figure 1.6b, eight (8) geo electric layers were delineated **($\rho_1<\rho_2<\rho_3<\rho_4<\rho_5<\rho_6>\rho_7>\rho_8$)** representing the **AKQ** curve type.

Table 1.2: Layer Parameters of Model for VES2a

GEOELECTRIC LAYER	***RESISTIVITY (ohm-meter)***	***THICKNESS(m)***	***CUMMULATIVE THICKNESS(m)***	***INFERED LITHOLOGY***
1.00	49.80	1.42	1.42	Top soil
2.00	263.00	3.02	4.44	Sandy clay
3.00	546.00	8.58	13.02	Sand
4.00	1233.00	20.20	33.22	Sand
5.00	10266.65	47.43	80.65	Dry sand
6.00	15176.00	41.85	122.50	Dry sand
7.00	13305.00	55.80	178.30	Dry sand
8.00	7041.00	infinity	Infinity	Dry sand

RMS error = 3.09%

The first layer is made up of top soil with resistivity 49.80 ohm-meters and thickness 1.42meters, the second layer representing sandy clay with resistivity 263.00 ohm-meters and thickness 3.02meters and a third layer with resistivity 546.00 ohm-meters and thickness 8.58meters representing sand. From the fourth layer through the eight layers is high resistive dry sand with variable thickness.

CONCLUSION

The results of the interpreted VLF_EM and the VES within the premise of Irrua Specialist Teaching Hospital (I.S.T.H) and environ located in Esan central Local Government Area of Edo State, Nigeria are presented in the study. From the study, ground water is expected to be found in the first aquifer, beyond which the underlying aquifer may be too dry or too thin to allow for ground water accumulation in profile one and the trend of the VES 2 curves in figure 4.3, which is a typical A curves; locating ground water in this profile three (along Benin-Auchi Express Road) should be focused at greater depth. It is obvious that the result of the VLF-EM, did not agree with the VES in this profile. I wish to attribute the reason to cultural noise probably due to a functional fuel station located in this profile.

It is recommended that pumping test be carried out to the drilled wells in order to further determine the aquifer efficiency and productivity of the area so that other VES stations in the area could be considered for exploitation.

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