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Determination of Appropriate Earthling Electrode Medium for Catholic Protection of Underground Pipes Using Electric Resistivity Method

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Abstract: *Metallic pipes used in conveying gas and crude oil are prone to corrosion with some reactive mineral elements in the soil. The soil corrosivity and the effect of soil (mineral) resistivity and conductivity on metallic pipe is evaluated to determine the appropriate medium of earthing electrode for cathodic protection of the underground gas and crude oil pipeline for Pan Ocean Oil Corporation Gas Processing plant at Ovade-Ogharefe. The geophysical survey data was acquired using ABEM SAS 300 TERRAMETER and the resistivity investigations carried out include the Vertical Electrical Soundings (VES) using the Schlumberger electrode array and the Wenner electrode configuration for the Constant Separation Traversing (CST). Consequently, six Vertical Electrical Soundings (VES) and two constant Separation Traversing (CST) were carried out in the area. The VES were made with an AB/2 ratio of 100m at intervals, thus probing down to depths of 12.5m. The results from this exercise show that there are five horizons (layers) at the project site with thickness varying between 1.3m and 3.15m. The apparent resistivity values of the soil indicated a range between 17Ω-m and 8,855Ω-m and the conductivity values of the soil so investigated have a range between 0.059 and 0.0001129 Siemens per meter. The impressed current cathodic protection method is recommended for the gas processing plant project since the soil resistivity values has exceeded 50Ω-m which is the threshold value between the impressed current cathode protection and the sacrificial (Galvanic) anode cathodic protection.*

Keywords: *Soil Corrosivity, Metallic Pipes, Cathodic Protection, Vertical Electrical Sounding (VES), Constant Separation Traversing (CST)*

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I. Introduction

A metal that has been extracted from its primary ore (metal oxides or other free radicals) has a natural tendency to revert to that state under the action of oxygen and water through the process of corrosion and the most common example is the rusting of steel (Uhlig, 1985, Ekott *et al*, 2012).

Iron rusts when it comes into contact with air and water because electrochemical cells are set up at the surface of contact (Ababio, 2001).

According to Ekine and Emujakporue (2010), Obadina (1999) all the oil spilled incidences from Shell Petroleum Development Company facilities in 1997, greater percentage was due to corrosion of ageing pipes. In August 1983, a major pipeline (Ogoda-Brass 24) failed at Oshika Village in Ahoada Local Government Area of Rivers State and an estimated 5,000 barrels of oil was spilled. The cost of the incident was conservatively put at $1.5 million (Powel et al., 1998).

NAOC, 2005 reported 8 cases of oil pipe failure arising from corrosion along the pipeline route between 1994 and 2004.

II. The Study Area

Ovade-Ogharefe, in Ethiope West Local Government Area of Delta State, Nigeria, is located approximately on Latitude 05^0 59' North of the Equator and Longitude 05^0 42' East of the Greenwich Meridian (Figure 1).

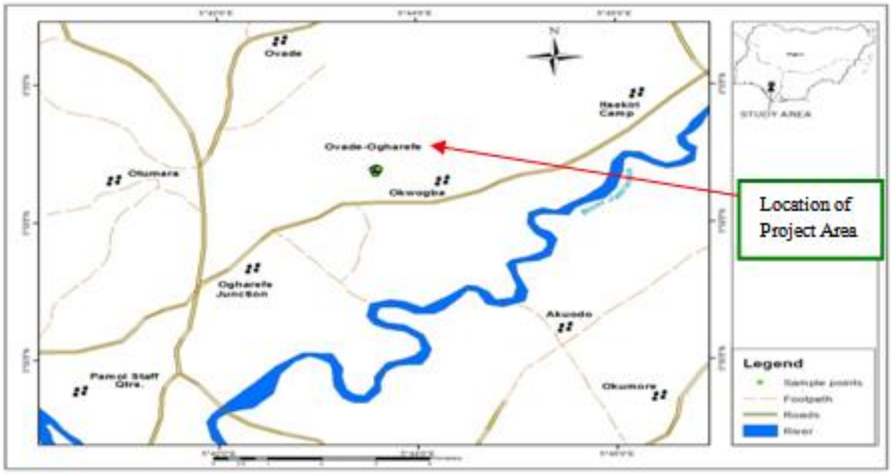

Figure 1: Map of Ethiope West Local Government showing Location of the study Area

2.1 Regional Geology and Topography

The area is part of the *Benin Formation* often referred to as *the Coastal Plain Sands* of the lower Quaternary period and Pliocene-Pleistocene epoch. The inclusive Aluvium belongs to the upper Quaternary (Recent Sediments) and consists of silty clayey sands, sand and gravels. Topographically, the area is flat lying with both marine and fluvial sediments. The flat-floored river Ethiope traversed the area and drains into the Atlantic Ocean. The floodplains are prone to flooding in the wet season mainly due to heavy rainfall, high ground water table and the flat-floored valleys (figure 1).

III. Materials and Methods

3.1 Data Acquisition

The geophysical survey data was acquired using ABEM SAS 300 TERAMETER. This is a signal averaging system where consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is displayed as resistance automatically. It uses a micro-processor to monitor and control all the measurement to ensure optimal accuracy and sensitivity. The apparent resistivity of the subsurface was calculated using the formula:

$$\rho a = \pi R \frac{[(AB/2)^2-(MN/2)^2]}{MN}$$

Where:

$$\left\{ \frac{[(AB/2)^2-(MN/2)^2}{MN} \right\}$$ is the geometric factor

ρa = apparent resistivity (Ohm-m), R = resistance (Ohm), AB = distance between current electrodes (m), MN = distance between potential electrodes (m), π = Constant = 3.142.

A total of six (6) Vertical Electrical Soundings (VES) and two (2) Constant Separation Traversing (CST) were carried out. The VES was run for the earthing and corrosivity tests while the CST was run across for information on cathodic protection tests.

The Schlumberger Electrode Array was used for the Vertical Electrical Sounding because shallow resistivity variations are constant with fixed potential electrodes, hence, the lateral heterogeneities can easily be identified and the apparent resistivity curves can be shifted accordingly to remove such local in-homogeneities. The Vertical Electrical Sounding (VES) technique determines the variation in the electrical earth properties with depth and this consists of taking a succession of apparent resistivity values for increasing electrode spacing.

The Wenner Electrode Configuration was used for the Constant separation traversing (CST) which involves maintaining the current and the potential electrodes separation and moving the entire array progressively along a profile. The electrode spacing of 20 meters and station interval of 10 meters were used and the geometric factor as calculated from the formula, GE = $2\pi a$ is 125.68. The sounded point is the mid-point between the two current electrodes. The inter-electrode distance was 20m. The specific depth equivalent according to Becks (1981) is about 6 meters based on the empirical formula:

$$D = 0.11AB$$

Where: D = the specific depth of investigation, AB = the total length of array, 0.11 = Constant.
This makes for delineation of lateral changes in the soil resistivity down to 6 meters depth.

IV. Results and discussion

Oyedele *et. al* (2012) observed the usefulness of electrical resistivity tomography in studying soil corrosivity in the coastal terrain and that the subsoil layers whose resistivity values fell within 6 and 16 Ohm-m were classified as very corrosive and corrosive, those ranging from 24 to 92 Ohm-m were classified as moderately and mildly corrosive while those of 100 Ohm-m and above were classified as none corrosive. Electrical resistivity method therefore has become a handy tool for detecting the corrosivity of soil as to enable the establishment of cathodic protection procedure for an effective earthing electrode system.

The data acquired from the VES was processed qualitatively, semi-qualitatively (tables 1 and 2) and quantitatively and the sounding curves showed the KH type with five soil layers for the entire site (figures 3a, 3b, and 3c).

From table 1, the apparent resistivity trend indicates an initial decrease with depth from 0.75m to about 4 meters, but picks up and increases in value with increase in depth from 5.0m to the maximum depth explored. However, the areal distributions of resistivity values are generally high implying that the soil conductivity is low (table 3). Due to the distribution of the sounded points along the route, further semi qualitative method is considered, which involves the drawing of the apparent resistivity section by plotting the apparent resistivity values on the transect AA' and BB' as contours. The intention is to see the areal distribution of the resistivity values with depth. This is presented in figures 4a and 4b. The contour was drawn at an interval of 500 Ohm-m.

However, there is large variation in these values as one move from the beginning of the pipeline route to the area beneath VES 3, VES 4 and VES 5 which has very low apparent resistivity values (17 Ohm-m to 99 Ohm-m), suggesting moderately to mildly corrosive environment. This could be due to high clay or increase in soil moisture content. This kind of variation usually leads to development of corrosive cells because of metallic exposure to different soil types that form the bulk of the electrolyte. Potential differences will always develop on any long continuous pipeline that passes through different types of soils. Apart from this, substantial natural pipeline currents ("long-line currents") may also occur and generates corrosion cells. Hence in soils of low resistivity (clay/clayey silt) pipe will continuously donate electrons to the electrolyte (in this case the soil), thus causing the metal at the donating points to be lost by anodic dissolution (corrosion).

4.1 Quantitative Interpretation of the Vertical Electrical Sounding (VES) Data

VES data was interpreted quantitatively by means of graphs. The resulting curves were interpreted manually using the partial curve matching method of Orellana and Mooney (1966). The results were further iterated using the **RESIST** computer software by Vander (1988) to obtain the layering model/parameters as shown in figures 3a, 3b and 3c and further as 2-D geo-electric sections beneath transect AA' and BB' in figures 5a, and 5b and again as shown in figures 6a and 6b traverses and figure 7 as 3-D geo-electric section.

V. Conclusion

Five different soil layers were delineated from both 2-D geoelectric sections and the two traverses. In all, soil resistivity ranged between 17 to 8855 Ohm-m across the layers.

Alternate wet and dry seasonal changes will affect the resistivity of the soil as this will cause variation in the soil moisture resistivity values. Again, the rate of aeration is expected to vary from one end of the surveyed area to the other because the sandy area will have higher diffusivity/concentration of oxygen than the more clayey area and this will lead to redox potential between the two soil types and will result in the formation of corrosion cells along the pipeline. Apart from the above reasons, geomagnetic disturbance could induce large electric currents along pipelines (Campbell, 1978; 1980) and changes in the potential of the pipeline with respect to the surrounding soil will lead to corrosion (Shapka, 1993). Therefore, the "impressed current method" of cathodic protection is recommended because the average resistivity of the area is greater than 50 Ohm-m which is the threshold value between using the "Sacrificial Anode Method" and the "Impressed Current Method" (Romanoff, 1957).

TABLE 1: SUMMARY OF THE SPECIFIC DEPTHS WITH THEIR CORRESPONDNG APPARENT RESISTIVITY

TOTAL ELECTRODE DISTANCE (AB) (m)	***SPECIFIC DEPTH (m)***	***SPECIFIC RESISTANCE (ohm)***	***APPARENT RESISTIVITY (ohm-m)***
2	0.25	334.0 – 729.0	2518.36 – 5496.66
4	0.50	133.0 – 198.0	4146.96 – 6159.78
6	0.75	66.7 – 85.2	4694.35 – 6221.59
8	1.00	100.8 – 125.4	4518.44 – 5988.29
12	1.50	41.2 – 46.0	4066.35 – 5167.16
16	2.00	41 – 43.9	3787.87 – 4344.78
20	2.50	22 – 24.1	3221.66 – 3888.25
24	3.00	30.9 – 33.7	3057.99 – 3705.99
32	4.00	16.52 – 17.88	2767.34 – 3539.35
40	5.00	9.11 – 11.81	2833.76 – 3673.62
50	6.25	6.11 – 7.79	2980.46 – 3799.96
60	7.50	12.55 – 14.13	3450.37 – 3884.76
80	10.0	7.08 – 8.73	3503.68 – 4320.22
100	12.5	4.91 – 5.72	3818.26 – 4448.16

TABLE 2: FIELD DATA SHOWING SPECIFIC RESISTANCE AND APPARENT RESISTIVITY FOR THE VERTICAL ELECTRICAL SOUNDING USING SCHLUMBERGER ELECTRODE CONFIGURATION

FIELD PARAMETERS			SPECIFIC RESISTANCE (OHM-S)						APPARENT RESISTIVITY (OHM-M)					
HCE	HPE	GE	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6
1	0.2	7.54	534.0	487.0	334.0	729.0	651.0	569.0	4026.36	3671.98	2518.36	5496.66	4908.54	4290.26
2	0.2	31.11	169.0	180.7	133.3	198.0	182.8	182.0	5257.59	5621.58	4146.96	6159.78	5686.91	5662.02
3	0.2	70.38	72.2	88.4	66.7	85.3	82.0	85.2	5081.44	6221.59	4694.35	6003.41	5771.16	5996.38
3	0.5	27.50	184	223	182.8	215	210.0	216.5	5060.00	6132.50	5027.00	5912.50	5775.00	5953.75
4	0.5	49.49	91.3	125.4	100.8	117.9	116.0	121.0	4518.44	6206.05	4988.59	5834.87	5740.84	5988.29
6	0.5	112.33	36.2	45.2	41.2	45.3	46.0	45.6	4066.35	5077.32	4628.00	5088.55	5167.16	5122.25
6	1.0	54.99	82.9	86.2	86.1	86.2	91.1	88.65	4558.67	4740.18	4734.64	4740.14	5009.59	4874.86
8	1.0	98.97	38.3	41.0	43.9	42.3	42.5	41.75	3787.87	4057.77	4344.78	4186.43	4206.23	4132.00
10	1.0	155.53	21.1	22.0	25.0	23.8	24.1	23.1	3281.68	3221.66	3888.25	3701.61	3748.27	3592.74
10	2.0	75.41	45.0	50.2	53.2	52.1	47.5	48.8	3393.45	3785.58	4011.81	3928.86	3581.98	3680.01
12	2.0	109.97	27.8	31.7	33.7	32.5	30.9	31.3	3057.17	3486.05	3705.99	3574.03	3398.01	3442.06
16	2.0	197.95	13.98	16.52	17.3	16.87	17.88	17.2	2767.34	3270.13	3424.54	3339.42	3539.35	3404.74
20	2.0	311.06	9.11	10.35	10.7	10.91	11.81	11.08	2833.76	3219.47	3328.34	3393.66	3673.62	3446.54
25	2.0	487.80	6.11	6.79	6.73	7.60	7.79	7.29	2980.46	3312.16	3282.89	3751.18	3799.96	3556.06
25	5.0	188.52	18.43	17.8	17.91	18.57	19.66	18.73	3474.42	3355.66	3376.39	3500.82	3706.3	3530.98
30	5.0	274.93	12.64	12.55	13.05	13.75	14.13	13.34	3475.12	3450.37	3587.84	3780.29	3884.76	3667.57
40	5.0	494.87	7.08	7.55	7.66	8.28	8.73	8.14	3503.68	3736.27	3790.70	4097.52	4320.22	4028.24
50	5.0	777.65	5.03	4.92	4.91	5.44	5.72	5.32	3911.58	3826.04	3818.26	4230.42	4448.16	4137.10

NOTE: HCE = HALF CURRENT ELECTRODE SPACING
HPE = HALF POTENTIAL ELECTRODE SPACING;
GE = GEOMETRIC FACTOR

TABLE 3: SPECIFIC RESISTANCE AND THEIR CORRESPONDING APPARENTRESISTIVITY/CONDUCTIVITY FOR THE CONSTANT SEPARATION TRAVERSING (CST) USING WENNER ELECTRODE CONFIGURATION

STN NO.	***SPECIFIC RESISTANCE (OHM)***		***APPARENT RESISTIVITY (OHM-M)***		***CONDUCTIVITY $(OHM\text{-}M)^{-1}$ OR SIEMENS PER METER***	
	CST 1	**CST 2**	**CST1**	**CST 2**	**CST 1**	**CST 2**
1	26.8	32.1	3368.22	4034.33	0.000297	0.000248
2	27.6	31.3	3468.77	3933.78	0.000288	0.000254
3	28.5	30.2	3581.88	3795.54	0.000279	0.000263
4	29.1	31.2	3657.29	4034.33	0.000273	0.000248

5	30.3	31.8	3808.10	3996.62	0.000263	0.000250
6	29.7	31.1	3732.70	3909.90	0.000268	0.000256
7	27.5	31.0	3456.20	3896.08	0.000289	0.000257
8	27.6	31.2	3468.77	3921.22	0.000288	0.000255
9	28.6	29.1	3594.45	3657.29	0.000278	0.000273
10	29.4	30.0	3694.99	3770.40	0.000271	0.000265
11	28.6	29.9	3594.45	3757.83	0.000278	0.000266
12	28.3	32.0	3556.74	4021.76	0.000281	0.000249
13	27.7	30.8	3481.34	3870.94	0.000287	0.000258
14	28.4	31.9	3569.31	4009.19	0.000280	0.000249
15	27.6	30.7	3468.77	3858.38	0.000288	0.000259
16	29.4	29.3	3694.99	3682.42	0.000271	0.000272
17	28.6	30.1	3594.45	3782.97	0.000278	0.000264
18	27.8	32.0	3493.90	4021.76	0.000286	0.000249
19	30.1	30.4	3782.97	3820.67	0.000264	0.000262
20	29.9	30.5	3757.83	3833.24	0.000266	0.000261
21	27.4	31.2	3443.63	3921.22	0.000290	0.000255
22	28.1	30.8	3531.61	3870.94	0.000283	0.000258
23	26.4	29.8	3317.95	3745.26	0.000301	0.000267
24	27.2	32.0	3418.50	4021.76	0.000293	0.000249
25	28.3	31.6	3556.74	3971.49	0.000281	0.000252
26	29.0	30.6	3644.72	3845.81	0.000274	0.000260
27	28.6	31.1	3594.45	3908.65	0.000278	0.000256
28	28.4	29.8	3568.31	3745.64	0.000280	0.000267

NB: STN NO = STATION NUMBER Electrode spacing (a) = 20m, Geometric factor = 125.68, Station interval = 1

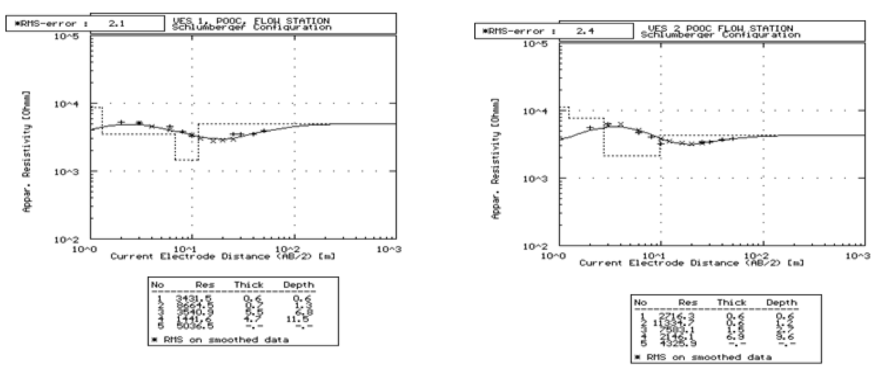

Figure 3a: The Schlumberger Depth Sounding Curves Beneath VES 1 and VES 2 Locations at Pan Ocean Oil Corporation, Ovade-Ogharefe

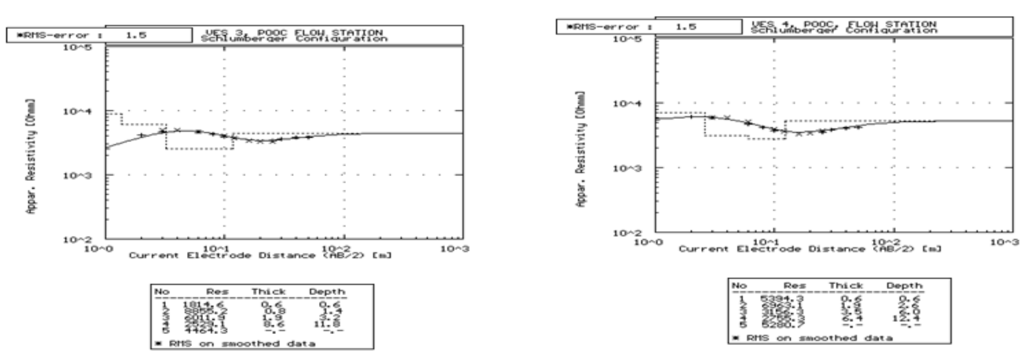

Figure 3b: The Schlumberger Depth Sounding Curves Beneath VES 3 and VES 4 Locations at Pan Ocean Oil Corporation, Ovade-Ogharefe

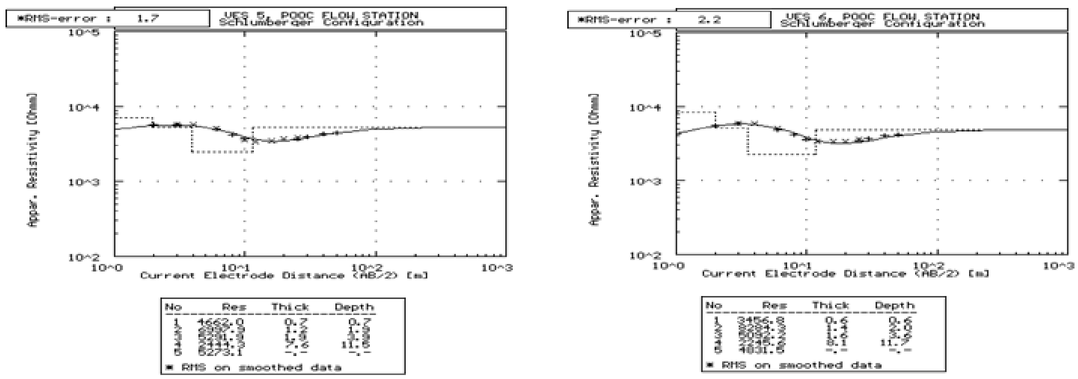

Figure 3c: The Schlumberger Depth Sounding Curves Beneath VES 5 and VES 6 Locations at Pan Ocean Oil Corporation, Ovade-Ogharefe

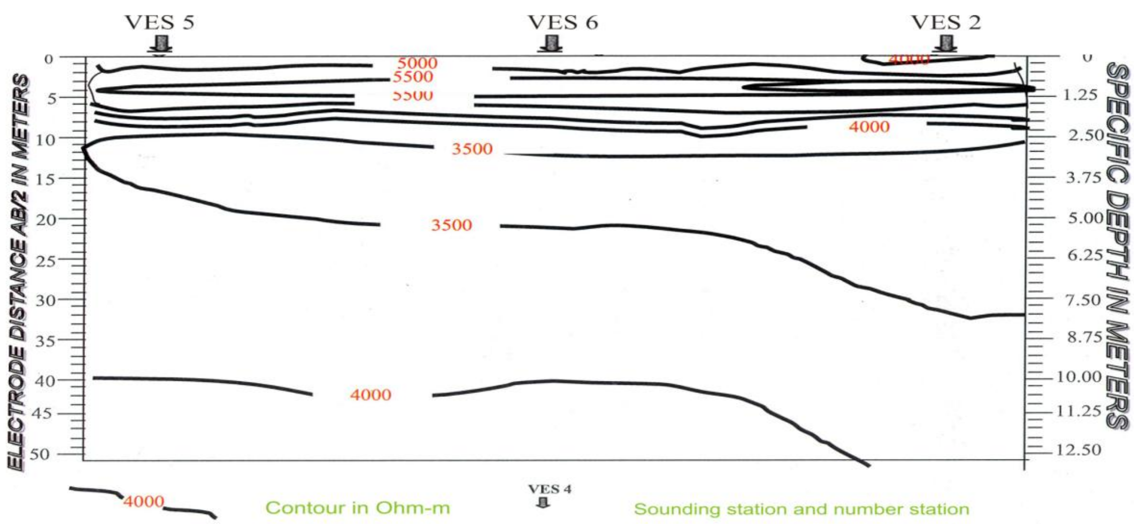

Figure 4a: The Apparent Resistivity Section Beneath Transect AA' connecting VES 5, VES 6, and VES 2.

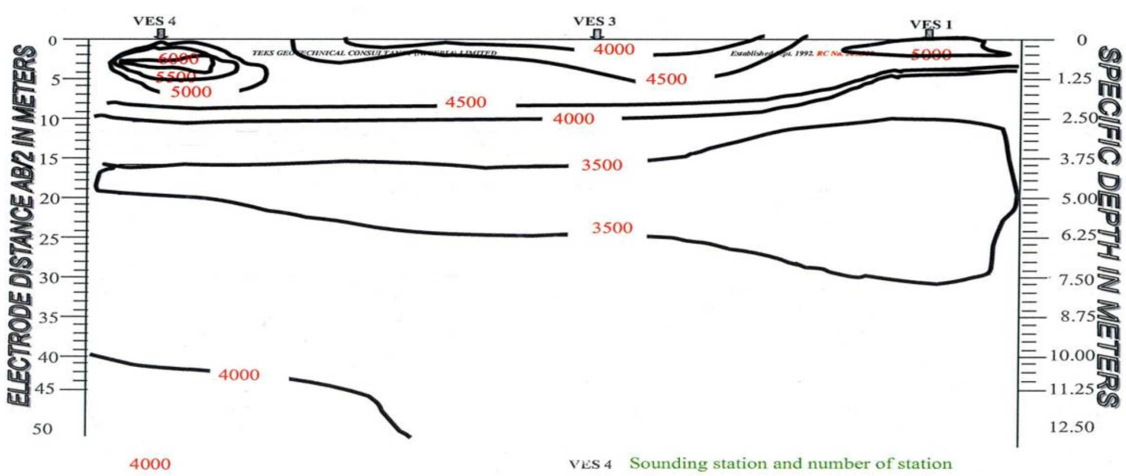

Figure 4b: The Apparent Resistivity Section Beneath Transect BB' Connecting VES 4, VES 3, and VES 1.

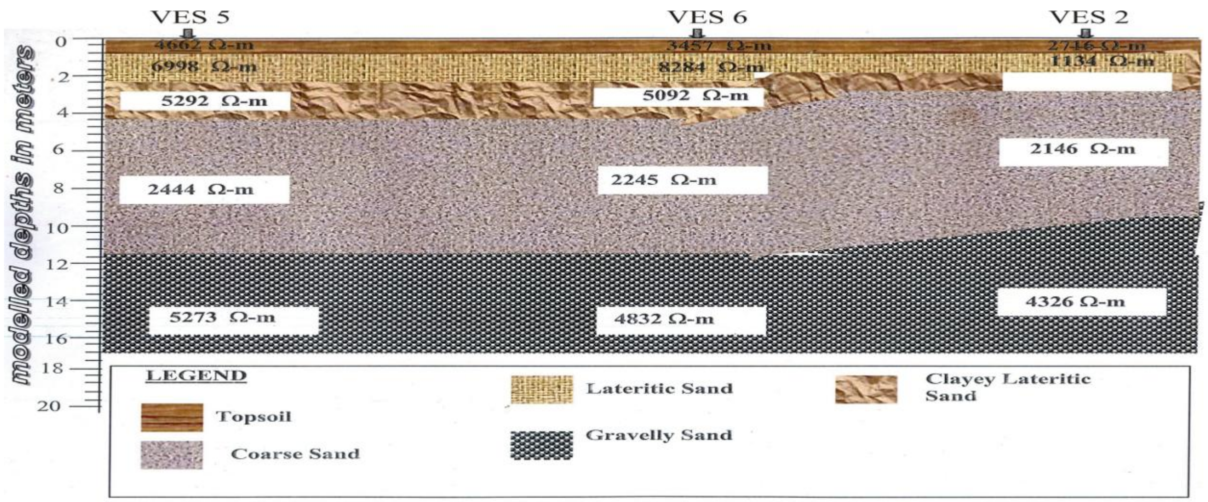

Figure 5a: 2-D Geo-electric section Beneath Transect AA' Connecting VES 5, VES 6 and VES 2

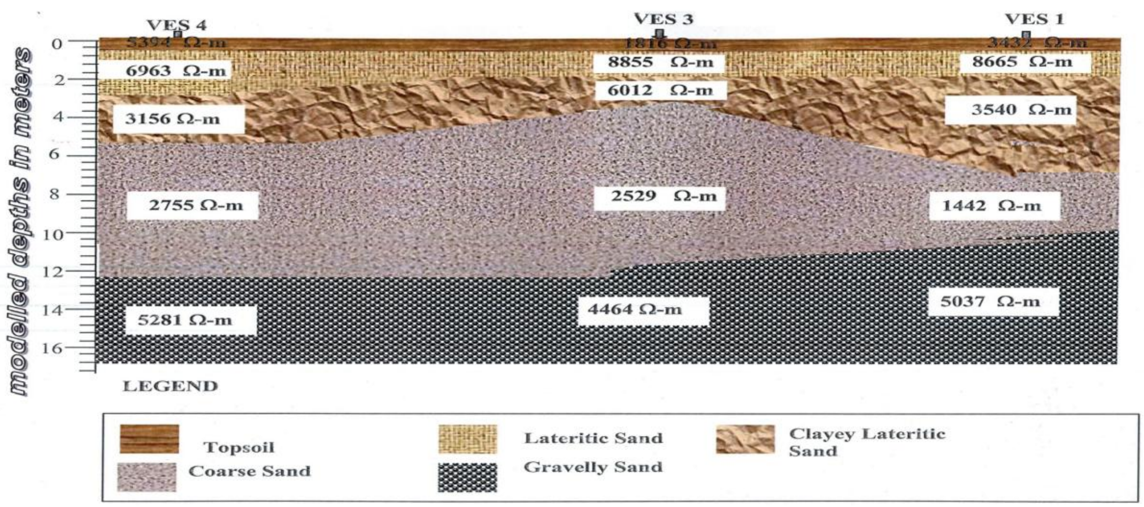

Figure 5b: 2-D Geo-electric section Beneath Transect BB' Connecting VES 4, VES 3 and VES 1

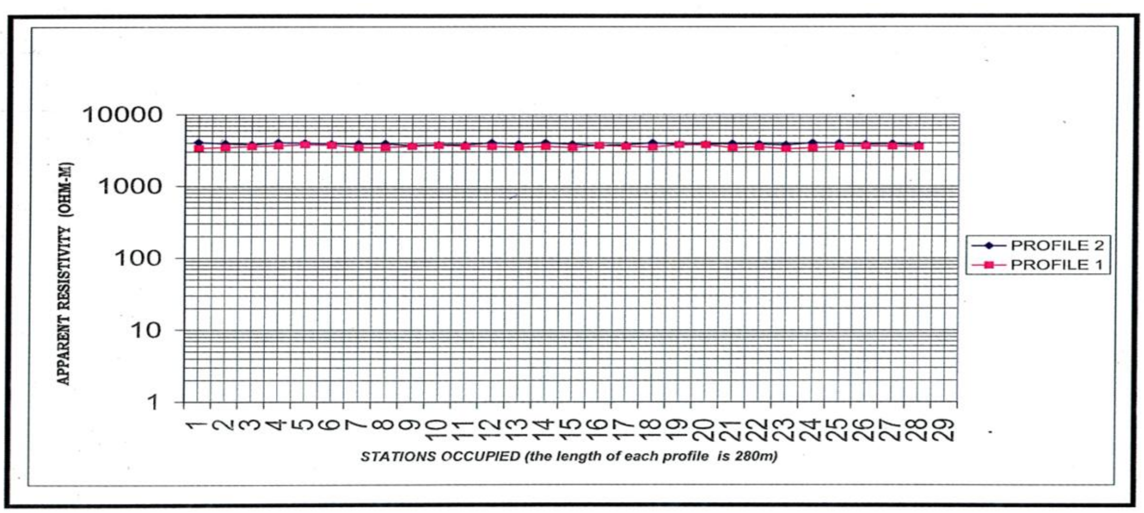

Figure 6a: The Wenner (CST) Traverse Curves beneath VES 1, VES 2 and VES 3 along Profile F1 and F2.

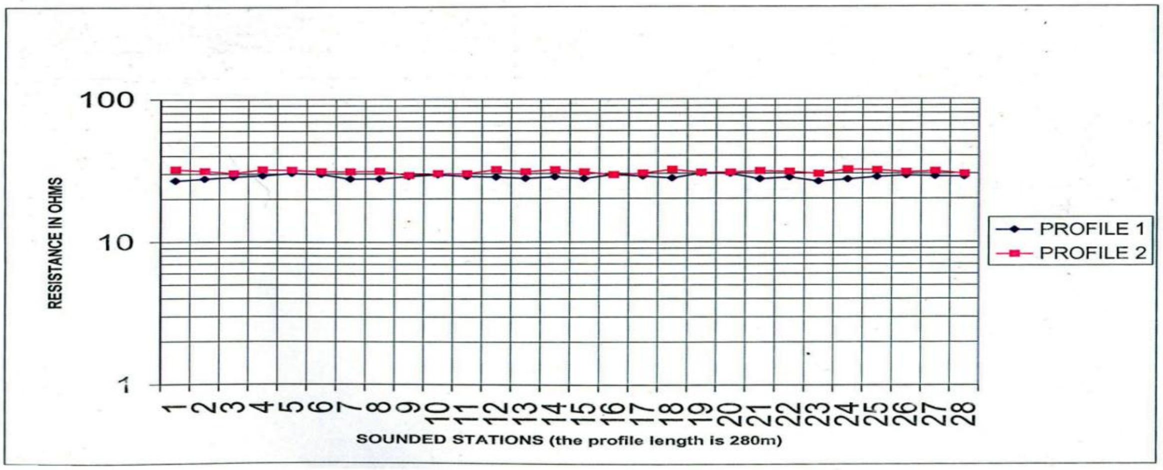

Figure 6b: The Wenner (CST) Traverse Curves beneath VES 4, VES 5 and VES 6 along Profile F1 and F2.

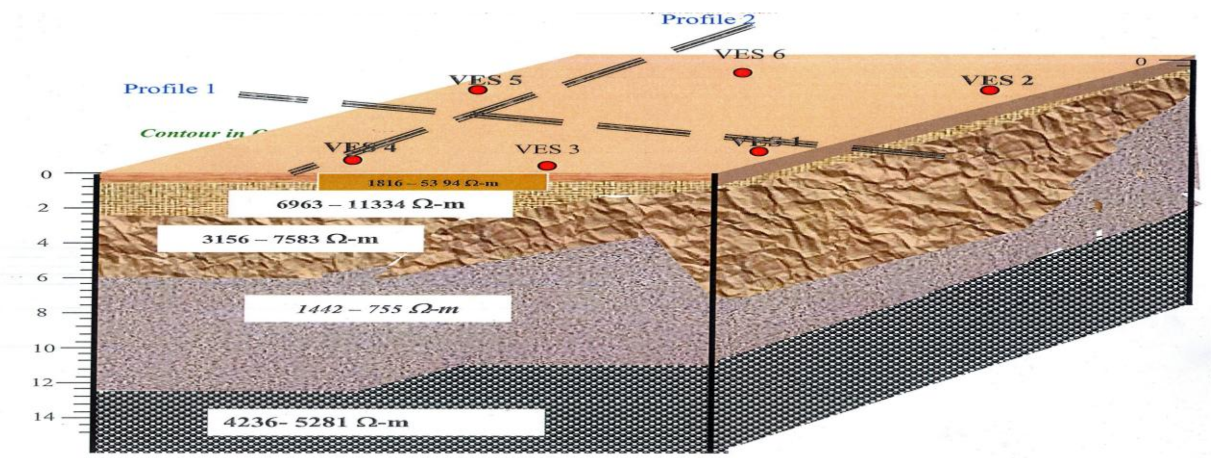

Figure 7: 3-D Geo-electric Model of the Surveyed Area

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