Seepage Investigation on an Existing Dam using Integrated Geophysical Methods

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Abstract

Integrated geophysical methods involving VLF-electromagnetic, magnetic intensity and electrical resistivity (ER), were employed to investigate the probable internal seepage at University of Ilorin Dam, Kwara State, Southwestern Nigeria. Five (5) profiles were established in the south-north and west-east orientations, along the dam and reservoir axis. VLF-em conductivity response from -65 % to 50 % with estimated average anomalies of -7.5 % and; magnetic susceptibility distribution range between 2.27 nT and 756.24 nT, with average response of 163.6 nT suggests resistive basement rock contrasts in the area. Twenty seven (27) vertical electrical sounding (VES) points using the schlumberger array configuration were distributed along the profile lines. The lithologic units delineated with geo-electric sections established; 22 % wet/gravelly topsoil and 78% hard lateric pan – granitic outcrop having resistivity variation between 28.8 Ωm and 2612.8 Ωm with average response of 870 Ωm and thickness range of 0.8 m to 2 m; straddled with 22 % clayey - sand and 78 % sandy – clay, having resistivity distribution between 63.2 Ωm and 316 Ωm with average response of 148 Ωm and thickness range of 3.4 m to 8 m and; fresh bedrock. The area is underlain by fairly thin superficial soil (overburden) materials with an average thickness of 6.5 m which shows that the bedrock is close to the surface and serves as support to the dam. The clay materials which could serve as conduit, exist within the shallow overburden and has been excavated during construction. It is therefore concluded that the dam retains its strength and the observed reduction in reservoir water level could be a result of other environmental factors.

Keywords: Unilorin Dam, internal seepage, anomalies, conductivity, weathered zones, geo-electric sections

1.0   Introduction

The study area (Unilorin Dam) is located within the University of Ilorin main campus. It was designed as a concrete gravity dam (Figure 1) whose geometry is to retain 1.8 million cubic meters of water with a reservoir length and height of 200 m and 8 m respectively (Adedeji, 2007). It is intended for domestic water usage of the institution and as a relaxation centre (among the benefits of a dam). During the dry season, the depth to reservoir's water level reduces to ≤ 2.5 m while in the wet season; it is always filled and overflows the dam's axis. The reduction in water level necessitated the investigation of the possible cause; which could be as a result of several environmental or natural factors such as seepage, substandard dam construction, dam gate damage and many more.

Seepage through a dam is a slow discharge or escape of liquid that is supposed to be retained in the reservoir, through conduits (fracture/fault lines) to the flank of the dam. It reduces the expected quantity of water, weaken dam construction and damage dam gates. Certain soil can swell if they get saturated with the seeping water and when there is loss of water in them, they shrink drastically. These expansions and shrinkages of soils can result to cracks and collapse of the dam. Seepage is one of the major reasons for embankment dam failures and may constitute a significant potential social dislocation (displacement of people, loss of valuable life and properties) if not examined. Cost of reconstruction of a failed dam can be worrisome and shortage of water supply may hinder the objective of dam construction. The purpose of the current geophysical work is to identify present-day seepage areas and provide information about subsurface geologic structures that may control subsurface flow and seepage, since geophysical methods have the potential of detecting internal erosion and anomalous seepage at an early stage before the safety and integrity of the dam is at stake.

Very Low Frequency electromagnetic (VLF-em) method, among the geophysical methods literarily serves as reconnaissance survey tool for subsurface delineation while magnetic survey has been extensively used in basement mapping and to delineate subsurface linear geologic structures which may be related to groundwater accumulation by locating rocks or minerals having unusual magnetic properties which reveal themselves as anomalies in the intensity of the earth's magnetic field (Abderahman & Essa, 2005) and electrical Resistivity (ER) alone of the most sensitive geophysical methods for the changes in soil moisture and a very effective tool to determine depth to water saturated zone and groundwater flow pattern. In the case of water seepage through a dam, it can be detected as resistivity low using electrical resistivity methods (Aina, Olorunfemi, & Ojo, (1996); Gamal, Ahmed, Neil, & Estella, 2004).

The geophysical methods of VLF-em, ER and magnetics anomalies has been employed for investigating the present condition of the dam and the recreation centre through delineation of geologic features such as;

overburden thickness, bed rocks morphology, weathering/fractures in the subsurface. Thus, enabling the evaluation of possible seepage paths; resulting from fracturing or dissolution of the bedrock and its adverse effect on the dam embankment.

2.0 Location and Geology of the Area

University of Ilorin dam is located within the university campus, situated at about 15 kilometers east of Ilorin Township, Western part of Central Nigeria. It is bounded by longitudes 4° 39′ 51.6″ - 4° 40′ 02.50″ E and latitudes 8° 27′ 54.2″ - 8° 28′ 4.7″ N and occupies about 15,000 hectares of land (Figure 2). It is assessable by a major road leading through Tanke area from Ilorin and minor roads within the institution through to the dam. The climate of the area is characterized by both wet and dry seasons which begin in the late March to October and in November to early March respectively. The total annual rainfall ranges from 800 mm to 1200 mm with a mean annual temperature of 30°C - 35°C (Oyegun, Jimoh, & Irove, 2007). The zone is a semi-arid region of Nigeria with vegetation mainly of the guinea savannah type with shrubs and undergrowth. The main river within the campus is river Oyun which flows from southeast-northwest direction. It hosts rocks of categorized as crystalline basement complex of Nigeria consisting of high-grade metamorphic rocks in the form of gneiss migmatites and Granite suites (Rahaman, 1989). The western part of the university is made up of gneiss rocks with strike foliation in NW-SE direction and dipping 10° - 45° westerly. In the eastern part, granite rock suites emplaced in the NE-SW direction dip 70°- 90° easternly (Figure 3). The area appears to have been isoclinically folded into a south plunging antiform with a steep eastern limb. Several joints trending 120° – 160° dominated the rocks in the area.
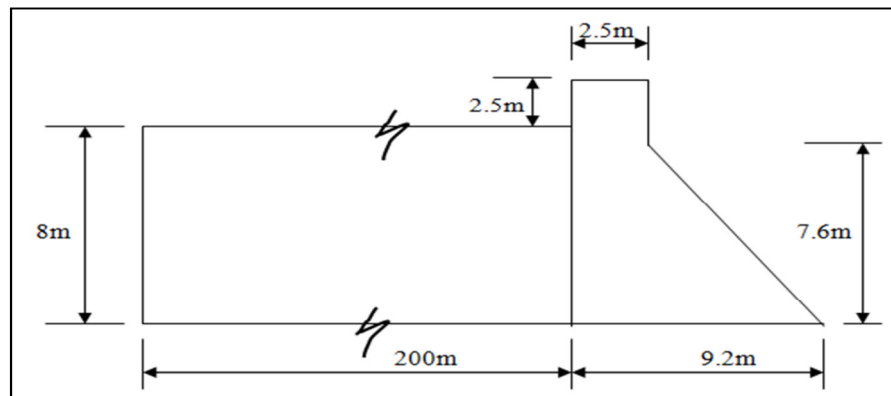

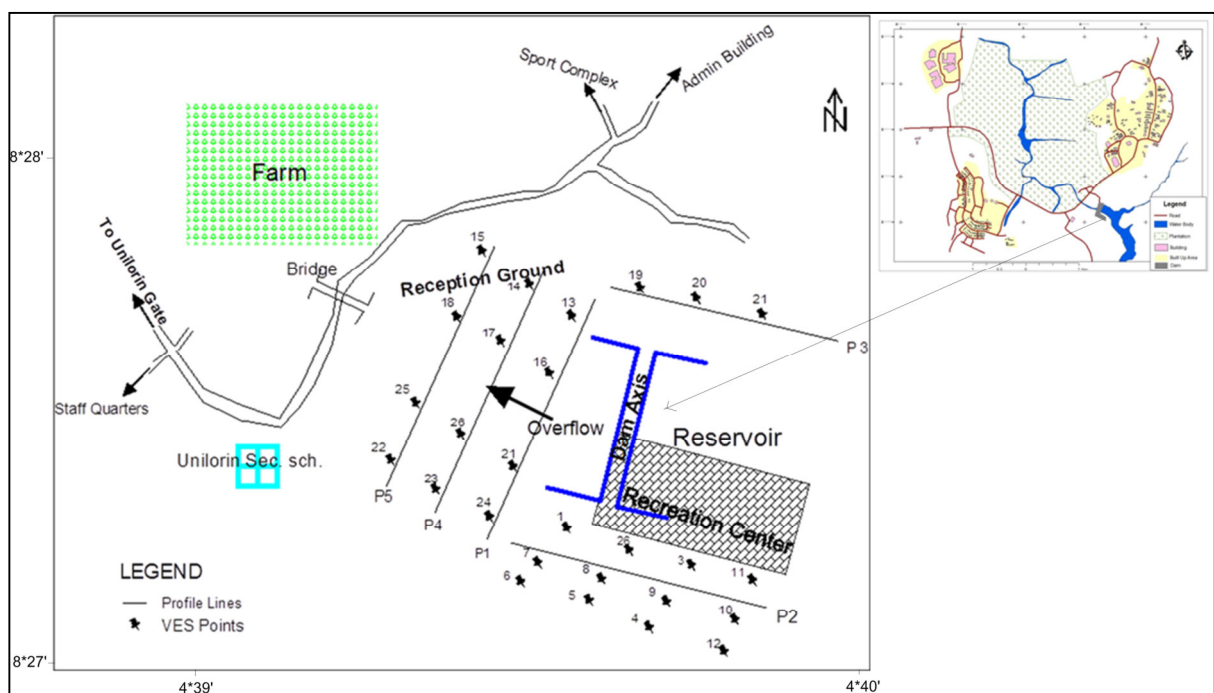Figure 1: The Unilorin Concrete Gravity Dam Geometry

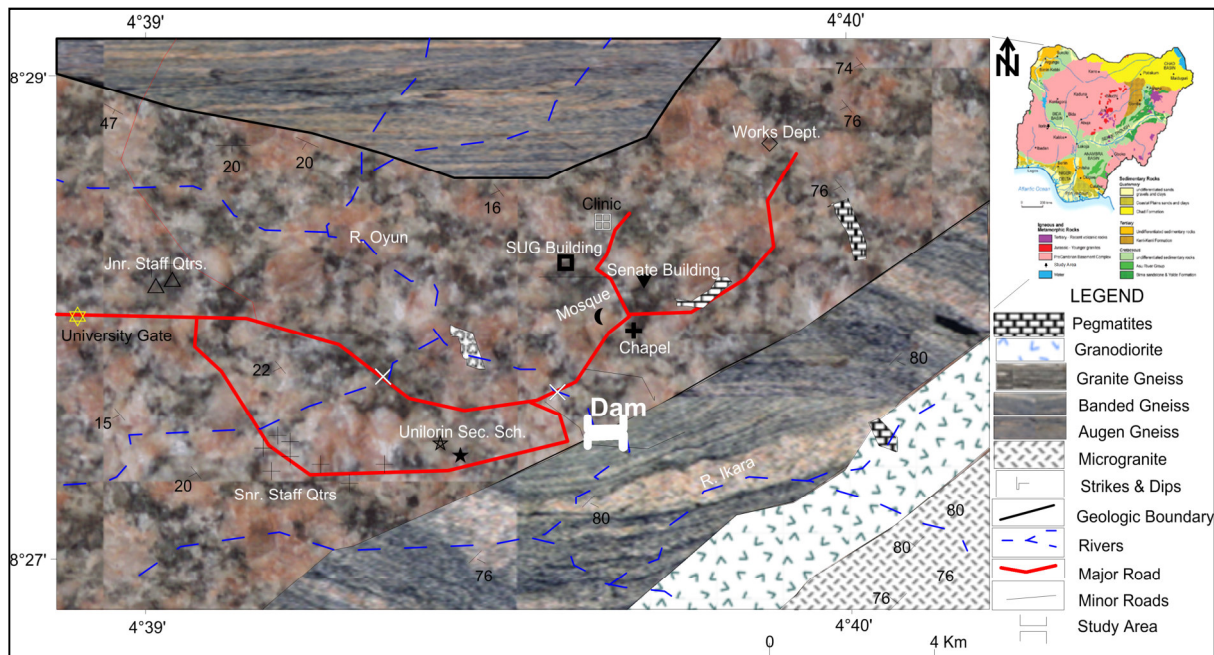Figure 2: Location Map of the University of Ilorin showing the Dam

Figure 3: Local Geology Map of Unilorin showing the study area.

3.0 Materials and Methods

The VLF-EM and Magnetic survey were carried out within the month of May, 2015 while the electrical resistivity survey was carried out within December, 2015; which accounts for the two seasons in the area. Five (5) VLF-EM profiles were established with; Profile 1, 4 & 5 in the south-north direction at 2 m, 7 m and 12 m away from the dam axis and profiles 2 & 3 along the reservoir flank. The data were obtained using Abem Wadi VLF-EM equipment and presented as profiles with extent of 170 m – 350 m while the coordinate readings were obtained with Garmin etrex 10 Global Positioning System (GPS). The AbemWadi measures the field strength and the phase displacement around the fracture zone and presents it as raw and filtered data. The EM data was interpreted and inverted into a 2-D section using the Karous-Hjelt filtering (Karous & Hjelt, 1983). The anomaly inflections appear as peak positive anomalies and false VLF anomaly inflections as negative anomalies on the profiles.

The depth of penetration (*d*) at which the amplitude of the field A_d is decreased by a factor e^{-1} compared with its surface amplitude was adopted:

$$A_o A_d \ = A_o \mathrm{e}^{-1} \qquad\qquad 1.0$$

In this case,

$$d = 503.8 \ (\sigma f) \ ^{1/2} \qquad\qquad 2.0$$

where '*d*' is metres, the conductivity of the ground σ is in Sm^{-1} and the frequency *f* of the field is in Hz. The depth of penetration thus increases as both the frequency of the electromagnetic field and the conductivity of the ground decrease.

Total Magnetic intensity was obtained with Geometries Proton Precession Magnetometer, model G- 856 along the VLF-EM profiles. The regional magnetic field were removed from the TMI using SignProc computer software and recorded as the residual anomaly for each traverse. The data were further enhanced using the Analytic Signal Amplitude for magnetic edge detection and basement depth estimate (Nabighian, 1972, 1974). The principle shows that the amplitude yields a bell-shaped function over each corner of a 2D body polygonal cross-section and for an isolated corner, the maximum of the bell-shaped curve is located exactly over the corner and the width of the curve at half its maximum amplitude equals twice the depth to the corner. The mathematical expression is;

$$/A/= \sqrt{\left(\frac{dT}{dx}\right)^2 \ + \ \left(\frac{dT}{dy}\right)^2} \ \ldots\ldots\ldots\ldots\ldots 3.0$$

Where /A/ is known as the analytic signal and T is the magnitude of the Total Magnetic Intensity (TMI).

Electrical resistivity has been reported as an effective geophysical tool in dam-seepage studies because it is sensitive to changes in lithology, water saturation, and water chemistry (Minsley, Bethany, Ikard, & Power, 2011; Binley & Kemna, 2005). In assessing geologic units that may be more likely to conduct seepage through foundation or embankment materials, or to map regions of increased saturation, images of subsurface bulk

electrical resistivity can be used. It proved useful in identification of seepage pathways associated with dam foundation materials and internal erosion detection (Kim, Yi, Song, Seol, & Kim, 2007; Sjo¨ dahl, Dahlin, Johansson, & Loke, 2008). The electrical resistivity method employed the Vertical Electrical Sounding (VES) techniques using Schlumberger Array for this study by applying the basic principle of Ohm's.

$$V_r = \frac{\rho I}{2\pi r} \quad \text{………………….}4.0$$

Where V_r is the electric potential at any point P distance r from a point electrode emitting an electric current I in an infinite homogenous and isotropic medium of Resistivity ρ.

The resistance data were acquired with the Campus-Omega resistivity meter which contains both the transmitter unit, through which current enters the ground and the receiver unit, through which the resistance is recorded and multiplied by the standard geometric factor (G) of Schlumberger array technique to get the apparent resistivity of each points.

$$G = \pi \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{2\left(\frac{MN}{2}\right)^2} \quad \text{…………………}5.0$$

$$\rho_a = R.G \quad \text{…………………………}6.0$$

The maximum electrode spread (AB/2) of 50 m - 60 m was adopted. The electrical resistivity data were processed by plotting the apparent resistivity values against the electrode spread. This was subsequently interpreted quantitatively using the partial curve matching method and computer assisted 1-D forward modeling with WinResist 1.0 version software (Vander Velpen, 2004).

4.0 Results and Discussions
4.1 VLF-em Profiles
The anomaly curves generated from the filtered component of the vlf-em response enabled qualitative identification of linear features and possible depth of occurrences. These features (geological interface/fault zones) are delineated as positive peaks of the real component anomalies with the sharp and broad peaks indicating depth of conductive zones (Oladunjoye, Adabanija, & Adeboye, 2013). The series of positive peaks alternated fairly with troughs along the five (5) profile lines revealing basement rock contrast. The responses revealed changes in subsurface conductivity varying from -65 % to 50 % for profile 1 (Figure 4a); -10% to 10% for profile 2 (Figure 4b); -7% to 8% for profile 3 (Figure 4c); -7% to 7% for profile 4 (profile 4d); and -5% to 5% for profile 5 (profile 4e). The Karous-Hjelt and Fraser for filtering VLF-em measurement revealed maximum peak and relatively high real component signature at distance 125 m and 145 m on profile 1; which is an indicating of moderately thick overburden between 95 m - 120 m and 140 m. The obvious feature of this signature is the real and imaginary component in the same order at about 135 m and 145 m which is an indicative of weathered/conductive zones revealed on the equivalent current density pseudo-section. It is possible to qualitatively discriminate between conductive anomalies (red color) and resistive structures (blue to yellow color) on the sections (Karous & Hjelt, 1983).

The other south-north profiles (lines 4 and 5) host real component signatures that indicates materials of generally high resistivity; except at distances 45 m and 80 m of profile 4 that shows moderate conductive materials. The weathered zone of profile 1 is discontinuous on profiles 4 and 5 which infer the signature as a possible result of water percolation (not conduit).

4.2 Magnetic Profiles
The magnetic anomalies revealed series of positive peaks (magnetic highs) alternated fairly with troughs (magnetic lows) along the five (5) profile lines showing that the location is generally of undifferentiated basement rock with rock contacts; inferred from the analytic signal amplitude (ASA), horizontal and vertical derivatives model on the submenu of SignProc Geosoft. These derivatives are sensitive to rock susceptibility near the ground surface rather than at depth. The magnetic low zones corresponds weathered or saturated zone from the results of the VLF-em interpretation.

Susceptibility distribution of profile 1 ranges between 5.39 nT and 252.09 nT with estimated basement depth range of 2.1m to 7.8m (Figure 5a); relatively low magnetic intensity of 2.27 nT to 67.29 nT with average estimated overburden thickness of 8.3 m for profile 2 (Figure 5b); magnetic intensity range within 6.89 nT to 68.18 nT with average depth estimate of 6.9 m for profile 3 (Figure 5c); several rock contacts of magnetic intensity range between 5.08 nT and 756.24 nT with estimated depth to magnetic source range of 0.1m to 31.6 m for profile 4; and intrusive rocks of magnetic intensity values within 16.94 nT and 455.63 nT with estimated depth to bedrock between 0.6 to 32.1m for profile 5. The quantitative summary of the depth to magnetic source estimate is presented on Table 1, which shows an average thickness of 6.5 m.

Table 1: Depth to magnetic source estimate

Profile		1	2	3	4	5
Overburden Thickness 'h' (m)	$h_{min.}$	2.1	5.3	7.1	0.1	0.6
	$h_{max.}$	7.8	11.5	10.5	31.6	32.1
	h_{mean}	3.9	6.9	8.3	5.7	7.7

4.3 Electrical Resistivity Sounding

The electrical resistivity method showed a complementary report of the vlf-em and magnetic interpretations. The apparent resistivity revealed that the vertical electrical sounding (VES) curves (Figure 6) in the area are predominantly H-type curve ($\rho1 > \rho2 < \rho3$; Figure 6a) and A-type curves ($\rho1 < \rho2 < \rho3$; Figure 6c). The corresponding correlated geoelectric sections are depicted on Figure 7. VES(s) 13, 16, 24 and 27 along the dam axis (profile 1) revealed a gravely/lateritic topsoil with thickness range of 0.9 m to 2.7 m for resistivity distribution between 27 Ωm and 759 Ωm. The topsoil is straddled with saturated gravel/clayey sand with thickness range of 4.8 m to 5.2 m and resistivity values between 67 Ωm to 110 Ωm. The average thickness along this profile estimated as 6 m, suggests shallow overburden underlay with fresh basement having resistivity value range between 2121 Ωm and 2834 Ωm.

Along the Recreation Centre (profile 2); the geo-electric section comprising VES(s) 14, 17, 23 and 26, indicate a topmost layer having thickness range of 1.0 m to 3.1 m with resistivity variation of 75 Ωm to 611 Ωm. It is underlined by clayey sand having resistivity values between 63 Ωm to 270 Ωm and average thickness of 4.9 m which accounted for average overburden thickness of 6.5 m. Profile 3 comprising of VES(s) 15, 18, 22 and 25 revealed three-layer sequence of *resistive-conductive-resistive* with; topmost layer having resistivity value between 250 Ωm and 1276 Ωm, and thickness range 0.8 m to 1.5 m; the gravelly layer having resistivity variation between 87 Ωm and 142 Ωm, and thickness of 5.8 m for estimated average overburden of 6.8 m. The fresh basement rocks beneath this profile have resistivity value range between 1627 Ωm to 3258 Ωm. Summary of the resistivity distribution is presented on Table 2.

5.0.   Conclusion

The geophysical investigation involving the application of VLF-em, magnetic and electrical resistivity methods; conducted at University of Ilorin dam has shown that the area is underlain by fairly thin superficial soil (overburden) materials with an average thickness of 6.5 m which shows that the bedrock is close to the surface. The alternating responses from the vlf-em and magnetic anomalies revealed changes in subsurface having; conductivity variation from -65 % to 50 % with average response of -7.5 % and; magnetic susceptibility distribution range between 2.27 nT and 756.24 nT, with average response of 163.6 nT. This is an indication that the rocks in the area are generally resistive.

The lithologic units delineated with geo-electric sections established 22 % wet/gravelly topsoil and 78% hard lateric pan – granitic outcrop having resistivity variation between 28.8 Ωm and 2612.8 Ωm with average response of 870 Ωm; which is straddled with 22 % clayey - sand and 78 % sandy – clay, having resistivity distribution between 63.2 Ωm and 316 Ωm and; extending downward to the fresh bedrock. The clay materials exist within the shallow depth and could serve as conduit but excavation to 8 m depth has taken care of the possible damage of clay. It is therefore concluded that the dam retains its strength and the observed reduction in reservoir water level could be a result of other environmental factors.

Table 2: Qualitative Interpretation of the Electrical Resistivity Survey

| VES	Resistivity(Ωm) ρ_1 / ρ_2/ ρ_3	Thickness(m) t_1/ t_2/ t_3	Depths (m) h_1 / h_2/ h_3	Curve Type
1	783 / 258 / 893	1.2 /10.38 / --	1.2/ 11.58/ --	H
2	2343.1 / 142.6 / 4366.7	1.4 /8.8 / --	1.4 /10.1 /-	H
3	2612.8 / 118.5 / 1317.3	1.0 /11.3 / --	1.0 /12.3 /--	H
4	1489.1 / 119.6 / 1326.8	1.2 /5.4 /--	1.2 /6.5 /--	H
5	514.2 / 143.4 / 3483.9	2.5 /9.1 /--	2.5 /11.6 /--	H
6	1464.4 / 148.6 / 3566.4	1.7 /9.3 /--	1.7/11.0/--	H
7	2039.8 / 187.5 / 4376.9	1.2 /8.3 /--	1.2/9.4/--	H
8	724.5 / 117.6 / 2056.3	1.8 /3.8 /--	1.8/5.6/--	H
9	1111.2 / 164.2 / 5690.7	1.8 /8.8 /--	1.8/10.6/--	H
10	1785.7 / 170.5 / 549.1 / 3234.6	1.3/9.4/13.8/--	1.3 /10.7/24.4/-	HA
11	840.3 / 119.3 / 2089.8	1.6 /5.5 /--	1.6 /7.1 /--	H
12	628.0 / 157.6 / 2506.4	1.9 /5.9 /--	1.9 /7.8 /--	H
13	28.8 / 2297.6	2.7 / --	2.7 / --	A
14	611 / 189 /1667	1.0 / 7.7 / --	1.0 / 8.7 / --	H
15	975.6 / 123.2 /1627.3	1.5 / 4.5 / --	1.5 / 6.0 / --	H
16	122.3 / 67.6 / 2121.6	1.0 / 4.9 / --	1.0 / 5.9 / --	H
17	608.6 / 120.2 / 2014.1	1.0 / 3.4 / --	1.0 / 4.4 / --	H
18	1276 / 142.7 / 2639.9	1.0 / 8.9 / --	1.0 / 9.9 / --	H
19	470.6 / 146.9 / 622.0	3.0 /5.9 /--	3.0 /8.9 /--	H
20	397.6 / 198.5/1232.5/164.6/3820.3	1.1/1.8/3.2/ 6.6 /--	1.1/2.9/6.1/12.7/--	HKH
21	626.9 / 316.8 / 2091.4	1.2 / 12.1 / --	1.2 /13.3 /--	H
22	487.1 / 87.1 / 3258.0	0.8 / 4.7 / --	0.8 / 5.5 / --	H
23	75.7 / 270.7 / 2165.2	3.1 / 4.9 / --	3.1 / 8.0 / --	H
24	217.8 / 107.1 /2780.2	1.2 / 4.8 / --	1.2 / 6.0 / --	H
25	290.0 / 91.2 / 3235.4	0.8 / 5.1 / --	0.8 / 5.9 / --	H
26	221.7 / 63.2 / 3083.6	1.2 / 3.7 / --	1.2 / 4.9 / --	H
27	759.0 / 110.8 /2834.1	0.9 / 5.2 / --	0.9 / 6.1 / --	H
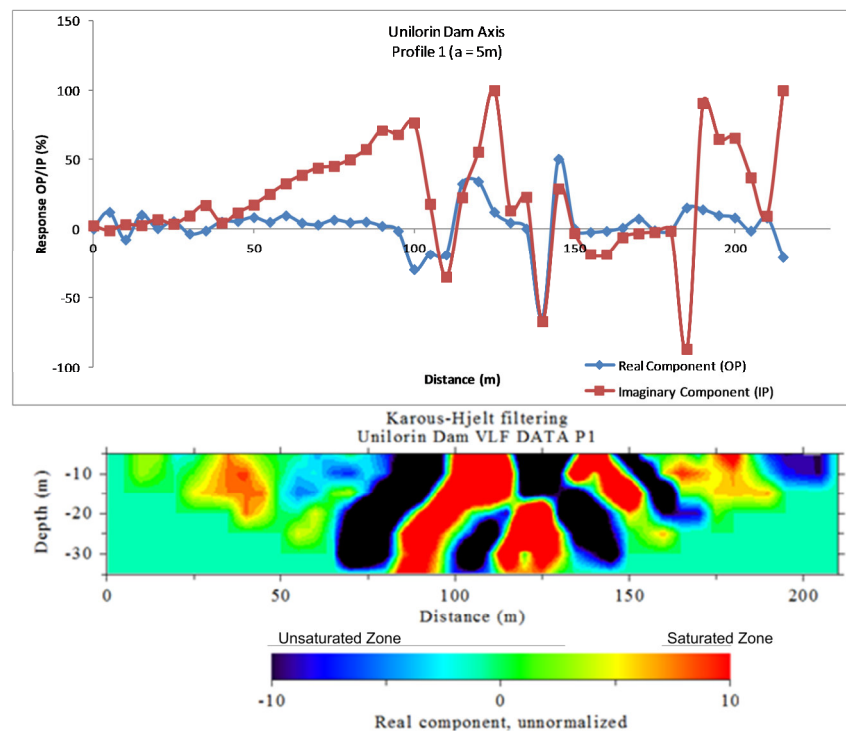
Figure 4a: VLF plot with its equivalent Pseudo-section of the Dam Axis
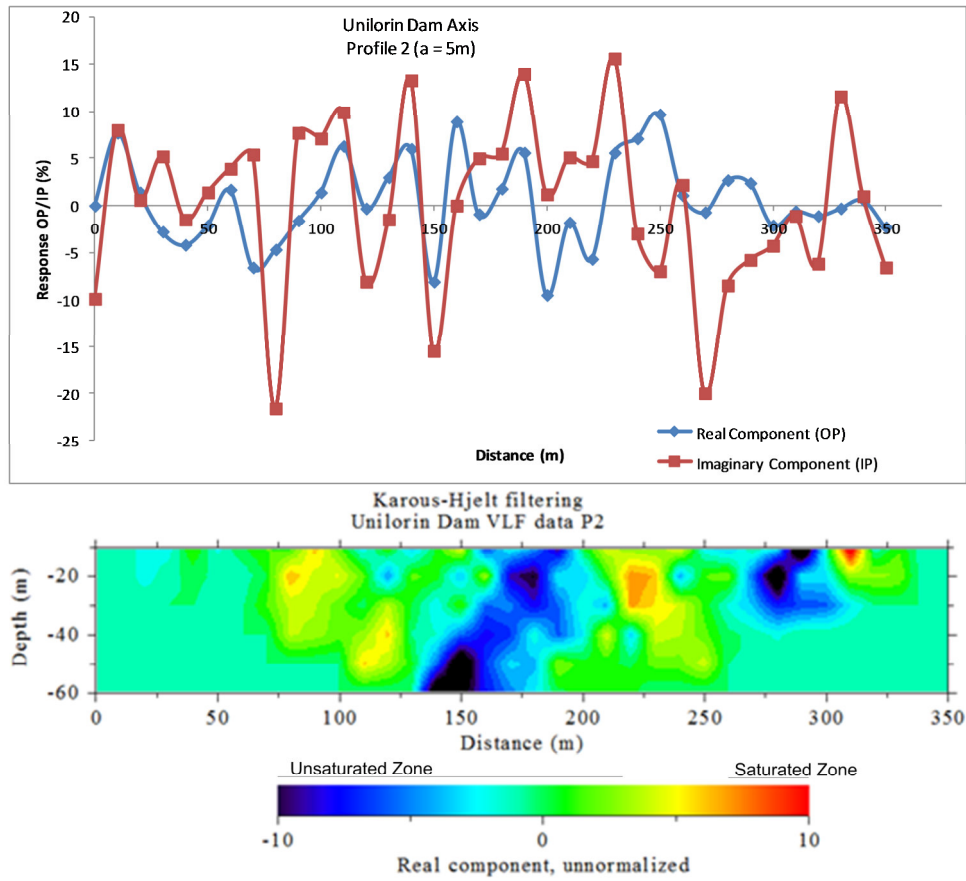
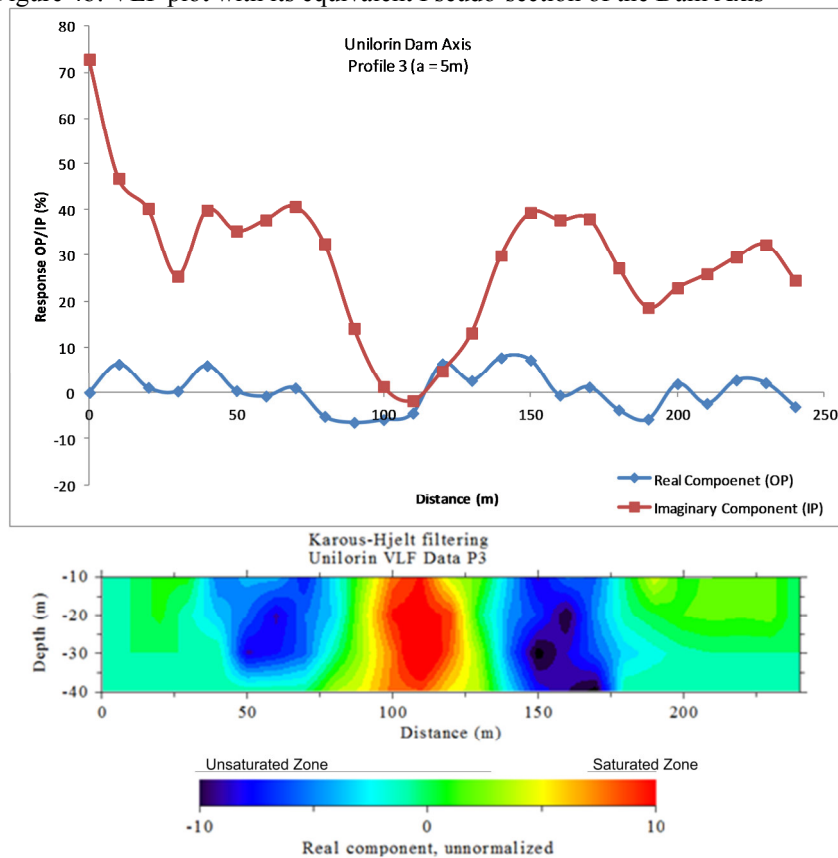Figure 4b: VLF plot with its equivalent Pseudo-section of the Dam Axis

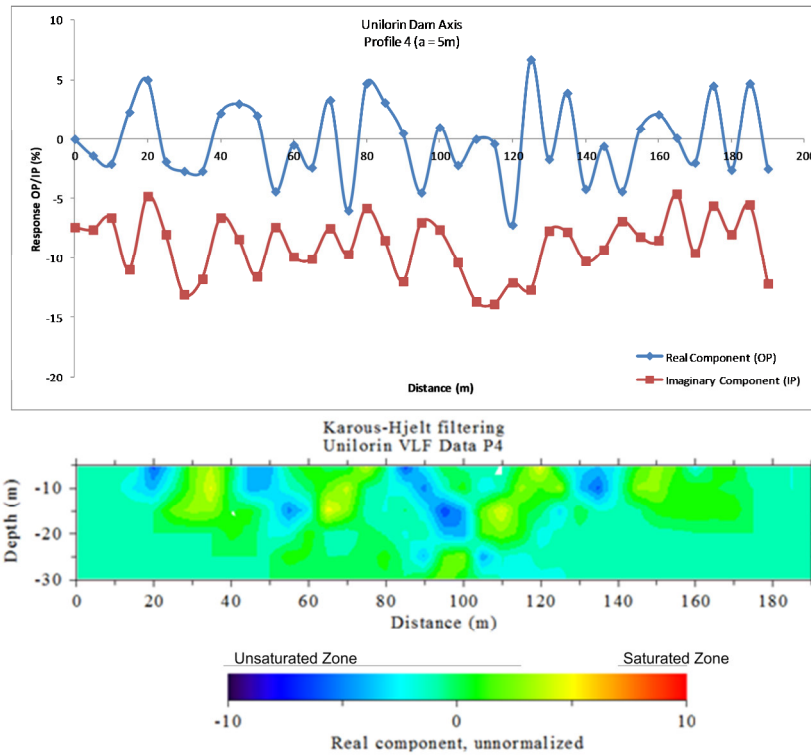Figure 4c: VLF plot with its equivalent Pseudo-section of the Dam Axis

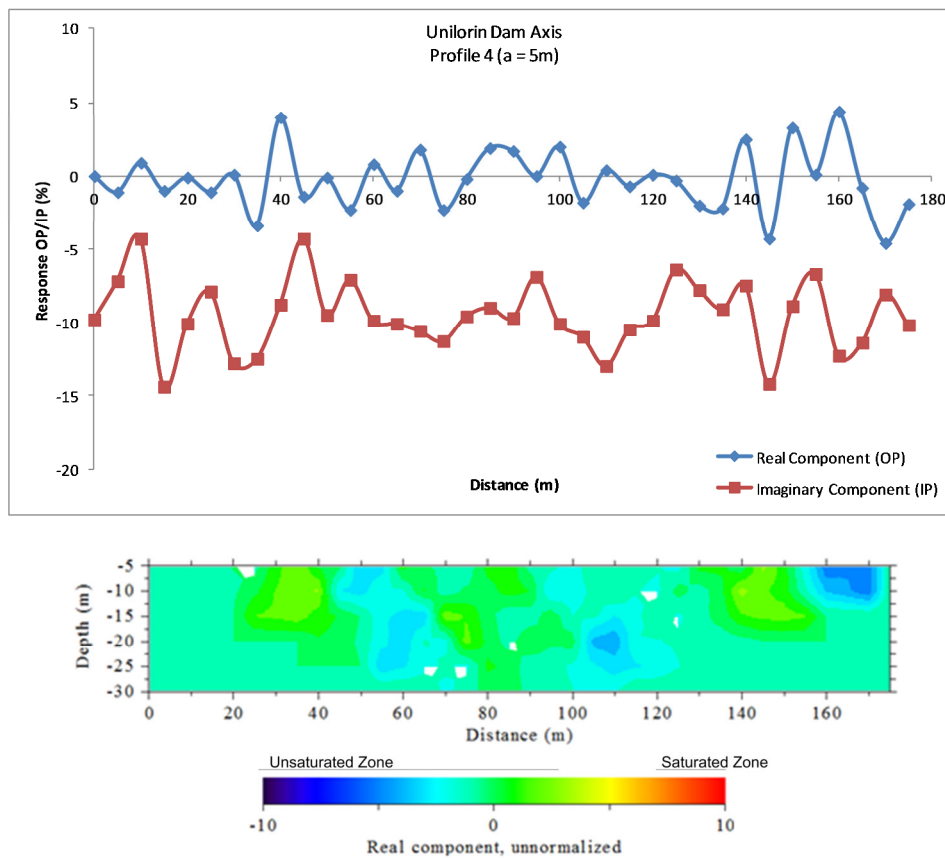Figure 4d: VLF plot with its equivalent Pseudo-section of the Dam Reservoir

Figure 4e: VLF plot with its equivalent Pseudo-section of the Dam Reservoir
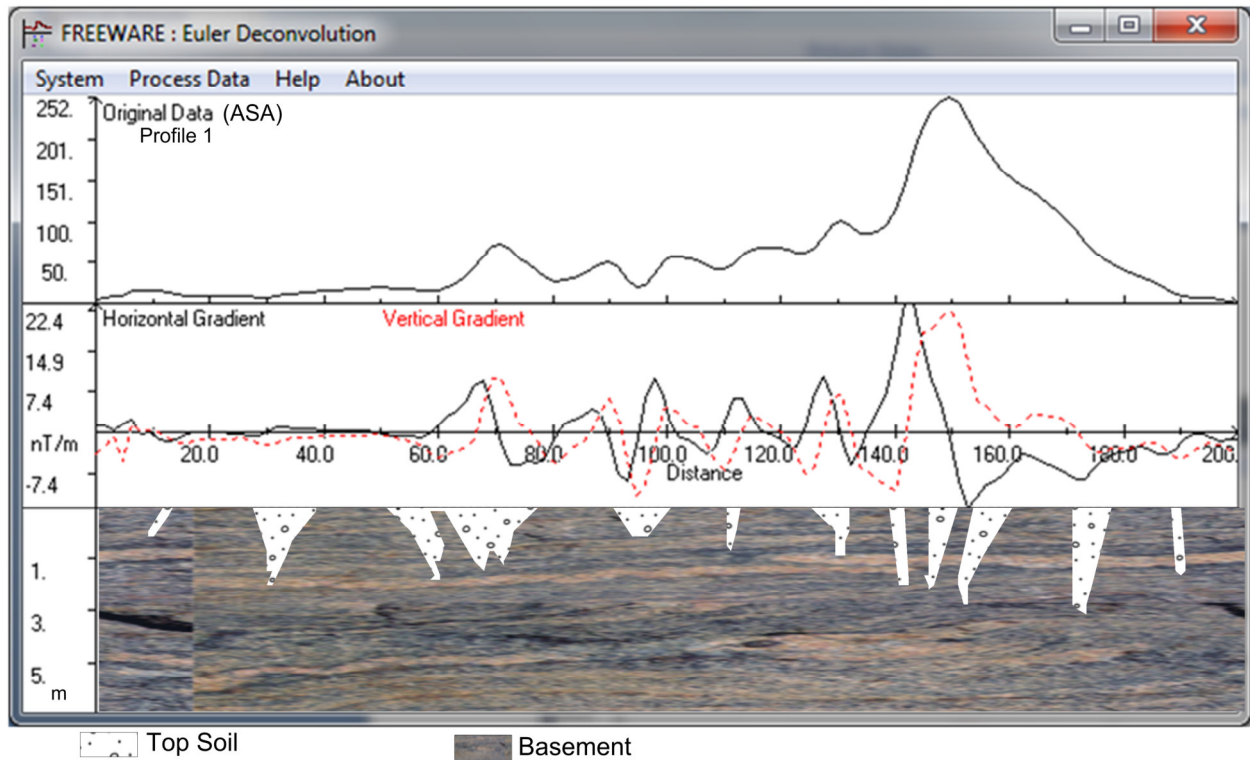
Top Soil   Basement

Figure 5a: Analytic Signal Amplitude, Vertical Gradient and Horizontal Derivative and equivalent Lithology along profile 1 of the Study Area
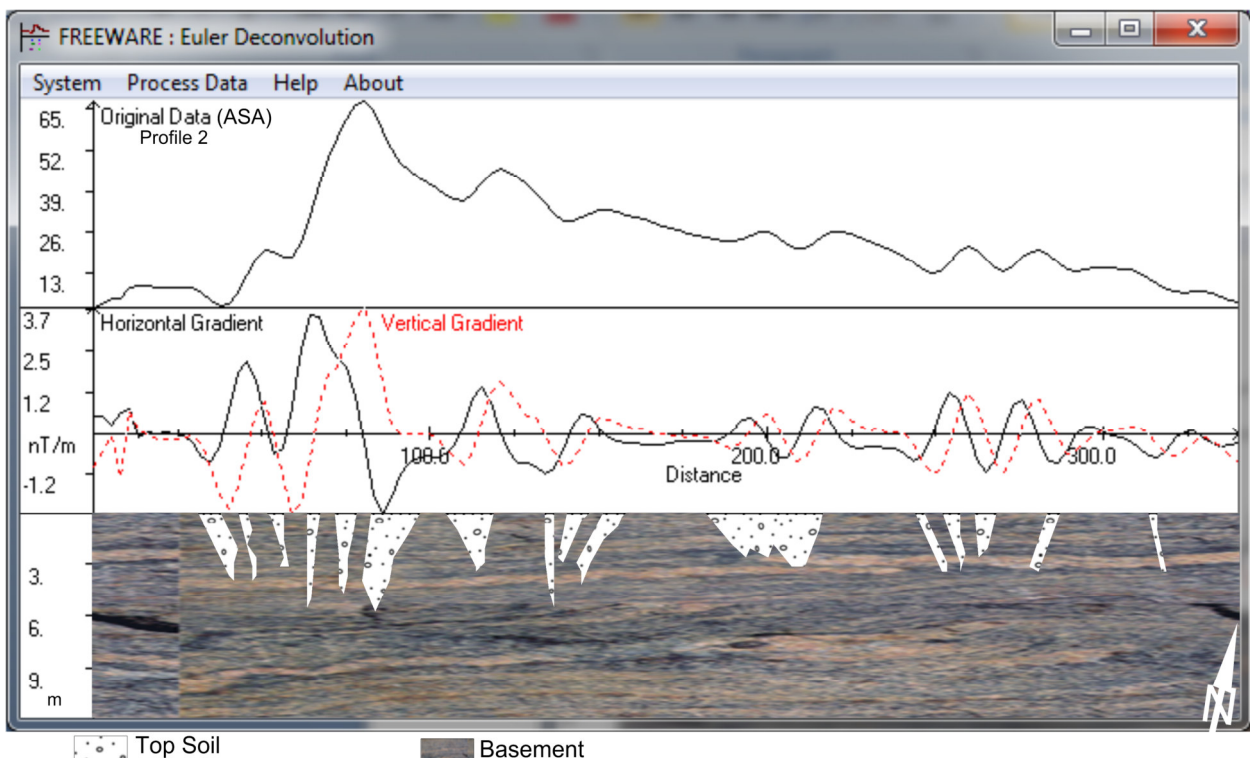

Top Soil   Basement

Figure 5b: Analytic Signal Amplitude, Vertical Gradient and Horizontal Derivative and equivalent Lithology along profile 2 of the Study Area
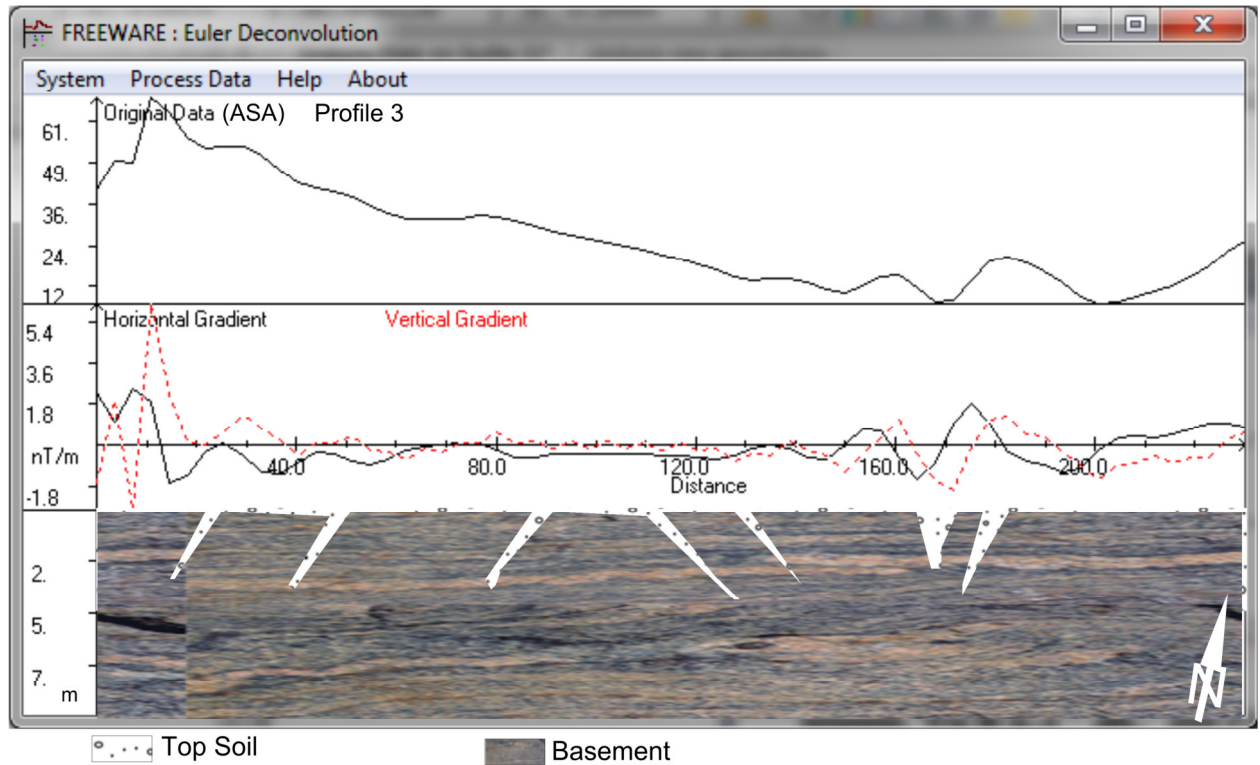
Figure 5c: Analytic Signal Amplitude, Vertical Gradient and Horizontal Derivative and equivalent Lithology along profile 3 of the Study Area
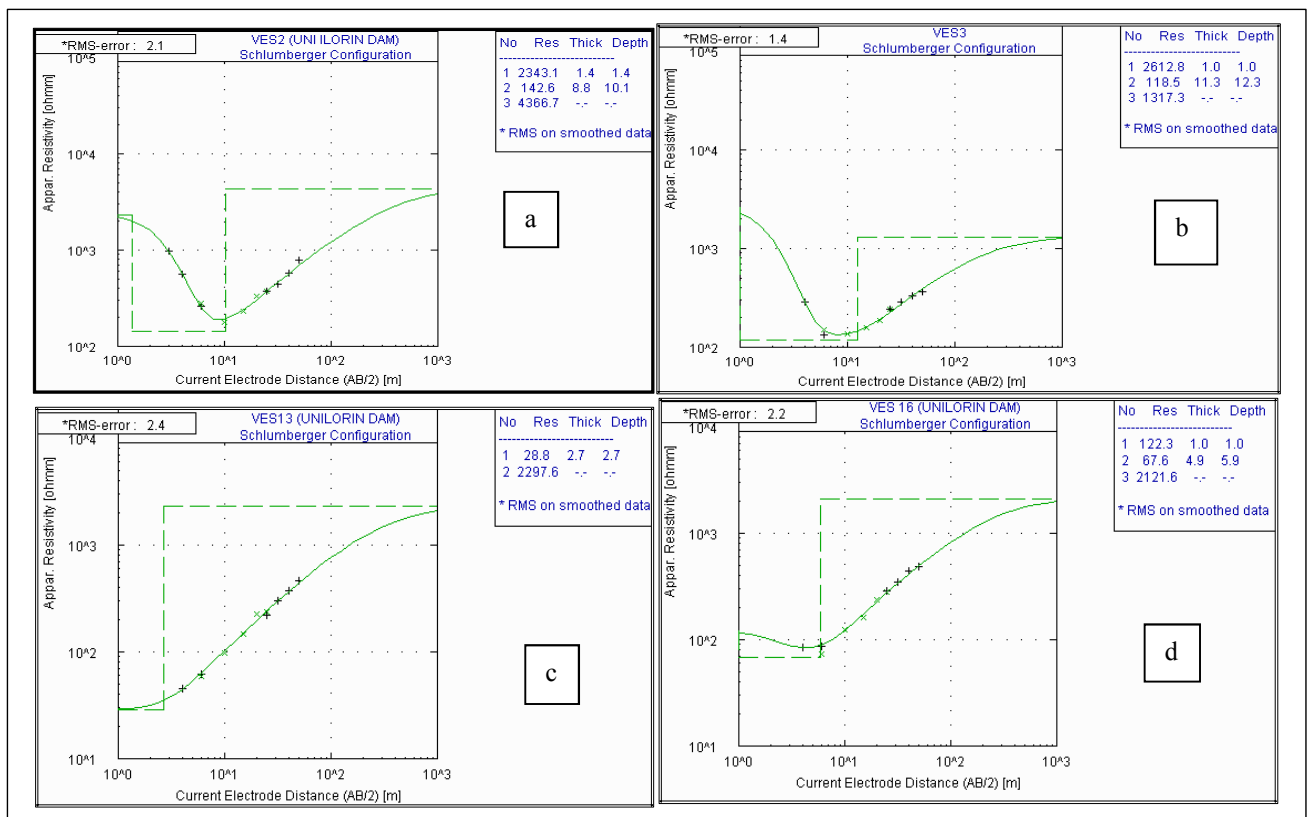

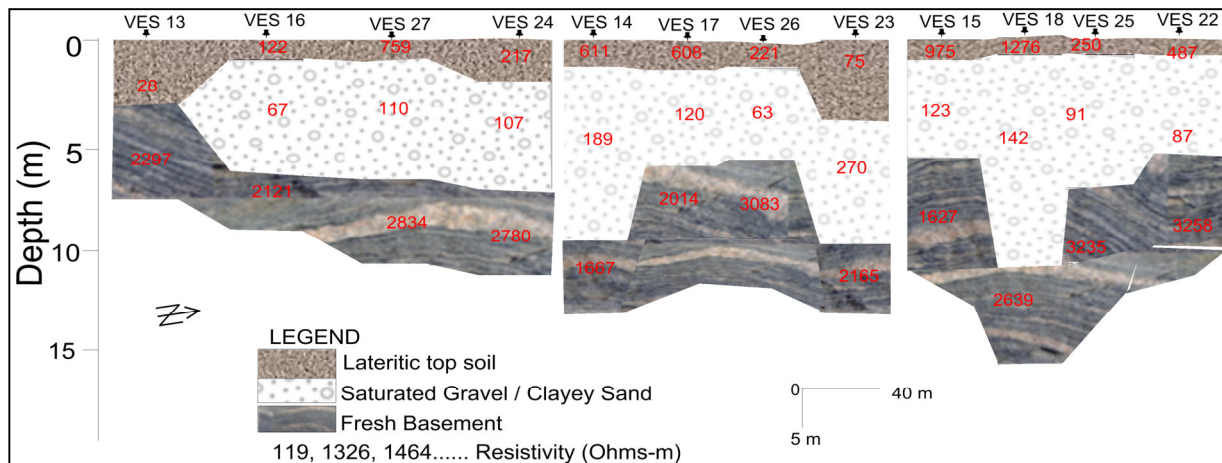Figure 6: Modeled Curves along Unilorin Dam axis and Recreation Center

Figure 7: Geo-electric Sections along the Dam Axis

Works Cited

Abderahman, E. M., & Essa, K. S. (2005). Magnetic interpretation using a least-squares depth-shape curves method. *Geophysics , 70* (3), L23 –L30.

Adedeji, A. A. (2007). Seismic analysis of earth wall gravity dams using decoupled modal Approach. *Global Research Publication , 1*.

Aina, A., Olorunfemi, M. O., & Ojo, J. S. ((1996)). An integration of Aeromagnetic and Electrical Resistivity Methods in Dam Site Investigation . *Geophysics , 61* (2), 349-356.

Binley, A., & Kemna, A. (2005). DC resistivity and induced polarization methods Rubin, Y., and Hubbard, S.S. (eds.), Springer, Netherlands, 129–156. *Hydrogeophysics* .

Gamal, Z. A., Ahmed, M. I., Neil, L. A., & Estella, A. A. (2004). *Geophysical investigation of seepage from an earth filled dam,Washington County MO*. Retrieved from www.dot.state.fl.us.

Karous, M., & Hjelt, S. E. (1983). Linear filtering of VLF dip-angle measurements. *Geophysical Prospecting* , 782–794.

Kim, J. H., Yi, M. J., Song, Y., Seol, S. J., & Kim, K. S. (2007). Application of geophysical methods to the safety analysis of an earth dam. *Journal of Environmental and Engineering Geophysics , 12*, 221–235.

Minsley, B. J., Bethany, L., Ikard, S., & Power, M. H. (2011). *Hydrogeophysical investigations at Hidden Dam.* Raymond, California: USGS Staff-Published Research.

Nabighian, M. N. (1974). Additional comments on the analytic signal of two-dimensional magnetic bodies with polygonal cross section. *Geophysics* , 85 - 92.

Nabighian, M. N. (1972). The analytic signal of two-dimensional magnetic with polygonal cross sections: its properties and use for automated anomaly interpretation. *Geophysics* , 507 - 517.

Oladunjoye, M., Adabanija, M., & Adeboye, O. (2013). Groundwater prospecting and exploration in a low potential hard rock aquifer: case study from Ogbomoso North, south-western Nigeria. *Journal of Environmental and Earth Science , 3*, 84 - 102.

Oyegun, R. O., Jimoh, H. I., & Irove, K. A. (2007). Opening up the Rural Area in Kwara State through the Provision of Water Resources: the Policy Options. . *Confluence Journal of Environmental Studies* , 1-14.

Rahaman, M. A. (1989). Review of Basement Geology of South-Western Nigeria. In C. A. Kogbe, *Geology of Nigeria.* (pp. 41 - 58). Lagos: Elizabeth Publ.

Sjö dahl, P., Dahlin, T., Johansson, S., & Loke, M. H. (2008). Resistivity monitoring for leakage and internal erosion detection at Ha llby embankment dam. *Journal of Applied Geophysics* (65), 155–164.

Vander Velpen, B. P. (2004). WinRESIST Version 1.0 Resistivity Depth Sounding Interpretation Software. *M.Sc Research Project* .