Multi-Array Hydro-Geoelectric Characterization of a Crystalline Basement Complex environment

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AUTHORS' CONTRIBUTIONS

This work was carried out by the three authors. The lead author conceived the idea and designed the field parameters. The second author put the original manuscript in a research format and forwarded same to the publisher. The third author undertook the field data acquisition, interpreted the data, generated the diagrams and wrote the initial manuscript. The three authors have reviewed the analyses of the study results and approved the final manuscript.

ABSTRACT

The efficiency of integrated geoelectric arrays study was undertaken on a ubiquitous shallow Precambrian Crystalline Basement Complex rocks terrain of School of Earth and Mineral Sciences (SEMS) of The Federal University of Technology, Akure, southwestern Nigeria. Geophysical data acquisition was undertaken on fifteen (15) traverses in the area using Gradient, Dipole–Dipole and Schlumberger Vertical Electrical Sounding (VES) techniques. The field data were interpreted using both manual and computer iterations. The results are presented as map, sounding curves and sections. The results of the Gradient array, Dipole-Dipole and Schlumberger VES enabled qualitative, semi-quantitative and quantitative hydrogeophysical evaluations respectively. Both Gradient and Dipole-Dipole arrays indicate existence of fairly favourable hydro-geoelectric setting on the north central precinct of the area. The combined results of both arrays informed the location of 13 Schlumberger - VES points in the favourable hydro-geophysical environment. The Schlumberger VES results show that clayey overburden materials (31 – 58 Ω-m) with thickness varying between 8.7 and 16.9 m that can plausibly support abstraction of some quantity of groundwater underlie the fairly favourable northern flank. However, a fractured basement column delineated beneath VES 7 may sustain fairly adequate groundwater yield. Despite the high cost of implementing multiple geoelectrical arrays in groundwater projects, the outcome may justify the expenditure especially in cases where point of water abstraction is successfully identified principally where properties have been developed in a ubiquitous shallow bedrock environment similar to the terrain of study.

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Key words: Hydrogeoelectric, Hydrogeophysical, Resistivity, Aquifer and Basement rock

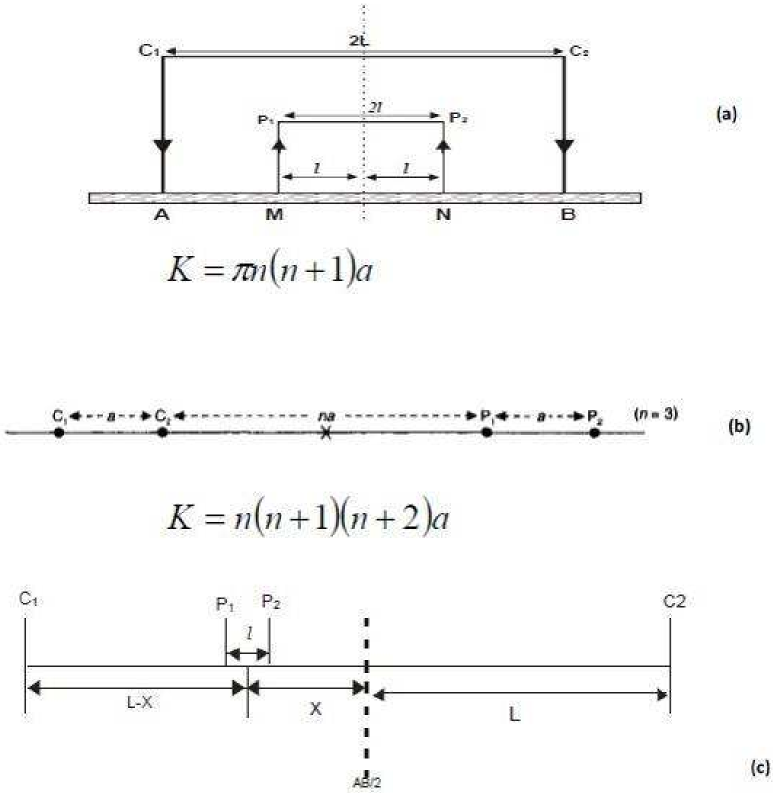
1. INTRODUCTION

Application of geophysical methods to hydrogeological problems is continuing to gain more ground in groundwater decision making process Rubin and Hubbard [1]. The established geophysical methods widely utilized in hydrogeophysics studies include seismic refraction Sundararajan et la., [2], magnetic Sultan and Santos [3], electromagnetic (including the VLF-EM) Sharma and Barawal [4], Meju et al., [5], Ehinola et al., [6], Amadi and Nurruden [7], seismic reflection Gruba and Rieger [8] and the direct-current (*DC*) electrical resistivity method [9]; Jupp and Vozoff [10]. Among these various methods the electrical resistivity method has been noted for its efficiency in solving hydrogeologic problems. The dominance of the electrical resistivity method in solving groundwater related problems is due to its non-invasive attribute, low cost, speed of data acquisition and ability to map both geological layers as well as determining the nature and composition of unseen subsurface formations [Fitterman et al., 11]; Hinnell et al., [12]. In the field of hydrogeophysics where characterization of aquifer properties results in optimal exploitation of groundwater resources, the electrical resistivity method has played very dominant role [Loke et al., 13], [14], Margiotta et al., [15]). For effective utilization of electrical resistivity method in hydrogeophysics, some of the varieties of electrode configurations (especially Schlumberger, Dipole–Dipole and Gradient) may need to be integrated for field mapping. However, the choice of any of the electrode configurations depends largely on the objective of the survey, scope of study, local geology and the sensitivity of any or combination of the arrays to vertical and/or lateral variations in the subsurface resistivity distribution (Loke and Barker [16], [17]. In many hydrogeological studies, each of these electrode configurations is often utilized individually or in combination to further enhance information on the hydrogeologic setting. The Schlumberger configuration which is best utilized in vertical electrical sounding (VES) enables 1-D geoelectric study of a point while combination of several soundings in an environment will enable 2-D or 3-D overview of the hydrogeoelogic setting. The Dipole-Dipole electrode configuration enables a 2-D evaluation of the hydrogeologic setting while multiple traverse combinations enable 3-D hydrogeologic evaluation. The gradient electrode configuration which is a non-conventional electrode configuration has been found more unique in resistivity survey for solving hydrogeologic problems (Aizebeokhai and Oyeyemi [18]). The output of gradient array subsurface resistivity images often present good resolution attributes which are essential for characterization of subsurface geologic features that can enhance hydrogeologic decision making process Aizebeokhai and Oyeyemi [18]. The three different electrode configurations have their peculiar attributes in hydrogeophysics Loke and Barker [16]. Exploring their potential attributes in complimentary form can enhance hydrogeologic decision making output. Very few geoelectrical investigations for groundwater studies have considered exploring the use of both conventional and non-conventional arrays in a complementary form.
This study has been conducted utilizing combination of rarely used gradient arrays with those of conventional Schlumberger and Dipole–Dipole arrays with a view of characterizing the subsurface features and delineation of the underlying aquifer units. The study result is expected to enable the location of aquifer units and their lateral extent in the study area.

2. ELECTRODE ARRAYS AND THEIR UNIQUE ATTRIBUTES

In order to achieve the objectives of this study, three (3) array types viz: Schlumberger, Dipole–Dipole and Gradient were adopted. The arrays have different geometric factor equations which often determine their operational functionality for any specific resistivity survey task. Figure 1 presents the layout of the electrode configurations and their geometric factors. Generally across the electrode configurations (Figure 1 a to c), the C_1 and C_2 are the injecting current electrodes while P_1 and P_2 are the measuring potential electrodes. The letters L, l and X of Figure 1c, implies that L = the distance from electrode C_2 to the middle of distance C_1 - C_2 and the "l" denotes the distance between P_1P_2, whereas X represents the distance from the point of measurement to the middle of C_1-P_1 (P_2-C_2) electrodes to the spacing ("a"), respectively. The "n" and "a" in Figure 1 a & b are the minimum electrode spacing as well as the ratio of the distance between the C_1-P_1 (P_2-C_2) electrodes to the spacing ("a") between the P_1-P_2 potential pair, respectively. The position and location of both the current and the potential electrodes and their separating factors often determine the probing depth and resolution of the delineated subsurface features in all the electrode configurations of choice.

However, the gradient array has deeper probing depth compared to both Schlumberger and Dipole–Dipole. This is because of the field layout arrangement of gradient array which allows large current electrode separation.



$$K = \pi n(n+1)a$$

$$K = n(n+1)(n+2)a$$

$$K = \frac{\pi\left[L^2 - X^2\right]^2}{\left[L^2 + X^2\right]2l}$$

Figure 1: The electrode configurations used for data measurement where (a): The Schlumberger, (b) The dipole–dipole, (c): The gradient and K: The geometric factor

3. LOCATION DESCRIPTION AND LOCAL GEOLOGY

The study area (School of Earth and Mineral Sciences (SEMS)) is located within the central area of the Federal University of Technology, Akure, southwestern Nigeria (Figure 2). The university campus is situated on the northwestern flank of Akure metropolis and on the southern flank of Ibadan-Akure-Benin Federal Highway. The university which occupies an area of about 5 km^2 is situated within latitudes 7° 16'N and 7° 18'N and longitudes 5° 07' E and 5° 09'E. The university campus is situated on a slightly rugged terrain with elevation between 350 m (on the southeastern flank) and 390 m a.s.l. at the northern flank. The area lies in the tropical rain forest with mean annual rainfall of about 1300 mm. Generally, the annual mean temperature in the area varies between 18°C and 33°C. The campus is well drained with the dendritic drainage pattern via three major streams that flow in the southern direction. The study area is underlain by the Precambrian Crystalline Basement Complex rocks of southwestern Nigeria [17]. The lithologic units include granites, gneisses, quartzites and charnockite. Low-lying outcrops of granites, gneiss and quartzites occur in several locations, mostly in the northwestern and central parts of the study area (Figure 3).

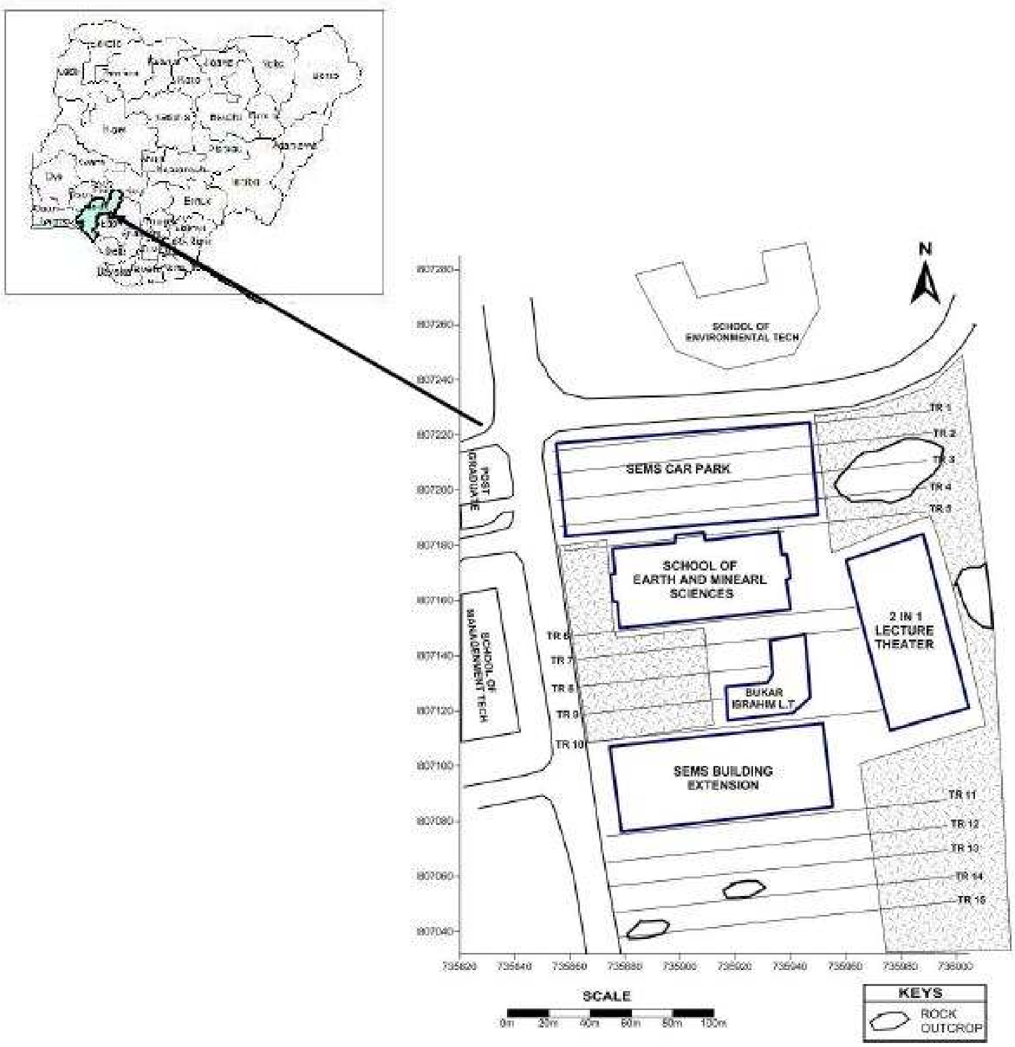


Figure 2: Layout map of the area of study with the map of Nigeria as inset

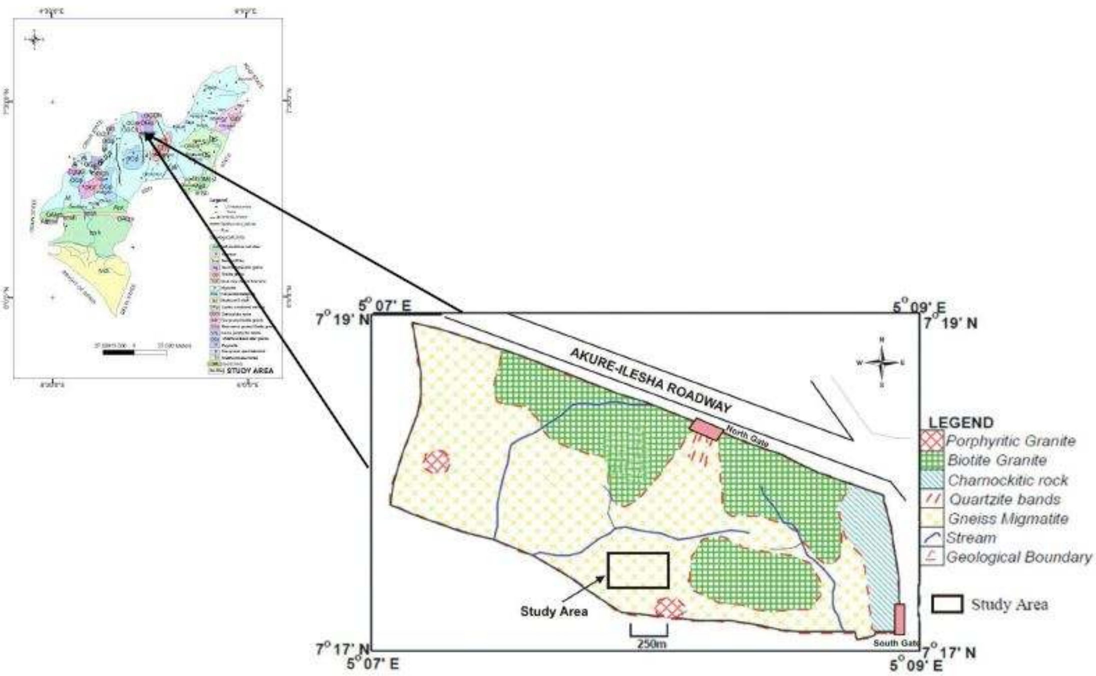


Figure3: Geological map of the study area with the geological map of Ondo State as inset (After [17])

4. MATERIALS AND METHOD OF STUDY

Resistivity profiling measurements involved both the Gradient and Dipole-Dipole arrays (see Fig 4) while the Schlumberger array was adopted for vertical electrical soundings. The ABEM Terrameter (SAS 1000/4000 series) was utilized for data acquisition. For data measurements with the gradient array, the current electrodes (C_1C_2) were fixed at a separation of 360 m while the potential measuring electrodes (P_1P_2) were moved within the current electrodes for each data measurement at constant electrode spacing of 10 m along each traverse. The data acquisition with dipole-dipole array involved constant electrode spacing of 5 m while the inter-dipole electrode expansion factor (n) was varied from 1 to 6. The Schlumberger array on the other hand, was adopted for VES data acquisition with maximum half-current electrode spread (AB/2) of 130.0 m.

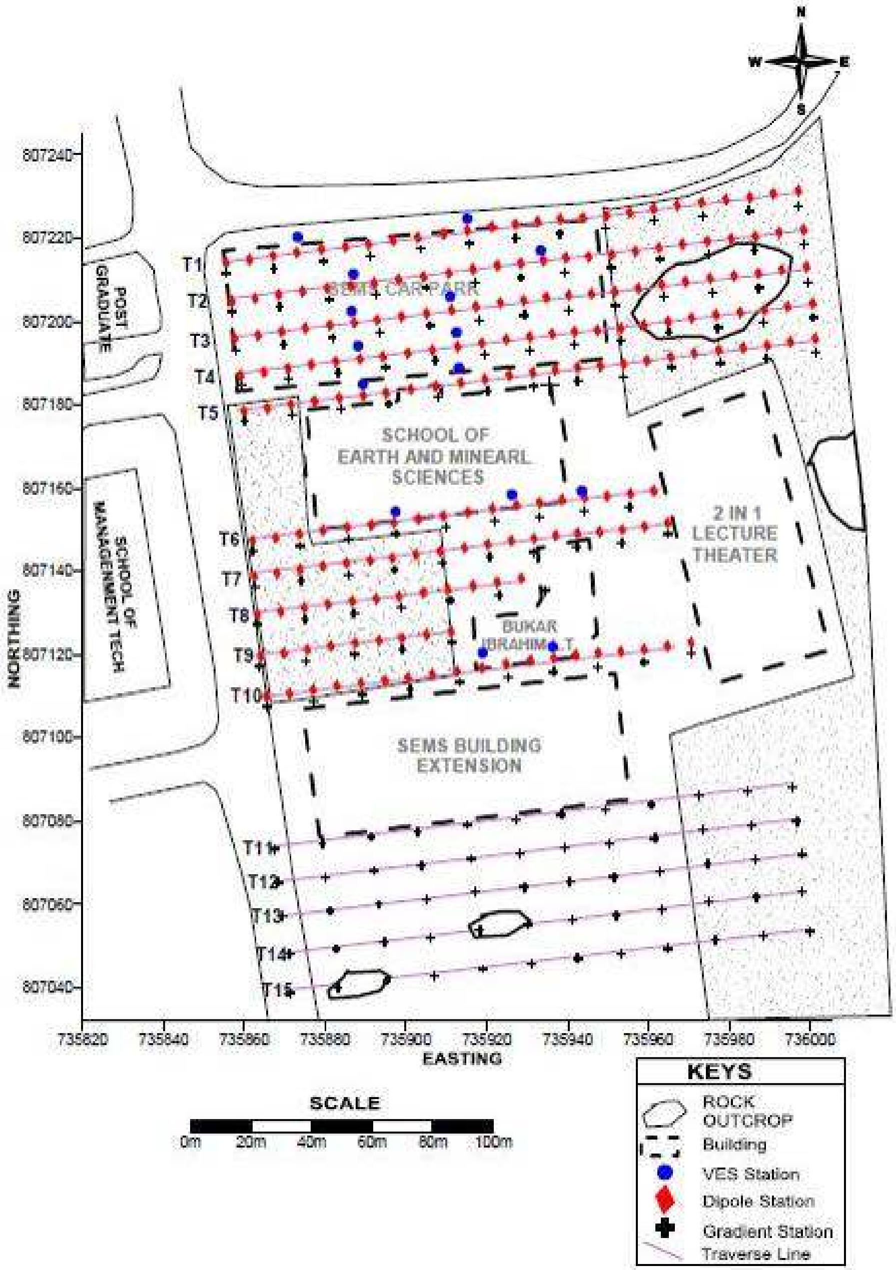


Figure 4: Layout map of the study area showing geophysical data points

4.1. Data processing and inversion

The Gradient array data are presented as apparent resistivity map and 3-dimensional resistivity vector model (Figure 5a and b). The Dipole-Dipole data are presented as field and theoretical data pseudo-sections and 2-D resistivity structure sections using the DIPRO™ Software (Figure 6 a - i). Typical Schlumberger VES curves are presented in Figure 7a - d. The field curves were curve-matched using Schlumberger master curves to determine geoelectric parameters (layer resistivity and thickness) of the delineated layers. The geoelectric parameters from the interpreted curves were then used as the initial models for computer iteration using WinResist™ to obtain model geoelectric parameters for the delineated layers.

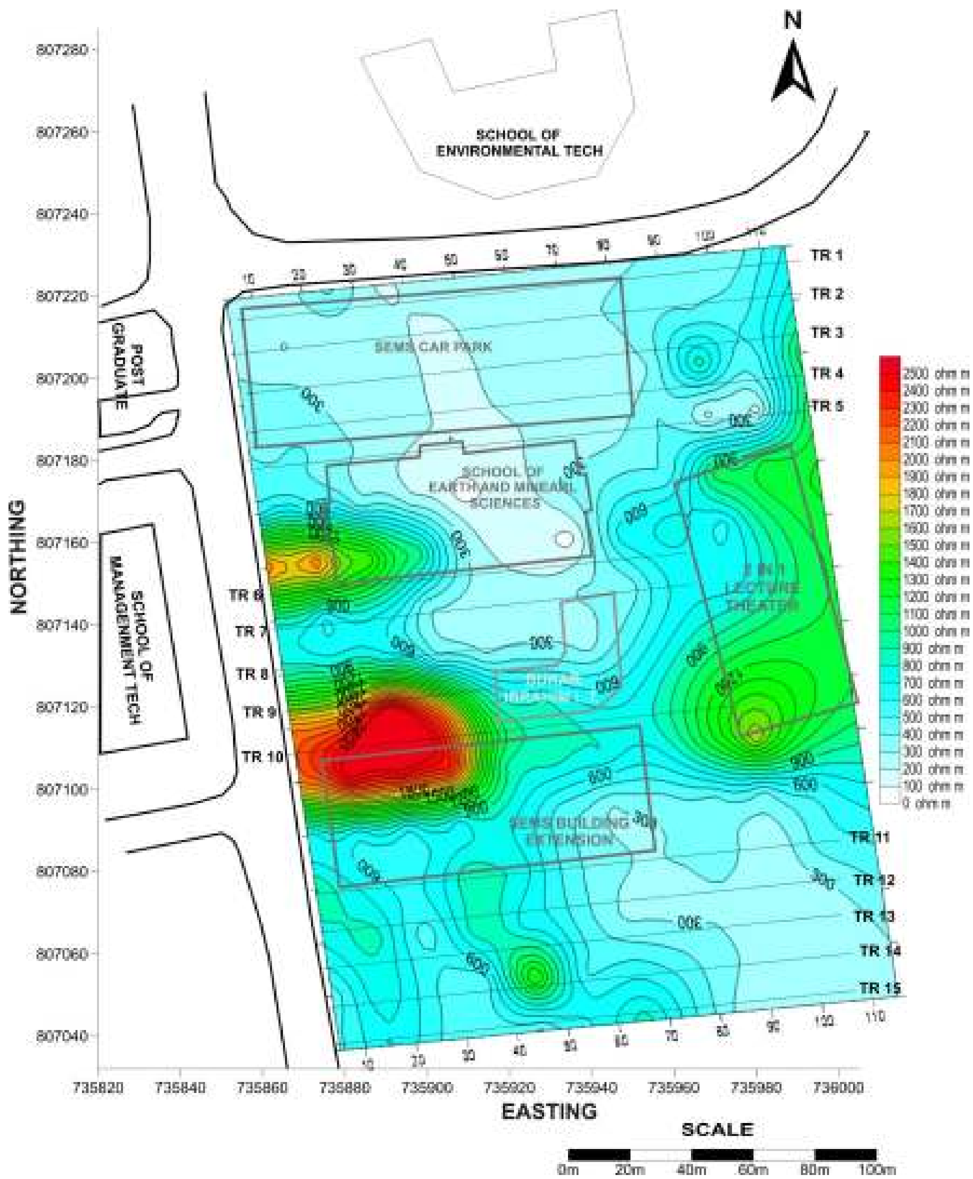


Figure 5a: The Gradient Array subsurface resistivity map of School of Earth and Mineral Science, Federal University of Technology, Akure Nigeria

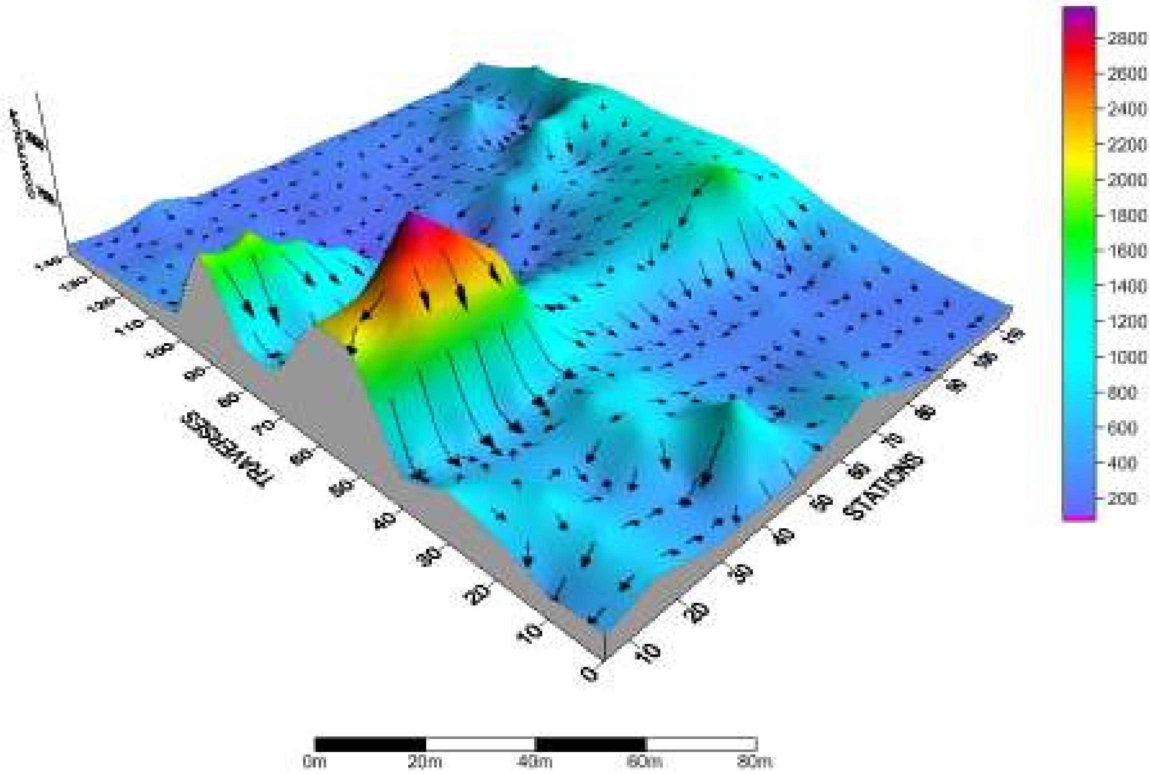
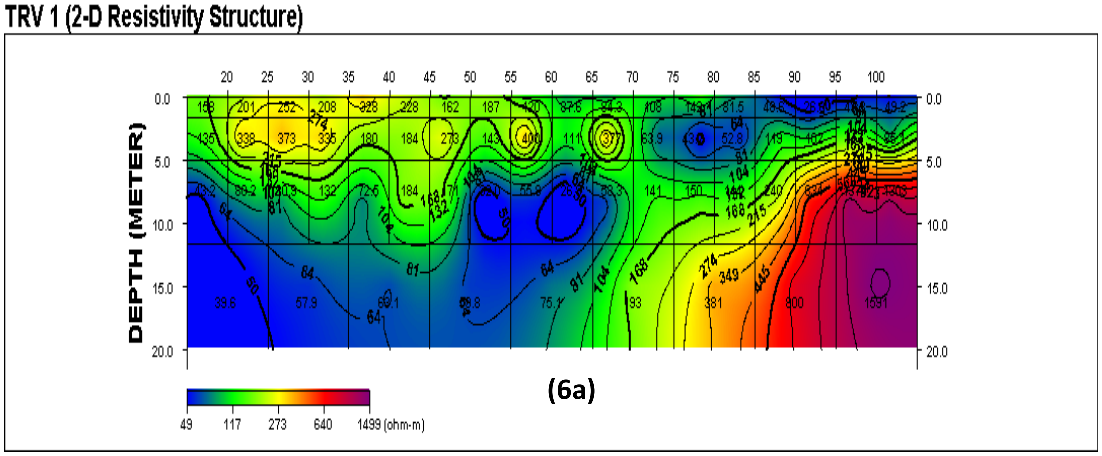
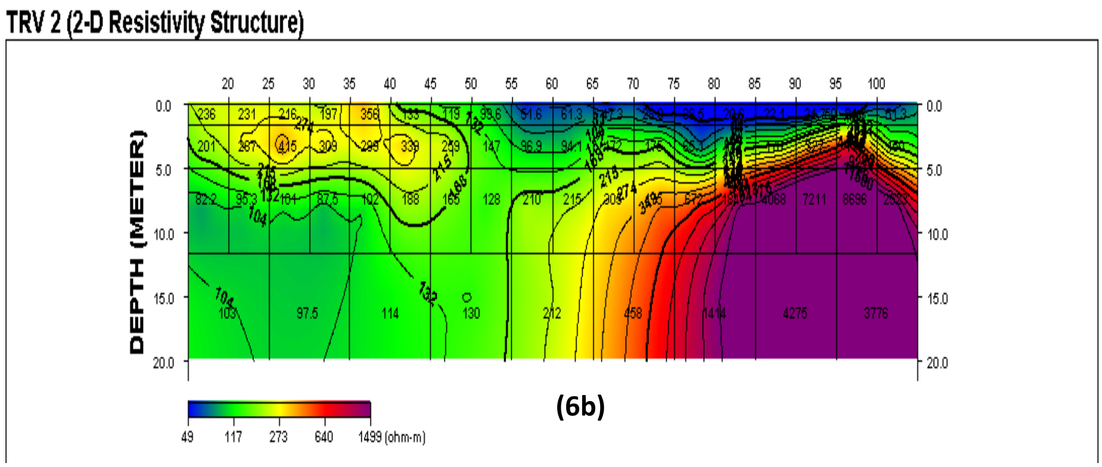


Figure 5b: The 3 – dimensional resistivity vector model of the study area



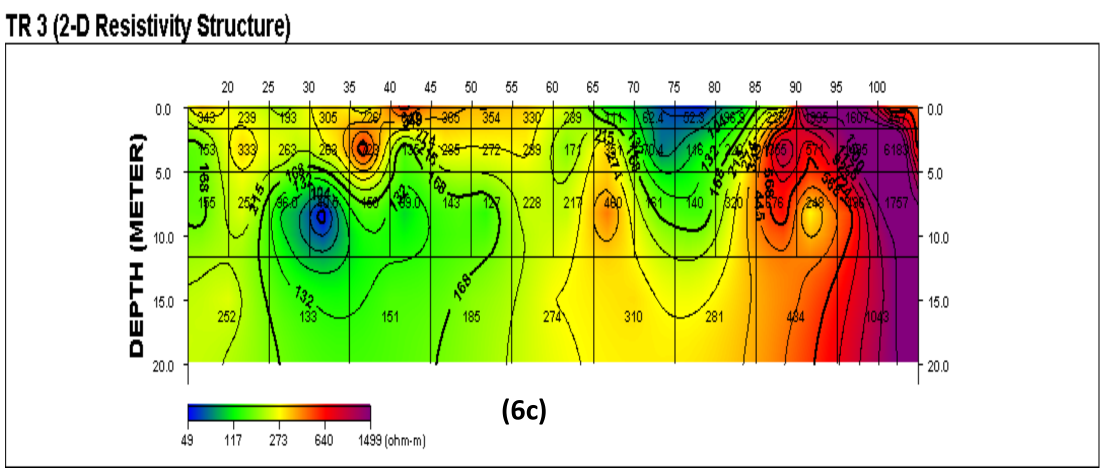
TRV 1 (2-D Resistivity Structure)
DEPTH (METER)
49 117 273 640 1499 (ohm-m)

(6a)



TRV 2 (2-D Resistivity Structure)
DEPTH (METER)
49 117 273 640 1499 (ohm-m)

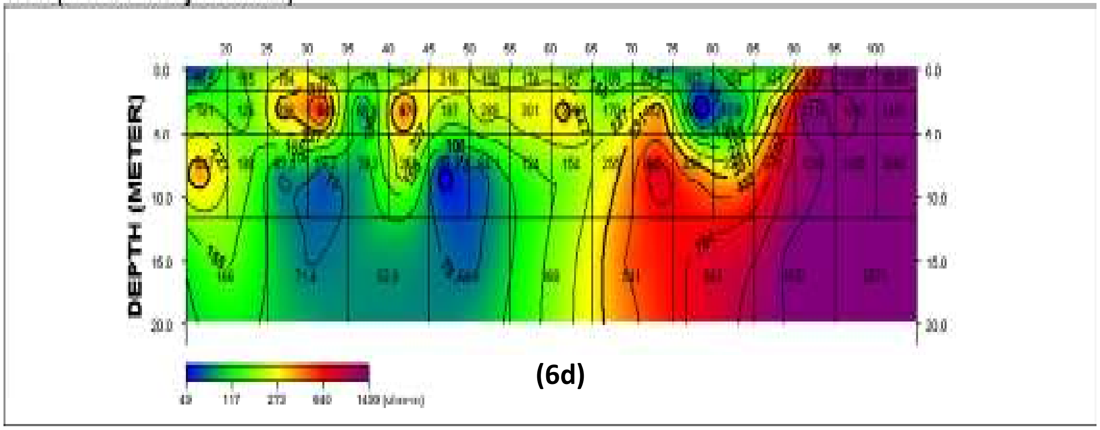
(6b)



TR 3 (2-D Resistivity Structure)
DEPTH (METER)
49 117 273 640 1499 (ohm-m)

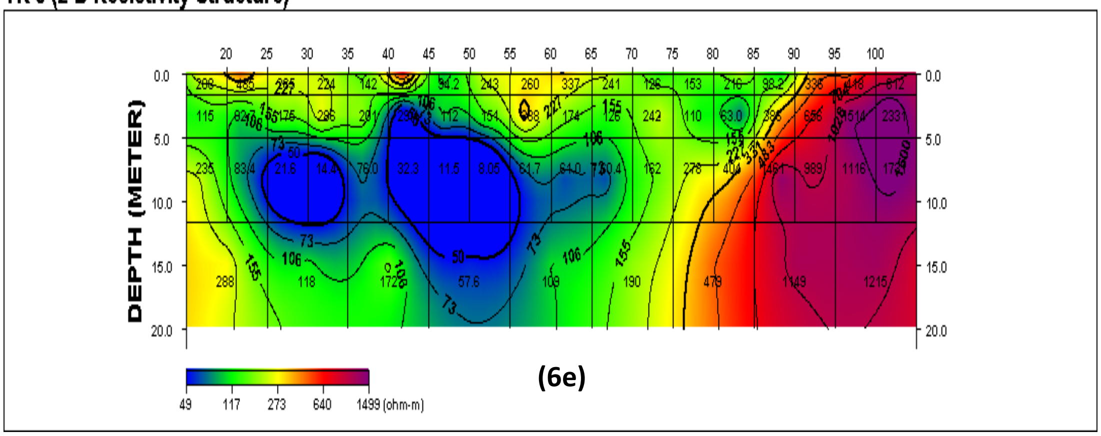
(6c)

TR 4. (2-D Resistivity Structure)



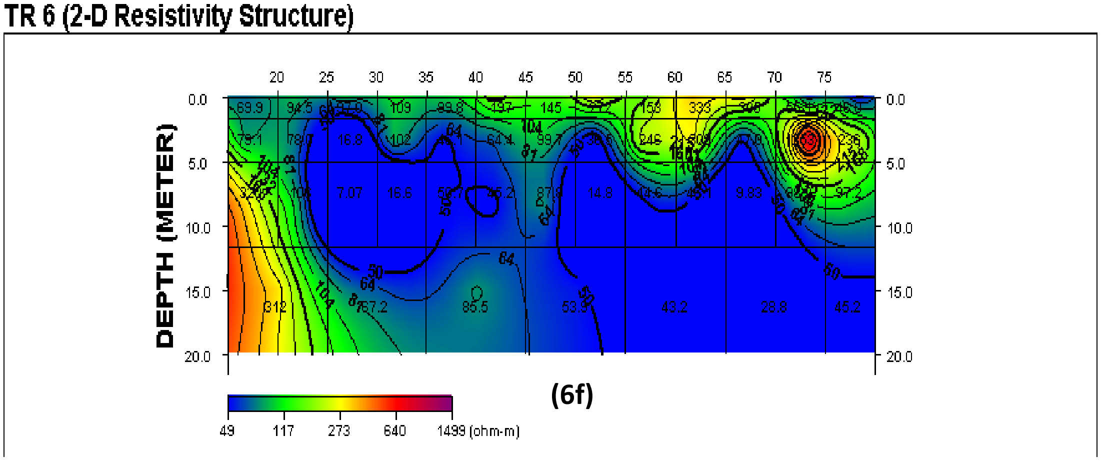
(6d)

TR 5 (2-D Resistivity Structure)



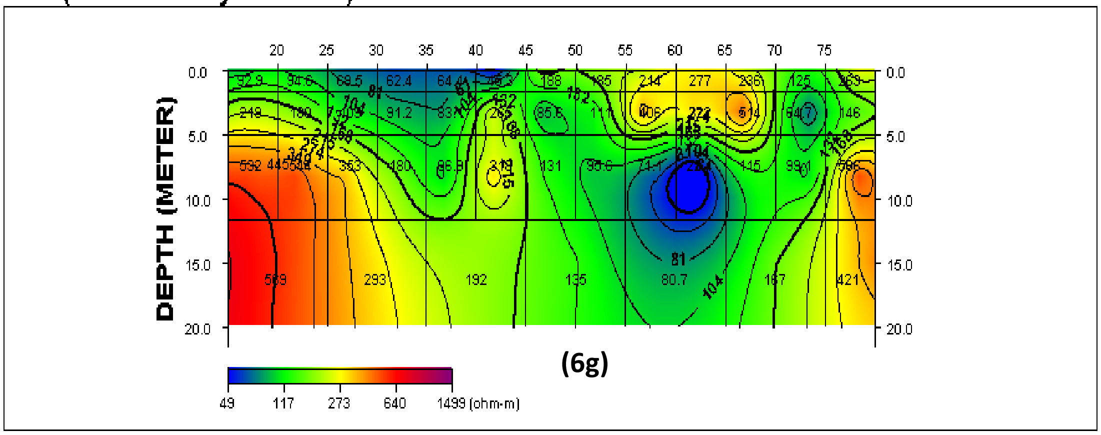
(6e)

TR 6 (2-D Resistivity Structure)

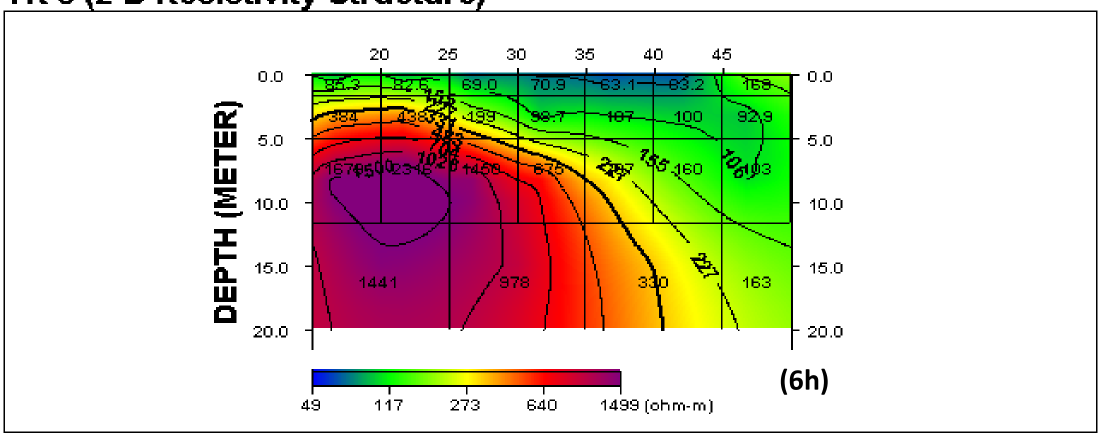


(6f)

TR 7 (2-D Resistivity Structure)



TR 8 (2-D Resistivity Structure)



TR 9 (2-D Resistivity Structure)

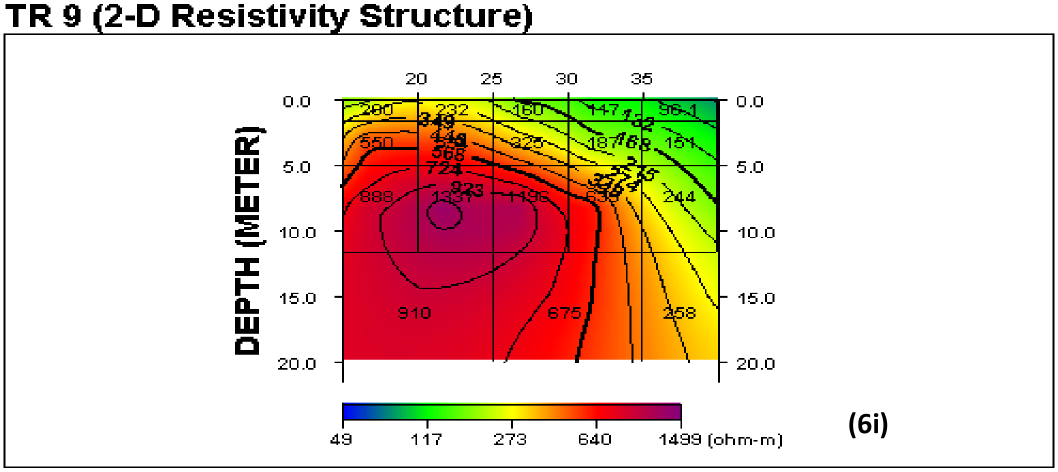
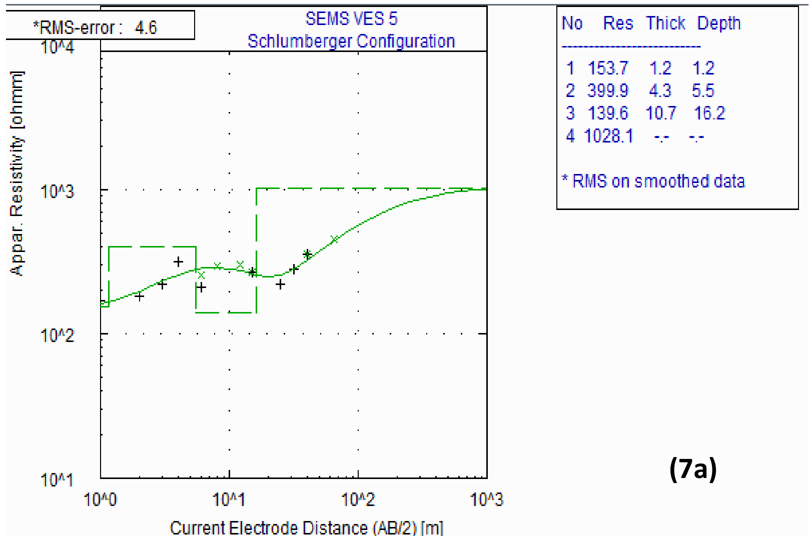
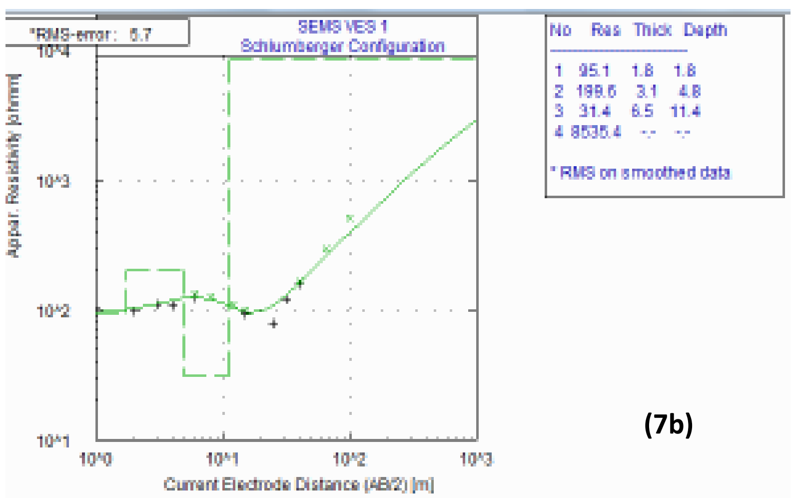


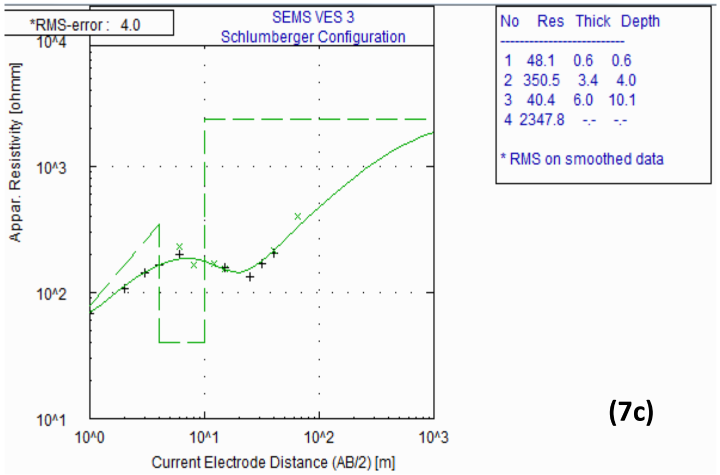
Figure 6 a - i: The 2-D Resistivity structure sections obtained from the Dipole-Dipole data


*RMS-error : 4.6
SEMS VES 5
Schlumberger Configuration
No Res Thick Depth
1 153.7 1.2 1.2
2 399.9 4.3 5.5
3 139.6 10.7 16.2
4 1028.1 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]

(7a)


*RMS-error : 6.7
SEMS VES 1
Schlumberger Configuration
No Res Thick Depth
1 95.1 1.8 1.8
2 199.6 3.1 4.8
3 31.4 6.5 11.4
4 8535.4 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]

(7b)



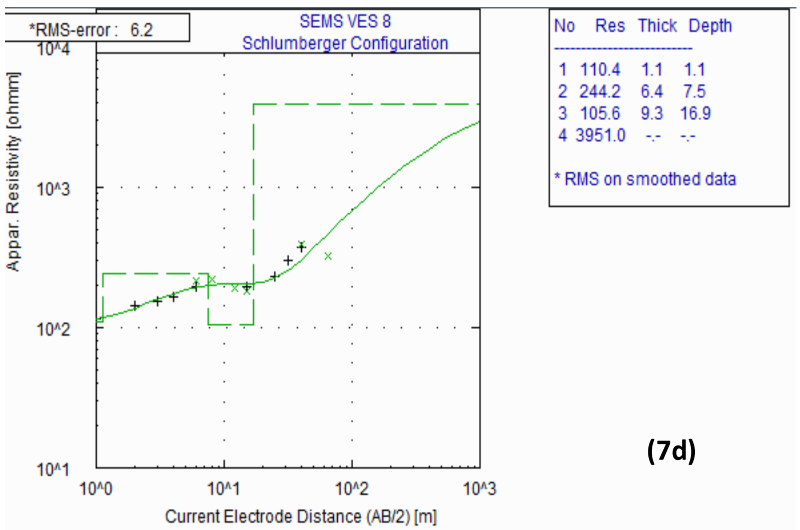


Figure 7 a - d: Typical vertical electrical sounding curves obtained from the area

5. RESULTS AND DISCUSSION

5.1 Gradient Array

The subsurface lateral and vertical hydro-geoelectric (hydrogeophysical) characterization of the study area were facilitated using the results of the interpreted gradient and dipole-dipole arrays respectively. The gradient array measurements results output in form of terrain resistivity map is presented in Figure 5a. The subsurface resistivity values obtained from the study vary widely across the traverses (100 – 2500 Ω-m) typifying subsurface structural complexity associated with the Basement Complex rocks environment. Low resistivity values (100 – 300 Ω-m) characterize the northern flank around traverses 1 – 4 (SEMS Car Park). Low resistivity values also characterize traverses 5 - 8 but with intrusion of some resistive features (diagnostic of shallow bedrock) on the eastern and western flanks. A significantly high resistivity features were obtained at the western flank around traverses 9 and 10 indicating the occurrence of shallow bedrock in the environment. There also exists a bedrock depression typified by low resistivity values at the central zone of the area. The southern flank is characterized by low resistivity values cutting across traverses 11 – 15. The low resistivity zones may be of some hydrogeologic significance. In addition, the result of the generated 3-D resistivity vector model revealed the pseudo bedrock relief within the environment (Figure 5b) and shows the existence of a fairly favorable hydrogeologic setting beneath the northern flank of the area.

5.2 Dipole-Dipole Array

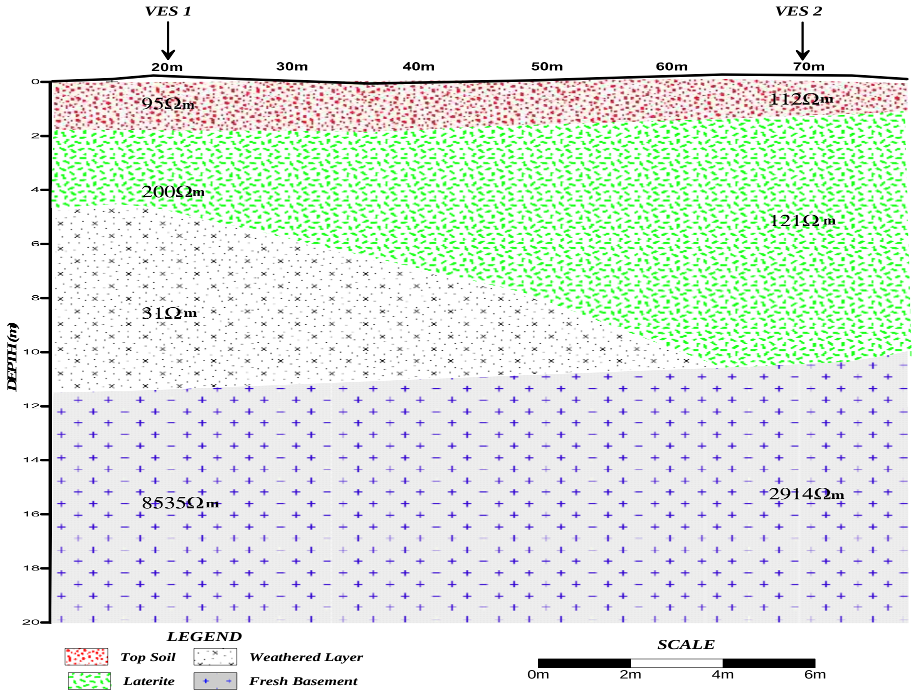
The dipole–dipole array results present low resistivity values at shallow depth (5 m) on the northwestern fringe of the area around Traverse 1 (Figure 6). The northern flank presents resistivity distribution contrasts suggesting some lithologic contrasts. The lithological features are presumably fault zones filled with conductive materials such as clay or weathered materials. Some features characterized by low resistivity values were delineated on traverses 2, 3 and 4. However, high resistivity features characterizing same traverses suggest the presence of shallow fresh crystalline rocks. Low resistivity features to depth of 15 m were also delineated on traverses 6 and 7 with increase in thickness westwards. Such fairly thick feature may be of hydrogeologic significance (see Figure 6a-i). However, high resistivity values characterized traverses 8 and 9 also indicating the presence of shallow crystalline rock. A presumably water saturated zone (low resistivity characteristics) was encountered on Traverse 10. Lateral resistivity imaging of the study area was attained via gradient array whereas lateral and vertical imaging of subsurface features was attained by dipole–dipole array. The results of the gradient array has enabled qualitative establishment of aquifer units in the area while semi-quantitative confirmation was achieved using dipole-dipole array. The combined results of both arrays informed the locations of the Schlumberger - Vertical Electrical Sounding points in the area.

5.3. The Vertical Electrical Sounding results

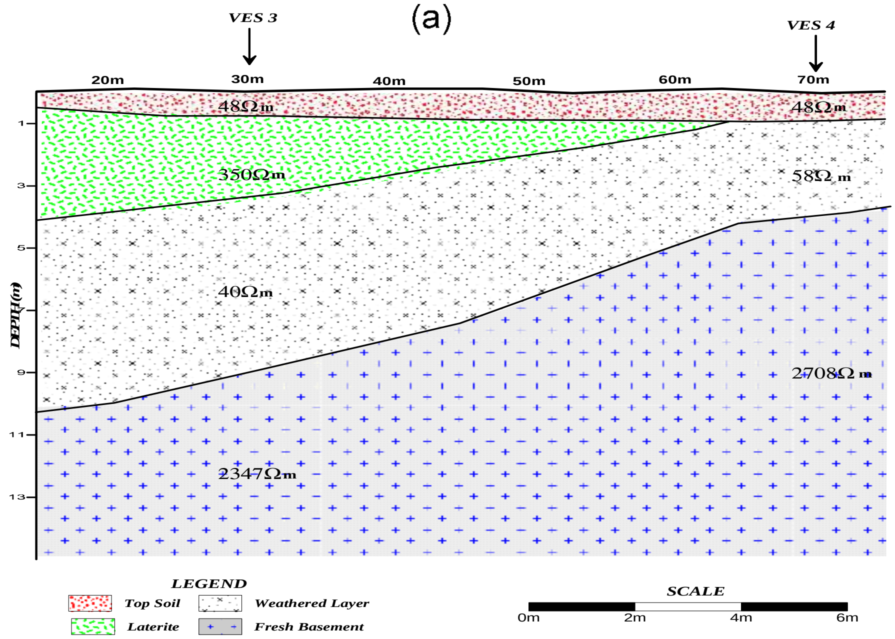
Quantitative hydrogeophysical evaluation is achievable using the Schlumberger VES technique. Using the results of both gradient and dipole-dipole arrays as guide, fifteen (15) VES points were occupied in the area. The VES field data are presented as field curves (Figure 7a-d). Geoelectric parameters (layer resistivity and thickness values) were derived from the interpreted field curves and the summary is presented in Table 1. The curve types obtained from the area varies from 3-layer A and H to predominant 4-layer KH. The geoelectric parameter were utilized for generating geoelectric sections thus indicating the lithological sequence in the environment (see Figure 8 a - c).

Table 1. Summary of geoelectric parameters obtained from VES data interpretation

VES No.	Resistivity (Ω-m) $\rho_1/\rho_2/\ldots/\rho_n$	Depths (m) $d_1/d_2/\ldots/d_{n-1}$	Curve Type
1	95/200/31/8535	1.8/4.8/11.4	KH
2	112/121/2914	1.2/10.4	A
3	48/350/40/2347	0.6/4.0/10.0	K H
4	48/58/2708	0.9/4.0	A
5	153/400/140/1028	1.2/5.5/16.2	KH
6	87/322/106/2490	0.8/3.4/9.7	KH
7	76/592/109/296	0.6/1.6/6.7	KH
8	110/244/106/3951	1.1/7.5/16.9	KH
9	65/373/19/300	0.6/1.9/5.4	KH
10	91/197/35/671	0.8/3.7/10.2	KH
11	84/26/347	2.8/9.8	H
12	53/35/1199	2.2/8.7	H
13	45/77/15/118	0.7/2.8/5.3	KH

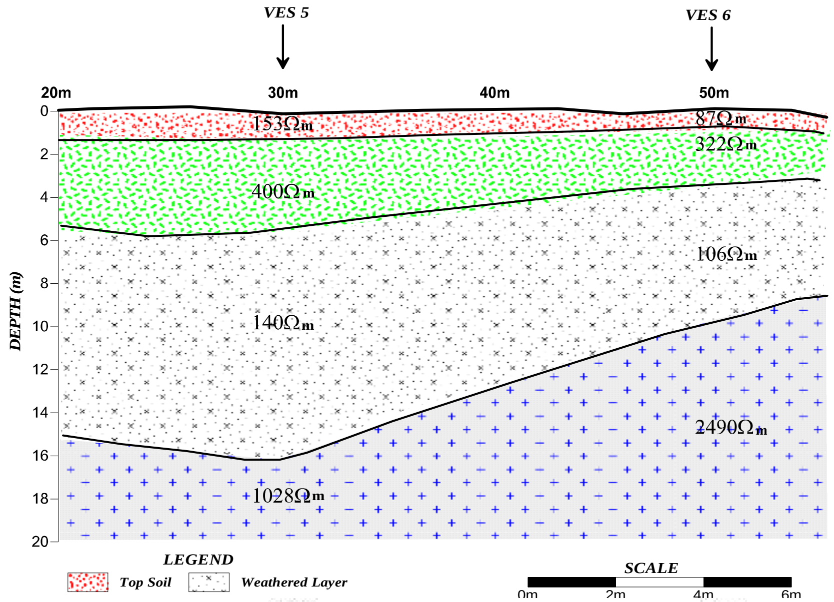


(a)

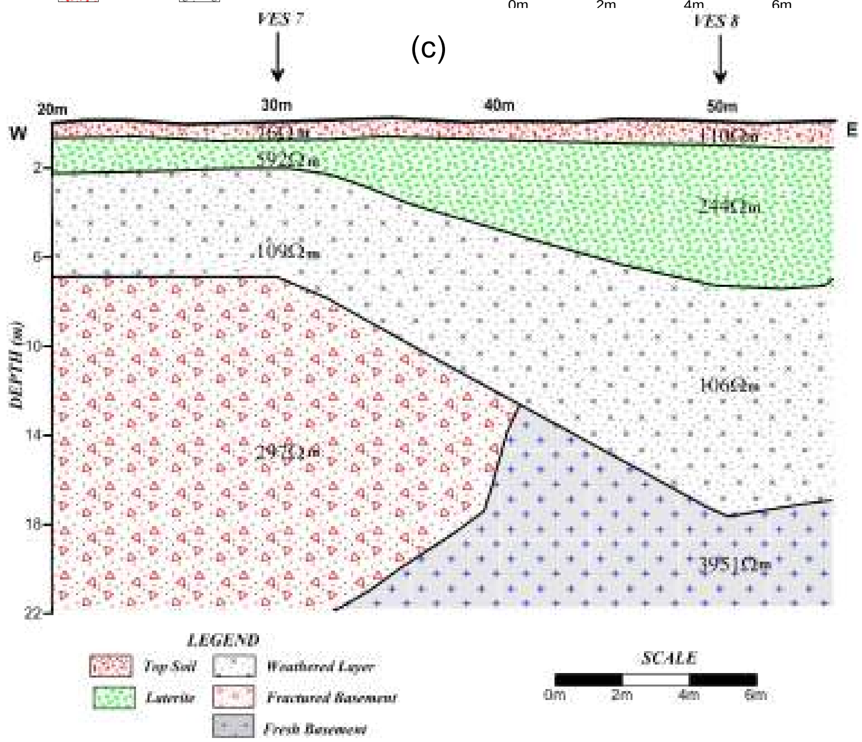


(b)

Figure 8a: Geoelectric sections of (a) Traverse 1 and (b) Traverse 2



(c)



(d)

Figure 8b: Geoelectric sections of (c) Traverse 3 and (d) Traverse 4

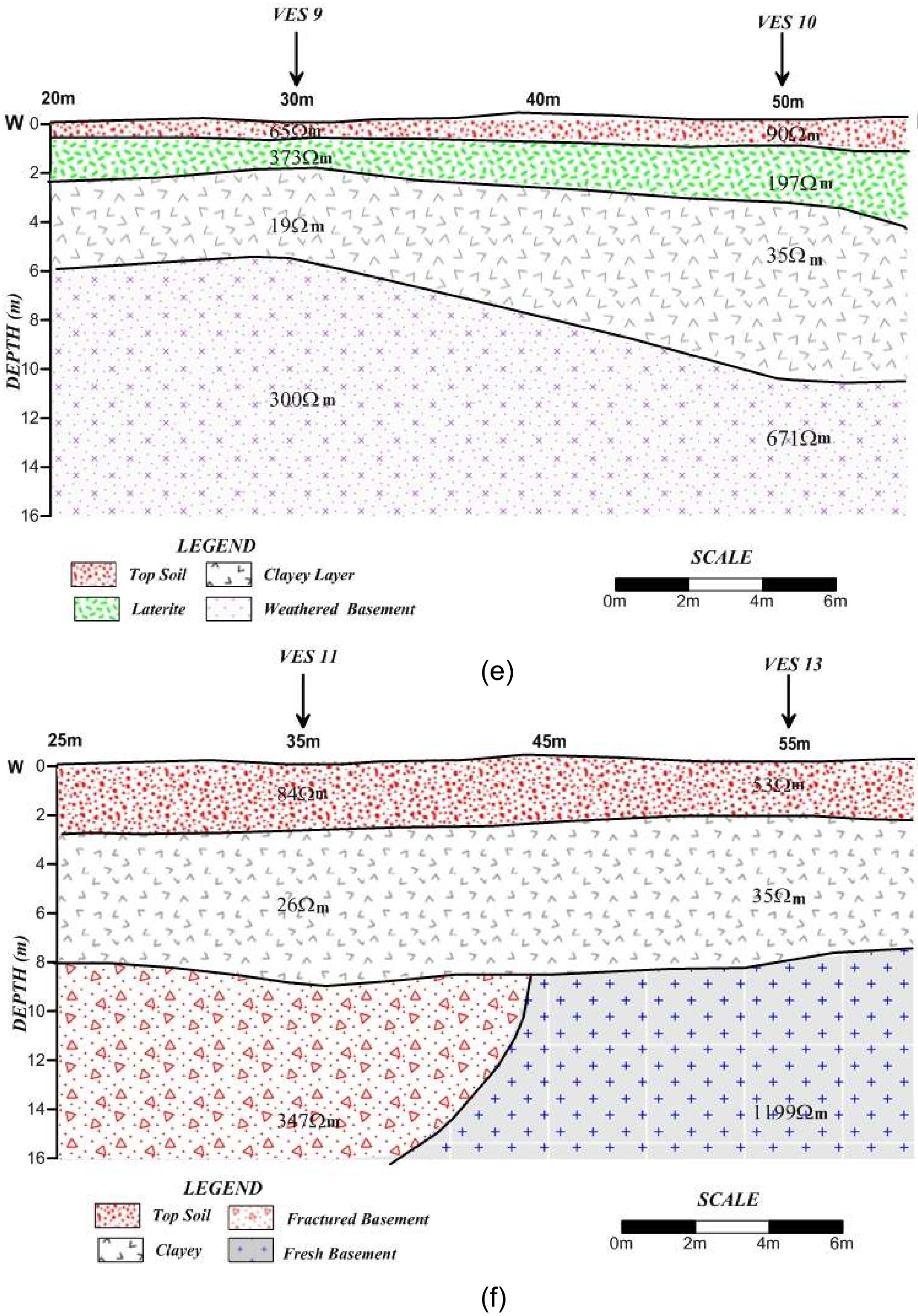


Figure 8c: Geoelectric sections of (e) Traverse 5 and (f) Traverse 6

5.4 Groundwater Potential Evaluation

In order to enhance hydro-geoelectric characterization of the area, the results of the gradient, dipole-dipole and Schlumberger soundings are integrated. The concept for the use of the Schlumberger - vertical electrical sounding output has been established in the study of Lenky et al., [19]. The underlying subsurface lithological layers delineated in the area include the topsoil, lateritic substratum, weathered layer, fractured basement and fresh basement. These geoelectric layers are laterally continuous within the limit of the traverses though with varying thickness values. It is worth mentioning that the most appropriate approach of calibrating as well as establishing accurate interpretation of the delineated geoelectric layers is via exploring borehole lithological information (Lenky et al., [19], Utom et al., [20]; Oborie and Udom [21], Aizebeokhai and Oyeyemi [18]). The borehole information often provides control on the lithologic contact delineation and consequently the subsurface stratigraphy. However, due to non-availability of borehole information in the study area, the lithological sequence underlying each VES location were interpreted adopting guides from previous works (Omosuyi et al., [22]; Ofomola et al., [23]) for the generation of Figures 8a – c.

Interpretation of the geoelectric sounding curves shows that overburden column thicknesses within the SEMS area of the university campus vary between 5.6 m and 10.4 m. The overburden materials are therefore very thin and essentially constitute shallow aquifer units at all the VES locations. Arising from the geoelectric characteristics presented by the results of this survey, groundwater potential is of poor ranking at VES 4, VES 9 and VES 13 while it is of low ranking at VES 1, VES 2, VES 3, VES 5, VES 6, VES 8, VES 10, VES 11 and VES 12. The delineated topsoil (vegetative matters) presents thickness and resistivity values in the range of 0.6 to 1.8 m and 48 to 112 Ω-m respectively. For the lateritic substratum, the resistivity values vary from 121 to 350 Ω-m with higher thickness values underlying the eastern flank. The weathered layer that is presumably water bearing is clayey due to its low resistivity characteristics (31 – 58 Ω-m). Marginally thick weathered materials (8.7 – 16.9 m) delineated beneath VES 1, VES 2, VES 3, VES 5, VES 6, VES 8, VES 10, VES 11 and VES 12 can plausibly support hand-dug well or shallow motorized borehole for abstracting some quantity of groundwater. However, fractured bedrock was delineated beneath VES 7 on Traverse 4 (northern car park area) that can apparently sustain fairly deep water abstraction motorized borehole with fairly adequate groundwater yield.

6. CONCLUSION

A hydrogeophysical characterization of a typical Crystalline Basement Complex environment has been carried out via combined use of different geoelectrical arrays. The study has established the disappointing hydrogeologic characteristics prevalent within the vicinity of the School of Earth and Mineral Science of Federal University of Technology, Akure, Nigeria. However shallow aquifer units have been identified in the area which can be developed for some groundwater exploitation with the fairly favourable hydrogeological point identified at VES 7 providing some relief. However, despite the high cost of implementing integrated multiple geoelectrical arrays in hydrogeophysical investigation the outcome may serve as compensation especially in cases where properties have been developed in a similar ubiquitous shallow bedrock terrain.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the assistance provided by the undergraduate students of 2012/2013 academic session and technologists of the Department of Applied Geophysics, Federal University of Technology, Akure during the fieldwork.

REFERENCES

1. Rubin, Y., Hubbard, S. S. eds Hydrogeophysics, water science and technology library, v. 50: Dordrecht, The Netherlands, Springer, 2006:523 p.
2. Sundararajan, N., Srinivas, Y., Chary, M. N., Nandakunmar, G., Chary, A .H. Delineation of structures favourable to groundwater occurrence employing seismic refraction method. A case study from Tiruvuru, Krishna district, Andhra Pradesh. Proceedings of Indian Academic Science (Earth Planet. Sci.), 113, (3), 2004:259-267.
3. Sultan, S. A.and Santos, F.M.. Combining TEM/resistivity joint inversion and magnetic data for groundwater exploration: application to the northern part of Greater Cairo, Egypt. Environmental Geology, 2009: 58, 521-529.
4. Sharma, S. P., Barawal, V.C. Delineation of groundwater –bearing fracures zone in hardrock area integrating very low frequency electromagnetic and resistivity data. Journal of Applied Geophysics2005: 57, 155-166.
5. Meju, M.A., Denton, P., Fenning, P. Surface NMR sounding and inversion to detect groundwater in key aquifers in England; comparison with VES-TEM methods. Journal of Applied Geophysics 2002: 50, 95-111.
6. Ehinola, O.A., Opoola, A.O., Adesokan, H.A. Emperical analysis of electromagnetic profiles for groundwater prospecting in rural areas of Ibadan Southwestern Nigeria. Hydrogeology Journal, 2006: 14, 613-624. doi:10.1007/s10040-005-0468-z.
7. Amadi, U.M.P., Nuruden, S.I.. Electromagnetic survey and the search for groundwater in the crystalline basement complex of Nigeria. Journal of Mining and Geology.1990: 26, 45-53.
8. Gruba, W., Rieger, R. High resolution seismic reflection –constraints and pitfall in groundwater exploration. RMZ-Materials Geoenvironment. 2003: 50, (1), 133-136.
9. Koefoed. O. Geosounding principles 1: resistivity sounding measurements. Elsevier Science Publishing Co, Amsterdam. 1979.
10. Jupp, D.L.B., Vozoff., K. Joint inversion of geophysical data. Geophys J Roy Astron Soc.1975: 42, 977–991.
11. Fitterman, D.V., Deszcz-Pan, M., Prinos, S.T. Helicopter electromagnetic survey of the Model Land Area, Southeastern Miami-Dade County, Florida: *U.S. Geological Survey Open-File Report* 2012: 1176, 77 p.
12. Hinnell, A.C., Ferre, T.P.A., Vrugt, J.A., Huisman, J.A., Moysey, S., Rings, J., Kowalsky, M.B. Improved extraction of hydrologic information from geophysical data through coupled hydrogeophysical inversion. *Water Resources Research,* 2010: *doi*:10.1029/2008WR007060.
13. Loke, M.H., Chambers, J.E., Rucker, D.F., Kuras, O., Wilkinson, P.B. Recent developments in the direct-current geoelectrical imaging method, *Journal of Applied Geophysics* doi: 10.1016/j.jappgeo.2013.02.017.
14. Slater, L. Near surface electrical characterization of hydraulic conductivity: from petrophysical properties to aquifer geometries - a review. *Surveys in Geophysics'*2007:*28,* 169-197.
15. Margiotta, S., Mazzone, F., Negri, S., Calora, M. The role of integrated high resolution stratigraphic and geophysic surveys for groundwater modelingLaboratorio di modellistica idrogeofisica e stratigrafica per i rischi naturali, Dipartimento di Scienza dei Materiali, Universit `a del Salento, via per Monteroni, Lecce 73100, Italy. 2008.
16. Loke, M.H., Barker, R.D. Practical techniques for 3D resistivity surveys and data inversion.Geophys. Prospect.1996b :44, 499–524.
17. Rahaman, M.A. Recent advances in the study of the Basement complex of Nigeria Precambrian Geology of Nigeria. A Publ. of Geological survey of Nigeria.1988. Pp.
18. Aizebeokhai, A.P. 2D and 3D geoelectrical resistivity imaging: theory and field design.Sci. Res. Essays.2010: 5 (23), 3592–3605.
19. Lenky, L,. Hamori, Z., Mihalffy, PInvestigating the hydrogeology of water – supply area using direct – current vertical electrical soundings. GEOPHYSICS. . 2005: VOL. 70, No 4.
20. Utom, A.U., Benard, I.O., Boniface, C.E.E., Nkechi, E. E., Harold, C.O. Estimation of subsurface hydrologicalparameters around Akwuke, Enugu, Nigeria using surface resistivity measurements. J. Geophys. Eng.2013: 10 (2013) 025016 (8pp).
21. Oborie, E., Udom, G.J. Determination of aquifer transmissivity using geoelectrical sounding and pumping test in pats of Bayelsa State, Nigeria. Journal of physical and Environmental Science Research. 2014:Vol. 2(2), pp. 32 – 40.

22. Omosuyi, G.O., Ojo, J.S., Enikanselu, P.A. Geophysical investigation for groundwater around Obanla-Obakekere in Akure area within the Basement Complex of Southwestern Nigeria. *Journal of Mining and Geology.*2003.
23. Ofomola, M.O., Adiat, K. A .N., Olayanju, G.M., Ako, B.D. Integrated geophysical methods for post foundation studies, Obanla Staff Quarters of the University of Technology, Akure, Nigeria. Pac J Sci Technol. 2009: 10(2):93–111.