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Integrated Geophysical Investigations for Groundwater Development in a Challenging Hard Rock Terrain: Case Study of SEMS Phase 3, Federal University of Technology, Akure Nigeria

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Abstract: *The School of Earth and Mineral Sciences (SEMS) of the Federal University of Technology, Akure Nigeria is facing an acute water shortage. At the moment the entire school depends only on a seasonal hand dug well and several hydro-geophysical surveys carried in the environment to locate possible point for groundwater development were unsuccessful. This study combined two techniques of electrical resistivity method; the Wenner-Schlumberger (a 2-Dimensional resistivity technique) and Schlumberger arrays (vertical electrical survey). The Wenner-Schlumberger array was deployed as a reconnaissance tool to determine probable locations for the vertical electrical sounding (VES) survey. The Wenner-Schlumberger survey was done along 8 traverses. Nine (9) VES points were selected based on the qualitative interpretation of Wenner-Schlumberger pseudo-sections. The vertical electrical sounding (VES) survey results delineated 3 - 4 geoelectric layers across the study area which corresponds to the topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock. The layers' resistivity varies from 52 - 132 Ωm, 29 - 513 Ωm, 24 - 76 Ωm and 1869 - 36,227 Ωm in topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock respectively. The layer thickness varies from 1.0 - 2.5 m, 0.7 - 9.3 m and 10.1 m - infinity in the topsoil, weathered layer and partially weathered/partially fractured basement. The geoelectric section along north-south direction reveals the presence of bedrock depression beneath VES 2 and this correlate well with traverse 1 Wenner-Schlumberger pseudosection. VES 2 has a highly saturated weathered layer with resistivity value of 24 Ωm and thickness of 10.1 m. The partially weathered basement layer can also serve as an aquifer based on its lower resistivity value (205 Ωm). VES 1 can also be considered for groundwater development since it has 3 subsurface layers that can serve as aquifer layer; the weathered layer, partially weathered basement and partially fractured basement. The resistivity of the weathered layer is 92 Ωm with thickness of 9.3 m. The partially weathered basement and partially fractured basement have resistivity values of 24 and 76 Ωm respectively, while the thickness value of the former is 10.2 m. VES 1 and VES 2 can be developed into a motorized borehole. VES 3 can also be considered for groundwater development due its low resistive (106 Ωm) weathered layer, but the layer is thin (5.6 m) and thus VES3 can only be considered for a hand dug well.*

Keywords: *Electrical resistivity method, Wenner-Schlumberger array, vertical electrical sounding, geologic contact, fractures, faults and bedrock depression.*

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I. Introduction

The Federal University of Technology, Akure situated in the southwestern part of Nigeria is a growing University with increasing population due to increase in number of academic programmes, staff and students. The increase in the University population though desirable is also over stretching the available facilities in the University. The School of Earth and Mineral Sciences (SEMS) which is presently domiciled in SEMS phase 1 and 2 buildings and the proposed phase 3 are struggling with acute shortage of potable water supply. Several hydro-geophysical surveys carried in the environment to locate possible location for groundwater development have not proven successful. At the moment the entire school depends only on a seasonal hand dug well located at phase 3. The peculiar nature of the study area indicates that the only possibility of finding a suitable point for groundwater development at SEMS is possible presence of rock contact, faults, fractures or bedrock depressions. Groundwater exploration have been done successfully in many places with similar geologic environment using different geophysical methods such as electrical resistivity, electromagnetic and magnetic (Olayinka and Olorunfemi,1992; Omosuyi et al, 2003; Abiola et al, 2009; Amadi et al, 2011; Olayanju et al, 2011; Mogaji et al, 2011; Adiat et al, 2012; Adiat et al, 2013; Akintorinwa and Olowolafe, 2013; Nwankwo et al, 2013; Adeyemo et al, 2014; Adeyemo et al, 2017). Geographic information system based multi-criteria approach have used successfully in hard rock terrain (Fashae et al, 2013). This study however employed the use of electrical resistivity method only in exploring for possible location for groundwater development in the proposed phase 3 of the School of Earth and Mineral Sciences (SEMS), Federal University of Technology, Akure, southwestern Nigeria.

II. The Study area

The study area is proposed phase 3 of the School of Earth and Mineral Sciences (SEMS), Federal University of Technology, Akure southwestern Nigeria. The study area is about 0.011354 km^2 in size (Figure 1). The area is moderately undulating with surface elevation ranging from 375 -390 m above sea level (Figure 1). The SEMS buildings (phase 1, 2 and the proposed phase 3) are located on an extensive fresh granite gneiss (Figure 2) which occurs at shallow depth beneath phase 1 and 2, and as a low lying outcrop at phase 3. The rocky nature of SEMS environment is a major reason for the poor groundwater potential of the area.

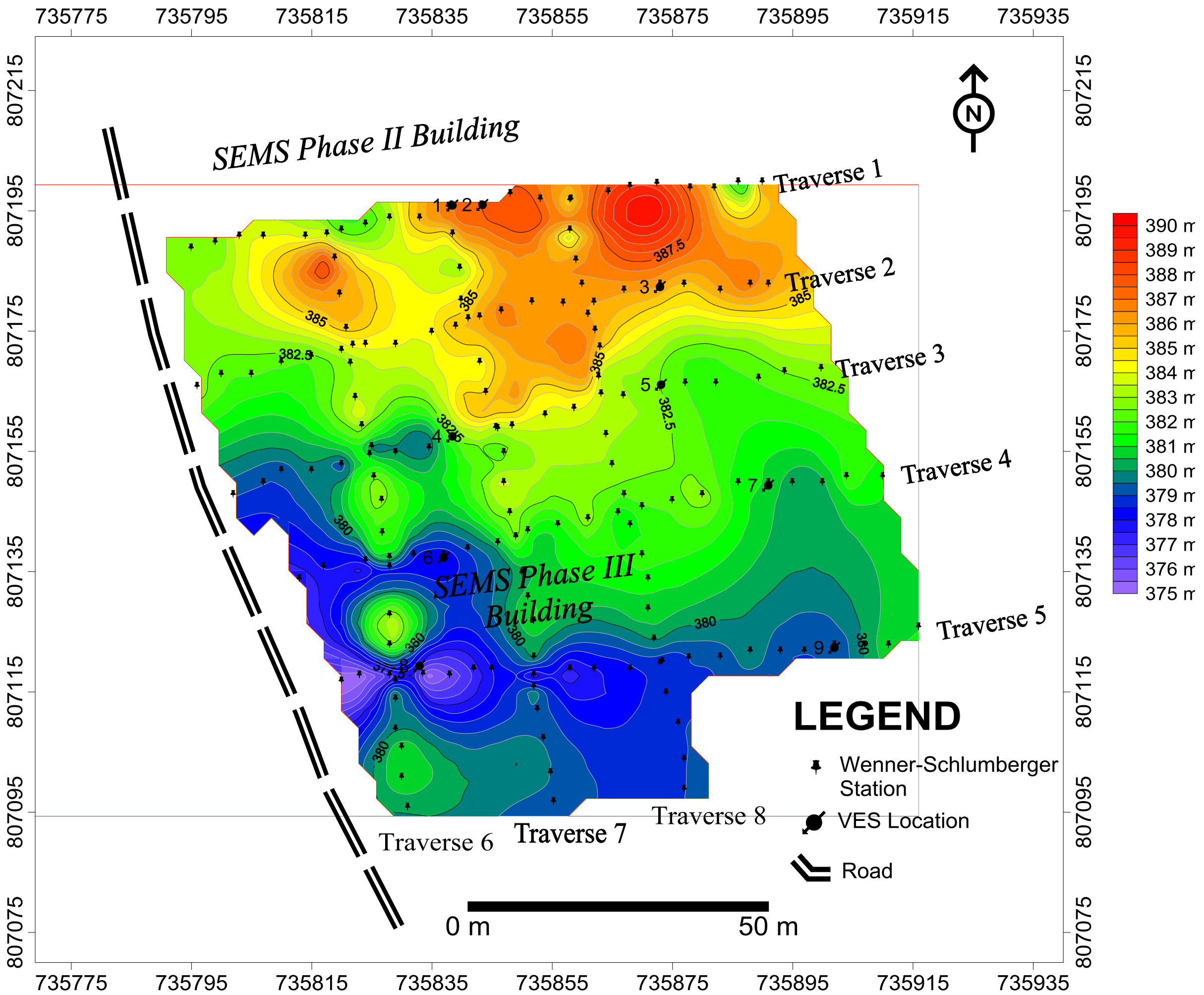


Figure 1: Topographic Map of FUTA SEMS Phase 3

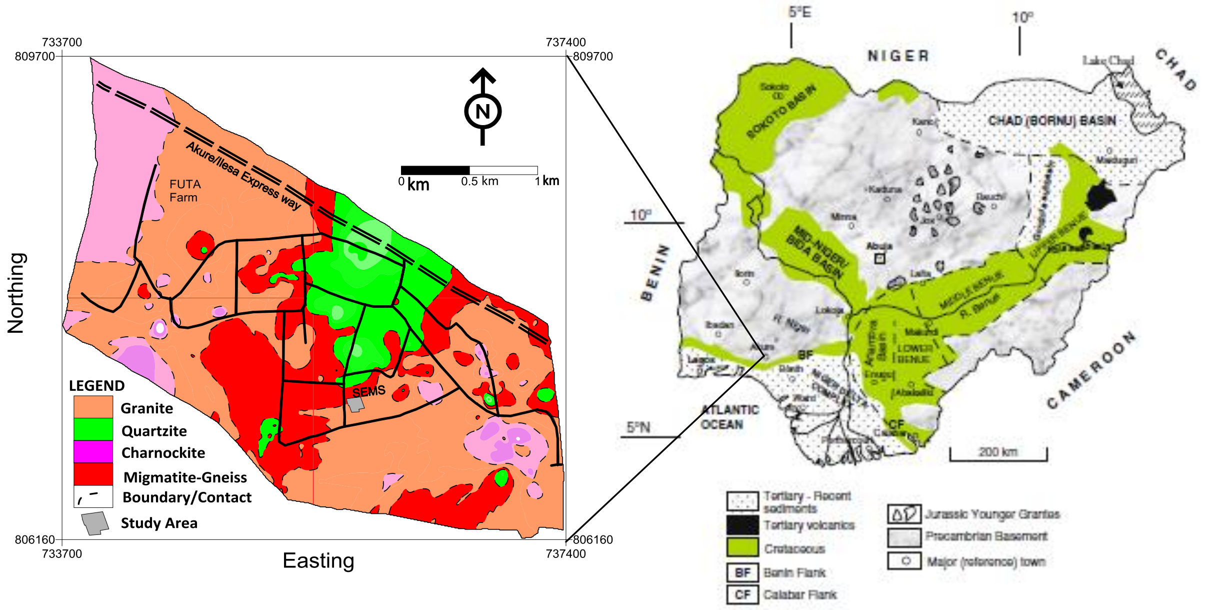


Figure 2: (Left) Modified Geological Map of FUTA (Source: Olayanju and Ojo, 2015) (Right) Simplified Geological Map of Nigeria (Source: Obaje, 2013)

III. Methodology

This study combined two techniques of electrical resistivity method; the Wenner-Schlumberger (a 2-dimensional resistivity technique) and Schlumberger arrays (vertical electrical sounding technique). The Wenner-Schlumberger array was used as a reconnaissance tool to determine probable locations for the vertical electrical sounding (VES) survey. The Wenner-Schlumberger was carried along 5 west-east traverses and 3 north-south traverses (Figure 3). All the 8 traverses were 100 m long and their data were inverted using Dipro^{TM} 2D inversion programme (Dipro for Windows, 2000) and the inverted results were presented as pseudo-sections to enable their qualitative interpretations.

The Wenner-Schlumberger array apparent resistivity was derived using the following relationship;

$\rho_a(\text{Wenner-Schlumberger}) = R\pi n(n+1)a$ (equation 1)

Where,
R = Resistance
n = expansion factor
a = electrode spacing

Nine (9) locations (Figure 3) were selected for vertical electrical sounding survey based on the qualitative interpretation of Wenner-Schlumberger pseudo-sections. The zones of depressions, fractures, faults and contact zones were selected as VES points since groundwater normally flows from higher elevation towards lower elevation and along easy pathways (Delleur, 1999; Fashae et al, 2013 and Adeyemo et al, 2014). Schlumberger array was adopted for the VES survey and the maximum current electrode spread (AB/2) of 65 m was used for the VES survey (Figure 4). The VES data were interpreted using partial curve matching method involving the use of 2-layer Schlumberger master curve and auxiliary curves (Zohdy, 1965 and Koefoed, 1979) and thereafter a 1-D forward modeling programme, Window Resist version 1.0 (Vander Velpen, 1989) was used to enhance the resultant geoelectric parameters (layer thickness and resistivity). The VES results were presented as model curves, table and a geo-section.

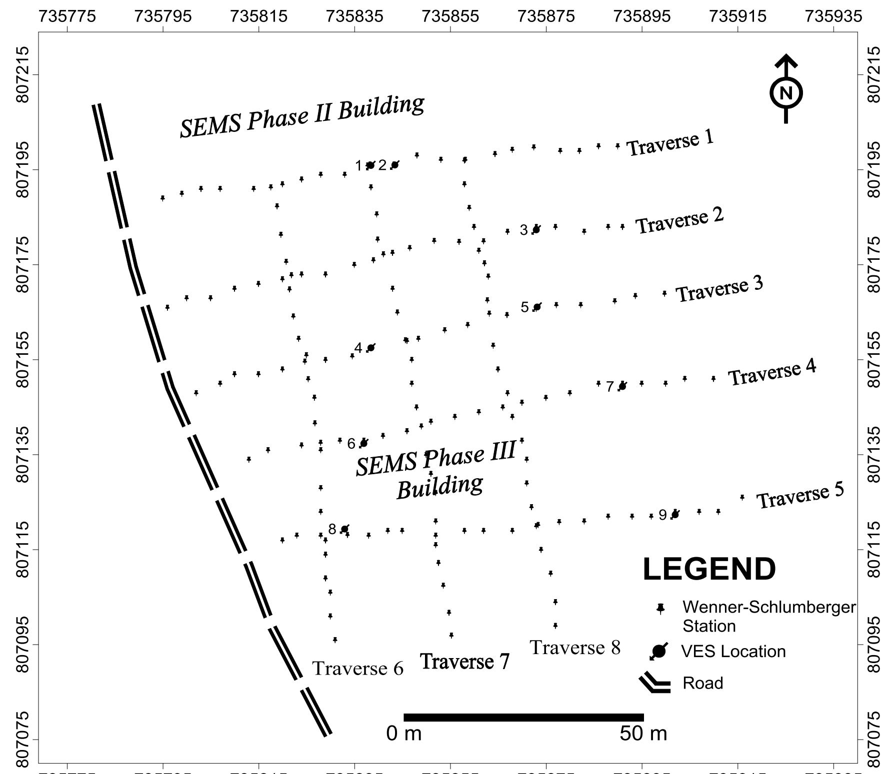


Figure 3: Layout map of FUTA SEMS Phase 3 showing the Wenner-Schlumberger and VES stations

The Schlumberger array apparent resistivity was derived using the following relationship;

$\rho_a(_{\text{Schlumberge}}r) = \rho_a = 2\pi R \left[\frac{L^2 - l^2}{4l}\right]$ (equation 2)

Where,
R = Resistance
L = half distance between the two current electrodes
l = half distance between the potential electrodes

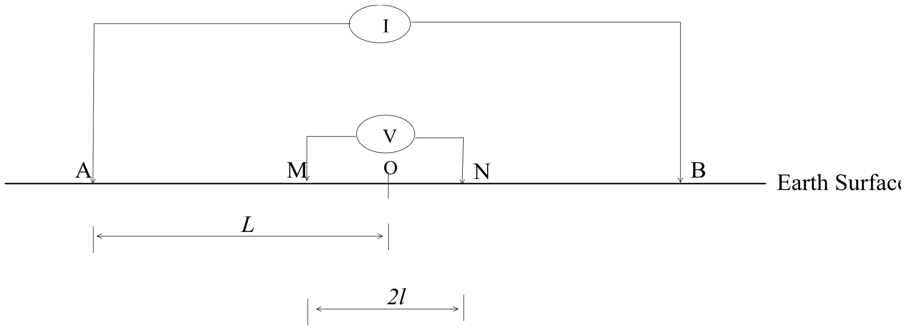


Figure 4: Schlumberger Electrode Configuration (Source: Zohdy et. al., 1974).

IV. Discussion of Results

Wenner-Schlumberger Pseudo-sections

Figure 5 is the first Wenner-Schlumberger pseudo-section, along traverse 1 in the west-east direction. The 100 m long traverse is probably along a migmatite-gneiss and granite contact zone (Figure 2) and can also be a depression zone. Geologic contact, fractured and bedrock depressions are generally considered as area with high groundwater potential in the basement environment (Fashae et al, 2013; Adeyemo et al, 2014 and Adeyemo et al, 2017). A low resistive zones was delineated around distance 35 - 60 m along this pseudo-section. This is probable zone for groundwater development along this traverse. Distance 50 and 55 along this traverse was selected as vertical electrical sounding (VES) points VES 1 and VES 2 respectively.

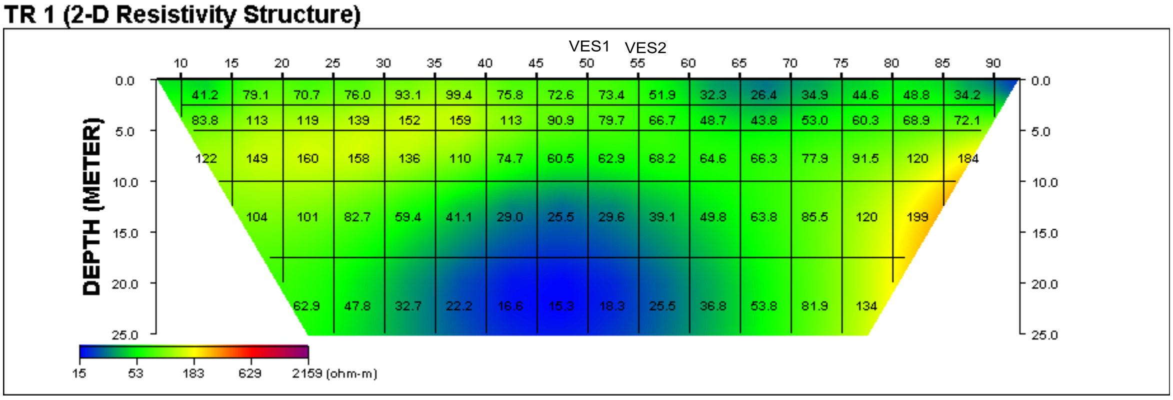


Figure 5: Wenner-Schlumberger pseudo-section for traverse 1

Figure 6 is the second Wenner-Schlumberger pseudo-section, along traverse 2 in the west-east direction. The traverse is also 100 m long in length. The Wenner-Schlumberger pseudo-section reveals the presence of bedrock depression at the extreme east of the traverse from distance 70 - 100 m. zone. This zone of depression was characterized by low resistive geologic materials which can serve as good aquifers. Consequently, distance 80 m was selected as a point for vertical electrical sounding (VES 3).

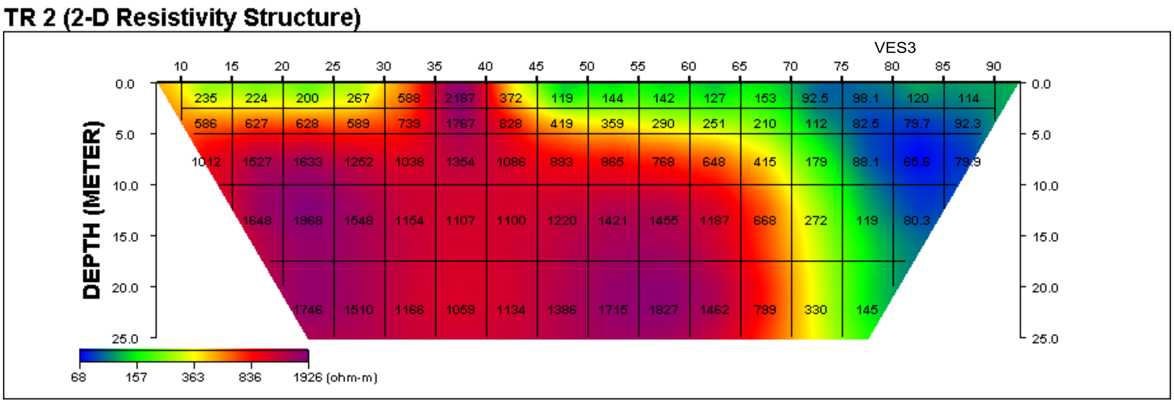


Figure 6: Wenner-Schlumberger pseudo-section for traverse 2

Figure 7 is the third Wenner-Schlumberger pseudo-section, along traverse 3 in the west-east direction. The traverse is 100 m long in length as well. There is a lot of similarity between this traverse 3 and traverse 2. The Wenner-Schlumberger pseudo-section reveals the presence of bedrock depression at distances 35 m and the extreme east of the traverse from distance 70 - 100 m. These zones of depression were characterized by low resistive geologic materials which can serve as good aquifers. Distances 35 and 80 m were selected as points for vertical electrical sounding (VES 4 and VES 5).

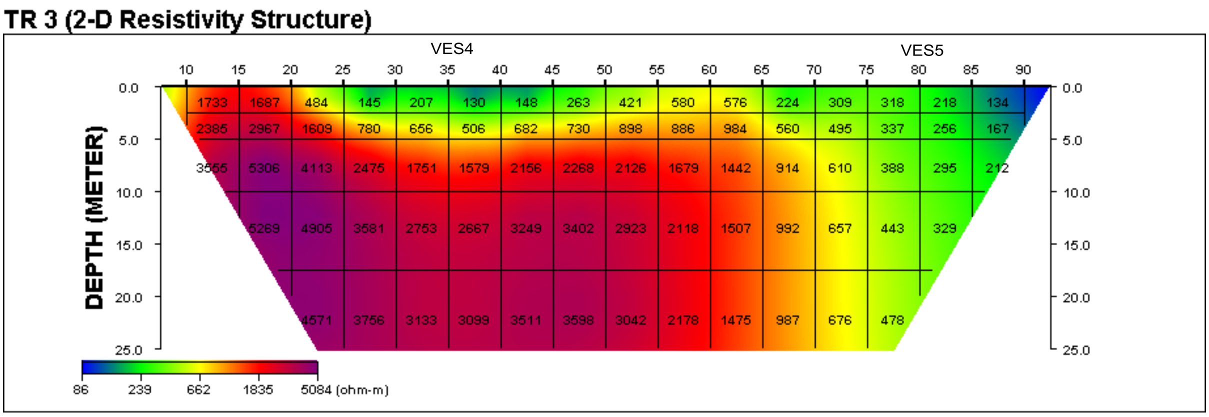


Figure 7: Wenner-Schlumberger pseudo-section for traverse 3

Figure 8 is the fourth Wenner-Schlumberger pseudo-section, along traverse 4 in the west-east direction. The traverse is 100 m long in length just the previous traverses. The Wenner-Schlumberger pseudo-section reveals the presence of bedrock depressions at both extremes. Bedrock depressions were delineated at distances 0 - 40 m and distances 70 - 100 m. These zones of depression were characterized by low resistive geologic materials which can serve as good aquifers. Consequently, distances 25 and 85 m were selected as points for vertical electrical sounding (VES 6 and VES 7).

TR 4 (2-D Resistivity Structure)

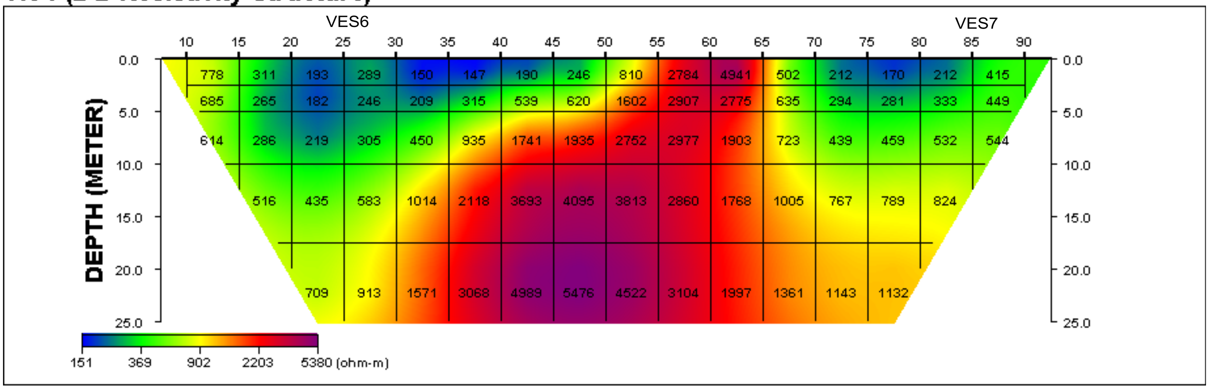


Figure 8: Wenner-Schlumberger pseudo-section for traverse 4

Figure 9 is the fifth Wenner-Schlumberger pseudo-section, along traverse 5 in the west-east direction. The traverse is 100 m long in length just the previous traverses. The Wenner-Schlumberger pseudo-section reveals the presence of shallow bedrock depressions at distances 0 - 25 m, 45 - 55 m and 70 - 100 m. These zones of depression were characterized by low resistive geologic materials which can serve as good aquifers. Consequently, distances 25 and 85 m were selected as points for vertical electrical sounding (VES 8 and VES 9).

TR 5 (2-D Resistivity Structure)

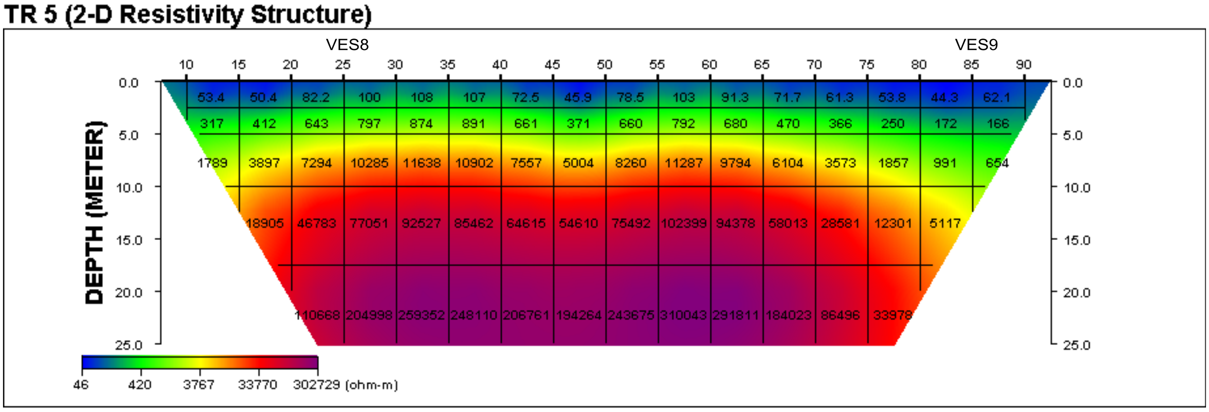


Figure 9: Wenner-Schlumberger pseudo-section for traverse 5

Figure 10 is the sixth Wenner-Schlumberger pseudo-section, along traverse 6 in the north-south direction. The traverse is 100 m long in length just the west-east traverses. The Wenner-Schlumberger pseudo-section only reveals a minor bedrock depression at distances 60 - 75 m. This zone of depression was not considered as a good potential for groundwater development due to its shallow nature and consequently no point was selected along this traverse for vertical electrical sounding.

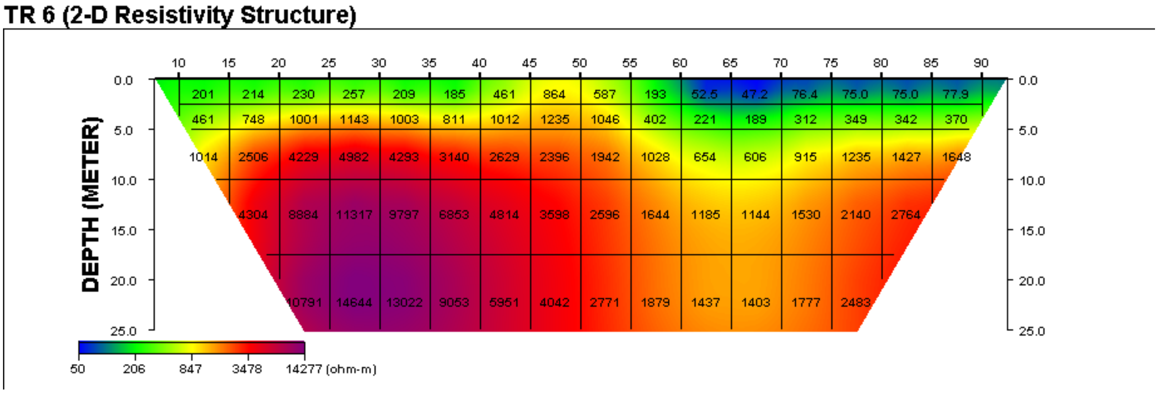


Figure 10: Wenner-Schlumberger pseudo-section for traverse 6

Figure 11 is the seventh Wenner-Schlumberger pseudo-section, along traverse 7 in the north-south direction. The Wenner-Schlumberger pseudo-section only reveals a minor bedrock depression at distances 0 - 20 m and 70 - 100m. Distance 0 m along this traverse corresponds to distance 55 m (VES 1) along traverse 1 (west - east direction). The zone of depression delineated around distances 0 - 20 m along this traverse is probably a contact between migmatite-gneiss and granite. Rock contact, fracture and fault zones are usually considered as a good potential for groundwater development.

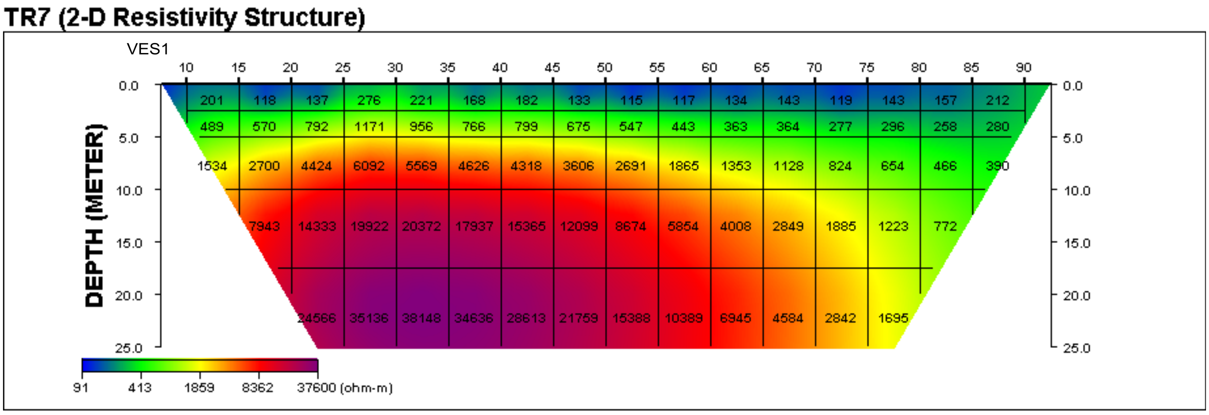


Figure 11: Wenner-Schlumberger pseudo-section for traverse 7

Figure 12 is the eight Wenner-Schlumberger pseudo-section, along traverse 8 in north-south direction. The traverse is 100 m long in length like other previous traverses. The Wenner-Schlumberger pseudo-section delineated the presence of shallow bedrock depressions at distances 0 - 15 m and 80 - 100 m. These zones of depression were probably characterized by low resistive geologic materials which can serve as good aquifers. No points were selected for vertical electrical sounding along this traverse due to presence of rock outcrops at the southern and eastern sides of the traverse.

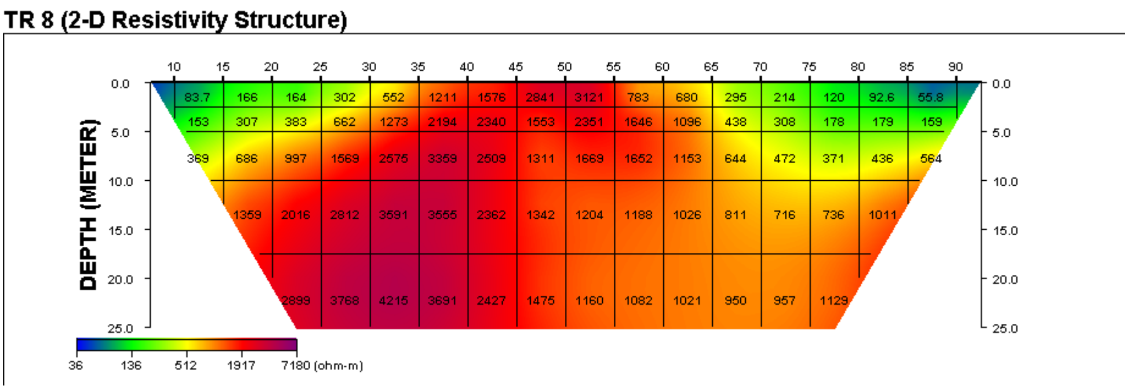


Figure 12: Wenner-Schlumberger pseudo-section for traverse 8

Vertical electrical Sounding Results

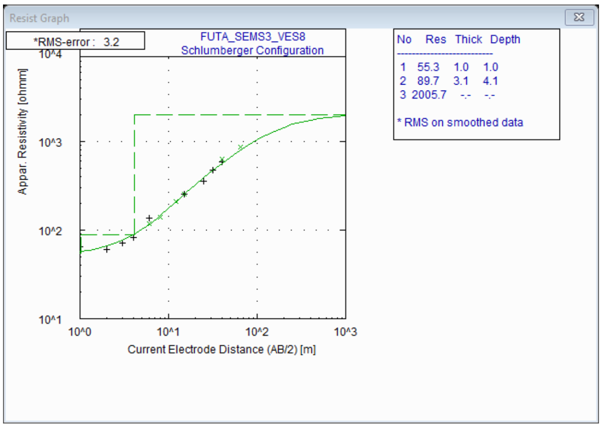
The vertical electrical sounding (VES) survey results delineated 3 - 4 geoelectric layers across the study area (Table 1 and Figure 13). The geoelectric layers corresponds to the topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock. The layers' resistivity varies from 52 - 132 Ωm, 29 - 513 Ωm, 24 - 76 Ωm and 1869 - 36,227 Ωm in topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock respectively. The layer thickness varies from 1.0 - 2.5 m, 0.7 - 9.3 m and 10.1 m - infinity the topsoil, weathered layer and partially weathered/partially fractured basement. From the VES results four different curve types were obtained from the study area, namely A, AK, HK and KH types (Figure 12 and Table 1). The HK and KH curve types are the only curve types with meaningful hydro-geophysical significance. The A curve is the predominant type with frequency of 5, followed by type KH with frequency of 2, while AK and HK curve types occurs only once (Table 1).

The VES results were also presented as geoelectric section which connects VES points 2, 4, 6 and 8 along north-south direction (Figure 14). The geosection also reveal the presence of bedrock depression beneath VES2 which was earlier delineated in traverse 1 Wenner-Schlumberger pseudosection (Figure 4). The geosection shows that VES2 is the only point where groundwater development is feasible along this geosection. VES2 has a highly saturated weathered layer with resistivity value of 24 Ωm and thickness of 10.1 m. The partially weathered basement layer can also serve as an aquifer based on its lower resistivity value (205 Ωm) but its total thickness cannot be determined because it is the last layer delineated beneath this VES point. The presence of the bedrock depression beneath VES2 indicates that this part of the traverse can serve as collecting trough for groundwater to accumulation.

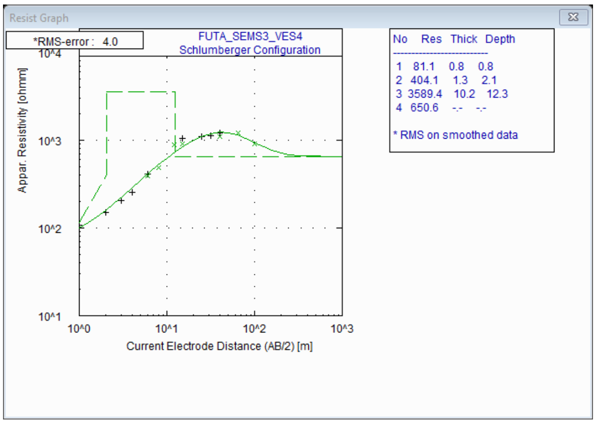
In addition to VES 2, VES 1 is another point that can be considered for groundwater development. VES 1 has 3 subsurface layers that can serve as aquifer layer; the weathered layer, partially weathered basement and partially fractured basement. The resistivity of the weathered layer is 92 Ωm with thickness of 9.3 m, this indicates that the layer can be considered as an aquifer and its thickness is appreciable. The partially weathered basement and partially fractured basement have resistivity values of 24 and 76 Ωm respectively, while the thickness value of the former layer is 10.2 m. this suggest that the two subsurface geoelectric layers can yield appreciable volume of groundwater. VES 1 and VES 2 can be developed into a motorized borehole. VES 3 can also be considered due the low resistivity (106 Ωm) value observed in its weathered layer, but the layer is thin (5.6 m) thus VES 3 can only be considered for a hand dug well.

Table 1: Vertical Electric Sounding Results

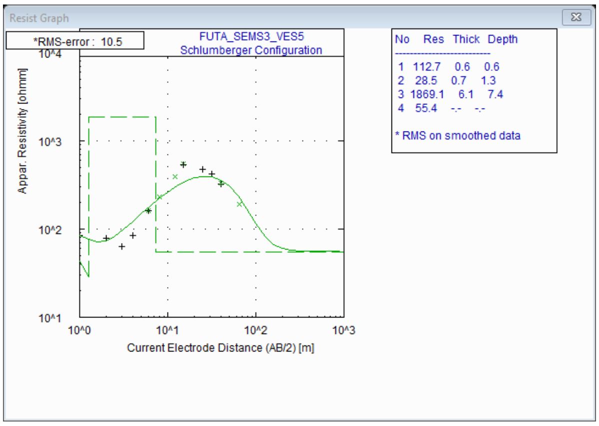
VES NO	Layer Resistivity (Ωm) $\rho_1/\rho_2/\rho_3\ldots\ldots h_n$	Layer Thickness (m) $h_1/h_2/h_3\ldots\ldots h_n$	No of Layer	Curve Type
1	65/ 92/ 24/ 76	1.1/ 9.3/ 10.2	4	KH
2	57/ 187/ 24/ 205	2.5/ 4.0/ 10.1	4	KH
3	102/ 106/ 2948	0.8/ 5.6	3	A
4	81/ 404/ 3589/ 651	0.8/ 1.3/ 10.2	4	AK
5	113/ 29/ 1869/ 55	0.6/ 0.7/ 6.1	4	HK
6	56/ 513/ 6851	1.3/ 1.9	3	A
7	132/ 3456/ 36227	1.0/ 1.2	3	A
8	55/90/ 2006	1.0/ 3.1	3	A
9	52/ 60/ 3961	1.2/ 2.1	3	A



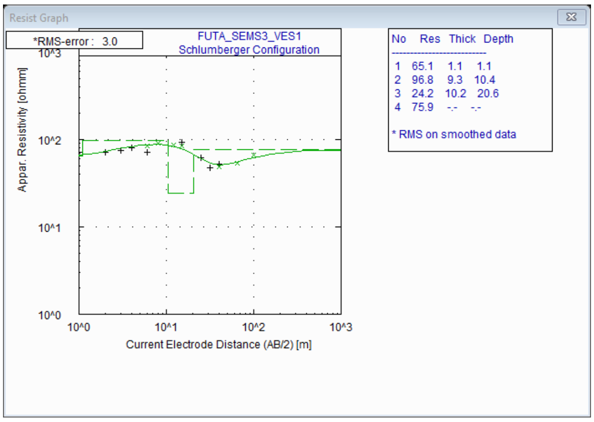
(a) A curve type



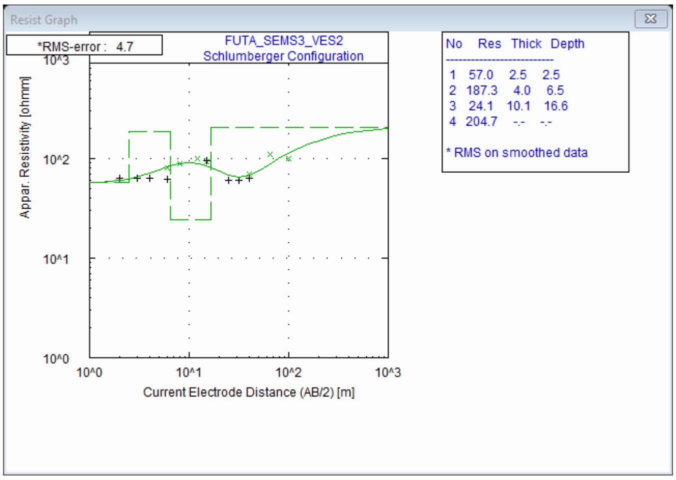
(b) AK curve type



(c) HK curve type



(d) KH curve type



(e) KH curve type

Figure 13$_{a\text{-}e}$: Typical VES curves obtained from SEMS phase 3

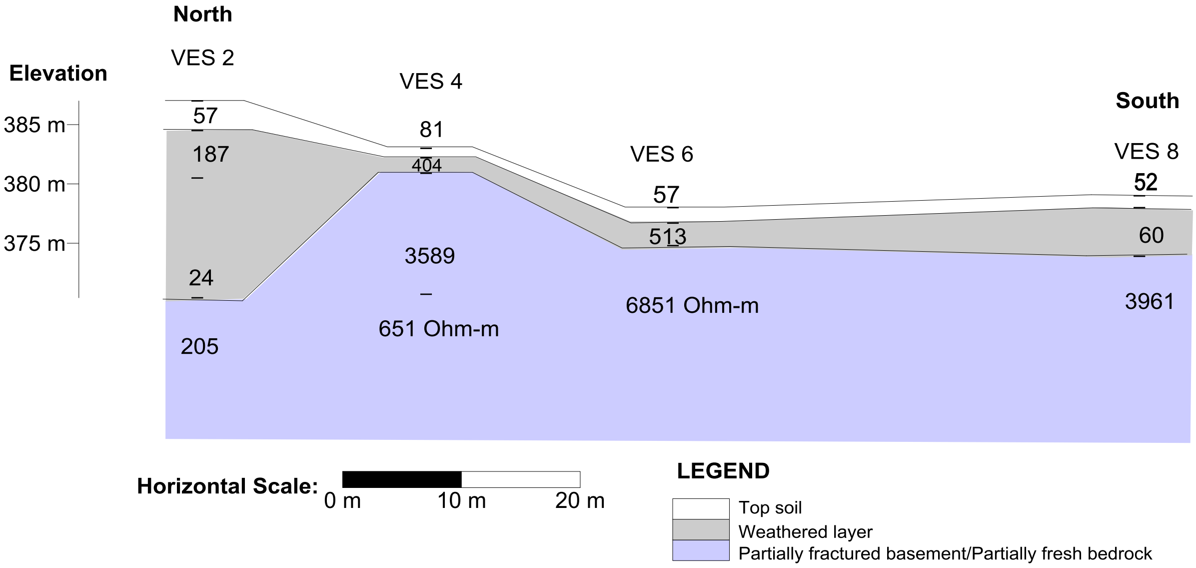


Figure 14: Geoelectric section connecting VES 2, 4, 6 and 8 at SEMS phase 3

V. Conclusion and Recommendation

The School of Earth and Mineral Sciences (SEMS) of the Federal University of Technology, Akure Nigeria is experiencing an acute water shortage. The entire school depends only on a seasonal hand dug well and several hydro-geophysical surveys carried in the school environment to locate possible location for groundwater development have proved abortive. This study combined two techniques of electrical resistivity method namely the Wenner-Schlumberger (a 2-Dimensional resistivity technique) and Schlumberger arrays (vertical electrical survey). The Wenner-Schlumberger array was utilized as a reconnaissance tool to determine probable locations for the follow up vertical electrical sounding (VES) survey. The Wenner-Schlumberger was carried along 5 west-east traverses and 3 north-south traverses. Nine (9) VES locations were selected based on the qualitative interpretation of Wenner-Schlumberger pseudo-sections. The vertical electrical sounding (VES) survey results delineated 3 - 4 geoelectric layers across the study area. The geoelectric layers corresponds to the topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock. The layers' resistivity varies from 52 - 132 Ωm, 29 - 513 Ωm, 24 - 76 Ωm and 1869 - 36,227 Ωm in topsoil, weathered layer, partially weathered/partially fractured basement and the presumed fresh bedrock respectively. The layer thickness varies from 1.0 - 2.5 m, 0.7 - 9.3 m and 10.1 m - infinity in the topsoil, weathered layer and partially weathered/partially fractured basement. The geoelectric section which connects VES 2, 4, 6 and 8 along north-south direction reveals the presence of bedrock depression beneath VES 2 and this correlate well the traverse 1 Wenner-Schlumberger pseudosection. VES 2 has a highly saturated weathered layer with resistivity value of 24 Ωm and thickness of 10.1 m. The partially weathered basement layer can also serve as an aquifer based on its lower resistivity value (205 Ωm). VES 1 can also be considered for groundwater development because it has 3 subsurface layers that can serve as aquifer layer; the weathered layer, partially weathered basement and partially fractured basement. The resistivity of the weathered layer is 92 Ωm with thickness of 9.3 m. The partially weathered basement and partially fractured basement have resistivity values of 24 and 76 Ωm respectively, while the thickness value of the partially weathered basement is 10.2 m. VES 1 and VES 2 can be developed into a motorized borehole. VES 3 can also be considered for groundwater development due the low resistivity (106 Ωm) value observed in its weathered layer, but however the layer is thin (5.6 m) thus VES 3 can only be considered for a hand dug well.

Acknowledgments

The authors acknowledge numerous students of Applied Geophysics Department who assisted in acquiring data for this work.

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