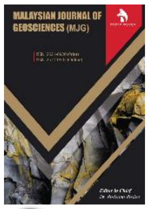
ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0920 (Print)
ISSN: 2521-0602 (Online)
CODEN: MJGAAN

Malaysian Journal of Geosciences (MJG)

DOI: http://doi.org/10.26480/mjg.01.2024.01.09



CrossMark

RESEARCH ARTICLE

DELINEATION OF GROUNDWATER POTENTIAL USING ELECTRICAL RESISTIVITY IMAGING TECHNIQUES AT IBULE AKURE, SOUTHWESTERN NIGERIA

Adeniyi Ariyo Emmanuel[a], Osisanya O. Wasiu[b*], Moses Oghenenyoreme Eyankware[c]

[a]Department of Applied Geophysics, Federal University of Technology, Akure, Ondo State, Nigeria.
[b]Department of Physics, University of Benin, Benin City, Edo state, Nigeria
[c]Department of Geology, Denis Osadadey University, Delta State, Nigeria.
[*]Corresponding Author's Email: wasiu.osisanya@uniben.edu

ARTICLE DETAILS

Article History:

Received 18 November 2023
Revised 20 December 2023
Accepted 28 January 2024
Available online 30 January 2024

ABSTRACT

Population growth and heightened water demand in the study area, exacerbated by insufficient surface and groundwater resources, lead to severe water shortages, particularly during the dry season. In response, our study in Atibioke Street, Aule Road, Ibulesoro, Akure, Ondo State, employed Horizontal Profiling (HP) and Vertical Electrical Sounding (VES) with electrical resistivity methods. Conducted across three traverses at 5m intervals, with probing levels from 1 to 5, the Combined HP and VES generated 2-D pseudosections, highlighting features and conducive layers for groundwater accumulation. Using Schlumberger configuration with electrode spacings from 1 to 100 m, three Vertical Electrical Soundings classified subsurface layers into Topsoil, Weathered Layer, and Fresh Bedrock within the basement complex terrain. The study emphasized the significance of electrical resistivity in assessing groundwater potential, with recommendations highlighting the unsuitability of VES 1 and VES 2 for exploitation, while VES 3 exhibited favorable conditions. Overall groundwater potential was rated as medium, emphasizing the need for alternative water supply solutions. VES 3 was recommended for well drilling based on promising characteristics, concluding with a suggestion to use these findings as a reference for future geophysical investigations.

KEYWORDS

Electrode, Schlumberger, Resistivity, Vertical electrical sounding, Akure, Nigeria.

1. INTRODUCTION

Groundwater, described as nature's hidden treasure, is an essential resource with unalloyed needs that persist in importance (Nwankwo, 2011). Its significance is magnified by the impending shortage of surface water predicted over the next decades, particularly in sub-Saharan African countries (Oyeyemi et al., 2017). This prediction stems from factors such as the exhaustion of existing supplies, increased consumption, and contamination, making groundwater a vital substitute for human use (Adagunodo, 2017a). In comparison to other water sources like streams and rivers, groundwater stands out for its hygienic attributes, boasting excellent natural microbiological quality and generally adequate chemical quality for diverse uses (Obaje, 2015). Its utility extends to domestic, industrial, and agricultural sectors (Olafisoye et al., 2012). To comprehend the mystery of groundwater, a comprehensive geophysical and hydrogeological understanding of aquifer types and their spatial distribution becomes imperative for characterizing hydraulic zones in an area.

Surface geophysical surveys emerge as indispensable tools in groundwater exploration, offering the advantage of cost savings in borehole construction by precisely locating target aquifers before drilling (Akintorinwa et al., 2013). Among the various surface geophysical techniques, the electrical resistivity method holds a prominent position and is widely adopted in groundwater exploration campaigns (Oyeyemi et al., 2017; Sunmonu et al., 2015; Adagunodo et al., 2017). Vertical Electrical Sounding (VES), a configuration within the electrical resistivity method, stands out as the most utilized, especially in developing nations, justified by its cost-effectiveness, deep subsurface mapping capabilities, and ability to cover large land expanses (Abudulawal et al., 2015).

While VES measures resistivity variations in one dimension, it proves highly effective in characterizing basement geology and exploring groundwater (Nwankwo, 2011; Adagunodo et al., 2013; Abudulawal et al., 2015). The reliance on resistivity alone for identifying promising aquifers within a basement terrain is cautioned, as fractured and weathered activities may impart secondary porosity and permeability to the rocks, rendering them suitable aquifers (Adelusi et al., 2014).

The study area, Ibule, situated near Akure in the Precambrian basement complex of Southwestern Nigeria, faces challenges of water scarcity exacerbated by population growth. The hydrogeological settings comprise Precambrian basement rocks, constituting one of the four hydrogeological provinces in sub-Saharan Africa (Sunmonu et al., 2012). Understanding the geological nature of the terrain is crucial for groundwater potential mapping, particularly in basement terrains where aquifers may be compartmentalized (Sunmonu et al., 2012; Abudulawal et al., 2015; Badejo et al., 2015). Others carried out an investigation with the aim of delineating the subsurface geological sequences, determining their geoelectric parameters, identifying the composition of subsurface layers and soils best related for high yield of cocoa. It was reported that fairly thick subsoil spectrum from the topsoil to weathered - partially weathered column, formed from the weathered products from rock units including Grey Gneiss - Charnockite rocks, make up the most important underlying lithologic units most suitable for optimal cultivation of cocoa crop in the study area (Abayomi et al., 2021).

Quick Response Code	Access this article online	
	Website: www.myjgeosc.com	**DOI:** 10.26480/mjg.01.2024.01.09

Cite The Article: Adeniyi Ariyo Emmanuel, Osisanya O. Wasiu, Moses Oghenenyoreme Eyankware (2024). Delineation of Groundwater Potential Using Electrical Resistivity Imaging Techniques at Ibule Akure, Southwestern Nigeria. *Malaysian Journal of Geosciences, 8(1): 01-09.*

Ibule, experiencing severe water shortages during dry seasons, necessitates a focused effort to map groundwater potential and identify suitable points for development. The objectives of this study are outlined as follows:

1. Produce a 2D resistivity image at the subsurface.
2. Locate and identify potential water-bearing zones in a typical basement complex terrain.
3. Identify the geoelectric sequence/subsurface lithology of the area.
4. Predict suitable points for groundwater development and abstraction in the study area.

By addressing these objectives, the study aims to contribute valuable insights into groundwater exploration and alleviate the water supply challenges faced by the residents of Ibule.

1.1 Location and Climate

The study area is located in Atibioke Street, Aule Road, Ibulesoro, Akure South L.G.A, Ondo State. Its geographical coordinates extends from 0732975E - 0733056E along the easting and 0808634N - 0808731N along the northing on the WGS 84 system and UTM-31N datum (Figure 1).The topography of the study area is gently undulating. The site is located within the sub-equatorial climatic belt with tropical rain-forest vegetation. The mean annual temperature is 24°C-27°C, while the annual rainfall varies between 1500mm and 3500mm (Ogunrayi et al., 2016h). Its elevation ranges from 350m – 352m. Also, the temperature of the study area (using the general temperature of Akure) is between 25°C-30°C (Agro-climatological and Ecological Monitoring unit Akure, 1998). As at the time of this probe, the study area consists of fast-growing shrubs and weeds. An intensive human activity over the years has depleted the natural vegetation of the area.

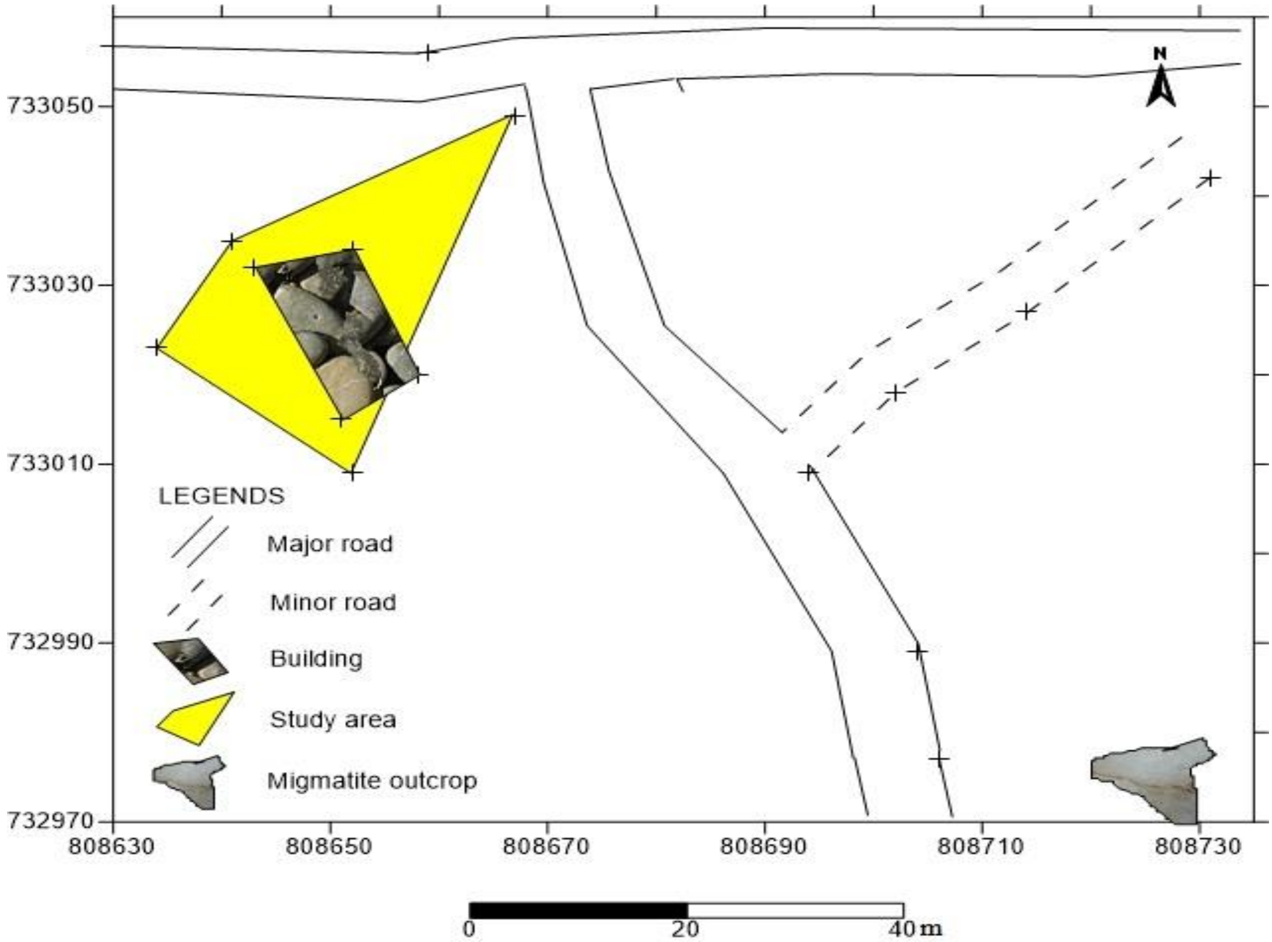


Figure 1: Location map of the study area

1.2 Geology of the study area

The study area is underlain by Precambrian basement complex of southwestern Nigeria, which is part of the basement complex of Nigeria. The Basement rocks are found in four broad segments; in the northwest, southwest, northeast and southeast (Mambilla Plateau and Oban Massif) segments.

Therefore the geology of the study area can only be explained within the ambit of the geology of the basement complex of southwestern Nigeria. According to the works of Rahman (1976, 1989), he recognized five major groups of rocks in this area which includes the following:

a) Unmetamorphosed crosscutting dolerite and syenite dykes

b) Older granite

i. Porphyroblastic Older granite

ii. Granite gneiss

c) Charnokite rocks

d) Slightly migmatised to unmigmatisedpara-schists and meta-igneous rocks

e) Migmatite-gneiss complex rocks

1.3 Dolerite Dykes

This rock type is believed to be the youngest member of the basement complex (Rahaman 1988). They occur as tabular, unmetamorphosed bodies discordant to the foliation plane of the country rock (law of crosscutting). Dykes vary greatly in thickness from a few millimeters to many metres but widths of two to seven metres are most common. Dolerite are also fracture filling with sharp contact with the host rock. The rock is generally dark coloured and fine grained. Mineral constituents includes but not limited to pale green spots of olivine, augite, plagioclase and andesine-labradorite composition.

1.4 Older Granites

The older granites were first differentiated from the younger granites by (Falconer, 1911). They range in size from plutons to batholiths. They includesgranodiorites, adamallites, quartzodiorites, quartz-monzolites, coarse-grained porphyritic granites and fine grained granites. Some are distinctly granular (phaneritic texture) while some however have fine grains that are not visible (alphanitic texture). Also some of the granites have porphyritic intrusion. The older granite is fractured, jointed and faulted. The mineral composition include quartz (which is the dominant mineral), feldspar, biotite, nicrocline, hornblende and other ferromagnesian minerals.

1.5 Charnockitic Rocks

The charnockitic rocks are younger than the schist. They occur as rounded boulders of various sizes within the basement complex in association with older granites.

1.6 Slightly MigmatisedTo Un-Migmatised Para-Schists and Meta-Igneous Rocks

This group of rocks is younger than the migmatite gneiss complex. Schist is a member of this group described as the youngest metasediment in the Nigeria basement complex (Rahaman 1988). The rocks are weak and easily weathered hence it outcrops in the low lying area having been worn down. They are mainly covered by insitu weathered regolith and superficial deposits.

1.7 The Migmatite-Gneiss Quartzite Complex

This unit can be divided into the migmatite-gneiss and quartzite units. This group is the most widespread in the basement complex of the southwestern Nigeria. It is also the oldest and it accounts for about 45% of the geology of the study area as shown in the geological map of the study area. The migmatite-gneiss occurs as a mixed rocks of constrasting composition with alternating mafic and quartzo-feldspathic streaks materials.

1.8 Quartzite

The quartzites are metasediments likely to be contemporaneous with the migmatite-gneiss complex. This rock is predominantly jointed and fractured being a brittle rock. They exist as cobbles, rubbles and gravels .They are schistose with medium to coarse grained texture. Quartz accounts for about 90% of the mineral in the rock with minor amount of muscovite and zircon. (Rahman, 1989).

1.9 Local Geology of the Study Area

The study area geology is composed of migmatite, gneiss and quartzite (Figure 2). The basement bedrocks are associated with low porosity and trivial permeability. This is as a result of their composition. Thus, accessibility of groundwater in crystalline bedrock is attributed to the formation of secondary porosity and interconnected pores as a result of weathering and fractures.

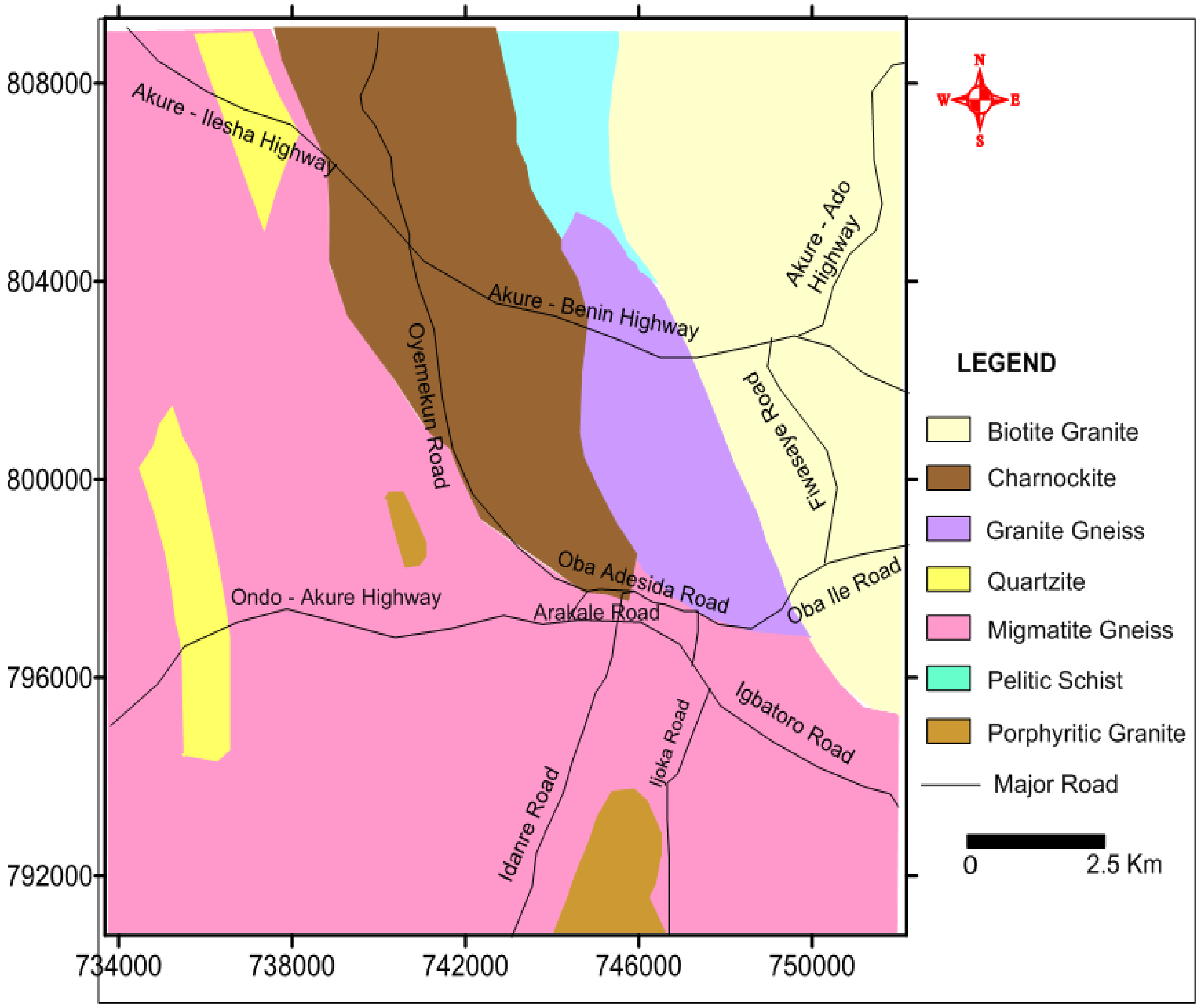


Figure 2: Geological Map of Akure (Falowo et al., 2019)

2. Methodology

2.1 Data Acquisition

2.1.1 Dipole-Dipole

Dipole-Dipole and VES technique was adopted for this investigation and a total of three traverses were probed in the North-south direction. The survey site was covered by three (3) traverses with traverse 1 and 2 running in the North – South Direction and spanning a length of 40 m each. Traverse 3 was established in the East – West Direction, covering a length of 35 m (Fig.3).

2.1.2 Vertical Electrical Sounding (VES)

For the vertical electrical sounding, Schlumberger configuration was employed and half Schlumberger configuration was used on VES 3 because of space constraint in that section of the study area. Three (3) vertical electrical sounding were carried out with AB/2 varying from 1 to 40 m for the study area see Fig.3. The position of each sounding stations were recorded using GPS.

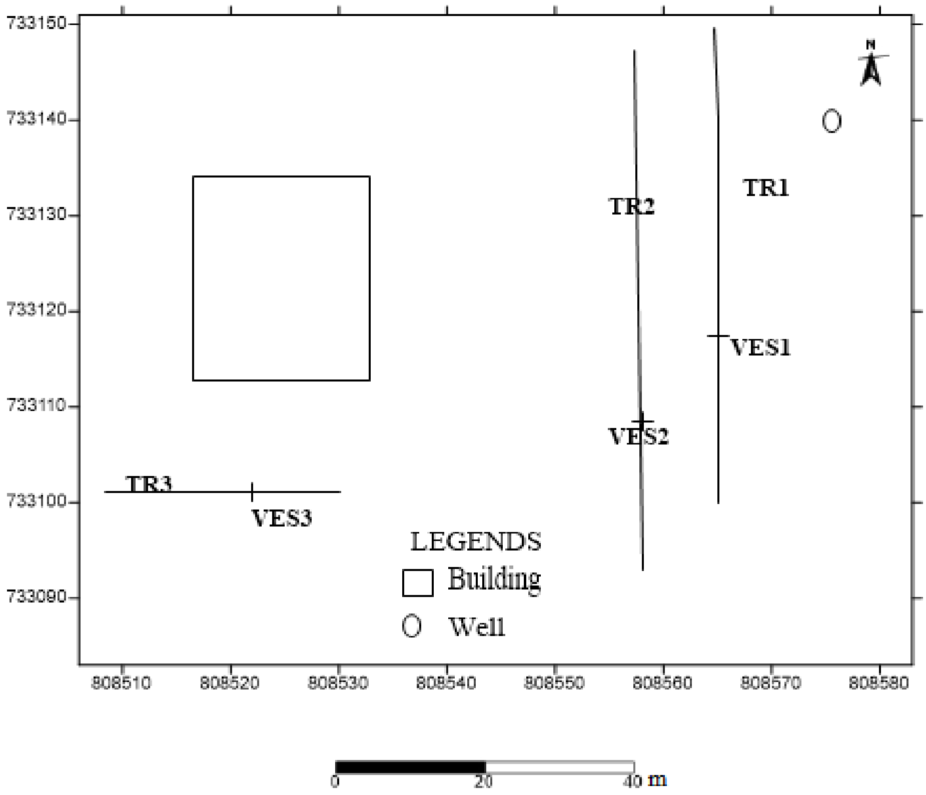


Figure 3: Base Map of the Study Area Showing the Traverses and VES points.

3. Data Processing

Dipole-dipole: The acquired data were processed using computer aided software, DIPPRO. The results are presented as two-dimensional pseudosections and inverted 2D resistivity imaging models. The 2D models were used to locate point of weak or fractured zone for further probing using the Vertical Electrical Technique.

VES: Apparent resistivity data were plotted against electrode spacing on a log-log graph and were qualitatively and quantitatively interpreted. The quantitative interpretation involves partial curve matching, using a 2-layer master curve and its corresponding auxiliary curves. The geo-electric parameters from this manual interpretation were further fine-turned through the application of computer iteration using software; WinResist Verson.1 (Ahzegbobor et al., 2018). Sets of two-dimensional geo-electric sections were generated from the inversion of derived geo-electric parameters

4. Results and Discussion

4.1 2-D Resistivity Image

4.1.1 T raverse 1

Figure 4.1a illustrates the dipole-dipole pseudo-sections along SW-NE direction. The traverse is 40 m long, the section shows relatively low - moderate apparent resistivity values (47-310Ωm) in the north southern part of the traverses.

The 2-D resistivity image (Figure 4.1a) show three continuous subsurface lithologic units namely; the topsoil (blue), weathered layer (green) and the basement bedrock (reddish purple). The topsoil is suspected to have merged with the weathered layer due to overlapping low resistivity values and relatively small thickness value whereas the basement bedrock is characterized by high resistivity values. The VES point was carried out on region of low resistivity value which may be the result of electrolyte percolation into the subsurface and high permeability in this area. The 2 - D resistivity plot revealed a relatively thin overburden and shallow basement across the traverse.

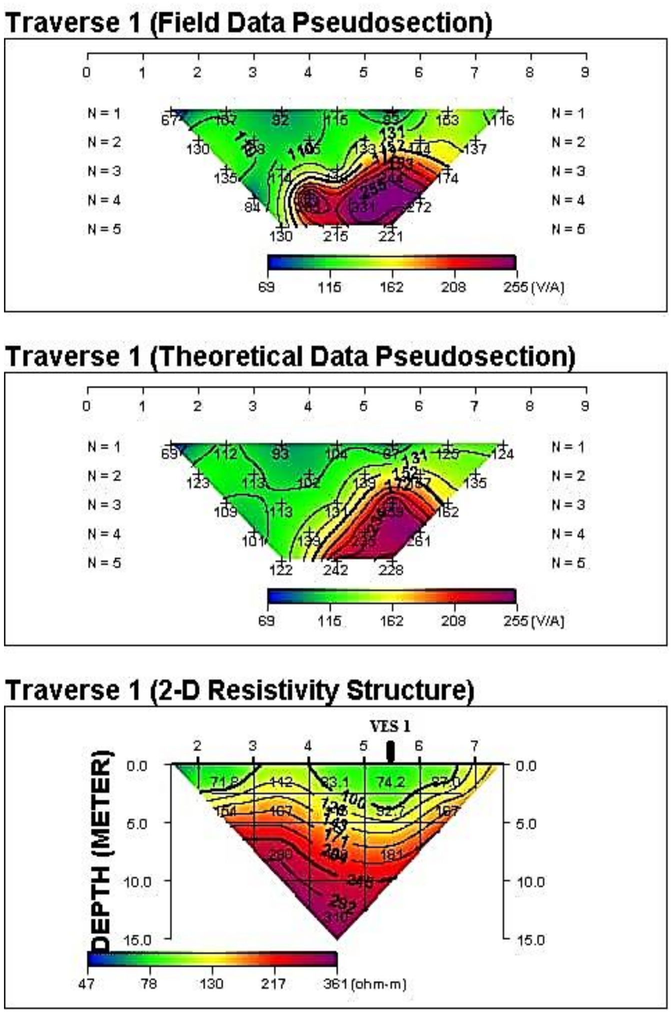


Figure 4.1a: Dipole-dipole pseudo-section and 2-D Resistivity structure along Traverse 1

4.1.2 Traverse 2

Figure 4.1b illustrate the dipole-dipole pseudo-sections along SW-NE direction. The traverse is 40 m long, the section shows relatively low - high apparent resistivity values (48-968Ωm) in the north southern part of the traverses.

The 2-D resistivity image (Figure 4.1b) show three continuous subsurface lithologic units namely; the topsoil (blue), weathered layer (green) and the basement bedrock (reddish purple). The VES point was carried out on region of low resistivity value which may be the result of electrolyte percolation into the subsurface and high permeability in this area.

The 2 -D resistivity plot revealed a relatively thick overburden and deep basement across the traverse.

4.1.3 Traverse 3

Figure 4.1c illustrate the dipole-dipole pseudo-sections along SW-NE direction. The traverse is 35 m long, the section shows relatively low - high apparent resistivity values (48-968Ωm) in the north southern part of the traverses.

The 2-D resistivity image (Figure 4.1c) shows three continuous subsurface lithologic units namely; the topsoil (blue), weathered layer (green) and the basement bedrock (reddish purple).The topsoil is suspected to have merged with the weathered layer due to overlapping low resistivity values and relatively small thickness value whereas the basement bedrock is characterized by high resistivity values. The VES point was carried out on region of low resistivity value which may be the result of electrolyte percolation into the subsurface and high permeability in this area.

The 2 -D resistivity plot revealed a relatively thick overburden and deep basement across the traverse.

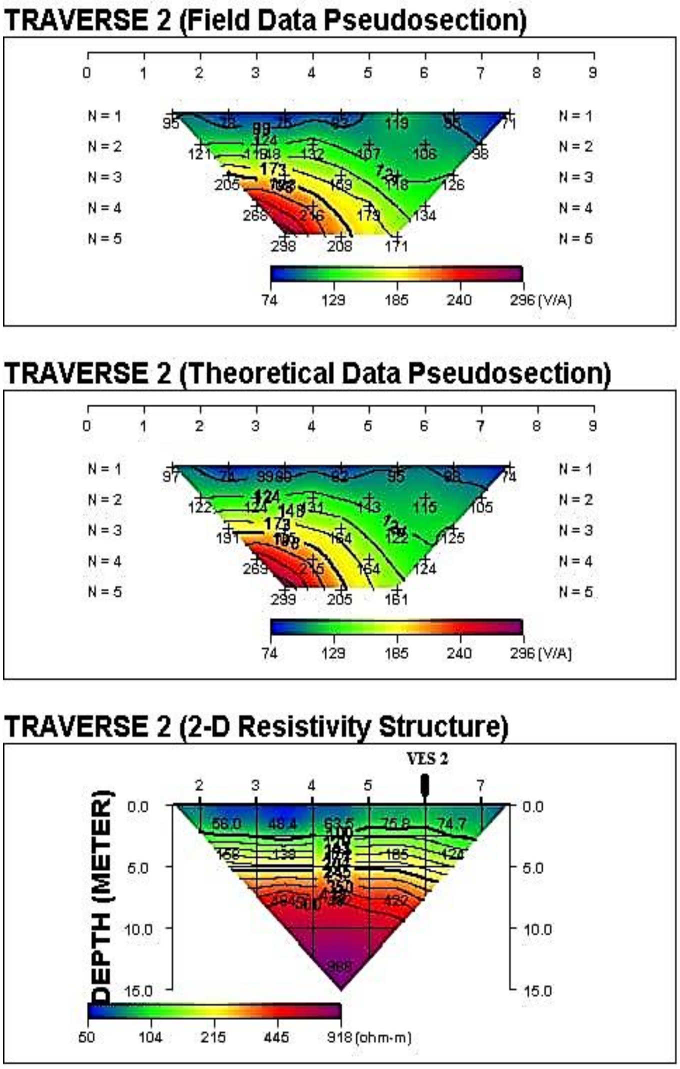


Figure 4.1b: Dipole-dipole pseudo-section and 2-D Resistivity structure along Traverse 2

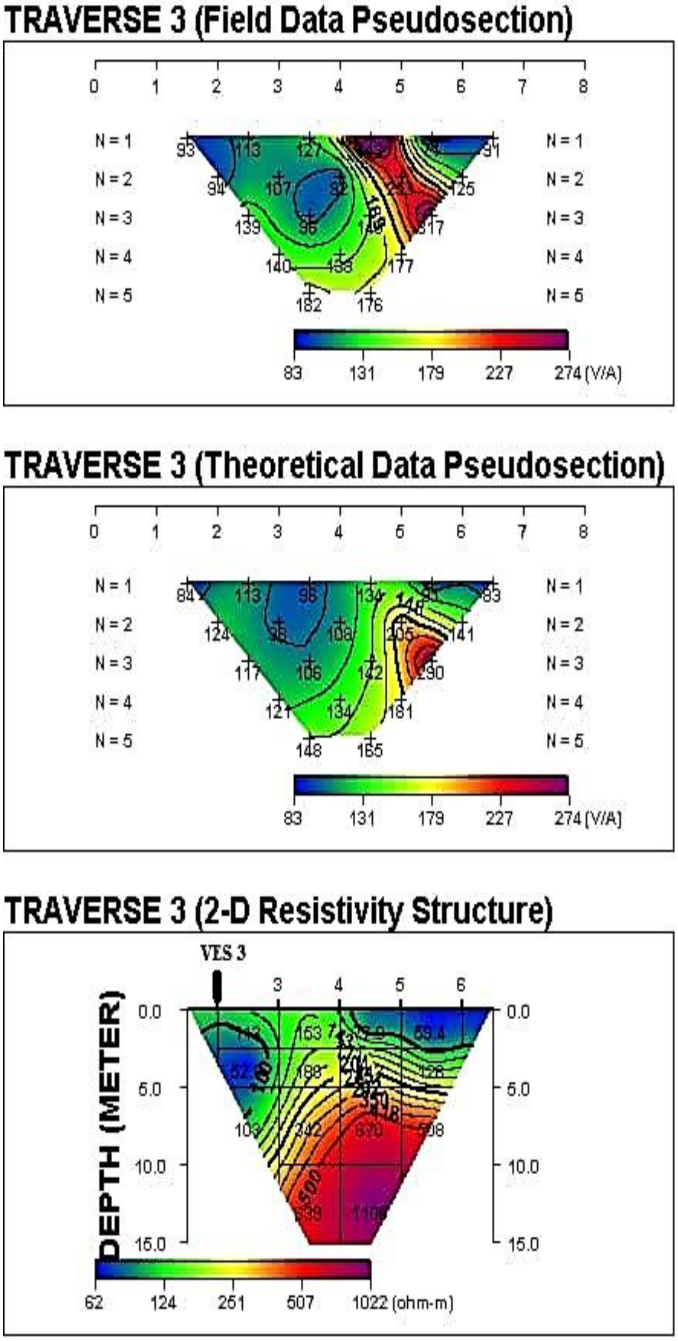


Figure 4.1c: Dipole-dipole pseudo-section and 2-D Resistivity structure along Traverse 3

4.1.4 VES- CURVES TYPE

Vertical Electrical Sounding (VES) data were obtained and interpreted qualitatively and quantitatively see Table 1. These involved identification of signatures, partial curve matching and computer iteration using WIN RESIST software to obtain corresponding resistivities and layer thickness. The observed VES curve types in the study area is H (Table 1).

4.2 Curve Type

4.2.1 Curve Type H

Figure 4.2a – c depict typical H curve type. This is a three layer curve type. It constitutes all the three (3) VES stations with a 100% occurrence (Table 2). The resistivities relationship is $\rho_1 > \rho_2 < \rho_3$ i.e the resistivity value of layer one is greater than the resistivity value of layer two while that of layer two is less than that of layer three.

This curve type are typically found in a basement terrain and are good for drilling because of its low resistivity values (possible saturation zones) with the aquifer thickness favouring accumulation of significant quantities of groundwater.

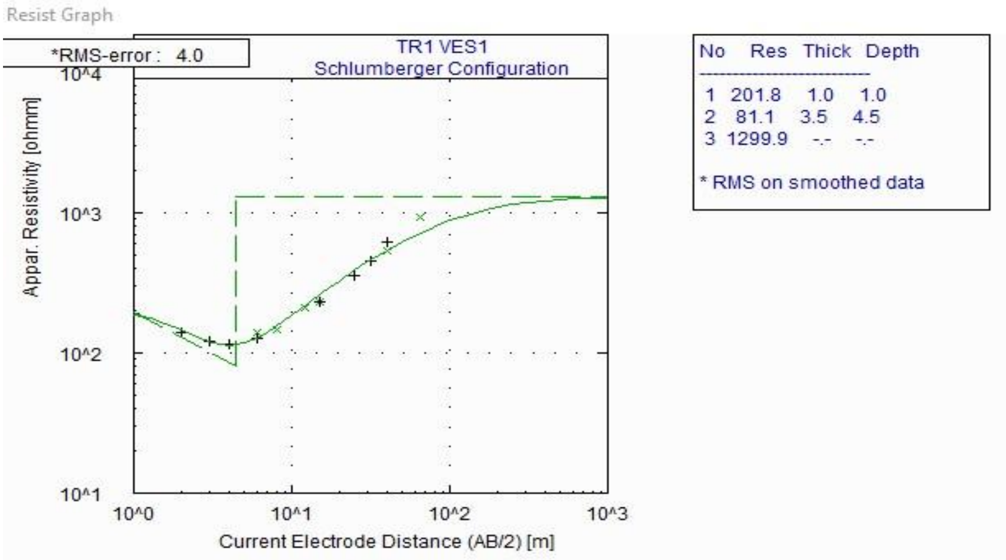


Figure 4.2a: H field curve obtained at traverse 1 VES 1 (**$\rho_1>\rho_2<\rho_3$**) at 27m

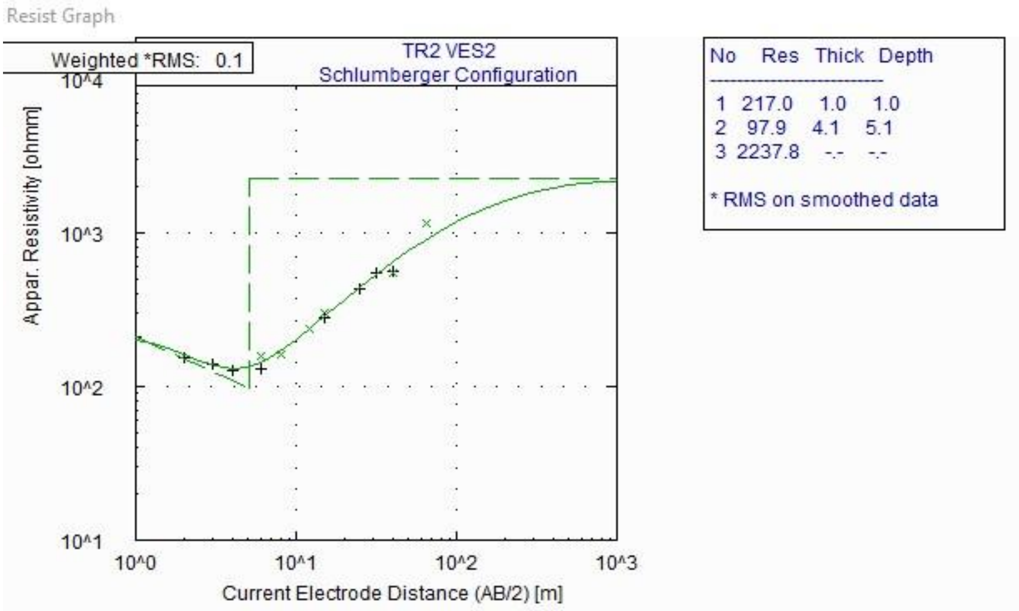


Figure 4.2b: H-type field curve obtained at traverse 2 VES 2 (**$\rho_1>\rho_2<\rho_3$**) at 30m

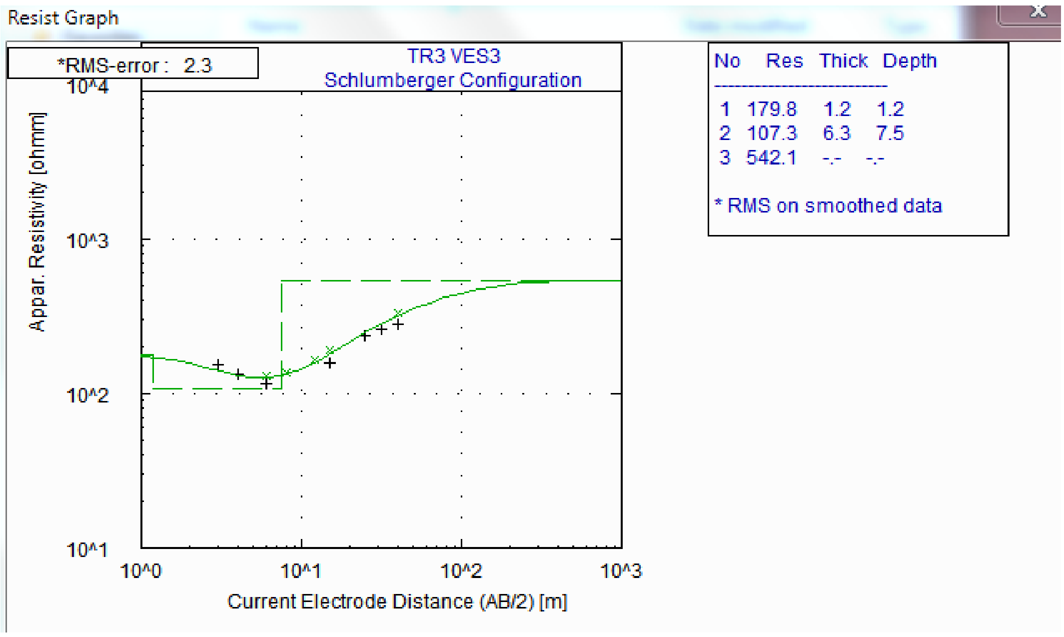


Figure 4.2c: H-type field curve obtained at traverse 3 VES 3 (**$\rho_1>\rho_2<\rho_3$**) at 10m

Table 1: Shows the Geo-Electrical Parameters and the Curve Types within the Study Area.

VES NO	LAYER NO	RESISTIVITY (Ohm-m)	THICKNESS (m)	DEPTH (m)	LITHOLOGY	CURVE TYPES	COORDINATE	
							NORTHING	EASTHING
1	1	202	1.0	1.0	Top Soil	H	733121	808554
	2	81	3.5	4.5	Weathered Layer			
	3	1300			Fresh Bedrock			
2	1	217	1.0	1.0	Top Soil	H	733113	808548
	2	98	4.1	5.1	Weathered Layer			
	3	2238			Fresh Bedrock			
3	1	180	1.2	1.2	Top Soil	H	733105	808538
	2	107	6.3	7.5	Weathered Layer			
	3	542			Fresh Bedrock			

Table 2: Showing the Curve Type and their Percentage of Occurrence

CURVE TYPE	NUMBER OF VES	% OF OCCURRENCE
H	3	100
TOTAL	3	100

4.3 Description of VESs 1 to 3

4.3.1 VES 1

Fig 4.3a shows the columnar section along Traverse 1. One (1) VES station is obtained on the traverse which is VES 1. It comprises three (3) geologic units namely; Top soil, Weathered layer and Fresh bedrock. The topsoil is composed of sand/clayey sand with resistivity value of 201.8 Ωm, thickness of 1.2 m, the weathered layer is composed of sandy clay with resistivity value of 81.1 Ωm, thickness of 3.5 m and the fresh bedrock has resistivity of 1299.9Ωm with infinite thickness. This column is indicative of poor prospect for groundwater development in the study area due to abysmally low thickness of the weathered layer.

4.3.2 VES 2

Fig 4.3b shows the columnar section along Traverse 1. One (1) VES station is obtained on the traverse which is VES 2. It comprises three (3) geologic units namely; Top soil, Weathered layer and Fresh bedrock. The topsoil is composed of sand/lateritic sand with resistivity value of 217 Ωm, thickness of 1m, the weathered layer is composed of sandy clay with resistivity value of 97.9 Ωm, thickness of 4.1 m and the fresh bedrock has a resistivity of 2237.9 Ωm with infinite thickness. This column suggests a poor prospect for groundwater development in the study area due to the low thickness of the weathered layer.

4.3.3 VES 3

Fig 4.3c shows the columnar section along Traverse 1. One (1) VES station is obtained on the traverse which is VES 3. It comprises three (3) geologic units namely; Top soil, Weathered layer and Fresh bedrock. The topsoil is composed of sand/clayey sand with resistivity value of 179.8 Ωm, thickness of 1.2m, the weathered layer is composed of sand/sandy clay with resistivity value of 107.3 Ωm, thickness of 6.3 m and the fresh bedrock has resistivity of 542.1 Ωm with infinite thickness. This column suggests a better prospect for groundwater development in the study area due to the relatively high thickness value of the weathered layer.

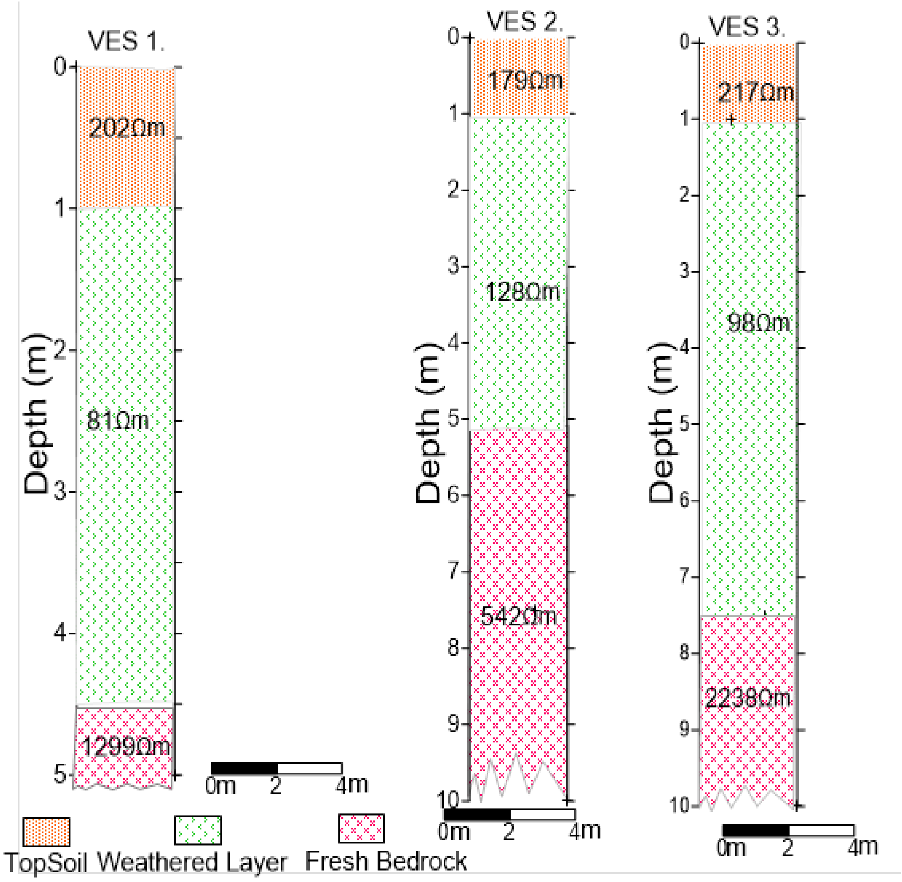


Figure 4.3a-c: VES 1, VES 2 and VES 3

4.4 Evaluation of Groundwater Potential

Given the average resistivity values and low thicknesses of the top soil and weathered layer and the overburden thickness of VES 1 and VES 2 (Table 1 and Figure 4.2a & Figure 4.2b), the groundwater potential in these two zones are rated as low. VES 3 have average resistivity values and relatively thick weathered layer thus the groundwater potential here is rated as medium. The mild thickness of the overburden materials and presence of a moderately weathered layer are largely responsible for the groundwater potential. Akinseye et al. (2023) conducted a geophysical investigation in the study area to assess the groundwater potential and aquifer vulnerability. The groundwater in the study area is modest, while the groundwater potential in the northern and western parts of the study area seems to be higher compared to other areas. However, the northern and western parts were rated as having low groundwater potential, while other areas had a medium rating (Adagunodo et al., 2018). Additionally, according to Eebo and Yusuf (2021), only a small portion of the study area is non-aquiferous.

Observed thickness and nature of the weathered layer are important parameters in the groundwater potential evaluation of a basement complex terrain (Ako, 1979; Akintorinwa et al., 2013). Horizon is regarded as a significant water – bearing layer if significantly thick and the resistivity parameters suggest saturated conditions. The presence of a weathered layer with a thickness value of 6.3 m and resistivity of 98 Ωm and of low clay content in VES 3 is suggestive of a medium/moderate groundwater potential. As a result of the moderate thickness of the aquiferous unit in VES 3, hand-dug well is prescribed for groundwater exploitation.

5. Conclusions

In this study, the groundwater potential of Atibioke street, Aule Road, Ibule, Akure, Southwestern Nigeria was evaluated using Combined Horizontal Profiling and three Schlumberger vertical electrical soundings (VES).

The Combined HP and VES technique was first conducted across three traverses of varying lengths at 5m spacing. Results obtained from this technique enabled the location of the most suitable points for Vertical Electrical Sounding (VES). One VES point was therefore carried out on each traverses.

The curve type generated for the three VES was H. The computer assisted profiling and sounding interpretation revealed three different subsurface lithologic sequences namely: topsoil, weathered layer and basement bedrock. The topsoil and weathered layer materials are characterize with relatively low resistivity value while the basement bedrock materials are typified with high resistivity values. The moderate thickness of the overburden materials and presence of an averagely weathered layer are largely responsible for the groundwater potential. The yield of the weathered layer material is dependent on the amount of clay content. The higher the clay content, the lower the groundwater yield. The topsoil has limited hydrological significance.

The adopted geophysical method provided information(s) as related to the viability of the surveyed area for groundwater development hence, the important of electrical resistivity method in groundwater development in a typical basement complex terrain cannot be over emphasized.

Recommendation

As regards to the information obtained from the results of geophysical survey conducted at the study area. VES 1 and VES 2 are poor areas for groundwater exploitation. However VES 3 appears favourable for groundwater development because of the availability of a weathered layer of moderate thickness as well as a reasonably mild overburden thickness and the favourable resistivity values of the VES point. The groundwater potential rating of the area is considered medium. VES 3 could be considered for well drilling because of the presence of a weathered layer with moderate thickness.

References

Abayomi G. Osotuyi, Muraina Z. Mohammed, Isaac R. Ajayi, Adebayo O. Salako, 2021. Assessment of geoelectric properties and localized geology as indicators on cocoa (Theobroma cacao) yield in a part of southwestern Nigeria, Heliyon, Vol. 7, No. 12.

Abudulawal, L., Amidu, S. A., Apanpa, K. A., Adeagbo, O. A., and Akinbiyi, O. A. 2015. Geophysical investigation of subsurface water of Erunmu and its environs, Southwestern Nigeria using electrical resistivity method. J. Appl. Sci. 15, 741–751. doi: 10.3923/jas.2015.741.751

Adagunodo T.A, Margaret K. Akinloye, Lukman A. Sunmonu, Ahzegbobor P. Aizebeokhai, Kehinde D. Oyeyemi, Felicia O. Abodunrin, 2018. Groundwater Exploration in Aaba Residential Area of Akure, Nigeria. front. Earth Sci., 06 June 2018. Volume 6 - 2018. https://doi.org/10.3389/feart.2018.00066

Adagunodo, T. A. 2017a. Groundwater contamination: performance, effects, limitations and control, in Groundwater Contamination: Performance, Limitations and Impacts, ed A. L. Powell (New York, NY: Nova Science Publishers, Inc), 33–64.

Adagunodo, T. A., Adeniji, A. A., Erinle, A. V., Akinwumi, S. A., Adewoyin, O. O., Joel, E. S., et al., 2017. Geophysical investigation into the integrity of a reclaimed open dumsite for civil engineering purpose. Interciencia J. 42, 324–339.

Adagunodo, T. A., Sunmonu, L. A., Oladejo, O. P., and Ojoawo, I. A., 2013. Vertical electrical sounding to determine fracture distribution at Adumasun Area, Oniye, Southwestern Nigeria. J. Appl. Geol. Geophys. 1, 10–22. doi:10.9790/0990-0131022.

Adelusi, A. O., Ayuk, M. A., and Kayode, J. S., 2014. VLF-EM and VES: an application to groundwater exploration in a Precambrian basement terrain SW Nigeria. Ann. Geophys. 57: s0184. doi: 10.4401/ag-6291.

Agro-climatological and Ecological monitoring unit, Akure, 1998. Average Temperature of Akure, Ondo State.

Ahzegbobor P. Aizebeokhai n, Olubukola Ogungbade, Kehinde D. Oyeyemi, 2018. Geoelectrical resistivity data set forcharacterising crystalline basement aquifersin Basiri, Ado-Ekiti, southwestern Nigeria. Elsevier 19. 810–816

Akinrinade, O. J., and Adesina, R. B. 2016. Hydrogeophysical investigation of groundwater potential and aquifer vulnerability prediction in Basement complex terrain – a case study from Akure, southwestern Nigeria. RMZ-M G 63, 55–66. doi: 10.1515/rmzmag-2016-0005.

Akinseye V.O, Osisanya, W.O, Eyankware M.O, Korode A.I, Ibitoye T.A. 2023. Application of second‑order geoelectric indices in determination of groundwater vulnerability in hard rock terrain in SW. Nigeria. Sustainable Water Resources Management. 9: 169. https://doi.org/10.1007/s40899-023-00936-w

Akintorinwa, O. J., and Olowolafe, T.S. 2013. Geoelectric evaluation of groundwater prospect within Zion estate, Akure, Southwestern, Nigeria. Int. J. Water Resour. Environ. Eng. 5, 12–28. doi: 10.4236/gep.2017.53017.

Ako, B. D. 1979. Geophysical Prospecting for Groundwater in Parts of Southwestern Nigeria. Unpublished Ph.D. thesis, O.A.U. Ife.

Badejo, A. A., Ndambuki, J. M., Kupolati, W. K., Adekunle, A. A., Taiwo, S. A., and Omole, D. O. 2015. Appraisal of access to safe drinking water in Southwest Nigeria. Afr. J. Sci. Technol. Innov. Dev. 7, 441–445. doi: 10.1080/20421338.2015.1096669.

Eebo Festus Olusola and Yusuf Gbenga Ayodele. 2021. Geophysical Investigation of Groundwater Potential of a Site in Obale Area of Akure, Nigeria. International Journal of Engineering Applied Sciences and Technology, 2021. Vol. 6, Issue 1, ISSN No. 2455-2143, Pages 88-93

Falconer, J. D. 1911. The geology and geography of Northern Nigeria. MacMillan, London.

Falowo, OO; Oluwasegunfunmi, V; Akindureni, Y; Olabisi, W; and Aliu, A; 2019. Groundwater Physicochemical Characteristics and Water Quality Index Determination from Selected Water Wells in Akure, Ondo State, Nigeria. American Journal of Water Resources, vol. 7, no. 2: 76-88. doi: 10.12691/ajwr-7-2

Nwankwo, L. I. 2011. 2D resistivity survey for groundwater exploration in a hard rock terrain: a case study of MAGDAS observatory, UNILORIN, Nigeria. Asian J. Earth Sci. 4, 46–53. doi: 10.3923/ajes.2011.46.53

Obaje, N. G. 2015. Geology and Mineral Resources of Nigeria, in Lecture notes in Earth Sciences 120, eds S. B Brooklyn, H. J. N. Bonn, J. R. Gottingen, and K. S Graz (New York, Ny: Springer), 221.

Ogunrayi, O. A., Akinseye, F. M., Goldberg, V., and Bernhofer, C. 2016. Desriptive analysis of rainfall and temperature trends over Akure, Nigeria. J. Geogr. Reg. Plann. 9, 195–202. doi: 10.5897/JGRP2016.0583.

Olafisoye, E. R., Sunmonu, L. A., Ojoawo, A., Adagunodo, T. A., and Oladejo, O. P. 2012. Application ofvery low frequency electromagnetic and hydro-physicochemical methods in the investigation of groundwater contamination at Aarada waste disposal site, Ogbomoso, Southwestern Nigeria. Aust. J. Basic Appl. Sci. 6, 401–409.

Oyeyemi, K. D., Aizebeokhai, A. P., Adagunodo, T. A., Olofinnade, O. M., Sanuade, O. A., and Olaojo, A. A. 2017. Subsoil characterization using geoelectrical and geotechnical investigations: implications for foundation studies. Int. J. Civil Eng. Technol. 8, 302–314.

Rahaman M. A. 1976. Review of the Basement Geology of SW Nigeria in Geology of Nigeria. Elizabithan Publishing Company, Nigeria. pp. 41-58.

Rahaman, M.A. 1988. Recent Advances in the Study of the Basement Complex of Nigeria. In Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna South, 11-43.

Rahman, M.A. 1989. Review of the Basement Geology of South – Western Nigeria. In C.A Kogbe 2nd Ed. Geology of Nigeria, Rock View, Jos, Nigeria pp: 39 – 56.

Sunmonu, L. A., Adagunodo, T. A., Adeniji, A. A., Oladejo, O. P., and Alagbe, O. A. 2015. Geoelectric delineation of aquifer pattern in crystalline Bedrock. Open Trans. Geosci. 2, 1–16. doi: 10.15764/GEOS.2015.01001.

Sunmonu, L. A., Adagunodo, T. A., Olafisoye, E. R., and Oladejo, O. P. 2012. The groundwater potential evaluation at industrial estate Ogbomoso, Southwestern Nigeria. RMZ Mater. Geoenviron. 59, 363–390.