

Integrated Geophysical Characterization of Weathered and Fractured Subsurface Zones for Groundwater Exploration in Abeokuta, Southwestern Nigeria

Adegoke Qudus Olayinka

qolayinka12@gmail.com

University of Lagos

Richter Olalekan Omonayin

University of Lagos

Research Article

Keywords: groundwater exploration, integrated geophysics, seismic refraction, EM-VLF, electrical resistivity, constant separation traversing, vertical electrical sounding, weathered basement, fractured zone, Abeokuta

Posted Date: September 11th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10865353/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Integrated Geophysical Characterization of Weathered and Fractured Subsurface Zones for Groundwater Exploration in Abeokuta, Southwestern Nigeria

Abstract

Groundwater exploration in complex geological terrains requires reliable delineation of subsurface lithological units and structural features that may control groundwater occurrence and movement. This study investigated the subsurface architecture and groundwater potential of part of Moshood Abiola Polytechnic, Ojere, Ogun State, southwestern Nigeria, using an integrated geophysical approach. The investigation employed seismic refraction, very low frequency electromagnetic (EM-VLF), two-dimensional electrical resistivity using constant separation traversing (CST), and vertical electrical sounding (VES). Seismic refraction delineated three principal velocity zones comprising topsoil, partially weathered material and a deeper high-velocity unit interpreted as fresh basement, with a possible fractured interval occurring within the weathered horizon. EM-VLF profiling revealed conductive anomalies along the traverse that were interpreted as possible fractured and/or clay-rich zones and used to guide subsequent resistivity soundings. The CST results showed marked lateral resistivity variations, including low-resistivity zones interpreted as clay or weathered material and higher-resistivity zones associated with partially weathered to fresh/fractured basement. Three VES stations were interpreted using the Schlumberger configuration and yielded layered models comprising topsoil, lateritic clay, clay/shale and deeper high-resistivity units interpreted in the report as limestone. The interpreted weathered horizon, where it coincides with conductive anomalies, represents a potential groundwater-bearing zone; however, its limited thickness suggests relatively low groundwater productivity. The integration of seismic, electromagnetic and electrical resistivity observations improves confidence in identifying subsurface zones of hydrogeological interest and provides a basis for selecting targets for subsequent hydrogeological verification. The study demonstrates the usefulness of integrated near-surface geophysical methods for groundwater reconnaissance in the transition between crystalline basement and sedimentary geological environments of southwestern Nigeria.

Keywords: groundwater exploration; integrated geophysics; seismic refraction; EM-VLF; electrical resistivity; constant separation traversing; vertical electrical sounding; weathered basement; fractured zone; Abeokuta.

Introduction

Groundwater is an important component of the hydrological system and constitutes a major source of water for domestic, agricultural and industrial uses. Its occurrence in hard-rock and transition terrains is controlled strongly by the development of weathered materials, fractures, joints and other secondary porosity features. Because these features are commonly discontinuous and cannot always be recognized from surface observations alone, geophysical investigation provides an efficient means of characterizing subsurface conditions before borehole drilling.

Geophysical methods respond to contrasts in physical properties of the subsurface. Electrical resistivity methods are particularly useful for identifying changes in lithology, degree of weathering and possible water-bearing materials, while electromagnetic methods can rapidly locate conductive anomalies that may be associated with clay-rich or water-bearing/fractured zones. Seismic refraction provides complementary information on seismic velocity contrasts and the geometry of shallow subsurface interfaces. The integration of these methods can therefore reduce ambiguity that may arise when any single technique is interpreted in isolation.

Previous studies in southwestern Nigeria have demonstrated the value of integrated geophysical techniques for groundwater exploration. VLF-EM and electrical resistivity surveys have been used to delineate conductive/fractured zones, while seismic refraction and electrical soundings have been applied to characterize overburden and basement conditions (Ariyo et al., 2009; Adeoti et al., 2012; Badmus & Olatinsu, 2012; Bayewu et al., 2017; Olorunfemi & Oni, 2019). Electrical resistivity imaging has also been shown to be useful for mapping weathering profiles, regolith thickness and fractured basement structures around Abeokuta (Aizebeokhai et al., 2018).

The present study focuses on part of Moshood Abiola Polytechnic (MaPoly), Ojere, Abeokuta, Ogun State. The work was originally undertaken as an independent field-mapping exercise, but the dataset contains complementary seismic, electromagnetic and electrical resistivity observations that can be synthesized into a focused hydrogeophysical investigation. The objective of this manuscript is to characterize the shallow subsurface, delineate weathered/fractured zones, and assess their implications for groundwater occurrence.

Study Area

Location and physiography

The survey area is located at Moshood Abiola Polytechnic, Ojere, within the Abeokuta metropolis of Ogun State, southwestern Nigeria. The source report places the broader area between approximately $03^{\circ}17'56.77''\text{E}$ and $03^{\circ}26'02.78''\text{E}$ and $07^{\circ}10'04.42''\text{N}$ and $07^{\circ}15'05.70''\text{N}$. The site is accessible through major and minor roads, facilitating field mapping and geophysical data acquisition.



Figure 1. Basemap of the study area and survey traverse, reproduced from the field report.

The area is characterized by hummocky and undulating terrain with prominent hills. Elevations reported for the broader Abeokuta area range from about 30 to 180 m above sea level. Drainage is dominated by the Ogun and Oyan river systems and numerous smaller streams. The regional climate is tropical, with distinct wet and dry seasons. The report gives a mean annual rainfall of approximately 1,270 mm and a mean annual temperature of about 28 °C.

Geological setting

The study area lies within a geological transition between Precambrian basement rocks and sedimentary units of the Abeokuta Group. The basement complex is described as comprising gneiss-migmatite assemblages, granite, quartzite, schist, amphibolite and related rocks. Brittle deformation has produced joints and fractures that may provide secondary porosity and permeability. The sedimentary succession of Ogun State forms part of the southeastern Dahomey Basin and includes units of the Abeokuta Group and younger formations. This geological setting is important to groundwater exploration because groundwater occurrence may be controlled by both weathered/fractured basement and permeable sedimentary horizons.

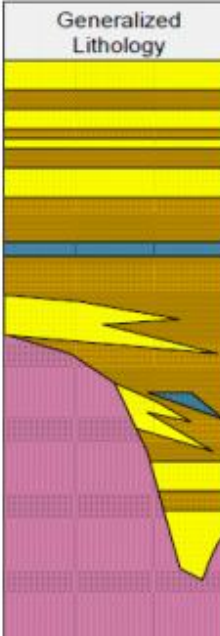
Generalized Lithology	Formation	Age	Thickness (feet)	Comments	
	Benin Fm., Coastal Plains Sands	Tertiary	Pleistocene - Oligocene	0 - 1600	coastal-plain clastics
	Oshosun - Ilaro - Ameki Fms.		Eocene	200 - 1000	fluvial and marine sands and clays
	Ewekoro Fm.		Paleocene	400 - 1000	marine shale, limestone
	Araromi Fm.	Cretaceous	Maastrichtian	500 - 1000	coastal sand, shale; marine shale
	Abeokuta Fm.				
	Afowo Fm.				
	Turonian Sst. Albian Sst.				
	Ise Fm.	Barremian - Neocomian	0 - 6000+	continental and lacustrine rift-basin fill	
	crystalline basement (undifferentiated)	Cambrian - Precambrian			metamorphic and igneous complex

Figure 2. Stratigraphic framework of the southeastern Dahomey Basin as presented in the source report.

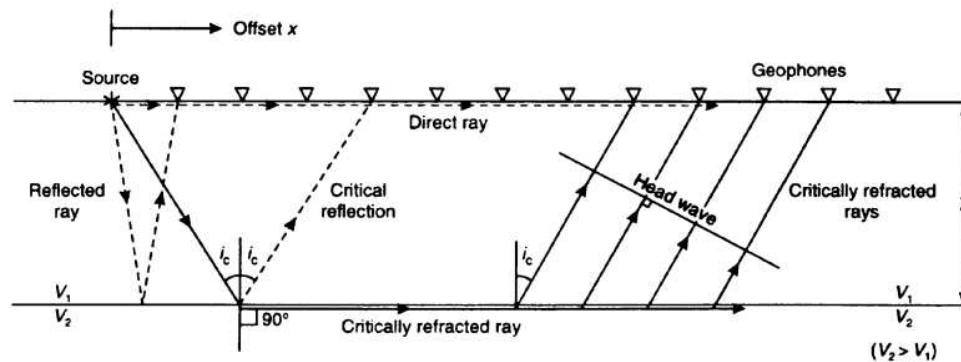
Materials and Methods

The field investigation combined seismic refraction, EM-VLF, two-dimensional electrical resistivity using constant separation traversing (CST), and one-dimensional vertical electrical sounding (VES). The wider field exercise also documented gravity, magnetic and spontaneous-potential methods; however, the quantitative results used in this manuscript are restricted to seismic refraction, EM-VLF, CST and VES because these are the methods for which interpretable results and numerical values are presented.

Seismic refraction

Seismic refraction data were acquired with an ABEM Terraloc Mark 6 seismograph, 24 geophones, a sledge hammer and steel base plate. The geophones were deployed at 5 m intervals using end-on and split-spread arrangements. The field survey was conducted along the principal traverse with repeated shots to improve

signal quality. The source report indicates three spreads and multiple shot positions, with end offsets recorded for coverage.



Electrical resistivity: CST

Vertical electrical sounding

EM-VLF

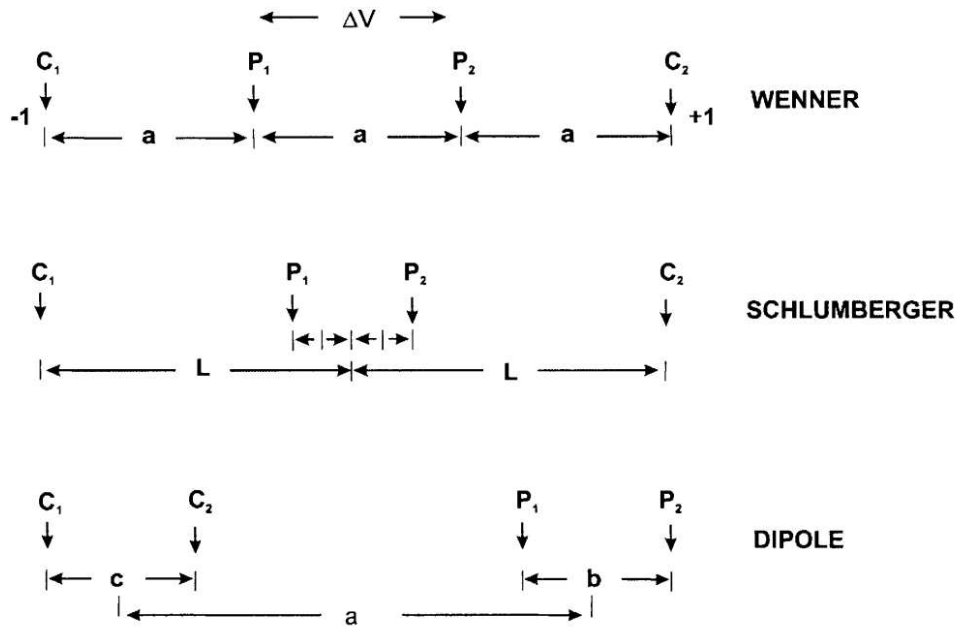


Figure 4. Electrode configurations used for the electrical resistivity survey.

Results

Seismic refraction results

The interpreted seismic section extends to approximately 30 m depth in the report. Three principal velocity zones were identified. The uppermost zone has an average P-wave velocity of approximately 500–750 m/s and extends from the surface to about 3 m depth; it is interpreted as topsoil. The second zone has an average velocity of approximately 1,500 m/s and is interpreted as partially weathered basement. A possible fractured interval is reported at a lateral position of about 85 m. The deeper zone has an average velocity of approximately 2,500 m/s and is interpreted as fresh basement.

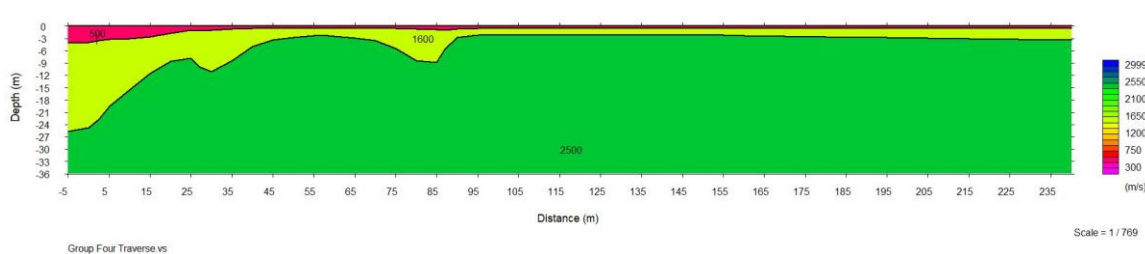


Figure 5. Two-dimensional seismic refraction result showing interpreted shallow velocity zones.

EM-VLF results

The EM-VLF profile indicates variable conductivity along the traverse. The report identifies notable anomalies around 105 and 165 m as possible fractured zones, while acknowledging that the conductivity response may also arise from clay-rich materials. Because clay and water-filled fractures can both produce conductive responses, the EM-VLF anomalies were used as targets for more vertically resolved resistivity investigation rather than treated as direct proof of groundwater.

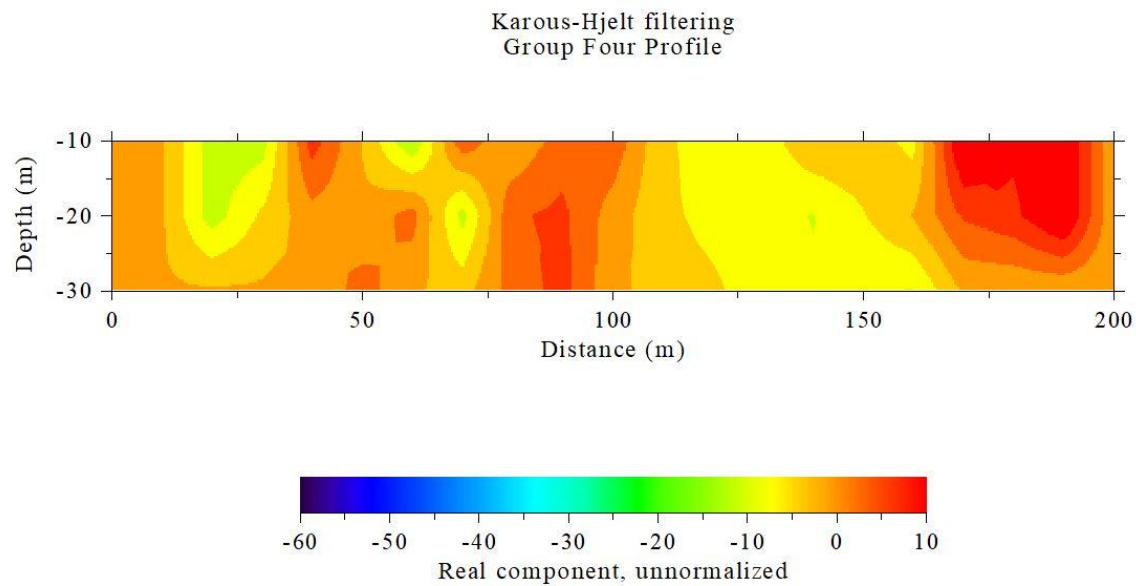


Figure 6. EM-VLF conductivity pseudo-section along the survey profile.

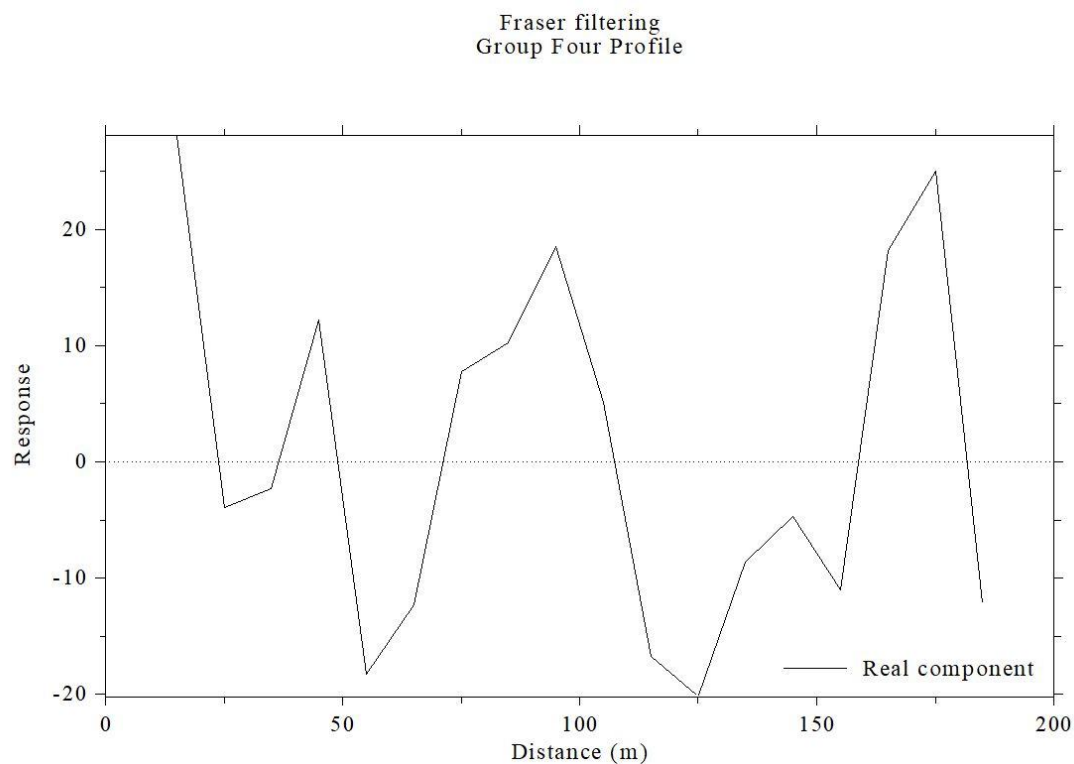


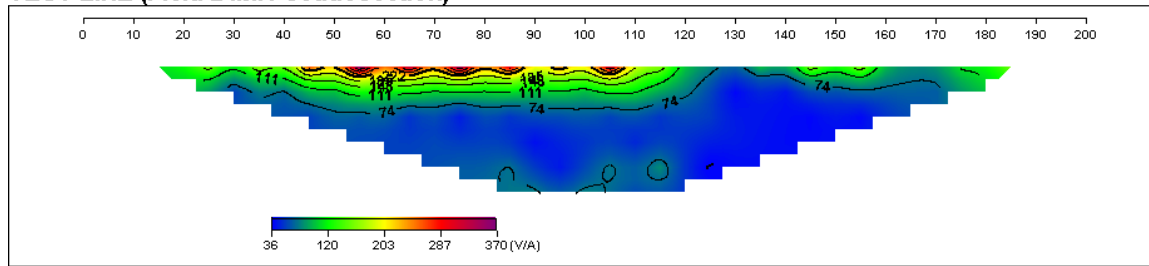
Figure 7. EM-VLF filtered profile showing lateral conductivity variation.

CST results

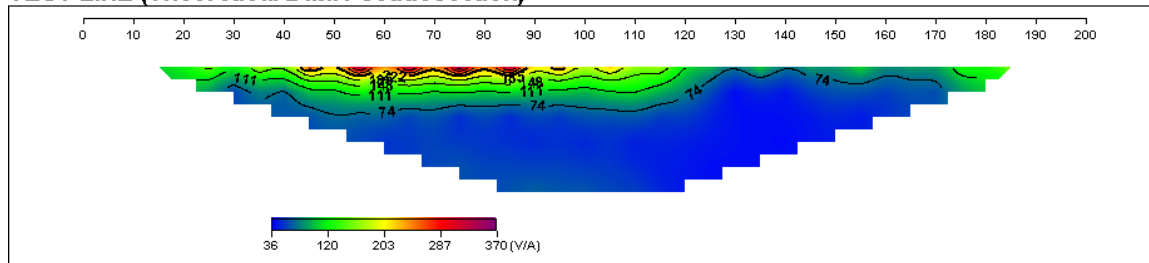
The 2-D CST section shows substantial lateral and vertical resistivity variation. The report gives a principal resistivity range of approximately 36–370 Ωm . Below about 10 m depth, a relatively low-resistivity unit of approximately 22–36 Ωm occurs over substantial portions of the profile and is interpreted as clay or weathered material. A second unit, with resistivity of approximately 65–116 Ωm , occurs between about 65 and 105 m and is interpreted as partially weathered material. Higher resistivity values of approximately 207–370 Ωm are

associated with fresh and/or fractured basement. A fractured basement zone is particularly emphasized between approximately 130 and 165 m.

TEST LINE (Field Data Pseudosection)



TEST LINE (Theoretical Data Pseudosection)



TEST LINE (2-D Resistivity Structure)

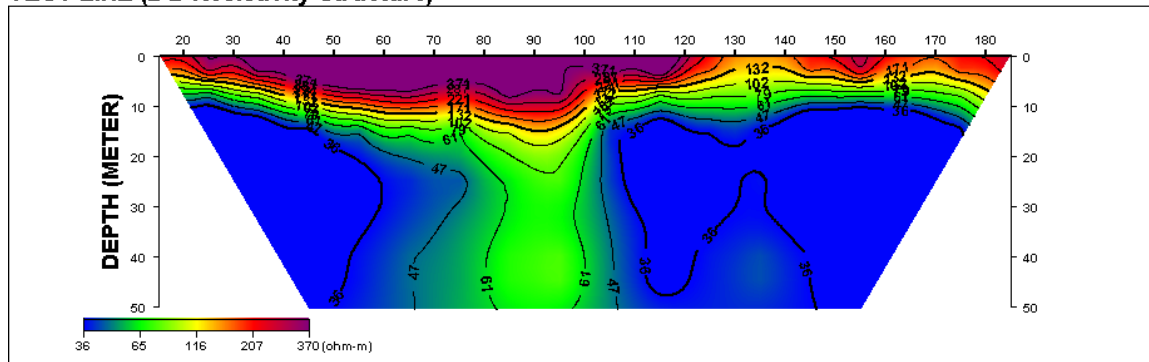


Figure 8. Two-dimensional electrical resistivity/CST pseudo-section used to delineate lateral and vertical resistivity variations.

VES results

The VES interpretation produced three layered models. VES 1 and VES 2 are classified as KH-type curves, whereas VES 3 is classified as a QH-type curve. The interpreted parameters are summarized below.

VES	Resistivity (Ωm)	Thickness (m)	Depth (m)	Interpreted lithology	Curve
VES 1	478.9	1.0	1.0	Topsoil	KH
VES 1	1427.8	3.3	4.3	Lateritic clay	KH
VES 1	686.1	11.4	15.7	Clay/shale	KH
VES 1	473.7	10.3	26.0	Clay/shale	KH
VES 1	104.1	—	—	Limestone	KH
VES 2	222.9	0.8	0.8	Topsoil	KH
VES 2	297.5	3.2	4.0	Lateritic clay	KH
VES 2	1794.2	5.0	9.0	Clay/shale	KH
VES 2	2570.2	12.3	21.3	Clay/shale	KH
VES 2	84.4	—	—	Limestone	KH
VES 3	310.4	0.6	0.5	Topsoil	QH
VES 3	172.5	4.4	5.0	Lateritic clay	QH
VES 3	338.4	7.2	12.2	Clay/shale	QH
VES 3	7025.7	98.0	110.2	Clay/shale*	QH
VES 3	365.8	—	—	Limestone	QH

Table 1. Interpreted VES parameters reproduced from the source report.

VES 1 has a 1.0 m topsoil layer followed by approximately 3.3 m of lateritic clay and successive clay/shale units, with the report placing the top of the interpreted limestone at about 26 m. VES 2 has a 0.8 m topsoil, approximately 3.2 m lateritic clay and deeper clay/shale units, with interpreted limestone at about 21.3 m. VES 3 differs markedly, with a thin topsoil, approximately 4.4 m lateritic clay and a thick high-resistivity interval extending to about 110.2 m before the interpreted limestone. The source report notes that this VES 3 result may represent structural deepening or an inversion anomaly and requires independent confirmation before deep drilling.

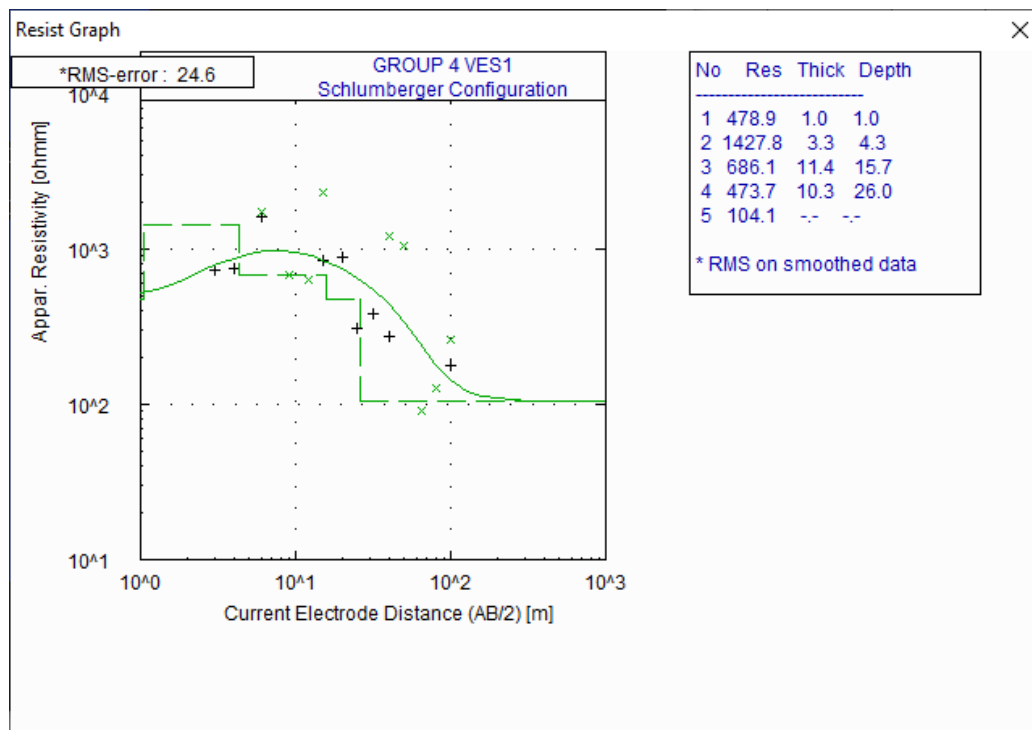


Figure 9. WinResist interpretation for VES 1.

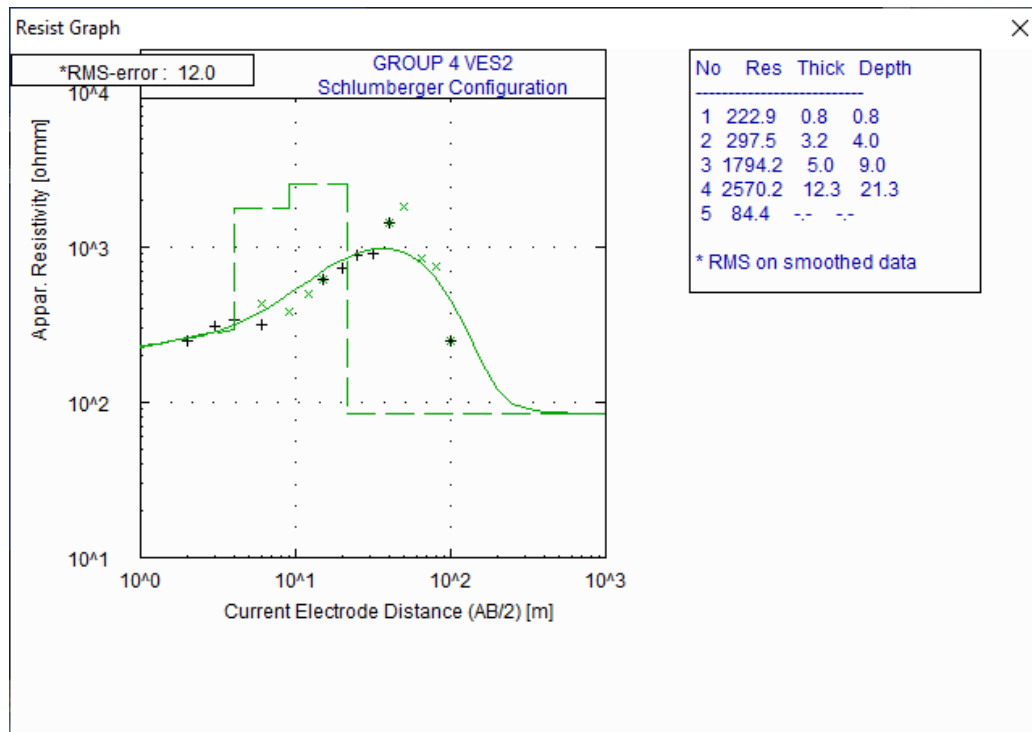


Figure 10. WinResist interpretation for VES 2.

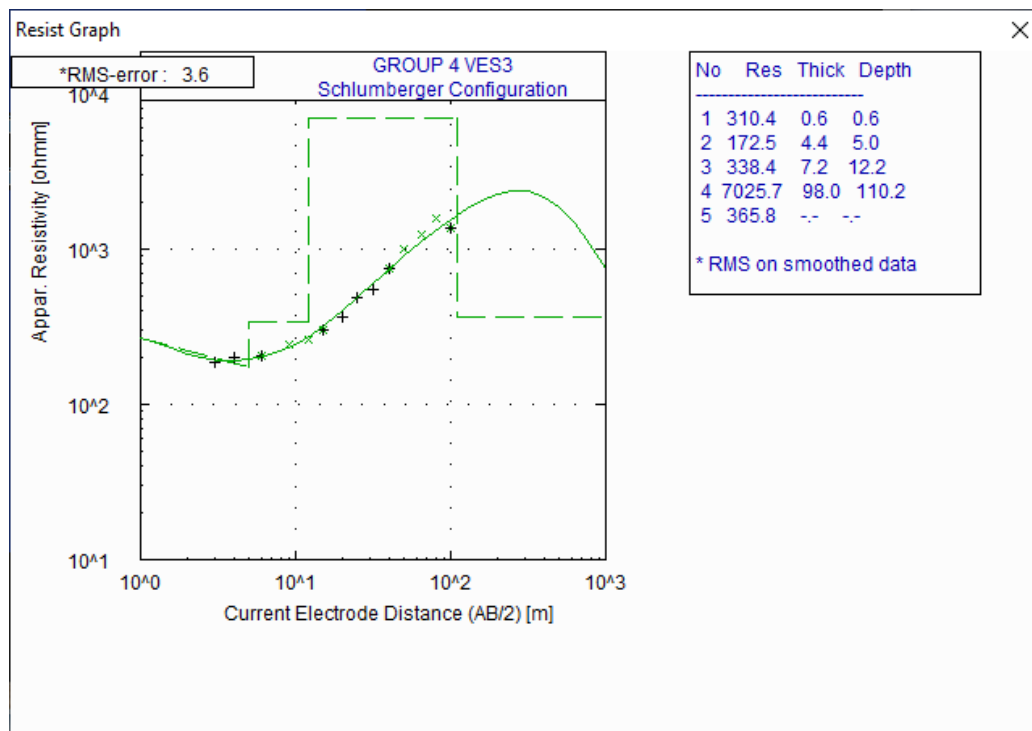


Figure 11. WinResist interpretation for VES 3.

Discussion

Integrated subsurface model

The combined results indicate a heterogeneous shallow subsurface consisting of thin topsoil, lateritic/partially weathered materials, clay- or shale-dominated horizons, and deeper competent high-resistivity material interpreted in the report as limestone and/or basement-related units. Seismic refraction provides the velocity framework, CST defines lateral resistivity changes and EM-VLF highlights conductivity anomalies. VES provides a more detailed vertical resistivity model at selected locations.

The principal hydrogeophysical implication is the correspondence between low-resistivity/weathered materials and EM-VLF conductive anomalies. Such correspondence increases the plausibility that these zones contain either weathered materials with enhanced moisture content or fractured zones capable of storing and transmitting groundwater. However, geophysical conductivity does not uniquely distinguish groundwater from clay; consequently, the EM-VLF response should be interpreted together with resistivity, seismic and geological evidence.

Groundwater potential

In crystalline and transition terrains, groundwater potential depends strongly on the thickness and permeability of the weathered zone and on the presence and connectivity of fractures. The interpreted weathered layer in this study has relatively low resistivity and is spatially associated with conductive anomalies. The report therefore identifies this interval as a potential groundwater-bearing horizon but considers its limited thickness likely to result in relatively low yield. The sandy-clay unit is also interpreted as a possible aquifer and/or basal seal.

The CST result emphasizes a possible fractured-basement target between approximately 130 and 165 m. The EM-VLF survey also highlights anomalies in the vicinity of selected sounding locations. Together, these observations support the use of coincident anomaly zones as reconnaissance targets. Nevertheless, aquifer presence, productivity and groundwater quality are separate considerations; the present dataset primarily addresses subsurface conditions and inferred groundwater potential and does not provide sufficient evidence for water-quality assessment.

Comparison with previous studies

The interpretation is broadly consistent with previous investigations in southwestern Nigeria. Ariyo et al. (2009) demonstrated that VLF anomalies can assist in identifying geological interfaces and possible fractured zones. Badmus and Olatinsu (2012) identified weathered and fractured units as important aquifer components in a basement-complex setting near Abeokuta. Bayewu et al. (2017) reported agreement between VLF-EM and VES responses in delineating conductive/fractured groundwater targets. Aizebeokhai et al. (2018) showed that resistivity imaging can characterize weathering profiles, regolith thickness and fractured basement structures in Abeokuta. The present study similarly shows the benefit of integrating methods with different physical sensitivities when investigating heterogeneous near-surface environments.

Conclusions

An integrated geophysical investigation was carried out at Moshood Abiola Polytechnic, Ojere, Abeokuta, southwestern Nigeria, to characterize the subsurface and assess groundwater potential. Seismic refraction, EM-VLF, CST and VES provided complementary information on subsurface layering, lateral resistivity variation, conductivity anomalies and possible weathered/fractured zones.

The seismic results indicate a shallow topsoil layer, a partially weathered horizon and a deeper high-velocity competent unit interpreted as fresh basement, with a possible fractured interval. EM-VLF identified conductive anomalies along the traverse, while CST delineated low-resistivity weathered/clayey zones and higher-resistivity partially weathered to fresh/fractured material. The VES models further resolved thin topsoil and lateritic clay overlying clay/shale and deeper high-resistivity units interpreted in the report as limestone.

The integrated interpretation indicates that weathered and fractured zones constitute the principal groundwater targets. Their limited thickness in parts of the area suggests that groundwater productivity may be modest and more appropriate for domestic-scale development. Areas where seismic, EM-VLF and electrical-resistivity responses coincide should receive priority for further hydrogeological investigation.

References

- Adelusi, A. O., Kayode, J. S., & Akinlalu, A. A. (2013). Interpretation of aeromagnetic anomalies and electrical resistivity mapping around Iwaraja area, Southwestern Nigeria. *Journal of Geology and Mining Research*, 5(2), 38–57.
- Adeoti, L., Alile, O. M., Uchegbulam, U., & Adegbola, R. B. (2012). Seismic refraction prospecting for groundwater: A case study of Golden Heritage Estate, Ogun State. *Research Journal of Physics*, 6(1), 1–18.
- Aizebeokhai, A. P., Alile, O. M., Kayode, J. S., & Okonkwo, F. C. (2010). Geophysical investigation of some flood prone area in Ota, Southwestern Nigeria. *American-Eurasian Journal of Scientific Research*, 5(4), 216–229.
- Aizebeokhai, A. P., Oni, A. A., Oyeyemi, K. D., & Ogungbade, O. (2018). Electrical resistivity imaging (ERI) data for characterising crystalline basement structures in Abeokuta, Southwestern Nigeria. *Data in Brief*, 19, 2393–2397.
- Alabi, A. A., Adewale, A. O., Adeleke, O. O., Akinboro, F. G., Afe, A., & Ganiyu, A. (2020). Geo-electric investigation of groundwater potential in Laderin Housing Estate, Abeokuta, Southwestern Nigeria. *Journal of Natural Science, Engineering and Technology*, 19(1–2), 74–91.
- Alabi, A. A., Ganiyu, S. A., Idowu, O. A., Ogabi, A. F., & Popoola, O. I. (2021). Investigation of groundwater potential using integrated geophysical methods in Moloko-Asipa, Ogun State, Nigeria. *Applied Water Science*, 11, 70.
- Ariyo, S. O., Adeyemi, G. O., & Oyebanji, A. O. (2009). Electromagnetic VLF survey for groundwater development in a contact terrain: A case study of Ishara-Remo, Southwestern Nigeria. *Journal of Applied Sciences Research*, 5(9), 1239–1246.
- Ariyo, S. O., Folorunso, A. F., & Ajibade, O. M. (2011). Geological and geophysical evaluation of the Ajana area's groundwater potential, Southwestern Nigeria. *Earth Sciences Research Journal*, 15(1), 35–40.
- Badmus, B. S., & Olatinsu, O. B. (2012). Aquifer characteristics and groundwater recharge pattern in a typical basement complex, Southwestern Nigeria. *African Journal of Environmental Science and Technology*, 4(6), 328–342.
- Bayewu, O. O., Oloruntola, M. O., Mosuro, G. O., Laniyan, T. A., Ariyo, S. O., & Fatoba, J. O. (2017). Geophysical evaluation of groundwater potential in part of Southwestern Basement Complex terrain of Nigeria. *Applied Water Science*.
- Bello, A. E. (2009). An assessment of water supply potential for crop production; comparative study of river basins under the jurisdiction of two river basin development authorities located in different ecological zones of Nigeria. *Journal of Meteorology and Climate Science*, 7(8), 49–57.
- Cardimona, S. (2000). Electrical resistivity techniques for subsurface investigation. Department of Geology and Geophysics, University of Missouri-Rolla.
- Farquharson, F., & Bullock, A. (1992). The hydrology of basement complex regions of Africa with particular reference to Southern Africa. *Geological Society Special Publication*, 66, 59–76.
- Ishola, K. S. (2019). GPS802 Electrical and electromagnetic methods of geophysical exploration.
- Jones, H. A., & Hockey, R. D. (1964). The geology of parts of Southwestern Nigeria. *Geological Survey of Nigeria*, 8(1), 95–101.

- McDowell, P. W., Barker, R. D., Butcher, A. P., Culshaw, M. G., Jackson, P. D., McCann, D. M., & Arthur, J. C. (2002). *Geophysics in engineering investigation*. Geological Society Engineering Geology Special Publication.
- Olorunfemi, M. O., & Oni, A. G. (2019). Integrated geophysical methods and techniques for siting productive boreholes in basement complex terrain of Southwestern Nigeria. *Ife Journal of Science*, 21(1), 1–13.
- Osinowo, O. O., & Olayinka, I. A. (2012). Very low frequency electromagnetic (VLF-EM) and electrical resistivity (ER) investigation for groundwater potential evaluation in a complex geological terrain around the Ijebu-Ode transition zone, Southwestern Nigeria. *Journal of Geophysics and Engineering*, 9, 374–396.
- Oyedele, K. F., & Momoh, E. I. (2010). Geophysical evaluation of hydrostratigraphic and lithostratigraphic units of a coastal terrain and its environmental implications. *Journal of Science, Technology & Environment*, 10, 1–7.
- Rahaman, M. A. (1976). A review of the basement geology of Southwestern Nigeria. In *Geology of Nigeria* (pp. 41–58). Elizabethan Publishing.
- Reynolds, J. (1997). *An introduction to applied and environmental geophysics*. John Wiley & Sons.
- Ufoegbune, G. C., Lamidi, K. I., Awomeso, J. A., Eruola, A. O., Idowu, O. A., & Adeofun, C. O. (2009). Hydro-geological characteristics and groundwater quality assessment in some selected communities of Abeokuta, Southwest Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, 1(1), 10–22.