

Determination of Aquifer Depth and Geoelectric Layering Using Vertical Electrical Sounding (VES) In Afikpo Area, Southeastern Nigeria

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ABSTRACT

Determination of groundwater depth within the undulating ridge-and-valley topography of the Afikpo sub-basin, southeastern Nigeria, is critical to groundwater development. This study utilizes a high-density matrix of fifty (50) Schlumberger Vertical Electrical Soundings (VES) to delineate regional geoelectric horizons, structural framework variations, and determine aquifer depths. Total spread AB = 400 m (i.e., AB/2 = 200 m) was traversed to probe into the depth of linear structures using an Allied OhmMega resistivity meter (2115A model). The data were interpreted using computerized iterative inversion modeling (IPI2Win software), yielding low RMS fitting errors below 5%. Subsurface configurations across the 50 mapped communities reveal three-layer to six-layer geoelectric systems with dominant HK, KH, and QH curve configurations. The interpreted regional depth to the principal aquifer horizons ranges from **3.6 m to 113.0 m**, with an overall average regional aquifer depth of **33.5 m** and a mean localized aquifer layer thickness of **24.7 m**. Delineated aquifer horizons showcase a pronounced structural partitioning controlled by local formations. In the southern and southwestern sectors underlain by tight argillaceous units (Oso, Ekoli Edda, Nguzu), aquifer zones are localized within fractured shales and mudstones at shallow depths ranging between 10.67 m and 19.32 m, showcasing low resistivities ($\rho < 50 \Omega \cdot \text{m}$). Conversely, central and eastern zones (Mgbom, Amachara, Ugwuegu, Ozizza) tap into the highly prolific Afikpo Sandstone member, where true sub-confined regional water tables descend deeper to horizons between 16.00 m and 45.25 m (locally exceeding 74.70 m) with higher matrix resistivities. The results map out groundwater targets, providing engineers with precise target thresholds to minimize dry-well risks and improve borehole yields across the Afikpo sub-basin.

Keywords: Groundwater, Vertical Electrical Sounding, Aquifer, Depth

INTRODUCTION

The increasing necessity of global groundwater availability evaluation has led to rising awareness in groundwater management study. The knowledge of aquifer parameter including depth is very necessary for groundwater resource development and management (Ani, *et al.*, 2023, Obasi *et al.*, 2022., Lachassagne, 2020; Anomohanran and Orhiunu, 2018; Khadri and Pande, 2016). Delineating these subsurface reservoirs however, remains highly complex within the southern margins of the Benue Trough. In Nigeria, aquifer parameter studies span diverse hydrogeological provinces including the Chad Basin, Sokoto Basin, Anambra Basin, and Benue Trough (Offodile, 2002). The hydro-stratigraphy is marked by rapid lithological variations, complex fault networks, and localized sandstone-shale horizons (Ekweet *et al.*, 2020). Surface electrical geophysics, specifically Vertical Electrical Sounding (VES), remains the most non-invasive, cost-effective tool to profile structural resistivity contrasts before drilling (Obasi *et al.* 2020, Ani *et al.*, 2023). Differentiating dry overburden zones from saturated, fluid-bearing fractures becomes very pertinent. Vertical Electrical Sounding (VES) is applied for aquifer thickness and protective capacity (Ekweet *et al.*, 2020; Bala and Ike, 2001). The VES method has been successfully employed in sedimentary environment in water-table and hydraulic gradients estimation (Onwuemesiet *et al.*, 2006; Emenike, 2001, Obasi *et al.*, 2020, Ani *et al.*, 2023). Some authors have worked on the hydrogeology of Anambra Basin but no attempt have been made to couple geophysical method in

hydrogeological studies in case of sparse data availability. Application of field hydro-geological method in aquifer parameter estimation is time consuming and capital intensive. In the alternative, surface geophysical method may provide rapid and effective techniques for groundwater exploration and aquifer evaluation (Corriolset *al*, 2007). The integration of aquifer parameter calculated from the existing/existed boreholes and surface resistivity parameters extracted from surface electrical measurements can be highly effective not only for aquifer hydraulic conductivity estimation but also for group of hydraulic parameters. These aquifer parameters are best obtained through surface electrical and borehole measurement standard techniques (George *et al.*, 2017; Ofomola, 2014). Drilling blind wells without precise geoelectric profiling in this terrain routinely triggers borehole failures, including premature structural silting, caving shales, or dry holes that miss the water table completely (Obasi and Chime, 2020). It is against this background that the determination of the depth to aquifer of groundwater in the Afikpo area is being carried out. This work shall infer the depth to aquifers, thickness and distribution of the geologic formations using geophysical survey data

Study Area, Physiography and Geological setting

The study area is bounded by Latitudes 5° 40' N to 5° 55' N and Longitudes 7° 48' E to 8° 02' E (fig 1). The structural grid spans 50 distinct positions across Afikpo urban, Amasiri, Ekoli Edda, Nguzu, Oso, Ozizza, Uwana, Ndibe, and laterally toward Ebomand Ediba along the Cross River margins. The Iyioka, Iyiechi, Obeyi, Itara, Asuu, Otoni, and Elummahi rivers drain the area into the Cross River in the east. The drainage patterns are largely controlled by the geology. The area is part of the rainforest region of southeastern Nigeria and is mostly made up of the evergreen vegetation composed of very dense trees and undergrowth of creepers. These trees are mostly tall, with buttress roots (Oko-Amaet *al.*, 2023). The climate is characteristic of the tropical rain forest zone of eastern Nigeria. It has eight months rainy season (march- October) with four months of dry season (November- February). The rain fall is most heavy between July and September. The area experiences a tropical wet-and-dry climate, or seasonal tropical climate, characterized by distinct wet and dry periods. The harmattan wind brings dusty, cool conditions during the dry season. Temperatures remain warm year-round, with the hottest months typically occurring between February and March. Annual rainfall ranges between 1,500 mm and 2,000 mm. The relative humidity is consistently high, particularly during the wet season, ranging from 60% to 95%. (Iloeje, 2001)

The geology of the Afikpo area is dominated by the tectonics of the Afikpo Synclinorium. This structural arrangement hosts porous, heavily jointed Afikpo Sandstone beds right alongside thick, impermeable shale units of the Nkporo Group and Ezeaku Formation (Ibiam and Agbasi, 2021). This complex setup causes extreme variation in aquifer accessibility; well depths range from very shallow water tables to deep regional regimes (Moses and Osi-Okeke, 2017). The regional stratigraphy is structurally defined by Cretaceous sediment deposits resulting from multiple marine transgression and regression cycles (Ekwe et al., 2020). The older Ezeaku Formation (Turonian) and the younger Nkporo Shale Group (Campanian-Maastrichtian) form the thick, low-permeability basinal shales (Okoro and Igwe, 2018). Within the Afikpo and Anambra basins were deposited, post-Santonian Nkporo Formation sediments as basal units on unconformable (severely folded and eroded) older strata, superposed by off lap complexes of the coaliferous Mamu Formation, the flaggy Ajali Sandstone and the paralic Nsukka Formation that terminated the Cretaceous- proto Niger Delta successions in southern Nigeria (Reyment 1965). The sediments comprising the formations in the Afikpo and Anambra Basins were predominantly deposited in shallow shelf environments (Reyment, 1965) recognized four lithostratigraphic units designated as formations in the Anambra Basin. These units also occur in the Afikpo Sub-basin. This implies the complete absence of Coniacian and Santonian units in the Afikpo area, an age gap of some 10 Ma probably due to combination of erosion and non-deposition (Nwajide, 2013). The Mamu Formation, the Ajali Sandstone and the Nsukka Formation were termed the Coal Measures by Nwajide, (2005). The Mamu Formation conformably overlies the Nkporo Shale.

Table 1: stratigraphic sequence of the Afikpo Area.

Age	Lithostratigraphic unit		Basin
	Formation	Subunits	

Upper Maastrichtian	Nsukka Formation		Afikpo Sub-basin
Middle Maastrichtian	Ajali Formation		
	Mamu Formation		
Lower Maastrichtian	Nkporo Formation	Amaiyi Shale, Owutu Sandstone, Asaga Shale	
Campanian	Afikpo Sandstone		Southern Benue Trough
Santonian	Angular unconformity		
Turonian	Eze-Aku Group	Amasiri Sandstone, Eze-Aku Shale	

MATERIAL AND METHOD

Fifty (50) VES field data (see fig 1) were acquired using the Schlumberger electrode configuration in the area (figure 1), expanding the current electrodes (A and B) systematically to achieve deep subsurface current penetration. Vertical Electrical Sounding (VES) was conducted. Electrical current was injected into the subsurface by using a pair of current electrodes, followed by measurement of potential difference using potential electrodes. Schlumberger electrode array was used. Total spread $AB = 400$ m (i.e., $AB/2 = 200$ m) was traversed to probe into depth of linear structures using Allied OhmMega resistivity meter (2115A model). Station locations were mapped using high-sensitivity GPS trackers (see Table 2). The field apparent resistivity values (ρ_a) were processed using a two-stage workflow. Initial layer parameters were generated via manual log-log segment modeling using standard master curves. These parameters were then refined using IPI2Win geoelectric software through automated iterative software inversions. This iterative process adjusted layer thickness (h) and resistivity (ρ) values to match the true measured field configurations. The computerized refinement was executed until convergence was reached, maintaining highly acceptable inversion accuracy with root-mean-square (RMS) errors routinely falling below 5% across the 50 processed VES stations.

Table 2: Field Survey Locations and GPS Spatial Coordinates

VES ID	Station Location Name	Latitude (N)	Longitude (E)
1	Amagbala	5.879166	7.935833
2	Oso no 2	5.870277	7.803611
3	Ekoli Edda	5.748333	7.838333
4	Mgbom	5.879722	7.931388
5	Amachara	5.890277	7.930555
6	Nguzu	5.751111	7.818055
7	Ozziza	5.881111	7.974444
8	Owutu	5.811111	7.851944
9	Ozizza	5.891944	7.961388

10	McGregor	5.890555	7.913333
11	Owutu	5.813611	7.853888
12	Mgbom	5.871111	7.930000
13	Nguzu	5.753055	7.820555
14	Ugwuegu	5.895833	7.957500
15	EnohiaIti	5.888333	7.961944
16	Amuro	5.923055	7.899166
17	NdiObasi	5.873888	7.816388
18	Ekureku	6.004166	8.005555
19	Igonigoni	5.808655	7.971111
20	Ndibe	5.869444	7.939722
21	Amaizu	5.878888	7.938888
22	Ekoli	5.760011	7.840833
23	Fed. Poly	5.802777	7.919444
24	Amachara	5.888888	7.931388
25	Uwana	5.806944	7.923611
26	Ekoli Edda	5.750277	7.840833
27	Mgbom	5.876666	7.924722
28	Ekoli	5.748611	7.836111
29	Ibii	5.934166	7.940011
30	Amaeta	5.913888	7.995277
31	Amaozara	5.885555	7.954722
32	Amuro	5.886666	7.932777
33	Amauzu	5.874166	7.953055
34	Amaozara	5.878611	7.955277
35	Amankwo	5.870555	7.951666
36	Ndibe	5.853611	7.946388
37	Amagbala	5.874722	7.940277

38	Egeburu	5.884722	7.942222
39	Ukpa	5.892222	7.931944
40	Amaozara	5.878611	7.955277
41	Nguzu	5.751388	7.818055
42	Amagbala	5.882777	7.940277
43	Amasiri	5.928333	7.891111
44	Mgbom	5.876388	7.916666
45	Amasiri	5.918055	7.886111
46	Ediba	5.876666	8.023333
47	Amasiri	5.919444	7.877777
48	Ebijakara	5.855833	7.970833
49	Ebom	5.850011	7.966666
50	Oso	5.878611	7.818888

RESULT AND DISCUSSION

Geoelectric stratigraphy and layer parameters: The interpretation of the 50 VES stations outlines a multi-layered geoelectric sequence across the sub-basin, ranging from 3 to 6 distinct subsurface layers. To analyze the VES data, both descriptive and quantitative approach were employed an attempt was made to delineate and map the geo-electrical layers using numerical (factor) analysis of the conventional vertical electrical sounding data, with a partial curve matching technique. This numerical approach in concatenation with resistivity imaging or other techniques would prove to be an effective tool in geo-electric section and lithological delineation, and aquifer mapping. The curve type represents a description of how layers change their resistivity values with depth under the array midpoint. Therefore, curve type represents a part of the descriptive interpretation. Curve types must be determined for all of the (VES) points in the surveyed area during the manual interpretation. It's important to mention here that the curve type is not important as a descriptive tool only, but it also represents the key that leads the way during the quantitative interpretation, especially if the partial curve matching method with the standard resistivity curves adopted.

The quantitative interpretation of vertical electrical sounding (VES) data was used to determine the resistivity and thicknesses of the different geoelectric horizons (Table 4). The delineated depth to the principal aquifer horizons ranges from 3.6 m to 113.0 m, with an overall average regional aquifer depth of 33.5 m. The statistical distribution reveals that the majority of the aquifer depths fall within a mid-range threshold: 29 out of the 50 VES points (58%) occur between 20 m and 60 m, 14 stations (28%) lie at shallow horizons below 20 m, and 7 stations (14%) descend deeper than 60 m. Across the study area, the calculated mean thickness of the localized aquifer layers is 24.7 m.

THE GEOLOGIC MAP OF THE AFIKPO AREA INDICATING THE VES POINTS

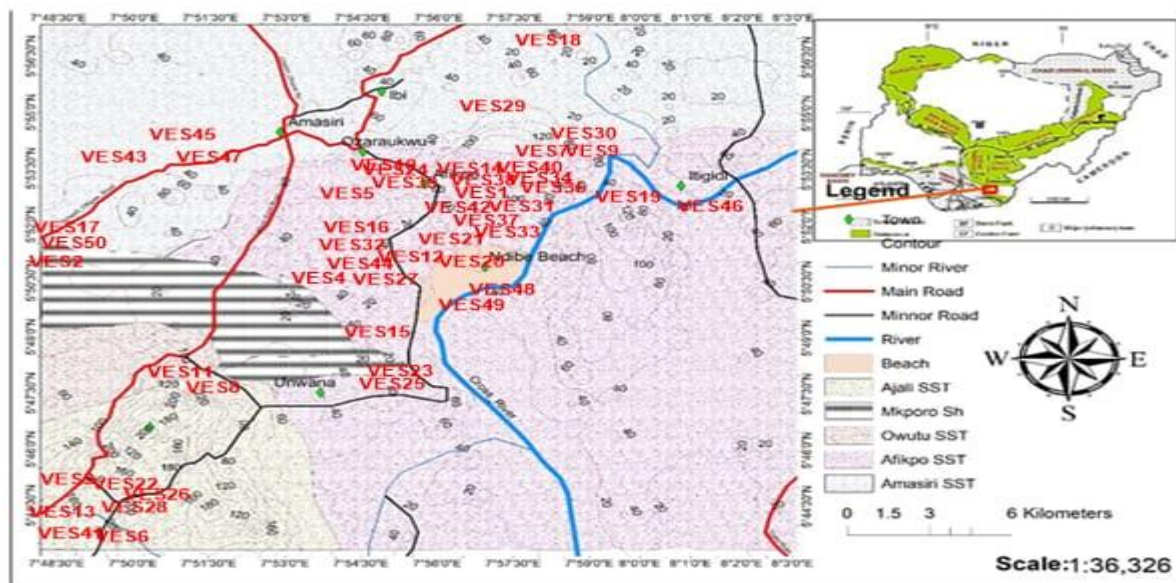


Figure 1: Map of the Study Area showing VES points and Local geology

Representative stations showing the typical geoelectric properties of these various geological formations are summarized in Table 3.

Table 3: Geoelectric Parameters and Hydrogeological Inferences for Key Stations

VES Station ID	Location Name	Layer Number (N)	Layer Resistivity (ρ , Ω -m)	Layer Thickness (h, m)	Cumulative Depth (d, m)	Lithological / Hydrogeological Interpretation
VES 1	Amagbala	1 2 3 4 5	8674.0 46.28 580.9 140.3 28.3	0.30 0.55 0.57 14.57 --	0.30 0.85 1.42 16.00 --	Dry sandy topsoil veneer Weathered silty clay overburden Dry consolidated sandstone crust Saturated Fractured Sandstone (Aquifer) Nkporo Shale bedrock base
VES 2	Oso no 2	1 2 3 4	786.5 81.9 4.28 6020.0	2.92 17.80 12.80 --	2.92 20.72 33.52 --	Compacted sandy loam overburden Weathered silty shale layer Conductive Fractured Shale Aquifer Zone Fresh, unweathered shale/limestone basement
VES 3	Ekoli Edda	1 2 3 4 5	2816.0 18.7 1723.0 3.12 279.0	0.34 0.69 2.18 16.10 --	0.34 1.04 3.22 19.32 --	Lateritic sand top veneer Saturated silt/clay top layer lens Tight sandstone outcrop escarpment Conductive Saturated Fractured Clayey-Sand Shale structural basement bed

VES 4	Mgbom	1 2 3	247.0 773.0 74.6	1.63 9.04 --	1.63 10.67 --	Sandy humic loam profile Dry massive sandstone cap layer Saturated Fractured Sandstone Aquifer
VES 12	Mgbom	1 2 3 4 5 6	771.0 283.0 3339.0 207.0 34.1 15220	0.89 1.01 2.34 41.00 47.10 --	0.89 1.90 4.25 45.25 92.35 --	Silty topsoil overburden Weathered shaly sand matrix Highly resistive tight sandstone ridge cap Upper Sandstone Aquifer Sub-unit Main Deep Sub-confined Sandstone Aquifer Unweathered bedded baseline shale strata

Table 4: Master Geoelectric Inversion Data Ledger

The quantitative layer totals, thickness parameters, estimated or absolute aquifer horizons, and respective curve classification shapes extracted via computerized iterative spline inversion modeling across all 50 occupied Vertical Electrical Sounding (VES) survey targets are logged below.

VES ID	Station Location Name	Mapped Layer Count	Geoelectric Layer Resistivities (ρ, $\Omega \cdot m$)	Modeled Layer Thicknesses (h, m)	Delineated Aquifer Depth Horizon (m)	Curve Family Typology
1	Amagbala	5	8674, 46.28, 580.9, 140.3, 28.3	0.30, 0.55, 0.57, 14.57, --	14.57 (d = 16.00)	KH / QH
2	Oso no 2	4	786.5, 81.9, 4.28, 6020	2.92, 17.80, 12.80, --	12.80 (d = 33.52)	H / QH
3	Ekoli Edda	5	2816, 18.7, 1723, 3.12, 279	0.34, 0.69, 2.18, 16.10, --	16.10 (d = 19.32)	HK / QH
4	Mgbom	3	247, 773, 74.6	1.63, 9.04, --	> 10.67	K
5	Amachara	4	409, 101, 1158, 28.32	2.28, 1.67, 3.79, --	> 7.74	HK
6	Nguzu	3	33.4, 3.49, 86.91	11.30, 8.21, --	> 19.50	H
7	Ozziza	3	1851, 496.7, 198.3	1.56, 21.43, --	> 22.98	Q
8	Owutu	5	138, 12.4, 622, 19.9, 284.5	2.14, 1.35, 3.10, 15.50, --	15.50 (d = 22.10)	H / KH
9	Ozizza	3	104, 15.3, 344	22.30, 12.20, --	> 34.50	H
10	McGregor	3	3589, 238, 29.69	4.52, 23.18, --	> 27.70	Q
11	Owutu	6	58953, 282, 22.4, 336, 22.2, 7634	0.23, 1.84, 1.44, 2.89, 82.20, --	82.20 (d = 88.60)	HK / H
12	Mgbom	6	771, 283, 3339, 207, 34.1, 15220	0.89, 1.01, 2.34, 41.00, 47.10, --	47.10 (d = 92.35)	KH / K

13	Nguzu	3	3.1E+6, 60.1, 127	0.13, 6.30, --	> 6.43	H
14	Ugwuegu	5	980.1, 8.26, 341, 17.4, 5287	0.36, 0.75, 1.78, 71.80, --	71.80 (d = 74.70)	H / KH
15	Enohialti	4	605, 131.3, 4.285, 3478	2.69, 16.18, 16.46, --	16.46 (d = 35.34)	Q / H
16	Amuro	5	20588, 135, 1475, 332, 37.07	0.34, 0.48, 11.20, 101.0, --	101.0 (d = 113.0)	HK / H
17	NdiObasi	3	332, 20.3, 227	0.66, 3.99, --	> 4.65	H
18	Ekureku	3	195, 171, 99.3	0.81, 2.82, --	> 3.63	Q
19	Igonigoni	3	134, 4.55, 2488	26.10, 19.10, --	> 45.10	H
20	Ndibe	3	179, 72.4, 25.5	2.05, 42.80, --	> 44.90	Q
21	Amaizu	5	686, 98.82, 1654, 9.578, 280.4	2.08, 1.08, 4.28, 12.13, --	12.13 (d = 19.56)	HK / H
22	Ekoli	5	480, 68.06, 1174, 6.818, 5655	1.88, 1.65, 4.96, 10.95, --	10.95 (d = 19.43)	HK / H
23	Fed. Poly	5	161.2, 23.43, 351.1, 22.13, 121.6	2.58, 1.41, 4.14, 6.48, --	6.48 (d = 14.60)	HK / H
24	Amachara	3	257.8, 96.97, 25.07	13.86, 34.05, --	> 47.91	Q
25	Uwana	4	27.98, 1412, 83.99, 35.77	0.55, 1.22, 35.02, -	> 36.79	K / H
26	Ekoli Edda	3	4.657, 1.062, 54.73	3.84, 1.63, --	> 5.47	H
27	Mgbom	4	30753, 84.11, 41.38, 27.04	0.24, 10.77, 70.16, --	> 81.17	Q
28	Ekoli	3	62.9, 14, 28.52	3.12, 19.90, --	> 23.00	H
29	Ibii	4	2402, 422, 15.2, 25849	1.10, 12.60, 11.58, --	11.58 (d = 25.28)	Q / H
30	Amaeta	4	1466, 766, 92.1, 803	1.37, 14.60, 7.21, -	> 23.20	Q / H
31	Amaozara	3	143, 36.7, 31657	25.30, 17.50, --	> 42.80	H
32	Amuro	4	5301, 99.1, 51.59, 9.763	0.33, 9.60, 35.50, -	> 45.40	Q / H
33	Amauzu	5	234.6, 35.65, 681.6, 4.472, 5163	2.11, 2.20, 5.49, 19.62, --	19.62 (d = 29.43)	HK / H
34	Amaozara	5	926.8, 58.92, 1707, 4.978, 29.01	2.07, 1.16, 4.74, 15.71, --	15.71 (d = 23.68)	HK / H

35	Amankwo	4	24.76, 368.6, 10.88, 176.8	2.98, 2.67, 12.75, -	> 18.40	K / H
36	Ndibe	4	149.3, 3135, 106.1, 28.31	0.46, 0.73, 34.15, -	> 35.34	K / H
37	Amagbala	3	569.2, 6.905, 202	7.53, 12.43, --	> 19.96	H
38	Egeburu	4	187310, 231.4, 9.194, 74.5	0.22, 14.87, 4.97, -	> 20.05	Q / H
39	Ukpa	3	769.8, 51.06, 36537	28.89, 35.73, --	> 64.62	H
40	Amaozara	5	557, 1819, 231.1, 1856, 308.3	3.43, 2.42, 7.88, 15.65, --	15.65 (d = 29.37)	K / HK
41	Nguzu	4	28.9, 335.5, 7.069, 191.2	1.51, 6.93, 10.31, -	> 18.74	K / H
42	Amagbala	3	30.04, 51.54, 13.28	5.06, 41.52, --	> 46.58	K
43	Amasiri	3	58.55, 95.46, 319.1	2.15, 7.63, --	> 9.78	A
44	Mgbom	5	95.97, 1072, 24.33, 769.7, 16.65	0.44, 0.86, 1.56, 21.00, --	21.00 (d = 23.86)	K / HK
45	Amasiri	4	50.51, 1930, 119, 21.7	0.46, 0.64, 70.06, -	> 71.17	K / H
46	Ediba	3	26.82, 5.934, 5980	13.05, 8.66, --	> 21.71	H
47	Amasiri	3	68.25, 12.1, 6987	1.38, 13.51, --	> 14.88	H
48	Ebijakara	4	72.16, 8.363, 116.1, 32.16	2.86, 1.26, 46.31, -	> 50.43	H / K
49	Ebom	4	44.64, 1104, 31.93, 51690	0.49, 15.48, 14.02, --	14.02 (d = 29.99)	K / H
50	Oso	4	231.2, 12.86, 170.2, 57.81	1.26, 0.54, 37.26, -	> 39.06	H / K

Note: In the Aquifer Depth Column, ">X" represents open unconfined base strata where the aquifer layer starts at the cumulative boundary depth threshold (X) and remains unpenetrated beyond the terminal maximum array spacing length. Clear fractional identifiers (e.g., d=16.00) show exact depth caps where intermediate target horizons terminate.

Geoelectric Curve Typologies

The apparent resistivity paths reflect the complex structural trends across the area: The whole set of three – layer sounding curves can be divided into four groups, depending on the relative values of ρ_1 , ρ_2 and ρ_3 , (Bhattacharya and Patra, 1968): 1- Minimum type: when $\rho_1 > \rho_2 < \rho_3$. This is also referred as (H-type) (associated with the name of Hummel). 2- Double ascending type: when $\rho_1 < \rho_2 < \rho_3$. This is also known as (A-type) (corresponding to the term anisotropy). 3- Maximum type: when $\rho_1 < \rho_2 > \rho_3$, this is known as (K-type) or is sometimes referred as DA-type (meaning displaced or modified anisotropy). 4- Double descending type: when $\rho_1 > \rho_2 > \rho_3$. This is known as (Q-type) and is sometimes referred to as DH-type (meaning displaced Hummel or modified Hummel).

- **HK and KH-Type Geoelectric Curves (e.g., VES 1, VES 12):** These reveal a resistive surface layer transitioning into intermediate weathered zones, underlain by a highly resistive sandstone unit. Below this protective sandstone cap, a sharp decrease in resistivity marks the secondary fracture zones that form productive aquifers.
- **H and QH-Type Trajectories (e.g., VES 2, VES 3):** These show a continuous drop in apparent resistivity with depth. This pattern indicates areas where the sand units disappear, shifting into thick conductive shale beds that hold water within localized fracture systems (Ibiam&Agbasi, 2021).

4.3 Aquifer Depth Delineation and Hydrogeological Mapping

Our findings reveal two distinct groundwater regimes across the sub-basin:

1. **Shallow Clayey/Fractured Shale Aquifers:** In the southern and western margins including Oso (VES 2), Ekoli Edda (VES 3), and parts of Nguzu (VES 6) the water table is relatively shallow, occurring at depths between **10.67 m and 19.32 m** (Moses & Osi-Okeke, 2017). These aquifers display low matrix resistivities ($\rho = 3.12 - 46.28 \Omega \cdot m$), indicating groundwater storage within thin silty interfaces or fractured shale intervals (Ekwe et al., 2020).

Deep Regional Sandstone Aquifers: Across the central and eastern sectors including Mgbom (VES 12) and Ugwuegu (VES 14) groundwater is hosted within the deep, porous Afikpo Sandstone member. Here, the true regional water table drops deeper, settled at depths from 16.00 m to 45.25 m, and extending past 74.70 m at VES 14. These systems yield clean, low-iron groundwater due to the excellent sorting and high secondary porosity of the sandstone matrix (Okiongbo&Akpofure, 2022). These systems are inferred to be highly productive due to the excellent sorting and high secondary porosity of the sandstone matrix; however, definitive local groundwater yield and hydrochemical properties (such as iron content) **warrant confirmation via future pumping tests and physicochemical water quality analyses**

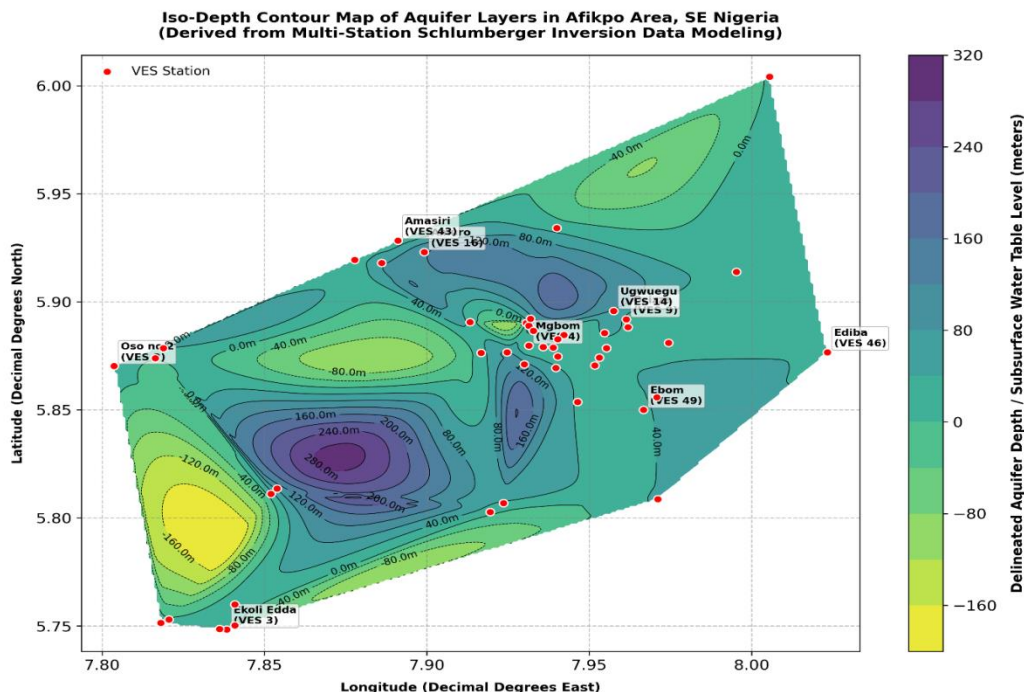


Figure 2: Iso-depth contour map of aquifer layers across the Afikpo study area, Southeastern Nigeria, derived from 50-station Schlumberger Vertical Electrical Sounding (VES) inversion data modeling.

Note on Spatial Presentation: The color-coded scale bar maps the regional geometry of the groundwater table relative to a local topographical baseline datum. Positive contour values indicate areas where deep, sub-confined regional water tables descend significantly below the elevated central sandstone ridges (e.g., Mgbom and Ugwuegu). Negative contour values represent localized shallow water tables where the unconfined aquifer

horizons sit close to or intersect low-lying topographic valley floors and structural shale troughs (e.g., Oso and Ekoli Edda)

CONCLUSION AND RECOMMENDATIONS

Conclusion

The VES across 50 key locations successfully delineates the depth to aquifer and subsurface framework of the Afikpo sub-basin. The subsurface is composed of multi-layered sequences under strong structural control, with water tables dropping from shallow depths in the western shale valleys to deep horizons within the central sandstone ridges. Computerized iterative inversions mapped these layers with high accuracy, establishing clear target boundaries for local groundwater exploitation. This study successfully demonstrates the efficacy of using a high-density matrix of fifty (50) Vertical Electrical Sounding (VES) stations to map the geoelectric layering and determine aquifer depths across the complex hydrogeological terrain of the Afikpo Area, Southeastern Nigeria. The automated iterative inversion modeling yielded robust subsurface profiles, mapping out 3-layer to 6-layer geoelectric structures governed closely by regional structural layouts. The integration of geoelectric data with spatial coordinate mappings reveals a highly partitioned aquifer network across the sub-basin:

1. **The Western and South-Western Margins (e.g., Oso, Ekoli Edda, Nguzu, Owutu):** These low-lying areas are underlain by argillaceous sequences where groundwater resources are constrained within fractured shales, mudstones, or thin clayey-sand interfaces. In this zone, the structural water table is shallow, localized primarily at depths between **10.67 m and 19.32 m**, displaying high matrix conductance (resistivities frequently dropping below 50 Ωm).
2. **The Central, Eastern, and south-eastern Ridges (e.g., Mgbom, Amachara, Ugwuegu, Ozizza, Enohia, Uwana):** These upland horizons tap into the classic **Afikpo Sandstone member**. Here, the true sub-confined regional water tables are situated much deeper, dropping down to horizons between **16.00 m and 45.25 m** and extending past **74.70 m to over 100 m** in areas such as Ugwuegu, Ozizza, Mgbom and Amuro. These systems display lower matrix conductance, characterizing them as prolific, high-yield, and low-iron aquifers due to prominent secondary porosity from regional joints and fractures.

Ultimately, the derived spatial iso-depth configurations confirm that regional groundwater movement and storage are closely controlled by structural changes within the Afikpo Synclinorium. This structural control explains why blind drilling carries an exceptionally high failure risk in this area.

Recommendations

To significantly mitigate borehole failures, optimize drilling budgets, and ensure long-term groundwater yield sustainability for communities across the Afikpo area, the following engineering guidelines are recommended:

- **Target Depth Protocols for Sandstone Terrains:** Drilling operations situated on the structural sandstone ridges such as *Mgbom, Amachara, Amuro, Ugwuegu, and Ukpa (majorly within the Afikpo Urban)*, must not be terminated prematurely upon hitting the first water-bearing interface. Drilling must explicitly pass through the tight sandstone ridge caps to tap the deeper sub-confined fracture systems located between **45 m and 90 m+**. This prevents well failure caused by shallow perched water tables drying out during peak dry periods.
- **Borehole Construction and Screen Matrix in Shale Valleys:** For exploration within clay-rich or shaly horizons (such as *Oso, Nguzu, Ekoli Edda, and Ediba*), wells must be securely cased down to the fractured targets mapped between **20 m and 35 m**. Continuous slot screens and high-quality sorted gravel packs are mandatory in these zones to prevent clay swelling, well caving, and premature silting.
- **Integrated Geophysical Workflows:** Future groundwater development schemes in the area should integrate these 1D VES soundings with 2D Electrical Resistivity Tomography (ERT) profiling. This

combined approach will map lateral fracture extensions even more accurately before heavy drilling equipment is deployed

REFERENCES

1. Ani, C.C; Akpa, C; Obasi, P. N; Chukwu, A (2023) Integrated electrical resistivity methods for evaluation of fracture terrain groundwater potentials, case study of indurated shale of Lower Benue trough, Southeastern Nigeria Groundwater for Sustainable Development 23 (2023) 101014
2. Anomohanran, O. and Orhiunu, M.E. (2018) Assessment of groundwater occurrence in Olomoro, Nigeria using borehole logging and electrical resistivity methods. Arab J Geosci 11, 219. <https://doi.org/10.1007/s12517-018-3582-7>
3. Bala, A. E., and Ike, E. C. (2001). The aquifer of the Chad Basin, NE Nigeria. *Journal of Mining and Geology*, 37(2), 177–184.
4. Corriols, M. and Dahlin, T. (2007). Geophysical Characterization of the Leon-Chinandega Aquifer. *Hydrogeology J.* 16 (2): 355.
5. Ekwe, A. C., Opara, A. I., Nnodu, I. N., and Okeugo, C. G. (2020). Determination of aquifer parameters from geosounding data in parts of Afikpo Sub-basin, southeastern Nigeria. *Arabian Journal of Geosciences*, 13(3), 110-123.
6. Emenike, E.A., (2001): Geophysical Exploration for groundwater in a sedimentary environment: a case study from Nanka over Nanka Formation in Anambra Basin, Southeastern, Nigeria. *Global Jour. of pure and applied Sciences*, 7 (1): 56
7. George, N.J.; A.E. Akpan and F.S Akpan. (2017). Assessment of spatial distribution of porosity and aquifer geohydraulic parameters in parts of the Tertiary – Quaternary hydrogeoresource of south-eastern Nigeria. *NRIAG Journal of Astronomy and Geophysics*. 6(2), 422-433 <https://doi.org/10.1016/j.nrjag.2017.09.001>
8. Ibiam, A. U., & Agbasi, J. C. (2021). Hydrogeophysical and aquifer protective capacity of Abakaliki-Afikpo area and environs, Southeastern Nigeria using geo-sounding data. *International Journal of Advanced Academic Research*, 7(4), 74-92. [IJAAR Official Portal](https://www.ijaarofficialportal.com).
9. Khadri, S.F.R., and Pande, C. (2016). Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin, India. *Model. Earth Syst. Environ.* 2, 39. <https://doi.org/10.1007/s40808-015-0049-7>
10. Lachassagne, P. (2020). What is Groundwater? How to manage Groundwater Resources. *Annals of Nutrition and Metabolism*, 76(suppl 1):17–24. [https://DOI: 10.1159/000515024](https://doi.org/10.1159/000515024)
11. Moses, O., and Osi-Okeke, I. A. (2017). Geostatistical study of the spatial variability of groundwater parameter: Aquifer thickness (H) and water table depth (WTD) in parts of Afikpo and Ohaozara, Southeastern Nigeria. *International Journal of Water Resources and Environmental Engineering*, 9(4), 88-97. [Academic Journals link](https://www.academicjournals.org).
12. Nwajide, C.S. (2005) Anambra Basin of Nigeria: Synoptic Basin Analysis as a Basis for Evaluation Its Hydrocarbon ProspectivityPTDF publication,
13. Nwajide, C.S. (2013). “Geology of Nigeria’s Sedimentary Basins”, CSS Bookshops Ltd Lagos.
14. Obasi, P. N., and Chime, C. H. (2020). Aquifer studies using well test and lithological data within Abakaliki and Afikpo areas, South-Eastern Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 10(2), 45-61. [ResearchGate Portal](https://www.researchgate.net).
15. Obasi, P. N; Ani, C. C; Akakuru, O. C. and Akpa, C. (2020) Determination of Aquifer Depth Using Vertical Electrical Sounding in Ihechiowa Area, Arochukwu, Southeast Nigeria. *EBSU Science Journal* Vol. 1(1) 2020 pp111-126
16. Obasi, P. N; Awara E., Akpa. C., Edene, E., (2022) Characterization of Subsurface Lithology and Aquifer Parameters Using Vertical Electrical Sounding (VES) for Groundwater Development in Igbo-Imabana, Southern Nigeria. *Advances in Geological and Geotechnical Engineering Research* <https://ojs.bilpublishing.com/index.php/agger>
17. Offodile, M.E. (2002) Groundwater Study and Development in Nigeria. 2nd Edition, MeconGeology and Engineering Services Ltd., Jos, 453 p.
18. Ofomola, M.O (2014). Aquifer Characterization and groundwater quality studies in part of Niger Delta Area using geoelectric and hydrogeochemical methods. *Nigeria Journal of Physics*, 25:96–106.

19. Okiongbo, K. S., & Akpofure, E. (2022). An assessment of the groundwater potentials of the farm with the integrated use of geology, grain size analysis, and vertical electrical sounding in Owutu-Ogbu area, Southeastern Nigeria. *Scientific African*, 16, e01155. [ScienceDirect Database](#).
20. Oko-Ama, C.T., Akudinobi, B. B., Obasi P. N. (2023). Hydrochemical evaluation of groundwater in parts of Afikpo, southeastern Nigeria. *International Journal of Innovative Science and Research Technology*.
21. Okoro A.U. and Igwe E. (2018). Lithostratigraphic characterization of the upper campanian-maastrichtian succession in the Afikpo sub-basin, southern anambra basin, Nigeria. *J.Afr. Earth Sci.*
22. Onwuemesi, A.G. and B.C.E. Egboka, (2006). 2-D Polynomial curve fitting techniques on watertable, and hydraulic gradients estimations in parts of Anambra Basin, Southeastern Nigeria, *Natural and Applied Sci. J.* 7 (1&2) pp 6-13.
23. Reyment, R.A (1965). "Aspects of the Geology of Nigeria" Ibadan University Press, Ibadan