

## A hydrogeological assessment of groundwater flow direction and aquifer potential in Ufuma and Environs, Anambra State

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**ABSTRACT** : Hydrogeological investigations were carried out in Ufuma and its environs, Anambra State, Southeastern Nigeria, to evaluate groundwater flow direction and assess aquifer potential. Fifteen vertical electrical soundings (VES) were conducted using the Schlumberger electrode configuration. The acquired geophysical data were interpreted using a combination of partial curve matching and computer-assisted iterative modelling techniques. The interpreted geoelectrical results delineated five curve types, namely K, HK, AK, KQ, and QK, with HK and AK types dominating approximately 80% of the soundings, while the remaining 20% comprised the other curve forms. The interpreted results reveal that the depth to the water-bearing sandstone aquifer ranges from 42.28 m at Ufuma to 132.99 m at Ndiokpalaeze. The aquifer unit is characterized by a relatively high average resistivity of 2016.93  $\Omega$ m. Spatial variation indicates that aquifer thickness is generally greater in the northeastern part of the study area, with an average thickness of 95.65m. Hydraulic parameter estimation indicates that hydraulic conductivity values vary from  $7.0 \times 10^{-2}$  m/day at Umuogem (VES 6) to  $7.35 \times 10^{-1}$  m/day at Ufuma (VES 3), with an average value of  $2.78 \times 10^{-1}$  m/day. Transmissivity values range between 7.95 m<sup>2</sup>/day and 50.32 m<sup>2</sup>/day, with a mean of 22.26 m<sup>2</sup>/day. Analysis of groundwater flow direction indicates a dominant northwest–southeast (NW–SE) trend, which is consistent with the regional geomorphological slope. The results suggest that the aquifer system in the study area possesses moderate to good groundwater development potential for domestic and small-scale water supply. However, the predominance of unconsolidated sandy formations indicates a high susceptibility to erosion and necessitates appropriate land-use and environmental management strategies.

**KEYWORDS:** Hydrogeophysical, lithologic unit, Aquifer, Resistivity, Transmissivity, Erodibility, hydrogeological

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### I. INTRODUCTION

Groundwater remains a vital component of freshwater resources, particularly in regions where surface water availability is limited or seasonally varies. In southeastern Nigeria, increasing population growth, urban expansion, and climate variability have intensified reliance on groundwater for domestic and small-scale agricultural water supply. Consequently, the need for reliable subsurface characterization has become critical for sustainable groundwater development and management (Ezeh et al. 2022; Opara and Egboka 2023).

Hydrogeophysical methods, especially electrical resistivity techniques such as vertical electrical sounding (VES), are widely applied in groundwater investigations due to their effectiveness in delineating subsurface lithological variations and aquifer geometry. These methods allow the estimation of key hydrogeological parameters, including aquifer depth, thickness, and hydraulic properties, which are essential for groundwater potential evaluation. Recent studies have demonstrated the effectiveness of VES in mapping aquifer systems and identifying productive

groundwater zones within sedimentary basins in southeastern Nigeria (Nwankwo et al. 2021; Okoro and Ugwu 2024).

The study area, Ufuma and its environs in Anambra State of Nigeria, lies within the Anambra Basin and is characterized by alternating sequences of sandstone, shale, and clay units. These lithological variations exert strong control on groundwater occurrence, storage, and movement. Previous investigations within adjacent parts of the basin have reported variable aquifer characteristics influenced by lithological heterogeneity and structural controls, resulting in spatially diverse groundwater potential (Chukwuma et al. 2022). Despite these contributions, limited studies have integrated groundwater flow direction analysis with aquifer potential assessment in Ufuma and the surrounding areas. Understanding groundwater flow dynamics is essential for identifying recharge and discharge zones, assessing contaminant transport pathways, and optimizing groundwater development strategies. Regional studies within the Anambra Basin suggest that groundwater flow is largely controlled by topography and subsurface stratigraphy, often exhibiting consistent directional trends across sedimentary units (Egboka and Nwosu 2021).

Accordingly, this study presents an integrated hydrogeophysical approach to delineate groundwater flow direction and evaluate aquifer potential in Ufuma and its environs. The findings are expected to improve the understanding of subsurface hydrogeological conditions and provide a scientific basis for sustainable groundwater resource exploitation in the area.

## II. MATERIALS AND METHODOLOGY

### 2.1 GEOLOGY OF THE PLACE

The study area is situated in Anambra State, southeastern Nigeria, between latitudes 7°09'N and 7°15'N and longitudes 6°00'E and 6°06'E (Fig. 2.1). It forms part of the Anambra Basin, a sedimentary

basin developed during the Late Cretaceous as a result of marine transgression associated with the Campanian–Maastrichtian phase of the second sedimentary cycle (Ezeh and Anike 2021; Nwankwo et al. 2022). The principal lithostratigraphic units within the area include the Ameki Group (particularly the Enenebe Sandstone) and the Imo Shale (Fig. 2.2). The Nanka Sands (Eocene), which are laterally equivalent to the Ameki Formation, constitute the dominant geological unit in the study area. This formation is composed predominantly of fine- to coarse-grained sands with intercalations of calcareous shale and thin limestone at the basal sections, and loose, cross-bedded sands with occasional sandy clay layers in the upper horizons (Ezeh and Anike 2021; Okeke et al. 2023). The sandy facies exhibit high porosity and permeability, thereby forming the principal aquifer system within the area. Underlying the Nanka Sands is the Imo Shale (Paleocene), characterized by thick sequences of clayey shale with minor interbeds of ironstone and thin sandstone layers. The formation typically exhibits dark grey to bluish-grey coloration and is composed predominantly of fine-grained materials with low permeability (Nwankwo et al. 2022). Consequently, it functions as an aquitard, restricting vertical groundwater movement and providing confinement to the overlying aquifer units. In some parts of the study area, the Ogwashi–Asaba Formation (Oligocene–Miocene) overlies the Ameki Formation. This formation comprises alternating sequences of sandstone and shale. The sandstone units vary in colour from yellow and whitish to reddish-brown and are often ferruginized and moderately indurated, although occasionally friable. The basal sections commonly consist of poorly sorted, coarse-grained to pebbly sands with admixtures of finer materials (Okeke et al. 2023). Overall, the geological framework reflects a complex sedimentary environment that exerts significant control on groundwater occurrence, aquifer geometry, and subsurface flow dynamics within the basin.

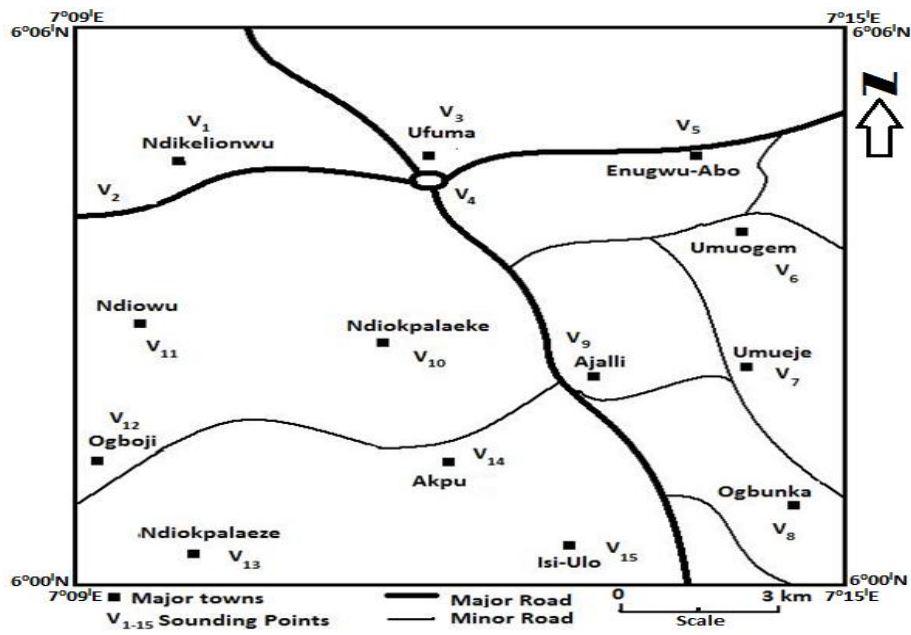


Fig.1: Map of the study area showing towns and VES locations (NGSA, 2010)

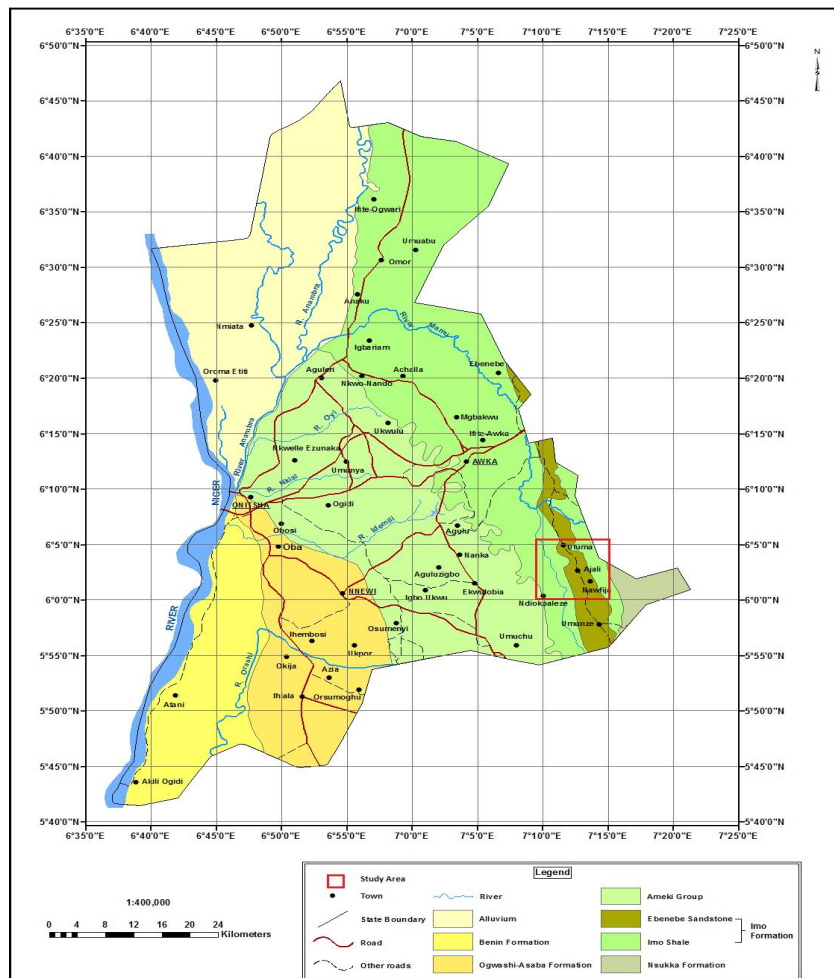


Fig. 2.: Geologic map of Anambra State showing the study area (NGSA, 2010)

## 2.2 METHODOLOGY

Vertical Electrical Sounding (VES) was conducted at fifteen (15) locations within the study area (Fig. 1) using an ABEM Terrameter SAS 1000 for groundwater investigation. The Schlumberger electrode configuration was adopted, with a maximum current electrode spacing (AB/2) of 300 m. Apparent resistivity values obtained from field measurements were plotted against half the current electrode spacing on bi-logarithmic graphs to determine the resistivity and thickness of subsurface layers. This approach remains widely applied in recent hydrogeophysical investigations for delineating aquifer geometry and subsurface lithology (Anizoba *et al.* (2015); Akinluyi *et al.* 2021; Olorunfemi *et al.* 2020; Adeyemo *et al.* 2022).

The VES curves were interpreted quantitatively using partial curve matching techniques with standard master curves and auxiliary charts, followed by computer-assisted inversion. One-dimensional inversion of the resistivity data was performed using IX1D software (Interpex Ltd.), enabling improved estimation of geoelectrical parameters such as layer resistivity, thickness, and depth to aquifer units. The combined use of manual and numerical inversion techniques enhances the reliability of subsurface interpretations (Okoli *et al.* 2023).

## III. RESULTS AND DISCUSSION

### 3.1 Qualitative Interpretation of VES Curves

Fifteen (15) geo-electrical sounding curves obtained from the study area (Fig. 2) were qualitatively interpreted. The results revealed five distinct curve types, comprising four-layer K-type curves (6.67%) and five-layer curves dominated by HK-type (40%) and AK-type (40%), with minor occurrences of KQ-

type (6.67%) and QK-type (6.67%). Curve-type classification is a fundamental approach in resistivity interpretation, as it reflects variations in subsurface resistivity distribution and assists in identifying lithological sequences and hydrogeological conditions (Chinwuko *et al.*, (2015). Differences in curve patterns are controlled by contrasts in layer resistivity and thickness, which are indicative of changes in lithology and fluid content (Olorunfemi *et al.* 2020; Akinluyi *et al.* 2021). In sedimentary terrains, HK and AK curve types are commonly associated with alternating conductive and resistive layers, often indicative of favourable aquifer conditions. The predominance of HK and AK curve types within the study area therefore suggests relatively favourable groundwater potential. These curve signatures are typically linked to aquiferous zones, and their occurrence provides a useful qualitative basis for assessing groundwater prospects within the area (Adeyemo *et al.* 2022; Okoli *et al.* 2023).

### 3.1.1 Quantitative Interpretation of VES

#### Depth to Aquifer

Four to five geoelectrical subsurface units were delineated across the study area, each characterized by distinct thicknesses and resistivity values (Fig. 3; Table 1). From the surface downward, these units comprise topsoil, shally-sand, shale, sandstone, and water-saturated sandstone (aquifer).

The interpreted results indicate that the depth to the water-bearing sandstone aquifer varies significantly across the study area, ranging from 42.28 m at Ufuma to 132.99 m at Ndiokpalaeze. The aquifer is characterized by an average resistivity value of 2016.93  $\Omega$ m and an average thickness of 95.65 m (Table 3.1).

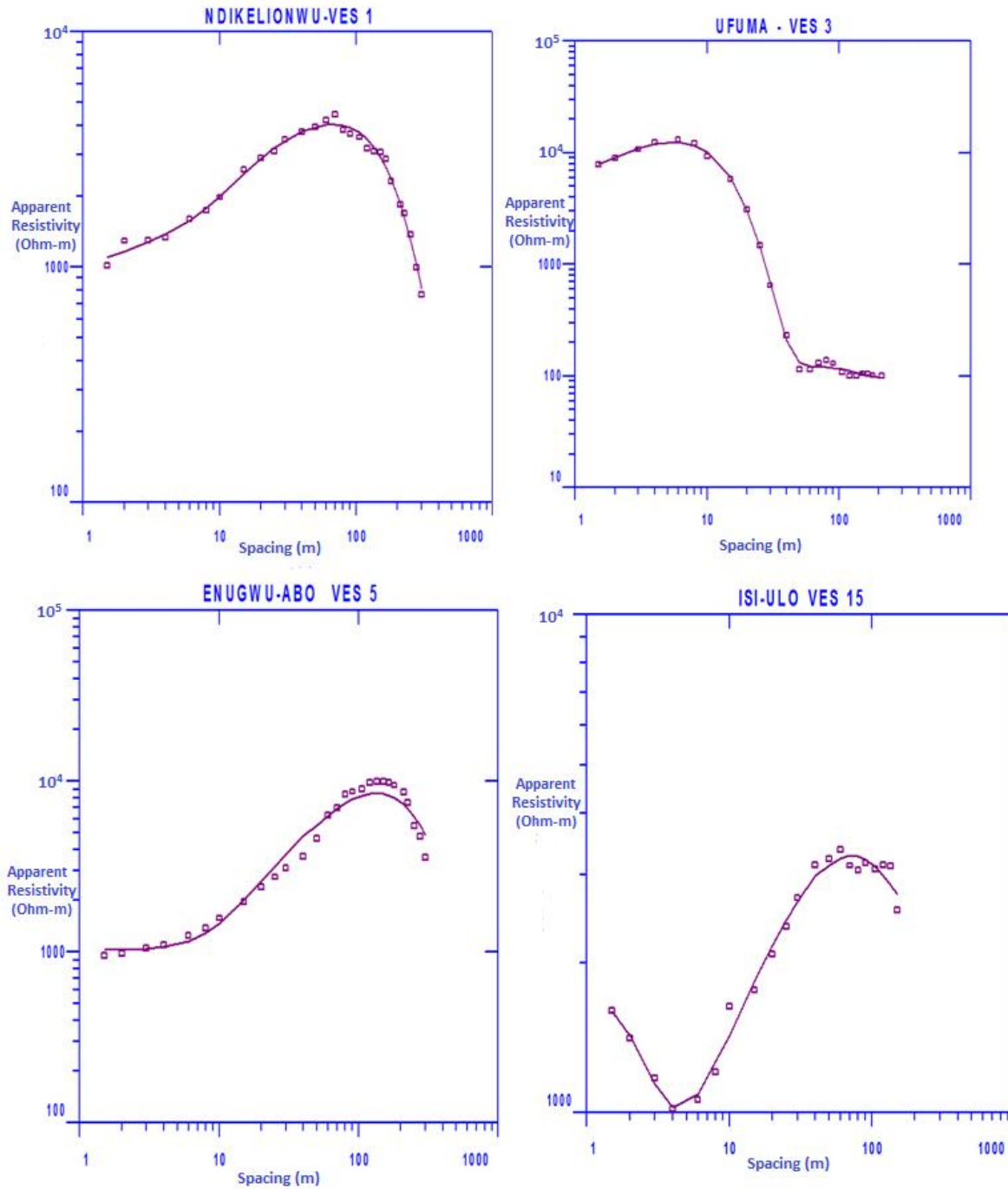


Fig. 3 : Representative geo-electric curves within the study area

**Table 1: Summary of VES Interpretation with respect to Aquifer**

VES No	Curve Type	b (m)	h (m)	$\rho$ (ohm)	R (Ohm-m)	S (Ohm-1)	$K_c$ (m/day)	$T_c$ (m <sup>2</sup> /day)
1	AK	75.78	99.54	1472	146522.900	0.0676	0.2449	24.3742
2	AK	78.02	70.21	503.66	35361.970	0.1394	0.7156	50.2460
3	KQ	44.44	18.73	490.60	9188.938	0.0382	0.7347	13.7610
4	HK	42.28	54.91	1994.02	109491.600	0.0275	0.1808	9.9257
5	QK	88.72	136.28	2446.00	333340.900	0.0557	0.1474	20.0824
6	HK	97.16	113.39	5144.15	583295.200	0.0220	0.0701	7.9451
7	HK	73.32	135.43	3711.90	502702.600	0.0364	0.0971	13.1510
8	AK	48.08	80.39	1870.30	150353.400	0.0430	0.1927	15.4928
9	HK	48.52	70.63	937.08	66185.960	0.0754	0.3846	27.1677
10	K	43.67	76.97	1656.40	127493.100	0.0465	0.2176	16.7493
11	AK	56.23	157.64	4281.70	674967.200	0.0368	0.0842	13.2706
12	AK	45.31	165.66	1186.73	196593.700	0.1396	0.3037	50.3159
13	HK	132.99	117.5	1064.90	125125.800	0.1103	0.3385	39.7712
14	AK	38.69	66.52	1158.75	77080.050	0.0574	0.3111	20.6920
15	HK	58.01	70.94	2335.70	165694.600	0.0303	0.1543	10.9475
Average		64.748	95.65	2016.93	220226.500	0.0618	0.278485	22.2595

**Key:**  $\rho$  = Aquifer resistivity;  $h$  = Aquifer thickness;  $S$  = Longitudinal Conductance;  $R$  = Transverse Resistance;  $K_c$  = Hydraulic Conductivity of Aquifer;  $T_c$  = Transmissivity of Aquifer

### 3.2 Aquifer Thickness Map

The aquifer thickness map was generated from the interpreted aquifer thickness values obtained across the study area (Fig. 4; Table 1). The map indicates a generally higher aquifer thickness in the northeastern portion compared to other parts of the study area. Contouring at 1 m intervals reveals the presence of two distinct hydrogeological zones. The northeastern sector, represented by a whitish colouration, corresponds to zones of relatively high aquifer thickness ranging from approximately 100 to 170 m,

indicating a more substantial water-bearing unit. In contrast, the brownish coloration dominating the remaining parts of the map represents areas of moderate aquifer thickness, generally between 20 and 90 m. Overall, the study area is characterized by a comparatively thick and potentially productive aquifer system, with greater groundwater storage potential concentrated in the northeastern direction.

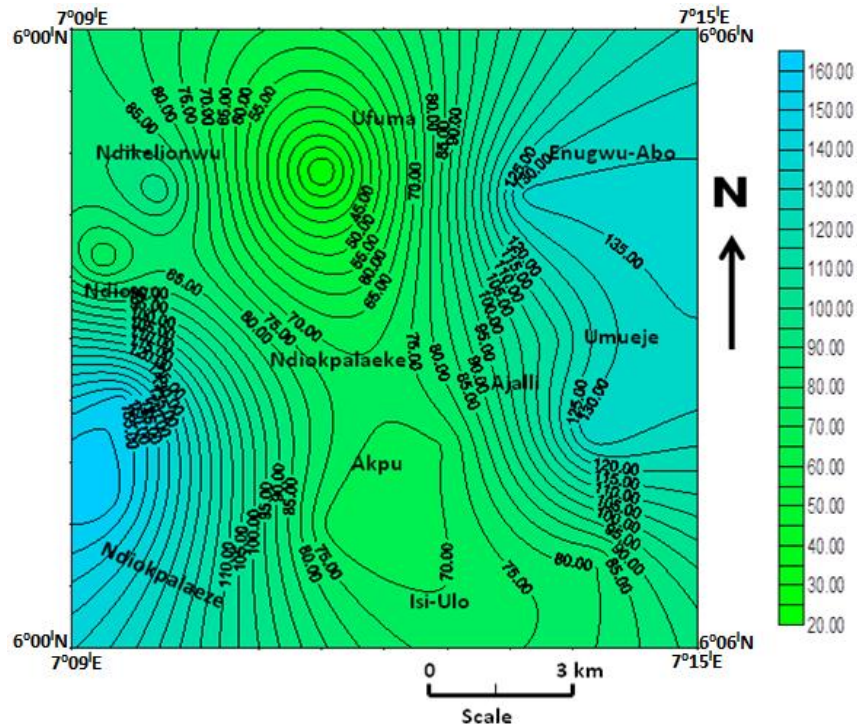


Fig. 4: Aquifer thickness map in the study area (Contour Interval~5m)

### 3.3 Aquifer Characteristics

The interpreted aquifer parameters (Table 1) exhibit significant spatial variability across the study area. The hydraulic conductivity values range from  $2.20 \times 10^{-2}$  m/day at Umuogem community (VES 6) to  $7.35 \times 10^{-1}$  m/day at Ufuma community (VES 3), with an average value of  $2.78 \times 10^{-1}$  m/day. Transmissivity varies between 7.95 m<sup>2</sup>/day at Umuogem (VES 6) and 50.32 m<sup>2</sup>/day at Ogboji (VES 12), with a mean value of 22.26 m<sup>2</sup>/day. The transverse resistance ranges from  $9.19 \times 10^3$  m·Ω at Ufuma (VES 3) to  $6.75 \times 10^5$  m·Ω at Ndiowu (VES 11), with an average of  $2.20 \times 10^5$  m·Ω. In contrast, longitudinal conductance values vary from  $2.20 \times 10^{-2}$  mhos at Umuogem (VES 6) to  $1.40 \times 10^{-1}$  mhos at Ogboji (VES 12). These variations reflect heterogeneity in lithology, degree of water saturation, and hydraulic continuity within the aquifer system. In general, the aquifer parameters show that some areas of the study region have moderate to high groundwater potential. The efficacy of geoelectrical methods in aquifer characterization and groundwater potential assessment is confirmed by the obtained hydraulic properties, which are in line with values reported in

corresponding sedimentary hydrogeological settings in southeast Nigeria (Ekanem et al. 2019; Obasi and Akudinobi 2021; Nwankwo and Ezeh 2023).

### 3.4 Geo-electric correlations within the study area

Cross-sections along the west–east (W–E) and north–south (N–S) directions were constructed from the interpreted resistivity data to elucidate the subsurface stratigraphy of the study area as shown in fig 5a and 5b below. The sections reveal four to five geoelectrical layers, comprising the topsoil, siltstone, dry sandstone, water-saturated sandstone, and shale. The topsoil layer exhibits resistivity values ranging from 347.58 to 2057.5 Ωm, with thicknesses between 1.09 and 3.08 m. It is generally thin across most locations and is composed of clayey, sandy, or lateritic materials. Beneath this unit lies the siltstone layer, which is characterized by resistivity values between 25.00 and 1341.30 Ωm and thicknesses ranging from 1.75 to 5.90 m; however, this layer is absent in the Ndiokpalaeke area. The underlying dry sandstone layer shows relatively high resistivity values ranging from 1656.4 to 20,895 Ωm, with thicknesses varying from 41.64 to 120.64 m. This is

followed by the water-saturated sandstone unit, which constitutes the principal aquifer. It is characterized by resistivity values between 713.00 and 5144.15  $\Omega\text{m}$  and considerable thicknesses ranging from 57.51 to 135.43 m. This aquiferous unit is laterally continuous across most parts of the study

area. The basal unit consists of shale, which is highly conductive, with low resistivity values ranging from 14.02 to 713  $\Omega\text{m}$ . This layer forms the underlying confining unit and marks the transition to less permeable formations.

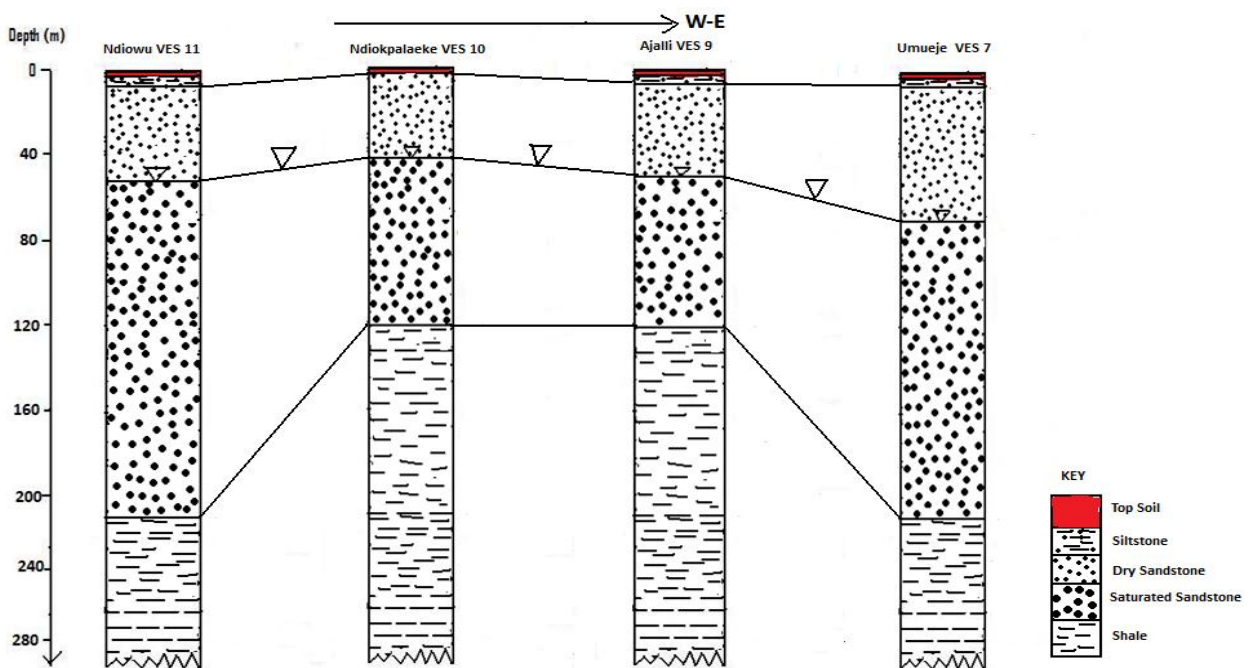


Fig5a: Geo-electric correlation along W-E

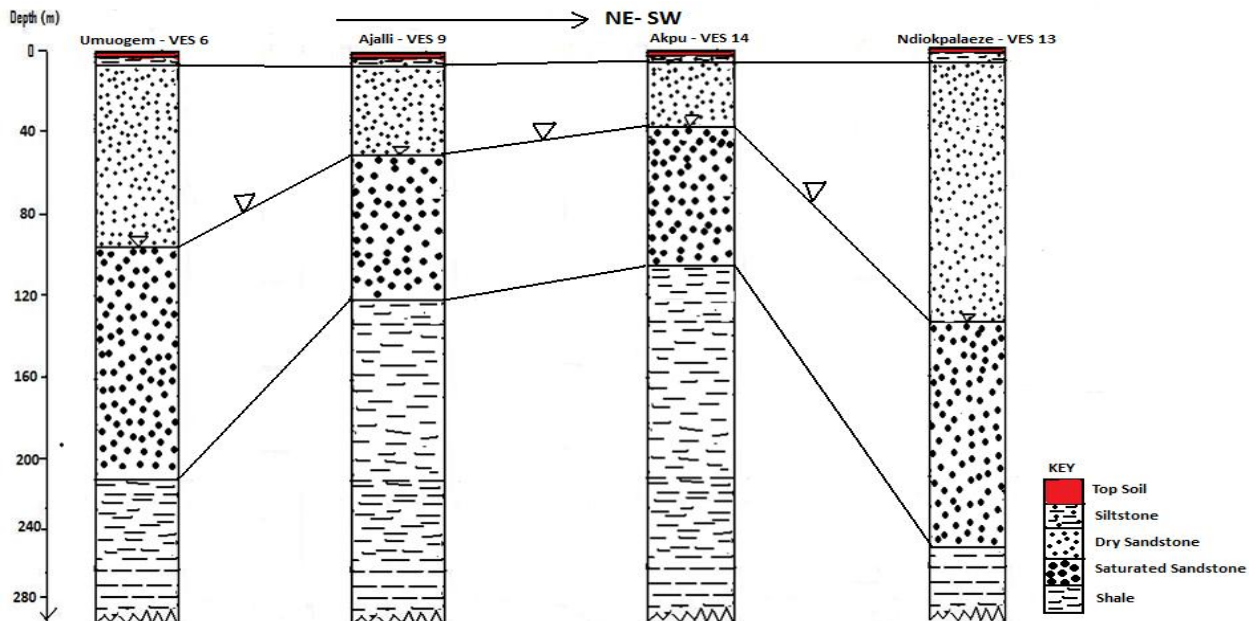


Fig5b: Geo-electric correlation along NE-SW

### 3.5 Comparison of Geo-electric section and Borehole section

The comparison between the lithologic log of a borehole located near one of the VES stations at Ufuma and the corresponding interpreted geoelectrical section (Fig.6) indicates a close, though not exact, agreement in subsurface characterization. The overburden thickness derived from the lithologic log is approximately 3.10 m, whereas the geoelectrical interpretation yields a slightly lower value of 2.61 m. At greater depths, the geoelectrical section exhibits partial suppression and merging of some lithologic units identified in the borehole log. This discrepancy arises from the fundamental difference between lithologic and geoelectrical classifications: geoelectrical units are defined by

resistivity contrasts rather than strictly by lithological boundaries. Consequently, a single lithologic unit with internal resistivity variations may be represented as multiple geoelectrical layers, while distinct lithologic units with similar resistivity values may be combined into a single geoelectrical unit. The depth to the water table shows minor variation between both datasets, occurring at approximately 43.59 m in the geoelectrical section and 49.54 m in the lithologic log. Despite these differences, there is a strong correlation between the borehole and geoelectrical interpretations at Ufuma (Fig. 3.4). This agreement provides validation for the geophysical results and supports the reliability of the estimated depth to the aquifer within the study area.

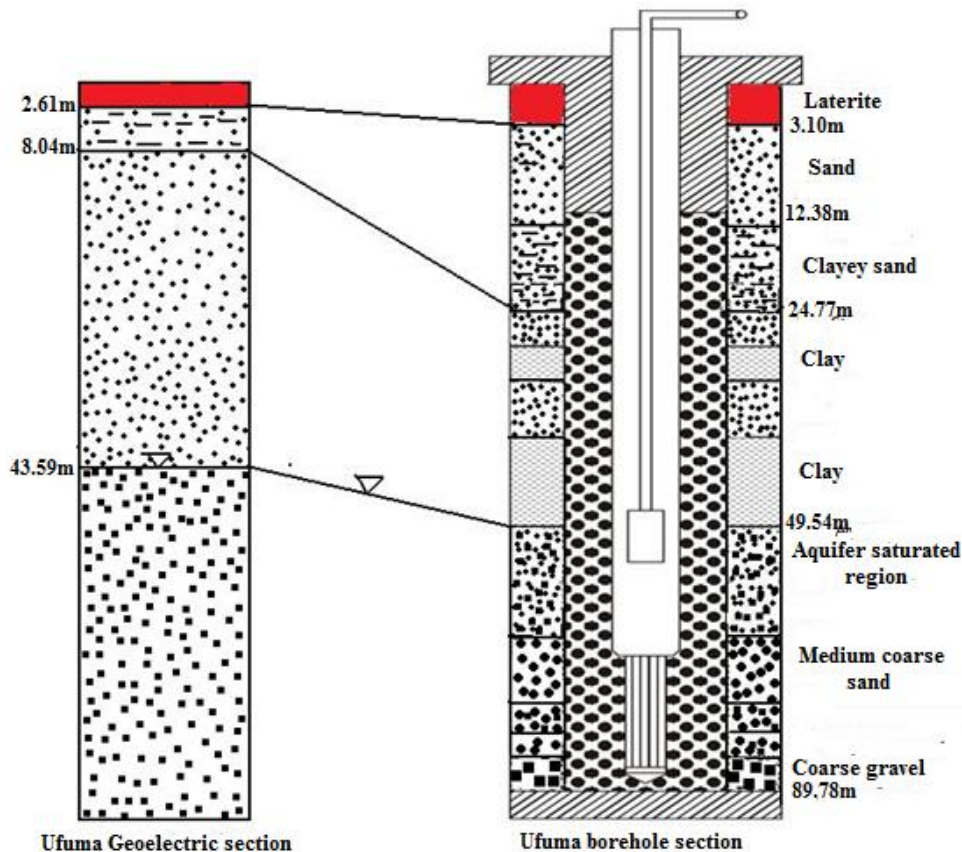


Fig.6: Correlation of geo-electric and borehole sections at Ufuma

strong hydraulic connection between surface relief and groundwater flow.

### 3.5 The Watertable Map

The water table represents the upper surface of the saturated zone within an unconfined aquifer. Its spatial distribution is influenced by topography, climatic conditions, and the lithological characteristics of near-surface materials. In this study, water-table elevations were computed by subtracting the depth to aquifer from the corresponding ground surface elevations referenced to mean sea level. Based on these results, a water-table contour map was generated (Fig. 7). To examine the relationship

between groundwater level and surface topography, a comparative cross-section (A–B) was constructed using both the topographic and water-table maps and subsequently superimposed (Fig. 8). The topographic profile is represented by the red curve, while the water-table surface is shown by the blue curve. The analysis indicates that the water table closely mimics the general trend of the topography, suggesting a

Groundwater flow is inferred to occur predominantly in the northwest-southeast (NW-SE) direction, consistent with regional slope orientation. Furthermore, areas such as Ogbunka exhibit relatively higher hydraulic gradients, as indicated by

closely spaced water-table contours, suggesting more active groundwater movement. In contrast, Ndikelionwu and Ndiowu areas show wider contour spacing, indicating lower hydraulic gradients and comparatively reduced groundwater flow intensity.

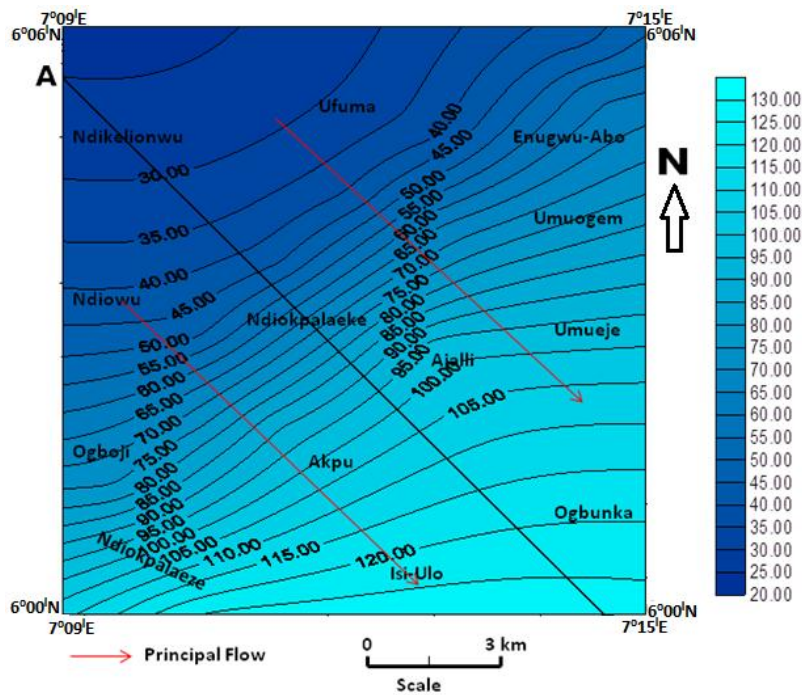


Fig. 7: The watertable map with reference to mean sea level (Contour Interval~5m)

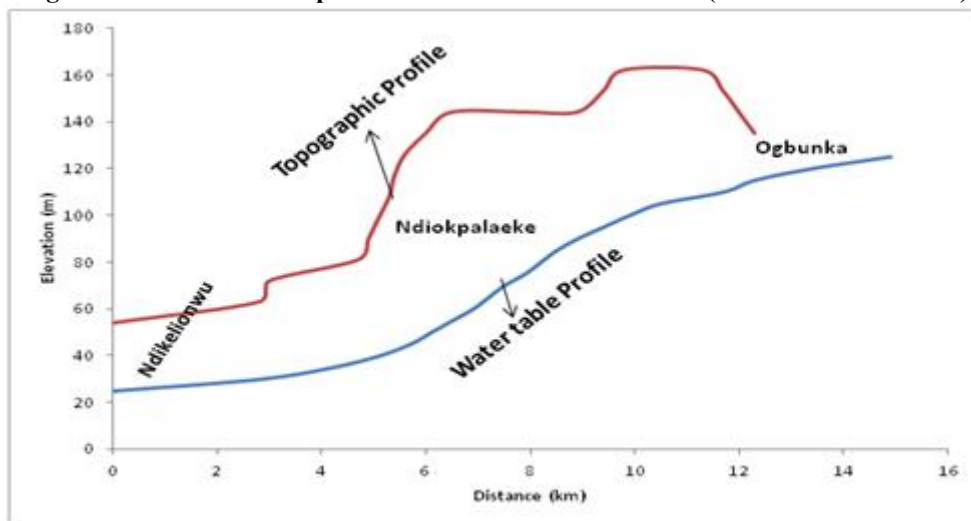


Fig. 8: Composite cross- section of water table and topography

#### IV. CONCLUSION

An integrated hydrogeological investigation for the assessment of groundwater flow direction and aquifer potential in Ufuma and its environs, Anambra State, Southeastern Nigeria, has been successfully carried out. The principal conclusions are as follows:

1. The geoelectrical interpretation identified five curve types: K, HK, AK, KQ, and QK. Approximately 80% of the sounding curves are dominated by HK and AK types, while the remaining 20% comprise the other curve types, indicating relatively consistent subsurface layering across the study area.
2. The depth to the water-saturated sandstone aquifer varies from 42.28 m at Ufuma to 132.99 m at Ndiokpalaeze, with an average resistivity value of 2016.93  $\Omega$ m, reflecting a predominantly sandy and permeable aquifer system.
3. The aquifer thickness distribution shows higher values in the northeastern part of the study area, with an overall average thickness of 95.65 m, suggesting enhanced groundwater storage potential in that zone.
4. The water-table configuration indicates a dominant northwest–southeast (NW–SE) groundwater flow direction, which corresponds closely with the regional topographic gradient.
5. The estimated aquifer parameters show that hydraulic conductivity ranges from  $2.20 \times 10^{-2}$  m/day to  $7.35 \times 10^{-1}$  m/day, with an average of  $2.78 \times 10^{-1}$  m/day, while transmissivity values range from 7.95 m<sup>2</sup>/day to 50.32 m<sup>2</sup>/day, averaging 22.26 m<sup>2</sup>/day. These values indicate moderate groundwater potential within the study area.
6. Overall, the hydrogeophysical results suggest that the aquifer system is capable of sustaining groundwater supply for domestic and local uses. However, the predominance of sandy formations indicates a soil structure that is susceptible to erosion, necessitating appropriate land-use planning and environmental management practices.
7. The Groundwater flow direction mimics the general trend of the topography, suggesting a strong hydraulic connection between surface relief and groundwater flow.

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