# Georesistivity, Aquifer Hydraulic Characteristics and Groundwater Potential Zones Using Vertical Electrical Sounding and Dar-Zarrouk Parameters at Umunze, Anambra State

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## ABSTRACT

A geophysical survey using Vertical Electrical Sounding and Dar – Zarrouk parameters was conducted at Umunze in Orumba South L.G.A of Anambra State, Nigeria to investigate the georesistivity, aquifer hydraulic characteristics, and groundwater potential zones. The survey areas lies between longitudes 7°14’1.85”E - 7°14’21.43”E and latitudes 5°57’27.49”N - 5°59’14.38"N. Vertical Electrical Sounding (VES) was carried out with a digital read out resistivity meter (ABEM SAS 1000). A total of four (4) soundings was carried out in the area. The VES data interpretations were done using INTERPEX software and the VES results were presented in terms of resistivity, thickness, depth and lithology. The lithology was inferred to the layers by correlating the lithology log of one of the boreholes drilled in the study area and the geology of the study area. The VES result shows 5 – 6 lithologic layers with the subsurface sequence varying as follows: Lateritic Silty Shaly Sand, Dry Silty Sandy top, Dry Sandstone, Silty Shale, Shaly Silty Sandy soil, Silty Lateritic Sandstone, Lateritic Sandstone, Sandstone, Silty – Sandstone, Water Saturated Silty Sand, Water Saturated Sandstone and Water Saturated Silty Shale.. The water saturated silty sand, water saturated sandstone and water saturated silty shale layers constituted the aquifer unit in the area and its thicknesses ranges from 37.5 – 89.1m. The aquifer transmissivity was determined by calculating for hydraulic conductivity and multiplying with the thickness of the aquifer layer. The aquifer transmissivity values obtained for VES 1 - 4 are 41814.81, 61487.78, 65731.90 and 85658.13 $m^2$/day which indicates a very good aquifer transmissivities respectively. VES 1 and 4 have been identified as the best areas for productive and sustainable borehole yield because of their high aquifer thickness and transmissivity.

**Keywords:** Aquifer, Dar-Zarrouk, Geophysical, Vertical Electrical Sounding, Aquifer Transmissivity and Umunze

## INTRODUCTION

Groundwater resources are crucial for sustaining human activities, especially in regions where surface water is scarce. Groundwater plays a vital role in providing a reliable source of water for domestic, agricultural, and industrial uses, especially in regions where surface water availability is limited or seasonal. Groundwater is the second largest freshwater reservoir in the world, accounting for 12% of world’s freshwater reserve, the largest resource being ice-locked water (87%), while surface water accounts for just around 1% of the world’s freshwater reserves (Gleick, 2011). Groundwater, under most conditions, is safer and more reliable for use than surface water. Part of the reason for this is that surface water is more readily exposed to pollutants from factories than groundwater. This by no means says that groundwater is invulnerable to contamination.

Geologically, in the basement terrain, groundwater is believed to occur within the overlying unconsolidated material derived from in-situ weathering of rocks and perhaps the fractured/faulted bedrock while in the sedimentary terrain, it is accumulated within the porous and permeable layer of the saturated zone in the subsurface (Clark, 1985; Jones, 1985; Bala and Ike, 2001).

In Nigeria, groundwater exploration has become increasingly important due to population growth and urbanization, which exert pressure on existing water resources. Umunze, located in Anambra State, is one such area where groundwater serves as a primary water source, necessitating proper assessment and management of aquifer systems. The effectiveness of groundwater exploration depends largely on understanding the subsurface characteristics that influence groundwater occurrence and movement. Geophysical methods, particularly Vertical Electrical Sounding (VES**)** using the Schlumberger configuration, have been widely employed to investigate subsurface resistivity variations, which are indicative of different geological formations and aquifer properties. Vertical Electrical Sounding (VES) techniques are a useful tool routinely used under a variety of field conditions and geological settings in hydrogeology, environmental geology and geotechnical engineering. Hence VES has proved to be effective in solving groundwater problems in most places in Nigeria (Ezeh and Ugwu 2010; Ugwu and Ezeh, 2012; Nzemeka *et al*., 2023).

Georesistivity studies help delineate groundwater-bearing formations and determine the thickness, depth, and extent of aquifers. Geophysicists have realized that the integration of aquifer parameters calculated from existing borehole locations and subsurface resistivity parameters extracted from resistivity measurements can be highly effective, since a correlation between hydraulic and electrical aquifer properties can be possible as both properties are related to the pore space structure and heterogeneity. For this purpose transformation of the aquifer resistivity distribution in terms of the aquifer Dar – Zarrouk parameters requires the application of physically consequential relation derived either theoretically or empirically.

Rocks/Geological formation with uniformly or tightly arranged texture have high water retaining ability (porosity) but less transmitting or mobility ability (permeability) while those with higher porosity and higher permeability have sufficiently enough to yield significant quantities of groundwater to wells and springs as such any geological formation with such characteristic is been referred to as an Aquifer.

According to geological terms an Aquifer could be referred to as a body of saturated rock or geological formation through which water can easily move (permeability) into wells and streams. It can also be defined as an underground layer of water-bearing permeable rock (Olisah *et al*. 2023). The top of the water level in an aquifer is called the water table. An aquifer fills with water from rain or melted snow that drains into the ground. In certain areas, water could pass through the soil of the aquifer while in other areas it enters through joints and cracks in rocks where it moves downwards until it encounters rocks that are less permeable.

Aquifer Transmissivity simply could be defined as the property of aquifer to transmit water. It could also be defined as the amount of water that can be transmitted horizontally through an aquifer unit by full saturated thickness of the aquifer under a hydraulic gradient of 1 or as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit gradient.

Hydraulic properties of aquifers, such as transmissivity, hydraulic conductivity, and storativity, are crucial for evaluating their ability to store and transmit water. These parameters can be estimated using Dar-Zarrouk parameters, including longitudinal conductance and transverse resistance**,** which are derived from resistivity and thickness values of subsurface layers. By integrating these geophysical and hydrogeological techniques, it is possible to identify groundwater potential zones and assess aquifer productivity.

This study focuses on the application of VES and Dar-Zarrouk parameters to evaluate the groundwater potential in Umunze. This study will also identify areas with good groundwater potential and the aquifer transmissibility of the study area and hence will give the populace idea on the actual depth and water flow rate where good water table can be harnessed. Given the area's dependence on groundwater, a comprehensive assessment of aquifer characteristics is necessary to guide borehole siting, improve water resource management, and prevent groundwater depletion or contamination. The findings from this study will contribute to a better understanding of the hydrogeological framework of Umunze and provide valuable insights for policymakers, hydrogeologists, and water resource managers.

**Location and Accessibility of Study Area**

The study areas are located at Ubaha Village, Umuovu Ororo Village, Ndimbara Nsogbu Village and Ndikpa Village Umunze, Orumba South Local Government Area of Anambra State, Southeastern Nigeria. The areas lies between longitudes 7°14’1.85”E - 7°14’21.43”E and latitudes 5°57’27.49”N - 5°59’14.38"N. The study area can

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be accessed through the notable Agulu – Ekwulobia road. Umunze is located in the Southern fringes of Anambra State. It is about 29.1 km East of Ekwulobia Metropolis. Umunze is situated in Anambra South Senatorial Zone and is notable for hosting the popular Federal College of Education (Technical), Umuze. Towns that share a common border with Umunze are Ezira, Umuchu, Achina, Arondizuogu, Ifite, Ihite, Eziama and Ogbuka. Orumba South Local Government Area has an area of 200.3 $km^2$ and a population of 184,548 at the 2006 census (National Population Commission of Nigeria, 2006).

**Geological Setting and Lithology**

The concept of Geological Setting refers to the physical environment in which geological processes operate, influencing the formation and characteristics of rock formations. It encompasses factors such as tectonic history, sedimentation patterns, and structural features like faults or folds. Understanding the Geological Setting is crucial for interpreting lithology, which pertains to the physical and chemical characteristics of rocks formed within that setting. Lithology describes properties such as mineral composition, grain size, texture, and sedimentary structures, all of which are influenced by the specific geological processes and conditions present during their formation. For instance, in sedimentary environments, lithology can vary widely from fine-grained shales deposited in quiet marine basins to coarse-grained conglomerates formed in high-energy fluvial environments. The geology of Anambra State consist of Alluvium (Holocene), Benin Formation (Miocene-Pleistocene), Ogwashi-Asaba Formation (Oligocene-Miocene), the Ameki Formation (Eocene) and Imo shale with its lateral equivalent (Paleocene) (Fig. 1). The Alluvium consist of lose sands with high percentage of quartz content. It is found along the banks at the lower ridges of the River Niger. The thickness of the deposit is tens meters in the Onitsha area (Egboka and Okpoko 1999). The Benin Formation underlies the Alluvium. The lithology consists of thick yellow and white sands with interbedded pebbles and alternation of clays and sandy clays (Egboka and Okpoko 1999). Formation thickness is estimated to be 200m.

Underlying the Benin Formation is the Ogwashi – Asaba Formation. The Ogwashi – Asaba which outcrops at Onitsha, Nnewi and Ihiala consists of alternation of seams of lignite with clays and shale. The thickness is about 300m (Ezenwa 1998). Underlying the Ogwashi – Asaba Formation is the Ameki Formation, which consists of lignite and sandstones. The formation thickness is estimated to be 1460m (Ekwe *et al.*, 2006). The Imo shale consist of thick clayey shale, fine textured, dark grey to bluish grey with occasional admixture of clay, ironstones and thin sandstone bands (Reyment 1965). Its sands member is the Ebenebe sandstone. The Ebenebe sandstone consists of medium to coarse – grained sandstone that forms the Ugwuoba – Ufuma – Umunze ridge. Its thickness is about 1200m. Fig 1 shows the summary of the geology of Anambra State.

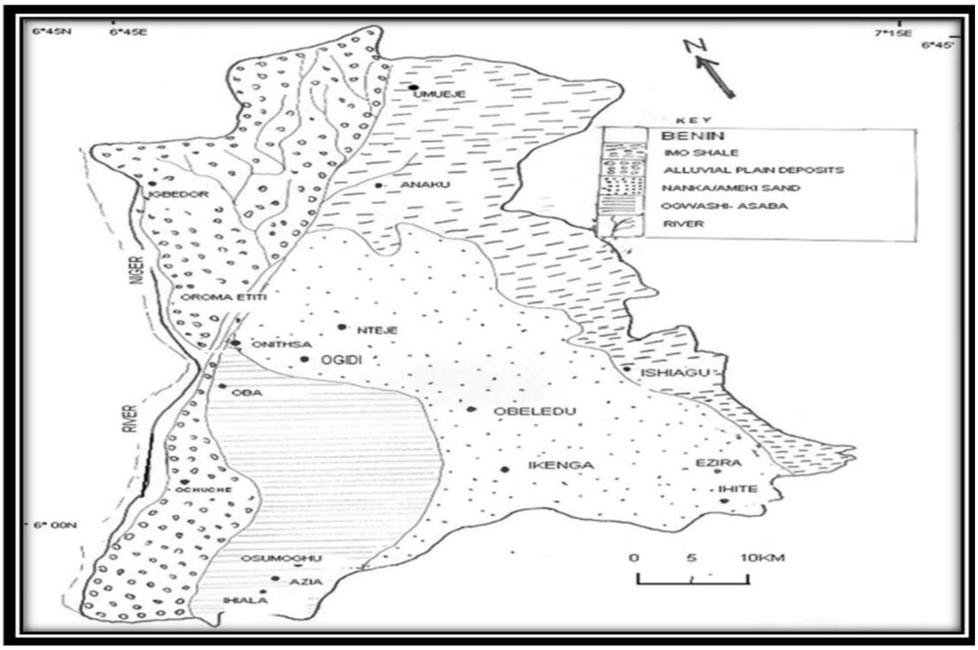


Fig 1: Geological map of Anambra State (Nfor *et al.*, 2007)

## Statement of the problem

Umunze, located in Anambra State, Nigeria, faces significant challenges in ensuring a reliable and sustainable supply of groundwater to meet the needs of its growing population and agricultural activities. Despite the critical importance of groundwater resources in the region, there is a lack of detailed hydrogeological data and comprehensive studies specifically targeting the subsurface characteristics of Umunze. Traditional methods of groundwater exploration have proven insufficient in accurately identifying and assessing aquifer properties, leading to inefficient and often unsuccessful drilling efforts. Most people have to trek a very long distance to fetch water from s spring-fed stream called Izo mmiri which is located at the foot of hills where water is discharged as underground seepage all year round. The unique geological and hydrological conditions of Umunze remain poorly understood, creating a gap in the effective management and utilization of groundwater resources. Without precise information on the subsurface resistivity structures and aquifer hydraulic characteristics, it is challenging to delineate groundwater potential zones accurately. This inadequacy hampers the development of sustainable water resource management practices, potentially exacerbating water scarcity issues in the region. Therefore, there is an urgent need for a study that employs advanced geophysical techniques, such as Vertical Electrical Sounding (VES) and the analysis of Dar-Zarrouk parameters, to provide a thorough evaluation of the groundwater potential in Umunze.

## Review of Previous Work

Various researchers have studied groundwater potential and transmissivity in Nigeria and all over the world. Ashhad and Quamrul (2019) investigated groundwater potential of an area in Delhi and concluded that the groundwater table at the pumping well lies at a depth of about 18.3m and goes to a depth of 47.6m. Mirzaei *et al.*, (2020) explore karst groundwater using electrical resistivity tomography and remote sensing North East Khuzestan concluded after the research that the geological fractures can have a significant effect on storage and flow of groundwater reservoir especially in areas with shallow bedrock fractures, water infiltration. Hossain *et al.*, (2022) estimated hydraulic conductivity transmissibility and specific yield of aquifer in Barind area, Bangladesh using pumping test and concluded that Hydraulic Conductivity (K), Transmissibility (T) and Specific Yield (Sy) at Nachol were found as 17.22 to 55.35 $m^3/m^2$/day, 430.48 to 1383.69 $m^2$/m/day and 4.03 to 5.17%, respectively, under different methods and Niamatpur area, the K, T and Sy were found as 37.58 to 103.90 $m^3/m^2$/day, 733.20 to 1027.28 $m^3$/m/day, and 4.05 to 9.16%, respectively.

Ismail *et al* (2008) estimated the transmissibility and storativity of aquifer using specific capacity of wells and concluded that it is possible to correct values of transmissibility and storativity by using the well – known Hantush modification (Hantush, 1961) of the Theis method or Boonstra method that consist of a matching procedure between the drawdown observed in the field and theoretical drawdown found from the analysis (Boonstra, 1992). Henriet, (1976) embarked on a study of Direct applications of the Dar Zarrouk parameters in groundwater surveys and analysis of Dar-Zarrouk parameters derived from VES data was used to evaluate aquifer properties and concluded that Dar-Zarrouk parameters could effectively estimate aquifer transmissivity and protective capacity. In Nigeria, Olatunji *et al.*, (2016) investigated groundwater potential using electrical resistivity method in parts of Kwara State polytechnic Ilorin Nigeria and concluded that the quality and quantity of the borehole could not be predicted until after drilling have been done and testing pumping carried out. Oseji *et al.*, (2006) determined the groundwater potential in Obiaruku and environ, after interpretation of the resistivity curve came to a conclusion that the area has great groundwater potential revealing the lithologic succession as an extensive sandy unit between range of 20m and 136m. Ekwok *et al.*, (2020) made assessment of ground water potential using a geophysical data in cross river state and concluded that the OM and IME have thin to, moderate sediment thicknesses, while the CF is predominated by thick sedimentation (6217m). Mohammed *et al.*, (2020) carried out a study on Hydrogeophysical investigation using Vertical Electrical Sounding for groundwater potential in the basement complex of Zaria, Northwestern Nigeria using Vertical Electrical Sounding (VES) to measure subsurface resistivity and determine aquifer properties and several high-potential groundwater zones with good aquifer characteristics were identified. Ehirim, & Nwankwo, (2010) carried out a study on geoelectric investigation of aquifer characteristics and groundwater potential in parts of Eleme, Southern Nigeria using VES to map subsurface resistivity and estimate aquifer parameters and their findings revealed some significant variations in resistivity corresponding to different aquiferous zones, indicating areas with high groundwater potential. Olayinka & Martins, (2019) carried out a study on delineating groundwater potential zones in crystalline basement areas of Southwest Nigeria using VES to investigate the resistivity profiles and identify potential groundwater zones and several zones with favorable aquifer characteristics were identified, indicating good groundwater potential. Bala & Ike, (2001) examined the aquifer characteristics of the crystalline basement rocks of Gusau area, Northwestern Nigeria using both VES and pumping test data to analyzed and determine aquifer characteristics and several productive aquifers with good transmissivity and storage coefficients were identified. Ezeh and Ugwu (2010) carried out a geoelectrical sounding for estimating groundwater potential in Nsukka L.G.A. Enugu State, Nigeria and concluded that the presence of thick and highly prolific auriferous zone assures the area of adequate water resource. Abdullahi *et al.*, (2014) carried out geoelectrical method in the evaluation of groundwater potential and aquifer protective capacity of overburden units around Opi area in Nsukka, Southeastern Nigeria and their results delineated three to five geoelectric sections in the study area, namely: the topsoil (which consists of lateritic clay), river sand and gravel and clayey sand. The Vertical Electrical Sounding (VES) results revealed heterogeneous nature of the subsurface geological sequence. Ezeh (2011) carried out a geoelectrical study for estimating aquifer hydraulic properties in Enugu State, Nigeria and concluded that it is possible to obtain quantitative results from VES that are useful for the determination of hydraulic properties of aquifers. Emmanuel *et al* (2022) evaluated transmissibility and hydrogeological properties of aquifer system at Edem, Enugu state and concluded that the area has high distribution of permeability, hydraulic capillary radius, transmissivity, hydraulic conductivity and porosity with low distribution of surface area per unit volume and tortuosity was observed along the western and some at the eastern parts suggest high indices of groundwater transmissibility magnitude along these parts. Austin *et al.*, (2017) estimated the georesistivity, aquifer hydraulic characteristics and groundwater potential zones of Mpu town and environs, Enugu State and concluded that the aquifer transmissivity shows low and moderate groundwater potential zones.

In Anambra State, Okafor Desire (2020) investigated ground water potential of the Nanka sands around Nanka - Oko and its environment Anambra state, the result of the interpretation of the geo physical data shows that the area is characterized by a variable sub surface layering ranging from six layer to eight layers. Okeke Florence (2012) investigated groundwater potential using direct geo electric method in a part of old Aguata and Anaocha local government area Anambra state and concluded that to harness potable water within the aquifer region, it was recommended that the borehole be drilled much beyond the depth range of 24.8m to 130.0m. Onuorah P. (2017) investigated groundwater occurrence using geo electric method in out-cha and environ Anambra state the result shows that the water saturation is more at the water table mound towards the north than the other areas. Chiwuko, A. I (2015) investigated ground water potential in Awka, Anambra state Nigeria using geo electric method and concluded that the aquifer are capable of yielding enough water that would serve the immediate environs. Delunzu *et al.,* (2018) made assessment of groundwater potential in Anambra state and got to a conclusion that the groundwater potential map could be useful for various purposes such as the development of sustainable scheme for groundwater in the area, the integration of geographical information system and data extracted from satellite images coupled with geophysical data and the geological knowledge of the area under investigation, could provide a powerful tool in groundwater investigation and groundwater potential zones map revealed that the plain areas are prospective zones in the catchment and can be helpful in better planning and management of ground resource.

Onyekwelu *et al.*, (2021) investigated ground water potential of Ogidi and environs, Anambra state south-eastern Nigeria using geo electrical method and concluded that the study area have good groundwater potential. Kenechukwu *et al.*, (2020) using geo electric technique for vulnerability and groundwater potential analysis of aquifer in Nnewi Anambra state Nigeria the result shows that the study area has stronger groundwater potential. Olisah *et al.*,(2023) investigated the groundwater potential and aquifer protective capacity at Aguleri and Nando, Anambra state and concluded that all the areas of study are areas of productive and sustainable borehole yield because of their high aquifer thicknesses.

**Materials**

The basic equipment used for this geophysical survey is the ABEM SAS 1000 resistivity meter.

The resistivity meter is equipped with a 12 volts battery, two current transmission cables on reels, two potential cables, four metal electrodes and a salt solution. Other auxiliary equipment for the survey include a Global

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Positioning System (GPS) for determining the resistivity survey locations and topography, geologic hammers for driving electrodes into the ground, two measuring tapes and cutlasses for clearing the traverses.

## METHOD

The study involved the use of electrical resistivity method. The technique adopted was Vertical Electrical Sounding (VES). The sounding was used to characterize the various lithologic units and to determine the depth to water table. This method involves the supply of direct current or low-frequency alternating current into the ground through a pair of current electrodes (Fig 3) and the measurement of the resulting potential through another pair of electrode called potential electrodes (Obiabunmo *et al*., 2014). Since the current is known and the potential can be measured, an apparent resistivity can be calculated. For Schlumberger soundings, the apparent resistivity values ($\rho_a$) were plotted against half current electrode separation (AB/2) on a log-log graph and a smooth curve indicative of the vertical distribution in the subsurface was drawn for each of the soundings. Then, the sounding curves were interpreted to determine the true resistivities and thicknesses of the subsurface layers. Figure 2 is a schematic illustration of the data processing techniques applied to the raw ER data.

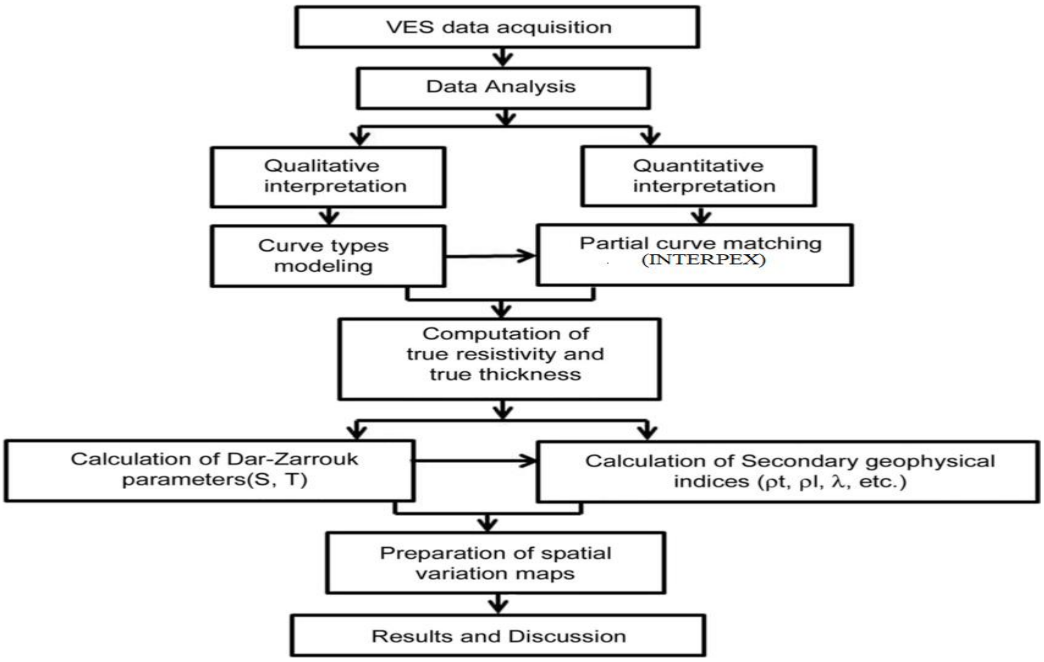


Fig 2: Flow diagram for Electrical Resistivity data processing Olawale and Olayinka (2012)

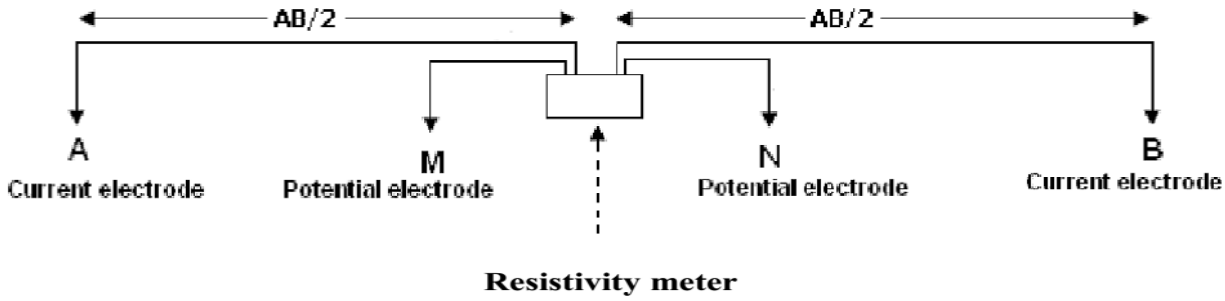


Fig 3: Schlumberger array

A total of four soundings using Schlumbeger array (fig 3) were carried out in the study area. The Vertical Electrical Sounding was used to determine the depth of water table and the subsurface geoelectric layers. The apparent resistivity ρ, for each electrode spacing was calculated using the formula

$$\rho a = \pi \left\{ \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right\} \Delta \frac{V}{I} \qquad 1$$

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where AB = Distance between the current electrodes (meters),

MN = Distance between the potential electrodes (meters),

∆V = Potential difference measured between the potential electrode (volts)

I = applied current strength (Ampere).

The geometric factor (k) for Schlumberger array is given as;

$$k = \pi\left\{\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right\} \quad 2$$

The VES field data were processed using the Schlumberger automatic INTERPEX analysis software, which generates model curves using initial layer parameters. The Dar-Zarrouk parameters were obtained from the first order geoelectric parameters (layer resistivities and thicknesses).These include the total longitudinal unit conductance (S) and total transverse unit resistance (T). These secondary geoelectric parameters are particularly important when they are used to describe a geoelectric section consisting of several layers (Zhody *et al.* 1974). For n layers, the total longitudinal unit coductance is

$$S = \sum_{i=1}^{n}\left(\frac{h_i}{\rho_i}\right) \quad 3$$

The total transverse unit resistance is given as

$$T = \sum_{i=1}^{n}\rho_i h_i \quad 4$$

where $h_i$ is the thickness of the ith layer and ρi is the resistivity of the ith layer. Hydraulic conductivity and transmissivity was computed using equations 5 and 6. Hydraulic conductivity (Kh) values as given in Equation (5) (Heigold *et al.* 1979) were estimated from its relation with aquifer resistivity (Rw):

$$K_h = \frac{386.40}{R_w^{0.93283}} \quad 5$$

Hydraulic conductivity measures the opposition to the flow of water through a pore space. It helps in determining the renewal rate of groundwater, appraisal of groundwater yield and other hydraulic properties. It depends on the intrinsic permeability of the aquifer and its degree of saturation. Transmissivity (Tr) relating with hydraulic conductivity and thickness (h) was calculated using Equation (6) according to Todd (1980):

$$T_r = K_h h \quad 6$$

It controls groundwater flow, provides a general idea on the water-producing efficiency of an aquifer and describes the capacity of the aquifer to transmit groundwater wholly in its entire saturated thickness (Omeje *et al*. 2021).Using modified Freeze & Cherry 1979 classification, the results of transmissivity was used to classify areas into very good, good, moderately good, low/fairly good and poor aquifer transmissivity as shown in Table 1. The lithology was inferred to the layers from the correlation between the one of the borehole drilled in the study area and geology of the study area (Ugwu and Ezeh, 2012).

Table 1: Classification of Aquifer Based on Transmissivity (Modified after Freeze & Cherry 1979)

| Transmissivity Value ($m^2$/day) | Aquifer Rating |
|---|---|
| T > 500 | Very Good |

| | |
|---|---|
| 150 < T _< 500 | Good |
| 50 <_T <_ 150 | Moderately Good |
| 10 < T <_50 | Low/fairly Good |
| 1< T <_10 | Poor |

The ABEM SAS 1000 resistivity meter and the 12 volts battery were placed in the centre of the layout. The two inner electrodes are the potential electrodes while the two outer electrodes are the current electrodes as shown in fig. 3. Four cables were connected to the resistivity meter at the centre of the cable spread and the electrodes were connected at the other end of cables. Current is passed between electrodes A and B and monitored by the potential electrodes M and N. As the distance between A and B is increased, deeper horizon have more effect on the potential between M and N. Also when sounding with a Schlumberger array, as distance between the current electrodes are increased, the distance between the current and potential electrodes at the center of the array is also increased. It is this increase between the current and potential electrodes at the center of the array that actually matters in depth probing. The reasonable distance between M and N should be equal or less than one-fifth of the distance between A and B at the beginning. The ratio goes up to one – tenth or one – fifteenth depending on the signal strength. The electrode configuration having a maximum current electrode spread of 300 m was used with a maximum of 150 m on both sides. The current electrode spacing begins with a distance equal to 2 m and extends up to 150 m while the potential electrode spacing begins with a distance of 0.5m and extends up to 20m. The $\frac{AB}{2}$ or half current electrode spacing was increased to a maximum of 150 meters. In most cases $\frac{MN}{2}$ or half potential electrode spacing were overlapping two readings. This means that the potential electrodes were moved only when the potential drops or becomes too small to measure with sufficient accuracy. For the survey, it was not necessary to increase the $\frac{MN}{2}$ distance until the distance $\frac{AB}{2}$ was increased to 9, 75 and 150 meters. At this point, $\frac{\Delta V}{I}$ was measured for both the old and new value of $\frac{MN}{2}$. This procedure permits the detection of near surface inhomogeneities.

## RESULT AND DISCUSSION

Qualitative interpretation of the profiles and depth sounding curves were carried out based on distinctive geoelectric parameters of the layers represented by the four types of auxiliary curve (A, H, K and Q). VES 1 – 4 shows AQ, KHQ, KKQ and AK type of curves respectively (Fig 4 - 7). VES 1 and 3 have six geoelectric layers while VES 2 and 4 have seven (7) and five (5) geoelectric layers (Table 2). A summary of qualitative interpretation of VES curves is shown in Table 2 while Table 3 shows a summary of the quantitative interpretation results of the VES.

Table 2: Summary Of Qualitative Interpretation of Ves Curves

| VES | COORDINATE | CURVE TYPE | RESISTIVITY PROFILE | NUMBER OF LAYERS |
|---|---|---|---|---|
| 1 | Latitude N5$^0$ 57’ 27.49’’<br>Longitude E7$^0$ 14’ 1.85’’ | AQ | $\rho_1<\rho_2<\rho_3>\rho_4>\rho_5>\rho_6$ | 6 |
| 2 | Latitude N5$^0$ 57’ 58.14’’<br>Longitude E7$^0$ 15’ 2.80’’ | KHQ | $\rho_1<\rho_2>\rho_3>\rho_4<\rho_5>\rho_6>\rho_7$ | 7 |
| 3 | Latitude N5$^0$ 58’ 28.19’’<br>Longitude E7$^0$ 14’ 36.04’’ | KKQ | $\rho_1<\rho_2>\rho_3<\rho_4>\rho_5>\rho_6$ | 6 |

| | | | | |
|---|---|---|---|---|
| 4 | Latitude N5$^0$ 59’ 14.38’’<br>Longitude E7$^0$ 14’ 21.43’’ | AK | $\rho_1<\rho_2<\rho_3<\rho_4>\rho_5$ | 5 |

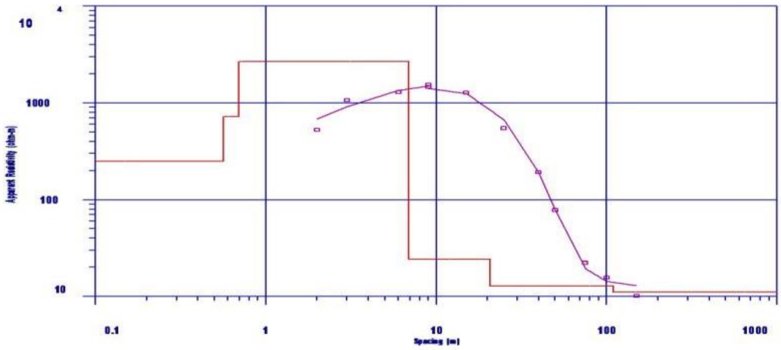


Fig 4: Interpretation result of VES 1 data

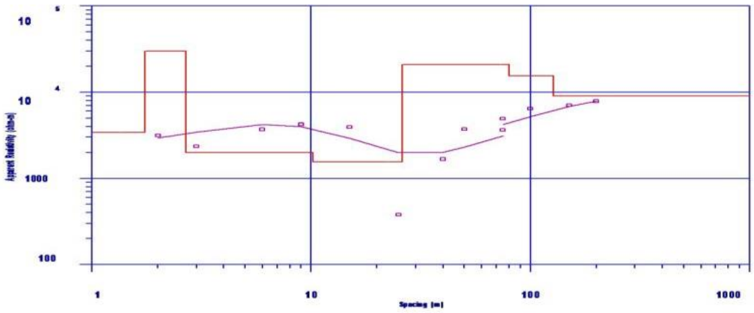


Fig 5: Interpretation result of VES 2 data

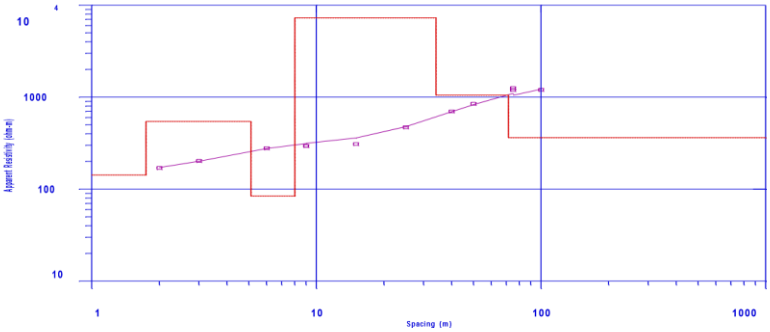


Fig 6: Interpretation result of VES 3 data

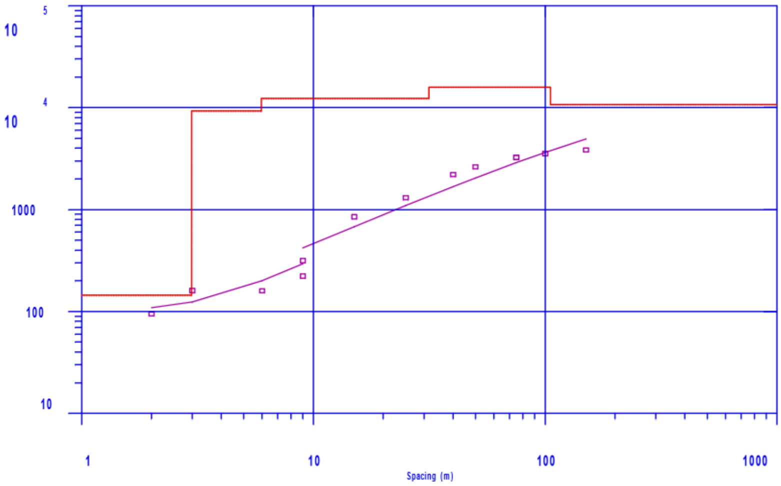


Fig 7: Interpretation result of VES 4 data

Table 3: Summary Of Ves Interpretation Results

| VES | layers | Resistivity (Ωm) | Thickness (m) | Depth (m) | Lithology | Longitudinal conductance S (mhos) | Transverse resistance (Ω) | Hydraudic conductivity | Cal. Transmissivity ($m^2$/d) | Aquifer Transmissivity Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 250.4 | 0.6 | 0.6 | Lateritic Silty shaly sand | 0.0024 | 150.24 | | | |
| | 2 | 724.5 | 0.1 | 0.7 | Lateritic sandstone | 0.00013 | 72.45 | | | |
| | 3 | 2680.6 | 6.2 | 6.9 | Sandstone | 0.0023 | 16619.72 | | | |
| | 4 | 24.4 | 13.9 | 20.8 | Silty – sandstone | 0.570 | 339.16 | | | |
| | 5 | 12.9 | 89.1 | 109.9 | Water saturated silty sand | 6.907 | 1149.39 | 36.38 | 41814.81 | Very Good |
| | 6 | 11.1 | ∞ | ∞ | Water saturated silty – shale | ∞ | ∞ | 41.82 | | |
| 2 | 1 | 3393.2 | 1.7 | 1.7 | Dry Silty sandy top | 0.0005 | 5768.44 | | | |
| | 2 | 29834.2 | 0.9 | 2.7 | Dry sandstone | 0.00003 | 28850.78 | | | |
| | 3 | 2001.7 | 7.5 | 10.2 | Silty – Sandstone | 0.0037 | 15012.75 | | | |
| | 4 | 1551.0 | 15.9 | 26.0 | Silty – shale | 0.0103 | 24660.9 | | | |
| | 5 | 20768.3 | 54.2 | 80.2 | Sandstone | 0.0026 | 1125641.86 | | | |
| | 6 | 15424.1 | 46.9 | 127.1 | Water saturated sandstone | 0.0030 | 723385.6 | 0.085 | 61487.78 | Very Good |
| | 7 | 9065.7 | ∞ | ∞ | Water saturated sandstone | ∞ | ∞ | | | |
| 3 | 1 | 142.6 | 1.7 | 1.7 | Shaly, silty sandy soil | 0.0119 | 242.42 | | | |
| | 2 | 545.2 | 3.4 | 5.1 | Silty lateritic sandstone | 0.0062 | 1853.68 | | | |
| | 3 | 84.1 | 2.9 | 8.0 | Silty-shale | 0.0345 | 243.89 | | | |
| | 4 | 7287.9 | 26.0 | 34.0 | Sandstone | 0.0036 | 189485.4 | | | |
| | 5 | 1051.5 | 37.5 | 71.5 | Water saturated silty shale | 0.0357 | 39431.25 | 1.667 | 65731.90 | Very Good |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 363.2 | ∞ | ∞ | Water saturated silty shale | ∞ | ∞ | | | |
| 4 | 1 | 144.6 | 3.0 | 3.0 | Shaly, silty sandy soil | 0.0207 | 433.8 | | | |
| | 2 | 9261.2 | 3.0 | 6.0 | Silty lateritic sandstone | 0.00032 | 27783.6 | | | |
| | 3 | 12298.9 | 25.5 | 31.4 | Silty-sandstone | 0.00207 | 313621.95 | | | |
| | 4 | 15878.2 | 73.9 | 105.4 | Water saturated sandstone | 0.0047 | 1173398.98 | 0.073 | 85658.13 | Very Good |
| | 5 | 10679.1 | ∞ | ∞ | Sandstone | ∞ | ∞ | | | |

A correlation between the lithologic logs of boreholes drilled 20m, 30m, 40m and 60m away from the study areas (VES 1 – 4) respectively obtained from the State Ministry of Water Resources and the interpretation results of VES 1 – 4 as shown in Table 3 shows the occurrence of six (6) lithologic layers or VES 1 and 3 while VES 2 and 4 shows seven (7) and five (5) lithologic layers namely: Shaly Silty Sandy soil, Silty lateritic sandstone, Silty shale, Silty – sandstone, Sandstone, Dry sandstone, Dry silty sandy top, Lateritic sandstone, Lateritic silty shaly sand, Water saturated silty shale and Water saturated silty sandstone as shown in Table 3. The first layers has resistivity values ranging from 142.60 – 3393.20Ωm, inferred to be Lateritic silty shaly sand, Dry Silty sandy top and Shaly, silty sandy soil respectively with thickness values ranging from 0.6 – 3.0m. The second layers inferred as lateritic sandstone, dry sandstone and silty lateritic sandstone respectivity with resistivity values ranging from 545.20 – 29834.20Ωm and thickness values ranging from 0.1 – 3.4m. The resistivity values of the third and fourth layers ranges from 24.4 – 15878.2Ωm with thickness values ranging from 2.9 – 73.9m.The aquifer layers are water saturated silty shale and water saturated silty sandstone which is located at the 5$^{th}$ - 7$^{th}$ layers in VES 1 – 3; fourth layer in VES 4, it is at these layers that the aquifer are located in agreement with the result of Oyeku and Eludoyin (2010), Nzemeka *et al.*, 2023 and Uma (2003). These layers has thickness values ranging from 37.5 – 89.1m. The fifth layer for VES 2 and 4 inferred as sandstone. Their resistivity values ranges from 10679.1 – 20768.3Ωm with thickness values of 54.2m. The aquifer transmissivity was determined by calculating for hydraulic conductivity and multiplying with the thickness of the aquifer layer in the VES 1 – 4. The aquifer transmissivity values obtained was 41814.81, 61487.78, 65731.90 and 85658.13m$^2$/day which indicates a very good aquifer transmissivities. Groundwater potential zones were determined based on transmissivity values in accordance with the result of Sylvia *et al* (2022) and Emmanuel *et al* (2022). VES 1 and 4 are seen to be areas with good groundwater potentials because of their high aquifer thickness (89.1 and 73.9m) and transmissivity values (41814.81 and 85658.13m$^2$/day) as such are good areas to site boreholes.

## CONCLUSION AND RECOMMENDATION

In this study, the georesistivity, aquifer hydraulic characteristics and groundwater potential zones at Umunze, Anambra State was undertaken using four Vertical Electrical Soundings and Dar-Zarrouk parameters. The results showed that VES 1 - 4 have a total of 5 - 7 lithologic layers. The subsurface sequence comprises of Lateritic Silty Shaly Sand, Dry Silty Sandy top, Dry Sandstone, Silty Shale, Shaly Silty Sandy soil, Silty Lateritic Sandstone, Lateritic Sandstone, Sandstone, Silty – Sandstone, Water Saturated Silty Sand, Water Saturated Sandstone and Water Saturated Silty Shale. The water saturated silty sand, water saturated sandstone and water saturated silty shale constituted the aquifer unit in the area and its thicknesses ranges from 37.5 – 89.1m. VES 1 and 4 have been identified as the best areas for productive and sustainable borehole yield because of their high aquifer thickness and transmissivity as shown Table 4.2. The aquifer transmissivity values obtained for VES 1 and 4 are 41814.81 and 85658.13 m$^2$/day which indicates a very good aquifer transmissivities respectively. VES 2 and 3 also showed a very good aquifer transmissivities but their aquifer thicknesses isn't good enough.

The results of this study have provided additional baseline data for an elaborate groundwater exploration and environmental factors to be considered for planning, development and siting of borehole, for residential and commercial facilities within Umunze. For effective groundwater development programmes in the study area, it is recommended that pre-drilling geophysical investigations such as to assess groundwater potential, to estimate the possible depth of aquifer in some areas in Umunze axis be conducted for economic and environmental purposes and add to the already existing knowledge.

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