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Water bearing unit, not everywhere; Resistivity study of shallow aquifer around Patani Milieu, Niger delta region of Nigeria

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ABSTRACT

This study was carried out to identify shallow aquifers in a number of villages in Southern Ughelli North and the Patani Local Government Area of Delta State, in Southern Nigeria, using vertical electrical sounding (VES) with the Schlumberger electrode configuration. A total of 12 VES surveys were performed, employing the Schlumberger configuration with a maximum electrode spacing of 150 meters. Deductions from the following aquifer resistivity, aquifer depth, transverse resistance, aquifer thickness, longitudinal conductance (*S*), transmissivity, and hydraulic conductivity were measured using primary geo-electric parameters. The values of the aforementioned parameters range from 500 to 700 Ωm, 13 to 25 m, 500 $\Omega{\cdot}m^2$ to 9000 $\Omega{\cdot}m^2$, 10 to 20 m, 0.001 to 0.2, 0.77 to 60.675 m^2/day, and 0.077 m/day to 5.04 m/day respectively. Aquifer across the study area was categorized based on varying degrees of polluted source susceptibility using the principal geo-electric characteristics and the geographical distribution of *S*. Aquifer vulnerability was investigated using the longitudinal conductance values, and the research region was classified as moderate, weak, and poor based on the aquifer protective capacity assessment.

Keywords: Aquifer, Sandstone, Vulnerability, Protective, Resistivity

1. INTRODUCTION

Water, a natural resource that is vital to the life of people, animals, and plants, is not equally distributed on Earth's surface and below. Natural water can vary greatly in both quality and quantity, whether it is found on the surface or beneath (Eyankware et al., 2022). Fresh water, however, is especially essential to human survival. This resource is available from a number of sources, including rivers, streams, open wells, boreholes, and taps. People frequently use unsafe or contaminated water sources to meet their daily needs when fresh water is limited, which can result in a number of health problems (Esi et al., 2026). A 2006 report from the United Nations Development Programme (UNDP) stated that the deterioration of groundwater quality in Africa is a serious problem that requires immediate attention in order to be developed and managed sustainably. In this regard, the capacity of groundwater to sustain boreholes and its hydraulic flow characteristics, as well as the protectivity of aquifers against the intrusion of contaminated fluids and other hazardous substances,

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are critical for the efficient management and preservation of the groundwater system, which is susceptible to contamination (George et al., 2025). Due to the paucity and pollution of surface water bodies, groundwater is heavily relied upon worldwide. However, the quality of underground water can be compromised through both anthropogenic and natural factors, including inadequate waste disposal practices, leaks from both surface and subsurface storage tanks, oil spills, sewage from latrines, saltwater intrusion, erosion, mining, and agricultural practices (Onwe, et al., 2024; Odesa, et al., 2025). These actions can lead to the downward movement of contaminated fluids (leachates) into the groundwater system, making it unfit for human consumption. The strata situated above the aquifer, often viewed as protective layers, possess the ability to either slow the movement of or filter the infiltrating fluids, contingent upon their composition and various physical characteristics such as thickness, porosity, and permeability (Eyankware, 2019). Aquifers' ability to generate water under specific hydrogeological conditions is known as their groundwater potential. Numerous elements have a substantial impact on groundwater potential, such as current groundwater levels, recharge rates, and geological structures. The same is true for groundwater accessibility, which is mostly influenced by geological factors. The assessment of groundwater potential requires the analysis of several hydrodynamic and flow properties, such as transmissivity, storativity, permeability, hydraulic conductivity, porosity, and transverse resistance (George, 2021; Ekanem and Udosen, 2023). It is important to understand that while evaluating groundwater availability, consideration should not only be given to quantity but also to groundwater quality and the identified aquifers' vulnerability to contamination. The degree to which a particular aquifer is susceptible to contamination that could jeopardize groundwater quality is known as the vulnerability assessment in the field of hydrogeology (Akinseye et al., 2023; Eyankware and Aleke, 2021; Umayah and Eyankware, 2022).

Vulnerability refers to the groundwater's vulnerability to pollutants, which is impacted by human activity, the characteristics of contaminants, and a number of physical elements. Vulnerability data is essential for determining appropriate sites for various activities, which helps prevent negative impacts on groundwater and preserve its integrity. Areas that are particularly susceptible to contamination are identified through research focused on vulnerability assessments. Numerous factors influence groundwater's susceptibility to contaminants, but two main ones are population growth and a lack of surface storage facilities. Subsurface groundwater availability and quality have significantly declined as a result of these variables. Geophysical techniques have effectively addressed many exploration challenges due to their speed, ability to cover large areas in a short timeframe, and capacity to penetrate deeper into the subsurface. Geoelectrical techniques are especially effective for groundwater investigations, as the hydrogeological attributes, including porosity and permeability, can be linked to values of electrical resistivity. In order to identify hydrogeological zones for groundwater exploration, the electrical resistivity technique has proven to be successful. The remarkable sensitivity of rock resistivity to its ionic composition makes this approach one of the most important techniques in groundwater geophysics. Additionally, this methodology uses a controlled source with specific dimensions to make it easier to collect quantitative data. The main goal of the resistivity approach is to assess potential variations at the surface brought about by electrical current flowing through the earth. There is a reciprocal relationship between hydraulic conductivity and electrical conductivity, as the mechanisms controlling fluid flow and electric current conduction are typically influenced by similar physical characteristics and geological features (George et al., 2015). The geoelectric parameters obtained through the electrical resistivity method contribute to a better understanding of the subsurface hydrological conditions as well as the evaluation of the aquifer's protective capacity. This study is designed to create a conceptual framework for assessing groundwater potential and mapping aquifer vulnerability in a standard sedimentary environment utilizing the geoelectric method. The main goals include locating subsurface layers and assessing their geoelectric properties, mapping groundwater-retaining geological formations, identifying aquifer units, assessing their hydrogeological characteristics, and producing maps that show groundwater potential and aquifer vulnerability in the designated study area.

Location, accessibility, climate, and topography

This area has low-lying topography that progressively dips down toward the Ethiopian River, making it a typical coastal plain (Fig.1). High temperatures between 23 and 37°C and humidity levels between 50 and 70% are characteristics of this equatorial environment. The wet season begins in March and peaks between July and October. The dry season is defined as the months of November through February. The average annual rainfall in the study area during the six-year period from 2000 to 2005 was 3317.8 mm (Irwin and Oghenevwede, 2014).

Geology of the study area

The Benin, Agbada, and Akata Formations are all part of the Niger Delta formation sequence, which is where the research area is mainly situated. The sands of the Somebreiro-Warri Deltaic Plain, the topmost strata of the Benin Formation, are located beneath Ughelli. The geology of the Niger Delta has been extensively studied and documented by a significant number of scholars.

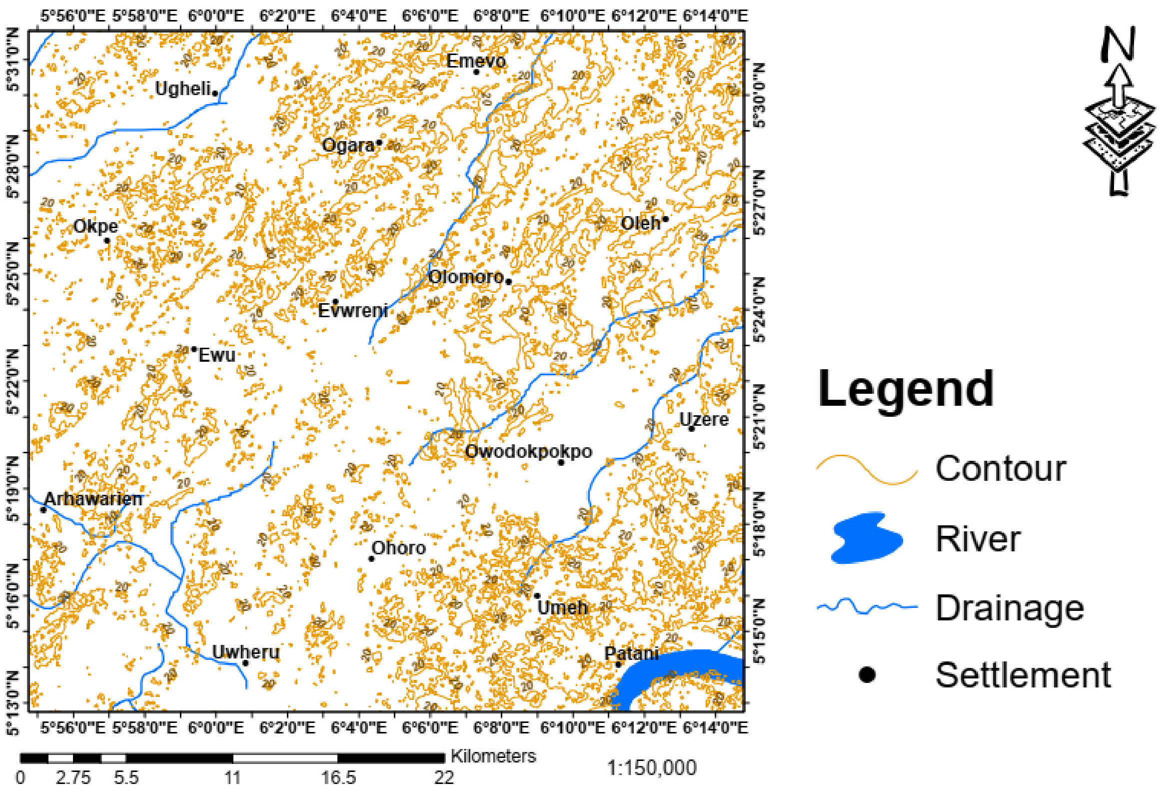

Figure. 1: Topographic Map of the study area

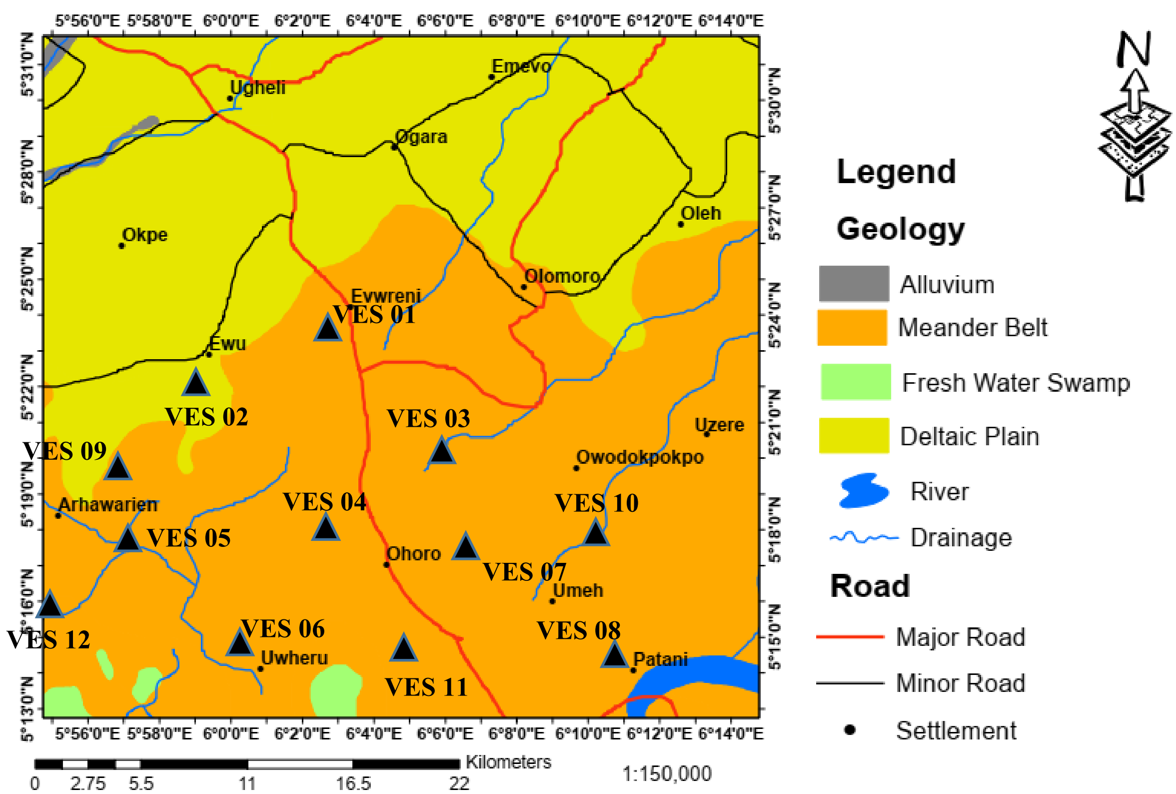

Figure. 2: Geology Map of the study area

The Somebreiro-Warri Deltaic Plain's sands, which have an estimated thickness of 120 meters, date from the Quaternary to Recent eras. This area's sediments exhibit an unconsolidated character, ranging from medium- to coarse-grained sand to fine plastic clay, sometimes combined with gravel (Fig. 2). The Benin Formation primarily comprises unconsolidated sand and gravel, with occasional layers of shale interspersed. This formation serves as the principal source of freshwater for the Niger Delta region and has an approximate thickness of 2000 m, dating from the Oligocene to the Pleistocene epochs.

2. METHODOLOGY

Twelve (12) Vertical Electrical Soundings (VES) were conducted within the chosen research area using the Schlumberger array approach, with half current electrode spacing (AB/2) ranging from 1 to 150 meters. The Ohmega resistivity meter was utilized to collect the data. For accuracy, a Geographic Positioning System (GPS) device was used to record the sounding stations' locations in Universal Traverse Mercator (UTM) coordinates. Data was gathered along roads, straight paths connecting residences, and other easily accessible open spaces. The computation of apparent resistivity values, which were obtained from the resistance (R) measurements captured by the apparatus, as well as the geometric factors (G) associated with the electrode separations corresponding to the particular spread lengths, were part of the VES data analysis. On a bi-logarithmic graph sheet, the apparent resistivity values for every VES station were then visually displayed in relation to the electrode spacing (AB/2). The properties of the underlying layers were then ascertained by qualitatively analyzing the resulting curves through visual inspection. For quantitative interpretation, partial curve matching was performed on the generated field curves. The outcomes of this curve matching, specifically the resistivity and thickness of the layers, were input into a computer as initial model parameters for an iterative forward modeling process utilizing WinResist Software. The geoelectric parameters derived, including resistivity, thickness, and depth, played a crucial role in determining both the thickness and resistivity of the aquifer, which are key considerations in assessing groundwater potential.

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

The apparent resistivity data were plotted against the current electrode spacing (AB/2) to generate the geoelectrical curves. The processing of the data has been enhanced by the use of the IX1D software, which has enabled the generation of sound curves. Geoelectric sections were drawn using the information from the sounding curves while the thickness of the aquifer was determined from the geoelectrical sections. Lithologies that correspond with the geoelectric section were inferred using the charts. Some parameters related to the different combinations of thickness and resistivity of the geoelectric layer are important for the analysis and understanding of the geologic model. Those parameters are Dar Zarrouk: longitudinal (S) and transverse (T), respectively, given by

$$S = \frac{h}{p} \quad (2)$$

$$T = hp \quad (3)$$

1. The total Longitudinal Unit Conductance (S) was calculated using the formula given below

For ‘n’ layers, the total longitudinal conductance is

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \quad (4)$$

2. The Transverse Resistance for a given VES curve is given by using the equation

The transverse resistance is

$$\rho_t = \frac{T}{H} = \frac{\sum_{i=1}^{n} h_i \rho_i}{\sum_{i=1}^{n} h_I} \quad (5)$$

According to Eyankware (2019), the aquifer hydraulic conductivity, K and transmissivity, T is obtained through the empirical relationship in the equations below.

$$K = 0.0538E^{0.0072\rho} \quad (6)$$

$$T = K \times h \quad (7)$$

Where ρ is the aquifer resistivity and h its thickness

3. RESULTS AND DISCUSSION

Aquifer Resistivity

Aquifer resistivity vary depending on the composition and intrinsic characteristics of rock formations. Measurements of resistivity in aquifers are generally higher than those in other types of rock. Analyzing the forms of VES data and modeling and assessing site-specific geological features are crucial for obtaining precise aquifer resistivity estimates (Eyankware et al., 2022; Okoli et al., 2024). The result from Fig. 3 revealed aquifer resistivity contour pattern is orientated towards the selected part of NE, SW, and SW. The value of aquifer resistivity for this study ranges from 500 to 700 Ωm.

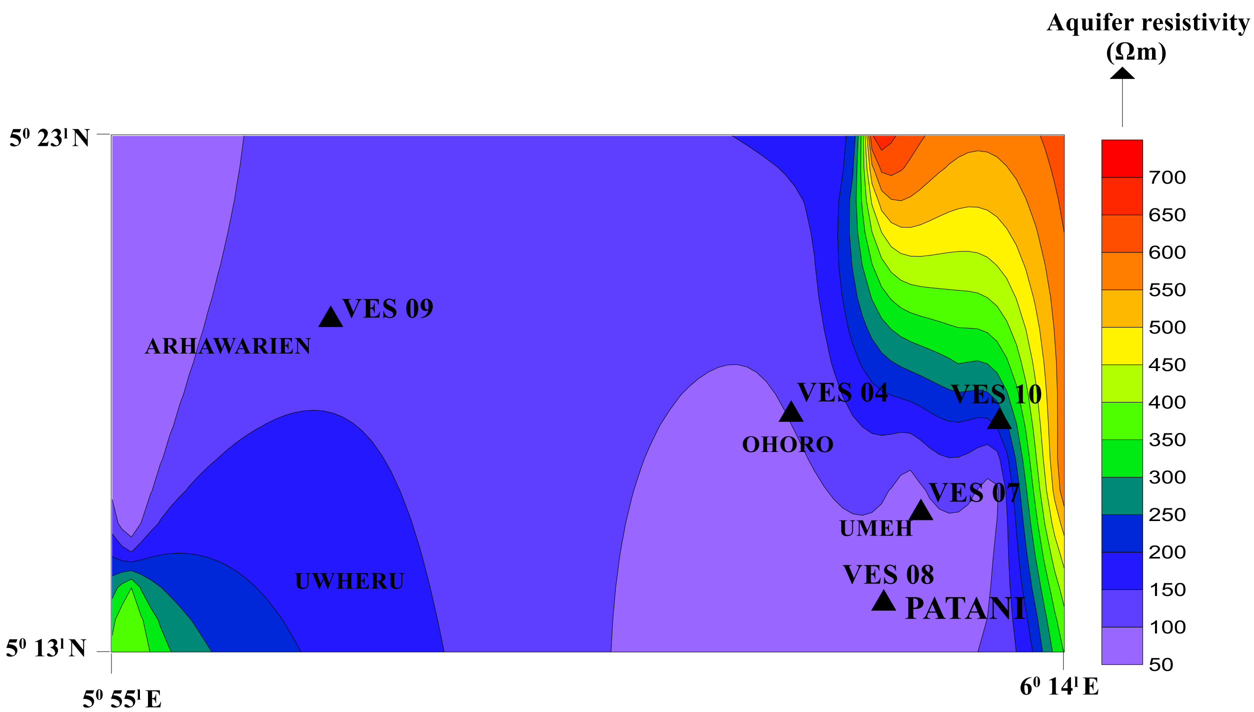

Figure 3: Spatial distribution of aquifer resistivity.

Table 1: Results of Second geoelectric parameters

VES POINTS	Latitude	Longitude	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Depth to Aquifer (m)	Longitudinal Conductance (S)	Transverse Resistance (Ω·m²)	Transmissivity (m²/day)	Hydraulic conductivity (m/day)
VES 01	5⁰ 23' N	6⁰ 01' E	210	10	14	0.013	2100	2.44	0.244
VES 02	5⁰ 23' N	6⁰ 02' E	700	12	15	0.02	8400	60.48	5.04
VES 03	5⁰ 19' N	6⁰ 07' E	300	10	15	0.05	3000	4.7	0.47
VES 04	5⁰ 17' N	6⁰ 04' E	80	10	14	0.2	800	0.95	0.095
VES 05	5⁰ 16' N	5⁰ 59' E	50	10	13	0.2	500	0.77	0.077
VES 06	5⁰ 15' N	6⁰ 03' E	80	20	24	0.044	1660	1.9	0.095
VES 07	5⁰ 17' N	6⁰ 09' E	80	20	25	0.042	1600	1.9	0.095
VES 08	5⁰ 14' N	6⁰ 11' E	180	12	16	0.013	2160	2.364	0.197
VES 09	5⁰ 20' N	5⁰ 58' E	60	10	13	0.15	600	0.83	0.083
VES 10	5⁰ 17' N	6⁰ 13' E	600	15	20	0.003	9000	9.477	0.6318
VES 11	5⁰ 14' N	6⁰ 08' E	100	15	20	0.001	1500	60.675	4.045
VES 12	5⁰ 15' N	5⁰ 59' E	400	14	20	0.004	5600	13.412	0.958
Min			**50**	**10**	**13**	**0.001**	**500**	**0.77**	**0.077**

Max	700	20	25	0.2	9000	60.675	5.04
Aver	700	20	25	0.2	9000	15.81	1.22

Aquifer Depth

Aquifer depth is determined by the vertical separation between the aeration zones above and the saturation zone below the water table. After rainfall, water seeps into the earth through soil and rock pores and fissures. This water slowly seeps deeper into the ground due to gravity. As a result, water builds up in the saturation zone at its lowest point. The water table is affected by variations in precipitation patterns; it rises when more water enters the saturation zone and falls when water is use. According to Umuayah and Eyankware (2022), while evaluating the groundwater potential of the sandstone aquifer along the Ughelli-Warri axis in Delta State, Nigeria, aquifer thickness and depth are crucial considerations. According to the data in Fig. 4, and Table 1, the aquifer's depth ranges from 13 to 25 m. Previous studies conducted in this area have verified the existence of a shallow aquifer, which is also defined by depths between 13 and 25m.The results of this study are consistent with those of Ernest et al. (2015), who found that the first aquifer, located in the Abraka region and its environs (in the Sombreiro-Warri deltaic plain deposits), is composed of fine to medium sand and is accessible at depths of less than 4 m.

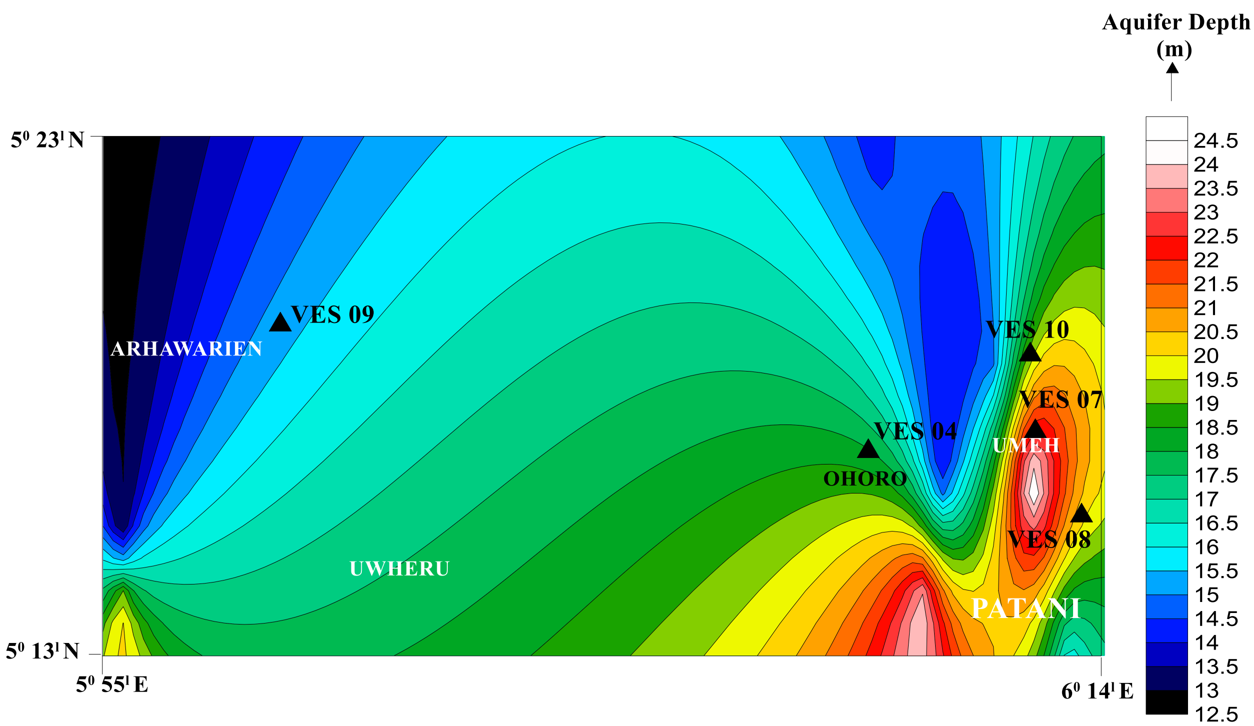

Figure 4: Spatial Distribution of aquifer depth of the study area.

Transverse Resistance (ϱt)

Tanverse resistance is one significant statistic that describes the spatial variation of resistance in different places. This measure is determined by multiplying the aquifer resistivity by its thickness across a specific area, according to Umoren et al. (2017; Umayah and Eyankware, 2022). When determining target areas with good groundwater potential, ϱt is one of the indicators employed. According to Eyankware and Aleke (2021) and Eyankware et al. (2022a, b), transmissivity and transverse resistance are directly correlated, with the highest transmissivity values of aquifers or aquiferous zones presumably reflecting the highest transmissivity values. According to Table 2, the ϱt for this investigation, which was calculated using equation 5, ranges from 500 Ω·m² at VES 05 to 9000 Ω·m² at VES 10, with an average value of 9000 as shown in Table 1. As illustrated in Fig. 5, this notable difference highlights the significance of aquifer transverse resistance in defining the subsurface hydrogeological properties within the research area.

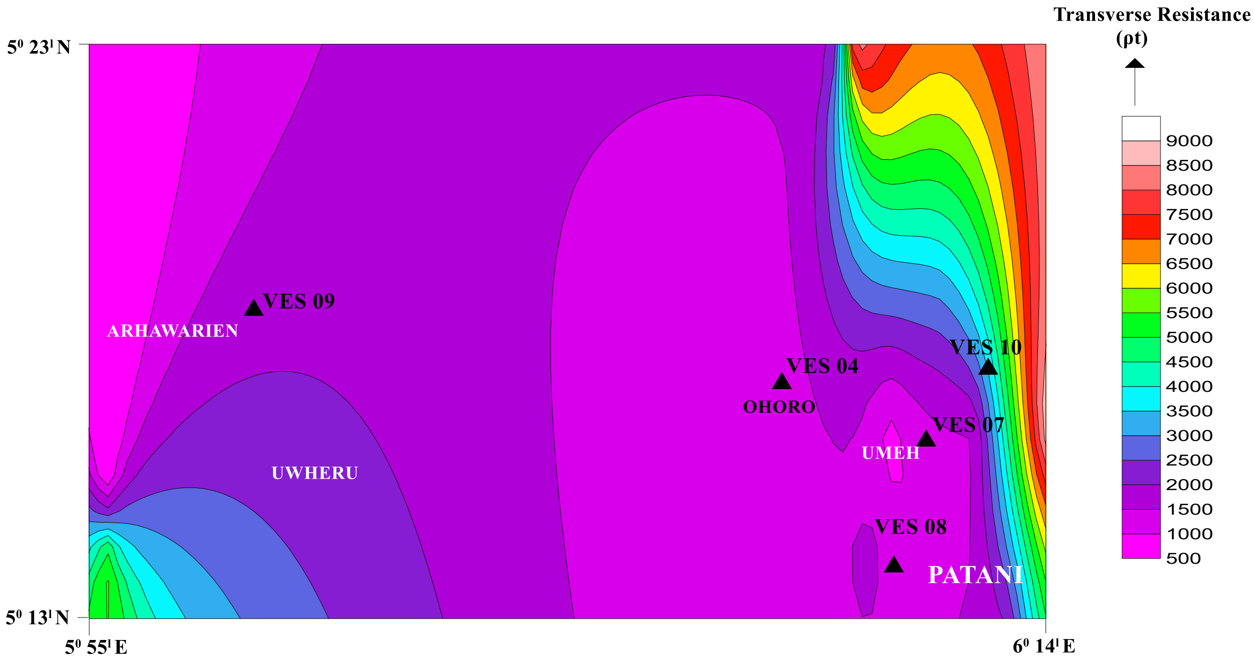

Figure 5: Spatial Distribution of Transverse resistance of the study area.

Aquifer thickness

According to Table 1, the aquifer's thickness averages 20 meters, with variations ranging from 10 to 20 m. The aquifer in the southeast section of the research area is thicker than in other areas (Fig. 6). The NW and NE portions of the research region have low aquifer thickness, according to the results from Fig. 7, hence it is advised that boreholes not be dug in these locations. The research area's southeast regions, which have thick aquifers, could be regarded as extremely productive.

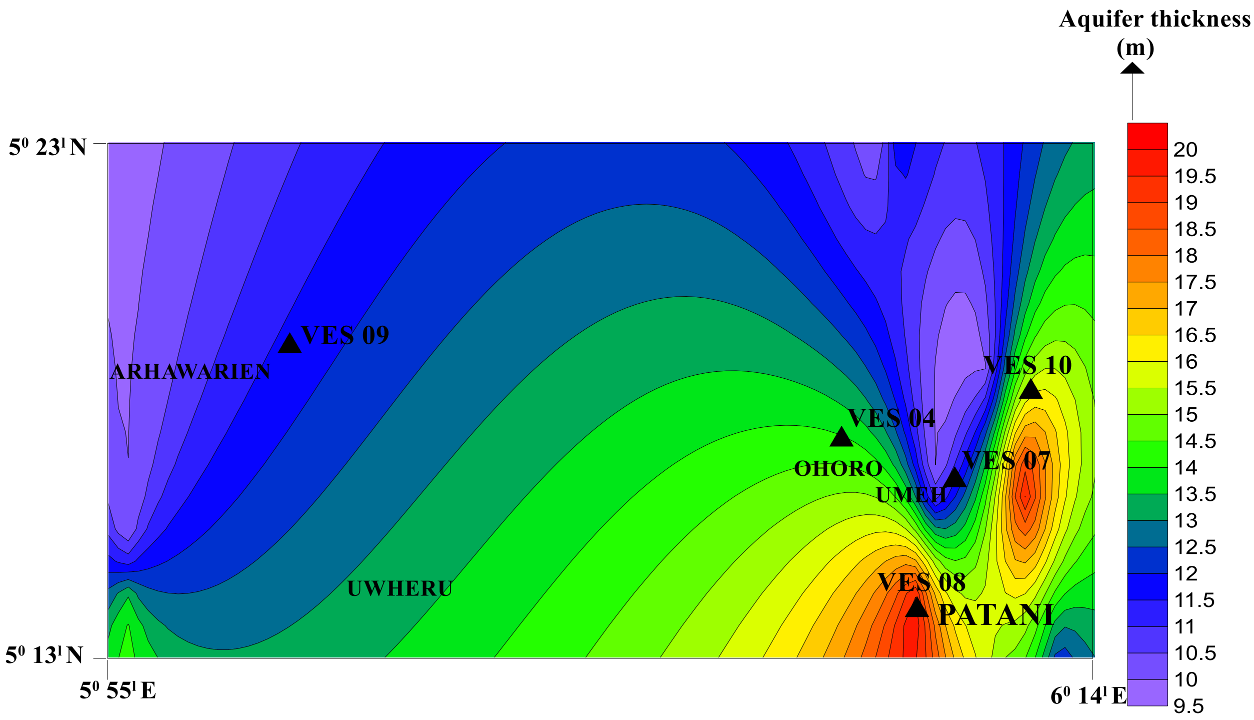

Figure 6: Spatial Distribution of aquifer thickness of the study area.

Longitudinal Conductance

The significant fluctuation, as shown in Fig. 7, emphasizes how crucial aquifer transverse resistance is for describing the study area's underlying hydrogeological characteristics. Longitudinal conductance is considered a secondary geoelectric property that is produced by the combination of two important geoelectric parameters: resistivity and layer thickness. Within the examined area, the longitudinal conductance values shown in Fig. 7 range from 0.001 at VES 11 to 0.2 at VES 4 see Table 1. This measure is a crucial indicator of subsurface electrical conductivity and provides information about the composition and structural features of the geological formations. The observed variations highlight the intricacy of the subsurface environment and the significance of longitudinal conductance in geophysical investigations. Much of the aquifer systems in Warri, Delta State, southern Nigeria, are unconfined. Aquifer yield, transmissivity, and specific capacity are some of the indicators that point to the region's significant groundwater potential. The majority of the materials in the unsaturated zone have high permeability and are mostly composed of sand or gravel. Because of the extremely permeable overburden and shallow water table, pollutants can quickly enter the aquifer system. Both vertical and horizontal transport of contaminants is made possible by the aquifer materials' permeability and porosity within the groundwater system. The area groundwater vulnerability has been classified as either low or high as shown in Table 2.

Table 2: Showing aquifer protective capacity rating (Olusegun et al.2016)

Rating	Protective Capacity	Remarks
> 10	Excellent	
>5-10	Very Good	
>0.7-4.9	Good	
>0.2-0.69	Moderate	VES 04, and 05
>0.1-0.19	Weak	VES 09
<0.1	Poor	VES 01, 02, 03, 06, 07, 08, 10, 11, and 12

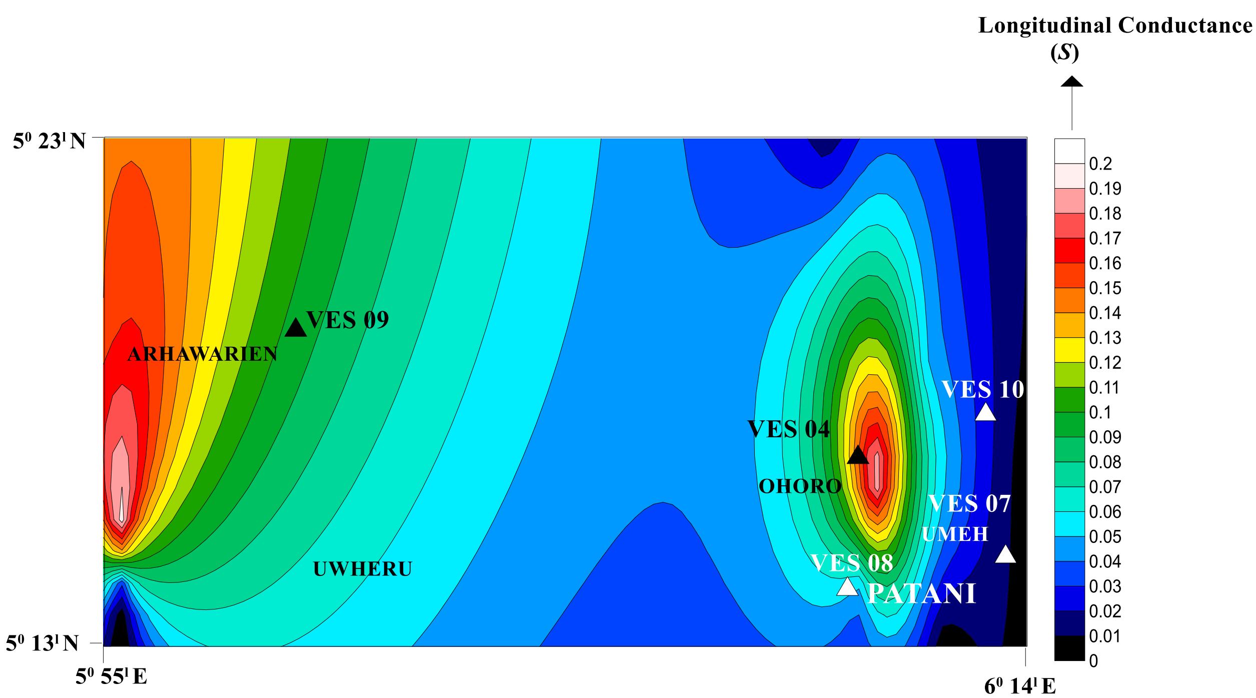

Figure 7: Spatial Distribution of longitudinal conductance of the study area.

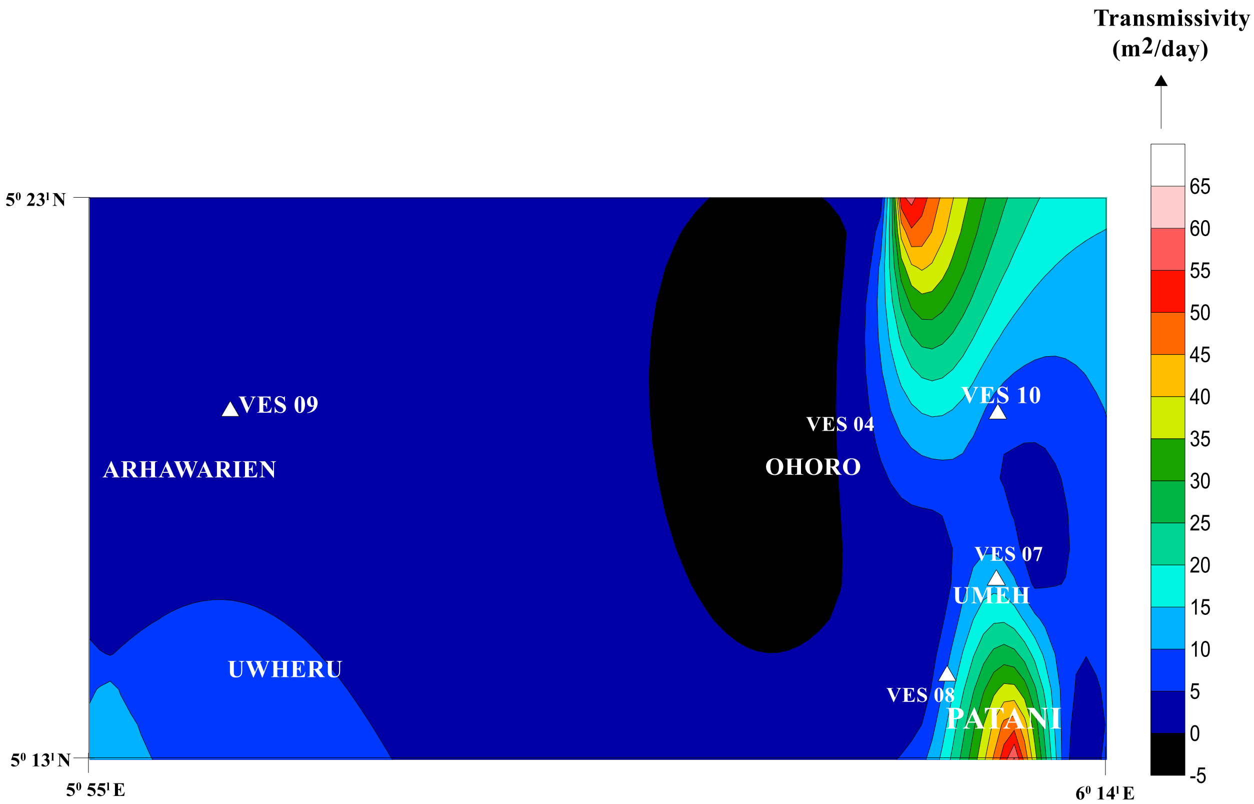

Figure 8: Spatial Distribution of transmissivity of the study area.

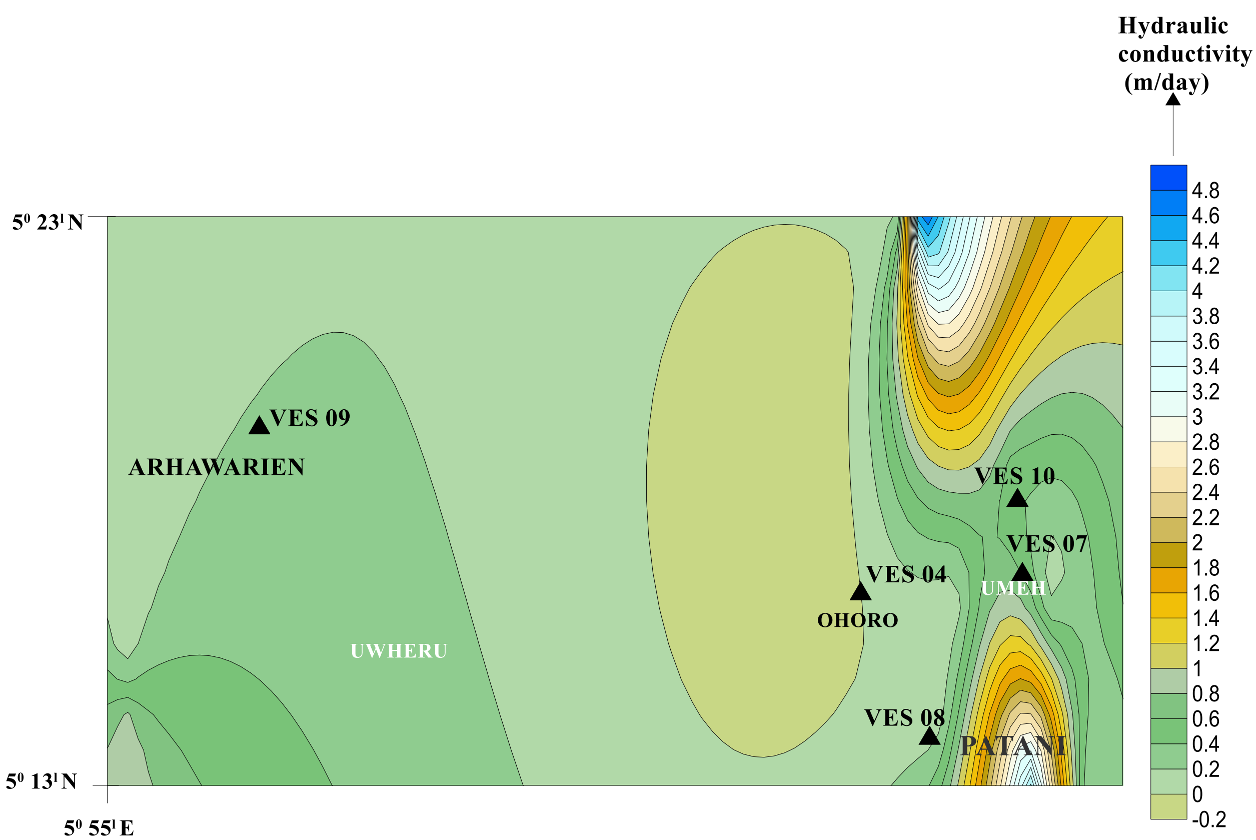

Figure 9: Spatial Distribution of hydraulic conductivity of the study area.

Transmissivity (m²/day)

Transmissivity is the capacity of an aquifer to transport groundwater over its whole saturated thickness (Eyankware, 2019). It also explains how quickly groundwater can move through a unit-width aquifer section in the presence of a unit hydraulic gradient. Table 1 shows that T for this investigation ranges from 0.77 at VES 5 to 60.675 at VES 11 m^2/day. The low T values indicate a low output from the aquifer, which was seen at some research sites (VES 01, 03, 04, 06, 07, 08, and 09). These illustrations (Fig.8) demonstrate that the transmissivity of aquifers is influenced by both the lithological features and the thickness of the aquifer materials. The aquifers with higher levels of transmissivity tend to have more favorable production potential. The aforementioned location might be considered to have a high groundwater output when compared to other areas in the research area, even if VES 02, 11, and 12 have high transmissivity values.

Hydraulic conductivity (m/day)

The ease with which the pore fluid can leave the constricted pore space is determined by its hydraulic conductivity. Hydraulic conductivity of the material is the ability of the fluid to pass through the pores and fractures in the rocks. Similarly, the type of rock that is present in a certain place determines the conductivity of the water there. K, according to Obiora et al. (2015), regulates how groundwater flows through an aquifer. Hydraulic conductivity value for this study ranges from 0.077 m/day at VES 05 to 5.04 m/day at VES 02 as shown in Table 1. The findings presented in Figure 9 demonstrate that the studied area's northeastern and southeast designated regions have higher hydraulic conductivity values. This implies that water may easily pass through the closely spaced pore pores in the sandstone of the research location and that groundwater can comparatively easily move through the sandstone formations.

4. CONCLUSION

Identifying geological formations, assessing rock strata, and defining aquifers are all made easier with the application of electrical resistivity techniques in hydrogeological study. Through the measurement of underground materials' resistance as electric current passes through them and an evaluation of changes in electrical potential, this method creates relationships between different physical characteristics like lithology, porosity, water saturation, and the existence of voids within rocks. It offers crucial insights for research on groundwater, especially in difficult terrain and sedimentary settings. In contrast to other sections, the northeastern and southeast regions of the research area exhibit greater aquifer resistivity values, ranging from 500 to 700 Ωm. According to the analysis of the aquifer resistivity spatial distribution map. Insights from the aquifer depth spatial distribution map also showed that some regions in the southwest and southeast have deeper aquifers than the rest of the research area. The ϱt spatial distribution map showed a rise in contour toward particular points in the southwest and northeast. Aquifer thickness assessment also showed an increasing trend along the research area's southern and southeast axes. Additionally, results from the southern parts of the study area showed that the values are substantially higher in the southwest, northwest, and southeast sectors of the study area that were allocated for that purpose. Further findings from T, and H revealed that NE, and SE parts of the study area showed that the aforementioned areas showed more prospect for groundwater exploration when compared to other parts of the study.

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Authors' Contributions:

All the authors jointly conceptualized and designed the study; MOE, OEE, KPU, FJO carried out material preparation, data collection and analysis; manuscript draft preparations were performed by MOE, OEE, KPU, FJO. All the authors read and authorized the final manuscript for submission and publication.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

REFERENCES AND NOTES

1. Akinseye VO, Osisanya WO, Eyankware MO, Korode IA, Ibitoye AT. Application of second order geoelectric indices in determination of groundwater vulnerability in hard rock terrain in SW. Nigeria. Sustainable Water Resources Management. 2023;9:169, doi: 10.1007/s40899-023-00936-w
2. Ekanem AM, Udosen NI. Hydrogeochemical–geophysical investigation of groundwater quality and susceptibility potential in Ikot Ekpene – Obot Akara Local Government Areas, Southern Nigeria. Water Practice & Technology. 2023; 8:11, 2675 - 2704. doi: 10.2- 166/wpt.2023.187
3. Ernest AO, Boniface CE, Egboka P. The Hydrogeology of Delta State, Nigeria. The Pacific Journal of Science and Technology. 2015;16:2, 257-269.
4. Esi EO, Orisekpabor OP, Eyankware MO. Integration of geophysical and radiological assessment of solid waste diposal impact on groundwater and human health in southern Nigeria. Geosystems and Geoenvironment. 2026;5(1): 100425. doi: doi: 10.1016/j.geogeo.2025.100425.
5. Eyankware MO, Akakuru CO, Eyankware, EO. Hydrogeophysical delineation of aquifer vulnerability in parts of Nkalagu areas of Abakaliki, SE. Nigeria. Sustainable Water Resources Management. 2022; 8:39. doi: 10.1007/s40899-022-00603-6.
6. Eyankware MO, Aleke G. Geoelectric investigation to determine fracture zones and aquifer vulnerability in southern Benue Trough southeastern Nigeria. Arabian Journal of Geosciences 2021; 2259. doi: 10.1007/s12517-021-08542-w.
7. Eyankware MO, Ephraim BE. A comprehensive review of water quality monitoring and assessment in Delta State, Southern Part of Nigeria. Journal of Environmental & Earth Sciences. 2021;3:1, 16-28. doi: 10.30564/jees.v3i1.2900
8. Eyankware MO. Integrated landsat imagery and resistivity methods in evaluation of groundwater potential of fractured shale at Ejekwe area, southeastern Nigeria. Unpublished PhD Thesis, 2019.
9. George NJ, Bassey NE. Geoelectric and hydro-geochemical assessments of waterlogging and drainage for soil and agronomic groundwater evaluation at Akwa Ibom State University: Field and laboratory data mining approaches. Geosystems and Geoenvironment. 2025; 100464. doi: 10.1016/ j.geogeo.2025.100464
10. George NJ, Emah JB, Ekong UN. Geohydrodynamic properties of hydrogeological units in parts of Niger Delta, Southern Nigeria. Journal of African Earth Sciences. 2015;105, 55–63. doi: 10.1016/j.jafrearsci.2015.02.009
11. George NJ. Modelling the trends of resistivity gradient in hydrogeological units: a case study of alluvial environment. Modeling Earth Systems and Environment. 2021;7:1, 95-104. doi: 10.1007/s40808-020-01021-3
12. Irwin AA, Oghenevwede E. Groundwater conditions and hydrogeochemistry of the shallow Benin Formation aquifer in the vicinity of Abraka, Nigeria. Int J Water Resour Environ Eng. 2014;6:1, 19–31. doi: 10.5897/IJWREE2013.0446
13. Obiora DN, Ibuot, JC, George, JN. Geophysical assessment of potential hydrological units in hydrologically challenged geomaterials of Makurdi, Benue State, Nigeria. International Journal of Physical Sciences. 2015;10:16, 479 –489. doi: 10.5897/ IJPS2015.4386
14. Odesa GE, Okanigbuan PN, Eyankware MO, Ngozi-Chika, C.S, Efetobo Oghenetega. Health risk assessment of water resources within the lignite series of Obomkpa and environs, Southern Nigeria. Journal of Contaminant Hydrology. 2025;274:104665. doi: 10.1016/j.jconhyd.2025.104665
15. Okoli E, Akaolisa CCZ, Ubechu B.O, Agbasi OE, Szafarczyk, A. Using VES and GIS-Based DRASTIC analysis to evaluate groundwater aquifer contamination vulnerability in Owerri, Southeastern Nigeria, Ecological Questions. 2024:35:3:1–27. doi: 10.12775/eq.2024.031
16. Olusegun OA, Adeolu OO, Dolapo FA Geophysical investigation for groundwater potential and aquifer protective

capacity around Osun State University (UNIOSUN) College of Health Sciences. Am J Water Resour. 2016:4:6, 137–143

17. Onwe IM, Obasi, IA, Eyankware MO, Uchenna OL. An integration of hydrochemical data and stable isotopes in groundwater evaluation in Ngboejogu, Southern Benue Trough, Nigeria. Modeling Earth Systems and Environment. 2024;10:7207–7223 doi: 10.1007/s40808-024-02166-1.
18. Umayah OS, Eyankware MO. Aquifer evaluation in southern parts of Nigeria from geoelectrical derived parameters. World News of Natural Science. 2022:42, 28-43
19. Umoren E, Agbasi O, Emmanuel, E. Evaluation of ground water potential in Ekpri-Ikang, Bakassi local Government area, Cross River State, Nigeria. 'A case study of open Bible standard church premises'. International Journal of Advanced Geosciences. 2017:51:26. doi: 10.14419/ijag.v5i1.7447