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Groundwater Potential Assessment Using Dar Zarrouk Parameters in Pariya and Environs, Yola Arm, Upper Benue Trough, Northeastern Nigeria

Victor Vitalis, Kamureyina Ezekiel, Garba Mohammed Ali, Bello Abubakar Dauda

***Abstract:** This study was conducted to evaluate the groundwater potential of Pariya and its environs in the Yola Arm of the Upper Benue Trough, Northeastern Nigeria, in response to increasing dependence on groundwater for domestic and agricultural water supply and the limited availability of surface water resources. The research applied hydrogeophysical techniques to determine the distribution, productivity, and protective capacity of subsurface aquifers. Groundwater conditions were investigated using thirty (30) Vertical Electrical Sounding (VES) measurements acquired with the Schlumberger array and interpreted using IX1D Interpex software. Dar-Zarrouk parameters—longitudinal conductance and transverse resistance—were derived from the interpreted geoelectric layers and integrated with borehole lithologic data to estimate key aquifer properties, including hydraulic conductivity and transmissivity. The results reveal that unconfined-to-semi-confined sandstone aquifers of the Bima Sandstone Formation underlie the area. Longitudinal conductance values range from 0.080 to 1.918 Ω^{-1}, indicating weak to moderate protective capacity across most of the study area, while transverse resistance ranges from 13.17 to 1576.40 Ωm^2. Estimated hydraulic conductivity ranges from 3.23 to 55.34 m/day, and transmissivity values vary from 13.76 to 880.99 m^2/day, classifying the area into zones of low to high groundwater potential. VES stations 3, 10, and 20 exhibit the most favourable groundwater-yield prospects. This research was conducted to provide a scientific basis for sustainable groundwater development and management in Pariya and surrounding communities. The findings demonstrate the effectiveness of the Dar-Zarrouk parameters for groundwater potential assessment and provide reliable guidance for borehole siting and water resource planning within the Upper Benue Trough.*

***Keywords:** Groundwater Potential, Dar-Zarrouk Parameters, Vertical Electrical Sounding (VES), Aquifer Characterization, Transmissivity, Hydraulic Conductivity, Bima Sandstone, Upper Benue Trough.*

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Nomenclature:

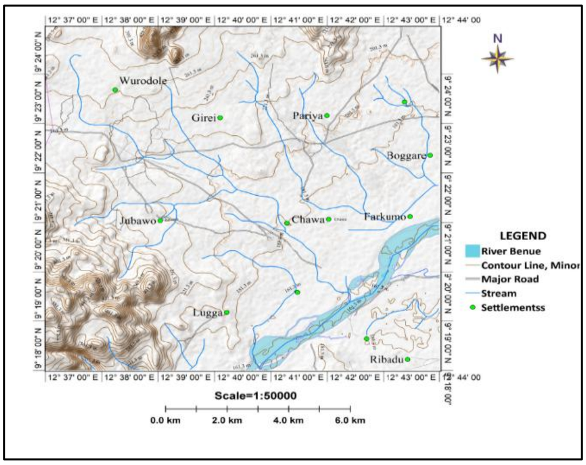
VES: Vertical Electrical Sounding
LoT: Longitudinal Conductance
Tr: Transverse Resistance
Tr: Transmissivity
K – Hydraulic Conductivity
T: Transmissivity
ABEM: Applied Bentonite Electrical Method (resistivity meter manufacturer)
GPS: Global Positioning System
IX1D: One-Dimensional Inversion Software (Interpex)
DC: Direct Current

I. INTRODUCTION

Groundwater is a finite and vulnerable natural resource that plays a critical role in domestic water supply, agriculture, and socio-economic development, particularly in semi-arid regions where surface water availability is limited. It serves as a significant source of essential minerals required for both human and ecological health, making its availability critical to survival and growth (Seli, Ankidawa, & Ishaku, 2021) [7]. Groundwater resides within the saturated zone, commonly referred to as an aquifer, where water occupies interconnected pores and fractures in rocks or sediments. In many rural and semi-arid regions, groundwater remains the most dependable and safe source of water, particularly where surface water development is technically or economically unfeasible. The challenge associated with groundwater supply largely stems from the inherent difficulty in visualizing the subsurface occurrence and flow of groundwater, as it remains concealed beneath the surface. This invisibility complicates efforts to comprehend and manage groundwater-related issues effectively. To address this limitation, detailed geophysical investigations, particularly the integration of Vertical Electrical Sounding (VES), are essential for delineating the characteristics and behaviour of groundwater-bearing formations within an area. Key hydrogeophysical parameters such as aquifer transmissivity (m^2/day), hydraulic conductivity (m/day), aquifer thickness (m), transverse resistance (Ωm^2), longitudinal conductance (Ω), and storage coefficient are commonly evaluated to characterize aquifer systems (Ugbor & Ogbodo, 2023 [8]; Ishola & Bukar, 2024).

A. Location and Accessibility

The area under study is in Pariya and environs, Yola Arm, Upper Benue Trough, Northeastern Nigeria. It is situated within latitudes 9° 18' 00" – 9° 25' 00" N and longitudes 12° 37' 00" - 12° 44' 00" E (Fig. 1) and covers an area of about 174 km^2.



[Fig.1: Topographic Map of the Study Area (After Federal Survey of Nigeria, 2025) [3], Geology of the Study Area]

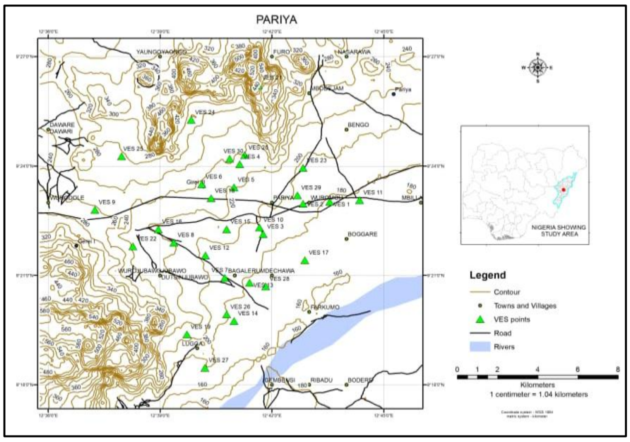
B. Geology and Hydrologic Setting

The Upper Benue Trough comprises two major sub-basins—the Gongola and Yola Arms—separated by the Zambuk Ridge. Its geology is dominated by Cretaceous continental-to-marine sedimentary successions that overlie the Precambrian Basement Complex. The sequence begins with fluvial Bima Sandstone, overlain by transitional to marine Yolde, Dukul, and Sekuliye Formations, and capped by regressive continental formations including Jessu and Lamja Sandstones (Seli, Ankidawa, & Ishaku, 2021). The Numanha Shales represent deeper marine deposition and form potential hydrocarbon source rocks (Nwozor et al., 2025) [6]. Tertiary to Recent volcanic activity around Biu and Longuda marks the last significant tectono-magmatic phase (Falowo et al., 2023) [2]. Hydrologically, groundwater occurs mainly within the Bima and Yolde Sandstones, serving as principal aquifers, while secondary aquifers develop in weathered and fractured basement zones. Recharge is primarily derived from rainfall infiltration and percolation through permeable sandy horizons (Ugbor & Ogbodo, 2023).

II. ELECTRICAL RESISTIVITY SURVEY

Thirty (30) VES Stations were surveyed within the study area using an ABEM SAS 4000 resistivity meter. The obtained data were interpreted using the IX1D Interpex software. Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground and to measure the potential difference between two additional electrodes that do not carry current. The concealed nature of groundwater occurrence makes direct investigation difficult, necessitating the use of indirect geophysical methods for aquifer characterization. (Ishola & Bukar, 2024; Nwozor et al., 2025) [4].

The ABEM SAS 4000 resistivity meter was used to collect field data. This instrument measures and displays the subsurface resistance. Other instruments used include metal electrodes that induce current into the ground and measure potential, a measuring tape to lay out electrodes, a hammer to drive the metal electrodes into the ground, a car battery and a roll of wire, and IX1-D software for computer modelling. A Geographical Positioning System (GPS) that functions to determine the altitude and position of VES points. Fig 2 shows the topographic map showing VES points in the study Area.



[Fig.2: Topographical Map of the Study Area Showing the Location of VES Stations]

Consequently, for accurate interpretation and application of geoelectric data, it is essential to integrate Vertical Electrical Sounding (VES) results with borehole lithologic information through geoelectrical-lithological correlation. In this study, potential groundwater-bearing units were delineated from geoelectric section interpretations, and VES data were correlated with borehole logs to ensure subsurface accuracy. The correlation involved two models: a borehole model manually constructed from field and existing borehole logs, and a geoelectrical model derived from interpreted resistivity values and layer thicknesses.

A. Dar-Zarrouk Parameter

Dar-Zarrouk parameters, derived from layer resistivity and thickness, provide a quantitative basis for estimating aquifer protective capacity and transmissivity in layered earth models. (Adeyemo et al., 2017) [1]. Components of parameters, e.g., ρ and h, for individual geoelectric layers are important in evaluating the Dar Zarrouk parameters. Various sequences of n homogenous, horizontal, and isotropic layers of resistivity ρi and thickness hi. The Dar Zarrouk parameters (longitudinal conductance (S) and transverse resistance (T) are defined, respectively.

$$S_i = \frac{\sum^{n} hi}{pi} \text{ (Seimens)} \ \dots \quad (1)$$

$$i=1$$

Si is longitudinal conductance; h is thickness, and ρi is the apparent resistivity of the layers of the aquifer. (Tr) stands for transverse resistance, and it is a product of the aquifer's Apparent resistivity, as well as the aquifer thickness.

$$\text{Thus: }_i = \sum^{n} pi * \ (\text{ohm.m}^2) \ \dots \quad (2)$$

$$i=1$$

Ti represents transverse resistance, i represents thickness, and pi symbolises the apparent resistivity of the aquifer's layer.

The most productive borehole is commonly associated with such a zone. It usually has the highest

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transverse resistivity. The prospective groundwater potential zone is commonly determined through transverse resistance (Tr) because of its direct relationship with transmissivity; however, suitable transmissivity data can also be estimated from the highest Tr values of the groundwater-bearing aquifer zone.

T = Kh (m2/day) (Daniel et al., 2015) (3) Hence, K = Tb-1 (m/day), h = Aquifer thickness (m).

III. RESULTS AND DISCUSSION

B. Dar Zarrouk Parameters and Aquifer Properties

Table 1 presents the computed values of Dar Zarrouk parameters (transverse resistance and longitudinal conductance) and Aquifer parameters, such as Transmissivity and Hydraulic conductivity, derived from the interpreted VES results.

C. Longitudinal Conductance

Longitudinal conductance is commonly used as an index of aquifer protective capacity, where higher values indicate better natural protection against surface contamination. (Seli, Ankidawa, & Ishaku, 2021). The longitudinal unit conductance values vary from 0.080178875 Ω^{-1} to 1.917795707 Ω^{-1} Siemens in the study area (Table 1). It was observed that sixty-six per cent (66.6%) of the VES points show weak protective capacity, thirteen per cent (13%) show good, thirteen-point five per cent (13.5%) show poor, and six-point six per cent (6.6%) show excellent protective capacity. Most of the VE'S points in the study area exhibit weak protective capacity, indicating that the aquifers are susceptible to contamination. The qualitative use of this parameter is to demarcate changes in the total thickness of low-resistivity materials. Areas classified as poor to weak protective capacity suggest a predominance of sandy or coarse-grained lithology, with limited overlying clay or shale layers that provide natural filtration (Ugbor & Ogbodo, 2023).

D. Transverse Resistance

The transverse resistance of the aquiferous layer in the study area was calculated from the VES data. The transverse resistance values range from 13.169721 Ωm² to 1576.395084 Ωm², with an average value of 794.779 Ωm², indicating a very high groundwater development class (Adeyemo, Omosuyi, & Akinluyi, 2017; Falowo et al., 2023). He stated that values of transverse resistance below 200,000 Ωm² may not necessarily indicate the absence of an aquifer but could imply inadequate aquifer thickness or high mixing of finer sediments within the aquifer.

E. Hydraulic Conductivity (K)

Table I: Aquifer Properties of the Study Area (Dar Zarrouk Parameters)

VES No	Layer Resistivity (Ωm)	Layer Thickness (m)	Longitudinal Conductance (S = σh)	Transverse Resistance (R = he)	Hydraulic Conductivity (m/day)	Transmissivity (m²/day)
1	15.97	13.29	0.8321853	212.2413	29.144606	387.33182
2	67.41	7.7399	0.1148183	521.74666	7.6058578	58.868579
3	13.138	25.196	1.9177957	331.02505	34.965478	880.99019
4	143.95	24.576	0.1707259	3537.7152	3.7479391	92.109352
5	13.183	5.711	0.4332094	75.288113	34.854128	199.05193
6	12.595	4.5851	0.3640413	57.749335	36.369661	166.75853
7	17.947	13.567	0.7559481	243.48695	26.138213	354.61713
8	10.437	3.61	0.3458848	37.67757	43.339028	156.45389
9	149.85	48.7	0.3249917	7297.695	3.6101	175.81187
10	40.759	38.676	0.9488947	1576.3951	12.161085	470.34211
11	49.802	23.33	0.4684551	1161.8807	10.087752	235.34726
12	11.585	6.7582	0.5833578	78.293747	39.319046	265.72598
13	133.78	3.428	0.0256242	458.59784	4.0130597	13.756769
14	26.771	6.0004	0.2241381	160.63671	17.999845	108.00627
15	27.19	3.7816	0.1390805	102.8217	17.740962	67.089224
16	94.495	9.7544	0.1032266	921.74203	5.5503005	54.139852
17	120.69	8.2455	0.0683197	995.1494	4.4176539	36.425765
18	11.86	7.3481	0.61957	87.148466	38.467919	282.66612
19	36.014	15.925	0.4421891	573.52295	13.649412	217.36688
20	9.4347	8.7805	0.9306602	82.841383	47.619136	418.11982
21	23.126	8.3724	0.3620341	193.62012	20.63304	172.74807
22	11.664	4.951	0.4244685	57.748464	39.070571	193.4384
23	9.0148	1.4609	0.1620557	13.169721	49.685015	72.584838
24	16.992	8.5381	0.5024776	145.0794	27.506045	234.84936
25	43.494	3.4873	0.0801789	151.67663	11.446193	39.916309
26	8.0318	5.0587	0.6298339	40.630467	55.335076	279.92355
27	169.08	28.596	0.169127	4835.0117	3.2255653	92.238264
28	92.908	13.862	0.1492014	1287.8907	5.6386889	78.163505
29	22.094	2.9375	0.1329546	64.901125	21.530677	63.246362
30	41.737	3.9887	0.0955675	166.47637	11.895051	47.445789

The hydraulic conductivity of the aquiferous layer in the study area was calculated from VES data to range from 3.225565 m/day to 55.335076 m/day, with an average of 29.28032 m/day. This range is typical of fine- to coarse-grained sands. (day (Ugbor & Ogbodo, 2023; Ishola & Bukar, 2024).

F. Transmissivity (Tr)

Transmissivity values greater than 500 m²/day indicate high potential; 50–500 m²/day, moderate potential; 5–50 m²/day, low potential; 0.5–5 m²/day, very low potential; and less than 0.5 m²/day, negligible potential (Nigeria; Seli,

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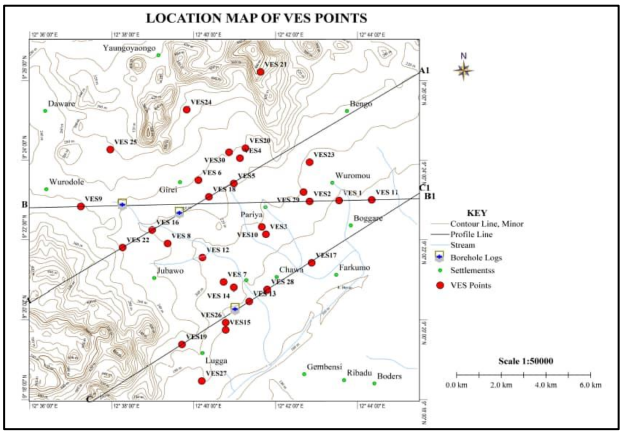
Ankidawa, & Ishaku, 2021). The transmissivity values in the study area range from 13.756 m²/day to 880 m²/day, with a mean of 194.205 m²/day. VES 3 recorded the highest potential (880 m²/day), followed by VES 10 and VES 20 (470 m²/day and 418 m²/day respectively). VES 13 and VES 25 showed the lowest transmissivity (13 and 39 m²/day), indicating moderate groundwater productivity. Approximately 3.3% of VES points indicate high potential, 86.6% moderate potential, and 10% very low potential.

IV. DELINEATION OF AQUIFER SYSTEM

A. Sub-Surface Geo-Electric Section

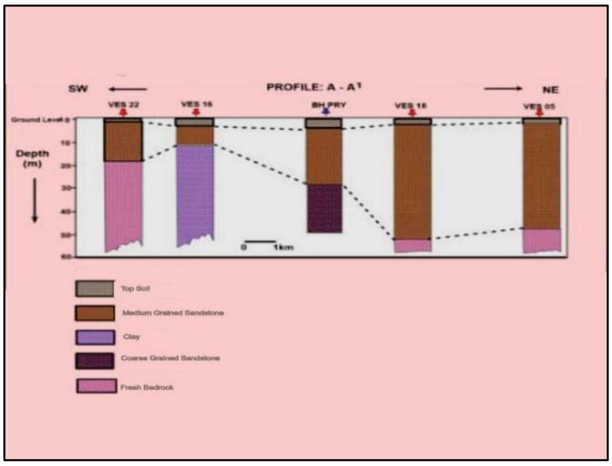
Correlation of geoelectric sections with borehole lithologic logs enhances the reliability of VES interpretations and reduces ambiguity in aquifer delineation. Three lines of sections (A – A', B – B', and C – C') were established in the area of study for the construction of geo-electric sections and lithologic sections Fig.3) [5].



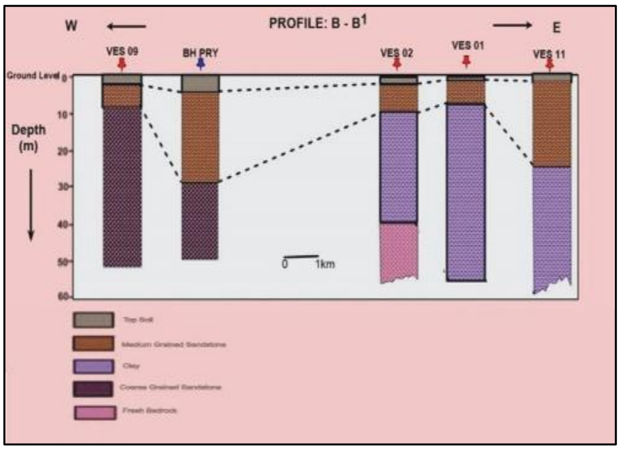
[Fig.3: Topographical Map of the Study Area Showing a Cross-Section of VES Points]

B. Correlation of Geo-electric Section and Lithologic Section

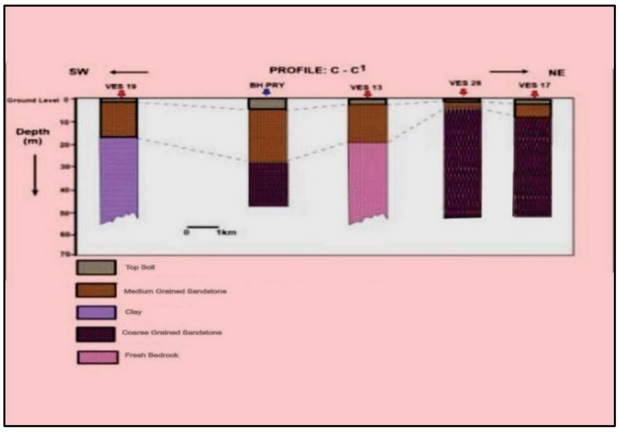
To assess the accuracy of the VES interpretations, soundings were carried out in the proximity of three existing wells. The geo-electric sections were then correlated with the borehole lithologic section along A-A', which connects VES 22, BH1, with VES 16, VES 18, and VES 5 (Fig. 4). The lithological section is characterized by lithology of top soil, and medium to coarse-grained sandstone with total depth of 50 m, and thickness ranging from 2 m to 53 m. Section along B-B' links VES 9, VES 29, BH2, VES 1, and VES 11 (Fig 5). The aquiferous layers (medium- to coarse-grained sandstones) range in thickness from 13 m to 60 m at a depth of about 50 m. The aquiferous layer is the Bima Sandstone, and the aquifer system is delineated as unconfined, with medium-grained sandstone. Section along C-C', which connects VES 19, VES 13, VES 28, BH3, and VES 17 respectively (Fig. 6). The lithological section is characterized by the lithology of top soil and medium to coarse-grained sandstone, which is the aquiferous layer with a total depth of 55 m.



[Fig.4: Correlation of Geoelectric and Lithologic Section Along Profile A – A']



[Fig.5: Correlation of Geoelectric and Lithologic Section Along Profile B – B']



[Fig.6: Correlation of Geoelectric and Lithologic Section Along Profile C – C']

V. CONCLUSION

The assessment of groundwater potential in Pariya and environs using Dar Zarrouk parameters has provided a clear understanding of the subsurface characteristics and aquifer distribution. The geoelectric results revealed that the area comprises an unconfined-to-semiconfined aquifer that serves as the principal groundwater-bearing formation. The variation in longitudinal conductance and transverse resistance values delineates

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areas of differential groundwater potential, ranging from low to high. The protective capacity results indicate that while certain zones have sufficient overburden to prevent contamination, others remain moderately vulnerable due to thin overburden or high-resistivity formations. Generally, the central and northeastern parts of the study area exhibit higher groundwater potential compared to the southern and western portions.

RECOMMENDATION

Regular monitoring of groundwater quality is also recommended in areas of poor protective capacity to prevent contamination from agricultural and domestic activities. Future investigations should integrate geophysical methods with hydrogeochemical and remote sensing analyses to enhance the accuracy of groundwater potential mapping and sustainable water resource planning in the region.

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DECLARATION STATEMENT

As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

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- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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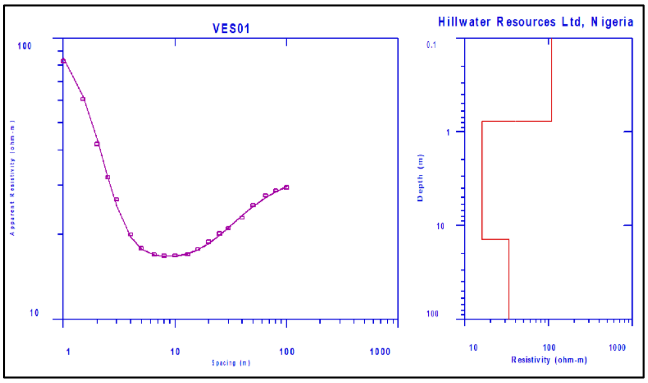
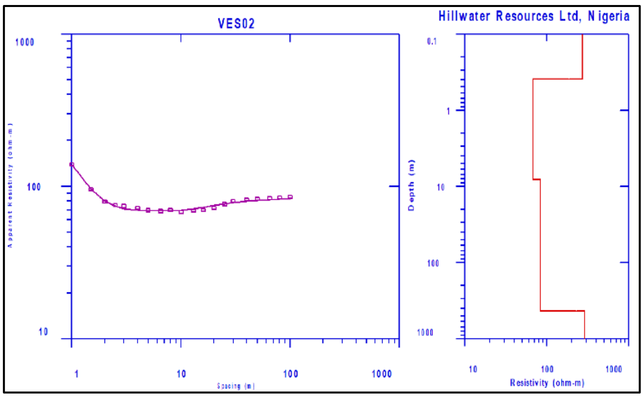
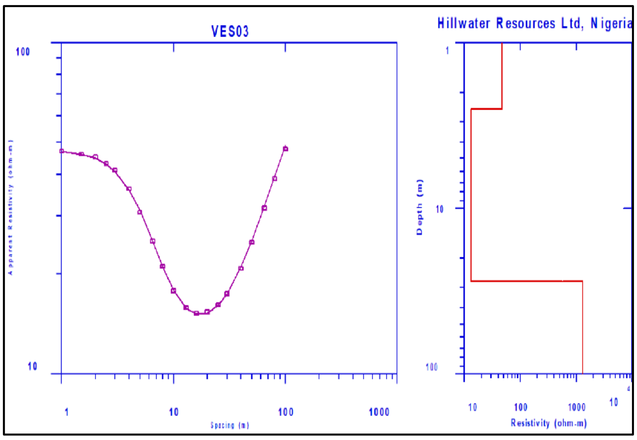
SUPPLEMENTAL DATA

A. Appendix







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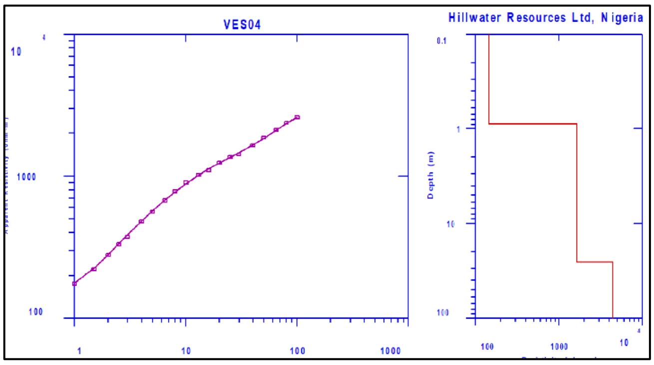

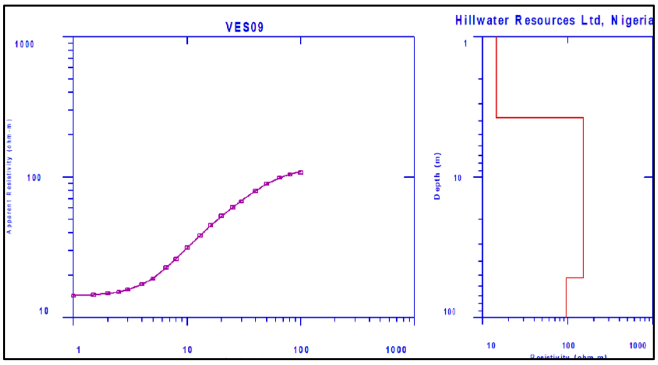

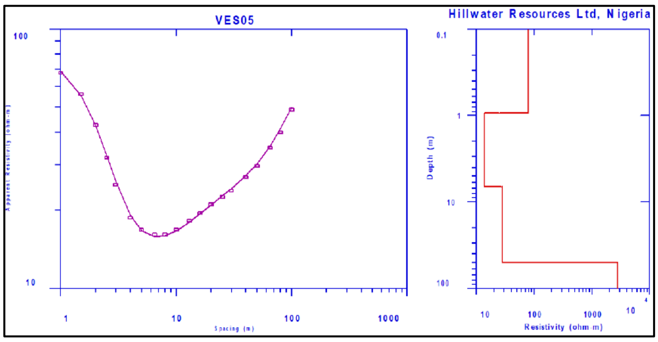

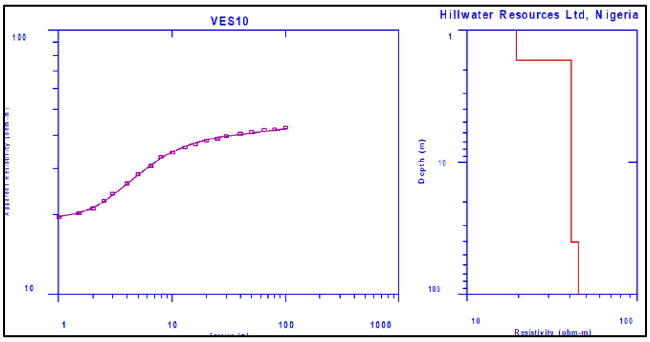

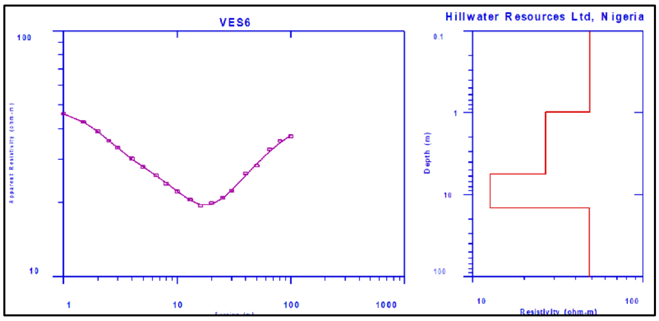

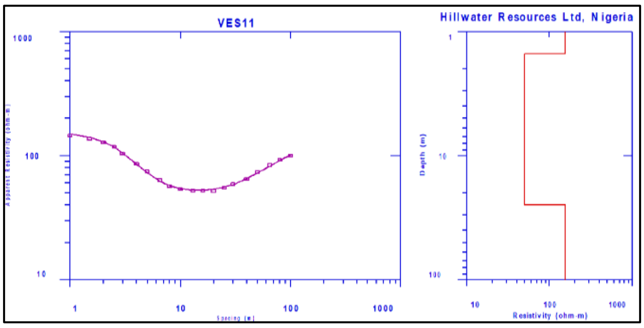

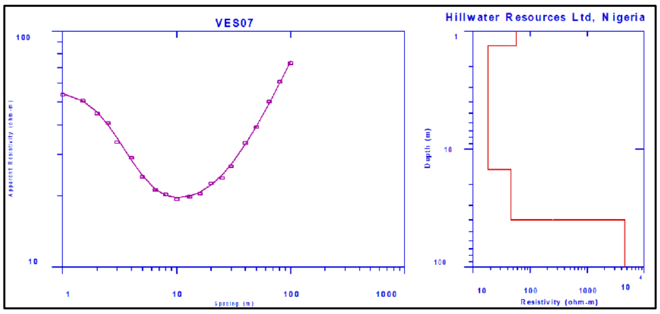

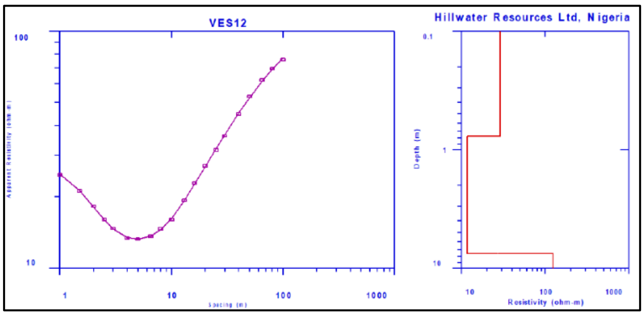

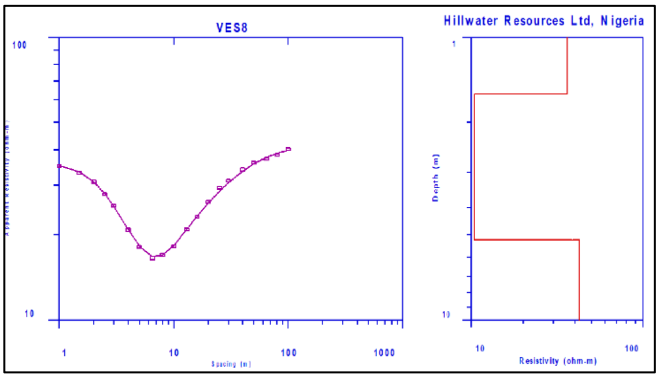

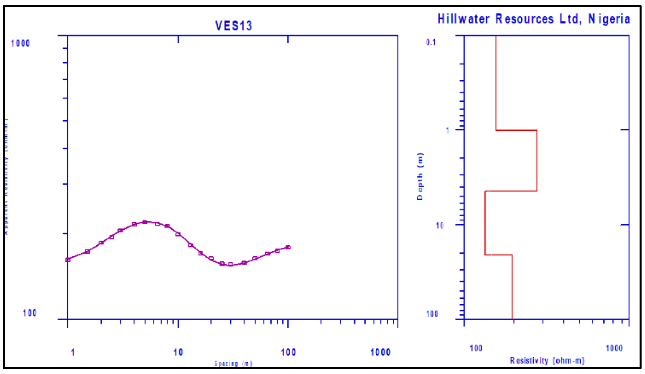

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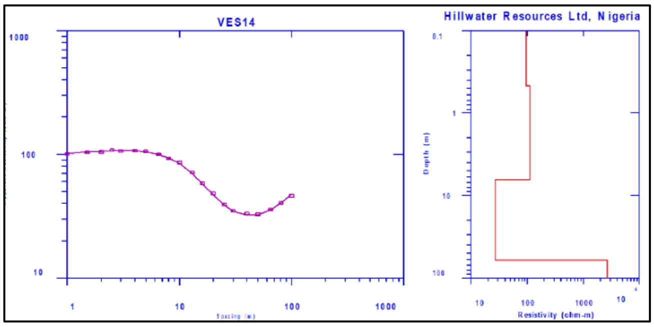
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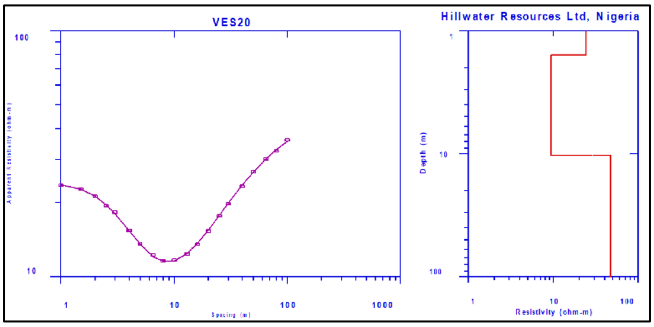
Resistivity (ohm-m)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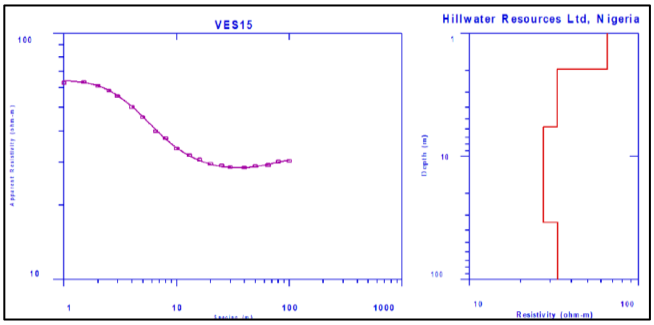
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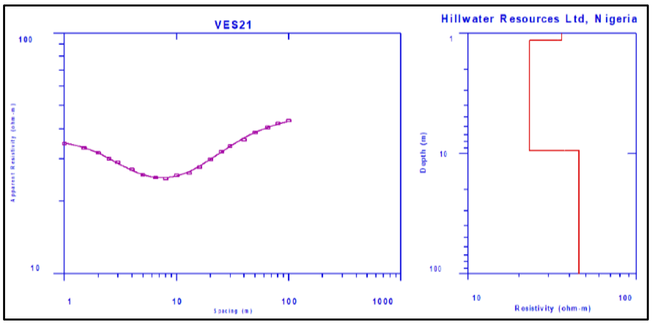
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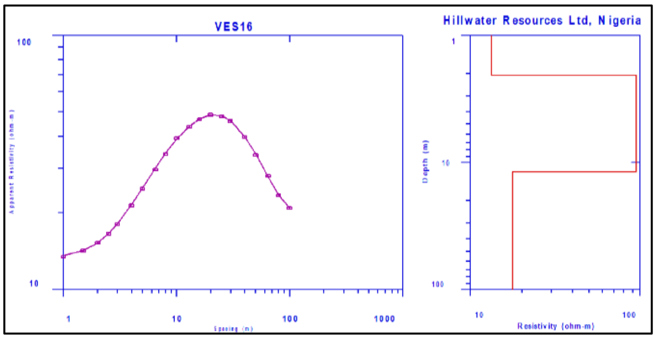
Resistivity (ohm-m)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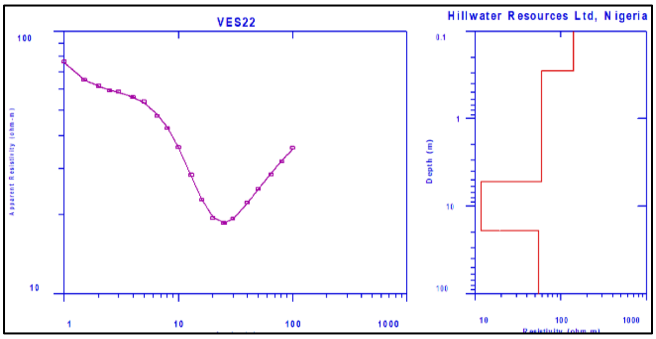
Resistivity (ohm-m)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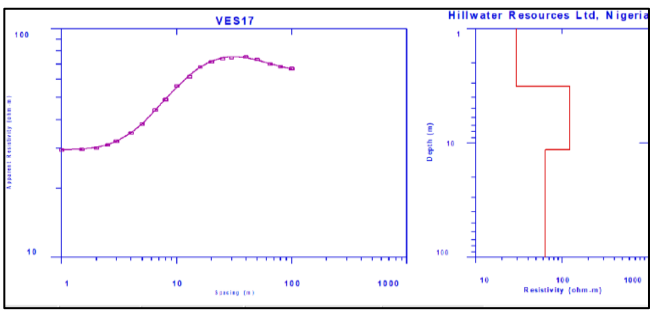
Depth (m)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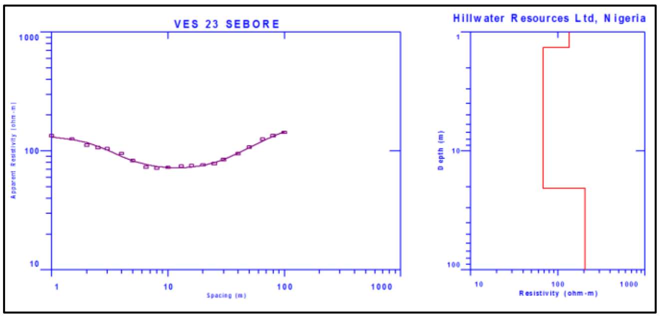
Depth (m)
Resistivity (ohm-m)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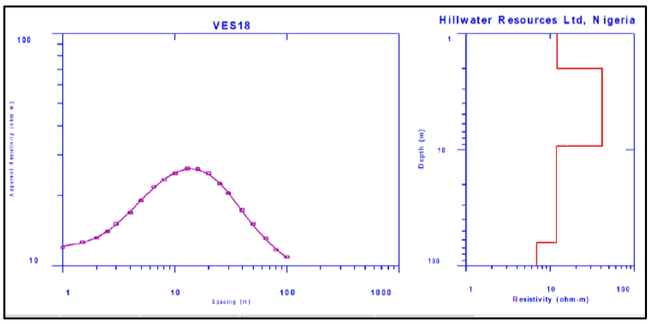
Depth (m)
Resistivity (ohm-m)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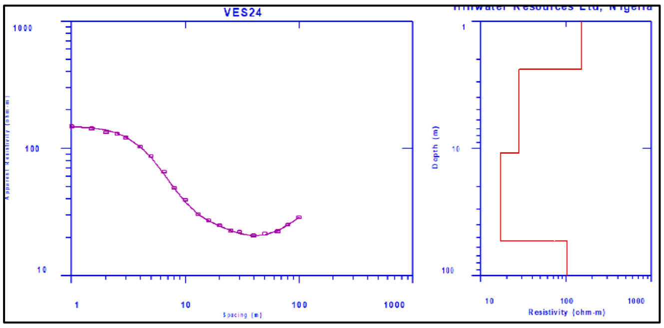
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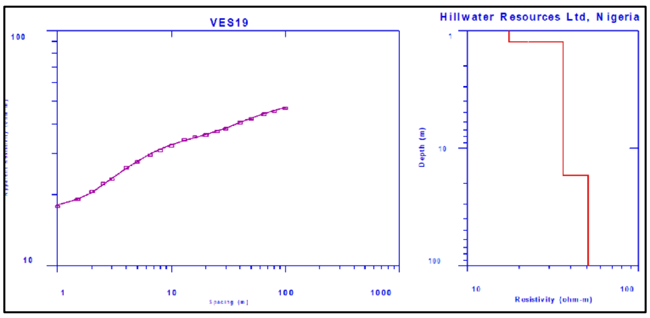
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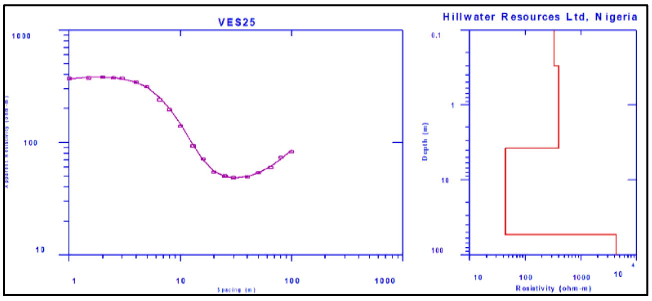

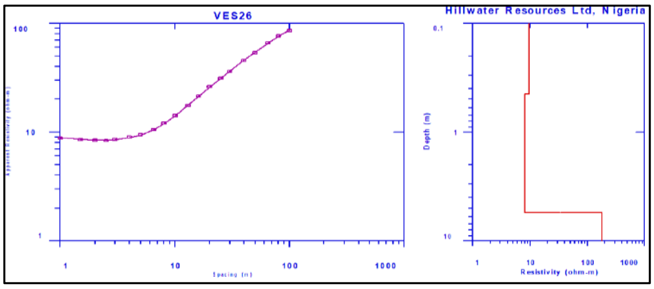

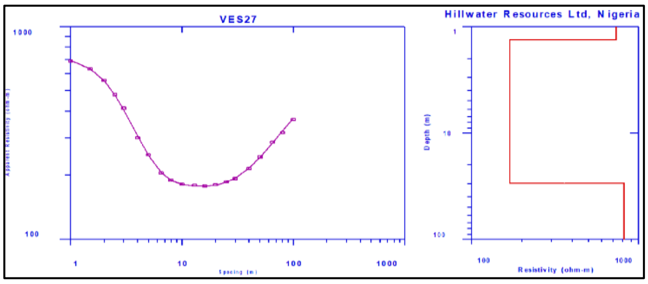

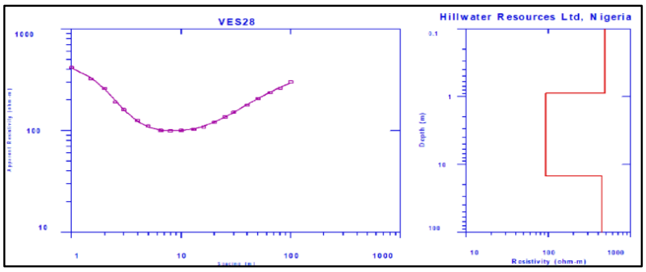

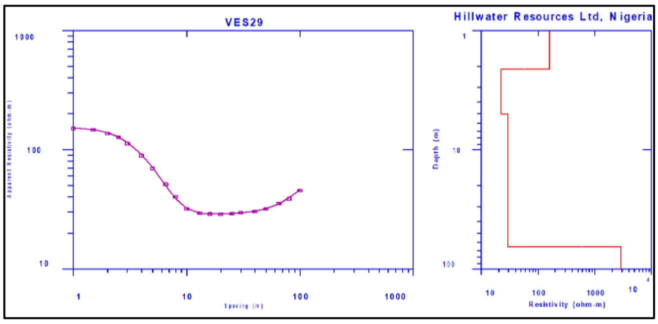

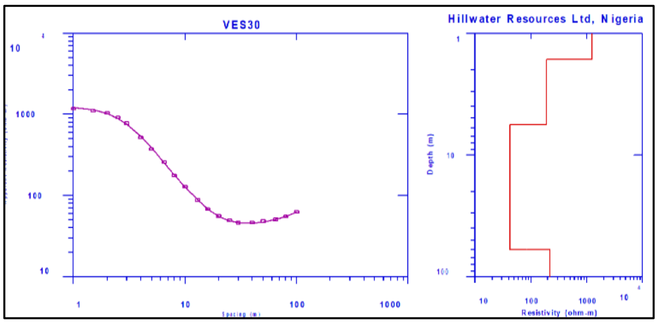

AUTHOR'S PROFILE

Mr. Victor Vitalis is a Nigerian geologist specializing in hydrogeology, engineering geology, and water resources management. He holds a B.Sc. in Geology from the University of Maiduguri and an M.Sc. in Hydrogeology/Engineering Geology from Modibbo Adama University, Yola. He is a Lecturer at Adamawa State University, Mubi, with research interests in groundwater quality assessment and applied geophysics.

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Associate Professor Garba Ali Mohammed holds a PhD in Exploration Geophysics from Curtin University, Australia. He has over fifteen years of experience in teaching and research, with expertise in seismic interpretation, electrical resistivity methods, and groundwater exploration. He is a faculty member at Gombe State University and a member of SEG and NMGS.

Mr. Bello Abubakar Dauda, B. A Dauda, B. Tech, M.Sc, is an indigene of Gombe state, North East Nigeria. He has an academic background in Geology. He acquired his first degree in Applied Geology from Abubakar Tafawa Balewa University and a Master's in Hydrogeology and Engineering Geology from Modibbo Adama University, Yola. He is currently working as a research fellow II in the Geology Department at the Federal University of Dutsin-ma. His research interests include hydrogeology, engineering geology, geophysics, and integrated techniques and interdisciplinary approaches to problem-solving. He has contributed to studies on groundwater potential, water quality and Environmental Impact assessment in Northern Nigeria. He is actively involved in research aimed at using an integrated approach to groundwater potential mapping in hard-rock terrain (using GIS, Remote Sensing, and Electrical Resistivity). Also having five (5) years of teaching experience at the University, contributing his quarter to the development of Nigeria's future leaders in both character and learning.
