

## Evaluation of Groundwater Potential using Vertical Electrical Sounding and Dar Zarouk Parameters in Guyuk and its Environs, Northeastern Nigeria

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### ABSTRACT

Eighteen Vertical Electrical Sounding (VES) points were carried out to evaluate the groundwater potential in Guyuk and its environs, Northeastern Nigeria, using the Schlumberger configuration with a maximum current electrode spacing of 200m to evaluate groundwater potential and aquifer protective capacity. Interpretation of the VES data identified four curve types: H-type (50%), Q-type (22.22%), A-type (16.67%), and HA-type (11.11%). These percentages were calculated by dividing the number of occurrences of each curve type by the total number of VES stations (18) and multiplying by 100. Iso-resistivity contour maps generated at  $AB/2 = 20$  m and 80 m identified two major groundwater-favourable anomalies within the north-western and south-western parts of the study area. The computed Dar Zarouk parameters yielded longitudinal conductance values ranging from 0.001 to 0.87 S, corresponding to weak to good aquifer protective capacity, and transverse resistance values ranging from approximately 1,200 to 19,000  $\Omega\text{m}^2$ , indicating low to high groundwater potential. The highest groundwater potential was associated with VES 7, VES 10, VES 15, and VES 18, where elevated transverse resistance values reflect thick and permeable aquifer units capable of supporting productive groundwater development. Areas characterized by relatively high longitudinal conductance values possess enhanced natural protection against contamination, making them suitable for sustainable groundwater exploitation. Overall, the north-western and south-western sectors were identified as the most favourable zones for borehole development. The integration of VES data with Dar Zarouk parameters provides a reliable approach for aquifer characterization, groundwater exploration, optimal borehole siting, and groundwater-resource management in the study area.

### Keywords:

Guyuk and Environs,  
Groundwater potential,  
VES,  
Aquifer zones,  
Dar Zarouk parameters.

### INTRODUCTION

The study area lies between longitudes  $11^{\circ}55'00''\text{E}$  and  $11^{\circ}58'00''\text{E}$ , and latitudes  $9^{\circ}51'30''\text{N}$  and  $9^{\circ}54'30''\text{N}$ , on topographical map sheet 174 of Guyuk NE (Figure 1), covering a total area of approximately 30.25  $\text{km}^2$ . Groundwater remains the most reliable source of freshwater supply in most parts of northeastern Nigeria, particularly in areas where surface water sources are seasonal and often inadequate. Its importance for domestic, agricultural, and industrial uses cannot be overemphasised, especially in semi-arid environments characterised by low rainfall and high evapotranspiration. The occurrence, distribution, and productivity of groundwater in basement complex and sedimentary terrains are largely controlled by lithology, the degree of weathering, fracturing, and the structural

disposition of the rocks (Olorunfemi, 2009; Amadi & Olasehinde, 2010; Nur & Matazu, 2011).

Geophysical methods, particularly the electrical resistivity method, have been widely applied in groundwater exploration due to their cost-effectiveness, non-invasive nature, and ability to delineate subsurface aquifer systems (Nur & Ayuni, 2011; Oyedele et al., 2009). Vertical Electrical Sounding (VES) has been extensively used for aquifer delineation, estimation of depth to bedrock, evaluation of weathered and fractured zones, and siting of productive boreholes in both basement complex and sedimentary terrains (Nur & Kujir, 2006; Ademilua & Eluwole, 2013).

Although several hydrogeophysical investigations have been conducted in different parts of northeastern Nigeria, including Michika, Fufore, Song, Piu, and Lassa (Nur &

Kujir, 2006; Nur & Ayuni, 2011; Nggada & Nur, 2017; Nur et al., 2021), there is limited information on the groundwater potential, aquifer protective capacity, and subsurface hydrogeoelectrical characteristics of Guyuk and its environs. In particular, no detailed study has integrated Vertical Electrical Sounding data with Dar Zarouk parameters to evaluate groundwater productivity and aquifer vulnerability within the area. This knowledge

gap has contributed to uncertainties in groundwater development, resulting in poorly sited boreholes, low-yield wells, and inefficient utilisation of groundwater resources. Consequently, there is a need for a comprehensive hydrogeophysical investigation to provide reliable information for sustainable groundwater exploration and development in Guyuk.

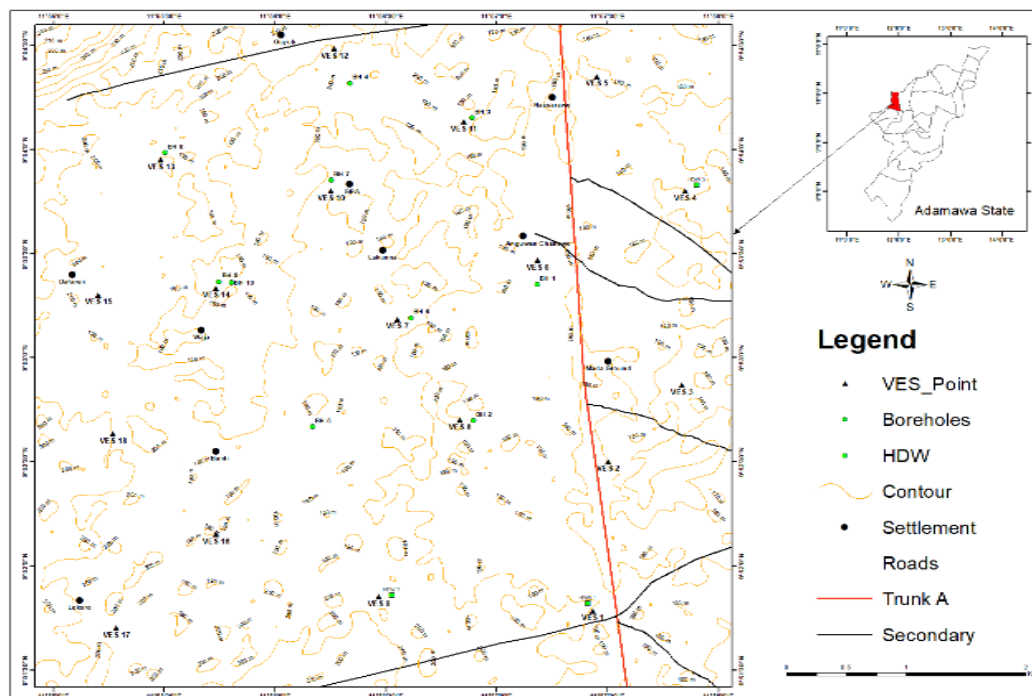


Figure 1: Topographic map of Guyuk and environs showing VES points (modified from NGS, 2011)

In Guyuk and its environs, communities rely mainly on hand-dug wells, boreholes, and seasonal streams for water supply. However, the productivity of these wells and boreholes is often low due to poor siting, inadequate hydrogeological investigations, and the heterogeneous nature of aquifer distribution. By integrating geoelectrical data with Dar Zarouk parameters, this study provides an empirical framework for identifying high-yield aquifer zones, evaluating aquifer protective capacities, and delineating areas vulnerable to contamination. Consequently, the study aims to investigate the groundwater potential of Guyuk and its environs using the Vertical Electrical Sounding (VES) technique.

The findings of this study are expected to support more effective groundwater resource planning, guide the siting of productive boreholes, and minimise failed drilling projects that often result from inadequate subsurface information. Furthermore, the results will serve as a baseline for future hydrogeophysical and environmental studies in northeastern Nigeria, thereby promoting

efficient water resource utilisation and enhancing community resilience to water scarcity.

### Geology and Hydrogeology of the Study Area

The study area, Guyuk and its environs, is situated within the Yola Arm of the Upper Benue Trough in Adamawa State, northeastern Nigeria. It is bounded to the northeast by the basement rocks of the Hawal Massif and to the south by the Adamawa Massif. Accessibility is facilitated by a network of major and minor roads, as well as footpaths linking the local settlements.

Geologically, the area is underlain predominantly by the Cretaceous Bima Sandstone Formation (Carter et al., 1963; Nwajide, 2013), which represents the oldest and most extensively exposed unit in this part of the trough.

The Bima Sandstone consists mainly of coarse to medium-grained sandstones (Dike, 2002), interbedded with shales and clay lenses. These sandstones are generally well-jointed, fractured, and locally weathered, characteristics that enhance secondary porosity and permeability and make them favourable for groundwater occurrence.

Overlying the Bima Sandstone is the transitional Yolde Formation, composed of interbeds of shale, siltstone, and calcareous mudstone. This is succeeded by the Dukul Formation, which predominantly comprises grey shales

with thin silty beds, followed by the Jessu and Numanha Formations. The sequence is finally capped by the Lamja Formation, consisting of poorly to moderately sorted sandstones (Figure 2).

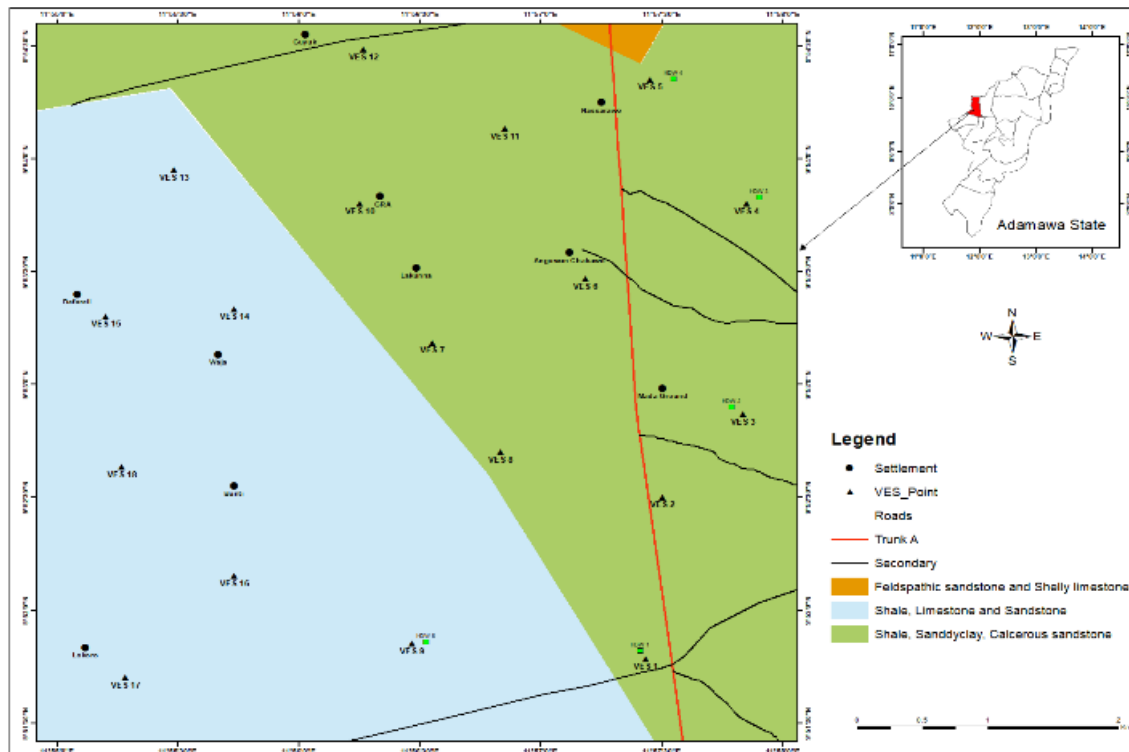


Figure 2: Geological map of Guyuk and environs (modified from USGS, 2022)

The terrain is characterised by low-lying plains interspersed with ridges and gentle undulations. The geological framework—especially the porous sandstones, fractures, and joints—provides suitable conditions for groundwater accumulation and movement. Climatically, the area experiences two distinct seasons: a wet season from late April to October and a dry season from November to March, often accompanied by harmattan conditions. The mean annual rainfall is approximately ranges from 100mm and above, with peak precipitation in July and August (Adebayo, 1999), rainfall is a key contributor to groundwater recharge, influencing both the quantity and quality of groundwater resources (Oniku et al., 2025). Vegetation belongs to the Sudan to Northern Guinea Savannah type, composed mainly of grasses, scattered shrubs, and sparsely distributed trees along stream channels (Offodile, 2002). Groundwater occurrence and recharge are primarily influenced by rainfall, surface infiltration, and geological structures such as fractures and weathered zones (Nur & Ayuni, 2011). The local population depends largely on hand-dug wells, boreholes, and seasonal streams for water supply.

## MATERIALS AND METHODS

The Vertical Electrical Sounding (VES) method, employing the Schlumberger array, was used to investigate subsurface resistivity distribution and delineate potential groundwater zones in Guyuk and its environs. A total of eighteen (18) VES stations were strategically positioned to ensure adequate spatial coverage and to capture both lateral and vertical variability in subsurface materials. Field traverses were oriented approximately along the dominant geological trend and accessible terrain within the study area to ensure adequate coverage of the major lithological units. The Schlumberger configuration was selected because of its sensitivity to vertical variations in resistivity and its proven effectiveness in groundwater investigations.

A maximum current electrode spacing (AB) of 200 m was adopted to achieve sufficient depth of penetration for delineating potential aquifer horizons. The coordinates of each station were recorded using a Global Positioning System (GPS) receiver to allow accurate mapping and correlation with surface geological features.

Field measurements were conducted with an ABEM Terrameter SAS 4000. At each station, the current electrode spacing was progressively increased while the

potential electrode spacing remained relatively small compared to the current spacing. Apparent resistivity values were automatically computed by the instrument and plotted against half the current electrode spacing on a log-log scale to generate field curves. The field curves were visually inspected, and background noise was minimised through appropriate smoothing before inversion. During inversion, initial layer parameters were obtained from partial curve matching and subsequently refined through iterative forward and inverse modelling. Model convergence was assessed using the root mean square (RMS) error between measured and calculated apparent resistivity values. The final interpreted models produced fitting errors ranging from 0.73% to 1.27%, indicating excellent agreement between observed and theoretical curves and confirming the reliability of the derived layer parameters.

Quantitative interpretation of the VES data was carried out using Interpex IX1D and IPI2Win software packages. These iterative forward and inverse modelling tools provided reliable estimates of layer resistivity and thickness, which were subsequently used to compute key geoelectric parameters such as transverse resistance (T) and longitudinal conductance (S) (Nur and Kujir, 2006; Nur et al., 2021). The summary of results obtained from the 18 VES stations is presented in Table 1.

The iso-resistivity maps presented in Figures 3 and 4 (for  $AB/2 = 20$  m and  $AB/2 = 80$  m, respectively) illustrate both lateral and vertical variations in subsurface resistivity across the study area, revealing key hydrogeological features. Iso-resistivity contours, which connect points of equal resistivity ( $\Omega \cdot m$ ), help identify zones of contrasting lithology and moisture content.

In both maps, high resistivity values likely represent coarse-grained sediments such as sand or gravel, while low resistivity values indicate clay-rich or water-saturated formations (Nur and Ayuni, 2011; Yakubu and Nur, 2015).

At shallower depths (Figure 3), the subsurface appears moderately heterogeneous, with closely spaced contours in some regions suggesting rapid lateral changes in material properties. The deeper iso-resistivity map (Figure 4) highlights pronounced high-resistivity zones in the central part of the study area, interspersed with low-resistivity pockets that may correspond to clayey deposits or water-bearing horizons. Collectively, these maps provide a clear understanding of the spatial distribution of subsurface materials, supporting the delineation of potential aquifers, confining layers, and fracture zones.

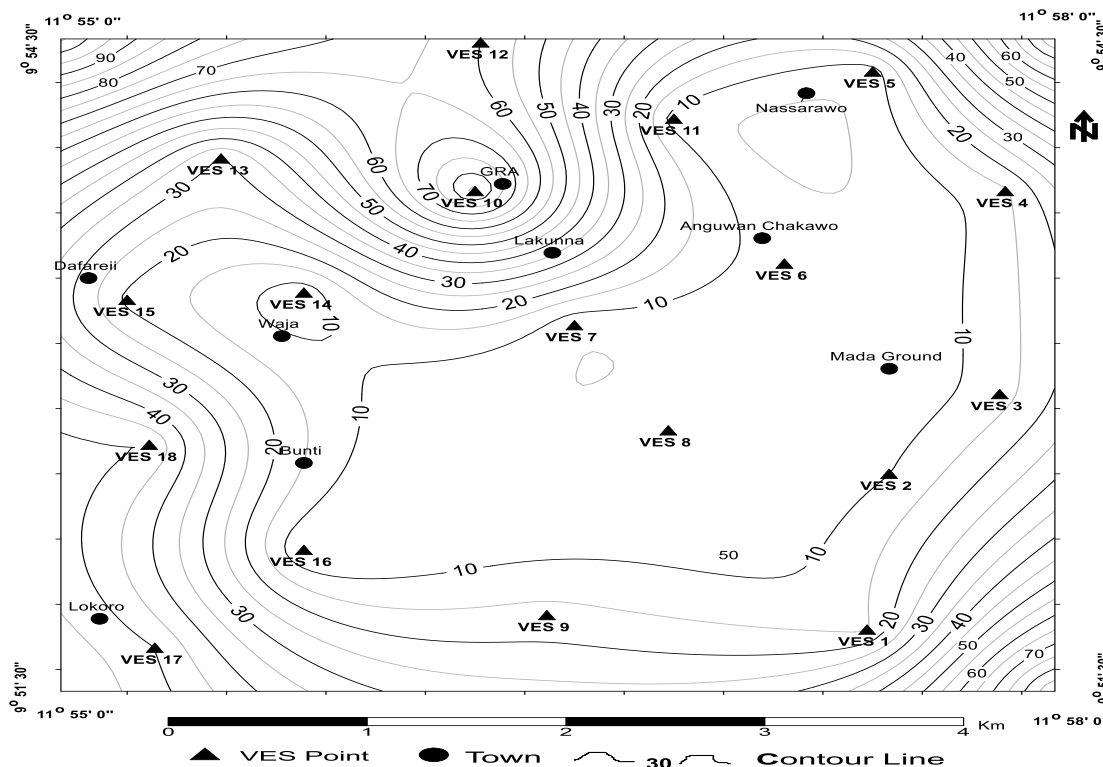


Figure 3: Iso-resistivity contour map for  $AB/2 = 20$  m (Contour interval =  $5 \Omega m$ )

**Table 1: Summary of results obtained from the computer output of the 18 VES stations**

S/N	VES	Layer thickness h1 (m)	h2 (m)	h3 (m)	$\rho_1$ ( $\Omega m$ )	$\rho_2$ ( $\Omega m$ )	$\rho_3$ ( $\Omega m$ )	$\rho_4$ ( $\Omega m$ )	T1	T2	T3	S1	S2	S3	Fitting error (%)	Curve type
1	VES 1	3.09	9.77	—	78.87	18.27	5.53	—	243.9	178.60	—	0.0392	0.535	—	1.00	Q
2	VES 2	0.60	5.07	—	12.87	5.56	15.03	—	7.84	28.21	—	0.0473	0.911	—	0.92	H
3	VES 3	2.48	7.53	—	1.61	301.9	1596.6	—	4.02	2273.7	—	1.53	0.0249	—	1.11	A
4	VES 4	1.29	11.09	—	20.56	9.56	38.74	—	26.57	93.79	—	0.0628	1.02	—	1.02	H
5	VES 5	0.63	4.86	8.89	8.92	2.76	12.72	70.22	5.70	13.44	113.1	0.0715	1.75	0.698	0.92	HA
6	VES 6	1.14	7.60	—	37.26	3.93	16.59	—	42.49	29.93	—	0.0306	1.92	—	0.91	H
7	VES 7	1.48	8.97	—	14.39	5.78	102.9	—	21.35	51.88	—	0.103	1.55	—	1.03	H
8	VES 8	1.87	6.34	—	84.87	21.79	5.39	—	159.30	138.30	—	0.0221	0.291	—	1.27	Q
9	VES 9	3.80	5.80	—	3.98	31.33	1054.2	—	15.16	181.90	—	0.955	0.185	—	0.73	A
10	VES 10	1.09	5.33	—	104.8	52.09	132.4	—	114.80	277.90	—	0.0104	0.102	—	0.80	H
11	VES 11	0.61	12.68	—	25.62	5.77	19.34	—	15.83	73.27	—	0.0241	2.19	—	0.99	H
12	VES 12	2.12	31.44	—	160.4	50.71	215.1	—	340.10	1783.20	—	0.0132	0.554	—	1.13	H
13	VES 13	0.59	4.15	—	6.13	7.33	1397.4	—	3.63	30.45	—	0.0965	0.565	—	1.07	A
14	VES 14	4.80	25.53	59.43	13.56	5.17	3672.7	5626	65.26	132.20	218308.40	0.354	4.920	0.0161	1.01	HA
15	VES 15	2.60	14.22	—	109.3	22.04	2.92	—	285.10	313.50	—	0.0238	0.645	—	1.01	Q
16	VES 16	1.35	10.82	—	14.13	3.53	11.90	—	19.17	38.24	—	0.0959	3.0600	—	0.96	H
17	VES 17	1.27	9.42	—	101.8	37.50	88.74	—	130.10	353.60	—	0.0125	0.251	—	0.98	H
18	VES 18	2.00	5.17	—	119.8	69.21	47.30	—	240.00	358.40	—	0.0167	0.0748	—	0.97	Q
Mean	—	1.79	10.32	34.16	51.05	36.35	468.6	2848	96.68	352.8	109210.75	0.1949	1.14159	0.35705	0.99	—

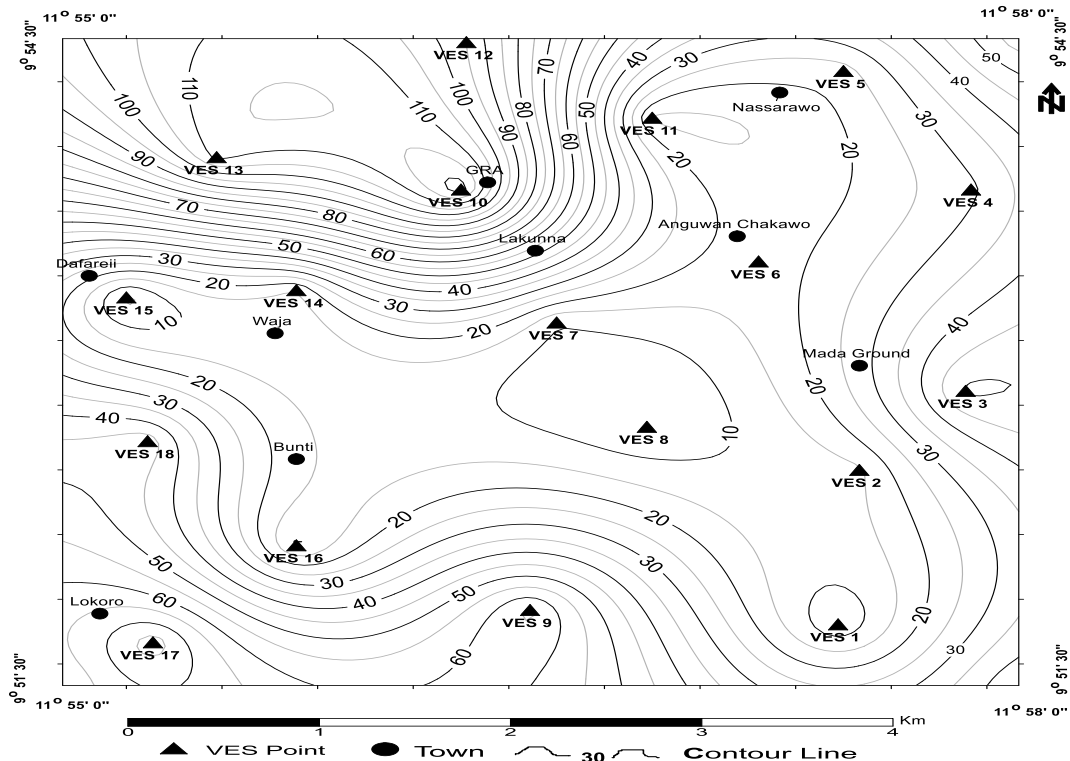


Figure 4: Iso-resistivity contour map for  $AB/2 = 80\text{ m}$  (Contour interval =  $5\ \Omega\text{m}$ )

During the interpretation stage, maps of Transverse Resistance (T) and Longitudinal Conductance (S) were generated from the processed VES data to evaluate aquifer potential and protective capacity across the study area (Henriet, 1976). The Transverse Resistance Map (Figure 5) was used to delineate areas of varying groundwater potential, whereas the Longitudinal Conductance Map (Figure 6) illustrated the protective ability of the overburden materials against surface contamination (Olorunfemi & Fasuyi, 1993).

A contour interval of  $500\ \Omega\text{m}^2$  was adopted for the Transverse Resistance Map to distinguish zones of different groundwater potential. The integration of T and S values formed the basis for hydrogeophysical zonation, helping to identify areas of high, moderate, and low groundwater potential, as well as regions with differing

levels of aquifer vulnerability. This integrated approach provided a reliable and non-invasive means of assessing groundwater resources and guiding sustainable borehole development within the study area. Groundwater potential was evaluated primarily from the transverse resistance (T) values, whereas aquifer protective capacity was assessed using longitudinal conductance (S) values following the classification proposed by Olorunfemi and Fasuyi (1993). Areas characterised by high transverse resistance were interpreted as possessing favourable aquifer thickness and permeability, while high longitudinal conductance values indicate enhanced protection against surface contamination due to the presence of clay-rich overburden materials. The classification scheme adopted for groundwater potential and protective capacity is presented in Tables 2 and 3.

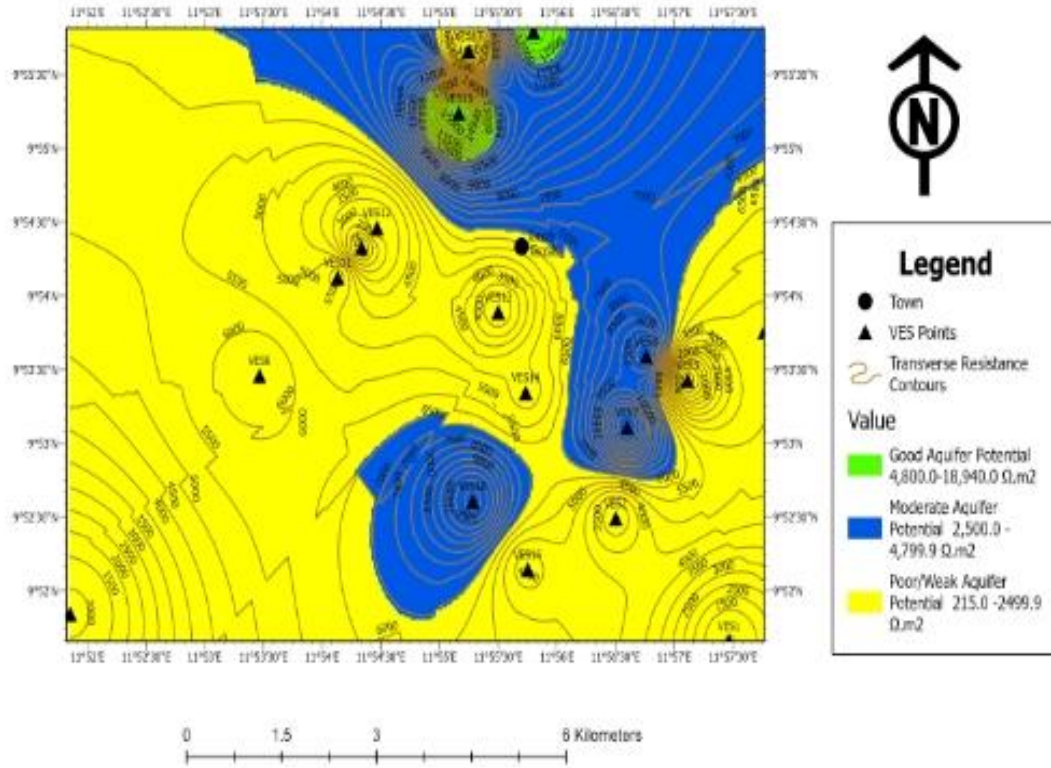


Figure 5: Protective capacity contour map of the study area (contour interval 0.01 Siemens)

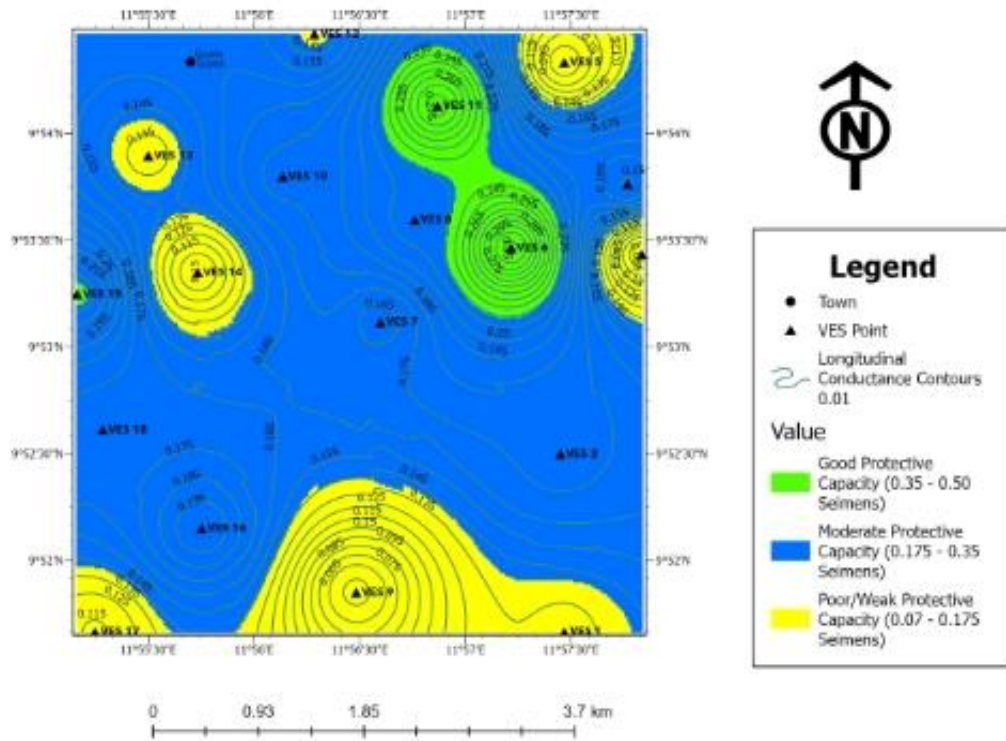


Figure 6: Groundwater potential contour map of the study area (contour interval 500 $\Omega m^2$ )

The Dar Zarouk parameters, derived from the interpreted layer models, were used to further quantify aquifer characteristics across the study area. Transverse resistance (T) and longitudinal conductance (S) were determined from the cumulative contributions of the resistivity layers obtained from the VES data. High T values indicate thick, permeable formations with good groundwater storage capacity, whereas high S values signify clay-rich overburden materials that offer effective natural protection against contamination (Olorunfemi & Fasuyi, 1993; Nggada and Nur, 2017).

The integration of both parameters through T–S classification allowed a simultaneous assessment of groundwater productivity and aquifer protective capacity. Zones exhibiting high T but low S were

interpreted as productive yet vulnerable, requiring careful management, while areas with low T and high S were identified as poorly permeable but well protected. This analytical approach, summarised in Tables 2 and 3, provided a sound framework for correlating aquifer productivity with protective capacity throughout the study area. Although the Groundwater Potential Index (GPI) has been employed in some groundwater assessment studies, the present investigation relied on the integration of Dar Zarouk parameters, iso-resistivity mapping, and T–S classification, which provided sufficient hydrogeophysical information for evaluating groundwater potential and aquifer protective capacity within the study area.

**Table 2: Dar Zarouk parameters and aquifer evaluation**

S/No.	VES No.	Transverse Resistance T ( $\Omega\text{m}^2$ )	Longitudinal Conductance S (S)	Groundwater potential	Aquifer protective capacity
1	VES 1	982.4	0.128	Low	Moderate
2	VES 2	3,146.7	0.174	Moderate	Moderate
3	VES 3	215.6	0.062	Low	Weak
4	VES 4	4,875.9	0.201	Moderate	Good
5	VES 5	1,023.5	0.084	Moderate	Weak
6	VES 6	6,423.8	0.312	Moderate–High	Very good
7	VES 7	12,548.2	0.156	High	Moderate
8	VES 8	3,419.7	0.214	Moderate	Good
9	VES 9	879.3	0.047	Low–Moderate	Weak
10	VES 10	14,376.5	0.183	High	Moderate
11	VES 11	5,682.1	0.284	Moderate–High	Good
12	VES 12	3,212.8	0.133	Moderate	Moderate
13	VES 13	2,658.4	0.126	Moderate	Moderate
14	VES 14	4,803.6	0.091	Moderate	Moderate
15	VES 15	18,940.0	0.226	High	Good
16	VES 16	4,278.9	0.198	Moderate	Moderate
17	VES 17	2,417.2	0.109	Moderate	Moderate
18	VES 18	10,687.5	0.167	High	Moderate
	Mean	4,820.3	0.146	Moderate–High	Moderate

**Table 3: Transverse Resistance and Longitudinal Conductance for Groundwater Evaluation**

S/N	Combination	Combination	Management implication
1	High T + High S	High T + High S	Ideal for groundwater development
2	High T + Low S	High T + Low S	Requires protection and monitoring
3	Low T + High S	Low T + High S	Suitable for limited abstraction and local supply
4	Low T + Low S	Low T + Low S	Not suitable for water supply; may be acceptable for foundation work

## RESULTS AND DISCUSSION

The inversion results and geoelectrical investigation provide a comprehensive view of subsurface structure, aquifer potential, protective capacity, resistivity distribution, and lithological variations across the study area and within Guyuk and its environs. The discussion integrates the Dar Zarouk analysis and the T–S classification, presenting both scientific interpretation and practical guidance. Model fitting errors are

consistently low, ranging from 0.73% to 1.27%, demonstrating a strong convergence between measured and theoretical resistivity curves, which attests to the stability of the field measurements and the reliability of the inversion models (Loke, 2004; Nggada and Nur, 2017). Stations with slightly higher errors were inspected for local noise or acquisition inconsistencies; however, no systematic bias affecting the regional interpretation was observed.

Across most VES stations, three to four geoelectric layers were identified, corresponding to the topsoil, weathered or fractured zones, and fresh basement or consolidated layers. Layer resistivities indicate that the topsoil ranges from 1.61 to 160.4  $\Omega\text{m}$  with thicknesses of 0.6–4.8 m, representing sandy or clayey soils with variable moisture content. The weathered zone exhibits resistivities between 3.5 and 301.9  $\Omega\text{m}$  and thicknesses from 4.15 to 31.44 m, comprising sandy clay, lateritic materials, and partially decomposed basement rocks that serve as an important aquifer horizon. Deeper layers show high resistivity values of up to 5,626  $\Omega\text{m}$ , corresponding to fresh or slightly fractured basement rocks (Olayinka & Barker, 1990).

Curve types obtained from the VES data include predominantly H, A, Q, and HA forms. The H-type curve, which dominates the area, reflects a resistive top layer over a conductive weathered or saturated layer underlain by resistive basement or fractured sandstone, conditions favourable for groundwater accumulation (Nggada and Nur, 2017). The A-type curves indicate thickened consolidated layers, while Q and HA types signify more complex clay-rich or multilayered conditions. The dominance of H-type curves implies that the typical subsurface configuration across much of the study area consists of a resistive surface layer over a conductive weathered or saturated zone underlain by a resistive fractured sandstone or basement unit — a setting favourable for fracture-hosted aquifers where secondary porosity enhances groundwater storage.

Iso-resistivity mapping further supports these interpretations. At  $AB/2 = 20$  m, low resistivity values ( $\leq 50$   $\Omega\text{m}$ ) in the north-western sector around Lakumna indicate clay-rich or water-saturated layers, whereas higher resistivity zones in the central part suggest sandy or lateritic materials. At  $AB/2 = 80$  m, two pronounced anomalies were identified in the north-western (Lakumna–Anguwan Chakawo) and south-western (Lokoro) sectors, with resistivity values ranging from 20  $\Omega\text{m}$  to 123.5  $\Omega\text{m}$ , consistent with fractured and saturated sandstone capable of yielding productive aquifers.

The computed Dar Zarouk parameters reveal significant spatial variation in aquifer characteristics. The highest transverse resistance (T) values were recorded at VES 15 (18,940  $\Omega\text{m}^2$ ), VES 10 (14,376.5  $\Omega\text{m}^2$ ), VES 7 (12,548.2  $\Omega\text{m}^2$ ), and VES 18 (10,687.5  $\Omega\text{m}^2$ ), corresponding to thick, moderately resistive to resistive sandstone formations with high groundwater productivity. In contrast, the highest longitudinal conductance (S) values occurred at VES 6 (0.312 S), VES 11 (0.284 S), and VES 8 (0.214 S), signifying thick clayey overburden materials that enhance aquifer protection.

The hydrogeophysical interpretation is further supported by hydrogeological evidence reported from the same study area. The hydrogeological investigation revealed that productive boreholes are predominantly located

within the north-western and south-western sectors of Guyuk, where thick weathered and fractured aquifer units occur. Borehole logs from these areas indicate the presence of permeable sandstone and fractured horizons with appreciable saturated thicknesses capable of sustaining groundwater abstraction (Baba A.U, Nur A, & Sulaiman A, 2026). These findings correspond closely with the high transverse resistance values identified at VES 7, VES 10, VES 15, and VES 18, thereby providing independent validation of the inferred groundwater potential. The spatial agreement between the hydrogeological and geoelectrical results confirms that aquifer productivity within the study area is strongly controlled by aquifer thickness, degree of fracturing, and lithological characteristics. Furthermore, the hydrogeological study identified groundwater occurrence primarily within weathered and fractured sandstone units, which agrees with the low-to-moderate resistivity anomalies delineated on the iso-resistivity maps. The consistency between the hydrogeological observations and the Dar Zarouk parameter analysis increases confidence in the delineated groundwater potential zones and supports the recommendation of the north-western and south-western sectors as priority targets for future groundwater development.

The mean T and S values of 4,820  $\Omega\text{m}^2$  and 0.146 S, respectively, classify the study area as having moderate groundwater potential and protective capacity, though local variations remain significant. Sites such as VES 3 and VES 9, which display both low T and low S values, are characterised by thin, clayey, or less permeable formations and are therefore poor candidates for groundwater development.

## CONCLUSION

The study demonstrated that the Vertical Electrical Sounding method, supported by Dar Zarouk parameters, is highly effective for delineating groundwater potential and assessing aquifer protective capacity in Guyuk and its environs. The integration of transverse resistance and longitudinal conductance, together with iso-resistivity mapping and T–S classification, provided a detailed and reliable picture of subsurface lithology, permeability, and groundwater yield potential, highlighting critical spatial variations across the study area. Results show that the northwestern and southwestern zones possess thick, permeable formations with high groundwater productivity, while some locations characterised by relatively high longitudinal conductance values benefit from moderate to good natural protection due to clay-rich overburden. Conversely, areas represented by low transverse resistance and low longitudinal conductance values are characterised by low groundwater productivity and higher vulnerability to contamination. These findings establish a robust framework for identifying optimal borehole locations, guiding sustainable groundwater

management, and supporting resource planning in the region.

### RECOMMENDATIONS

Groundwater development should prioritise the north-western and south-western parts of the study area with high aquifer potential, while zones with high transverse resistance but low longitudinal conductance require monitoring and protective measures to prevent contamination, and areas with low T and S values are unsuitable for major abstraction, supporting only limited local supply or foundation assessment. Future projects should integrate VES and Dar Zarouk analyses with hydrogeological and geochemical studies to ensure sustainable yield and water quality, alongside continuous monitoring of aquifer levels to mitigate seasonal fluctuations and overextraction.

### ACKNOWLEDGEMENT

The authors gratefully acknowledge UB Hydrogeological Company for providing the facilities and technical support necessary for this study. Our sincere appreciation goes to the local communities in Guyuk and its environs for their cooperation and for granting access to boreholes and wells during the fieldwork.

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