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ASSESSMENT OF GROUNDWATER POTENTIAL USING DAR ZARROUK PARAMETERS IN THE BASEMENT COMPLEX TERRAIN OF JALINGO, NORTHEASTERN NIGERIA

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ABSTRACT

Access to reliable groundwater resources is critical in the crystalline basement complex regions of Jalingo, north-eastern Nigeria, where surface water availability is limited and seasonal. Despite the increasing dependence on groundwater, challenges persist in accurately identifying productive zones due to the complex and variable nature of the subsurface. This study seeks to address the gap in hydrogeological information and improve borehole siting strategies through the application of Dar Zarrouk parameters. The objective of this research is to evaluate groundwater potential within the Jalingo basement terrain using geophysical techniques, particularly vertical electrical sounding (VES), with a focus on the interpretation of Dar Zarrouk parameters—namely, longitudinal conductance and transverse resistance. A total of 15 VES surveys were carried out using the Schlumberger array configuration. The field data were analysed through a combination of manual curve matching and 1D computer-based inversion. These results provided resistivity and thickness values for subsurface layers, which were then used to derive the relevant Dar Zarrouk parameters. These parameters served as indicators for assessing aquifer capacity and protective characteristics. The interpretation of the data revealed that the area is dominated by weathered and fractured basement rock, with significant spatial variability in aquifer potential. Zones characterized by longitudinal conductance values exceeding 1.0 siemens (S) were considered to have good aquifer protection, while areas with transverse resistance above 1000 ohmmeter squared (Ωm²) were identified as favourable for groundwater development. Based on these findings, it is recommended that future groundwater development efforts in the Jalingo area prioritize locations exhibiting high conductance and resistance values. In addition, integrating these results with remote sensing data, lineament mapping, and hydrogeological information is suggested to improve the accuracy of groundwater exploration and resource management in the region.

Keyword: VES, Basement Complex, Groundwater, Aquifer, Transverse resistance, Longitudinal conductance, Jalingo

1 INTRODUCTION

The Jalingo area, located in north-eastern Nigeria, is predominantly underlain by crystalline rocks of the Precambrian Basement Complex, which represents some of the oldest geological formations in the country. These rocks form part of the eastern extension of the Nigerian Basement Complex, lying adjacent to the Upper Benue Trough, a major structural depression that has influenced tectonic and sedimentary processes in the region [1, 2]. Groundwater resources in basement complex terrains are often difficult to exploit due to the crystalline nature of the rocks, which have negligible primary porosity. However, secondary porosity resulting from fracturing and weathering makes groundwater accumulation possible [3, 4]. In Jalingo, where population growth and climate variability intensify pressure on water resources, groundwater remains a primary source for domestic and agricultural use. These structural elements are remnants of the intense tectonic activity during the Pan-African Orogeny and are critical in controlling groundwater flow and mineralization in the area [5, 6]. Weathering and fracturing have enhanced the permeability of these crystalline rocks, thereby supporting groundwater accumulation in secondary aquifers, especially within the regolith and fractured zones [2, 6]. This study applies geophysical techniques to delineate potential groundwater zones in Jalingo. It builds upon previous works in similar terrains across Nigeria [5, 7] emphasizing structural controls on groundwater occurrence and accessibility. The use of Dar Zarrouk parameters derived from VES has become an effective approach to characterize aquifer properties and assess protective capabilities of overburden layers [8, 9].

2 Study Area

Jalingo, the capital of Taraba State, lies on latitude 8°.80^{1}N- 9$^{0.}$00^{1}N and 11^{0}.25^{1}E – 11^{0}.45^{1}E within the basement complex of northeastern Nigeria (Figure 1). The terrain is underlain by Precambrian granitic and gneissic rocks, weathered, and fractured at various depths. The area experiences a tropical wet-and-dry climate, with annual rainfall ranging from 900–1200 mm. Groundwater occurs predominantly within weathered zones and fracture systems.

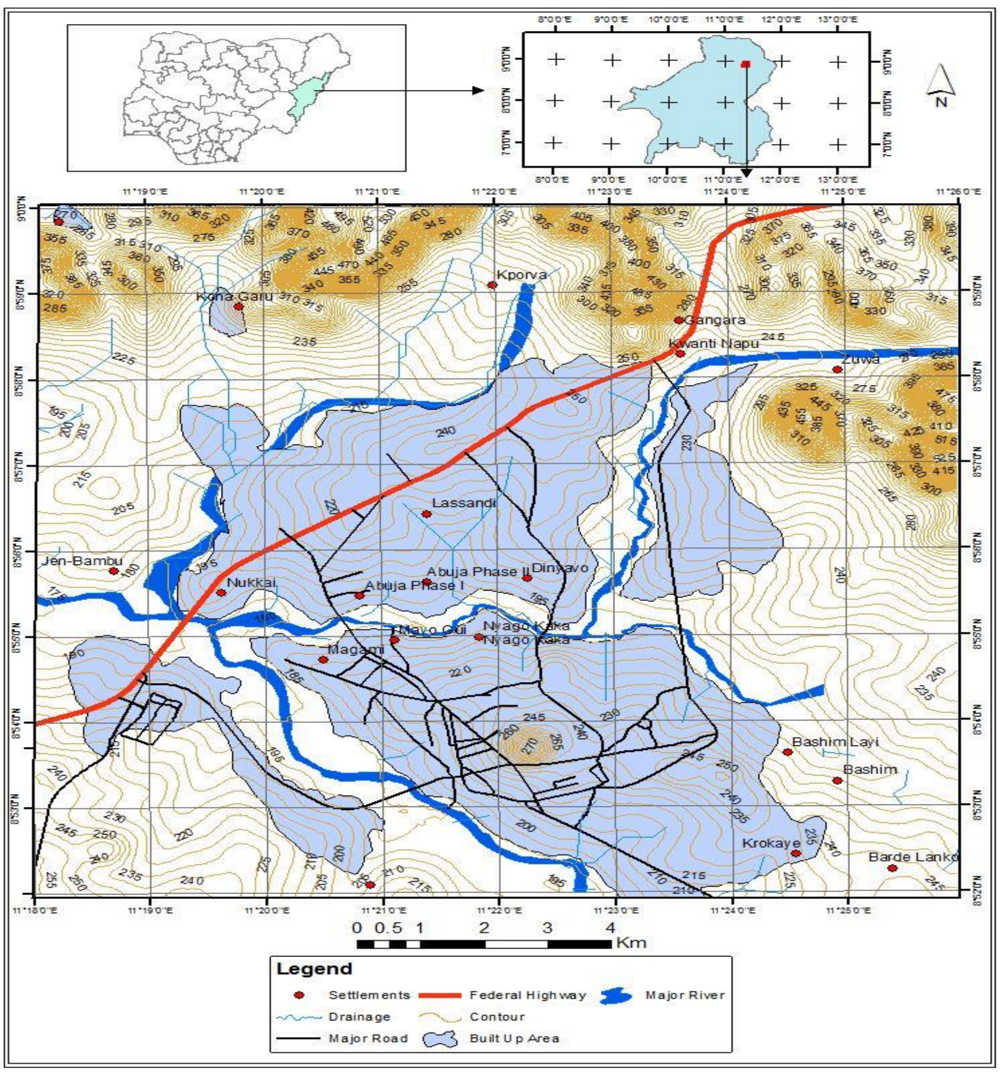

Figure 1. Map of the study area [8]

2.1 Geological and Hydrogeological Setting

Jalingo lies within the northeastern part of the Precambrian Basement Complex, which consists predominantly of migmatite-gneiss, granite, and quartzite intrusions [2]. Nigeria Geological Survey Agency [10]. The basement is characterized by limited aquifer units, often confined to weathered and fractured bedrock zones. The main lithological components of the basement rocks in this area include migmatite-gneiss complexes, schist belts, and Older Granites. (Figure 2). The migmatite-gneiss units are composed of highly deformed and foliated metamorphic rocks, considered to be the oldest rock types, and have undergone multiple episodes of deformation and metamorphism. These are intruded by the Older Granites, which are coarse-grained granitoids emplaced during the Pan-African orogenic event, estimated to have occurred around 600 million years ago [1]. The tectonic structure of the Jalingo basement terrain is marked by fractures, faults, and folds, primarily trending NE–SW and NW–SE. Though primarily crystalline, the Jalingo Basement Complex's proximity to the Upper Benue Trough has geological implications, including the reactivation of faults and the occurrence of economic mineralization. The area is known for hosting gold, baryte, and lead-zinc deposits, often associated with structurally controlled quartz veins within the basement rocks [11]. The topography is undulating, with elevations between 300 and 600 m above sea level. Seasonal rainfall and highly variable recharge patterns contribute to the heterogeneous nature of groundwater occurrence. The major hydrogeological units include Weathered zones, Fractured bedrock aquifers and Lateritic overburden, acting as a perching layer in some zones. In hydrogeological terms, geophysical investigations such as Vertical Electrical Sounding (VES) have revealed that the weathered and fractured basement zones provide the most promising aquifer systems, while fresh basement remains generally impermeable and unsuitable for water storage [6].

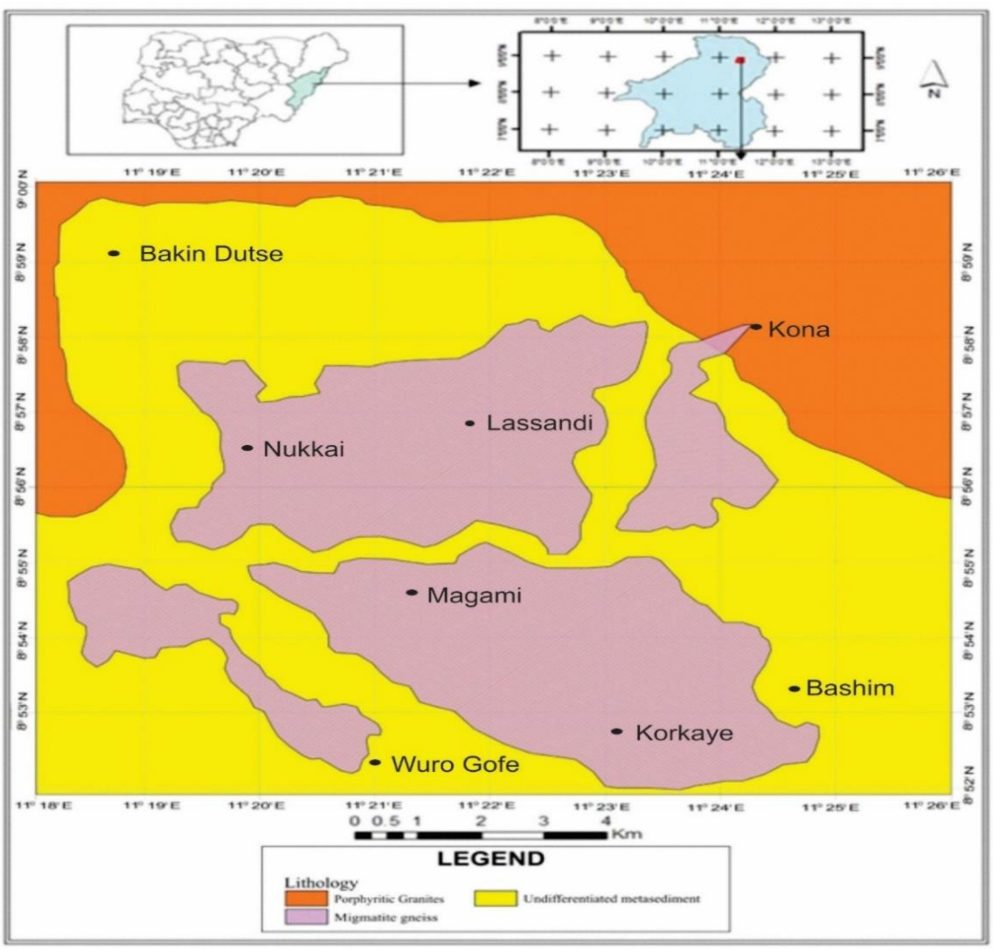

Figure 2. Geological Map of the Study Area [12]

3 MATERIALS AND METHODS

3.1 Geophysical Survey

Total of 15 VES points were surveyed using the Schlumberger array configuration. Interpretation involved curve matching and computer-assisted 1D inversion using WinResist software. Parameters derived include layer resistivity, thickness, and depth to basement.

3.2 Data interpretation

Data were interpreted using partial curve matching and 1D inversion techniques. For some geoelectric layer, resistivity (ρ) and thickness (h) were determined, as well as Dar Zarrouk parameters were computed: Transverse Resistance (T): Longitudinal Conductance (S): Total Transverse Resistance: Total Longitudinal Conductance (Table 1). Aquifer Parameters were estimated using empirical relations for fractured basement aquifers [13].

4 RESULTS AND DISCUSSION

4.1 Resistivity Profiles VES results

Resistivity Profiles VES results revealed geoelectric layers (Figure 3) (weathered and fractured bedrock) showing moderate resistivity (121–300 Ωm), indicative of saturated zones. Depths to basement ranged from 3–10.9 m, suggesting moderate groundwater potential (Table 1). [14] used geoelectrical sounding and Dar Zarrouk calculations to characterize groundwater-bearing formations. He observed that higher conductance values corresponded to thick weathered zones, offering natural protection to underlying aquifers. [15] used VES and Dar Zarrouk parameters in hard rock terrain to assess groundwater potential and protective capacity, concluded that zones with high transverse resistance (>1000 $\Omega \cdot m^2$) indicated significant groundwater prospects. Resistivity sounding data, provide a cost-effective approach to delineating groundwater-bearing zones and estimating aquifer protective capacity [16]. [17] applied the method to identify fractured zones and found that transverse resistance showed strong correlation with well yields, while high longitudinal conductance corresponded to clayey overburden zones. [18] examined aquifers within volcanic and basement terrains. Their findings showed strong agreement between high T values and well yields and confirmed the use of longitudinal conductance in identifying pollution-sensitive zones. Recent studies have used Dar Zarrouk parameters in conjunction with remote sensing and GIS to model aquifer vulnerability in fractured granitic terrains [19] and employed Dar Zarrouk models to locate zones with transverse resistance exceeding 2000 $\Omega \cdot m^2$, highlighting areas favourable for borehole drilling.

4.2 Dar Zarrouk Parameter Evaluation

VES locations with high transverse resistance ($T > 1000\ \Omega m^2$) were inferred to possess high groundwater yield due to thicker saturated zones and fractured basement rocks. Longitudinal conductance (S) values ranged from 7.86 to 60mhos; values >0.7 mhos indicate good protective capacity (thick clayey or weathered overburden), whereas values <0.1 mhos suggest vulnerability to pollution.

Table 1. VES Points and Dar-Zarrouk Parameters in Jalingo

S/NO	VES POINTS	Location	Lat (^{0}N)	Long (^{0}E)	ρa (Ωm)	Thickness h (m)	T= ρ.h Ωm^2	S= ρ/h
1	VES 1	ABBARE	8.91	11.32	121	7.1	859.1	17.042
2	VES 2	ABUJA WARD	8.92	11.34	90	10.9	981	8.256
3	VES 3	KONA	8.93	11.35	106	5.0	530	21.200
4	VES 4	YAMUSALA	8.95	11.36	87	9.0	783	9.667
5	VES 5	K/ YELWA	8.94	11.41	130	8.5	1105	15.294
6	VES 6	SANTALI	8.96	11.42	90	10.8	972	8.333
7	VES 7	S/GARI	8.96	11.40	115	3.0	356.5	38.333
8	VES 8	W/ SEMBE	8.95	11.37	60	3.1	186	19.355
9	VES 9	T/WADA	8.97	11.42	144	4.0	576	36
1	VES 10	MANGA	8.98	11.49	300	5.0	1500	60
1	VES 11	BARADE	8.98	11.33	55	7.0	385	7.86
1	VES 12	DOROWA	8.90	11.66	59	6.5	383.5	9.077
1	VES 13	SAURARA	8.98	11.43	50	5.2	260	9.62
1	VES 14	HAMDELA	8.97	11.47	89	4.1	364.9	21.710
1	VES 15	MUDIBBO	8.91	11.33	120	6.3	756	19.05
1		Ranged				3.0-10.9	186-1500	7.86-60

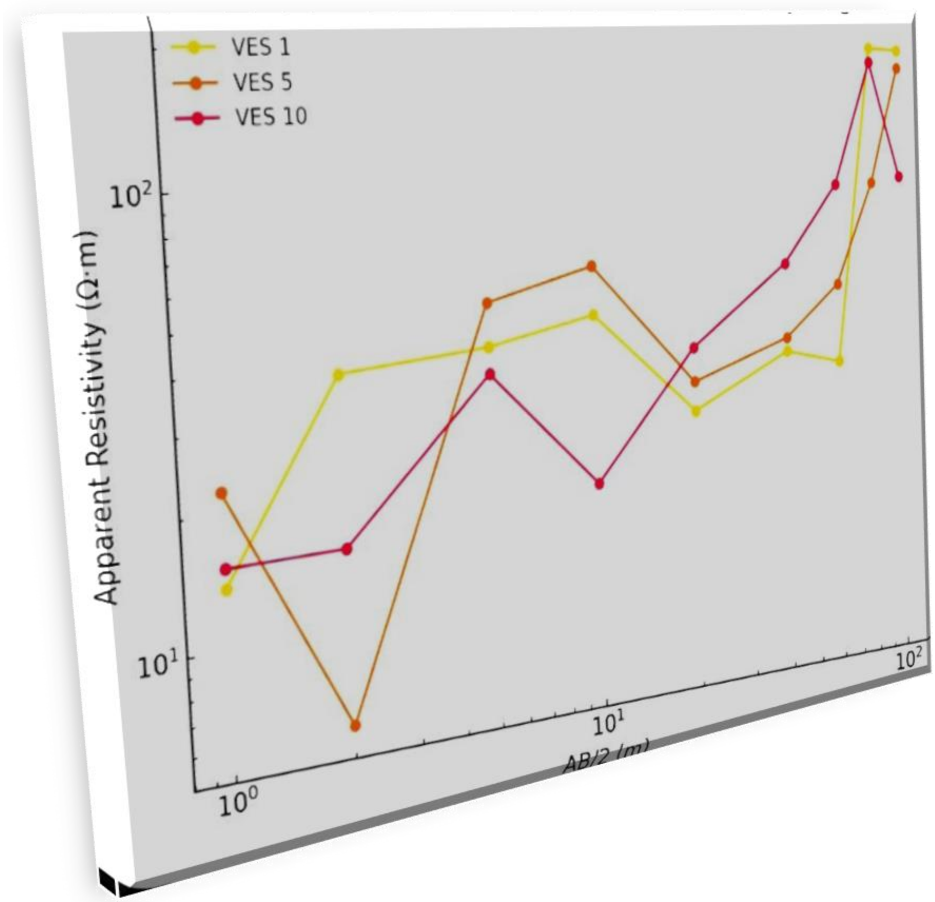

Figure 3. VES Sounding Curves

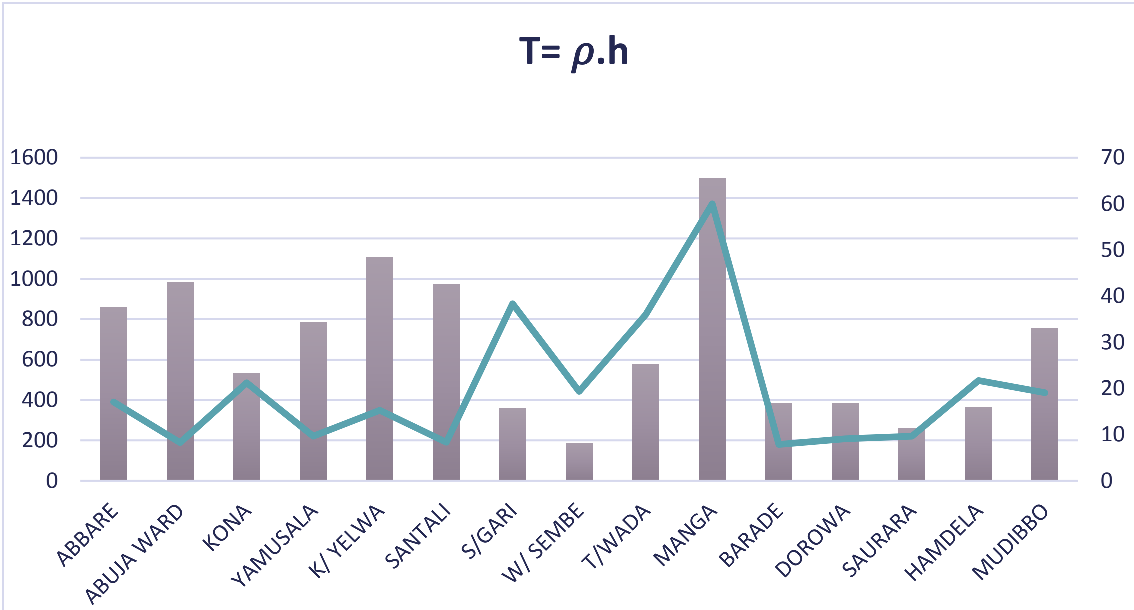

Figure 4. Cluster bar of Transverse resistance

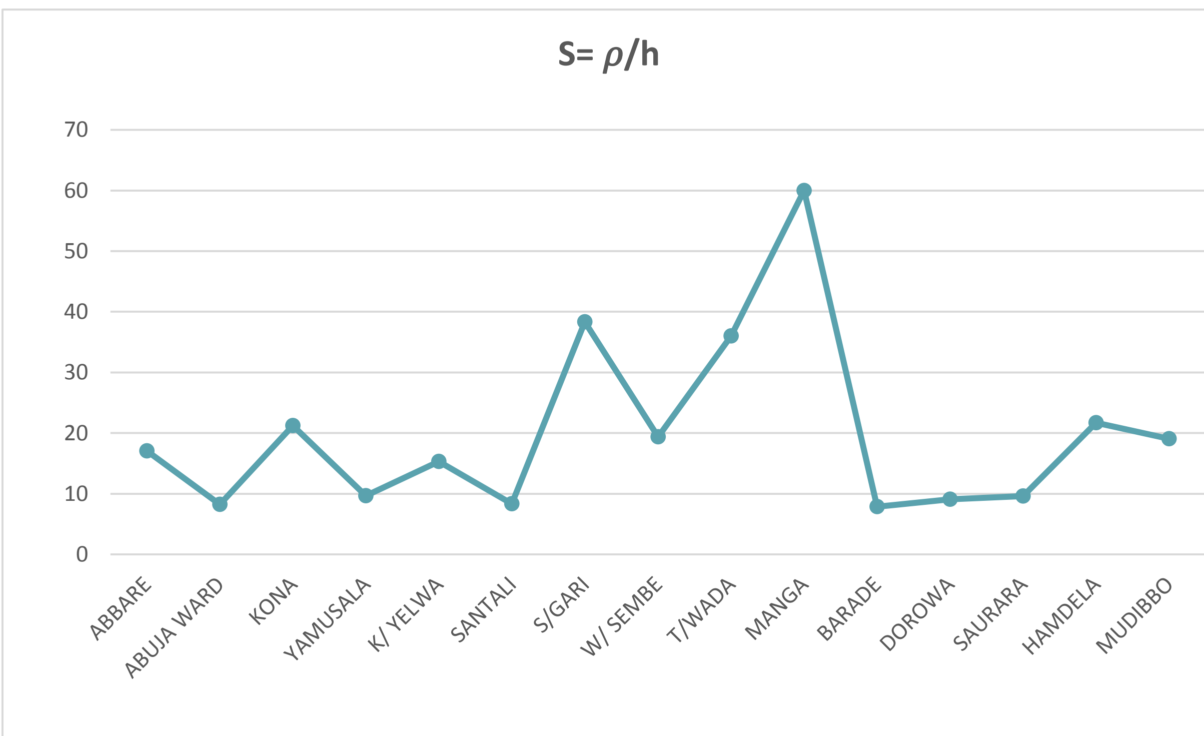

Figure 5. Longitudinal conductance line Graph

Lineament Analysis High lineament density correlated with known borehole yields, reinforcing the importance of structural control in groundwater exploration. Major lineaments trend NE-SW and NW-SE, consistent with regional tectonic fabrics. Hydrogeological Characteristics Pumping test data yielded transmissivity values between 0.8 and 13.1m²/day, typical of fractured basement aquifers (Table 2). From the result obtained well 2,4,8, Shows low yield well and poor yield at well 14 while 1,3,6,7,9,10,13 and15 with high yield also 5 and 12 are of moderates yields with higher yields in zones where fractures intersect weathered profiles [20].

Table 2. Pumping test Result for Locations 1-15 of the Study Area

S/N	Depth of Well(M)	Static Water Level (Swl)(M)	Pumping Rate(M^3/Hr)	Draw Down (M)	Specific Capacity (M^3/Hr/)	Transmisivity (M^2/Day)	Storativity
1.	41	9.6	3.0	11.0	0.31	4.6	1.2 X10-^{3}
2.	37	6.4	1.1	8.7	0.12	2.0	5.0 X 10^{-3}
3.	57	10.0	5.9	6.7	0.91	10.6	3.0 X 10^{-3}
4.	34	7.1	1.2	11.0	010	1.9	5.0 X10 $^{-4}$
5.	55	8.3	2.7.	8.7	0.32	5.1	1.4 X 10 $^{-3}$
6.	67	12.2	7.0	5.3	1.20	9.8	3.1 X 10 $^{-3}$
7.	47	10.1	3.6	7.7	0.50	7.0	1.5 X 10 $^{-3}$
8.	33	6.0	0.9	11.2	0.10	1.3	4.0 X 10 $^{-4}$
9.	58	10.0	3.8	6.8	0.58	8.3	2.6 X 10 $^{-3}$
10.	74	12.5	5.9	5.1	1.13	11.2	3.6 X 10 $^{-3}$
11.	28	4.0	0.7	9.1	0.07	0.8	2.9 X 10 $^{-4}$
12.	49	6.8	3.1	6.2	0.43	5.5	1.3 X 10 $^{-3}$
13.	66	11.0	5.8	5.8	0.90	9.7	3.2 X 10 $^{-3}$
14.	27	4.0	0.7	8.4	0.09	1.2	4.6 X 10 $^{-3}$
15.	21	1.6	7.6	4.7	1.50	13.1	4.2 X 10 $^{-3}$
16.	Range	1.6 -12.5	0.7-7.6	4.7-11.2	0.1-1.5	0.8-13,	

5 CONCLUSIONS

This study demonstrates the effectiveness of geophysical methods for groundwater exploration in basement complex terrains. In Jalingo, favorable groundwater zones are largely associated with weathered-fractured interfaces and high lineament density areas. The use of Dar Zarrouk parameters provided valuable insights into groundwater potential zones within the basement complex of Jalingo. Locations with high transverse resistance and moderate to high conductance values represent promising aquifer zones with varying degrees of natural protection. These findings support the use of VES and resistivity-derived parameters in groundwater exploration and management, especially in basement complex terrains. The approach can guide sustainable borehole siting and reduce the risk of dry wells.

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