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Research Paper

Geoelectric Evaluation of Groundwater Potential and Aquifer Vulnerability of Overburden Aquifers of Ado-Ekiti, Southwestern Nigeria.

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ABSTRACT: *Groundwater resources are crucial for the socio-economic development of regions with seasonal surface water sources. Characterization of groundwater aquifers typically involves assessing groundwater potential and vulnerability. This study utilized 40 Vertical Electrical Sounding (VES) measurements with a Schlumberger array to characterize the basement aquifers of Ado-Ekiti, Southwest Nigeria. The interpretation of the data was effected using IPi2Win and Interpex (IX1D). The findings reveal four geoelectric layers in 67.5% of the study area and five layers in 32.5%. The five identified layers include topsoil (0.24-21m; 0.97-327.76 Ωm), clay/laterite (0.89-4.43m; 6.22-368.07 Ωm), weathered basement (0.32-117.3m; 9.73-5705 Ωm), fractured basement (0.58-46.94m; 1.64-2200.2 Ωm), and fresh unweathered basement (23.47-48502 Ωm). Aquifer layers, consisting of weathered and fractured basement, have thicknesses ranging from 0.9 to 134.4m, while the protective layers of topsoil and clay range from 0.2 to 21.1m. 52.5% of the study area exhibits good groundwater potential, with hydraulic conductivity and transmissivity ranging from 0.3 to 53.7m^2/day and 41.7 to 4280.4m^2/day, respectively. Groundwater potential in the study area is classified based on the depth to the basement, with 17.5% of the area rated as negligible (depth < 10 m), 30% as low (10–20 m), 32.5% as moderate (20–30 m), and 20% as good (depth > 30 m). This indicates that 52.5% of the study area exhibits moderate to good groundwater potential, even when considering saprolite and fracture characteristics. Geoelectric cross-sections identify areas of high groundwater potential in valleys filled with weathered material. Longitudinal conductance ranges from 0.07 to 8.99 mho, with 70% of the area classified as poorly to very poorly protected, suggesting that localized management strategies may be necessary to prevent aquifer contamination.*
KEYWORDS: *Aquifer, Vulnerability, Longitudinal Conductance, Transmissivity, groundwater*

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I. INRODUCTION

Groundwater serves as an important resource for domestic, industrial and agricultural uses, especially in regions where surface water is scarce and unreliable. In the basement complex terrains, the evaluation of groundwater potential is challenging due to the heterogeneous and anisotropic nature of the underlying rock formations. Assessing groundwater potential in basement complex regions requires an integrated approach that considers the geological, geophysical and hydrological properties of the area.

Groundwater occurrence in Ado-Ekiti is majorly from fissure, joints, weathered and fractured zone of crystalline rocks of older granite, charnokites or metamorphic origin of Precambrian age. The void and joints are interconnected and this enables the movement of the groundwater and consequently the passage of contaminants from the overburden [1]. Generally, the movement of groundwater is influenced by topographical elevation and pressure.

Contaminants from the surface through run off can easily leak into aquifer depending on the bearing capacity of the soil. Weathered loose materials over lay aquifer expose ground water to contamination while aquifers overlain and underlain by confining layers are less vulnerable to contamination. Aquifer is generally overlain by different soil material of variable thickness, the soil material include lateritic soil, clay, sandy and silt –sized particles deposited by run off and surface water [2]. These aquifers are localized and of low porosity and permeability, the occurrence also depends on secondary porosity.

II. THE STUDY AREA AND HYDRO-GEOLOGICAL FORMATION

The area of study covers Ado-Ekiti municipal, Ekiti state Nigeria. It is within 733000mE to 765000mE and between 835000mN to 855000mN covering approximately $640km^2$. Ado Ekiti is situated at the centre of Ekiti region of western Nigeria. It is bounded in the South and East by Ondo state through Ikere Ekiti Local Government Area, in the North by Kwara state and Kogi state, in the West by Osun state. The population is about 427,700 according to 2016 population censor; the elevation is between 334m and 510m.

The geology of Ado-Ekiti area is dominated by crystalline and schistose rocks which belong to the Southwestern Nigeria basement complex [3]. The lithology in Ado-Ekiti area is made up of migmatite-gneiss, granite gneiss, charnockite, older granite and metasediments which are quartzite-muscovite schists. Field study shows that the charnockite and granite are closely associated in time and space [4]. According to [5] both granites and charnockites are contemporaneous or the charnockites formed shortly after the emplacement of the older granites. Older metasediments occur as ridges and mica schists and this constitutes part of the Schist belts in Nigeria [3] [6]. Ado Ekiti is surrounded by hills and inselbergs of different shapes in ridges, a rugged topography with rivers and streams meandering through the valleys. The major Rivers are Ireje, Omisanjana and Elemi that flow to River Ose and Owena in Ondo State at the southern part of Ekiti, this drain down to Atlantic Ocean in the southern part of Nigeria [7].

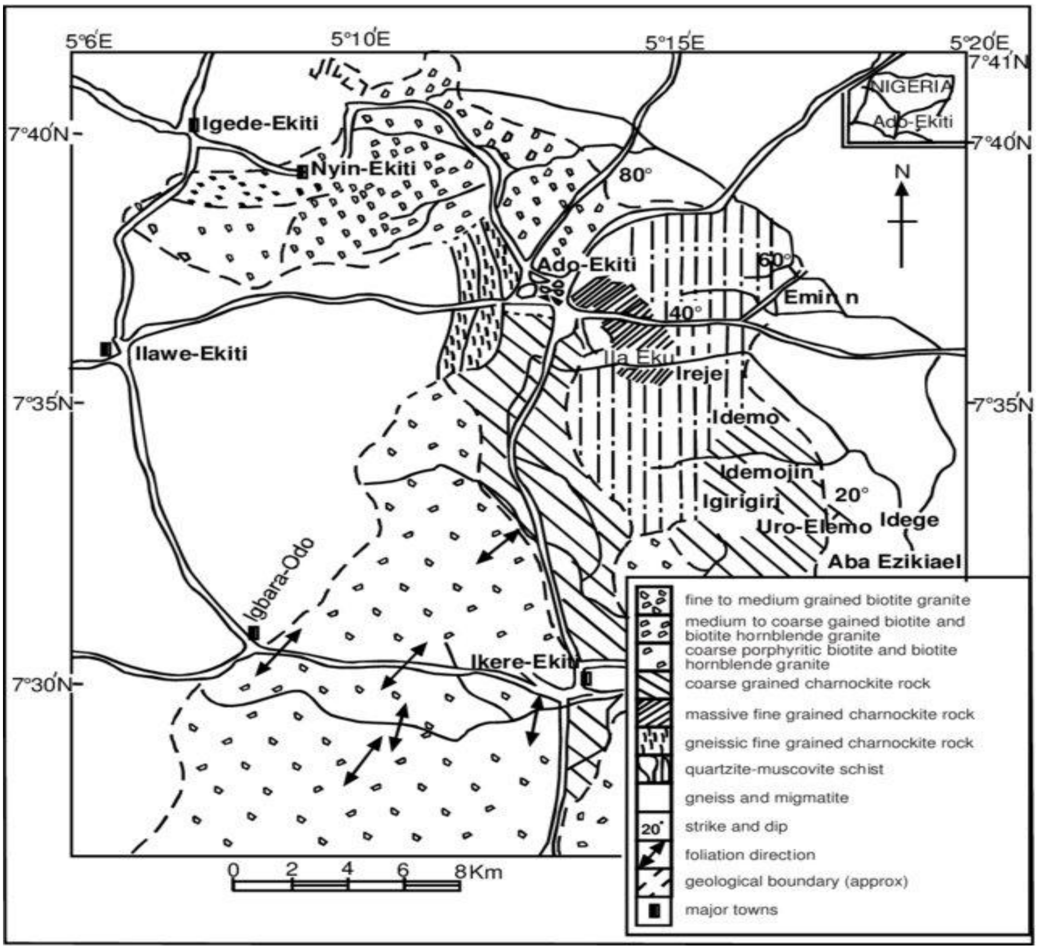

Figure 1: Geological map of Ado Ekiti Southwestern Nigeria [4]

III. MATERIALS AND METHODS

3.1 Vertical Electrical Sounding (VES)

This study utilizes the Electrical Resistivity (ER) method, employing the Schlumberger array setup to perform Vertical Electrical Sounding (VES). ER surveys are based on the principle that water enhances the conductivity of rocks, thereby reducing their resistivity [8]. The Schlumberger array configuration consists of two inner potential electrodes (MN) and two outer current electrodes (AB). The spacing between the potential electrodes is relatively small compared to the spacing between the current electrodes, which allows for the exploration of deeper subsurface resistivities as the current electrodes are spread farther apart. During the survey, the distance between the current electrodes (AB) is gradually increased. Although the potential electrodes may be slightly adjusted to maintain adequate signal strength, their spacing (MN) remains mostly unchanged. The guideline often followed is that AB should be at least five times MN [9] and [10]. The Schlumberger array configuration is particularly beneficial because it reduces the effects of near-surface heterogeneities, offering a more accurate representation of deeper subsurface resistivity variations.

The inversion of the vertical electrical resistivity (VES) data was carried out using Ipi2Win for data smoothing and then Interpex IX1D v3, which accurately computes layer boundaries and resistivities through an iterative curve-matching approach. This method involves iteratively adjusting model parameters, such as layer thickness and resistivity, to reduce the difference between the observed field data and the theoretical model curve.

3.2 Secondary Aquifer and Hydraulic Parameters

The secondary parameters calculated to interpret the inverted VES data in terms of aquifer potential and vulnerability include Dar Zarrouk parameters (longitudinal conductance and transverse resistance), the coefficient of anisotropy (λ), hydraulic conductivity (K), and transmissivity (T). These parameters were computed using the:

$$S = \Sigma \frac{h_i}{\rho_i} \quad (1)$$

$$T_r = \Sigma h_i \rho_i \quad (2)$$

Hydraulic conductivity, K was obtained after [11] and used by [12] and [13] in basement environment.

$$K = 386.4 \cdot \rho^{-0.93283} \quad (3)$$

ρ is aquifer resistivity

$$T = K \cdot h \quad (4)$$

3.3 Groundwater Potential

Groundwater classification based on transmissivity, as outlined by [14], categorizes aquifers into three potential classes: low (T < 50 m²/day), moderate (T = 50–500 m²/day), and high (T > 500 m²/day) (Table 1). The groundwater potential was assessed using the depth to bedrock function proposed [15], where depths of <10 m, 10-20 m, 20-30 m, and >30 m were rated as negligible, low, moderate, and good potential, respectively (Table 2). The potential of the weathered aquifer was evaluated using the saprolite resistivity function proposed by [16]. In this method, resistivity values of <20 Ωm were rated poorly due to potentially high clay content, while values between 20-100 Ωm indicated optimal groundwater potential. Resistivity values of 100-150 Ωm, 150-300 Ωm, and >300 Ωm were rated as medium, limited or poor, and negligible potential, respectively (Table 3). For the fractured bedrock aquifer potential, based on the function from [15], resistivity values of <750 Ωm, 750-1500 Ωm, 1500-3000 Ωm, and >3000 Ωm were rated as high, medium, low, and negligible potential, respectively (Table 4).

Table 1: Aquifer Potential classification based on Transmissivity values [14]

Transmissivity (m^2/day)	Classification of well
>500	High Potentials
50-500	Moderate Potential
5-50	Low Potential
0.5-5	Very low potential
<0.5	Negligible Potential

Table 2: Aquifer Potential classification based on Depth-to-basement function [15]

Depth (m)	Classification
<10	Negligible Potentials
10-20	Low Potential
20-30	Moderate Potential
>30	Good potential

Table 3: Aquifer Potential classification of weather aquifer based on Saprolite resistivity function [16]

Saprolite Resistivity (Ωm)	Classification of well
<20	Poor Potentials (due to high clay content)
20-100	Optimal Potential
100-150	Medium Potential
150-300	Limited/Poor Potential
>300	Negligible Potential

Table 4: Fractured bedrock aquifer potential based on the function from [15]

Resistivity (Ωm)	Classification
<750	High Potentials
750-1500	Medium Potential
1500-3000	Low Potential
>3000	Negligible Potential

3.4 Protective Capacity

Longitudinal conductance is employed to assess the protective capacity of the overlying layer, following the classification scheme proposed by [17]. In this classification, values greater than 0.5 mho suggest high protection, values between 0.5 to 0.1 mho indicate fair protection, values from 0.1 to 0.05 mho reflect poor protection, and values less than 0.05 mho denote very poor protection (Table 3.5).

Maps displaying isoconcentrations of various parameters were created using Golden Software Surfer 18, with computations performed in Microsoft Excel 2010. Geoelectric cross-sections were developed using Adobe Illustrator.

Table 5: Aquifer Protective capacity classification based on Longitudinal Conductance (mho) values [17]

Longitudinal Conductance (mho)	Protective Capacity Classification
>0.5	High Protection
0.1-0.5	Fair Protection
0.05-0.1	Poor Protection
<0.05	Very Poor Protection

IV. RESULTS AND DISCUSSION

4.1 Resistivity Data

The study identified between four and five geoelectric layers across the area, with the majority of sites (67.5%) showing four layers and the remaining 32.5% showing five layers. The identified layers include topsoil, clay/laterite, weathered basement, fractured basement, and fresh unweathered basement. This interpretation was supported by observations from hand-dug wells examined during the survey.

Nine distinct curve types were identified in the study. For the four-layer sites, the curve types include AA (5%), HA (22.5%), KH (20%), and QH (20%). In the five-layer sites, the curve types are AKQ (5%), HAA (5%), HAK (2.5%), HKH (17.5%), and KHK (2.5%). In basement terrains, lower resistivity values in deeper geoelectric layers—represented by curve types with "K" and "Q" in their nomenclature—are typically associated with higher groundwater potential. This suggests that 67.5% of the area, characterized by curve types such as KH, QH, AKQ, HAK, HKH, and KHK, could potentially be viable locations for high groundwater yield, provided the thickness of the low-resistivity layer is sufficient.

The topsoil layer shows a thickness range of 0.24 to 21 m and a resistivity range of 0.97 to 327.76 Ωm. This wide range in resistivity is primarily attributed to varying soil moisture content, with lower resistivity values indicating the presence of clayey and moist soil, while higher resistivity values suggest sandy or dry lateritic conditions. The clay/laterite layer serves as a protective barrier for the underlying aquifers, with thicknesses ranging from 0.89 to 4.43 m and resistivity values between 6.22 and 368.07 Ωm. This layer is vital for reducing contamination risks by preventing surface pollutants from infiltrating the groundwater. The weathered basement, with a thickness ranging from 0.32 to 117.3 m and resistivity values between 9.73 and 5705 Ωm, is a crucial component of the aquiferous layer in the region. Weathered basement zones with lower resistivity typically suggest higher porosity and permeability, which are favorable for groundwater storage and transmission. Conversely, areas with higher resistivity are indicative of more competent, less permeable materials. These findings align with several studies in the region. The fractured basement, with thicknesses ranging from 0.58 to 46.94 m and resistivity values between 1.64 and 2200.2 Ωm, plays a vital role in groundwater storage within the study area. This finding is consistent with previous research, where the fractured basement has been recognized as a key aquifer unit in basement terrains.

Table 6: Summary of layer parameters of the Study Area

	Layer_Resistivity (Ωm)					Thickness (m)				Depth (m)				Curve type
VES_ID	ρ1	ρ2	ρ3	ρ4	ρ5	h1	h2	h3	h4	d1	d2	d3	d4	
VES 1	132.2	49.11	75.193	7.193	1143.6	0.52577	4.0161	3.26	7.7704	0.52577	4.5419	7.8019	15.572	HKH
VES 2	179.11	77.394	854.69	24.4	28195	3.5189	2.1967	5.6927	3.0799	3.5189	5.7156	11.408	14.488	HKH
VES 3	154.73	69.713	5704.9	49.508	2153.2	5.2722	4.4264	46.891	8.3039	5.2722	9.6986	56.589	64.893	HKH
VES 4	95.291	183.2	466.21	35.84	352.68	2.8343	0.93407	2.3972	8.1762	2.8343	3.7683	6.1655	14.342	AKQ
VES 5	85.316	13.355	49.606	208.66	6450.8	1.5468	2.8341	2.003	2.1846	1.5468	4.3809	6.3839	8.5685	HAA
VES 6	151.29	135.2	501.5	23.756	1345.9	1.0599	3.7179	4.4344	10.991	1.0599	4.7778	9.2122	20.203	HKH
VES 7	13.379	11.584	68.402	4251.8		1.224	1.5774	1.9953		1.224	2.8014	4.7967		HA
VES 8	39.284	20.11	408.05	31.391	1231.5	1.011	1.1318	6.4055	15.115	1.011	2.1428	8.5483	23.663	HKH
VES 9	90.23	89.691	258.61	2200.2	28.336	1.0559	3.5899	2.4716	12.526	1.0559	4.6458	7.1175	19.643	HAK
VES 10	71.252	68.764	78.599	45.973	3120.4	0.84127	3.0765	5.0654	9.7397	0.84127	3.9178	8.9832	18.723	HKH
VES 11	6.826	6.2177	35.975	120.18	3433.7	1.1704	3.2336	1.6223	2.2954	1.1704	4.4039	6.0262	8.3216	HAA
VES 12	37.07	368.07	151.86	683.34	212.72	1.8329	2.5007	6.6674	12.413	1.8329	4.3335	11.001	23.414	AKQ
VES 13	0.96978	74.91	382.46	8669		0.26601	0.31534	0.57836		0.26601	0.58134	1.1597		AA
VES 14	38.767	35.881	39.294	9297.2		4.8829	8.1461	15.749		4.8829	13.029	28.778		HA
VES 15	282.44	270.34	268.2	306.06		4.1212	5.5232	12.181		4.1212	9.6444	21.826		QH
VES 16	35.817	155.72	330.14	42452		4.2023	2.1913	2.5587		4.2023	6.4936	9.0522		AA
VES 17	44.806	38.922	57.836	4036.8		3.1574	7.0945	17.001		3.1574	10.252	27.253		HA
VES 18	64.853	50.68	258.38	48502		4.5818	3.3917	4.3625		4.5818	7.9735	12.336		HA
VES 19	215.61	198.76	176.55	791.03		3.0345	6.4236	12.739		3.0345	9.4581	22.197		QH
VES 20	33.313	25.98	65.478	2509.1		2.7724	4.3172	9.0231		2.7724	7.0896	16.113		HA
VES 21	49.311	43.399	63.037	6245		5.1424	15.806	31.878		5.1424	20.949	52. 827		HA
VES 22	87.287	35.946	63.194	5519.1		1.9944	14.585	33.508		1.9944	14.585	48.093		HA
VES 23	55.386	148.17	24.56	317.58		1.1638	0.41817	10.677		1.1638	1.582	12.259		KH
VES 24	61.963	247.29	22.376	319.66	130.37	1.4786	0.88624	2.0444	4.5136	1.4786	2.3649	4.4093	8.9228	KHK
VES 25	269.45	153.95	1275.7	94.223	9020.4	6.396	1.0611	3.1269	46.936	6.396	7.4571	10.584	57.52	HKH
VES 26	17.299	81.012	63.696	6021		0.4753	1.4908	35.672		0.4753	1.9661	37.639		KH
VES 27	118.4	61.964	23.86	3960.2		6.1248	20.732	5.5329		6.1248	26.856	32.389		QH
VES 28	81.987	21.309	41.361	11849		7.2145	5.6428	2.7794		7.2145	12.857	15.637		HA
VES 29	34.025	101.83	34.642	1292.4		0.43314	11.099	6.0571		0.43314	11.532	17.589		KH
VES 30	12.52	28.213	11.662	2525		0.24064	15.294	13.567		0.24064	15.534	29.101		KH
VES 31	16.959	36.689	9.8686	4891		3.5145	8.7641	12.226		3.5145	12.279	24.505		KH
VES 32	49.639	26.017	7.7045	5547.2		6.5353	9.3212	13.87		6.5353	15.857	29.727		QH
VES 33	175.13	41.272	3.5626	2625.8		21.108	71.804	25.398		21.108	92.912	118.31		QH
VES 34	151.28	583.36	167.33	6095		1.733	12.403	8.321		1.733	14.136	22.457		KH
VES 35	14.866	79.743	26.247	256.25		4.3585	117.33	17.042		4.3585	121.69	138.73		KH
VES 36	327.76	34.363	12.834	33.749		2.6006	8.0651	0.90323		2.6006	10.6657	11.5689		QH
VES 37	309.36	90.081	4.9896	23.469		2.3292	3.3963	2.1041		2.3292	5.7255	7.8295		QH
VES 38	51.495	14.965	1.6364	643.74		6.0838	1.8008	3.2866		6.0838	7.8846	11.171		QH
VES 39	41.311	9.7254	10.375	405.53		4.4678	7.7238	12.81		4.4678	12.192	25.001		HA
VES 40	15.534	202.85	62.511	101.75		5.7884	5.8566	14.079		5.7884	11.645	25.724		KH

Table 7: Delineated aquifer resistivity and thickness

VES	Latitude	Longitude	ρ (Ωm)	h (m)	d (m)	Lithology	Curve type
VES 1	7.654	5.228	132.20	0.53	0.53	Top Soil	HKH
			49.11	4.02	4.54	Clay	
			75.19	3.26	7.80	Weathered	
			7.19	7.77	15.57	Fractured	
			1143.6			Fresh Basement	
VES 2	7.645	5.215	179.11	3.52	3.52	Top Soil	HKH
			77.39	2.20	5.72	Clay	
			854.69	5.69	11.41	Weathered	
			24.40	3.08	14.49	Fractured	
			28195			Fresh Basement	
VES 3	7.657	5.212	154.73	5.27	5.27	Top Soil	HKH
			69.71	4.43	9.70	Clay	
			5704.90	46.89	56.59	Weathered	
			49.51	8.30	64.89	Fractured	
			2153.2			Fresh Basement	
VES 4	7.648	5.2	95.29	2.83	2.83	Top Soil	AKQ
			183.20	0.93	3.77	Clay	
			466.21	2.40	6.17	Weathered	
			35.84	8.18	14.34	Fractured	
			352.68			Fresh Basement	
VES 5	7.667	5.233	85.32	1.55	1.55	Top Soil	HAA
			13.36	2.83	4.38	Clay	
			49.61	2.00	6.38	Weathered	
			208.66	2.18	8.57	Fractured	
			6450.80			Fresh Basement	
VES 6	7.628	5.211	151.29	1.06	1.06	Top Soil	HKH
			135.20	3.72	4.78	Clay	
			501.50	4.43	9.21	Weathered	
			23.76	10.99	20.20	Fractured	
			1345.90			Fresh Basement	
VES 7	7.614	5.188	13.38	1.22	1.22	Top Soil	HA
			11.58	1.58	2.80	Weathered	
			68.40	1.99	4.80	Fractured	
			4251.80			Fresh Basement	
VES 8	7.61	5.204	39.284	1.011	1.01	Top Soil	HKH
			20.11	1.13	2.14	Clay	
			408.05	6.41	8.55	Weathered	
			31.39	15.12	23.66	Fractured	
			1231.50			Fresh Basement	
VES 9	7.596	5.215	90.23	1.06	1.06	Top Soil	HAK
			89.69	3.59	4.65	Clay	
			258.61	2.47	7.12	Weathered	
			2200.20	12.53	19.64	Fractured	
			28.34			Fresh Basement	

VES	Latitude	Longitude	ρ (Ωm)	h (m)	d (m)	Lithology	Curve type
VES 10	7.575	5.209	71.25	0.84	0.84	Top Soil	HKH
			68.76	3.08	3.92	Clay	
			78.60	5.07	8.98	Weathered	
			45.97	9.74	18.72	Fractured	
			3120.40			Fresh Basement	
VES 11	7.612	5.229	6.83	1.17	1.17	Top Soil	HAA
			6.22	3.23	4.40	Clay	
			35.98	1.62	6.02	Weathered	
			120.18	2.30	8.32	Fractured	
			3433.70			Fresh Basement	
VES 12	7.572	5.219	37.07	1.83	1.83	Top Soil	AKQ
			368.07	2.50	4.33	Clay	
			151.86	6.67	11.00	Weathered	
			683.34	12.41	23.41	Fractured	
			212.72			Fresh Basement	
VES 13	7.606	5.238	0.97	0.27	0.27	Top Soil	AA
			74.91	0.32	0.58	Weathered	
			382.46	0.58	1.16	Fractured	
			8669			Fresh Basement	
VES 14	7.609	5.252	38.77	4.88	4.88	Top Soil	HA
			35.88	8.15	13.03	Weathered	
			39.29	15.75	28.78	Fractured	
			9297.20			Fresh Basement	
VES 15	7.602	5.297	282.44	4.12	4.12	Top Soil	QH
			270.34	5.52	9.64	Weathered	
			268.20	12.18	21.83	Fractured	
			306.06			Fresh Basement	
VES 16	7.628	5.229	35.82	4.20	4.20	Top Soil	AA
			155.72	2.19	6.49	Weathered	
			330.14	2.56	9.05	Fractured	
			42452			Fresh Basement	
VES 17	7.645	5.263	44.81	3.16	3.16	Top Soil	HA
			38.92	7.09	10.25	Weathered	
			57.84	17.00	27.25	Fractured	
			4036.80			Fresh Basement	
VES 18	7.664	5.272	64.85	4.58	4.58	Top Soil	HA
			50.68	3.39	7.97	Weathered	
			258.38	4.36	12.34	Fractured	
			48502			Fresh Basement	
VES 19	7.652	5.243	215.61	3.03	3.03	Top Soil	QH
			198.76	6.42	9.46	Weathered	
			176.55	12.74	22.20	Fractured	
			791.03			Fresh Basement	
VES 20	7.612	5.131	33.31	2.77	2.77	Top Soil	HA

VES	Latitude	Longitude	ρ (Ωm)	h (m)	d (m)	Lithology	Curve type
			25.98	4.31	7.09	Weathered	
			65.48	9.02	16.11	Fractured	
			2509.10			Fresh Basement	
VES 21	7.612	5.249	49.31	5.14	5.14	Top Soil	HA
			43.40	15.81	20.95	Weathered	
			63.04	31.88	52. 83	Fractured	
			6245			Fresh Basement	
VES 22	7.612	5.246	87.29	1.99	1.99	Top Soil	HA
			35.95	14.59	14.59	Weathered	
			63.19	33.51	48.09	Fractured	
			5519.10			Fresh Basement	
VES 23	7.609	5.248	55.39	1.16	1.16	Top Soil	KH
			148.17	0.42	1.58	Weathered	
			24.56	10.68	12.26	Fractured	
			317.58			Fresh Basement	
VES 24	7.612	5.213	61.96	1.48	1.48	Top Soil	KHK
			247.29	0.89	2.36	Clay	
			22.376	2.04	4.41	Weathered	
			319.66	4.51	8.92	Fractured	
			130.37			Fresh Basement	
VES 25	7.613	5.213	269.45	6.40	6.40	Top Soil	HKH
			153.95	1.06	7.46	Clay	
			1275.70	3.13	10.58	Weathered	
			94.22	46.94	57.52	Fractured	
			9020.40			Fresh Basement	
VES 26	7.61	5.304	17.30	0.48	0.48	Top Soil	KH
			81.01	1.49	1.97	Weathered	
			63.70	35.67	37.64	Fractured	
			6021			Fresh Basement	
VES 27	7.609	5.303	118.40	6.1248	6.1248	Top Soil	QH
			61.96	20.732	26.856	Weathered	
			23.86	5.5329	32.389	Fractured	
			3960.20			Fresh Basement	
VES 28	7.607	5.305	81.99	7.21	7.21	Top Soil	HA
			21.31	5.64	12.86	Weathered	
			41.36	2.78	15.64	Fractured	
			11849			Fresh Basement	
VES 29	7.605	5.304	34.03	0.43	0.43	Top Soil	KH
			101.83	11.10	11.53	Weathered	
			34.64	6.06	17.59	Fractured	
			1292.40			Fresh Basement	
VES 30	7.628	5.228	12.52	0.24	0.24	Top Soil	KH
			28.21	15.29	15.53	Weathered	
			11.66	13.57	29.10	Fractured	

VES	Latitude	Longitude	ρ (Ωm)	h (m)	d (m)	Lithology	Curve type
			2525			Fresh Basement	
VES 31	7.63	5.224	16.96	3.51	3.51	Top Soil	KH
			36.69	8.76	12.28	Weathered	
			9.87	12.23	24.51	Fractured	
			4891			Fresh Basement	
VES 32	7.626	5.225	49.64	6.54	6.54	Top Soil	QH
			26.02	9.32	15.86	Weathered	
			7.70	13.87	29.73	Fractured	
			5547.20			Fresh Basement	
VES 33	7.626	5.229	175.13	21.11	21.11	Top Soil	QH
			41.27	71.80	92.91	Weathered	
			3.56	25.40	118.31	Fractured	
			2625.80			Fresh Basement	
VES 34	7.601	5.231	151.28	1.73	1.73	Top Soil	KH
			583.36	12.40	14.14	Weathered	
			167.33	8.32	22.46	Fractured	
			6095			Fresh Basement	
VES 35	7.618	5.349	14.87	4.36	4.36	Top Soil	KH
			79.74	117.33	121.69	Weathered	
			26.25	17.04	138.73	Fractured	
			256.25			Fresh Basement	
VES 36	7.614	5.169	327.76	2.60	2.60	Top Soil	QH
			34.36	8.07	10.67	Weathered	
			12.83	0.90	11.57	Fractured	
			33.75			Fresh Basement	
VES 37	7.613	5.184	309.36	2.33	2.33	Top Soil	QH
			90.08	3.40	5.73	Weathered	
			4.99	2.10	7.83	Fractured	
			23.47			Fresh Basement	
VES 38	7.61	5.17	51.50	6.08	6.08	Top Soil	QH
			14.97	1.80	7.88	Weathered	
			1.64	3.29	11.17	Fractured	
			643.74			Fresh Basement	
VES 39	7.613	5.218	41.31	4.47	4.47	Top Soil	HA
			9.73	7.72	12.19	Weathered	
			10.38	12.81	25.00	Fractured	
			405.53			Fresh Basement	
VES 40	7.609	5.224	15.53	5.79	5.79	Top Soil	KH
			202.85	5.86	11.65	Weathered	
			62.51	14.08	25.72	Fractured	
			101.75			Fresh Basement	

Table 8: Hydraulic and Dar Zarrouk properties of the aquifer and protective layer

	Aquifer layer		Protective layer							
VES	ρ	h	ρ	H	S	Tr	S	K	T	λ
VES 1	41.2	11	90.7	4.5	0.05	567.8	1.21	12	599.9	1.7
VES 2	439.5	8.8	128.3	5.7	0.04	5740.9	0.18	1.3	105.2	2.2
VES 3	2877.2	55.2	112.2	9.7	0.09	269043.9	0.27	0.2	180.5	4.2
VES 4	251	10.6	139.2	3.8	0.03	1851.8	0.27	2.2	150.2	1.6
VES 5	129.1	4.2	49.3	4.4	0.09	725	0.28	4.1	150.6	1.7
VES 6	262.6	15.4	143.2	4.8	0.03	3148	0.51	2.1	284.3	2
VES 7	40	3.6	13.4	1.2	0.09	171.1	0.26	12.4	127.1	1.4
VES 8	219.7	21.5	29.7	2.1	0.07	3150.7	0.58	2.5	321.5	1.8
VES 9	1229.4	15	90	4.6	0.05	28616.1	0.07	0.5	41.7	2.2
VES 10	62.3	14.8	70	3.9	0.06	1117.4	0.33	8.2	169.8	1
VES 11	78.1	3.9	6.5	4.4	0.68	362.3	0.76	6.6	391.3	2
VES 12	417.6	19.1	202.6	4.3	0.02	10483.2	0.12	1.4	68.6	1.5
VES 13	228.7	0.9	1	0.3	0.27	245.1	0.28	2.4	155.8	7.1
VES 14	37.6	23.9	38.8	4.9	0.13	1100.4	0.75	13.1	371.6	1
VES 15	269.3	17.7	282.4	4.1	0.01	5924.1	0.08	2.1	45.3	1
VES 16	242.9	4.8	35.8	4.2	0.12	1336.5	0.14	2.3	77.8	1.5
VES 17	48.4	24.1	44.8	3.2	0.07	1400.9	0.55	10.4	274.1	1
VES 18	154.5	7.8	64.9	4.6	0.07	1596.2	0.15	3.5	83.7	1.3
VES 19	187.7	19.2	215.6	3	0.01	4180.1	0.12	2.9	65.1	1
VES 20	45.7	13.3	33.3	2.8	0.08	795.3	0.39	10.9	193.4	1.1
VES 21	53.2	47.7	49.3	5.1	0.1	2949	0.97	9.5	491.6	1
VES 22	49.6	48.1	87.3	2	0.02	2815.9	0.96	10.1	481.6	1
VES 23	86.4	11.1	55.4	1.2	0.02	388.6	0.46	6	239.1	1.1
VES 24	171	6.6	154.6	2.4	0.02	1799.3	0.13	3.2	72.6	1.7
VES 25	685	50.1	211.7	7.5	0.04	10298.2	0.53	0.9	318.3	1.3
VES 26	72.4	37.2	17.3	0.5	0.03	2401.2	0.61	7.1	312.1	1
VES 27	42.9	26.3	118.4	6.1	0.05	2141.8	0.62	11.6	307.5	1.1
VES 28	31.3	8.4	82	7.2	0.09	826.7	0.42	15.5	204.5	1.2
VES 29	68.2	17.2	34	0.4	0.01	1354.8	0.3	7.5	152.2	1.1
VES 30	19.9	28.9	12.5	0.2	0.02	592.7	1.72	23.7	814.8	1.1
VES 31	23.3	21	17	3.5	0.21	501.8	1.68	20.5	804.4	1.2
VES 32	16.9	23.2	49.6	6.5	0.13	673.8	2.29	27.7	1069.8	1.3
VES 33	22.4	97.2	175.1	21.1	0.12	6750.6	8.99	21.2	4280.4	2.1
VES 34	375.3	20.7	151.3	1.7	0.01	8889.9	0.08	1.5	47.4	1.2
VES 35	53	134.4	14.9	4.4	0.29	9868.3	2.41	9.5	1217.8	1.1
VES 36	23.6	9	327.8	2.6	0.01	1141.1	0.31	20.2	149.6	1.6
VES 37	47.5	5.5	309.4	2.3	0.01	1037	0.47	10.5	233.8	2.8
VES 38	8.3	5.1	51.5	6.1	0.12	345.6	2.25	53.7	1000.8	2.5
VES 39	10.1	20.5	41.3	4.5	0.11	392.6	2.14	44.9	964.2	1.2
VES 40	132.7	19.9	15.5	5.8	0.37	2158	0.63	4	336.3	1.4

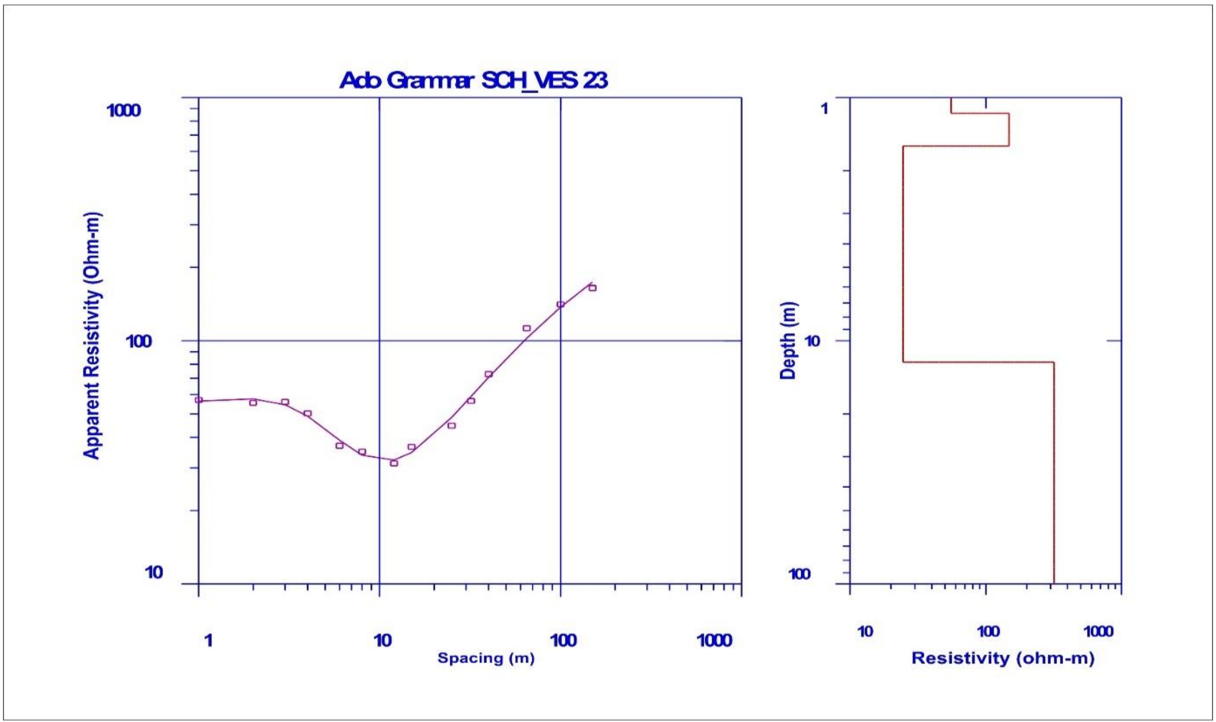

Figure 2: Vertical electric sounding curve and layers (KH-Curve Type, VES 23)

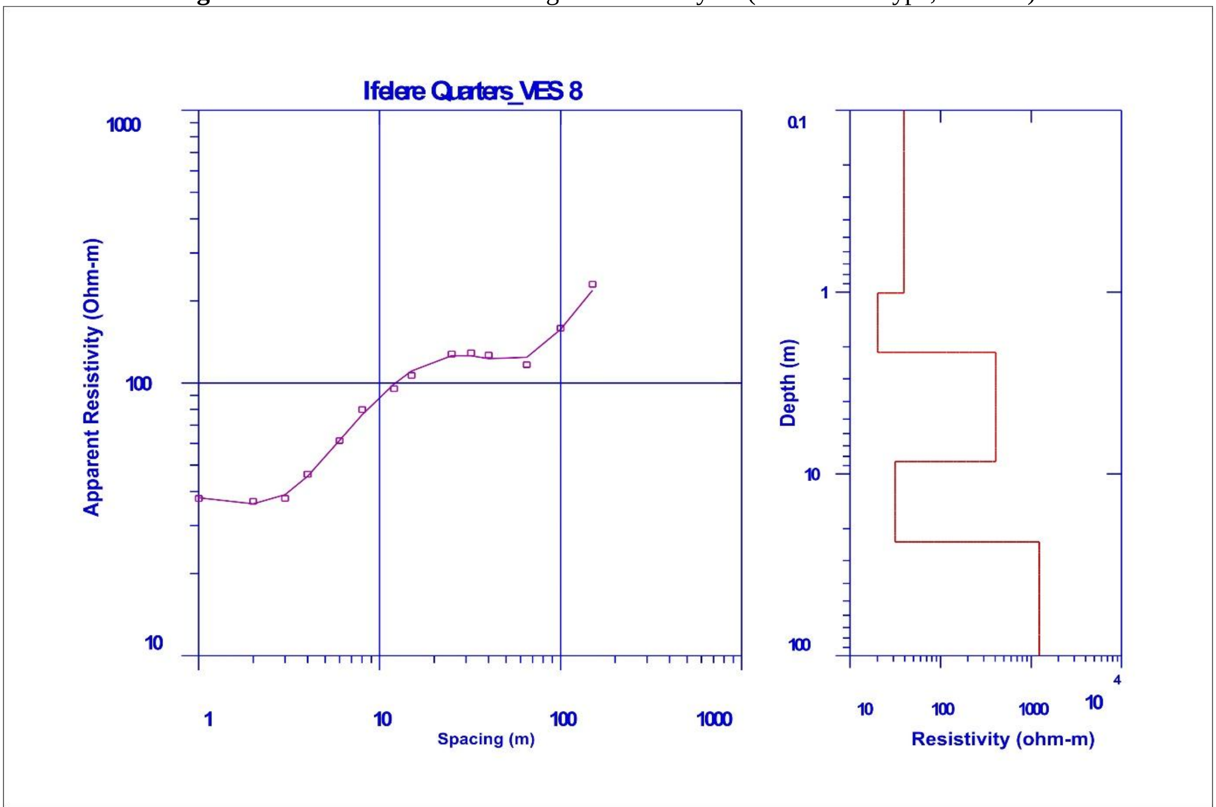

Figure 3: Vertical electric sounding curve and layers (HKH-Curve Type, VES 8)

4.2 Groundwater Potential

The depth to the top of the basement varies significantly, ranging from 1.16 m at VES 13 to 138.73 m at VES 35. Based on the depth-to-basement function proposed by [15], the groundwater potential across the VES positions is categorized as follows: 17.5% are rated as negligible (d < 10 m), 30% as low (10-20 m), 32.5% as moderate (20-30 m), and 20% as good (d > 30 m). This implies that a substantial portion (21 out of 40 VES) of the area exhibits moderate to good groundwater potential, particularly where the depth to the basement exceeds 20 meters. However, the presence of zones with negligible and low potential suggests that groundwater availability may be uneven. The weathered layer, where the depth to the basement exceeds 20 meters, was further categorized using [16] saprolite resistivity function. The results reveal that 52.38% of the areas are rated as optimum (20 < ρ < 100 Ωm), 19.05% as poor (150 < ρ < 300 Ωm), 23.81% as negligible (> 300 Ωm), and 4.76% as poorly rated due to high clay content (ρ < 20 Ωm). According to [15], fractured bedrock resistivity function, almost all (97.5%) of the fractured aquifers at these VES points exhibit high groundwater potential (< 750 Ωm). This indicates that where the weathered aquifer is not viable, the fractured aquifer could serve as a viable alternative for groundwater development.

Table 9: Aquifer Potential rating Using Transmissivity Values

VES No	Location	Longitudinal Conductance	Transmissivity m^2/day	Aquifer Potentials
VES 1	Adebayo Area	1.21	599.9	High
VES 2	Oluwatuyi Quarters	0.18	105.2	Moderate
VES 3	Owode Quarters	0.27	180.5	Moderate
VES 4	Ilamoye	0.27	150.2	Moderate
VES 5	FM Iworoko	0.28	150.6	Moderate
VES 6	EKSU G.House	0.51	284.3	Moderate
VES 7	Fajuyi H. Estate	0.26	127.1	Moderate
VES 8	Omisanjana Qtrs	0.58	321.5	Moderate
VES 9	Bamigboye Str.	0.07	41.7	Low
VES 10	Ajebandele Qtrs	0.33	169.8	Moderate
VES 11	Olope Idofin	0.76	391.3	Moderate
VES 12	Covenant Avenue	0.12	68.6	Moderate
VES 13	Ita-Eku Rd	0.28	155.8	Moderate
VES 14	Mother & Child Est.	0.75	371.6	Moderate
VES 15	Ado Fed Poly	0.08	45.3	Low
VES 16	Mary Hill	0.14	77.8	Moderate
VES 17	Wonder City	0.55	274.1	Moderate
VES 18	Elemi H. Estate	0.15	83.7	Moderate
VES 19	Onola Qtrs	0.12	65.1	Moderate
VES 20	Odo Community	0.39	193.4	Moderate
VES 21	Ado Grammar Sch	0.97	491.6	Moderate
VES 22	Ado Grammar Sch	0.96	481.6	Moderate
VES 23	Ado Grammar Sch	0.46	239.1	Moderate
VES 24	Ado Community	0.13	72.6	Moderate
VES 25	Ado Community	0.53	318.3	Moderate
VES 26	ABUAD	0.61	312.1	Moderate
VES 27	ABUAD	0.62	307.5	Moderate
VES 28	ABUAD	0.42	204.5	Moderate
VES 29	ABUAD	0.3	152.2	Moderate
VES 30	Oke-Ila Rd	1.72	814.8	High
VES 31	Oke-Ila Rd	1.68	804.4	High
VES 32	Oke-Ila Rd	2.29	1069.8	High
VES 33	Oke-Ila Rd	8.99	4280.4	High
VES 34	Agric Training Centre	0.08	47.4	Low
VES 35	Ayegunle	2.41	1217.8	High
VES 36	Olaoluwa Area	0.31	149.6	Moderate
VES 37	Olaoluwa Area	0.47	233.8	Moderate
VES 38	Olaoluwa Area	2.25	1000.8	High
VES 39	Igirigiri	2.14	964.2	High
VES 40	Igirigiri	0.63	336.3	Moderate

Table 10: Aquifer Potential rating based on Saprolite resistivity function

VES No	Location	Saprolite Resistivity Ωm	Aquifer Potentials
VES 1	Adebayo Area	75.19	Optimal
VES 2	Oluwatuyi Quarters	854.69	Negligible
VES 3	Owode Quarters	5704.90	Negligible
VES 4	Ilamoye	466.21	Negligible
VES 5	FM Iworoko	49.61	Optimal
VES 6	EKSU G.House	501.50	Negligible

VES 7	Fajuyi H. Estate	11.58	Poor
VES 8	Omisanjana Qtrs	408.05	Negligible
VES 9	Bamigboye Str.	258.61	Limited
VES 10	Ajebandele Qtrs	78.60	Optimal
VES 11	Olope Idofin	35.98	Optimal
VES 12	Covenant Avenue	151.86	Limited
VES 13	Ita-Eku Rd	74.91	Optimal
VES 14	Mother & Child Est.	35.88	Optimal
VES 15	Ado Fed Poly	270.34	Limited
VES 16	Mary Hill	155.72	Limited
VES 17	Wonder City	38.92	Optimal
VES 18	Elemi H. Estate	50.68	Optimal
VES 19	Onola Qtrs	198.76	Limited
VES 20	Odo Community	25.98	Optimal
VES 21	Ado Grammar Sch	43.40	Optimal
VES 22	Ado Grammar Sch	35.95	Optimal
VES 23	Ado Grammar Sch	148.17	Medium
VES 24	Ado Community	22.38	Optimal
VES 25	Ado Community	1275.70	Negligible
VES 26	ABUAD	81.01	Optimal
VES 27	ABUAD	61.96	Optimal
VES 28	ABUAD	21.31	Optimal
VES 29	ABUAD	101.83	Medium
VES 30	Oke-Ila Rd	28.21	Optimal
VES 31	Oke-Ila Rd	36.69	Optimal
VES 32	Oke-Ila Rd	26.02	Optimal
VES 33	Oke-Ila Rd	41.27	Optimal
VES 34	Agric Training Centre	583.36	Negligible
VES 35	Ayegunle	79.74	Optimal
VES 36	Olaoluwa Area	34.36	Optimal
VES 37	Olaoluwa Area	90.08	Optimal
VES 38	Olaoluwa Area	14.97	Poor
VES 39	Igirigiri	9.73	Poor
VES 40	Igirigiri	202.85	Limited

Table 11: Aquifer Potential rating based on Fractured bedrock function

VES No	Location	Resistivity Ωm	Aquifer Potentials
VES 1	Adebayo Area	7.19	High
VES 2	Oluwatuyi Quarters	24.40	High
VES 3	Owode Quarters	49.51	High
VES 4	Ilamoye	35.84	High
VES 5	FM Iworoko	208.66	High
VES 6	EKSU G.House	23.76	High
VES 7	Fajuyi H. Estate	68.40	High
VES 8	Omisanjana Qtrs	31.39	High
VES 9	Bamigboye Str.	2200.2	Low
VES 10	Ajebandele Qtrs	45.97	High
VES 11	Olope Idofin	120.18	High
VES 12	Covenant Avenue	683.34	High
VES 13	Ita-Eku Rd	382.46	High
VES 14	Mother & Child Est.	39.29	High
VES 15	Ado Fed Poly	268.20	High
VES 16	Mary Hill	330.14	High
VES 17	Wonder City	57.836	High
VES 18	Elemi H. Estate	258.38	High
VES 19	Onola Qtrs	176.55	High
VES 20	Odo Community	65.48	High
VES 21	Ado Grammar Sch	63.04	High
VES 22	Ado Grammar Sch	63.19	High
VES 23	Ado Grammar Sch	24.56	High
VES 24	Ado Community	319.66	High
VES 25	Ado Community	94.22	High
VES 26	ABUAD	63.70	High
VES 27	ABUAD	23.86	High
VES 28	ABUAD	41.36	High
VES 29	ABUAD	34.64	High
VES 30	Oke-Ila Rd	11.66	High
VES 31	Oke-Ila Rd	9.87	High
VES 32	Oke-Ila Rd	7.70	High
VES 33	Oke-Ila Rd	3.56	High

VES 34	Agric Training Centre	167.33	High
VES 35	Ayegunle	26.25	High
VES 36	Olaoluwa Area	12.83	High
VES 37	Olaoluwa Area	4.99	High
VES 38	Olaoluwa Area	1.64	High
VES 39	Igirigiri	10.38	High
VES 40	Igirigiri	62.51	High

Table 12: Aquifer Potential rating based on Depth-to-basement function

VES No	Location	Depth (m)	Aquifer Potentials
VES 1	Adebayo Area	15.57	Low
VES 2	Oluwatuyi Quarters	14.49	Low
VES 3	Owode Quarters	64.89	Good
VES 4	Ilamoye	14.34	Low
VES 5	FM Iworoko	8.57	Negligible
VES 6	EKSU G.House	20.20	Moderate
VES 7	Fajuyi H. Estate	4.80	Negligible
VES 8	Omisanjana Qtrs	23.66	Moderate
VES 9	Bamigboye Str.	19.64	Moderate
VES 10	Ajebandele Qtrs	18.72	Low
VES 11	Olope Idofin	8.32	Negligible
VES 12	Covenant Avenue	23.41	Moderate
VES 13	Ita-Eku Rd	1.16	Negligible
VES 14	Mother & Child Est.	28.78	Moderate
VES 15	Ado Fed Poly	21.83	Moderate
VES 16	Mary Hill	9.05	Low
VES 17	Wonder City	27.25	Moderate
VES 18	Elemi H. Estate	12.336	Low
VES 19	Onola Qtrs	22.20	Moderate
VES 20	Odo Community	16.11	Low
VES 21	Ado Grammar Sch	52.83	Good
VES 22	Ado Grammar Sch	48.09	Good
VES 23	Ado Grammar Sch	12.26	Low
VES 24	Ado Community	8.92	Negligible
VES 25	Ado Community	57.52	Good
VES 26	ABUAD	37.64	Good
VES 27	ABUAD	32.39	Good
VES 28	ABUAD	15.64	Low
VES 29	ABUAD	17.59	Low
VES 30	Oke-Ila Rd	29.10	Moderate
VES 31	Oke-Ila Rd	24.51	Moderate
VES 32	Oke-Ila Rd	29.73	Moderate
VES 33	Oke-Ila Rd	118.31	Good
VES 34	Agric Training Centre	22.46	Moderate
VES 35	Ayegunle	138.73	Good
VES 36	Olaoluwa Area	11.57	Low
VES 37	Olaoluwa Area	7.83	Negligible
VES 38	Olaoluwa Area	11.17	Low
VES 39	Igirigiri	25.00	Moderate
VES 40	Igirigiri	25.72	Moderate

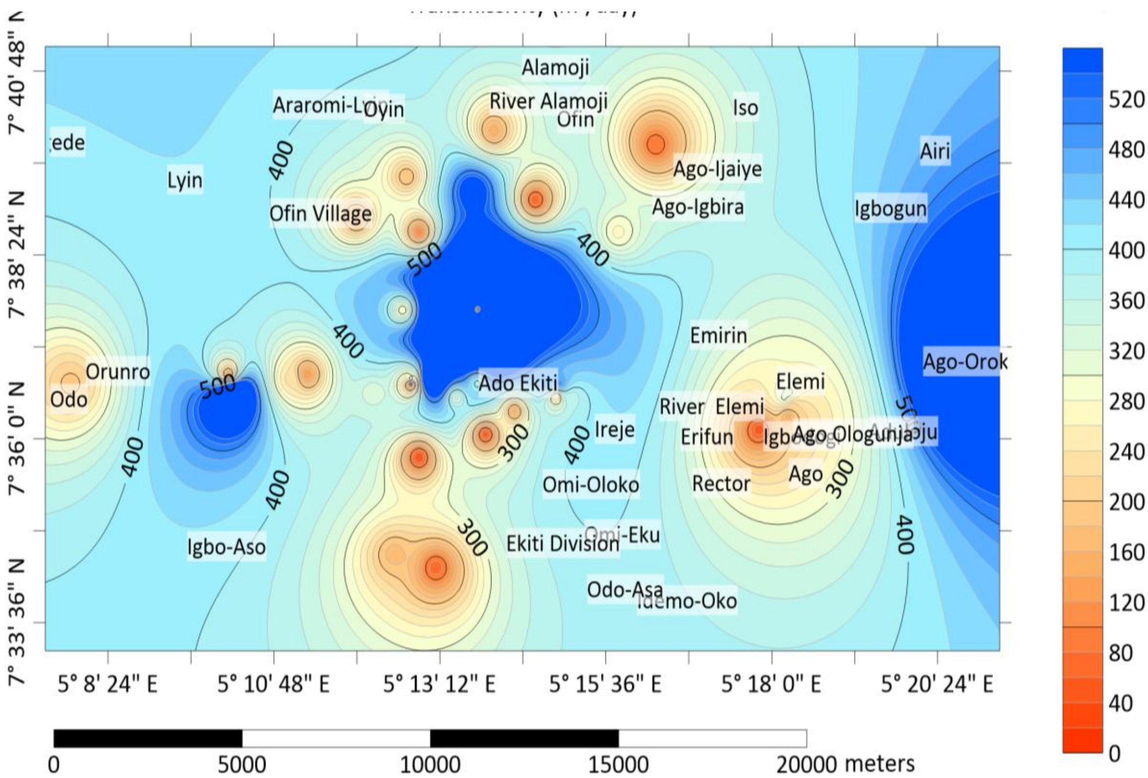

Figure 4: Transmissivity (m^2/day) of aquifer geoelectric layer

4.3 Protective capacity and vulnerability

The study reveals that the longitudinal conductance of the protective layers (clayey topsoil) ranges from 0.07 to 8.99 mho. 70% of the area is classified as poorly to very poorly protected, making it highly vulnerable to contamination. This may be due to differences in clay content and layer thickness across different regions. In areas with low protective capacity, localized management strategies are essential to prevent contamination from surface pollutants.

Table 13: Aquifer Protective Capacity Rating in the Study Area

VES No	Location	Curve Type	Longitudinal Conductance	Transverse Resistance	Protective Capacity Rating
VES 1	Adebayo Area	HKH	0.05	567.8	Poor
VES 2	Oluwatuyi Quarters	HKH	0.04	5740.9	Poor
VES 3	Owode Quarters	HKH	0.09	269043.9	Poor
VES 4	Ilamoye	AKQ	0.03	1851.8	Poor
VES 5	FM Iworoko	HAA	0.09	725	Poor
VES 6	EKSU G.House	HKH	0.03	3148	Poor
VES 7	Fajuyi H. Estate	HA	0.09	171.1	Poor
VES 8	Omisanjana Qtrs	HKH	0.07	3150.7	Poor
VES 9	Bamigboye Str.	HAK	0.05	28616.1	Poor
VES 10	Ajebandele Qtrs	HKH	0.06	1117.4	Poor
VES 11	Olope Idofin	HAA	0.68	362.3	Moderate
VES 12	Covenant Avenue	AKQ	0.02	10483.2	Poor
VES 13	Ita-Eku Rd	AA	0.27	245.1	Moderate
VES 14	Mother & Child Est.	HA	0.13	1100.4	Weak
VES 15	Ado Fed Poly	QH	0.01	5924.1	Poor
VES 16	Mary Hill	AA	0.12	1336.5	Weak
VES 17	Wonder City	HA	0.07	1400.9	Poor
VES 18	Elemi H. Estate	HA	0.07	1596.2	Poor
VES 19	Onola Qtrs	QH	0.01	4180.1	Poor
VES 20	Odo Community	HA	0.08	795.3	Poor
VES 21	Ado Grammar Sch	HA	0.1	2949	Weak
VES 22	Ado Grammar Sch	HA	0.02	2815.9	Poor
VES 23	Ado Grammar Sch	KH	0.02	388.6	Poor
VES 24	Ado Community	KHK	0.02	1799.3	Poor
VES 25	Ado Community	HKH	0.04	10298.2	Poor
VES 26	ABUAD	KH	0.03	2401.2	Poor
VES 27	ABUAD	QH	0.05	2141.8	Poor
VES 28	ABUAD	HA	0.09	826.7	Poor

VES 29	ABUAD	KH	0.01	1354.8	Poor
VES 30	Oke-Ila Rd	KH	0.02	592.7	Poor
VES 31	Oke-Ila Rd	KH	0.21	501.8	Moderate
VES 32	Oke-Ila Rd	QH	0.13	673.8	Weak
VES 33	Oke-Ila Rd	QH	0.12	6750.6	Weak
VES 34	Agric Training Centre	KH	0.01	8889.9	Poor
VES 35	Ayegunle	KH	0.29	9868.3	Moderate
VES 36	Olaoluwa Area	QH	0.01	1141.1	Poor
VES 37	Olaoluwa Area	QH	0.01	1037	Poor
VES 38	Olaoluwa Area	QH	0.12	345.6	Weak
VES 39	Igirigiri	HA	0.11	392.6	Weak
VES 40	Igirigiri	KH	0.37	2158	Moderate

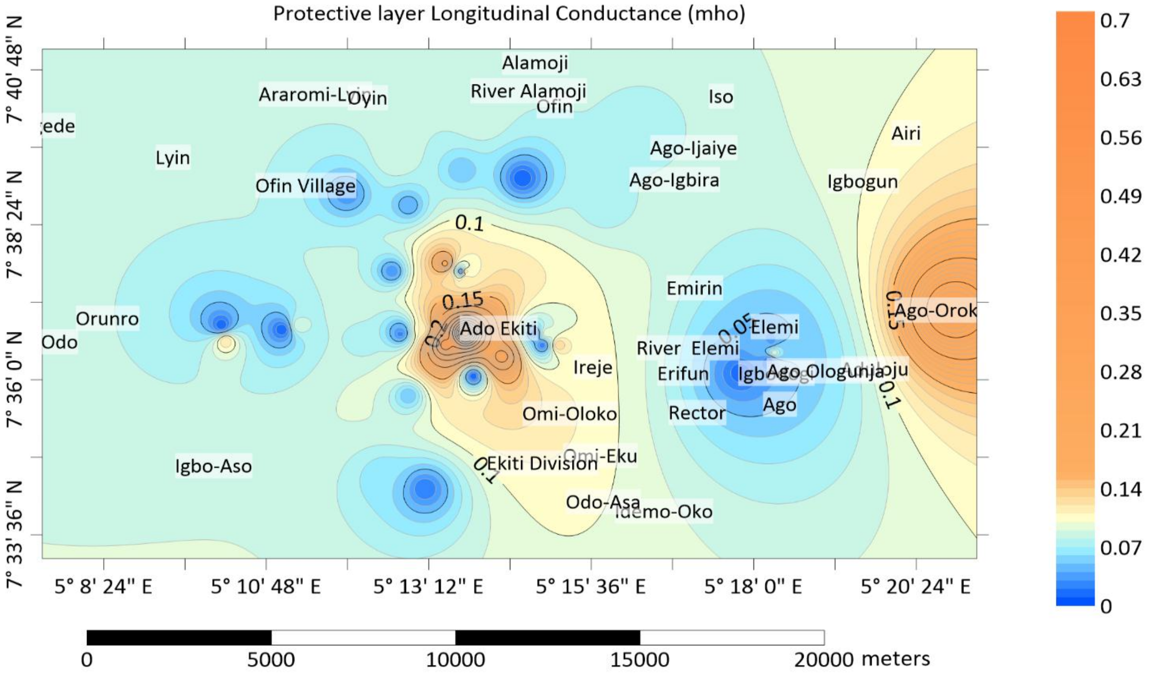

Figure 5: Protective Layer Longitudinal Conductance (mho) of the overburden geoelectric layer.

V. CONCLUSION

The study provides a comprehensive assessment of the groundwater potential, and vulnerability of Ado-Ekiti. The aquiferous layers, consisting of the weathered and fractured basement, exhibit moderate to high groundwater potential, particularly in regions with thick overburden and deep basement valleys. The poor protective capacity of the topsoil and clay layers raises concerns about the vulnerability of the aquifers to contamination. Localized management strategies will be essential to protect these valuable groundwater resources, especially in areas with high groundwater potential and poor protection.

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