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Groundwater Investigation and Characterisation in Marigat Area, Baringo County Using Electrical Resistivity Method

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Abstract: *Qualitative and quantitative interpretation of electrical resistivity data collected in Marigat area revealed the possible presence of 3-6 geoelectric layers which were categorized into three inhomogeneous formations. This data integrated with borehole data shows that the first formation represents alluvial deposits while the second formation comprising of weathered and fractured basalts and tuffs located along the sedimentary basin is good for groundwater extraction at shallow depths ranging between 35m–50m. Other deeper aquifers were also noted in the third formation with very low resistivity values ranging between 0.0685Ωm and 0.222 Ωm showing a possible geothermal fluid with high salinity. Dar Zarrouk parameters were computed and used alongside the pumping tests to estimate the aquifer hydrologic properties. It was found that the hydraulic conductivity values range between 0.614m/day – 56.934m/day while the transmissivity values range between 13.569m^2/day – 1429.052m^2/day. The regions with high transmissivities and hydraulic conductivities were interpreted as the fractured and weathered zones with high yield potential for potable groundwater development at shallow depths and a possible geothermal basement in the deep aquifers.*

Key Words: *Aquifers, Dar Zarrouk parameters, geothermal basement, groundwater, resistivity.*

I. Introduction

A Resistivity survey using Electrical profiling and Vertical electrical sounding method was carried out to determine the lateral and vertical variation of resistivity with depth and to characterise probable aquifers that can be developed into productive boreholes in Marigat area. Marigat area lies in the rift valley, an area known to have a geothermal potential as described by Simiyu *et al.* [1]. Groundwater in this area is unexploited and efforts by organizations and individuals to sink boreholes in this region have not been very successful due to challenges of undefined nature of fault lines in the rift valley, presence of underground geysers and lack of detailed hydro geophysical information of the area. This study was carried out using electrical resistivity method in order to establish the groundwater potentials in the upper crust and to delineate aquifers that could be developed into productive boreholes.

1.1 Geological Setting

Marigat area is delineated by longitudes $35^0$50'E to $36^0$00'E and latitudes $0^0$20'N to $0^0$35'E as shown in Fig. 1.1 below. Its floor is covered by Quaternary deposits and recent alluvium which form the main water bearing strata that are apparently unaffected by faulting and are characterized by almost total lack of boulders and pebbles as described by Walsh [2]. Kapthurin beds which are grid faulted and overlie the Lake Hannington phonolites form part of the geology of the area and they constitute a coarse boulder torrent-wash with subordinate silts and volcanic tuffs containing oogonia. Roure *et al.* [3] inferred that the Presence of oogonia in the Kapthurin formation tufa suggests that the water depths are moderate, alkaline and that low energy conditions prevailed.

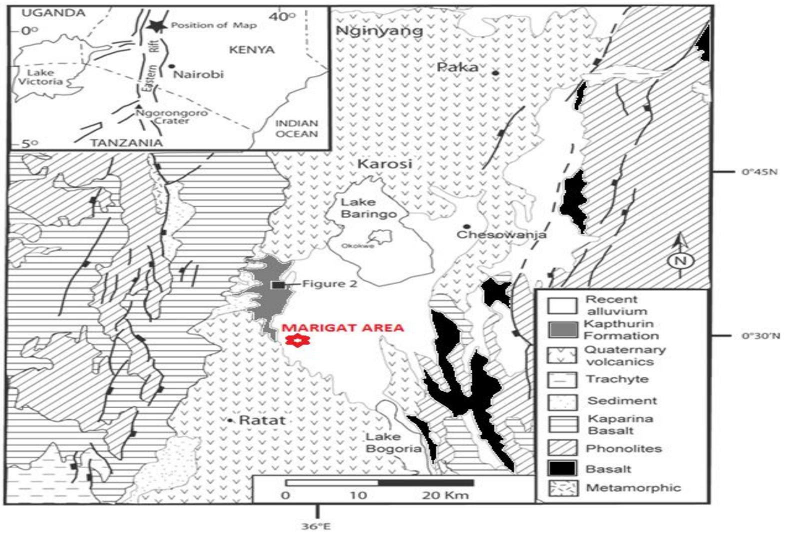


Figure 1.1: Geology of the Lake Baringo area (adapted from Chapman and Brook [4].

1.2 Hydrogeology

According to JICA report [5], the groundwater in Marigat area is distributed in unconsolidated sediments of sand layers, gravel layers, cracks of rocks below sedimentary layers and pyroclastics. This groundwater is locally recharged by infiltration of rainwater into the deep aquifers that are facilitated by open faults and fissure zones emanating from the Tugen hills. These faults and fissure zones are the main geological structures that determine the groundwater flow through the aquifers in the region.

II. Materials And Methods

2.1 Resistivity Survey

Resistivity measurements were made in the northern parts of Marigat area, referred to as Southern Baringo Zone by Mungania *et al.* [6] in Baringo Bogoria basin. The survey covered an area of approximately 20 km^2, and consisted of 5 profiles and 28 vertical electrical soundings (VES) points as shown in Fig.1.2. Two of the soundings were carried out near existing boreholes in which pumping tests had been done. Due to inaccessibility of the study area, especially parts which were occupied by prolific growth of *Prosobis juliflora* (Mathenge) and cactus plants, the profiles were discontinued and the VES points were selected based on accessibility and applicability of the method in the study area. The coordinates of the sounding points were recorded using Garmin GPS 12 while the resistivity measurements were conducted using ABEM SAS terrameter 1000/4000.

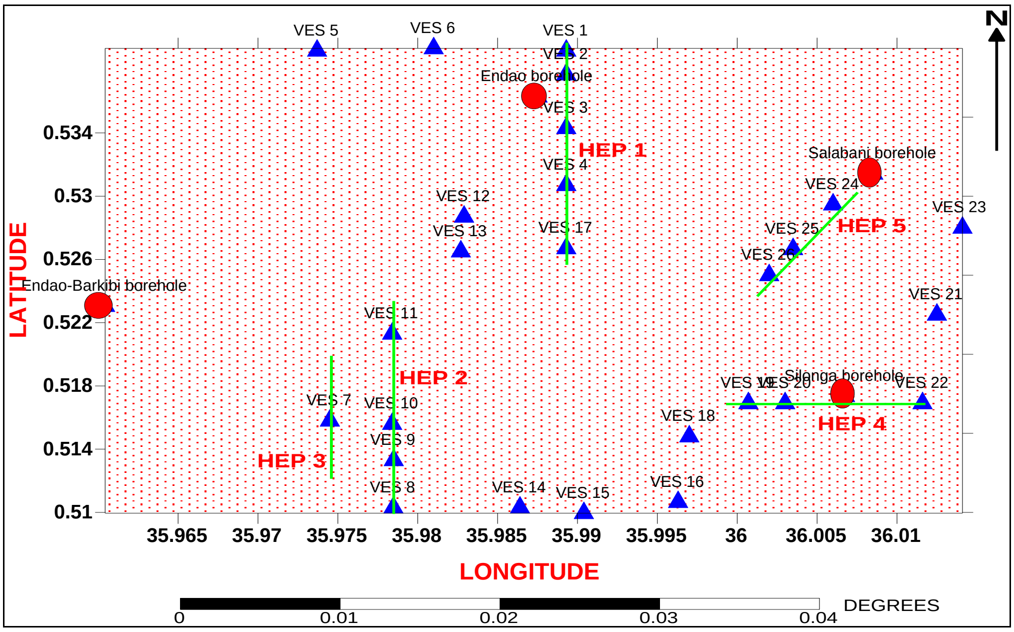


Figure 1.2: Location of HEP and VES stations.

Horizontal electrical profiling was used to determine the lateral variation of resistivity using Wenner electrode array. Regions where low resistivity values were observed were selected as points where vertical electrical sounding was carried out using Schlumberger array in order describe the vertical variation of resistivity with depth.

2.2 Mathematical Formulation

At any given layer, the general solution for the potential was defined in cylindrical coordinates since the electrical fields have cylindrical symmetry with respect to vertical line through the current source. Thus the potential $V(r)$ at the surface resulting from any number of horizontal layers was derived by solution of Laplace's equation according to Koefoed [7] as written in equation (1) below:

$$V(r) = \frac{\rho_1 I}{2\pi} \int_0^\infty K(\lambda) J_0(\lambda r)\, d\lambda \qquad (1)$$

In equation (1) above, $K(\lambda)$ is the Kernel function, $J_0(\lambda r)$ is the Bessel function of order zero, λ is a variable of integration and ρ_1 is the resistivity of the first layer.

According to Niwas and Singhal [8] the layer thickness and resistivity can be used to calculate the Dar Zarrouk parameters which form the basis of aquifer characterisation. The Dar Zarrouk parameters were determined and used alongside the recovery test measurements of Salabani borehole and Endao-Barkibi. The values of the time ratio $\left(\frac{t}{t'}\right)$ and residual drawdown (s') were obtained from the recovery test of the two boreholes within the study area and used to calculate the transmissivity (T) values and the hydraulic parameters of the other sounding points where pumping tests were not done using equation (2) below derived from Jacob and Cooper method:

$$T = \frac{2.303\, Q}{4\pi \Delta s'} \qquad (2)$$

The parameter $\Delta s'$ in equation (2) above represents the residual drawdown per log cycle and Q is is the discharge rate of the aquifer. Aquifer transmissivity T is related to the hydraulic conductivity K and the aquifer thickness h by equation (3) below:

$$T = Kh \qquad (3)$$

Equation (3) can be written as equation (4) below:

$$T = K \frac{R_T}{\rho} = K \sigma R_T \qquad (4)$$

Where σ is the conductivity while $R_T = h\rho$ is the transverse resistance as described by Niwas and Singhal [9] and Kumar *et al.* [10]. In areas of similar geologic setting and water quality, the product $K\sigma$ remains fairly constant and it can be expressed as equation (5):

$$A = K\sigma = \frac{K}{\rho} \qquad (5)$$

III. Results And Discussion

3.1 Qualitative Interpretation

3.1.1 Horizontal Electrical Profiles

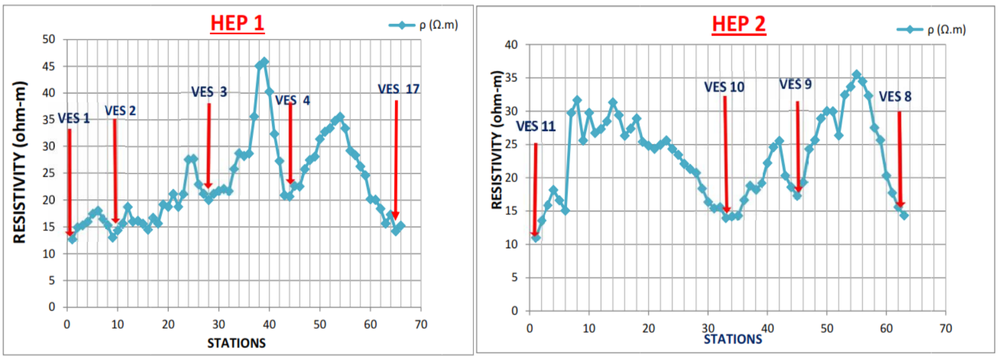


Figure 1.3: Graphs of Horizontal electrical profiles.

The graphs above in Fig.1.3 show the qualitative interpretation of two profiles in the study area obtained using Wenner configuration. The low resistivity anomalies seen in the profiles were interpreted as shallow bedrock formations, fractured zones and faults that were likely to be water bearing layers and conduits to groundwater. These points with low resistivity values were identified as the regions suitable for further groundwater investigation using vertical electrical sounding (VES).

3.1.2 Interpretation Of The Apparent Resistivity Curves

The vertical electrical sounding resistivity data collected were analyzed and apparent resistivity curves were drawn as shown in Fig.1.4, Fig.1.5 and Fig.1.6. These field curves were observed qualitatively to get an idea on the number of layers and the resistivity of the layers. It was observed that the dominant type of curve was of K-type followed by combination of curves that include Q, KH, QK, and HKH indicating three to six subsurface medium. The field curves shows that the top soil has both low resistivity and high resistivity since the subsurface is composed of varying superficial earth material ranging from weathered to dry formation. The middle layers tend to depict a uniform orientation with some layers being comparatively resistive indicating presence of compact formation while other field curves decrease exponentially indicating presence of dry to moist earth material. The basement rocks have comparatively low resistivity values (circled in red) at depth below 100 m in all the sounding points within the study area. These correspond to the deep aquifers that are highly conductive, thus can be attributed to presence of geothermal fluid that is saline in nature.

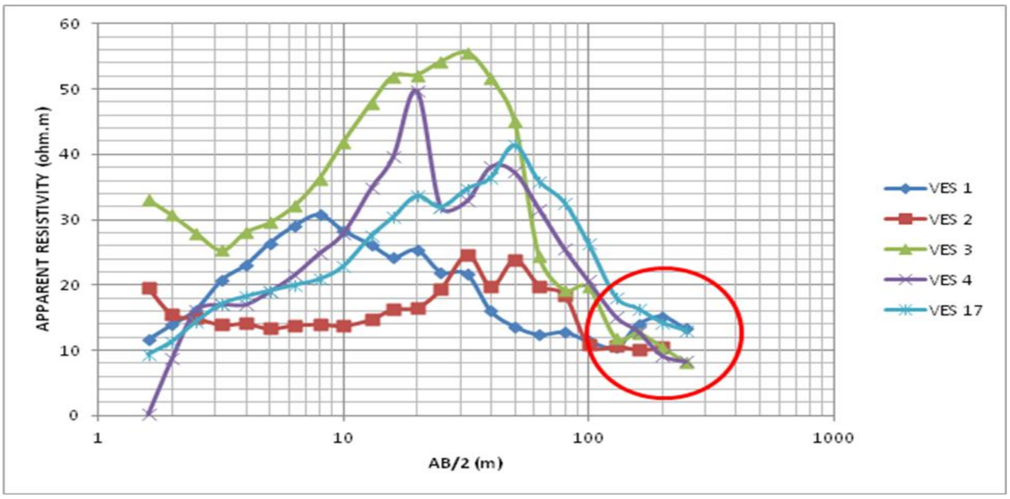


Figure 1.4: Graph of apparent resistivity versus electrode spacing for HEP 1

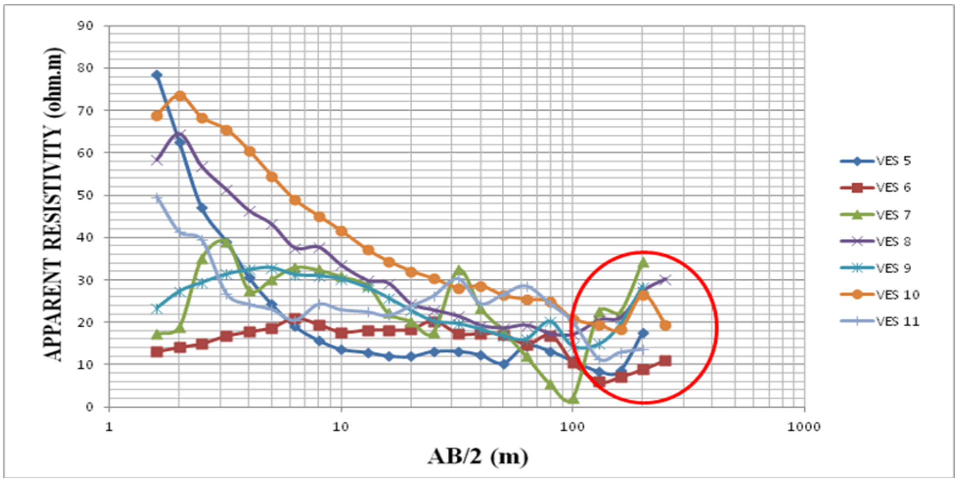


Figure 1.5: Graph of apparent resistivity versus electrode spacing for VES 5, 6, 7& HEP 2

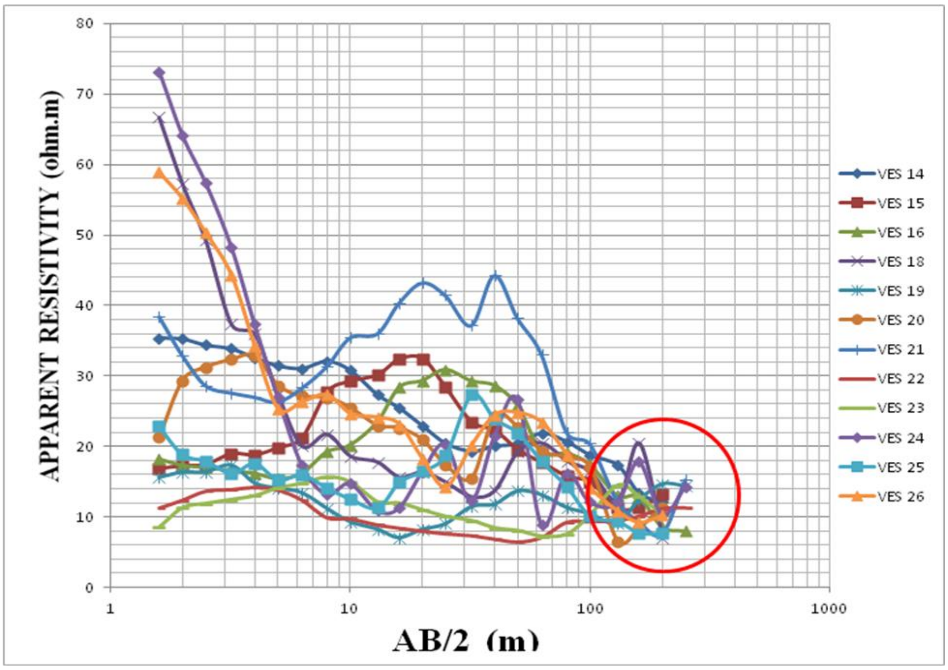
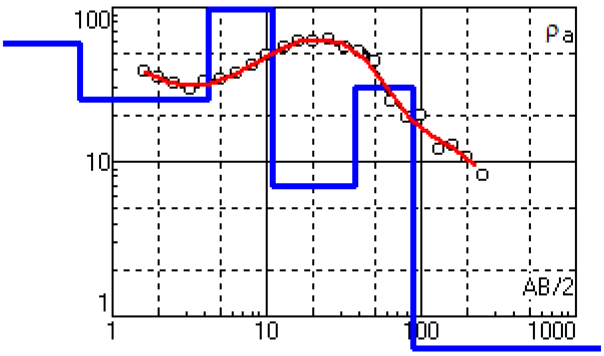


Figure 1.6: Graph of apparent resistivity versus electrode spacing for the remaining VES Points.

3.2 Quantitative Interpretation

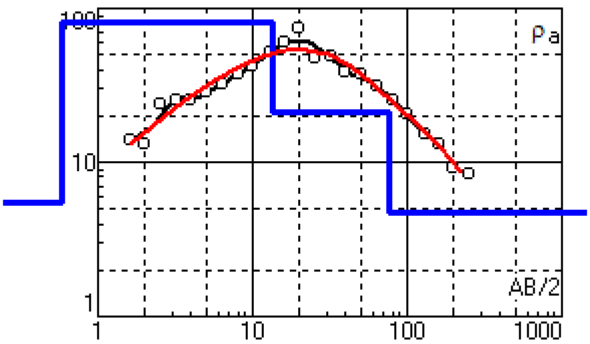
3.2.1 VES Models' Interpretation

Quantitative interpretation of VES data was done using IPI2win inversion software. This program calculates and display the information on the number of layers (N), apparent resistivity (ρ), thickness (h), depth (d) and altitude (alt) of each ground layer. The Fig. 1.7a to Fig. 1.7c below shows a graphical interpretation and presentation of the resistivity data and the modelled parameters of some sounding points in the study area.



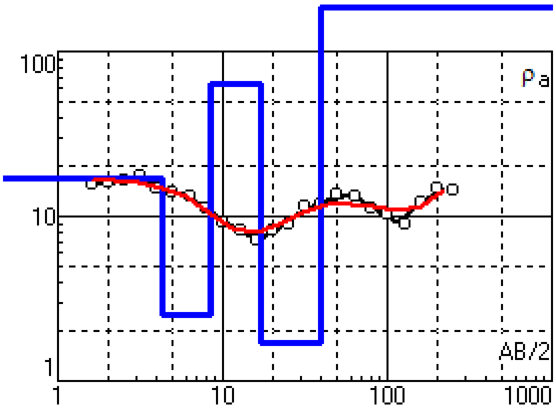
N	ρ	h	d	Alt
1	58.3	0.617	0.617	-0.6167
2	25.6	3.58	4.2	-4.201
3	208	6.72	10.9	-10.92
4	7.08	26.8	37.7	-37.74
5	30.2	52.1	89.8	-89.82
6	0.129			

Figure 1.7a: VES 3 along profile 1(RMS =3.84%)



N	ρ	h	d	Alt
1	5.58	0.58	0.58	-0.5804
2	80.1	12.9	13.5	-13.5
3	21.3	63.2	76.7	-76.72
4	4.77			

Figure 1.7b: VES 4 along profile 1(RMS = 8%)



N	ρ	h	d	Alt
1	16.8	4.25	4.25	-4.25
2	2.49	4.14	8.39	-8.39
3	64.2	8.58	17	-16.97
4	1.72	23.1	40.1	-40.07
5	975			

Figure 1.7c: VES 19 along profile 4 (RMS= 6.85%)

The resistivity and thickness parameters of all the VES points within the study area were tabulated as shown in Table 1.1. It is observed that the aquifers thickness is highly variable ranging from 7.55 m to 63.2 m with the second and third layers being the weathered formation.

Table 1.1: Table of resistivity and thickness of the Geoelectric layers

VES No.	ρ1(Ωm)	ρ2(Ωm)	ρ3(Ωm)	ρ4(Ωm)	ρ5(Ωm)	ρ6(Ωm)	h1 (m)	h2 (m)	h3 (m)	h4 (m)	h5 (m)
1	5.63	163	21.1	7.85	22.6		0.676	0.842	17.8	51.7	
2	135	19.9	26.9	2.16	385		0.393	4.51	38.3	41	
3	58.3	25.6	208	7.08	30.2	0.129	0.617	3.58	6.72	26.8	52.1
4	5.58	80.1	21.3	4.77			0.58	12.9	63.2		
5	82.9	12.7	2.98	1292			1.45	40.7	28		
6	4.59	19.8	1.3	740			0.251	44.1	30.2		
7	8.24	190	23.6	3.49	6979		0.516	0.464	25	18.6	
8	64.8	34.6	18.4	10	2555		1.58	6.67	39.9	53.8	
9	11.3	38.7	18.7	4.85	2106		0.37	4.53	36.3	26.8	
10	73.2	41.2	28.4	6.25	1542		2.13	3.79	49.4	49.4	
11	77	20.7	75.6	3.23	1398		0.831	13.9	14.6	51.5	
12	12.6	28.7	80.5	1.23	263		0.301	12.7	12.8	27.6	
13	258	12.6	71.5	1.92	540		0.284	11.1	12.3	35.8	
14	34	9.85	54.6	2.17	151		8.79	10.7	24.8	50.2	
15	16.5	128	17.3	2.99	748		3.55	2.32	47.4	37.3	
16	20.2	10.2	132	4.34	41.1	0.0685	1.74	2.62	5.51	11.6	36.4
17	3.33	31.8	51.7	11.2			0.304	6.69	29.3		
18	79.5	19.9	5.45	49.8	1.25		1.24	8.49	6.84	27	
19	16.8	2.49	64.2	1.72	975		4.25	4.14	8.58	23.1	
20	11.4	162	16	79.2	1.4	440	0.592	0.544	10.9	10.5	26.3
21	69.2	23	55.6	2.65	242		0.589	3.69	32.4	60.7	
22	6.7	43.5	8.04	2.45	13.2		0.636	0.661	15.9	7.55	
23	3.14	16.6	5.19	60	0.222		0.295	9.04	31	31.8	
24	79.5	9.28	89.3	1.44	364		1.78	10.4	12	28.3	
25	20.3	5.31	124	0.77	433		3.09	3.65	7.66	22.1	
26	72.4	27.2	6.35	71.4	1.15	499	1.14	6.61	4.33	14.4	25.1
EndaoBarkibi	63.7	33.1	18	6.11	3003		1.79	6.58	45.1	30.4	
Salabani	65.2	10.2	56.5	2.6	728		2.23	10.3	12.7	30.5	

This data in Table 1.1 integrated with the driller's logs reveal the possible presence of 3-6 geoelectric layers which were categorized into three inhomogeneous formations. The first formation represents dry to moist alluvial deposits that are very recent and sufficiently extensive with some points overlain by horizontal torrent wash and resistivity values ranging between 2.49 Ωm and 258 Ωm. The second formation has a lower resistivity range lying between 0.77 Ωm and 71.5 Ωm. This formation is described as the weathered and fractured basalts with thin bands of tuffaceous sediments. The third formation represents two zones composed of the Kapthurin sediments that are weakly faulted having very low resistivity values ranging between 0.0685Ωm and 0.222 Ωm and the other zone consists of the grid-faulted Lake Hannington lavas having high resistivity values ranging between 499 Ωm and 6979 Ωm. The low resistivity values represent a possible geothermal fluid with high salinity while the high resistivity values represent the fresh basement rock as described in Table 1.2 below.

Table 1.2: Probable lithology of the study area

FORMATION	LAYER(N)	PROBABLE LITHOLOGY	(ρ) RANGE (Ωm)	THICKNESSRANGE(m)
FIRST	1	Unsaturated top alluvial deposits.	**3.14 – 258**	**0.284 – 8.79**
	2	Dry to moist soil alluvial deposits.	**2.49 - 190**	**0.464 – 44.1**
SECOND	3	Slightly weathered and fractured basement	**5.19 – 71.5**	**4.33 – 63.2**
	4	Highly weathered and fractured basement	**0.77 – 11.2**	**7.55 – 60.7**
THIRD	5	Fresh basement rock compact and weathered basalts and tuffs	**0.222 - 6979**	**25.1 – 52.1**
	6	Basement rock(Geothermal basement)	**0.0685 - 499**	∞

3.2.2 Aquifer Hydraulic Properties

The discharge rates (Q) and recovery measurements obtained from the pumping tests of two boreholes; Salabani borehole and Endao-Barkibi shown in Table 1.3 were used to calculate the aquifer hydraulic conductivity and transmissivity values. This was done by drawing graphs of residual drawdown against time ratio as shown in Fig. 1.8 and Fig. 1.9 and then substituting the values of $\Delta s'$ in equations (2) and (3). The results obtained were used to estimate the aquifer hydraulic parameters of other sounding points within the study area as shown in Table 1.4

Table 1.3: The aquifer parameters of the two boreholes

Aquifer Parameters	Salabani borehole	Endao-Barkibi borehole
Q	2.7	2
$\Delta s'$	0.41174	1.17853
Transmissivity (m^2/h)	1.2018	0.31101
Hydraulic conductivity(m/day)	3.605	0.933

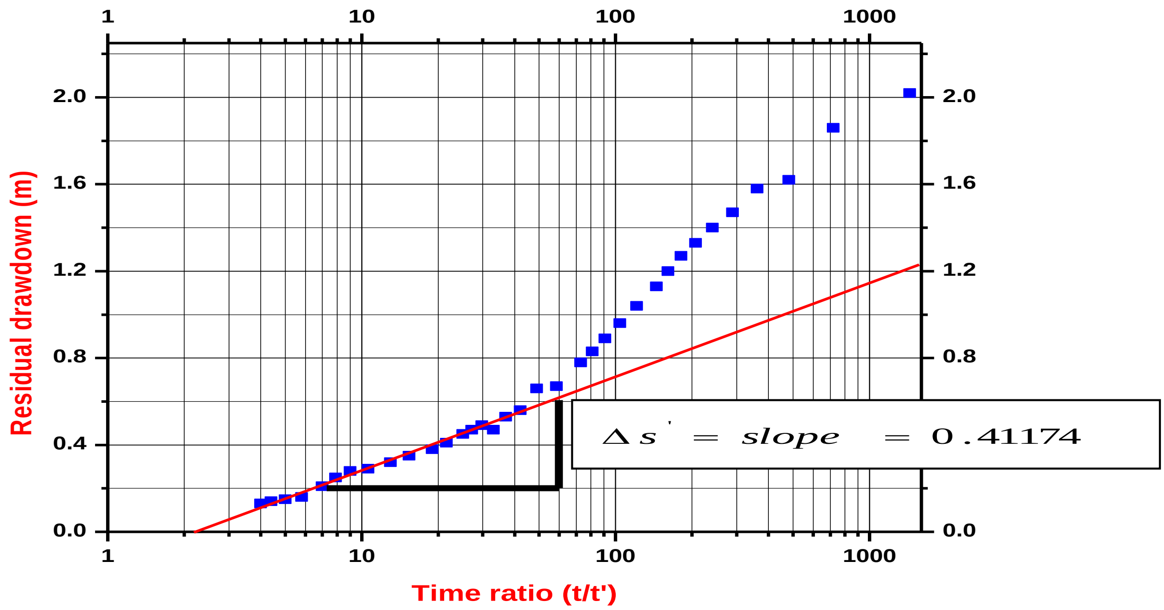


Figure 1.8: Graphs of Residual drawdown against time ratio for Salabani Borehole.

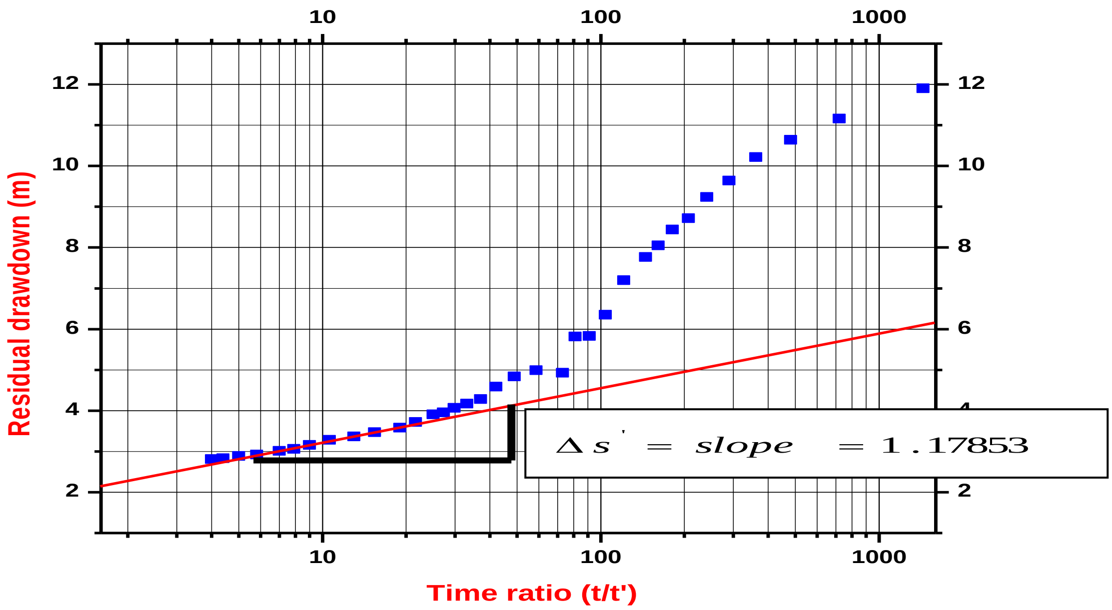


Figure 1.9: Graphs of Residual drawdown against time ratio for Endao-Barkibi Borehole.

Table 1.4: The aquifer parameters of the various sounding points in the study area

VES No.	h(m)	ρ (Ωm)	Transverse Resistance (R_T) (Ωm^2)	Hydraulic Conductivity from pump- test (m/day)	A =K/ρ	Calculated transmissivity $T=AR_T$ (m^2/day)	Calculated Hydraulic conductivity (m/day)	Aquifer Depth (m)
1	51.7	7.85	405.85			323.621	6.260	71.1
2	41	2.16	88.56			70.618	1.722	84.2
3	52.1	30.20	1573.42			1254.645	24.081	89.8
4	63.2	21.30	1346.16			1073.428	16.985	76.7
5	28	2.98	83.44			66.535	2.376	70.2
6	30.2	1.30	39.26			31.306	1.037	74.5
7	18.6	3.49	64.91			51.762	2.783	44.6
EndaoBarkibi	30.4	6.11	185.74	0.933	0.1527	148.112	4.872	81
8	53.8	10.00	538.00			429.001	7.974	102
9	26.8	4.85	129.98			103.646	3.867	68
10	49.4	6.25	308.75			246.197	4.984	105
11	51.5	3.23	166.35			132.644	2.576	80.8
12	27.6	1.23	33.95			27.070	0.981	53.4
13	35.8	1.92	68.74			54.810	1.531	59.5
14	50.2	2.17	108.93			86.864	1.730	94.5
15	37.3	2.99	111.53			88.932	2.384	90.5
16	36.4	41.10	1496.04			1192.942	32.773	57.9
17	29.3	11.20	328.16			261.675	8.931	36.3
18	27	49.8	1344.60			1072.184	39.711	43.6
19	23.1	1.72	39.73			31.682	1.372	40.1
20	26.3	1.40	36.82			29.360	1.116	48.9
21	60.7	2.65	160.86			128.266	2.113	97.4
22	7.55	13.20	99.66			79.469	10.526	24.7
23	31	5.19	160.89			128.294	4.139	72.1
SALABANI	30.5	2.60	79.30	3.605	1.442	60.802	1.994	50
24	28.3	1.44	40.75			32.496	1.148	52.5
25	22.1	0.77	17.02			13.569	0.614	36.5
26	25.1	71.40	1792.14			1429.052	56.934	51.6
					average A=0.7974			

The hydraulic conductivity values obtained range between 0.614 m/day and 56.934 m/day while the transmissivity values range between 13.569 m^2/day and 1429.052 m^2/day. High transmissivity values were located at the mid-central and the stretch towards the eastern part of the study area as shown in Fig. 1.10 below. These regions with high transmissivities and hydraulic conductivities were interpreted as the fractured and weathered zones with high yield potential for potable groundwater development at shallow depths and a possible geothermal basement in the deep aquifers.

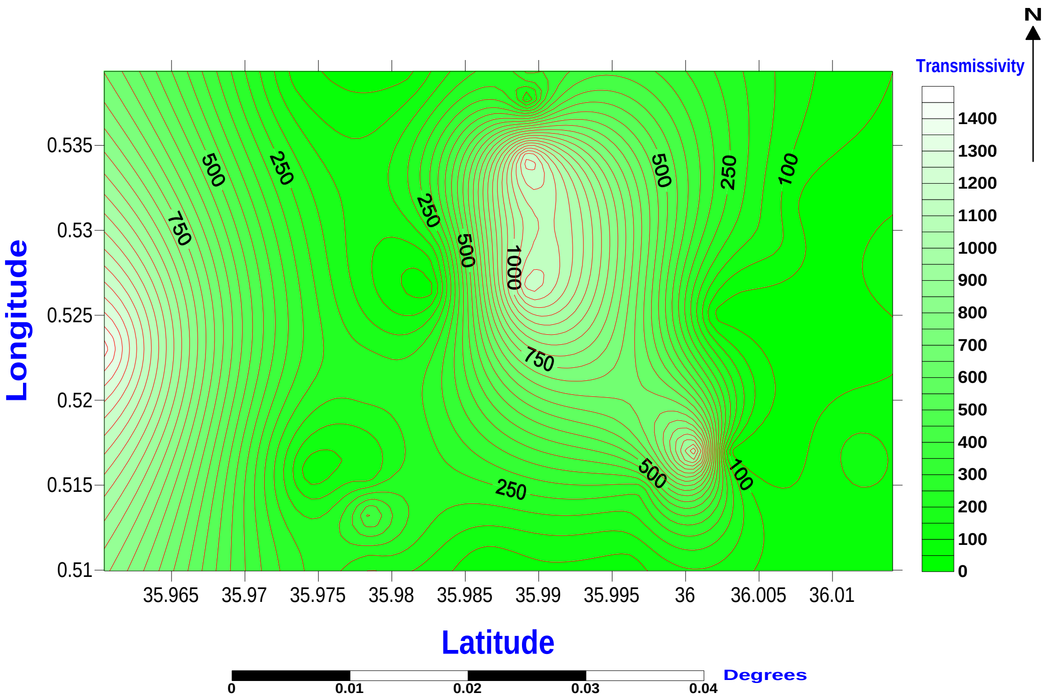


Figure 1.10: Aquifer transmissivity map of the study area

IV. Conclusion And Recommendation

The results of the geoelectrical resistivity investigation integrated with borehole data have established the existence of aquiferous units in Marigat area. This has provided an understanding of aquifer characteristics especially the thickness, depth to bedrock and fractured zones which are required for locating points with high potentials for groundwater occurrence prior to drilling. The results clearly show 3-6 interpretable geoelectric layers that are categorized into three inhomogeneous formations with the second formation being good for potable groundwater development at shallow depths ranging between 35 m – 50 m. The low resistivity values at a depth below 100m revealed possible presence of deeper aquifers that have a higher potential of geothermal fluid within the basement rock. It is recommended that the drilling of any borehole in search of potable water in the region should not exceed a depth of 50m and that laboratory analysis should be carried out to investigate on the salinity of the water. Further studies are required to achieve a more comprehensive understanding of this resource and their full potentials and vulnerabilities especially in areas surrounding HEP 1, the mid central and the stretch towards the eastern part of the study area where deep geothermal aquifers are likely to be located. This entails using other geophysical methods such as surface electrical tomography, remote sensing, gravity and aeromagnetic method in order clearly define the possible causative bodies.

Acknowledgement

We wish to acknowledge Mines and Geology department for providing the field instruments, geological maps and geological reports of Marigat area.

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