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Geophysical Investigation and Characterization Of Groundwater Aquifers In Kangonde Area, Machakos County In Kenya Using Electrical Resistivity Method.

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Abstract: *This study aimed at evaluating geophysical structure of water bearing aquifers of Kangonde area in Machakos County Kenya. Electrical resistivity l survey was carried out to delineate subsurface layers and characterization was done. A Global Positioning System (GPS) was used for positioning of the stations during survey. Schlumberger and Wenner arrays were used for Vertical Electrical Sounding (VES) and horizontal profiling respectively. ABEM SAS 1000 terrameter was used to measure the apparent resistivity. Surfer 10 software generated contour maps. Qualitative data analysis involved plotting apparent resistivity curves on log-log graph from field data. Quantitative data analysis involved the use of IP2Win software to describe true resistivity variations with depth. Resistivity results shows highly conductive zones at a depth of 70m to 160m with values of low resistivity ranging from 10Ωm to 100Ωm. Stations within 979900Northing 348000Easting and 980450Northing 349000Easting respectively displayed low resistivity measurements, high values of Transverse resistance* R_T *(*Ωm^2*), transmissivity (*m^2*/day) and longitudinal conductance* $S(\Omega^{-1})$ *with deeper aquifers at a depth of 123.84m and 84.30m respectively. Between Easting 348000 and 349000, low resistivity values lie on a steep gradient signifying the study area as tilted. The basement rock for the study area is compact with high resistivity values between 1000Ωm and 5000Ωm.*
Keywords: *Basement Rocks, electrical resistivity,Geophysical, Water bearing Aquifer.*

I. Introduction

This study report presents results of geophysical formations in Kangonde area, Machakos County in Kenya. Geophysical survey using electrical resistivity method was used to investigate water bearing potentials and aquifer characterization was done. Electrical resistivity technique was employed since it establishes electrical conductivity of parts of the earth providing qualitative and quantitative data about the subsurface. Electrical resistivity method has advantage of mapping resistivity variations for layered formations and structures such as fractures within rocks and groundwater exploration. Low resistivity values signified potential zones for ground water. Characterization was done using the information obtained from pumping test data for the study area. The empirical relations between aquifer parameters and resistivity are established for transforming resistivity distribution into porosity (permeability), transmissivity and hydraulic conductivity of the aquifer.

The study area.

Kangonde area is located in Machakos County in Kenya along Thika-Garissa highway approximately 106 km from Nairobi on eastern part of Kenya. The area isbounded by latitudes 1^0 04'S and 1^0 08' S and Longitudes 37^0 33'E and 37^0 43'E.The area lies at an altitude of about 1243m

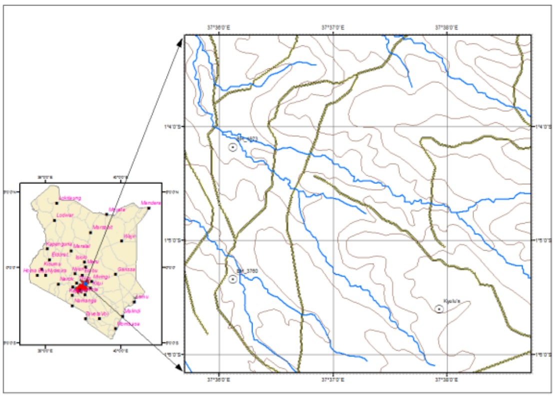

Figure1.1: Location of Kangonde area, in Machakos County.

Geology Of Study Area

The area of study is part of the extensive Mozambique belt segment which occurs east of the Rift System and is the largest of all the four major exposed segments of this belt in Kenya. The Eastern Mozambique Belt Segment (EMBS) stretches almost the full length of the country from north to south for a total distance of about 800 km and is about 200 km at its widest section. The other three segments of the Mozambique belt in Kenya are the north-west segment, the south-west segment (SWMBS) and the north-eastern segment (Nyamaiet al., 2003). In this study, the research location is within the Central sub-area II of the EMBS in Kenya North-East of Nairobi enclosed by such towns such as Thika, Machakos, Embu, Chuka, Kitui and Mwingi.

In the study area, the surface rocks comprise of Metamorphicrocks which are overlain bythe Yatta Plateau to the south. Kangonde area is entirely underlain by Precambrian rocks of the basement system. The area of interest is located in Eastern side of Gregory Rift Valley. Before formation of Rift Valley the whole area was made up of Precambrian basement system crystalline rock of Mozambique belt. These rocks were laid down, metamorphosed, exposed and eroded (Dodson 1953). At the beginning of Miocene period, the eruption of Phonolites resulted in large part sub-Miocene surface being covered by lava i.e. resulting Yatta Plateau. In Archaean times, the study area underwent powerful east –west compression resulting in folding and tilting which depressed the lower levels in the crust. Accession of heat and magmatic fluids, made the whole succession to be transformed into crystalline schist, gneisses and granulites making the region to tilt (Mathu 1992).

According to a geological report by Nyamai et al. (2003), Yatta District has many complex basement rocks and water bearing formations are very scarce. Much of groundwater in the area is found on temporary aquifers and fractures. The area generally has undergone shearing and thrust forces. The Yatta shear zone is one of the key deformations that have affected the occurrence of groundwater. Water scarcity has been a great challenge for the locals over the years. This is attributed to the fact that the area lies within the Arid and Semi-Arid region of Kenya associated with low and unreliable rainfall and very high temperatures during the dry spell, increasing the evaporation rates. Several boreholes have been dug in the area, most of which end up being unsuccessful due to poor exploration methods. Small scale earth dams, hand dug wells and boreholes have been used as the sources of water. Surface water sources have not been promising owing to the fact that the area receives inadequate rainfall and very high temperatures

Methods and Analytical Procedures

The resistivity equipment used in this research was a terrameter model ABEM SAS 1000. The resistivity technique utilized by the terrameter is direct coupling that occurs between the ground and current injected into the ground. It measures the current applied to the ground and it also has a potentiometer to measure output voltage. The GPS is a satellite based navigation system and was used to locate positions. A hammer was used to pin the electrodes to the ground to about 15cm to 40cm depth. To enhance contact and coupling between the current and electrodes, some water was poured on all the electrodes.Wenner Array for constant separation transverse was applied with arrangement as shown in figure 2.1. The four electrodes A, M, N, and B are placed at the surface of the ground along a straight line so that AM = MN = NB = a.

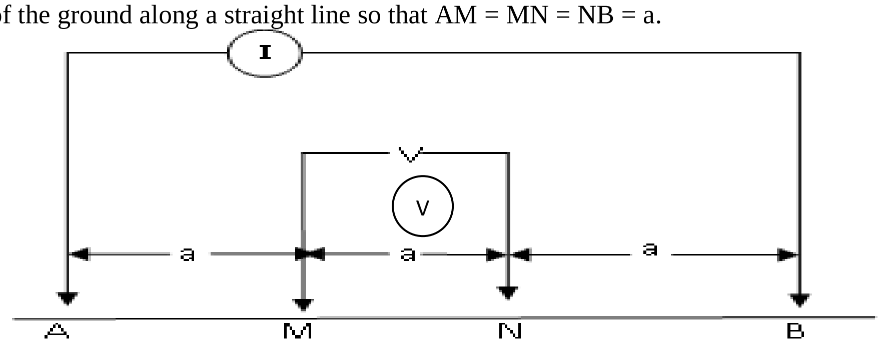

Figure 2.1: Wenner Array (Zohdy et al. 1990)

For Wenner array, equation 1 is used to calculate apparent resistivity where a=100m,

$$\rho_a = 2\pi a \Delta \frac{V_{MN}}{I} \quad (1)$$

Sclumberger array for vertical electrical sounding was also used as in wenner but AB≥5MN as in figure 2.2.

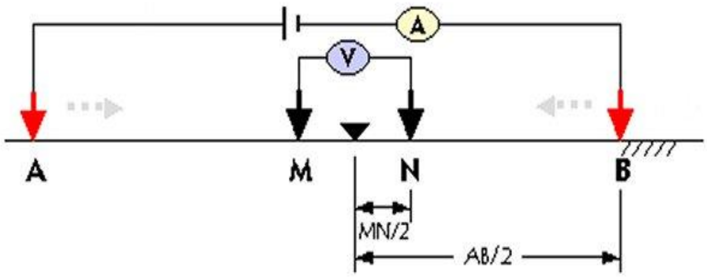

Figure 2.2: Schlumberger array (Zohdy et al. 1990)

For any linear, symmetric array AMNB of electrodes, equation 1 can be written in the form:

$$\rho_a = \pi \frac{\left(AB/2\right)^2 - \left(MN/2\right)^2}{MN} - \frac{\Delta V}{I} \quad (2)$$

Surfer software and IPI2Win software are used for qualitative and quantitative analysis respectively. Surfer is a powerful contouring, gridding, and surface mapping package for qualitatively analyzing geophysical data and is used to generate quality maps quickly and easily. This software is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid. IPI2WIN is software that applies the curve matching technique, where a graph of the field readings is matched against a theoretical curve which has been computed for different layer resistivity. The software converts the apparent resistivity (as a function of electrode spacing) to the true resistivity asλ a (function of depth) using the Laplace equation of cylindrical coordinates of this form given in equation 3.

$$\rho_a(s) = s^2 \int_0^\infty T(\lambda) J_1(\lambda s) \lambda d\lambda \quad (3)$$

Where sis half of the current electrode spacing (AB/2), T (λ)is the resistivity transform function, λ is the integral variable and J_1 denotes the first order Bessel function.

II. Data Analysis and Discussion of Results

Fieldwork

An area of 16km^2 was surveyed. Electrical resistivity data was collected along three (3) horizontal profiles with interspacing of 1000min line with the nothings. Each profile had 10 stations, totaling to thirty (30) stations, measured using the Wenner electrode configuration and inter electrode spacing of a 100 meters. The Vertical electrical Sounding (VES) profiles and design were dictated by the lateral resistivity anomalies sited by the Wenner data. Orientations spacing (AB/2) for each station, was a maximum of 250meters.Resistivity were measured at five potential electrode MN/2 spacing of 0.5 m, 2 m, 5 m, 10m and 25m. This was done in order to determine the depth at which there is a resistivity inversion, which would indicate conducting subsurface structure, in this case, groundwater accumulation.

Wenner contour map

Hachured contours and solid contours, represent resistivity lows and highs respectivelyalong 3 profiles P1, P2 and P3as shown in figure 4.2a.

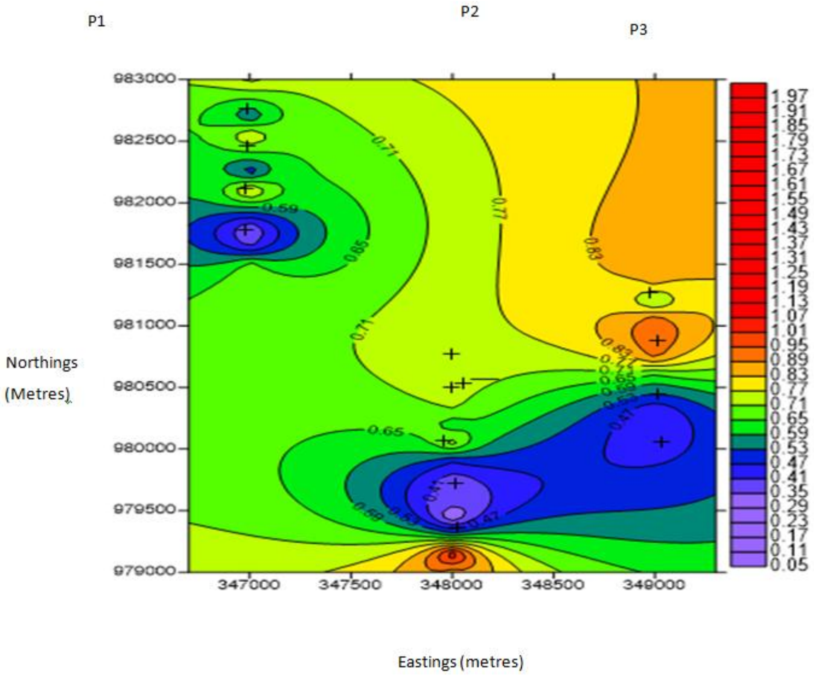

Figure 3.1a: 2D Contour map of the wenner profiles

Vertical electrical sounding data presentation.

Five (5) transect lines TI, T2, T3 and T4 were established in low resistivity zones established by wenner contour map. Each transect had four (4) VES stations totaling to twenty stations with a separation distance of 200m.Points where sclumberger soundings were done was picked as in the wenner contour map shown in figure 4.1b.

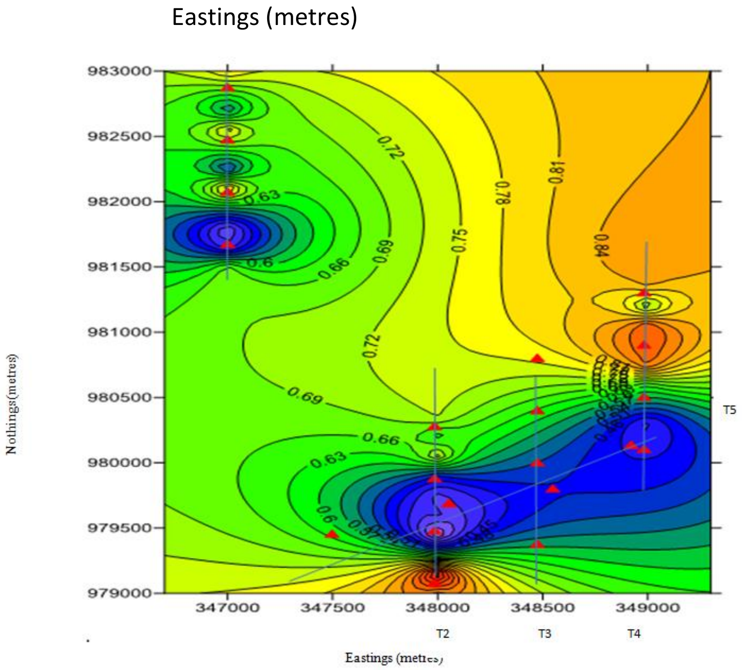

Figure 3.1b: 2D Contour map showing sclumberger VES points

Qualitative interpretation

Field data was qualitatively interpreted by use of apparent resistivity curves and Hummel's cumulative curves. The VES resistivity data was entered in Microsoft excel software and electrical sounding curves of apparent resistivity against half current electrode separation AB/2 were plotted on a log-log sheet. Through visual inspection, the trends of the curves were interpreted.

4.5.1 Apparent resistivity curves

Curves of apparent resistivity (Ωm) against depth (m) for transect 1, 2, 3, 4 and 5 were plotted and interpretation of each discussed.

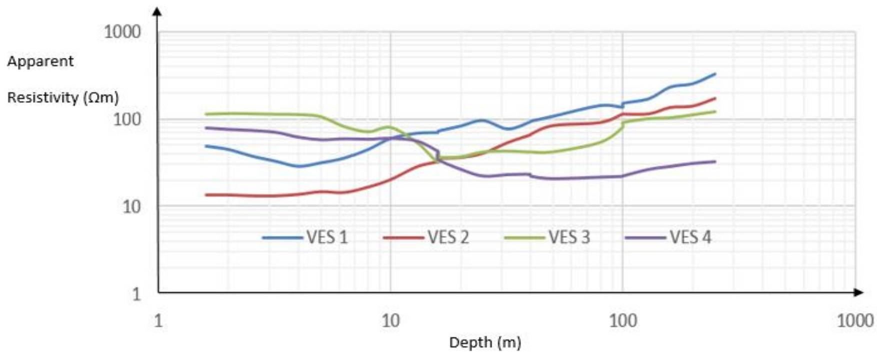

Figure 4.1a: Apparent Resistivity curves against depths for transect 1.

Transect 1, VES 1 and 2 and 3 indicate high resistivity variation with depth hence low porosity layer. Over a depth of 100m, the basement layer for the four VES points is compact basement. However, VES 4 shows the second layer as low resistive layer within high resistive layers an indication of shallow aquifers. This is a characteristic of p type curves.

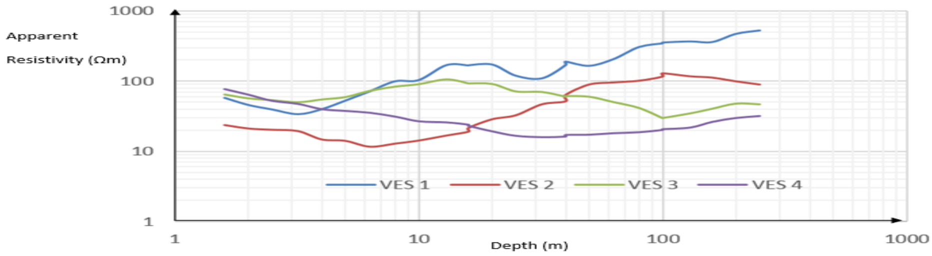

Figure 4.1b: Apparent Resistivity curves against depths for transect 2.

Transect 2 indicates highly resistive layers for VES 1 and 2 with the last layer being a compact basement. VES 3 and 4 indicates slightly low resistive layer between 10m and 100m and the last layer could either be highly conductive subsurface weathered material or presence of deeper aquifer within the subsurface.

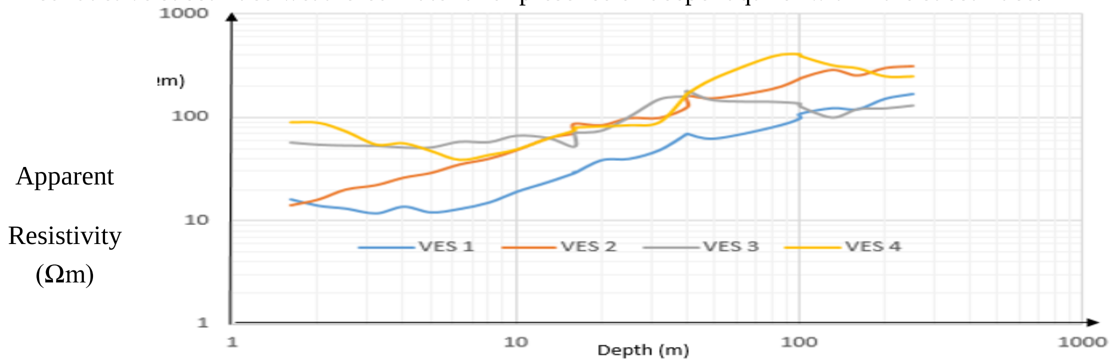

Figure 4.1c: Apparent Resistivity curves against depths for transect 3.

Transect 3 indicate highly resistive layers followed by compact basement layer for VES 1,2 and 3 apart from the last layer for VES 4 whose last layer is less resistive. This transect is characterized by low porosity layers.

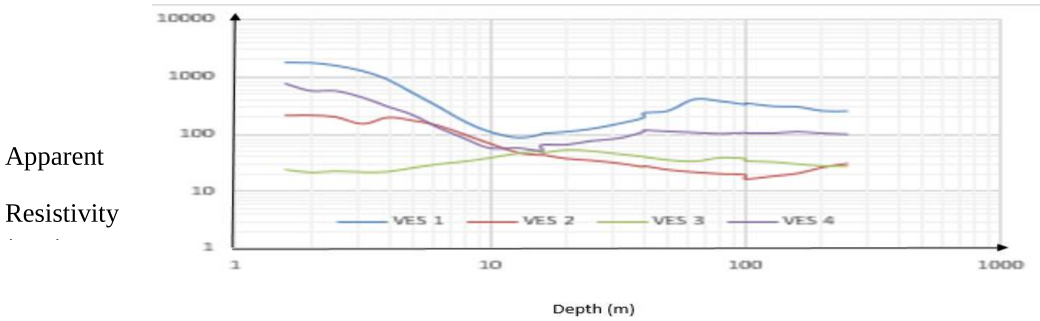

Figure 4.1d: Apparent Resistivity curves against depths for transect 5.

Transect 5 indicate high resistive layers near the surface which are due to top dry soils. The middle layer is a low resistive layer for the four profiles between 10m and 80 m. At a depth of 100m onwards the layer is a compact basement. This transect is characterized by low porosity layers for the middle section

4.5.2Hummel's cumulative resistivity curves

Cumulative sums of resistivity are plotted against corresponding electrode spacing values. Cumulative curves make use of assumption that equipotential hemispheres with a given radius are established around each current electrode. As electrode system is expanded to greater depth the button of hemisphere zones may involve layer of differing electrical resistivity, which produces a trend towards the lower or higher resistivity.

A curve of cumulative resistivity is generated from field data. The first point is plotted as per the value with the second point being the sum of the first and second data point respectively. Using constant increments of depth throughout, solid line curve constitutes a graphical integration of line curve. Straight lines drawn through the plotted lines in vicinity of the curve give the depth to the subsurface layer. Three consecutive lines drawn against the curve can be used to classify the corresponding theoretical curve

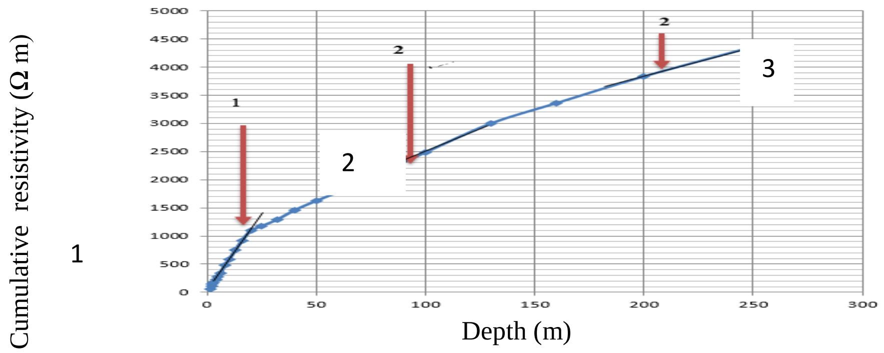

Figure 4.2a: Hummel's cumulative curves for transect 2 VES 2

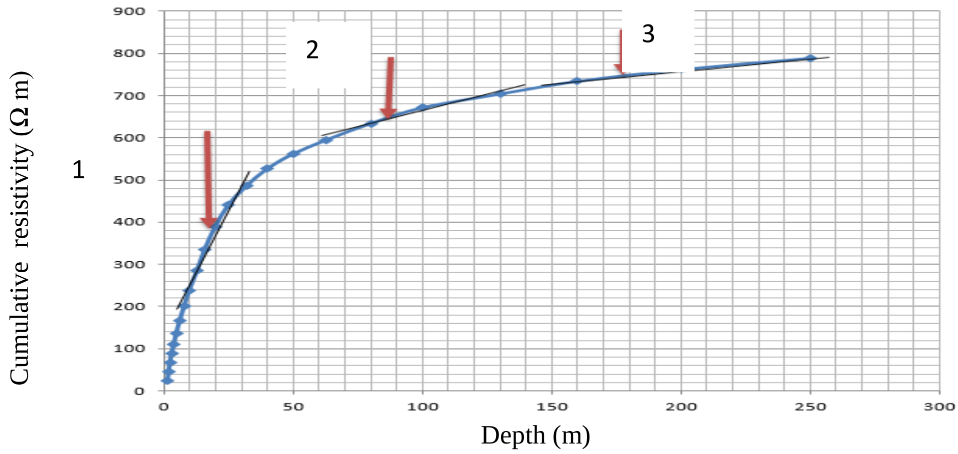

Figure4.2b: Hummel's cumulative curves transect 2 VES 4

The resistivity curves in figure 4.3a and 4.3b portray similar trends for VES 2 and 4. Three geo-electric layers1, 2, 3, represented by the gradient lines had a combination of $\rho_1 > \rho_2 < \rho_3$.This is H-type theoretical curve with layer 2 being more conductive than layer 1 and 3.

Quantitative Interpretation

Pseudo cross-sections and resistivity sections were modelled using IP2Win software. Subsurface is divided into rectangular cells where model blocks are tied to data points by use of default algorithm.

Modeling

The field data obtained for electrode spacing and resistivity values were uploaded in IP2Win worksheet. The software interactively semi-automate interpretation taking into account the effectiveness of field data and geological sense into consideration. Borehole lithological logs, geological reports, topographical maps, hydro geological and hydrological information were used to develop the conceptual model of the area.According to geological report of Kenya (14) by Dodson, the area is characterized by hard basement rock with ground water potential point a low resistivity layer within high resistive layers. The model parameters were the resistivity, the thickness and upper boundary depth and altitude which were presented by a blue line of the pseudo log plot in a curve window. The parameters were also listed in the table in separate window tilted with the fitting error values in model window. The error values represented relative difference theoretical and field apparent resistivity curves mean square deviations. The model was edited by altering Pseudo-crossections and resistivity sections generated. The model was edited by altering the quantity of layers by means of splitting or joining layers guided by least value fitting error which had to be less than ten percent. Pseudo-crossections showed the cumulative resistivity along the VES points while resistivity section shows the different layer formations.Pseudo-crossections and resistivity sections were showing formation of four to six layers as interpreted in figure 4.7.

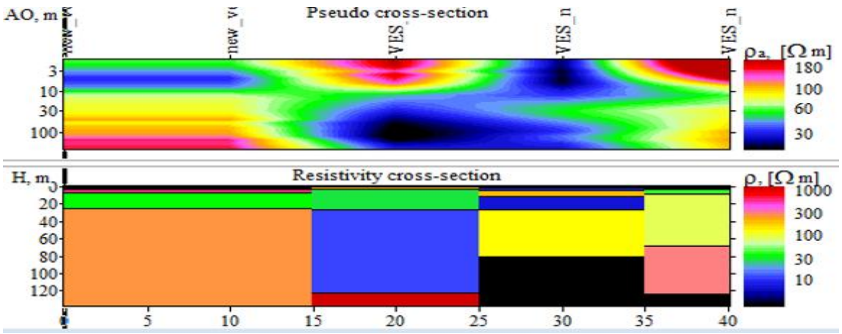

Figure 4.3a: Pseudo Cross-section and Resistivity section, Transect 2 VES 1, 2, 3 and 4

VES 1 and 2 shows the presence of four (4)resistivity layers with the last layer being a compact basement with resistivity ranging from 300Ω m to 1000Ω m. The third (3) layer from the surface for VES 2 shows the presence of a conducting layer within a depth of 80m to 100m while VES 2 indicate second (2) as a conducting layer at depth of 20m.VES 3 and 4 shows the presence of five (5) resistivity layers with VES 3 being highly resistive while VES 4 indicate third layer being conductive at a depth of 40m to 80m

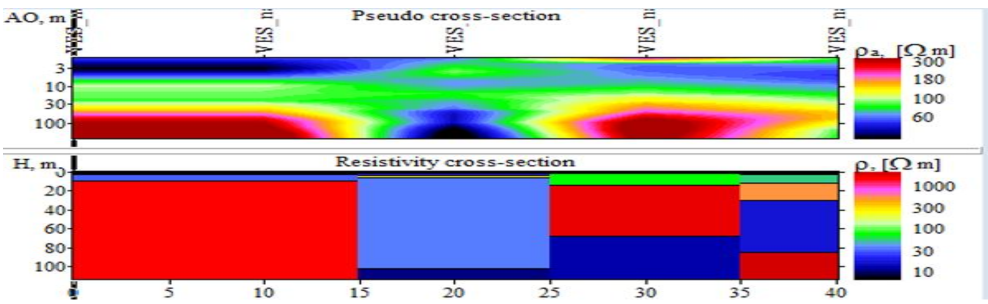

Figure 4.3b: Pseudo Cross-section and Resistivity section, Transect 4 VES 1, 2, 3 and 4

VES 1 shows four(4) layers with a thick compact basement below 20m.VES 2 and 4 shows the presence of six (6) resistivity layers with the last layer being a fresh basement and a compact basement respectively. VES 3 shows the presence of five (5) layers with high resistive layers ranging from 100 Ω m to 1000Ω m.

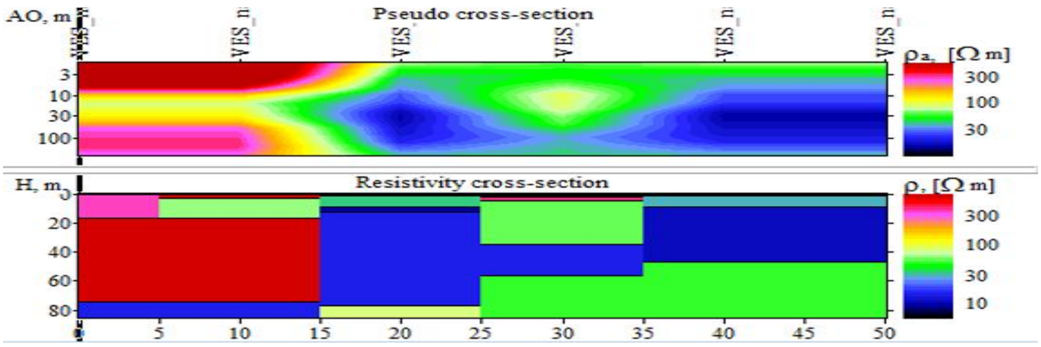

Figure 4.3c: Pseudo Cross-section and Resistivity section, Transect 5 VES 1, 2, 3 and 4

VES 1, 2 and 3 shows four (4) layers with a thick compact basement below 25m while between 5m to 20m there is conducting layer which is attributed to weathered sub-surface. VES 4 shows the presence of five (5) resistivity layers with the third layer being a fresh basement followed by a compact basement respectively.

Resistivity Curve Matching.

The computed apparent VES resistivity data for Five (5) VES soundings were was uploaded to the IP2WIN software and electrical sounding curves of apparent resistivity against half current electrode separation AB/2 were plotted on a log-log sheet. The software automatically plots the field and theoretical curves on the same logarithmic graph, with similar axes, and superimposes the field curve against the theoretical curves.

If a match is found, then the subsurface structure is assumed to be identical with the theoretical structure. The sounding curve windows for all the four VES soundings were represented as in figures 4.6a. On the right, next to the sounding curve window, is a table indicating the error of approximation; the first Column indicates symbols N, ρ, h and where N is the number of geo-electric layers is the specific depth of a geo-electric layer and is cumulative depth of geo-electric layers.

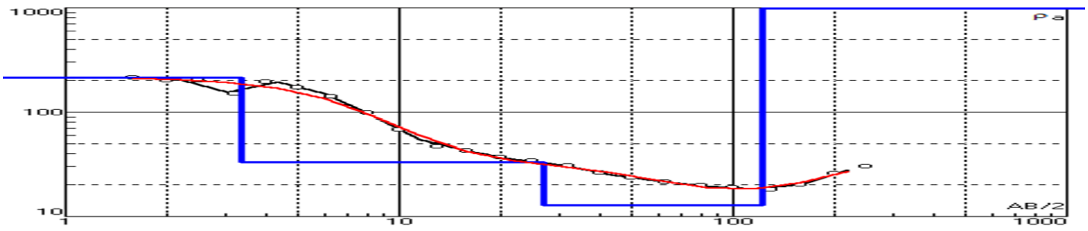

Figure 4.6a Resistivity (Ωm) against AB/2 (m), Transect 2 VES 2.

Table 4.3a: Geo-electric parameters transect 2 VES 2

Error = 7.58%				
N	P	**H**	**D**	**Alt**
1	214	3.36	3.36	-3.36
2	32.9	23.7	27.1	-27.06
3	12.9	95.4	122	-122.5
4	1041	-	-	-

The first sounding curve (Figure 4.6a) indicates a geo-electric section with four geo-electric-layers with the first, second, third and fourth layers having 214Ωm, 32.9Ωm, 12.9Ωm and 1041 Ωm respectively. The top layer has relatively high resistivity values, which could be due to unsaturated top soils while the second layer, which is imaged at 27.1 meters depth, could be a shallow aquifer followed by a deeper aquifer at a depth of 122m.

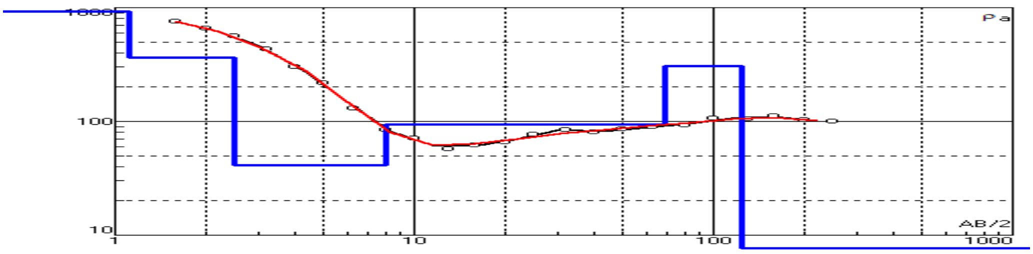

Figure 4.6b: Resistivity (Ωm) against AB/2 (m), Transect 2 VES 4.

Table 4.3b: Geo-electric parameters transect 2 VES 4

Error = 2.6%				
N	P	**H**	**D**	**Alt**
1	919	1.12	1.12	-1.12
2	365	1.,39	2.51	-2.51
3	41	5.53	8.04	-8.04
4	94.4	60.6	68.6	-68.6
5	305	55.2	124	-123.8
6	2.82	-	-	-

The second sounding curve (Figure 4.6b) indicates a geo-electric section with six geo-electric layers with resistivities 919 Ω m, 365 Ω m, 41 Ω m, 94.4 Ω m, 305 Ω m and 2.82 Ω m respectively. The top two layers and the fifth have relatively high resistivity, while the third, fourth and sixth layers, with an imaged cumulative depth of 124 meters, which is indicative of highly conductive infill within this layers. The sixth layer indicates very low resistivity value which indicates deeper aquifer at a cumulative depth of 124m.

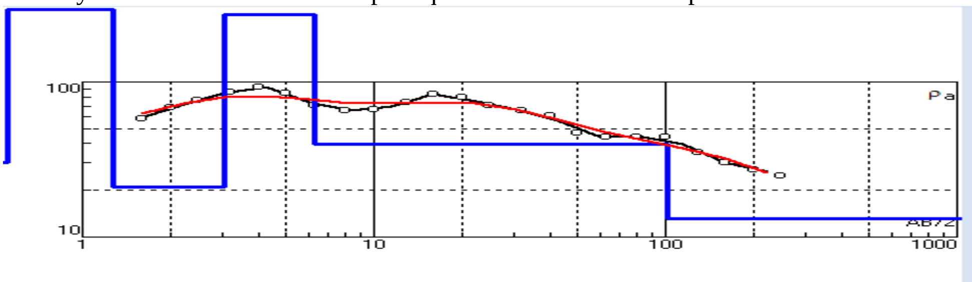

Figure 4.6c: Resistivity (Ωm) against AB/2 (m), Transect 4 VES 2.

Table 4.3c: Geo-electric parameters transect 4 VES 2

Error = 6.82%				
N	P	**H**	**D**	**Alt**
1	30.2	0.555	0.558	-0.5548
2	310	0.721	1.28	-1.276
3	20.9	1.77	3.05	-3.049
4	271	3.2	6.25	-6.255
5	39.6	95.8	102	-102.1
6	13.1	-	-	-

The third sounding curve (Figure 4.6c) show a geo-electric section with six geo-electric-layers with the first and third, fifth and sixth layers having 30.2Ωm, 20.9 Ωm, 39.6 Ωm and 13.1 Ωm. The second and fourth layers are high resistive layers. The top saturated soils could be responsible for the relatively low resistivity on the first geo-electric layer, while the third, fifth and sixth layer, signify highly conductive layer, signifying a shallow and a deeper aquifer.

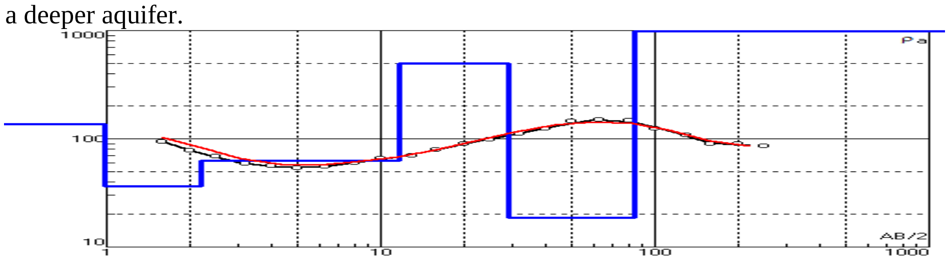

Figure 4.6d: Resistivity (Ωm) against AB/2 (m); Transect 4 VES Station 4.

Table 4.3d: Geo-electric parameters transect 4 VES 4

Error = 5.35%				
N	P	**H**	**D**	**Alt**
1	137	0.979	0.979	-0.979
2	36.6	1.22	2.2	-2.199
3	62.7	9.42	11.6	-11.62
4	497	17.6	29.2	-29.22
5	118.7	55.1	84.3	-84.32
6	4048			

The fourth sounding curve (Figure 32) also show a geo-electric section with six geo-electric layers with the first and second layers having 137Ωm, 36.6Ωm,62.7 Ωm,497 Ωm,18.7 Ωm and4048 Ωm respectively. The top unsaturated and loose soils could also be responsible for the relatively high resistivity on the first geo-electric layer, while the second layer and third layer, with an imaged cumulative depth of 2.2 meters, subsurface weathered formation. The fourth layer with high resistivity values, indicate the compact basement layer with thickness of 17.6m, followed by deeper aquiferous layer at a cumulative depth of 84.3m.the sixth layer is compact basement whose resistivity values are normally high

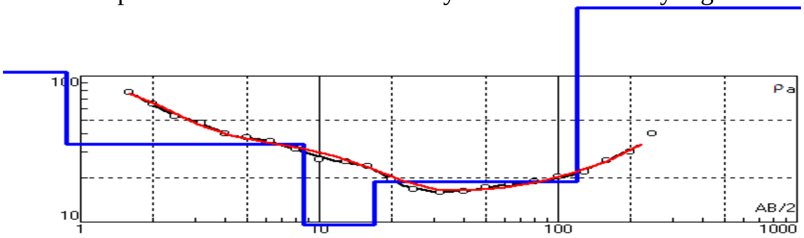

Figure 4.6e: Resistivity (Ωm) against AB/2 (m); Transect 5 VES Station

Table 4.3e: Geo-electric parameters transect 5 VES 4

Error = 6.82%				
N	P	**H**	**D**	**Alt**
1	107	0.87	0.87	-0.8704
2	34.1	7.74	8.61	-8.610
3	9.56	8.38	17	-16.99
4	18.9	103	120	-120.4
5	2027	-	-	-

The fifth sounding curve figure 4.6e indicates a geo-electric section with five geo-electric-layers with the first, second, third, fourth and fifth layers having 107Ωm, 34.1Ωm, 9.56Ωm,18.9c and 2027 Ωm respectively. The top layer has relatively high resistivity values, which could be due to unsaturated top soils while the third and fourth layer could be a shallow aquifer followed by a deeper aquifer at a depth of 120m. The basement is compact characterized by resistivity of 2027 Ωm.

Table 4.4: Summary of Resistivity and Thickness Inversion Results at VES Stations

VES No	**ρ1 (Ωm)**	**ρ2 (Ωm)**	**ρ3 (Ωm)**	**ρ4 (Ωm)**	**ρ5 (Ωm)**	**ρ6 (Ωm)**	**h1 (m)**	**h2 (m)**	**h3 (m)**	**h4 (m)**	**h5 (m)**	**Aquifer Depth(m)**
T2V2	214	32.9	12.9	1041	-	-	3.36	23.7	95.4	-	-	122.40
T2V4	919.0	365	41.0	94.4	305.0	2.82	1.12	1.39	5.53	60.6	55.2	123.84
T4V2	30.2	310	20.9	271	39.6	13.1	0.55	0.72	1.77	3.2	95.8	102.06
T4V4	137.0	36.6	62.7	497	18.7	4048	0.979	1.22	9.42	17.6	55.1	84.30
T5V4	107.0	34.1	9.58	18.9	2027	-	0.87	7.79	8.38	103.	-	120.00

However, borehole lithological logs, geological reports, topographical maps, hydrogeological and hydrological information were used to develop the conceptual model of the area. A constraint data was obtained from ministry of water for the borehole logs within Machakos County from the ministry of water (Kenya Ministry of Water, 2013) as given in table 4.5.

Table4.5: Borehole logs within Machakos County.

Ref: Kyuli's borehole (978050N 34800E)					
DIRECTION	**SERIAL NO.**	**TOTAL DEPTH**	**WSL(M)**	**WRL(M)**	**Q(M^3/day)**
6.7 NE	11885	70	41.4	14.1	0.7
4.0 SE	1595	82.3	64	30.5	10.9
4.3 NW	1973	121.3	30.2	20.4	2.83
3.4 WNW	3760	198.2	61	27.7	0.3
00(Ref point)	5024	110	52	16.24	1.1

The results for total depth of each borehole within this County correlated very well with the results obtained during this survey borehole. The reference borehole chosen for further analysis was Kyuli's borehole since it was within the study area with total depth of borehole as 110m and the remaining ones within 70m to

200m. Direction of the other boreholes are given in reference to Kyuli's borehole on coordinates 978050N 34800E.

Aquifer Characterization

Averaged values of hydraulic parameters were estimated through the use of archived test pumping data (Prime Rigs and Drillers, 2013). Conventional methods of measuring these parameters would require drilling boreholes which provides accurate information at every point of depth. However, collection of such detailed information was not viable economically for purposes of this study. The empirical relations between aquifer parameters and resistivity were established for transforming resistivity distribution into porosity (permeability). The total transverse resistance (T) and longitudinal conductance (S) are some of the Dar Zarrouk parameters used to define target areas of good groundwater potential. This characterization scheme was feasible as both electrical potential and groundwater channels through interconnected pore-spaces in the groundwater flow domain represented porosity.An analytical relationship between the aquifer transmissivity T_r and longitudinal conductance (S) was determined using equation 4.

$$T = Kb \qquad (4)$$

Where b is the aquifer thickness.

Pumping tests for Kyuli's borehole was used to calculate the hydraulic conductivity of the aquifers by plotting the graph of Residual drawdown against time ratio in a semi logarithmic paper governed by Theis's equation 5.

$$s' = \frac{Q}{4\pi T} \ln \frac{t}{t'} \qquad (5)$$

Where T is the transmissivity, t/t' is the time ratio, Q is discharge rate and s' is the residual draw down.

The Theis equation was created by Charles Vernon Theis (working for the US Geological Survey) in 1935 from heat transfer literature (with the mathematical help of C.I. Lubin), for two-dimension radial flow to a point source in an infinite, homogeneous aquifer. Typically this equation is used to find the average T and S values near a pumping well, from drawdown data collected during an aquifer test. This is a simple form of inverse modeling, since the result (s) is measured in the well, r, t, and Q are observed, and values of T and S which best reproduce the measured data are put into the equation until a best fit between the observed data and the analytic solution is found. From residual draw down analysis a straight line is fitted whereby it favours the data from the end of the recovery period which is close to the origin as horner time approaches one. The Theis solution is based on the following assumptions: homogeneous, isotropic, confined aquiferwell is fully penetrating (open to the entire thickness (b) of aquifer), the well and has a constant pumping rate Q.

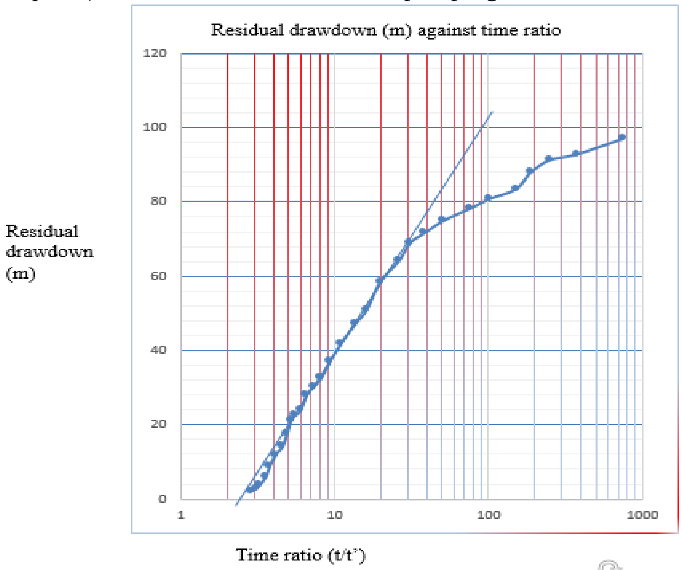

Figure 4.7: Residual Draw down (m) against Time Ratio.

$$T = \frac{2.303Q}{4\pi\Delta s'}$$

$$T = \frac{2.303 \times 26.4}{4\pi \times 4.82} \times 24 = 24.09 m^2 / day$$

Based on the geological logs of the Kyuli's boreholes within the area, aquifer thickness **T** is at 5 m. Thus, K = 24.09 / 5 = 4.818m/day. Transmissivity (T) and longitudinal conductance (S) values for all the five VES stations were calculated to characterize the potentially found aquifers.

Table 5: Dar Zarrouk parameters.

VES NO	Longitudinal Conductance S (Ω^{-1})	Hydraulic conductivity K (m/day)	Transverse resistance R_T (Ωm^2)	A(constant)=K/ρ	Transmissivity $T=AR_T$ (m^2/day)
T2V2	0.7204	4.8180	2729.42	0.0166	45.34
T2V4	0.7828	4.8180	7502.88	0.0166	124.54
T4V2	0.1171	4.8180	4943.10	0.0166	82.06
T4V4	3.1372	4.8180	9516.61	0.0166	157.97
T5V4	0.1358	4.8180	4410.00	0.0166	73.20

The values for aquifer depth correlated very well with constrain data for borehole logs within Machakos County in Kenya. High values of Transverse resistance R_T (Ωm^2) transmissivity (**m^2/day)** and longitudinal conductance S (**Ω^{-1}**) correspond to high porosity and permeability of the aquifers.

III. Conclusion and Recommendations

The purpose of this research work was to investigate the geophysical formations and characterize aquifers using electrical resistivity method. Specifically, the research was geared towards carrying out horizontal profiling using wenner configuration and vertical electrical sounding using sclumberger Configuration. Electrical resistivity method exploits the fact that ground layer formations conduct differently. This may be influenced by salinity, porosity and permeability of layered formations. Ground resistivity was measured using ABEM SAS 1000 terrameter and from the analysis, the results of the true resistivity with depth indicated presence of deeper groundwater aquifers within a depth of 70 m - 160 m.Transect 2, VES station 4 which is at 979900 Northing 348000 Easting and transect 4 VES station 4 which were at and 980450 Northing 349000 Easting displayed very distinct low resistivity measurements with high values of Transverse resistance R_T (Ωm^2), transmissivity (m^2/day**)** and Longitudinal conductance S (**Ω^{-1}**).These values were attributed to high porosity and permeability of the aquifers at a depth of 123.84m and 84.30m respectively. Locations within 348000E and 349000E showed a steep gradient which portrayed a tilted basement structure which is in line with geological formations along the Mozambique belt region. The basement structure was found to be compact with high resistivity values ranging within 1000Ωm and 5000Ωm. Further geophysical investigations should be carried out so as to further constrain the areas of most probable success. More schlumberger VES soundings along the northern side should be carried out with much longer spreads so as to investigate deeper within the subsurface. Follow-up test borehole should also be subsequently drilled to ascertain the geophysical findings and to understand the lithological stratigraphy of the area. Magnetic survey should be carried out along the tilted section to investigate the presence of a fracture or a fault.

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