Geophysical Mapping of Kyamwilu Area, Machakos County, Kenya, Using Electrical Resistivity Technique

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Abstract: ***Vertical Electrical Sounding method was carried out at Kyamwilu in Machakos County. The research was carried out within an area of about 2km^2 due to the rough terrain along the road reserve to map out electrical resistivity at with lower and upper coordinates spread of 031492E and 9942259N, respectively. Three H.E.P using the ABEM SAS 300B Terra-meter were identified with 12 VES sites analyzed and interpreted using the IpWin software and results were tabulated using the Surfer 10. The results revealed that the area is characterized by at least Eight geo-electrical layers, with Two surface layers of topsoil (alluvial and sandy clay)with resistivity and thickness values from 193 Ω m-700 Ω m,2.57m respectively in a Profile drawn NE-SE direction, Two fractured and slightly compact layer ranging from 158 Ω m-9249 Ω m,11.7m thickness for a profile drawn NW-SE, Three weathered/fractured layers (sandstones, limestones, silica clay, and Granite) ranging from 7.25 Ω m -51921 Ω m, at 10.8m-46.6m, a basement layer of weathered basalt rocks at resistivity >2043 Ω m. From the research, resistivity values varied due to clay deposits, the porosity of rocks and subsurface faults in the area.***

Keywords: 1D, One Dimensions, 3D, Three dimensions, VES, Vertical Electrical sounding, HEP, Horizontal Electrical Profiles

1. Introduction

1.1 Background to the study area

Geophysics uses the principles of analysis and investigations of the interior of the Earth. It involves making measurements at or near the Earth's surface that is influenced by the internal variation in physical parameters, Burman (2015), Analysis of these measurements can give evidence of how the physical property of rocks comprising the Earth's interior Zhan, Meisi (2013), Kyamwilu area has been largely viewed as an attraction site with various basic experiments being carried out which include free car wheeling, water flow in cans etc. Mythical studies for social discussions have been at the forefront of defining the area. https://www.standardmedia.co.ke(2015).

Geographical methods are suitably applied in such areas of research interest to establish subsurface layer formations and their characterization of rocks and mass materials to provide vital information such as recharge area, cap rocks, voids, charge of permeability, porosity, fluid-filled fractures and finally reservoir or a heat source. Freund, (2002).

Electrical conductivity of ionic conductors increases largely with temperatures depending on geologic factors such as rock alterations, facies, faults, fractures, stress field, diagenesis, Seeburger. (1982). rock mechanics, fluid chemistry and geochemistry control key parameters as high porosity and high permeability domains, fluid flow, lateral and vertical temperature gradient, and overall reservoir behavior during injection and production of geothermal reservoir.

1.2 Location of study area

Machakos County is located 65 Km from Nairobi; Machakos County is situated in Eastern Kenya with geological coordinates 1^o 31$^'$ 0'' south longitude, 37^0, 16' 0'' east longitude. The area is a sparsely populated rural region, Municipal Council of Machakos. (2007). Kyamwilu hill is 12km from Machakos town though Mutituni and Kivutini area. The area is surrounded by Kasaini and Ngelani valley. The area has an antigravity phenomenon which is a mystery, water poured at the foot of the hill flows upstream, a car, if left on free gear, will move uphill (Adopted from Machakos County integrated Development Plan 2015).

The study was undertaken to map out the electrical conductivity of the Kyamwilu area using the Schlumberger method as depicted the locational map in Figure 1-1.

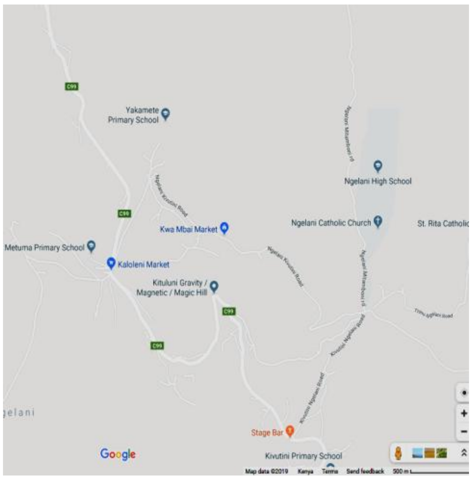


Figure 1-1: A map of Kyamwilu (Also known as Kituluni) showing the study area. *Source:* Google map

1.3 The objective

To map out the electrical conductivity of the Kyamwilu area using the Schlumberger method.

2. Literature Review

2.1 Resistivity Method

Electrical Resistivity is an intrinsic property of all materials. The method uses artificially generated electric currents, introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the expected pattern of potential differences from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities Ellis and Oldenburg1994. When subsurface inhomogeneities exist, however, the resistivity will vary with the relative positions of the electrodes. Any computed value is then known as the apparent resistivity and will be a function of the form of the inhomogeneity. Inhomogeneous ground, the depth of current penetration increases as the separation of the current electrodes is increased.

Two main types of procedures are employed in resistivity surveys Griffiths and Barker 1993.

2.2 Vertical Electrical Sounding (VES)

Vertical electrical sounding (VES) also known as 'electrical drilling' or 'expanding probe', is used mainly in the study of horizontal or near-horizontal interfaces. The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point Orellana and Mooney, 1996. Consequently, readings are taken as the current reaches progressively greater depths. The technique is extensively used in geotechnical surveys to determine overburden thickness and in hydrogeology to define horizontal zones of porous strata. Vertical electric sounding (VES) employs collinear arrays designed to output a1-D vertical apparent resistivity versus depth model of the subsurface at a specific observation point. The induced current passes through progressively deeper layers at greater electrode spacing Loke, 2004. The potential difference measurements are directly proportional to the changes in the deeper subsurface. Apparent resistivity values calculated from measured potential differences can be interpreted in terms of overburden thickness, water table depth, and the depths and thicknesses of subsurface strata. Egbai, 2011.

The two most common arrays used for Electrical surveying are the Wenner array and the Schlumberger array.

2.3 Constant Separation Traversing (CST)

Constant Separation Traversing (CST) known as Electrical Resistivity (ER) profiling, uses collinear arrays to determine lateral resistivity variations in the shallow subsurface at a fixed depth of investigation Telford,1976. The current and potential electrodes are moved along a profile with constant spacing between electrodes. It is also the use of an electrical prospecting arrangement with a fixed spacing of electrodes by moving the system progressively along profiles, detecting changes in resistivity as shown in Figure 2-1 of the earth as one moves along the profile. Hence, it measures the lateral variation of apparent resistivity Ward (1990).

This method is employed in mineral prospecting to locate faults or shear zones and to detect localized bodies of anomalous conductivity. It is also used in geotechnical surveys to determine more importantly the presence of steep discontinuities. Results from a series of CST traverses with fixed electrode spacing can be employed in the production of resistivity pseudo sections. The two most common types used for CST are the dipole-dipole and pole-dipole arrays.

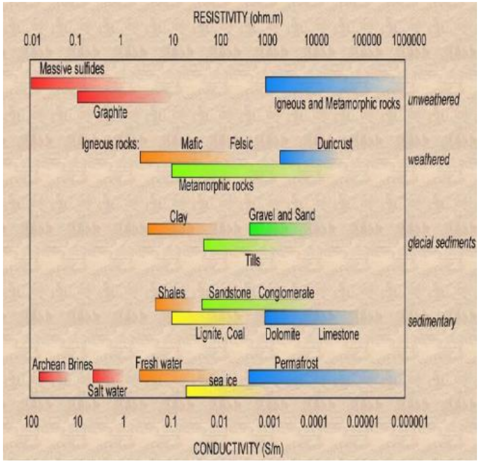
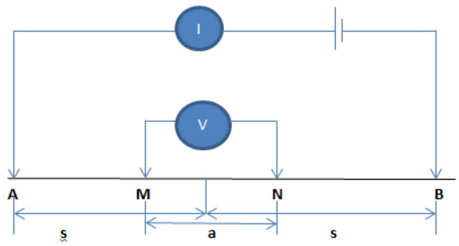


Figure 2-1: Electrical resistivity and conductivity ranges of some rocks *Source:* Palacky. (2001)

2.4 The Schlumberger array

The common electrode arrangement is the Schlumberger array which consists of 4 collinear electrodes, Figure 2-2, Pazdirek and Blaha (1996). The outer two electrodes are current (source) electrodes and inner two electrodes the potential (receiver) electrodes. The potential electrodes are installed at the center of the electrode array with small separation typically less than one-fifth of the spacing between the current electrodes.

The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage becomes too small to measure. The increasing separation of the current electrodes increases the depth of imaging into the ground with S=AB/2 and a =MN/2



$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a}\frac{\Delta V}{i}$$

Figure 2-2: Showing the Schlumberger array method of resistivity survey

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3. Methodology

3.1. Equipment

The electrical survey was carried out using the following equipment acquired from the Machakos Water and Sewerage Company. In the research work, the Schlumberger array was adopted. The equipment used for the survey was the Terra-meter SAS 300C. A 12V battery provided the power while a GPS was used to take the coordinates of the stations.

3.2. Data Collection

The four electrodes in Schlumberger array were placed equally along a straight line, i.e., the current electrodes (A and B) on the outside and the potential electrodes (M and N) which are also the inner electrodes place in between A and B. The Terra-meter was powered by DC source supply and further adjustments on the terra-meter were made such as: setting the number of circles to 4, automatic reading of values in ohms and sending a 30 mA of current into the ground. To vary the depth range of penetration, the current electrodes were moved outwards while the potential electrodes remained fixed. When the ratio of the space between the current electrodes to that of the potential electrodes became too large, the potential electrodes were displaced outwards otherwise the potential difference becomes too small to measure with the best accuracy. The maximum current electrode spacing (AB/2) was 200m and the Terra-meter was set to measured and record the resistance of the subsurface. The values of the resistance obtained in the field were multiplied with their respective Geometric factor (k) which gave the required apparent resistivity results. This was done for all the VES stations along each profile.

3.3 Survey work

Data was collected using ABEM resistivity meter which has a signal average system that improves noise ratio, the suitable current for field conditions was setup automatically by the instrument. The sounding locations were chosen aligned based on several factors;

1) Along the road reserve due to the easy measurement of the resistivity.
2) The alignment to the existing antigravity effect
3) The terrain surrounding the other coordinates had a valley and a stiff mountain.
4) Based on locality were clay mining was previously mined.

A standard data sheet paper was prepared before the survey work with header information on GPS location, name of the survey area, elevation, date of data collection, Azimuth location. Special features, e.g., rivers, vegetation, rocks were noted in a notebook. The location of the VES survey sites is shown in Figure 3-2 and b.

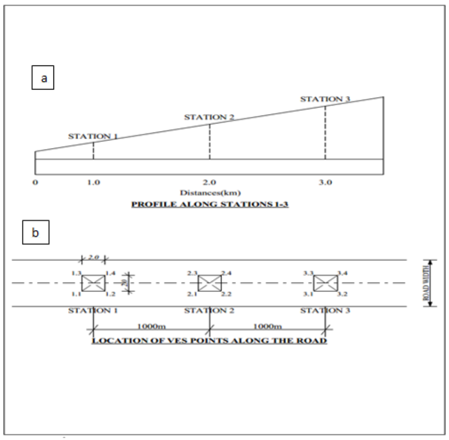

Figure 3-2: a and b showing the location of the Three Profile points and the Twelve VES points at the survey site

4. Results and Discussions

4.1 Qualitative interpretation

This was done by construction and use of apparent resistivity curves and the Hummel's cumulative curves. The VES resistivity data were entered into Microsoft excel software and data was plotted on a log-log sheet of apparent resistivity versus depth. These are shown in Figures 4-1 and 4-2 for Profiles 1, 2 and 3 respectively. The depth was represented by the AB/2 values.

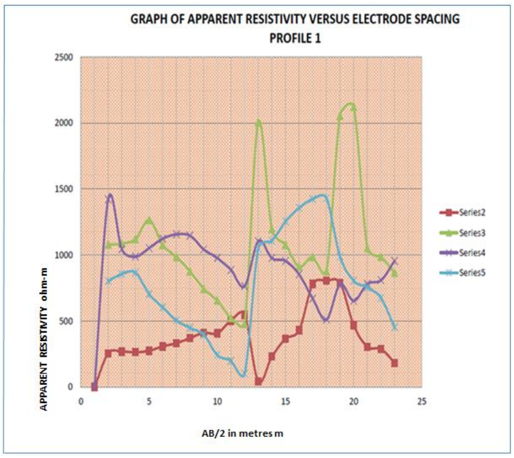

Figure 4-1: Apparent Resistivity variation with depth below stations VES1-1, VES-1-2, VES1-3 and VES1-4 along Profile 1.

At electrode spacing below 10m, low values of resistivity are evident. At spacing beyond 15m especially VES1-2 Profile 1 values of apparent resistivity increase beyond 2000Ω-m abruptly. Beyond 15m-25m low values of resistivity are maintained; except for Ves1-2 very high values of resistivity are visible.

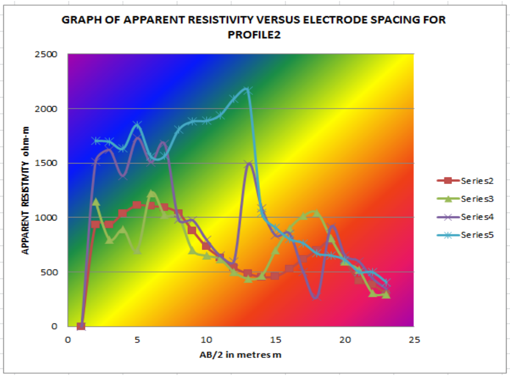

Figure 4-2: Apparent Resistivity variation with depth below stations VES2-1, VES2-2, VES2-3 and VES2-4 along Profile 2.

At electrode spacing, less than 10m resistivity values range between 1800m-600m for all VES.

VES 2-1 and VES 2-2 show low values of resistivity at 15m spacing, but for VES 2-3 and 2- 4 sudden increase in apparent resistivity is evident. Beyond 15m very low values of resistivity occur.

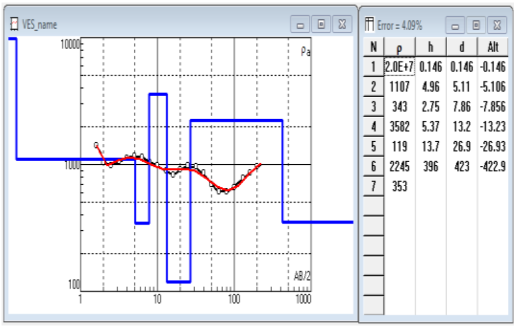

Figure 4-3: Apparent Resistivity curves against depths for VES 1-3, Profile 1. (R.M.S =4.09%) with depth, height, and altitude at different layers and spacing

Figure is apparent resistivity curves against depth for VES 1-3, Profile 1. It consists of seven geo-electric layers layer 1, 2, 4 and 6 with very high resistivity rocks of Quantize rock reference to Figure 2-4, which form surface and bed caps. Layer 3, 5 and 7 have low resistivity ranging 119 Ω m – 353 Ω m indicative of alluvial sandstone and limestone rocks.

5. Interpretation of Pseudo - Cross sections

The Pseudo and resistivity cross-sections are presented in Figure 4-4, which gave lateral variations of resistivity with depth. They help to delineate characteristics of the various earth materials for analysis of the area transects. Models were generated using IP2Win software to obtain interpolated Pseudo and resistivity cross-sections along the Profiles with inversion technique for the three Profiles and each of the four VES 1, 2, 3 and 4 data were combined to obtain individual Pseudo and resistivity cross-sections for analysis.

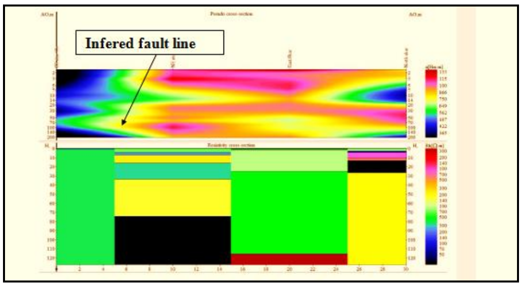

Figure 4-4: Pseudo-cross-section and Resistivity cross-section of Profile 1 showing the spatial distribution of layer structures across VES 1- 1, VES 1-2, VES 1- 3 and VES 1-4.

At VES 1-1, a transect dividing high and low resistivity areas can be depicted with values of the range of 600Ωm to values below 335Ωm. Towards NE of the reserve road high values of resistivity occurs at a range beyond 1000 Ωm as shown by Figure 4-4. A fault zone can be drawn between the SE and NE of the sharp corner; this indicates a highly permeable zone due to the availability of the porous rocks and different resistivity zones.

5.1 Key Findings

From the analysis and interpretation above the objective fully achieved after mapping the study area using electrical resistivity method. The findings were.

i) Low resistivity values were visible in Profile 1, VES 1-2 at a depth beyond 90.8 m with such rocks as sandstones, limestones, graphite, and dominantly clay in regard to the objective.

ii) At Profile 2, VES 2-3varying apparent resistivity values led to inferred fault line to be drawn in the pseudo-section. Different colors of the color scale of resistivities with lower and upper values gave a guide of fault lines. This further backed the objective on subsurface structures and anomalies in the study area. Possibility of low resistivity rocks and high resistivity rocks give varying permeability of rock structures hence a fault line drawn.

5.3 Conclusions

The following were outcomes of the research.

I) Low apparent resistivity values conformed to high conductivity at VES 2-3 due to the presence of silica clay, sandstone, and limestone.

ii) Clay layers of silicate firmed through chemically weathering which through absorption process causes a change in resistivity values and hence conductivity.

iii) Felsic rock traces of quartz deposits, through fractional crystallization, lead to release silica clay elements in the area.

iv) Fossil traces of carbonic rock structures lead to variation in resistivity in the area.

5.4 Recommendations

it) Carry out in-depth probing to quantify the varying charges at the study area using other geophysical methods such as MT, TEM, gravity studies and electrochemistry for more in-depth analysis of the area

ii) Carry out the feasibility study for the exact depth and quantity of silica clay, limestone, sandstone, and granite rocks deposits for mining.

5.5 Practical Contributions

a) The availability of granite rocks which is a quarried sedimentary rock can be mined for building applications.
b) Silicate clay available in the area can be mined and used for making porcelain, cosmetic products (eye shadows, face powders) and drilling mud.
c) Mining for Sandstones which have economic importance for gas exploration and high-quality glass manufacture, dimension Stone, Roofing Granules, Animal Feed Filler, Mine Safety Dust, Flux Stone, Cement manufacture, Agile, and Lime production.
d) Non-volcanic zones when studied to in-depth possess economically important resources except for tourist attraction sites as in the case of Canada, New Brunswick, California Santa Cruz or Oregon, Grants.

5.7 Future Research

A further analysis of the area can be done on the exact quantity of such viable rocks.

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