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Groundwater Potential Assessment Using Remote Sensing, Geographical Information System and Electrical Resistivity Methods in Crystalline Terrain in Kapuri Area, Jubek State, South Sudan

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Abstract:
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Background*: This research project was carried out in Kapuri area of Lury County, Jubek state South Sudan; an area that is geologically underlain by crystalline basement rocks. Groundwater investigations in the crystalline rocks is quite challenging because the overall permeability of these rocks is usually very low. The groundwater is typically confined within the fractured and weathered zones. Therefore, the yields from wells tapping these formations may not, in most cases, be sufficient for exploitation. The study area is further compounded by additional problems in that no borehole has been drilled in this area, the previous groundwater studies are scanty, and they experiences high water demand due to resettlement of refugees returning from neighbouring countries. The main aim of the investigation was to evaluate earth's subsurface geoelectric properties that might indicate suitable geological and/or structural aspects favourable for groundwater occurrence*.
Materials and Methods*: This main objective was achieved through use of remote sensing data, application of Geographic Information System (GIS) techniques and ground geophysical survey. As a first step, groundwater potential assessment was carried out using remote sensed data from Landsat ETM+8 and digital elevations from which thematic maps were derived using ArcGIS software. These thematic layers include lithology, geomorphology, Lineament density, DEM, slope, drainage density, Land Use Land Cover map. The individual thematic layer were assigned weights for the purpose of spatial analysis. On geophysical survey, electrical resistivity profiling using weaner configuration was carried out to delineate subsurface geological structures along 3 horizontal profiles each stretching over a distance of 1500 meters. The horizontal separation of the profiles was 500 metres. At each station, resistivity data was collected at three levels namely 15m, 35m and 45m below ground level. These profiles were plotted in Microsoft Excel and fractures along each profiles were identified. In addition, 192 vertical electrical soundings (VES) were performed using schlumberger array. These VES data were analysed using the Interpex IX1D computer software and the resistivity versus depth models for each location was estimated. This followed by construction of 2D profiles and 3D models using leapfrog software*.
Results*: The GIS and remote sensing results revealed that Kapuri area is characterized by relatively good to moderate groundwater potential confined at the western part of Lury County. The results from geophysical survey indicate that the area is generally underlain by four geologic section which include top soil (sandy clay), moderately weathered, fractured and fresh basement. Moderately weathered material ranging from less than one meter to several meters in thickness separate the overburden from the underlying weathered and fractured bedrock, while the basal layer is comprised of compact and massive fresh basement. The fractured and the moderately weathered rock make up the aquiferous zone within the study area*.
Key Word*: Groundwater Potential Assessment, Remote Sensing, Geographical Information System, Electrical Resistivity Methods, Crystalline Terrain,*

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I. Introduction

Water is an essential commodity for the survival of every living thing (plants and animals). Most human beings generally require about 2.5 liters of water every day for direct consumption. On average amount of water ,household can used about 200 liters of water daily (Hamil and Bell, 1986). Normally the most efficient means to meet this demand is the surface water resources. Nevertheless, fresh water from lakes, rivers and streams is not readily available to everyone because it is distributed irregularly throughout the world. It is approximated that by 2025 about 1.8 billion of the people who live in the world will not be able to access adequate water. While this is the case, about two-thirds of the population in the world will not have sufficient water for use in their home by this time (UN Water, 2007). Therefore, measures must be taken to investigate the possibilities of providing alternative sources of water to meet the challenges of water scarcity emanating from increased population pressure. Globally, groundwater is the second main source of water representing approximately 30 percent of the fresh water (Subramanya, 2008). As a result, over 1.5 billion people globally rely on groundwater for daily use.

South Sudan water source is transboundary water, it shared with the surrounding country. River Nile is the main water body share by 10 country, in facts this causes extreme water stress, which is when demand for water exceeds the amount available. Water stress is a problem that roughly a quarter of Africa's population suffer from (Islam and Susskind, 2015). 97% of South Sudan's water is used for Agriculture, an industry that employs 80% of the population, whilst only 2% of South Sudan water is for domestic use. South Sudan is suffering from a water crisis due to constant conflicts that left the water system neglected or destroyed. Poor rains combined with the after effect of the 2011 East Africa drought and increasing population has depleted the country's water supply system (Aghakouchak, 2014).

In Kapuri area, apart from suffering from insufficient water supply, most of the water sources are polluted, thereby vulnerable to various water-borne diseases such as cholera and guinea worm (UNESCO, 2004). From the time the peace agreement was signed in 2005, access to quality water has been a major issue for majority of the people living in South Sudanese rural areas especially the areas that do not have surface water. Kapuri is a newly demarcated area for settlement of persons who are returning from the neighboring countries like Uganda, Sudan, and Kenya as a refugees. This resettlement has resulted into increasing local industrial scheme and agricultural activities that demand proportionate increase in water demand. Therefore, access to sufficient supply of potable water is becoming increasingly difficult particularly in the face of the fast growing population. This suppresses the adequacy of the water that is not readily available in the area. For this reason, there is need to identify other sources of water that could be reliable.

Groundwater resource is important water supply mostly for domestic used particularly during dry season in areas that not located on the river and no permanent surface water. Throughout Jubek State, groundwater resource is important water source mostly used for domestic water supply and therefore its occurrence and distribution is pivotal to giving the required water demand for household, irrigation and industrial purposes (Anornul et al., 2012). The provision of groundwater through modern hand-dug wells, boreholes, and piped systems has augmented considerably over the past years in the Equatorial region and hence groundwater has now become vital resource of water for urban and rural water source (Nicola, 2005).

Groundwater data are scarce thereby resulted into lacks sufficient knowledge about factors responsible for the storage, movement and occurrence of groundwater that poses a great uncertainty resulting in drilling dry borehole and low yield borehole. Groundwater exploration will greatly increase the socioeconomic activities in the study area. It was noted by (WHO, 2010) that access of sufficient water for small- scale in such an area is thereby an important aspect because it helps in alleviating poverty. It may also be important in improving the quality of health benefits.

Kapuri area is geologically underlain by crystalline basement rocks (Hunting., 1980s). Groundwater investigations in the crystalline rocks is quite challenging because the overall permeability of these rocks is usually very low. The groundwater is typically confined within the fractured and weathered zones. Therefore, the yields from wells tapping these formations may not, in most cases, be sufficient for exploitation. Kapuri Area is further compounded by additional problems in that no borehole has been drilled in this area, the previous groundwater studies are scanty, and the area experiences high water demand due to resettlement of refugees returning from neighbouring countries. In addition, the kapuri area is located in a relatively tropical to sub-tropical area having medium groundwater potential due to average rainfall recharging the aquifers within fractured and highly weathered zone of basement complex rock. The main aim of the investigation was to evaluate subsurface geological structures and geo-electric properties that indicate occurrence and distribution of groundwater will lead to a recommending where drilling should be done in the study area. The specific objective of this study was to map Lithology and geological structures in the area lineaments, drainage geomorphology change from remote sensing data.

Statement of the Problem

Kapuri area is geologically underlain by crystalline basement rocks (Hunting., 1980s). Groundwater investigations in the crystalline rocks is quite challenging because the overall permeability of these rocks is usually very low. The groundwater is typically confined within the fractured and weathered zones. Therefore, the yields from wells tapping these formations may not, in most cases, be sufficient for exploitation. Kapuri Area is further compounded by additional problems in that no borehole has been drilled in this area, the previous groundwater studies are scanty, and the area experiences high water demand due to resettlement of refugees returning from neighbouring countries. In addition, the kapuri area is located in a relatively tropical to sub-tropical area having

medium groundwater potential due to average rainfall recharging the aquifers within fractured and highly weathered zone of basement complex rock.

Objectives of the Study

i) To delineate thickness of aquifer as well as lateral extent from geophysical data.
ii) To develop a 3D model showing ground water potential.

II. Material and Methods

Basic theory of resistivity method

The conductivity and geophysical resistivity methods concern themselves with study of the effects of sub-surface on water flow when electric current flows on that surface. The electrical resistivity one are utilized extensively in evaluating shallow sub-surfaces especially those concerned with resolving hydrogeological and environmental problems. An alternating current (AC) or direct one of about 20Hz can be used for the investigation. The electrical survey is used to investigate variation in the subsurface electrical properties like the resistivity distribution. The subsurface resistivity variation can be correlated to geological parameters, for instance, the minerals and amount of water, fracturing, porosity, conductivity of saturate and lithology. The technique is also valuable in recognizing the various layers, variations and discontinuities within the layers of the subsurface because of its exceptional sensitivity to subsurface resistivity. These peculiarities and variations are generally vital I the occurrence of groundwater (Owen *et al.,* 2005; Issah, 2015).

The occurrence of water controls is vital in the variation of ground resistivity. The degree of water saturation and network of opening space gives an estimation of the subsurface resistivity. This is because water is highly conductive and hence less resistive and current will move though regions of low resistance. Increase in salinity of ground water, increase saturation, increase porosity and degree of fracturing of rock, each of which tends to reduce resistivity. Increase in the degree of compaction within the lithology reduces the amount water and finally increases the resistivity. The occurrence of water reduces resistivity while the vicinity of pore air raises resistivity because air unsurprisingly has pronounced resistivity In the light of the fact that, the passage of current in the near surface results from movement of ions with the pore space, porosity controls the variation of resistivity. It is very tedious in estimating resistive anomalies than conductive anomalies, since the majority of minerals are non-conductive and rock structure has a tendency to affect resistivity (Cardimona, 2008; Issah, 2015).

Principle of Resistivity Methods

The majority of minerals forming rock are extremely non-conductive, and the passage electric current through is mainly ionic pore water. The vicinity and the degree of the dissolved ions in pore water determines their conductivity since pure water is less ionized (Milsom, 2003; Issah, 2015). The electrical properties of different materials are best explained by Ohm's law.

$$V = I \times R, \quad R = \frac{V}{I} \qquad (3.1)$$

R is the constant of proportionality that represents the resistance. The conductance, which is the reciprocal of the law, is measured in Siemens.

The link provided in the above analysis holds only for earth materials. Nevertheless, the resistance, *R*, does not represent the constant of material. This is because it does not rest on material of medium, but also on its geometry. The resistance, *R*, which is presented in ohms, equals proportionally to the length of a material especially for wire. Also, it relates to cross-sectional area, A, of the material in an inverse manner.

$$R = \rho \frac{I}{A} \qquad (3.2)$$

The resistivity ρ of a material has significant influence on the flow of electric current because it affects the resistance of that material. Because of this it can be regarded as resistance between opposing faces of unit cube in the light of current passing through it (Milsom, 2003).

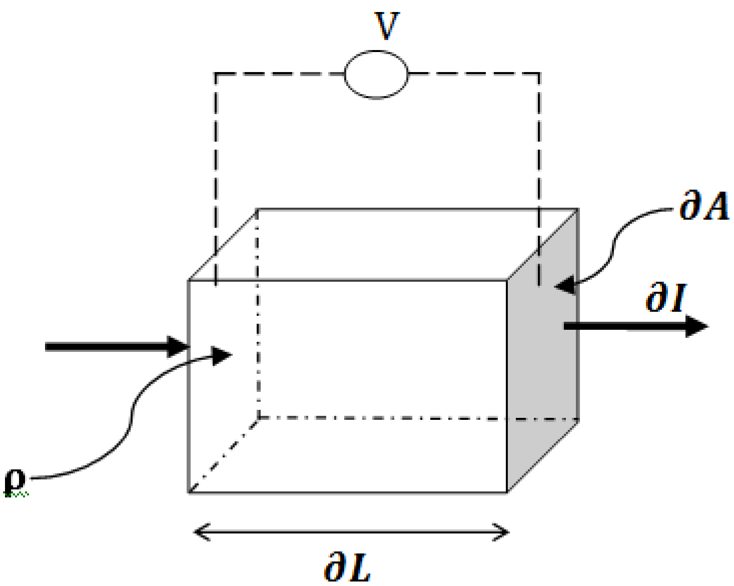


Figure 1: The basic definition of resistivity in a homogeneous block

A conducting block can be said to have resistivity given by Equation (3.2), which can be rearranged to give the following.

$$\rho = \partial R.\frac{\partial A}{\partial L} \quad (3.3a)$$

$$\rho = \frac{V}{I}.\frac{A}{L} \quad (3.3b)$$

The density of the medium at any point would be regarded as the current that passes through it in a unit area. This density, *J*, relates to electric field strength *E* via an ohm's law given as;

$$J = \sigma E = \sigma \nabla V \quad (3.4)$$

Where $\sigma = \frac{1}{\rho}$

$$J = \frac{1}{\rho} E \quad (3.5)$$

$$J = \frac{I}{A} = \frac{\nabla V}{\rho L} \quad (3.6)$$

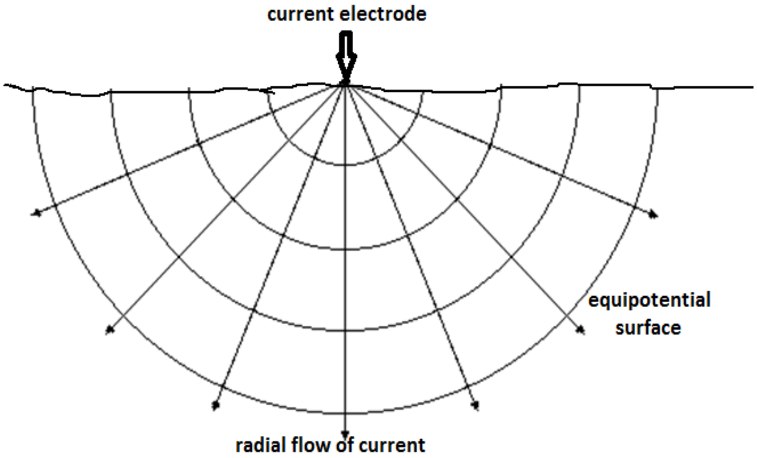


Figure *2.0***: The current flowing from electrode to distribute current uniformly over the shell**

The current's density reduces when distance from the source increases because it flows radially from electrode. As a consequence, it is distributed uniformly over the shells. From this, the voltage at a distance (r) is as shown above in figure 2

$$J = 1/\frac{1}{2}(4\pi r^2) = -\frac{1}{\rho}\frac{dv}{dr} \quad (3.7)$$

The equation (3.8) is a theoretical basis of the way current flows in a homogeneous isotropic subsurface with one current electrode. Current flows radially in an inverse manner. Hence, the resistivity ρ is given by

$V(r) = \frac{I\rho}{2\pi r}$ (3.8)

Practically, most of studies on resistivity use a minimum of one pair of current and potential electrodes (M. H. Loke, 1997). The values for potential electrode from such studies have symmetrical patterns provided by equation (3.4).

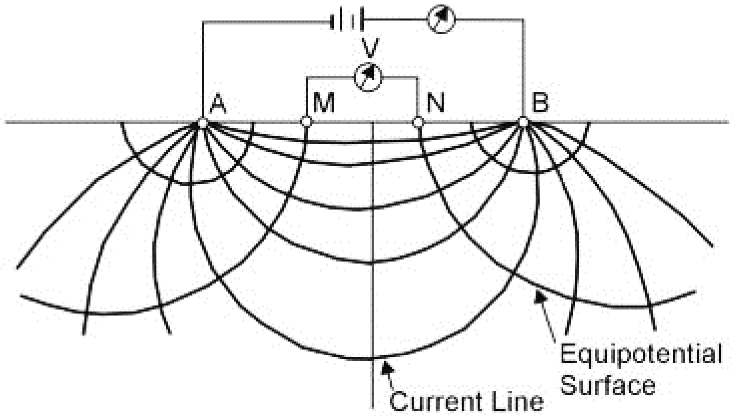


Figure 3: The potential distribution from a pair of current electrodes (U. S. Environmental Protection Agency, 2011)

Consider an arrangement with potential electrodes M and N and current electrodes, A and B. Making use of equation (3.5), A and B would acts as source and sink, respectively. This would give two points that would act as potential electrodes positions. In such a case, the electric potential would be impacted by sink and source to give potential difference between them.

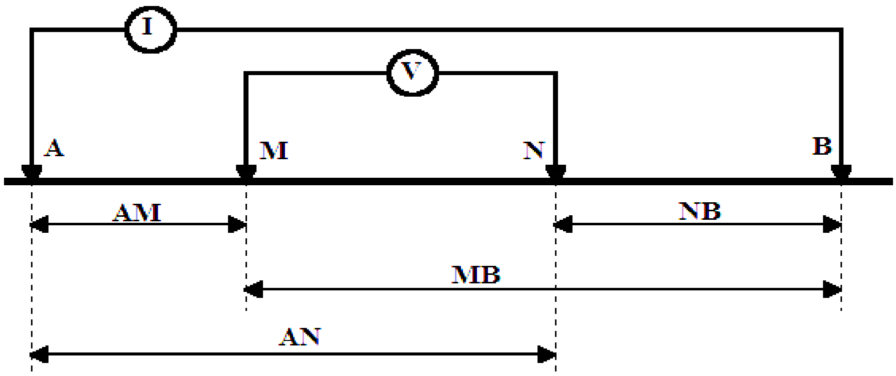


Figure 4: The generalized form of the electrode configuration used in resistivity measurements

The distance for electrode M is AM whereas that for B is MB. Conversely, for N the distances would be AN and NB. As a result, the potential VM would be;

$V_m = \frac{I\rho}{2\pi}(\frac{1}{AM} - \frac{1}{NB})$ (3.9a)

For VN, it would be;

$V_m = \frac{I\rho}{2\pi}(\frac{1}{AN} - \frac{1}{NB})$ (3.10)

Hence, the total difference between M and N would be;

$\nabla V = V_{M} - V_{N}$ (3.11)

$\nabla V = \frac{I\rho}{2\pi}[(\frac{1}{AM} - \frac{1}{NB}) - (\frac{1}{AN} - \frac{1}{NB})]$ (3.12)

For arrays, potential at any given electrode would be the sum that each of them contributes. Hence, the resistivity in a 4-electrode survey would be;

$\rho = \frac{\Delta V}{I} K$ (3.13)

Where

$K = 2\pi[(\frac{1}{AM} - \frac{1}{NB}) - (\frac{1}{AN} - \frac{1}{NB})]^{-1}$ (3.14)

K is a geometric factor that depends on positions of potential electrodes and current. Because sub-surfaces tend to be heterogeneous, resistivity attained are apparent (ρa). Worth noting that resistivity values measured on fields are never true, but apparent (Reynolds, 1997; Issah, 2015).

III. Material and Methods

In this research work, both VES and Horizontal profile surveys using both Schlumberger and Wenner arrays configuration respectively were adopted throughout the analysis and field work. The vital field equipment used for the study was ABEM SAS Terrameter 1000 which displayed apparent resistivity value in digital form as obtained from Ohm’s law. The Terrameter 1000 was powered by 12V D.C power source. The other materials included 4 hammers, a measuring tape, 12 metal electrodes (4 meters each) for VES and Profiling, cables, GPS to get the coordinates. The Schlumberger configuration was adopted with VES. This involved placing 4 electrodes systematically along a straight line; those on outside served as current electrodes whereas those on the inside served as potential electrodes. The current electrodes were displaced from the outside whereas the potential ones were not changed in any way in the process of changing the depths of measurements. Nevertheless, when the ratio of the distances are large, potential electrodes should be displaced outwards to ensure that potential difference is not small (koefoed,1979; Alile,2008; Pervaiz et al., 2010). The measurements of the position of both types of electrodes were marked such that AB/2 ≥ MN/2. Where AB/2 was the spacing for current electrode and MN/2 was for potential electrode.

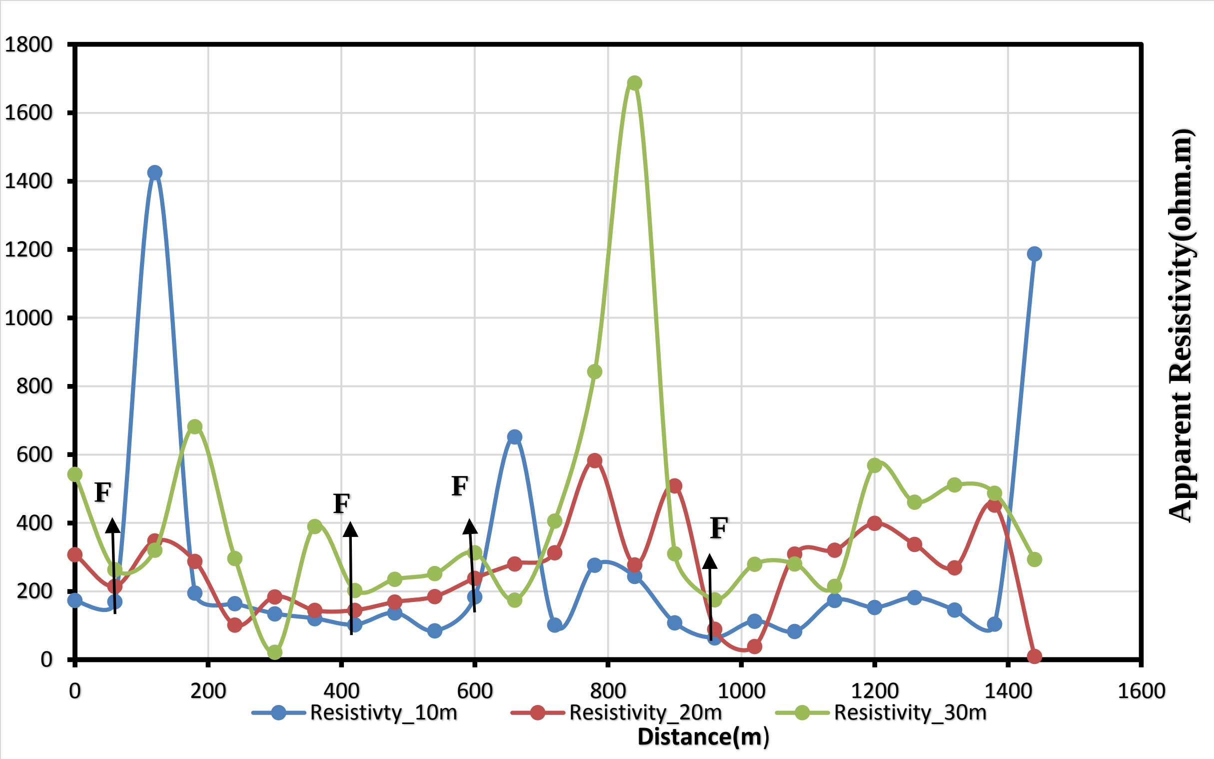
The aim of interpretation of the resulting curves is to verify the thickness and resistivity of every layer from observed sensitivities and use results to develop a geological overview of area under investigation (Zohdy et al.,1990). To obtain quantitative results that are more accurate, the data should be processed to provide true resistivity distribution (Elzein, 2007). Interpretation of resistivity measurements therefore must be carried out with regards to the available geologic information of the area including geologic maps and borehole logs (if available). The graphical curve matching method (which is rather obsolete technique) or computerbased techniques was used to interpret resistivity data (Zohdy et al.,1990). In graphical curve matching, the field curves are plotted on transparent logarithmic papers with similar modulus with master curves. Then they are shifted to master curves while keeping coordinate axes parallel till they match in a reasonable manner with either one of interpolated curve or master curves. The resistivity values for various layers can then be determined by matching them to sets of master curves presuming layered Earth (Shewa, 2007)

IV. Result and Discussion

4.3Delineation thickness of aquifer as well as lateral extent from geophysical data

4.3.1 Profile I

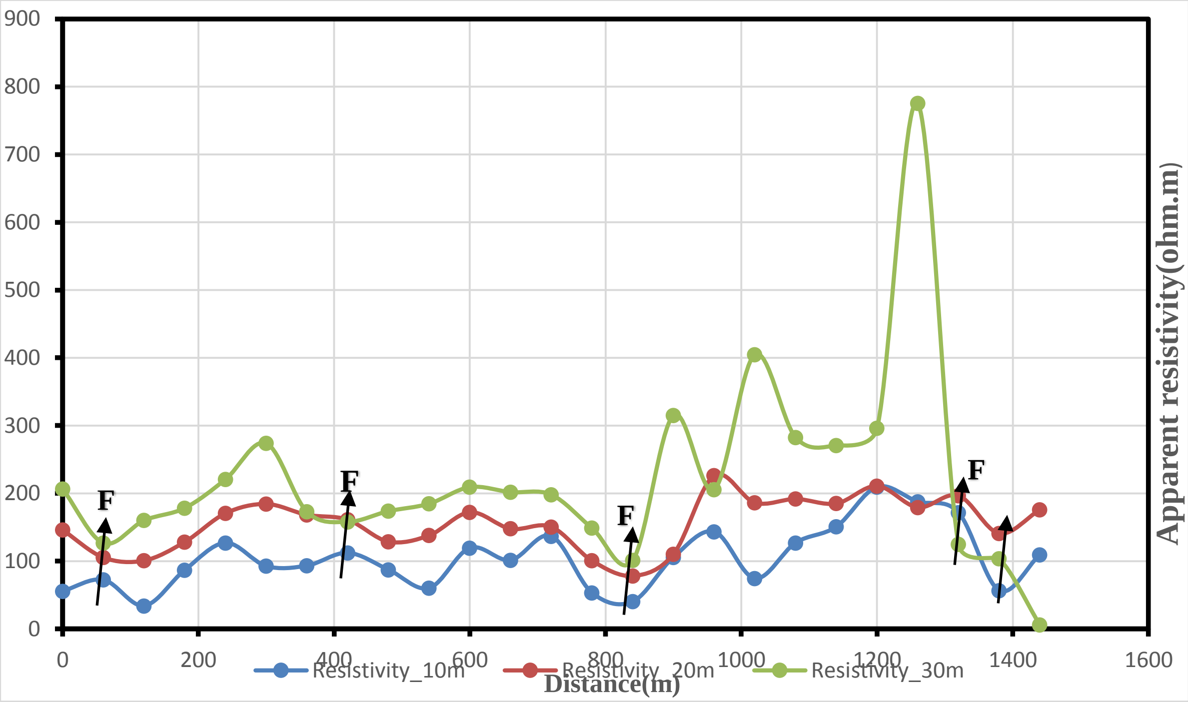
Figure 5 present measured resistivity data along the profile the field. The pattern shows the point that was measured during the field work. Figure 4.10 depicts the measured apparent resistivity at the depth of 15m, 35m and 45m respectively which were carried out at the interval of 10m, 20m and 30m respectively. The figure (4.10) was generated through the use of Microsoft excel showing variation in resistivity throughout the area under investigation. Due to the geological nature of study area being a crystalline area, there are resistivity’s values shows the subsurface structure of the study area. The profiling-I curve depicted a variation in resistivity throughout the Study area with low and high resistivity zones. The rate decreased suddenly between stations 4 to 13 (200m to 750m) with the resistivity ranges between 184 Ω.m to 313.19 Ω.m. At the interval of 10m which represent first layer of the subsurface structures, the resistivity is decreasing between stations 4 and 11(200m to 600m) and also between stations 13 and 24 (750m to 1420m) there resistivity ranges between 64.72 Ω.m to 195.54 Ω.m the resistivity value for the first layer indicate the topsoil moderate moisture. The second layer with resistivity value of 100 Ω.m to 500 Ω.m represents moderately fracture zone. The resistivity value between 200 Ω.m and 800 Ω.m indicates that the third layer is basement rock. Along the profile-I continues fracture have been identify and the point 2,8,11 and 17 with their resistivity ranges between 60Ω.m to 300Ω.m indicate the presence of fresh groundwater. Though the aquifer resistivity varies, it depends on the location where the study is being carried out.



F= Fractures
Figure 5: profile N0.I

4.3.2 Profile II

The profile-II of the survey was positioned 500m horizontally to profile-I the pattern shows the point that was measured during the field work. Figure 6 shows the measured apparent resistivity at the depth of 15m, 35m and 45m respectively which were carried out at the interval of 10m, 20m and 30m respectively. From the result it indicates that top soil which is first layer is having approximate resistivity value that ranges between 55.81 Ω.m to 180 Ω.m. The second layer of this second profile has resistivity value ranges between 100.98 Ω.m to 190 Ω.m which indicates fractures zone. The resistivity value that ranges between 200 Ω.m to 400 Ω.m approximately represents basement which is third layer. Along the profile-II continues fracture have been identify at the point 2, 8, 12, 15 and 24 (100m, 410m, 820m, 1360m and 1380m) with their resistivity ranges between 40 Ω.m to 160 Ω.m indicate the presence of fresh groundwater. Looking at the two profiles carefully it will be observed that the resistivity values of profile's layers are similar and the fractures are continuous

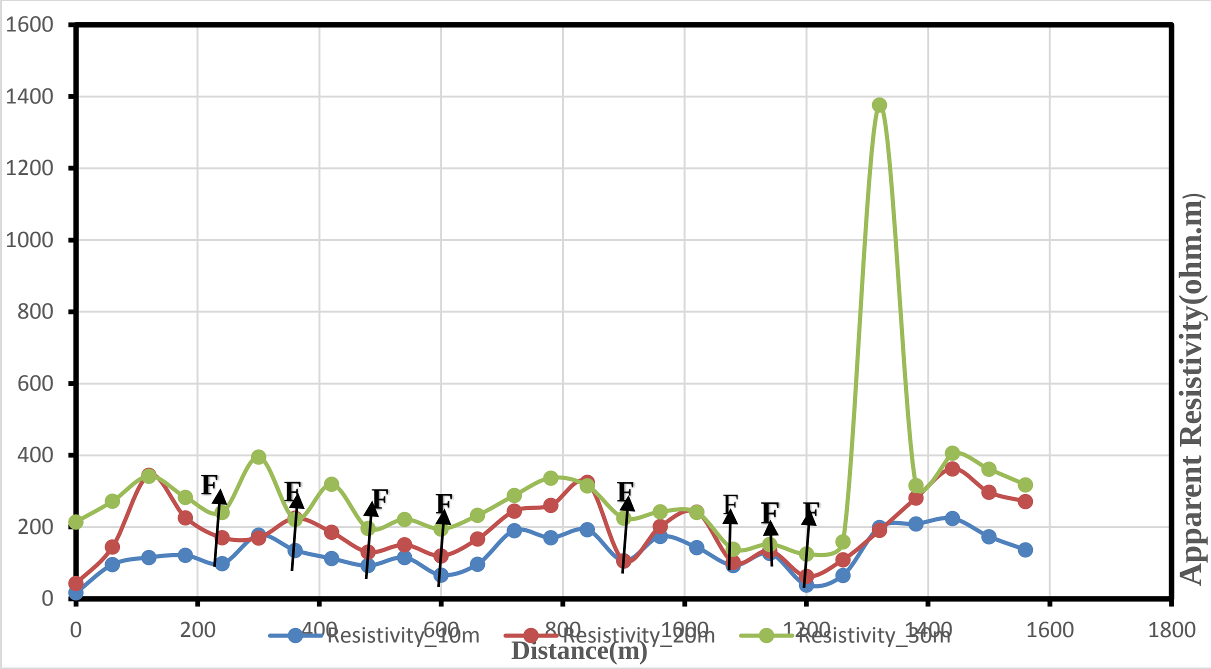


F= Fractures

Figure 6: Profile N0.II

4.3.3 Profile III

The profile-III of the survey was positioned 500m horizontally to profile-II the pattern shows the point that was measured during the field work. Figure 7 shows the measured apparent resistivity at the depth of 15m, 35m and 45m respectively which were carried out at the interval of 10m, 20m and 30m respectively. Preliminary review of the profile-III curve shows a variation in resistivity throughout the Study area with low and high resistivity zones. At the interval of 10m which represent first layer of the subsurface structures, the resistivity ranges between 10Ω.m to 190Ω.m the resistivity value for the first layer indicate the topsoil moderate moisture. The second layer with resistivity value of 40 Ω.m to 300 Ω.m represents moderately fracture zone. The resistivity value between 150 Ω.m and 300 Ω.m indicates that the third layer is basement rock. Along the profile-III continuous fracture zones have been identified at the point 5, 7,9,11,16,19,20 and 21 (240m,380m,500m,600m,900m,1100m1180m and 1200m), with their resistivity ranges between 30Ω.m to 200 Ω.m indicate the terrain is partially or totally saturated with water.



F= Fractures
Figure 7: Profile N0.III

4.4 3D Model showing groundwater potential zone

One hundred and ninety two (192) deep sounding using Schlumberger array were performed within the study area. The acquired field data and interpreted results are presented in tables, VES profile curves, geo-electric sections and 3D maps. Four geo-electric layers were interpreted applying both partial curve matching and computer software iterative technique. These layers correspond to the top soil, moderately weathered/fractured, fractured basement zone and fresh basement typical of the geological layering characteristics of the basement terrain. The geo electrical parameters interpreted from the 192 VES stations are present in Table 1. Four different curve types were interpreted; KH ($\rho1 < \rho2 > \rho3 < \rho4$), HA ($\rho1 < \rho2 > \rho3 < \rho4$) , QH ($\rho1 > \rho2 > \rho3 < \rho4$) ,QA ($\rho1 > \rho2 > \rho3 < \rho4$), Q($\rho1 > \rho2 > \rho3$), A($\rho1 < \rho2 < \rho3$) and H($\rho1 > \rho2 < \rho3 < \rho4$) . The interpreted VES results were used to model the subsurface rock in 2-D geo-electric sections (Figure 4.13). The model gave insights into the geometry and thickness variation of the various lithologic units along the cross section. Four major layers that correspond comparatively to the top soil, clay, weathered/ fractured basement and fresh basement, typical of the four basic lithological units defined in basement hydrogeology were interpreted (Salami and Ogbamikhumi, 2017; Bayode *et al.*, 2005). It is observed that for more than 50% of the sounding points, the resistivity of the bedrock is not less than 5000Ωm. As demonstrated by Salami and Ogbamikhumi, (2017) and Hazell, et al.,(1992)the bedrock can be described as incompetent and mostly fractured.

The first layer on the geo- electric section is the top soil characterized by clayey sand with resistivity value between 10.9-650.9Ωm (Abiola *et al*., 2013)) and thickness ranging between 0.19-2.35m. The second layer described as moderately weathered/fractures has resistivity values between 30- 500Ωm and thickness between 2.5- 4.5m. The third layer is defined as the fractured basement, and constitutes the main potential aquifer in the study area, with resistivity values between 50 -450Ωm, and thickness between 2.5 and 7m. The fourth layer is the fresh basement which extends to infinity into the subsurface. It has resistivity value between 600 -10000Ωm. This can extend to infinity with depth because of its crystalline nature (Figure 8).

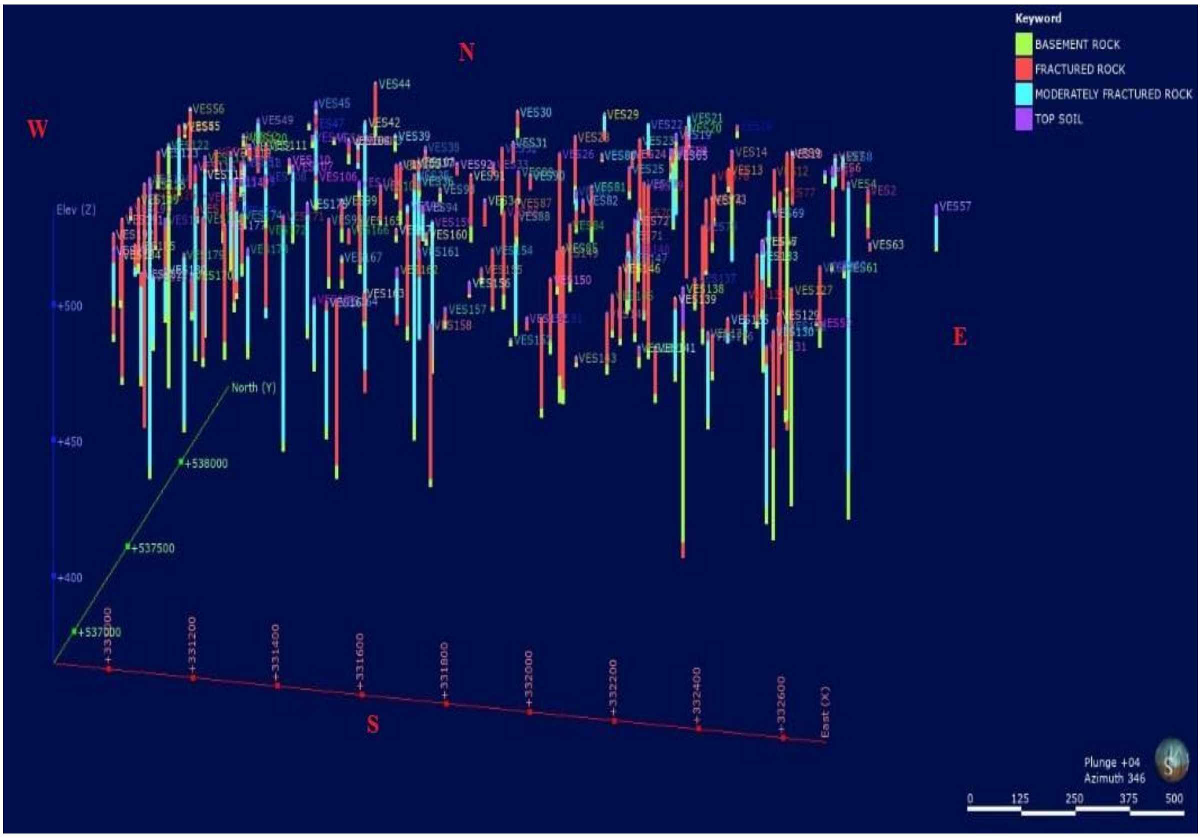


Figure 8: VES logs of Kapuri Area

4.4.1 3D resistivity Model for subsurface geological structures

The 3D image was generated using leapfrog software as shown in the figure (9, 10 and 11) below. In the 3D model the top layer as shown in the figure below having resistivity value ranges from 500Ωm to 1000Ωm with the average thickness of 0.45M and most part they are clearly seen because of the thin thickness. It's mainly composed of Sandy clay underlain by less resistive gneiss.

Normally, to establish an electrical resistivity scale, necessary to interpret the results. The result for geological formations that flourish in the site are as follows:

- Top soil resistivity ranges from 500Ωm t0 1000Ωm.
- Moderately weathered rock resistivity ranges from 200Ωm to 500Ωm.
- Fractured rock resistivity ranges from 20Ωm to 100Ωm.
- Fresh basement rock resistivity ranges from 1000Ωm above.

Special care was given to the process of analyzing and interpreting the results especially to the horizons that were below 100Ω m. This reflected the presence of fractured rock formation that might accumulate underground water (Figure 9).

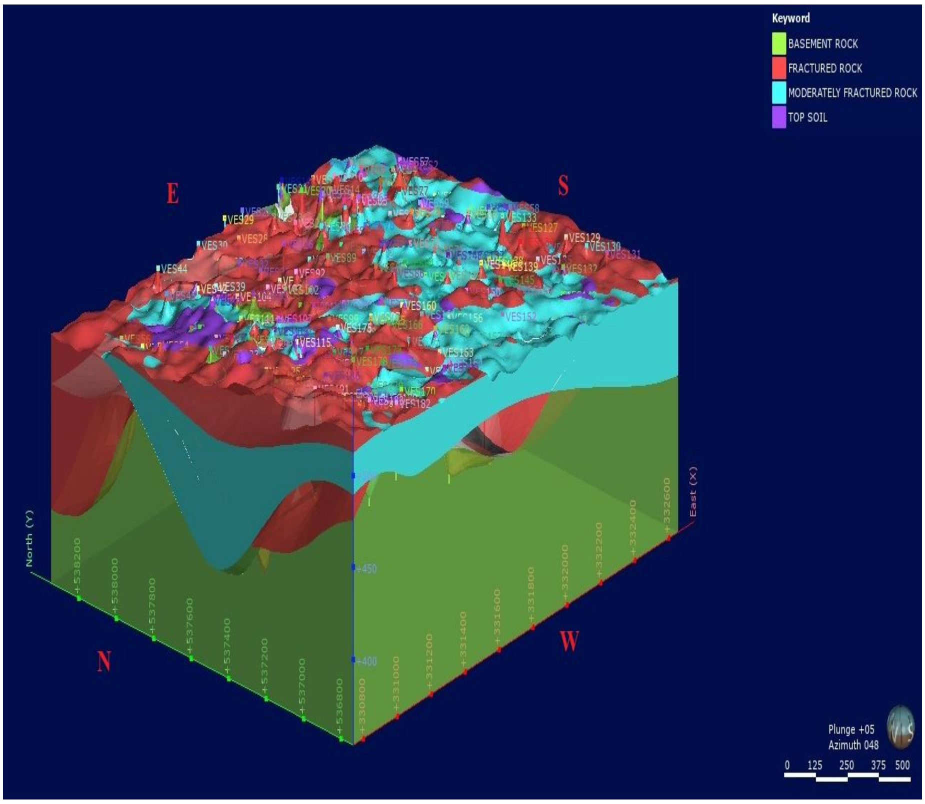


Figure 9: 3D Resistivity models showing North face of Kapuri Area

3D model Interpretation enable visualization of the resistant terrain evolution, from the sector's top part to the deepest zones, which are assumed to represent moderately fractured, fractured and basement rock. Moderately fractured and fractured rock is extend to eastern part of the study area overlaying the basement rock. The top soil is not clearly seen in the model because in most of the VES points it shows thin layer having a thickness of less than 1m. This model has proven the presence of moderately fractured and fractured rock only in the eastern and western part of the Kapuri area and the extension depth seems limited.

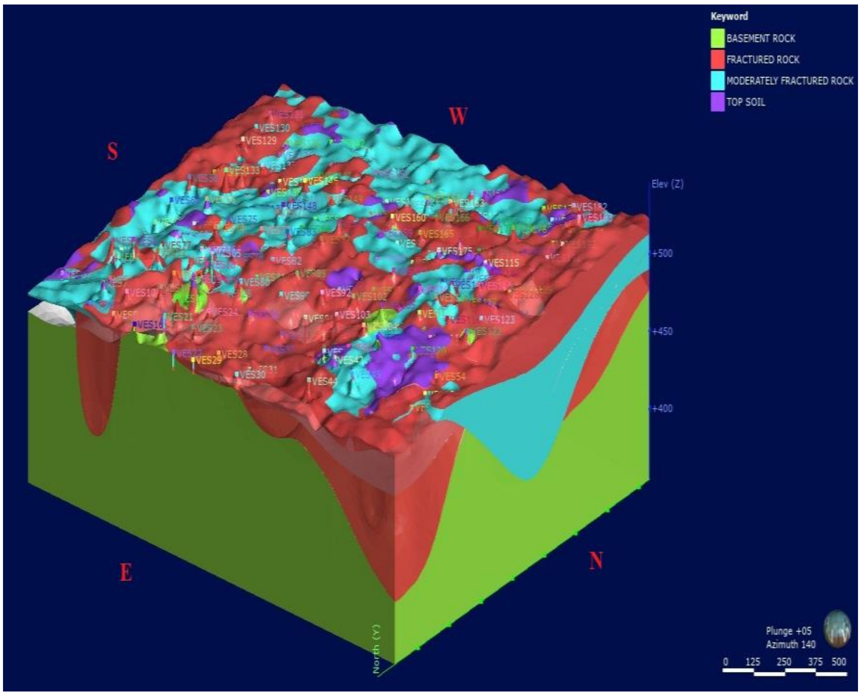


Figure 10: 3D Resistivity models showing south face Kapuri Area

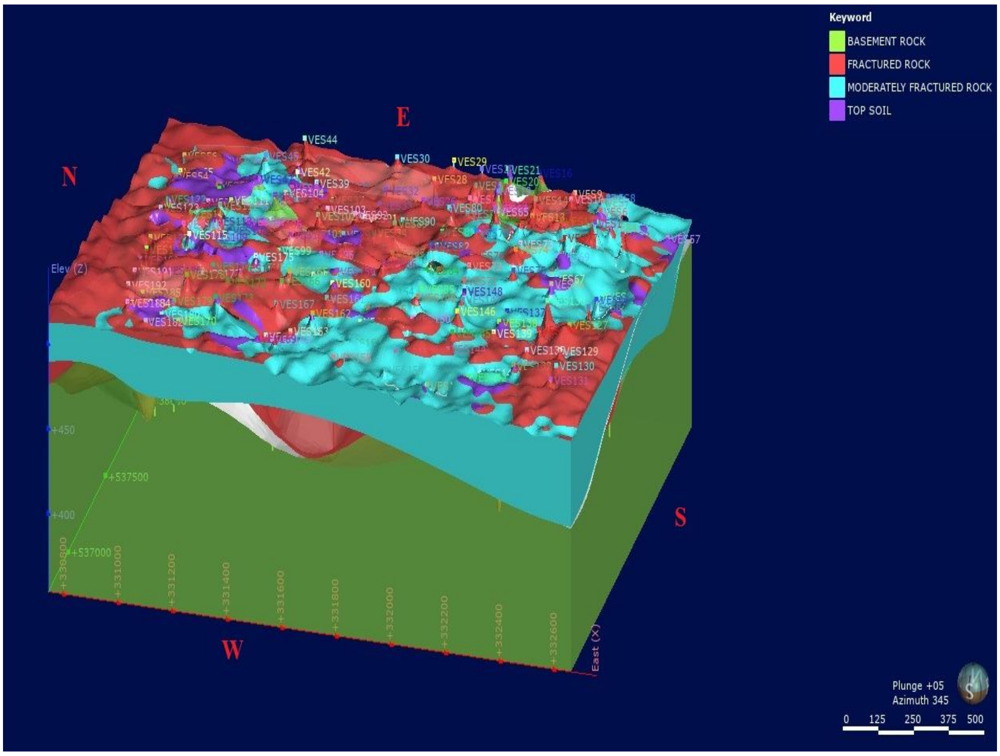


Figure 11: 3D Resistivity models showing East face Kapuri Area

V. Conclusion and Recommendation

The horizontal profiling results identified numerous fractured zones along the profile, while the three level probe depth (15m, 15m, 35m and 45m) determined the continuity of these fractures with depth. It is concluded for the fractured zones spanning all the probed depths mark local aquifers. The 3D geo-electrical model indicates that the area is underlain by four geologic section which include top soil (sandy clay), moderately weathered, fractured and fresh basement. Moderately weathered material ranging from less than one meter to several meters in thickness separate the overburden from the underlying weathered and fractured bedrock, while the basal layer is comprised of compact and massive fresh basement. The fractured and the moderately weathered rock make up the aquiferous zone within the study area. Results obtained from the present study is a baseline for further geophysical investigation. Drilling should be carried out in fractured zone. It is recommended that 2D and 3D electrical resistivity imaging be carried out for mapping fractured at higher resolution

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