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Using Integrated Geophysical Methods in Groundwater Exploration in the Fractured Crystalline Basement Aquifers in Sambuli in the Saboba District of Ghana

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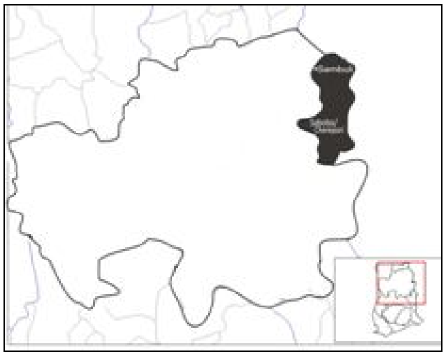
Abstract:
Geophysical investigation for groundwater potential of Sambuli in the Saboba District of Northern Ghana has been carried out with the aim of delineating suitable site for groundwater development and estimating the depth to aquifer. Electrical resistivity profiling and Vertical Electrical Sounding (VES) techniques using Schlumberger configuration was used to delineate the subsurface geology of the study area. Four geo-electric profiles were conducted of which electrical resistivity anomaly values were identified and selected for further VES investigations. Five VES locations were investigated and the data analysed. Interpretation of the VES data revealed a four-layered subsurface structure with sandy/rocky topsoil of electrical resistivity between 2059.9 and 100000Ωm and thickness between 0.4 and 2.3m. The electrical resistivity of the second layer ranges from 189.9 to 94025.4Ωm with thickness varying from 0.9 to 4.9m. The third layer, a partially convenient zone for groundwater has electrical resistivity ranging from 81.5 to 15224.1Ωm and thickness 7.2 to 10.3m. The fourth layer has resistivity ranging from 40.3 to 90660.1Ωm. Station SP1 revealed a highly weathered/ fractured zone of electrical resistivity 40.3Ωm at a depth of 13.9m, a potential location for borehole construction.

1. Introduction

Provision of safe and sustainable water supply for both domestic and industrial use has been a major indicator in determining the level of socio-economic development and health status of the people and societies. In developing countries, such as Africa, improvement in water supply has lately been recognised to have a direct, positive impact on public health (Odai et al, 2004). Water resources development has been identified as crucial to the control and eradication of communicable diseases and more importantly the well-being of the population. Many countries suffer from lack of fresh surface water and therefore it is necessary to exploit groundwater reserves. In contrast to surface water, groundwater is significantly protected from pollutants, safe for use and cheaper to develop. The source of groundwater is rain and snow that falls to the ground and percolates down into the ground. The proportion that soaks into the ground is influenced by climate, landscape, soil and rock type and vegetation. The proportion of rainwater percolating into the ground reaches the water table and flow through rocks of varying permeability towards discharge points (Brassington, 1988). Porosity and permeability are important properties in hydrogeology in determining the ability of a rock formation to hold and transmit water storage (Davies and Wiest, 1968). Though groundwater occurs in geological formations, its distribution is not uniform (Fetter, 1994). The most direct method of obtaining subsurface data is by drilling observation and water supply wells but this is expensive and often inefficient. The use of relatively inexpensive geophysical methods may greatly improve the cost-effectiveness of groundwater surveys by reducing the number of boreholes required and improving their location. The objective of the research was to map possible fractured assisted aquifer system and to determine layer thickness and depth to aquifer system. Numerous geophysical methods are available but the most common one for groundwater survey is the geo-electric. Geo-electric methods are sensitive to variation in earth resistivity and are therefore useful for identifying lithological units and variation within lithological units. Such features and changes are usually highly significant with respect to groundwater occurrence. The geo-electric method is capable of mapping changes in the vertical profile that may be highly significant with regards to the hydrogeological potential of the area (Acworth, 1987). Electrical Resistivity method was used for the study. This is based on the close relationship between electrical conductivity and common hydrogeological targets. The efficiency of electrical resistivity method is particularly high in the case where accurate estimate of the depth to aquifer is required.

1.1. Study Area

Sambuli is in the Saboba District of the Northern Region of Ghana and is located between latitudes $09^0\ 32^{'}$N and $09^0\ 36^{'}$N and longitudes $00^0\ 15^{'}$E and $00^0\ 17^{'}$E.



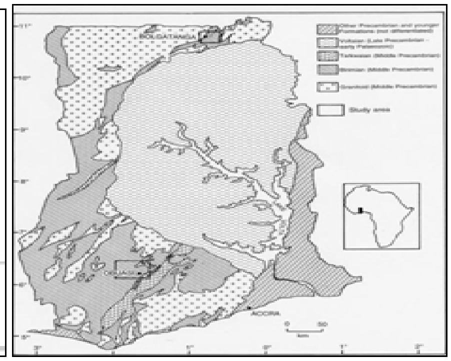


Figure 1: Map showing study area.
Figure 2: Shows Geological map of Ghana.

Geologically, the area falls within the Precambrian rocks and overlain by the Palaeozoic rocks of the Voltaian System (Kessey, 1985). The Voltaian formation covers 45% of the country as shown in figure2. The rocks of the Voltaian formation have little or no primary porosity. Groundwater occurrence is associated with the development of secondary porosity as a result of jointing, shearing, fracturing and weathering which has given rise to weathered and the fractured zone aquifers. The weathered zone aquifers usually occur at the base of the thick weathered layer which varies from 0m at outcrops to about 100m. The fractured zone aquifers usually occur at some depth beneath the weathered zone. Topographically, the area has a plain terrain with occasional gentle slopes. The soils are of laterite developed over the Voltaian shale and is characterized at shallow depths by cemented layer of ironstone called iron pan through which water does not penetrate easily. They however allow water to penetrate where the iron pan is not a continuous sheet. Beneath the iron pan are layers of sandstone and shale. Sandstone is porous and permeable hence creating a good zone for groundwater storage. Shale is however highly porous but relatively impermeable. The extremely small size of the pores together with the electrostatic attraction of clay minerals for water molecules prevent water from moving through shale beds (Babbith et al, 1959). Traditionally, wells drilled in shale beds are usually very unsuccessful however the presence of fissures and fractured rocks in such a formation offers good location for aquifers. The average monthly temperatures range from 25 to 35^0C with the maximum temperature usually recorded in April and the minimum in December-January. The area experiences one major rainy season from June to October with a total annual rainfall ranging between 1050mm and 1500mm with a long dry season experienced from November to May. The vegetation is that of Guinea Savannah or modified Guinea Savannah (Benneh and Dickson, 1988).

2. Materials and Methods

The study included assessing reports from the area, topographic maps (1:250000), soil, geological maps (1:250000) and lineaments from aerial photographs. Identification of appropriate target sites was done by means of a hand-held Garmin e'Trex Summit global positioning system (GPS) receiver. Mapping of groundwater sources was carried out at existing boreholes and also taking note of surface features such as topography, drainage and location of possible areas of groundwater recharge. The general appraisal of the geology, soil and hydrogeological characteristics of the area was made. Aerial photographs (1:40000) were analysed to obtain information on the drainage, general geomorphology and structural features as well as lithology. Fracture trace analysis of the aerial photograph that covers the area was studied. The Hydrogeological Assessment Project (HAP) revealed an overburden that constitutes aquifers. The Integrated Probabilistic Evaluation (IPE) revealed a formation that is more susceptible to fracturing and therefore has the potential for highly transmissive aquifers. The fracture trace analysis in the area yielded important hydrogeological information. The predominant features trend in a NW-SE direction. This is related to a regional folding episode which resulted in the formation of folds whose axes strike in a NE-SW direction (Spiers, 2011). During the resistivity profiling exercise the orientation was NW-SE direction in order to map these fractures that were being targeted. Borehole yields in such an area depend largely on the presence of these fractures in which relatively large volumes of water were stored. The Schlumberger configuration was used for the profiling over a range of 400m to 800m depending on access route of a particular area with electrode spacing of 20m. However, electrode spacing of 40m was intermittently used to check deeper depths of the geological formation. The electrical resistivity profiling was conducted to determine the lateral variation of resistivity along a horizontal traverse and to precisely locate resistivity values that deviate from the background resistivity of the area. Four geo-electric profiles were run using ABEM Terrameter LS to locate resistivity anomaly points. The Schlumberger array was used for both profiling and the Vertical Electrical Sounding. The profiling involves keeping the electrode spacing constant and moving the array to various points to map any resistivity anomaly along the traverses. The principle of the Electrical Resistivity method is that direct current was introduced into the ground via the current electrodes and the potential drop measured between the potential electrodes placed collinearly with the current electrodes as shown in figure 3.

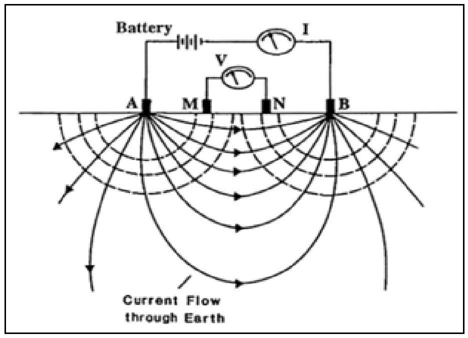


Figure 3: Typical electrode configuration for Schlumberger array.

- AB = current electrode spacing
- MN = potential electrode spacing
- ΔV = potential drop between P_1 P_2
- I = current

The proportion of current penetrating into the ground increases with increasing electrode spacing. In a heterogeneous subsurface the flow of current in the ground is influenced by density, porosity, mineral content and pore fluid which cause vertical variation in resistivity with depth. The VES array is an ordered arrangement of electrodes about the resistivity meter to simulate the characteristics of the ground in terms of the thickness of individual layers together with their respective apparent resistivity values along the vertical profile. The VES was based on modelling of the resistivity of horizontally layered-ground by measuring the apparent resistivity at the surface using the geometric factor (G) expressed by (Zohdy et al, 1974).

$$G = \left[\frac{(AB/2)^2 - (MN/2)^2}{MN}\right] \qquad (1)$$

The apparent resistivity (ρ_a) was calculated using the relation (Zohdy et al, 1974; Telford et al, 1994).

$$\rho_a = \pi \frac{\Delta V}{I} G \qquad (2)$$

The array was better for defining the vertical variation of resistivity up to a depth of 100 m with potential electrode spacing of 0.5 and 5.0 m.

One of the advantages of the VES technique is that it affords the user a view of the geo-electrical changes within the regolith which can be related to the changes in porosity and permeability values in a typical vertical profile through the regolith. The results from VES technique are useful in estimating the potential for obtaining groundwater, locating drilling sites and in particular estimating the depth to aquifer. Drilling site selection may be based on an understanding of the hydrogeological properties of the various lithologies as inferred from the resistivity values.

3. Results and Discussion

The electrical resistivity profiling was conducted along four traverses (A-D) as revealed by the fracture trace analysis. The resistivity equipment, ABEM Terrameter LS automatically generates a pseudo-section of the apparent resistivity of the subsurface. This information was processed using a 2D inversion program (Res 2Dinv) to obtain the inverse model resistivity section. This is depicted by the multiple colours of the resistivity colour spectrum. The selection of geological anomalies was carried out by considering the values of electrical resistivity of layers.

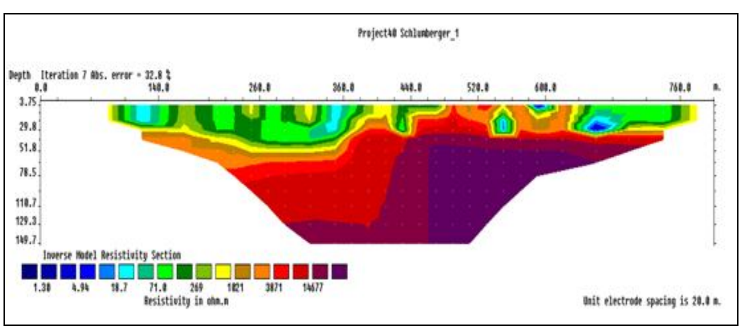


Figure 3a: Profile A

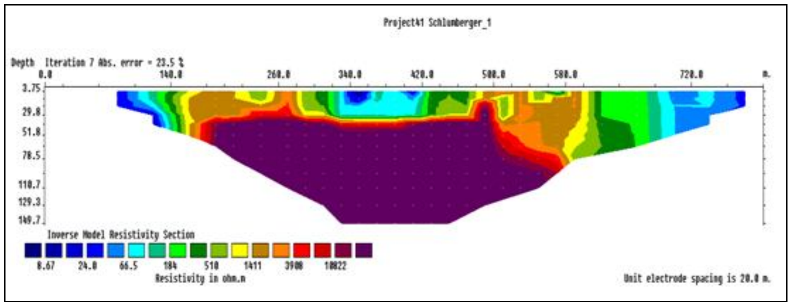


Figure 3b: Profile B

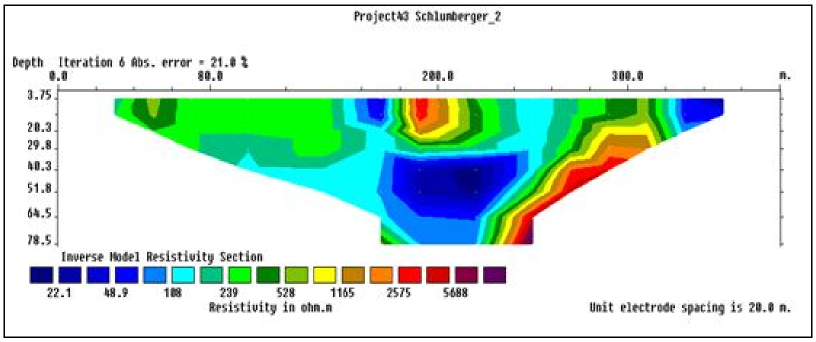


Figure 3c: Profile C

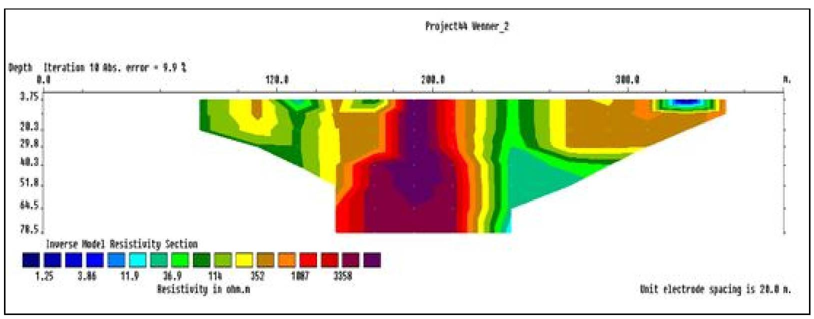


Figure 3d: Profile D

The inverse model resistivity sections of the profiles are shown in figure 3(a-d). Along profile A two points 140m and 350m of resistivity range 10 to 100Ωm, to a depth of about 50m were selected. Station 620 with resistivity range 184 and 510Ωm to a depth of 70m was selected on profile B for further VES investigations. Along profile C, the point 170m and SP1 (an offset at station 240m) with resistivity ranging from 48.9 to 108Ωm to a depth of about 64.5m were selected for the VES investigations. The equipment could not detect any signal on the inverse model resistivity section of profile D for further VES investigations.

VES was performed to simulate a one-dimensional depth profile of resistivity below the mid-point of the survey. Log-log plots of the apparent resistivity against AB/2 were made as shown in figure 4(a-e). The advantages of the log-log plot are that it emphasizes near surface resistivity variations and suppresses variations at greater depths. This is because interpretation of the results depends largely on the small variations in resistivity occurring at shallow depths.

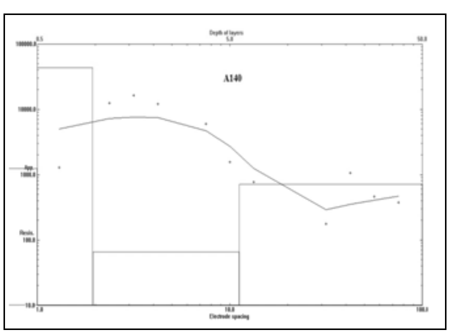


Figure 4a: Shows the VES curve at A140

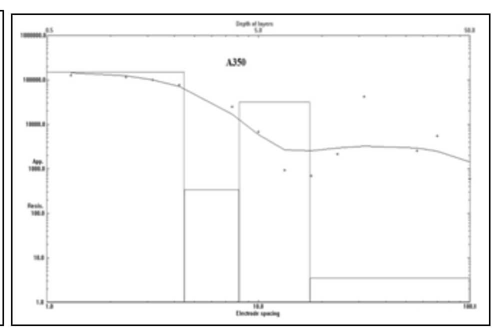


Figure 4b: Shows the VES curve at A350

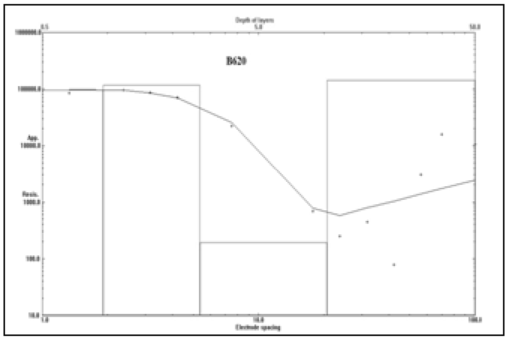


Figure 4c: Shows the VES curve at B620

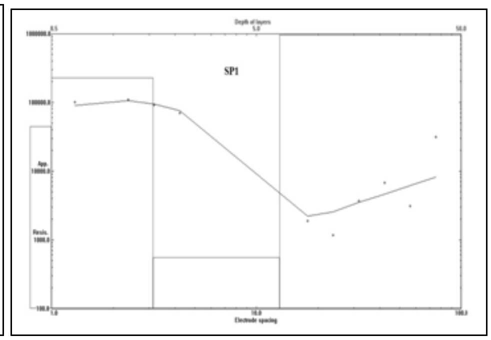


Figure 4d: Shows the VES curve at SP1

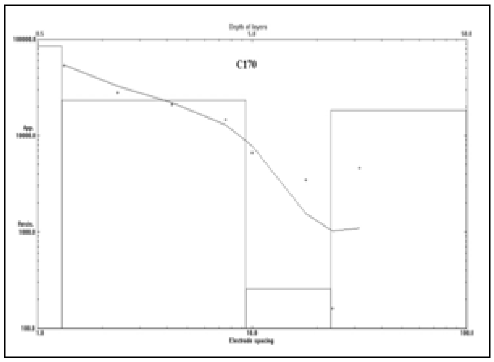


Figure 4e: Shows the VES curve at C170

Interpretation of the VES results showed a four-layered subsurface structure with a topsoil of resistive rocky formation that outcrop at some areas. The resistivity value of the first layer ranges from 2059 to 100000Ωm and thickness 0.4 to 2.3m. The second layer has resistivity ranging from 189.9 to 94025.4Ωm and thickness from 0.9 to 4.9m. The third layer has resistivity varying from 81.5 to 15224.1Ωm with thickness ranging from 7.2 to 10.3m. This layer is partially convenient for groundwater storage. The fourth layer has resistivity ranging from 40.3 to 90660.1Ωm. The fourth layer of station SP1 is a potential zone for groundwater storage. Table 1 shows the VES locations and the corresponding layer characteristics of the study area. An average VES data interpretation is shown in figure 5.

VES Location	**Layer number**	**Resistivity Ωm**	**Thickness M**	**Depth m**	**Layer Characteristics**
A140	1	2059.9	0.4	0.4	Dry sandy topsoil
	2	33999.7	0.9	1.3	Laterite sand
	3	81.5	10.3	11.6	Highly weathered/fractured rock
	4	1502.5	-	-	Slightly weathered
A350	1	100000	2.3	2.3	Hard crystalline topsoil
	2	750.9	4.0	6.3	Slightly weathered layer
	3	15224.1	9.8	16.1	Laterite sand
	4	134.6	-	-	Weathered/fractured basement
B620	1	100000	1.1	1.1	Hard crystalline topsoil
	2	94025.4	1.8	2.9	Dry Laterite sand
	3	222.2	8.6	11.5	Slightly weathered/ fractured rock
	4	90660.1	-	-	Fresh basement
C170	1	48883.1	1.0	1.0	Laterite sand
	2	25117.2	3.2	4.2	Sand
	3	364.6	7.2	11.4	Fractured basement
	4	10482.5	-	-	Basement rock
SP1	1	78599.4	0.5	0.5	Laterite sand
	2	189.9	4.9	5.4	Weathered zone
	3	1237.5	8.5	13.9	Slightly weathered
	4	40.3	-	-	Highly weathered/fractured basement

Table 1: Shows the VES location and the corresponding layer characteristics

+ +	**Dry sandy topsoil/Hard crystalline rock**
. . . . . . ,.	**Laterite sand**
<<<<<<<<<<<<<< <<<<<<<<<<<<<< <<<<<<<<<<<<<<	**Slightly weathered layer**
_ _	**Weathered/Fractured basement**
************* ************* *************	**Fresh rock**

Figure 5: An average VES data Interpretation

The aquifer system is composed of weathered/fractured basement layer. Among the geological formations overlying the aquifer system is the lateritic sand. The weathered/fractured altered basement had the lowest apparent resistivity. Weathering process lead to the dissolution of the unstable minerals within the basement rocks resulting in a highly conductive solution and hence a lower apparent resistivity. Underlying the water-bearing formations was the fresh rock with a very high resistivity range. This formation is composed of highly electrically resistive minerals which impede the flow of current through it.

3.1. Relationship between Lithology and Electrical Resistivity

Most rocks and minerals except metallic ores and clay minerals in their dry state are insulators and electrical conduction can occur in the presence of interstitial water contained in pores and fissures. Electrical properties of rocks depend on composition, micro-structure and interfacial effects (Ruffet et al, 1995). The alteration of cracks and pores in rocks produce a local reduction of the strength of the electric field in the vicinity of the mineral surface (Revil and Cathles, 1999) which modifies the contribution of the interfaces to the total electrical conductivity. In low permeability environments controlled by secondary and accessory minerals (eg clay minerals), electrical properties are significantly affected by surface conductivity. Therefore there is no direct connection expected between the electrical resistivity and permeability of the aquifer materials. In the case of the study area the suitability of a site for a borehole largely depended on thickness of weathered layer and fractured basement.

4. Conclusion

Groundwater is abundant in the earth crust however, its occurrence is localised and unpredictable. Siting of boreholes require comprehensive scientific approach. A combination of complimentary geophysical techniques together with other groundwater processes is required to locate sustainable groundwater sources. Electrical resistivity profiling and Vertical Electrical Sounding techniques have proved to be extremely cost effective in the location and delineation of water bearing formations. Four geo-electric layers were revealed by the VES investigations. Interpretation of the data showed that the topsoil was very resistive with resistivity values ranging from 2059.9 to 100000Ωm and thickness 0.4 to 2.3m. The second layer was equally resistive except station SP1 which showed some amount of weathering with resistivity value of 189.9Ωm. The third layer of station A140 showed significant amount of weathering (resistivity of 81.5Ωm) while the others were slightly weathered (resistivity ranging from 222.2 to 15224.1Ωm). The fourth layer of stations A350 and SP1 revealed a highly weathered/fractured zone (resistivity values 134.6m and 40.3m respectively) which is a potential groundwater storage zone.

5. Acknowledgements

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6. References

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