
Authors

Appiah Seth¹, Mensah Philip Kwasi², Gyasi Daniel Antwi³

University for Development Studies, Dept. of Physics, Navrongo Campus, Ghana.

Correspondence author: Appiah Seth
University for Development Studies, Faculty of Applied Sciences, Dept. of Physics, Box 24, Navrongo, Ghana.
Email: skappiah26@gmail.com

Abstract

Geophysical investigation for groundwater potential of Buma in the Gonja East 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 were used to delineate the subsurface geology of the study area. Three geoelectric profiles were conducted to measure electrical resistivity values along the terrain. The data were processed using a 2D inversion program (Res 2Dinv) to obtain an inverse resistivity model section. VES points were selected from the resistivity anomaly values. Five VES locations were investigated and the data analysed. Interpretation of the VES data identified a four-layered subsurface structure with a dry sandy topsoil of electrical resistivity values ranging between 19823.2 and 60716.3Ωm and thickness between 1.0 and 2.3m. The electrical resistivity of the second layer ranges from 637.3 to 48298.5Ωm with thickness varying from 2.0 to 13.2m. The third layer, a convenient zone for groundwater location has electrical resistivity ranging from 148.5 to 637.7Ωm and thickness 13.3 to 28.1m. The third layer of station A400 revealed significant amount of weathering/fracturing (resistivity value of 148.5Ωm and 39.7m deep), hence
a zone of potential groundwater location for borehole construction. The fourth layer has resistivity ranging from 181.5 to 94572.8Ωm, a partial layer for groundwater storage.

**Keywords:** permeability, porosity, groundwater, resistivity, weathering, fracturing

**Introduction**

The rapid development due to increased population and urbanization demands an increase and improvement of amenities especially potable water supply for domestic, industrial and Agricultural use. Provision of safe and sustainable water supply 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 [1]. 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. Groundwater accounts for about 98% of the world’s reasonably constant supply which is sustainable in contrast to surface sources. 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 [2]. Porosity and permeability are important properties in hydrogeology in determining the ability of a rock formation to hold and transmit water storage [3]. The distribution of groundwater in geological formations is not uniform [4], hence a more comprehensive geophysical investigation is required for its exploitation. Groundwater exploration in crystalline basement complex terrain requires detailed geophysical investigation to effectively characterise the hydrogeological zones to enhance successful identification of drilling sites. These zones are due to the development of secondary porosity and permeability by weathering/fracturing of these rocks. The search for groundwater in such rocks is aimed at mapping such secondary structures which constitute the basement aquifers. The objective of the research was to map possible fractured assisted aquifer system and to determine layer thickness and depth to aquifer system. Geo-electric methods are commonly used in solving groundwater problems. The 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 methods are capable of mapping changes in the vertical profile that may be highly significant with regards to the hydrogeological potential of the area [5]. In this study, Electrical Resistivity method was used for the survey. 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.

**Study Area:**

Buma is in the Gonja East District of the Northern Region of Ghana and is located between latitudes $08^033'N$ and $09^005'N$ and longitudes $0.29^015'W$ and $1.26^0W$. The map of the study area is shown in figure 1.

![Fig. 1 Showing map of Gonja East District.](image1)

Geologically, the area falls within the Precambrian rocks overlain by the Palaeozoic rocks of the Voltaian System [6]. The Voltaian formation covers 45% of the country as shown in figure 2. 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 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 [7]. 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°C 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 [8].

Materials and methods

The study included assessing reports from the area and 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 study area was studied. The Hydrogeological Assessment Project (HAP) data 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. Most streams in the area flow in the N-S direction. This is related to a regional folding episode which resulted in the formation of folds whose axes strike in a NE-SW direction [9]. 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 400 and 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. Three 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 is 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.

![Fig. 3 Typical electrode configuration for Schlumberger array.](image)

- **AB** = current electrode spacing
- **MN** = potential electrode spacing
- **ΔV** = potential drop between P₁ P₂
- **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 [10].

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

(1)

The apparent resistivity (\(\rho_a\)) was calculated using the relation [10], [11].

\[ \rho_a = \pi \frac{\Delta V}{I/G} \]  

(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.

Results and discussion

The electrical resistivity profiling was conducted along three traverses (A-C) identified in the fracture trace analysis of the study area. The 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 an inverse model resistivity section. This is depicted by multiple colours from the resistivity colour spectrum of which points were selected for further Vertical Electrical Sounding investigations. The selection of resistivity anomalies was carried out by considering the values of electrical resistivity of layers.
Fig. 4

**Fig. 4a Profile A**

**Fig. 4b Profile**

**Fig. 4c Profile C**
The inverse model resistivity sections of the profiles are shown in figures 4(a-c). Station 200m and 400m with resistivity range 10 to 658Ωm to a depth of approximately 130m were selected for VES investigation along profile A. Stations 320m and 400m along the profile B with resistivity range 6 to 375Ωm of an approximate depth of 50m were selected for further VES investigation. The point 170m with resistivity values ranging between 48.9 and 108Ωm to a depth of 64.5m was selected for VES investigation along profile C.

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 plotted as shown in figure 5(a-e). The advantages of the log-log plot are that near surface resistivity variations are emphasized whilst variations at greater depths are suppressed. This is simply because interpretation of the results depends largely on the small variations in resistivity occurring at shallow depths.

![Fig. 5a VES A200](image-url)
Fig. 5b VES A400

Fig. 5c VES B320

Fig. 5d VES B400
Interpretation of the VES results showed a four-layered subsurface structure with resistive topsoil. The resistivity value of the topsoil ranges from 19823.2 to 60716.3 Ωm and thickness 1.0 to 2.3 m. The second layer has resistivity ranging from 637.3 to 48298.5 Ωm and thickness from 2.2 to 13.2 m. The third layer has resistivity varying from 148.5 to 637.7 Ωm with thickness ranging from 7.2 to 29.4 m. The fourth layer has resistivity ranging from 181.5 to 94572 Ωm.

Table 1 shows the VES locations and the corresponding layer characteristics of the study area. An average VES data interpretation is shown in figure 6.

Table 1. VES location and the corresponding layer characteristics

<table>
<thead>
<tr>
<th>VES Location</th>
<th>Layer number</th>
<th>Resistivity Ωm</th>
<th>Thickness M</th>
<th>Depth M</th>
<th>Layer characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A200</td>
<td>1</td>
<td>56979.2</td>
<td>1.3</td>
<td>1.3</td>
<td>Dry sandy topsoil</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48298.5</td>
<td>2.2</td>
<td>3.5</td>
<td>Laterite sand</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>637.7</td>
<td>28.1</td>
<td>31.6</td>
<td>Slightly weathered/fractured rock</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>15647.1</td>
<td></td>
<td></td>
<td>Basement rock</td>
</tr>
<tr>
<td>A400</td>
<td>1</td>
<td>60716.3</td>
<td>1.8</td>
<td>1.8</td>
<td>Dry Laterite topsoil</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>670.9</td>
<td>9.0</td>
<td>10.8</td>
<td>Slightly weathered layer</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>148.5</td>
<td>16.3</td>
<td>27.1</td>
<td>Weathered/fractured layer</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>94572.8</td>
<td></td>
<td></td>
<td>Basement rock</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>19823.2</td>
<td>2.0</td>
<td>2.0</td>
<td>Sandy topsoil</td>
</tr>
</tbody>
</table>
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 very high resistivity range. This formation is composed of highly electrically resistive minerals which impede the flow of current through it.

**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 only occur in the presence of interstitial water contained in pores and fissures. Additionally, electrical properties of rocks depend on composition, micro-structure and interfacial effects [12]. 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 [13] which modifies the contribution of the interfaces to the total electrical conductivity. In low permeability environments controlled by secondary and accessory minerals (e.g. 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/fractured basement.

**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 VES data revealed dry sandy topsoil with resistivity values ranging from 19823.2 to 60716.3Ωm and thickness 1.0 to 2.3m. The second layer showed some amount of slight weathering with resistivity value between 637.3 and 48298.5Ωm. The third layer showed significant amount of weathering/facturing (resistivity ranges between 148.5 and 637.7Ωm). The third layer of station A400 revealed a highly weathered/fractured zone with resistivity value of 148.5Ωm and at a depth of 39.7m as a potential groundwater storage zone. A productive borehole can therefore be constructed at station A400. The fourth layer was identified to be resistive, however station B400 showed significant amount of weathering/fracturing (181.5m) which could be an alternative location for borehole construction.

**Acknowledgement:** The Authors wish to acknowledge Mr Carl Ofori Agyemang, Mr Addai Eric and The Water Research Institute of Ghana for their immense assistance towards this research.
References


