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Application of Integrated Geophysical Methods to Select Sites of High Groundwater in the Pru District of the Brong Ahafo Region of Ghana.

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ABSTRACT

Groundwater has been identified as the best source of rural water supply because it has eliminated the problem of water borne diseases which have affected communities in the Pru District in the Brong Ahafo Region for some years. Adequate and sustainable source of groundwater can be obtained by geophysical methods which ensure that potable and safe drinking water is available for the entire population. Integrated geophysical methods involving Electromagnetic and Electrical resistivity methods have been carried out to delineate groundwater potential and locate drilling sites for boreholes in the District. The Electromagnetic profiling method was used for reconnaissance survey to identify anomaly conductive spots for further investigation using the Vertical Electrical Sounding (VES) technique. The Schlumberger array was carried out for the VES investigation. Interpretation of the VES data revealed a general pattern of a three layered earth structure, namely topsoil, saturated sandy/ lateritic clay and weathered/ fractured/ fresh basement rocks. The presence of aquifer units included the weathered zones and the fractured basement. These units are found at depth ranging between 27.0 and 69.5 m.

Introduction

The growth of population, industry and Agriculture coupled with increasing urbanization has resulted in over abstraction of groundwater and enormous quantities of wastes. About two billion people around the globe depends on groundwater resource which in itself a vulnerable resource [Kemper, 2004]. According to the 2007 Ministry of Health report, the District was rated among the guinea worm endemic areas in the country and the highest in Region. Between 2004 and 2005, guinea worm cases had increased to 169 (2008 District profile, unpublished data). Some boreholes in the District show poor yield and subsequently dry up in the dry season. Thus the potential for groundwater in the District is apparently low because of the geological conditions of the area. Ironically, most rivers and streams, which serve as a traditional alternative source of water, dry up during the dry season and those that could survive the drought were often polluted by human, animal and industrial activities. The investigation was carried out in six selected beneficiary communities in the District; namely Komfourkrom, Parambo, Sawaba, Akokoa, Prang and Abease.

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 and improving their location. Applications of Electrical Resistivity and Electromagnetic methods are widely recognised when locating and identifying the presence of water bearing formations. Electrical resistivity and Electromagnetic methods are commonly used because of the close relationship existing between electrical conductivity and common hydrogeological targets. The objective of the research was to improve and locate successful boreholes through the use of integrated geophysical techniques.

Figure 1. The beneficial communities in the Pru District.

The earth is the largest accessible storage of potable water and accounts for about 94% of all fresh water [Plummer and McGery, 1993]. According to Fetter [1994], groundwater occurs in geological formations; however, its distribution in the earth crust is not uniform. 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. An underground formation saturated with water according to Michael Price [1994] is an aquifer. The potential for obtaining groundwater and the well yields are closely related to the nature of the regolith profile with the saturated thickness of the high porosity saprolite and the development of a high permeability transition zone between regolith and

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bedrock. Deep high capacity wells are located in zones of deep weathering, fractured and faults in hard crystalline rocks and porous sedimentary rocks. Generally, appreciable quantities of groundwater can be found in thick over burden, with moderate resistivity values. Thus weathered and fractured zones enhance chances of high yielding boreholes. Hydrologically, a 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 in storage [Davies and Wiest, 1968].

According to Patton [1990], the use of only one method is more vulnerable to errors than complimentary methods hence Electrical Resistivity and Electromagnetic methods were employed in the investigation. These methods are unique because of their physical properties (resistivity/ conductivity) used to characterised rocks. 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 [Parasnis, 1986]. The resistivity of rocks is linked to several parameters including mineral content, porosity, water content and electrical resistivity of water [Rein et al, 2004]. The electrical resistivity (ρ) of water saturated rock according to Parasnis [1986] is given by

$$P = a\Phi^{-b} f^{-c} \rho_w \qquad (1)$$

Where

Φ - Porosity

f – a fraction of pores saturated with water

ρw- resistivity of water

a, b and c are constants

1.1 Study area

The location of the district lies between longitudes 80 11' 14'' N and 80 16' 40'' N and latitudes 00 25' 24'' W and 00 43' 07'' W. Geologically, the area falls within the Precambrian rocks and overlain by the Palaeozoic rocks of the Voltaian System. This System consists of sandstone, shale mudstone, siltstone and intercalation of sandstone and shale [Kesse, 1985]. Topographically, the area is a plain ground with occasional gentle slopes which does not allow fast run-offs during rainy season. The soils are of laterites developed over the Voltaian shale and is characterised at shallow depths by cemented layer of ironstone called iron pan through which water does not penetrated easily. They, however, allow water to percolate through where the iron pan is not a continuous sheet. Beneath the iron pan are layers of sandstone and shale. Sandstone is both 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 mineral for water molecules prevent water from moving through shale [Babbith et al, 1959]. Traditionally, wells drilled in shale beds are usually very unsuccessful, however, fissures and fractured rocks in such a formation offers good location for aquifers.

1.2 Climate and vegetation

The area experiences bimodal type of rainfall; May-June and September-October. The mean annual rainfall ranges between 115 and 125 mm. The highest mean monthly temperature of 30 oC occurs in March and lowest 24 0C. The vegetation is the Guinea Savannah or a modified form of the Guinea Savannah [Dickson and Benneh, 1988].

2.0 Materials and Methods

The study included accessing hydrogeological investigation reports of the area, topographic and geological maps (1:250000) and aerial photographs to gather information on drainage and vegetation patterns. Identification of appropriate target sites was done by means of a hand- held Germin e'Trex Summit Global Positioning System (GPS) receiver.

Mapping of groundwater sources was carried out by taking note of existing boreholes, springs and surface features such as drainage patterns and hydrogeological characteristics of the area. Electromagnetic (EM) and Electrical Resistivity methods were the Geophysical methods employed in this research. The EM method was adopted as a fast reconnaissance tool to map the possible linear features (such as fault and fracture zones) whilst the Electrical Resistivity method was used for the Vertical Electrical Sounding (VES) technique to determine the vertical variation of resistivity of the subsurface at the EM anomaly points. The VES technique is capable of mapping changes in the vertical profile that may be highly significant with regards to the hydrogeological potential of the area. The EM method, though fast is not more accurate as the Electrical Resistivity method [Fetter, 1994]. The EM terrain conductivity profiles were conducted to precisely locate conductivity values that deviate from the background conductivity of the area using Geonics EM 34-3 meter. The instrument displays a direct reading of the apparent conductivity of the point under investigation.

2.1 Principles and theory

EM profiling makes use of the response of the ground to the propagation of electromagnetic waves which are composed of alternating electric field intensity and magnetising force. The primary field (Hp) generated by passing alternating current through the Transmitter coil and by the process of electromagnetic induction, the eddy current is induced in the subsurface conductor to generate its own secondary field (Hs). This is detected by an alternating current induced in the receiver coil. The resultant field measured is the ratio of the secondary field to the primary field.

$$\frac{H_s}{H_p} = \frac{i\omega\sigma s^2}{4} \qquad (2)$$

$$\sigma = \left(\frac{H_s}{H_p \sigma}\right)\left\{\frac{4}{i\omega\mu s^2}\right\} \qquad (3)$$

Where

ω =angular frequency

σ = conductivity of the ground

µ =permeability

s =inter-coil spacing

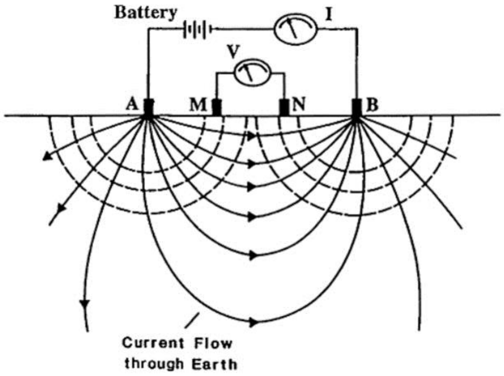


Figure 2. Typical electrode configuration for Schlumberger array.

Where

AB = current electrode spacing

MN = potential electrode spacing

ΔV = potential drop between P1 P2

I = current

A proportion of the current penetrate into the ground and the depth of penetration increases with increasing electrode spacing. In a heterogeneous subsurface the flow of current in the ground is influenced by density, porosity, mineral contents and pore fluid which cause vertical variation in resistivity with depth.

The Schlumberger configuration was used for the VES technique. 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 (Robert, et ai.,1993). The VES was based on modeling 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;Appiah and Mensah, 2014].

$$\mathbf{G = \pi \left[\frac{(AB/2)^2-(MN/2)^2}{MN}\right]} \quad (4)$$

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

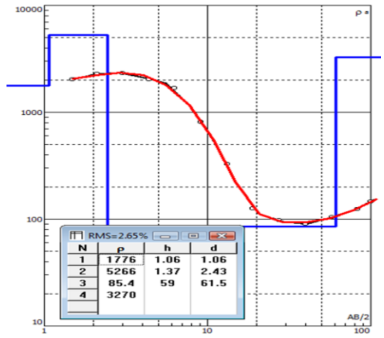
$$\rho_a = \frac{\Delta V}{I}\frac{1}{G} \quad (5)$$

One of the advantages of the VES technique is that it affords the user a view of the geoelectric 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 (Appiah et al., 2014). Drilling site selection may be based on an understanding of the hydrogeological properties of the various lithologies as inferred from the resistivity values.

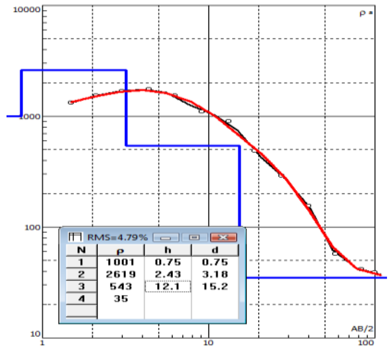
Three VES spots were selected for each locality based on the EM anomaly values of which the best site for drilling was chosen depending on the geophysical analysis and accessibility of the site by the drilling team. The down tool hammer method was used during the drilling procedure. Yield estimates were made for all the measurable water strikes using a bucket of 10L and a stop watch every time a new strike was observed during drilling. Borehole yield is often used as a fair indicator of aquifer productivity in the absence of specific capacity or transmissivity values [Banks et al, 2005]. The water level in the borehole was allowed to be stable first before pumping test was begun. An electrical submersible pump (Grundfos SP3A-30) was installed into the borehole and positioned several metres below the deepest water levels expected during the test. Water level measurements were made using Electrical groundwater meter (Comet-Anschlubspan gardena-24). The wells were constantly pumped until the draw downs stabilised and then the recovery was monitored over a similar period to that of pumping.

3. Results and Discussion

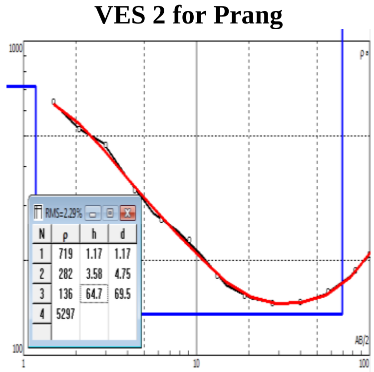
VES were performed to simulate as one-dimensional depth profile of resistivity below the mid-point of the survey. Log-log plots of the apparent resistivity against AB/2 were made (fig. 3).



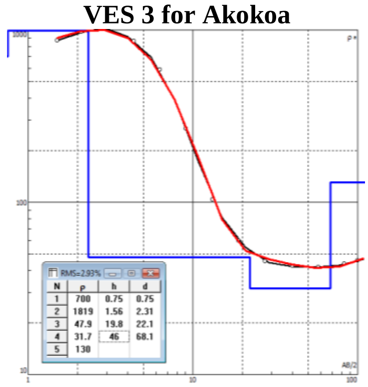
VES 1 for Komfourkrom



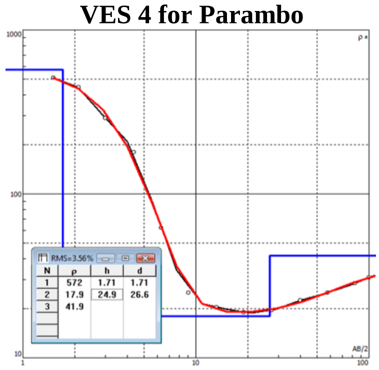
VES 2 for Prang



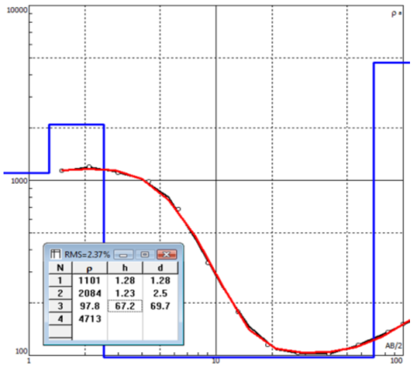
VES 3 for Akokoa



VES 4 for Parambo



VES 5 for Sawaba



VES 6 for Abease

Figure 3. Variation of apparent resistivity with depth at VES points.

The results of the interpretation of the VES data revealed the different layers in terms of their resistivity and depths which reflects the lithological variation with depth. VES 1, 2, 3 and 6 showed a general pattern of three geoelectric layers of which the top layer ranges in thickness from 0.75 to 1.28 m and resistivity ranging from 719 to 1776 Ωm. The underlying layer has a resistivity ranging from 282 to 5266 Ωm. The third layer has resistivity varying between 85.4- 543 Ωm. The third layer of VES 4 of thickness 19.8 m has resistivity of 47.9 Ωm whilst the fourth layer has a moderately low resistivity of 31.7 Ωm; a mud weathered zone. The third layer of VES 5 presents a moderately weathered zone (resistivity of 41.9 Ωm). These are the possible aquifer zones. The advantages of the log-log plot are that it emphasises near surface resistivity variations and suppresses variations at greater depths (Ahmed, 2013). This is because interpretation of the results largely depends on the small variations in resistivity occurring at shallow depths.

Electrical properties of rocks depend on composition, microstructure and interfacial effects. The cracks and pores in rocks produce local reduction of electric field strength at the interface of minerals which modify the contribution of the interfaces to the total electrical conductivity [Ruffet et al, 1995]. Electrical properties are much affected in clay environment where permeability is low, however, there is no direct connection between electrical resistivity and permeability of an aquifer material. A suitable location for borehole drilling therefore largely depends on the thickness of the regolith and fractured bedrock. Interpretation of the depth to bedrock as determined by the VES could be achieved after controlled logging from drilling is made available in fig. 4.

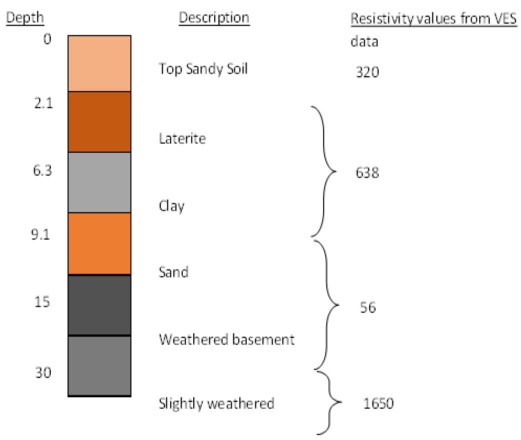


Figure 4. Typical borehole log in the study area.

Figure 4 shows an average borehole log of six different geological formations. The variation in the number of layers obtained from the VES data and the borehole log is due to the presence of suppressed layers. From the borehole log, the aquifer system consists of weathered basement and fractured bedrock. Overlying the aquifer system is a clay layer which displays the lowest resistivity range. The effect of clay minerals is the formation of a double layer of cations. The high cation exchange ability of clay minerals and its proportion in the weathered rock make it yield low resistivity. This is because of the surface conductivity which corresponds to an electrical conduction mechanism located in the close vicinity of the pore-water/mineral interface in the electrical double layer coating the mineral-water interface [Revil and Leroy, 2001]. The electrical double layer contributes to the enhancement of the electrochemical properties of clay minerals. The weathered formation within the aquifer system had a slightly higher resistivity range compared to the weathered and clay formations. The fractured altered basement in the aquifer system had a lower apparent resistivity. Below the water bearing formation is the slightly weathered formation with a very high resistivity. Electrical resistivity cannot, however, recognize suppressed layers which may contain water but not of very much significant. The yields of many boreholes were found to be between 4.8 and 6.0 m3/h.

4.Conclusions

Groundwater is abundant in the earth crust; however, its occurrence is not uniform and therefore requires a more scientific approach in citing boreholes. Integrated geophysical techniques together with other groundwater processes are necessary for locating sustainable boreholes. Electromagnetic and Electrical resistivity methods have proved to be more effective and inexpensive in the location and delineation of water bearing formations. The Vertical Electrical Sounding technique has been shown to be more accurate and rapid in the location of deeper zones of aquifer.

Acknowledgments

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