Available online at www.elixirpublishers.com (Elixir International Journal)

Nuclear and Radiation Physics

ISSN: 2229-712X

Elixir Nuclear & Radiation Phys. 147 (2020) 54905-54907

Using Integrated Geophysical Method in groundwater exploration in the Nkoranza- South District, Ghana

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ARTICLE INFO

Article history:

Received: 17 July 2020;

Received in revised form: 8 October 2020;

Accepted: 20 October 2020;

Keywords

Electrical Resistivity,
Groundwater,
Regolith,
Aquifers,
Nkoranza South

ABSTRACT

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. Adequate and sustainable source of ground water can be obtained by geophysical methods. Integrated geophysical methods involving electromagnetic and electrical resistivity methods have been carried out to delineate groundwater potential and locate drilling sites for boreholes in four communities in the Nkoranza South District. The electromagnetic method was used for profiling to identify anomaly conductive sites for further investigation using the vertical Electrical Sounding (VES) technique. Interpretation of the VES data revealed a weathered/ fractured zone at a maximum depth of 25.5 m which are potential aquifer zones.

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 society. In developing countries improvement in water supply has been recognised to have direct impact on public health. 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 flows through rocks of varying permeability towards discharge points (Brassington, 1998). Porosity and permeability are important in hydrology in determining the ability of a rock formation to hold and transmit water in storage (Davies and Wiest, 1968). It must be noted that the earth is the largest accessible storage of portable water and accounts for about 94 % of all fresh water (Plummer and McGery, 1993). Groundwater occurs in geological formations, however, its distribution in the earth is not uniform (Fetter, 1994). The potential for obtaining groundwater and the well-yield are closely related to the nature of the regolith profile, the saturated thickness of the high porosity saprolite and the development of a high permeability transition zone between regolith and bed rock. Deep high capacity wells are located in zones of deep weathering, fractured and faults in hard crystalline rocks and porous sedimentary rocks. Appreciable quantities of groundwater can be found in the thick overburden with moderate resistivity values. Fractured and weathered zones enhance high yielding boreholes. The hand-dug wells and some boreholes in the District showed 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 condition of the area. Most rivers and streams that survive the drought period were often polluted by human, animal and industrial activities. The use of only one method is more vulnerable to errors than complementary methods (Patton, 1990), hence electromagnetic and electrical Resistivity methods. Application of electromagnetic and electrical resistivity methods are widely used when locating and identifying the presence of water bearing formations as there exists close relationship between electrical conductivity and common hydro geological targets (Appiah and Mensah, 2017). According to Parasnis (1986) the electrical resistivity (ρ) of water-saturated rock is given by:

$$\boldsymbol{\rho = a\emptyset^{-b} f^{-c} \rho_w}$$

Where

$$\emptyset - \textbf{porosity}$$

$\mathbf{f - fraction\ of\ pores\ saturated\ with\ water}$

$\boldsymbol{\rho_w} - \textbf{resistivity of water}$

$\mathbf{a, b, and\ c - are\ constants}$

The objective of the research was to locate successful boreholes through the use of integrated geophysical techniques.

Study area

The District lies within longitudes 1°10'' W and 1° 55'' W and latitudes 7° 20" N and 7° 55" N. The beneficiary communities were Anama, Asuano, Nyamesomyede and Ahyiaem The geology of the area is the Precambrian rocks

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overlain by the palaeozoic rocks of the Voltaian formation. This formation consists of sandstones, shale, mudstone, quartzite conglomerate of pebbly beds, siltstone and intercalation of sandstone and shale (Kesse, 1985). The soils are of laterite developed over the Voltaian shale and is characterised at shallow depths by cemented layer of ironstone (iorn pan). This constitutes the iorn pan laterite and occupies about 50 % of the interior savannah. The cemented ironstone does not allow water to penetrate. They, however, allow the water to penetrate where the ironstone is not a continuous sheet. Beneath the ironstone are layers of sandstone and shale. Sandstone is porous and permeable hence creating 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 (Appiah and Mensah, 2017). Wells drilled in shale beds are usually very unsuccessful, however, fissures and fractured rocks in such a formation offers good location for aquifers.

Climate and vegetation

The study area experiences a bimodal type of rainfall, March- June and September- November. The month of August experiences a short dry season, with a prolonged one from December to February. The mean annual rainfall ranges between 800-1200 mm (Dickson and Benneh, 1988). The district forms part of the transitional zone between the savannah woodland of Northern Ghana and the forest belt of the south.

Materials and methods

The study was in three parts namely: the desk study, reconnaissance survey and geophysical survey. The desk study involves accessing hydrogeological investigation reports of the area, topographic and geological maps and aerial photographs to gather information on the drainage and vegetation patterns. The reconnaissance survey includes inspection of topographic features and vegetation lineaments. Identification of appropriate target sites was done by means of a hand held Germin e`Trex summit Global Positioning Systems (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 adopted as fast reconnaissance tool to map faults and fractured zones whilst the Electrical Resistivity Method was used for the Vertical Electric 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. According to Fetter (1994) the EM method though fast is not accurate as the Electrical Resistivity method. The EM profiling was conducted to locate conductivity values that deviate from the background conductivity of the area using Geonics EM 34-3 meter. The EM profiling makes use of the response of the ground to the propagation of electromagnetic waves. The primary field (H_p) generated by the passage of alternating current through the transmitter coil induces eddy current in the subsurface conductor by the process of electromagnetic induction. A secondary field (H_s) is generated which together with the modified primary is detected by the alternating current induced in the receiver coil. The resultant field measured is the ratio of the secondary field to the primary field;

$$\frac{H_S}{H_P} = \frac{i\omega\sigma\mu s^2}{4} \quad (1)$$

$$\sigma = \frac{4}{i\omega\mu s^2}\left(\frac{H_S}{H_P}\right) \quad (2)$$

Where

ω − angular frequency

σ − conductivity of the ground

μ − permeability

s − inter − coil spacing

The 20 m inter-coil spacing cable was used and with conductivity measurement made at a station interval of 10 m. The Geonics EM 34-3 displays the ground conductivity which can be interpreted on site. Deviations of conductivity values from the background values were selected for further VES investigation using the Schlumberger configuration. A proportion of the current penetrates into the ground and the depth penetration increases with increasing electrode spacing. In a heterogeneous subsurface, the flow of current in the ground is influenced by porosity, density, mineral content and pore fluid which cause vertical variation in resistivity with depth (Appiah and Mensah, 2014). Electrical properties of rocks depend on composition, microstructure and interfacial effects. The cracks and pores in rocks produce a 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, the electrical resistivity is independent of permeability of an aquifer material. A suitable location for borehole drilling depends largely on the thickness of the regolith and fractured bedrock. The VES array about the resistivity meter simulates 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 array was better for defining the variation of resistivity of resistivity up to a depth of 100 m with potential electrode spacing of 0.5 and 5.0 m. The apparent resistivity (ρ_a) was calculated from the relation (Telford et al. 1994);

$$\rho_a = \frac{\Delta V}{I}\left(\frac{1}{G}\right) \quad (3)$$

Where

ΔV − is the potential difference

I − current

G − geometric factor

The advantage 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 of a typical vertical profile through the regolith. The results from the VES are useful in estimating the potential for obtaining groundwater, locating drilling sites and estimating the depth to aquifer. Three VES points were selected for each locality based on the EM anomaly values of which the best site was chosen for drilling depending on the accessibility of the site by the drilling team and the geophysical analysis. The down tool hammer method was used during drilling procedure. Yield estimates were made for all the measurable water strikes and a mean of 600 L per minute was obtained. 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 before pumping test was begun. An electrical submersible pump (Grundfos SP3A-30) was installed into the borehole and positioned several meters below the deepest water levels expected during the best. Water level measurements were made using electrical groundwater meter (Cornet-Auschluspan Gardena-24). The wells were constantly pumped until the drawdowns stabilised and then the recovery was monitored over a similar period to that of pumping.

Results and Discussions

The selected anomaly points from the EM survey were investigated further using the VES technique. The VES was performed to simulate a one-dimensional depth profile of resistivity below the midpoint of the survey. A log-log plot of the apparent resistivity against depth were made as shown in figures 1-4

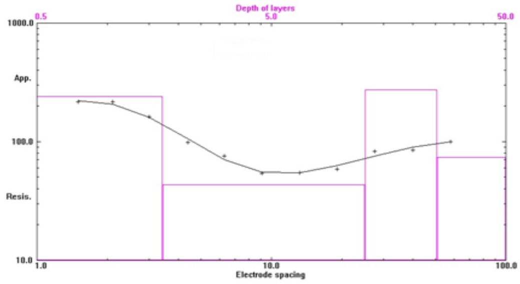

Figure1. VES curve of Anama

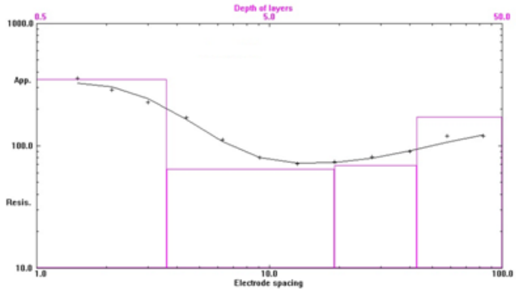

Figure 2. VES curve of Asuano

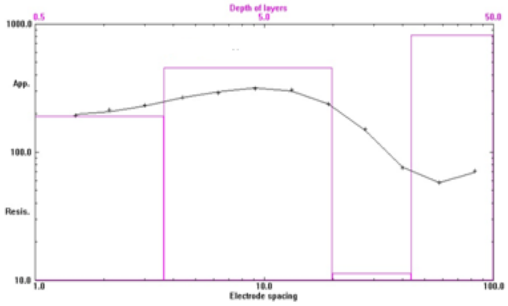

Figure 3. VES curve of Nyamesomyede

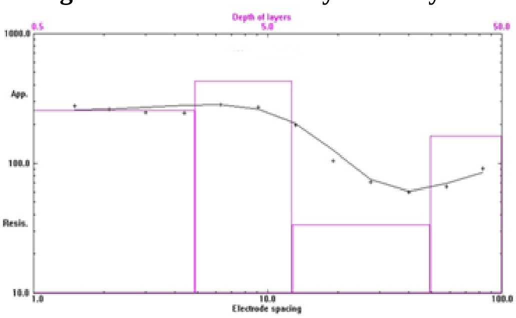

Figure 4. VES curve of Ahyiaem

The VES data revealed a general pattern of four geo-electric layers in the study area. The top layer is resistive with resistivity values ranging between 190 and 348 Ωm with thickness ranging between 1.7 and 2.4 m. The third and fourth layers of the study area from the log-log plot reveal a weathered/fractured zones indicating the presents of an aquifer at a maximum depth of 25.5 m.

Conclusion

The earth is the largest accessible storage of portable water and accounts for about 94% of all fresh water. Groundwater occur in geological formations, however, its distribution in the earth is not uniform. A more scientific method in siting boreholes is therefore, required in locating sustainable borehole. Electromagnetic and electrical Resistivity methods have proven more effective and inexpensive ways in locating and delineating water-bearing formations. The VES has been accurate and rapid in locating deeper zones of aquifer.

Acknowledgements

The authors are profoundly grateful to staff of Water research Institute, Geophysics Department, Ghana, and Flexi Ofori-Attah for their support in carrying out the survey.

Author contributions

Conceived and designed the experiments: AS, MP & OAC. Performed the experiments: OAC, AS &MP. Analyzed the data MP & AS. Wrote the paper: As, MP &OAC

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