IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 4, April 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

Groundwater Exploration in the Voltaian Formation Using 2-D Resistivity Survey: A Case Study of Tadieso Community, Ghana

Elvis Baffoe[1], Isaac Ahenkorah[2], Amoako Kojo[1], Isaac Kotei[1] and Theophilus A. Aryeetey[1]

[1]Department of Geological Engineering, Kwame Nkrumah University of Science and Technology (KNUST)
Kumasi, Ashanti Region, Ghana

[2]School of Natural and Built Environments, University of South Australia,
Adelaide, SA 5095, Australia

chobama.be@gmail.com

Abstract

Potential site delineation for groundwater abstraction in the hydrogeologically difficult terrain like the Voltaian formation was assessed through three VES traverse lines using the Ultra MiniRes IP and Earth Resistivity Meter and its accessories. The Schlumberger array was used for the investigation for AB of 20 to 240 m at station intervals of 10 m with MN spacing of 8 m. 2-D subsurface resistivity images of the terrain were produced using IP2WIN software and these images were used to delineate potential water zones. The analysis of the VES data revealed that the apparent resistivity values range from 22 to 3,900 Ωm for Traverse Line 1, 28 to 2,800 Ωm for the Traverse Line 2 and 5 to 207 Ωm for Traverse Line 3. Siting and drilling reports of work carried out in 2006 by Unihydro Ltd (a hydrogeological consultancy) at Kyebi one of the neighboring communities was used to calibrate the results. From the 2-D images, low apparent resistivity values within the range of 11 to 51 Ωm are likely to have good yield. Therefore, drilling should be done up to deeper depth of about 120 m.

Keywords: *1-D, 2-D, Resistivity, Groundwater, Tadieso, Traverse, Voltaian, Exploration.*

1. Introduction

Hydrogeological and geophysical investigations are often conducted to assess the groundwater potential of a particular area. The low success rate of about 55 % in the Voltaian formation (Dapaah-Siakwan and Gyau-Boakye, 2000; Darko, 2001) over the years has led to the need for intensive work on the most appropriate method for groundwater exploration. The pioneering works of Conrad Schlumberger in the electrical resistivity technique is widely used for groundwater exploration because of its low cost, simple operation and efficiency in areas with high contrasting resistivities such as between the weathered and the bedrock (Telford et al., 1990).

In groundwater exploration, the 1-D has been the commonest electrical resistivity technique employed to determine the possible points for drilling. However, the 1-D has not been able to delineate potential borehole sites successfully in the Voltaian formation which appears to be hydrogeologically difficult, although it has been successful in the other geological formations (Ewusi, 2006). The 1-D also provides discrete information of the subsurface resistivity distribution thereby making the selection of potential points for drilling a challenge. A practical example of a community in the Voltaian formation where the 1-D method has been used for groundwater investigation is Tadieso in the Sekyere-Central District of the Ashanti Region. The Ashanti Development (an NGO) drilled six boreholes in the community by employing the 1-D technique but out of the six, two were successful and four were unsuccessful.

Considering the situation in the Voltaian formation, there is the need to review the common 1-D technique in order to improve the chances of selecting potential points for groundwater abstraction by employing the 2-D resistivity technique which provides a better image of the subsurface apparent resistivity distribution in order to increase the chances of delineating potential water zones in the Tadieso community.

ISSN (Online) 2348 – 7968
www.ijiset.com

2. Location and Physiography of Study Area

Tadieso is located in the Sekyere Central District of the Ashanti Region within longitude 1.210 and 1.230 W and latitude 7.010 and 7.030 N. The community is about 3.8 km North of Nsuta, 4.8 km NNW from Kyebi and 3.8 km SSE from Gyetiase another neighbouring community (MOFA, 2015).

The general topography of the Tadieso community is flat, and the average elevation was found to be about 450 m (Unihydro, 2006). The District is generally low lying and gradually rising through rolling hills stretching southward towards Nsuta (MOFA, 2015).

Tadieso and its environs are characterised by bimodal rainfall pattern; the major season starts from May to July, and the minor season from September to November (SYTO, 2011). The mean annual rainfall of the area is between 1200 and 1500 mm. The dry period occurs between December and April and the mean monthly temperature ranges from 27 ^{0}C to 30 ^{0}C with very high relative humidity varying from 75 to 95 % (MOFA, 2015).

The vegetation is semi-deciduous forest type with thin undergrowth, grading gradually to savannah trees. The tall trees in the forest areas exhibit deciduous characteristics during the dry season (Unihydro, 2006).

The relief pattern of the District can generally be categorized into two, namely; the minor low-lying plains and the major forest dissected plateau.

3. Geology and Hydrogeology

Tadieso is underlain by the Voltaian Supergroup of the Neoproterozoic rocks in Ghana, precisely the Mpraeso formation of the Kwahu-Morago (Bombouaka) Group which is characterized by four types of sandstones; arkosic sandstone, laminated sandstone, micaceous sandstone and coarse grained sandstone towards the base lying on top of Eburnean plutonic suite as shown in Fig. 1.

The hydrogeology of the area is controlled basically by the presence of fracture zones in the bedrock and thick weathered zones. Where there are well developed fracture zones, the bedrock has high permeability and successful boreholes have intercepted some of such fractured zones (Unihydro, 2006). The weathered zones represent the main storage capacity of the aquifer, as this is where the rocks, having been leached by weathering processes, have resulted in an enhanced porosity where infiltrating water may be stored. However, the terrain has proven to have a low success rate in relation to groundwater exploration (Darko, 2001, Dapaah-Siakwan and Gyau-Boakye, 2000).

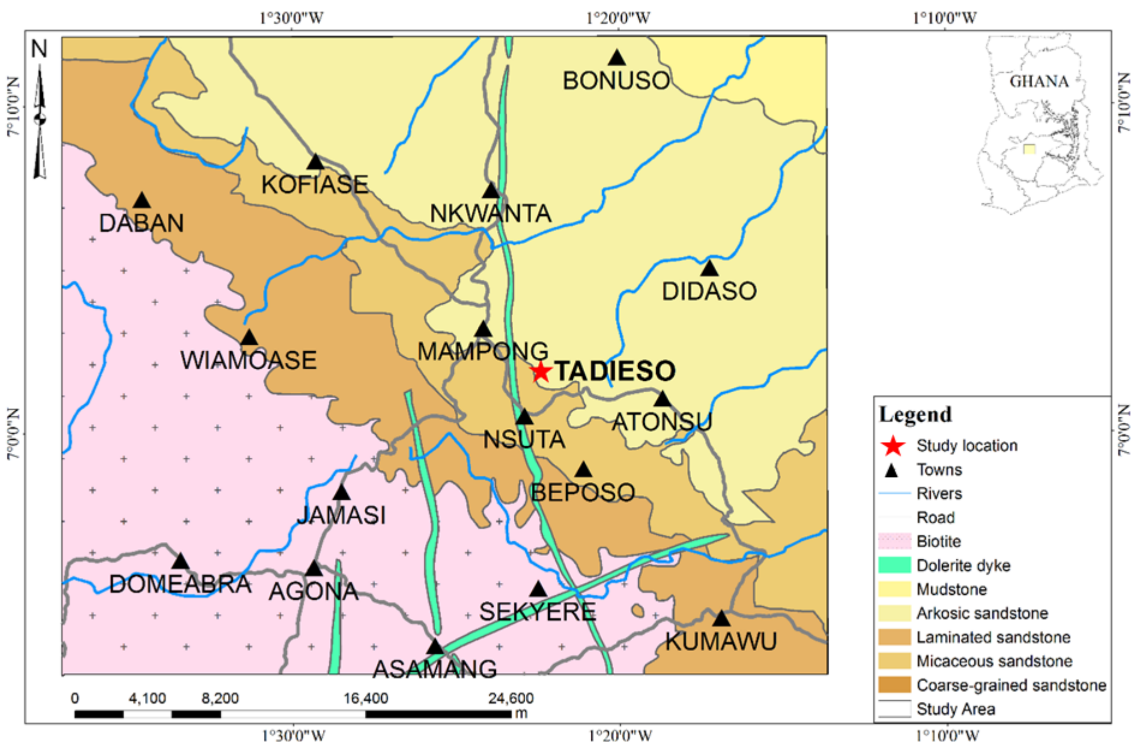

Fig. 1: Geological Map of the Study Area

4. Materials and Methods Used

During a reconnaissance survey, a check was conducted to assess the conditions of the six boreholes drilled in the Tadieso community, but only three were seen. The other three could not be found because they were drilled some years back and being dry had been decommissioned.

Based on the information from the reconnaissance survey, three traverse lines measuring 300 m each were selected; two along NW-SE direction at the Tadieso Saviour Missions area and one in the NNW-SSE direction at the outskirt of Tadieso. It was decided to investigate up to 120 m depth; in view of this, the choice of traverse lines was based on the availability of space in order that a maximum electrode spread (AB) of 240 m would be achieved beyond the extreme stations while ensuring that the traverse lines intercepted the existing boreholes. This would allow the existing borehole locations to be sounded for calibration. Fig. 2 shows the layout of traverse lines on the field. Sounding stations along the three selected traverse lines was established in order to produce a 2-D resistivity image of the subsurface.

The investigation was conducted using the Schlumberger configuration of the electrical resistivity method and the Ultra miniRes IP and Earth Resistivity Meter and its accessories were used. In this work, the general assumption by Schlumberger (1932) that the depth of investigation is half the electrode spread (AB) (i.e. d=AB/2) was used.

The Ultra miniRes IP and Earth Resistivity Meter and its accessories, GPS, measuring tape, field data sheet and cutlass were used to conduct the survey. The Ultra miniRes IP and Earth Resistivity Meter gives resistance (R) as the output, and this is multiplied by the geometric factor (K), which is dependent on the relative electrode spacing. Using Equation 1, the geometric factor is given as:

$$K = \pi \times \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \qquad (1)$$

The apparent resistivity   is therefore given as $\rho_a = KR$. From the calculated apparent resistivities for the respective stations and depths, a 2-D image of lateral variation of was made using the IP2WIN® software.

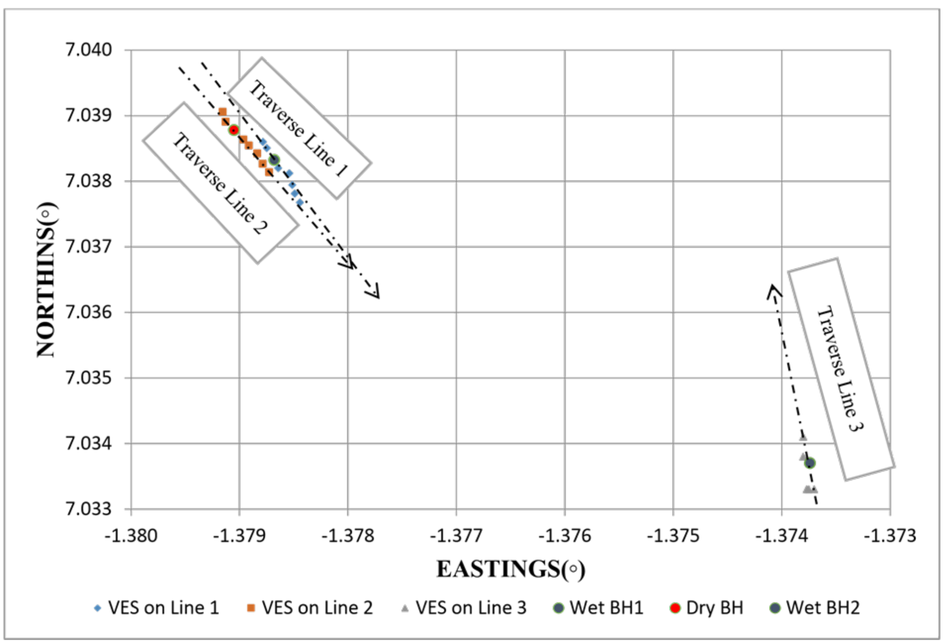

Fig.2: Layout of Traverse Lines at Tadieso

5. Results and Discussion

Vertical Electrical Sounding (VES) was carried out along the three traverse lines to intercept successful and unsuccessful boreholes in the community. Siting and drilling reports of work carried out in 2006 by Unihydro Ltd., at Kyebi one of the neighboring communities around Tadieso, was used to calibrate the results. The analysis of this secondary VES data with IP2Win shows that the apparent resistivity values range between 22 to 3,900 Ωm for traverse Line 1, 28 to 2,800 Ωm for the traverse Line 2 and 5 to 207 Ωm for traverse Line 3. Although there is limited published geophysical work for the study area, the results are consistent with the available secondary data.

For traverse Line 1, the subsurface resistivity image was divided into four distinct sections and the subsurface resistivity images for 2-D and 1-D plots are shown in Fig. 3 and 4 below. The 2-D subsurface resistivity image shows that there is near surface low apparent resistivities ranging between 106 to 211 Ωm from stations 80 to 130 m (Fig. 3). The presence of these low apparent resistivities may be attributed to the weathered layer and also the surface moisture.

Section 1 shows variation of low apparent resistivities which decrease with depth. The consistency in low apparent resistivity values from depths 10 to 80m in this section may be showing different degrees of weathering in the sandstone formation. There is a short break of low apparent resistivity values from depths 90 to 100m and a further decrease in apparent resistivities to about 28 Ωm from depths 110 to 120 m (Fig. 3). The short break of apparent resistivities from low to relatively high in this section may be attributed to a portion of the fresh hard sandstone. The distinct low apparent resistivity values which occurs from depths 110 to 120 m may be attributed to intense water-bearing fractures within the fresh sandstone.

Section 2 shows variation of apparent resistivity values which increase with depth. The presence of low apparent resistivities within the range of 57 to 232 Ωm which occur from depths 10 to 60 m (Fig. 3) may be attributed to the moisture in the weathered zone. High apparent resistivity values >3000 Ωm occur from depths 70 to 120m at station 110m and that may be attributed to a portion of the fresh dry sandstone formation.

Generally, section 3 shows low apparent resistivity values within the range of 70 to 175 Ωm (Fig. 3), however, there is an indication of relatively low apparent resistivity values averaging about 80 Ωm which occurs from depths 40 to 90m. The variation of low apparent resistivity values in this section may be attributed to the weathered sandstones and also the little water-bearing fractures within the bedrock.

Section 4 generally shows variation of high apparent resistivity values within the range of 90 to 2,141 Ωm which increase with depth (Fig. 3). The portions indicated by high apparent resistivity values may be attributed to the fresh dry sandstone. The portions indicated by very low resistivity values within the range of 23 to 80 Ωm in this image may be potential targets for groundwater exploitation as the wet borehole shows similar apparent resistivities.

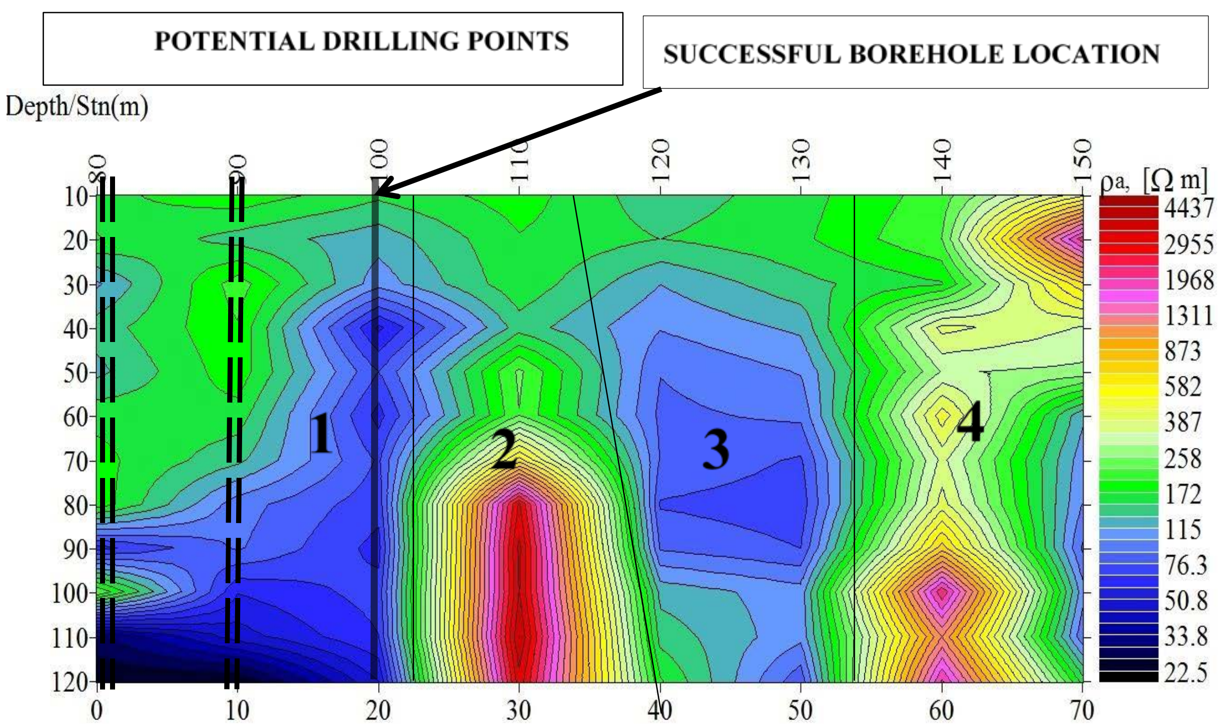

Fig. 3: 2-D Image of Subsurface Resistivity Values for Stations on Traverse Line 1

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 4, April 2018
ISSN (Online) 2348 – 7968
www.ijiset.com

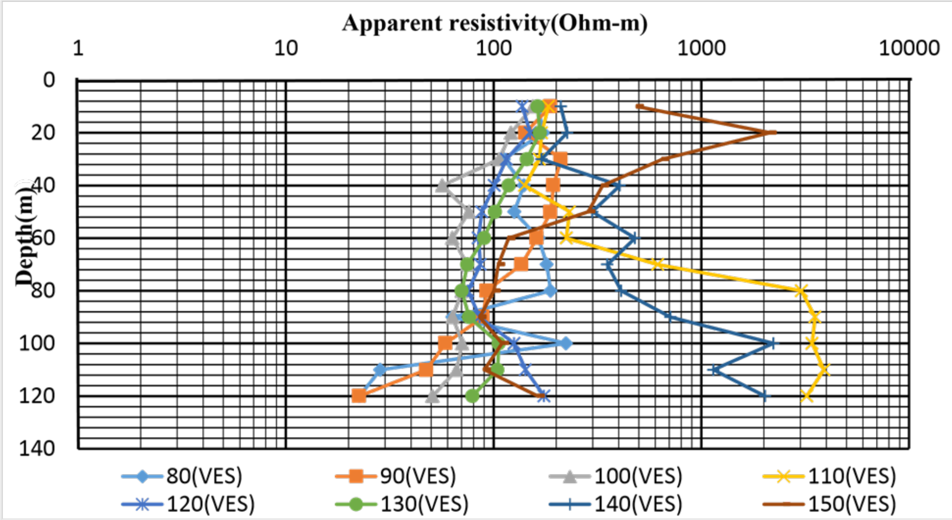

Fig. 4: 1-D Plot of Subsurface Resistivity Values for Stations on Traverse Line 1

For traverse Line 2, the 2-D subsurface resistivity image produced (Fig. 5), shows that there is near surface high apparent resistivities within the range of 45 to 523 Ωm which occurs from depths 10 to 20 m. The high apparent resistivity values may be attributed to the compacted layer as the place is used as a football field.

For section 1, the apparent resistivity values are within the range of 101 to 2276 Ωm from depths 10 to 120 m (Fig. 5). The relatively low apparent resistivities which occur from depths 10 to 80m may be showing various degrees of the weathered sandstones. The high apparent resistivities >1000 Ωm which occur from depths 80 to 120 m between stations 80 and 90 m may be attributed to the fresh dry sandstone.

For section 2, there are low apparent resistivity values within the range of 61 to 168 Ωm from depths 10 to 120 m (Fig. 5). These low apparent resistivities may be attributed to the weathered sandstone in the upper layer and also water-bearing fractures within the bedrock.

For section 3, there are zones of low apparent resistivity values within the range of 45 to 271 Ωm at the initial depths up to 20 m. These low apparent resistivity values may be showing the various degrees of the weathered sandstones. There is however an increase in apparent resistivity values with depth generally in this section. The very high apparent resistivity values within the range of 229 to 2,796 Ωm (Fig. 5) which occur from depths 60 to 120 m may be attributed to the fresh dry sandstones.

Generally, section 4 shows variation of apparent resistivity values which decrease with depth. But at the extreme part in the SE from depths 90 to 120 m (Fig. 5) there are indications of very low apparent resistivities within the range of 8 to 31 Ωm. These low apparent resistivities which decrease with depth may be showing various degrees of the weathered sandstones. Also, the very low apparent resistivities which occur from depths 90 to 120 m at the extreme part may be attributed to intense water-bearing fractures within the fresh sandstone. Station 150m may be a potential drilling point. Station 100 m although shows a potential target for groundwater exploitation, however to make a reasonable judgment, the thickness variation of the aquifer in this area is to be considered (Dogara et al., 1998) because the larger the thickness, the larger the amount of water the place can hold and vice versa and this may account for the dry borehole intercepted at that station after drilling as the distribution shows a very small aquifer thickness. The subsurface resistivity images for 2-D and 1-D plots are shown in Fig. 5 and 6.

For traverse Line 3, the 2-D subsurface resistivity image produced (Fig. 7) may be divided into three distinct zones with generally graded decrease in apparent resistivity values with depth. The profile depicted is probably underlain by horizontal lithologies with corresponding apparent resistivity values that are less than 250 Ωm. These variations in apparent resistivity values may also be showing different degrees of weathering in the sandstone formation. There are low apparent resistivities values within the range of 48 to 207 Ωm (Fig. 7) to a depth of 30m. These low apparent resistivities may be attributed to the laterites overlying the area and the various degrees of weathering of the sandstones.

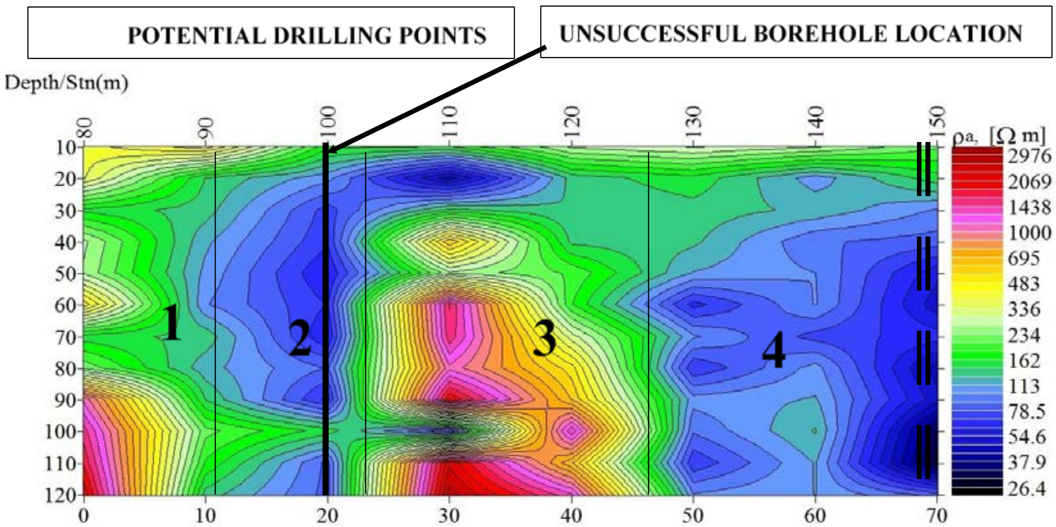

Fig. 5: 2-D image of subsurface resistivity values for stations on traverse Line 2

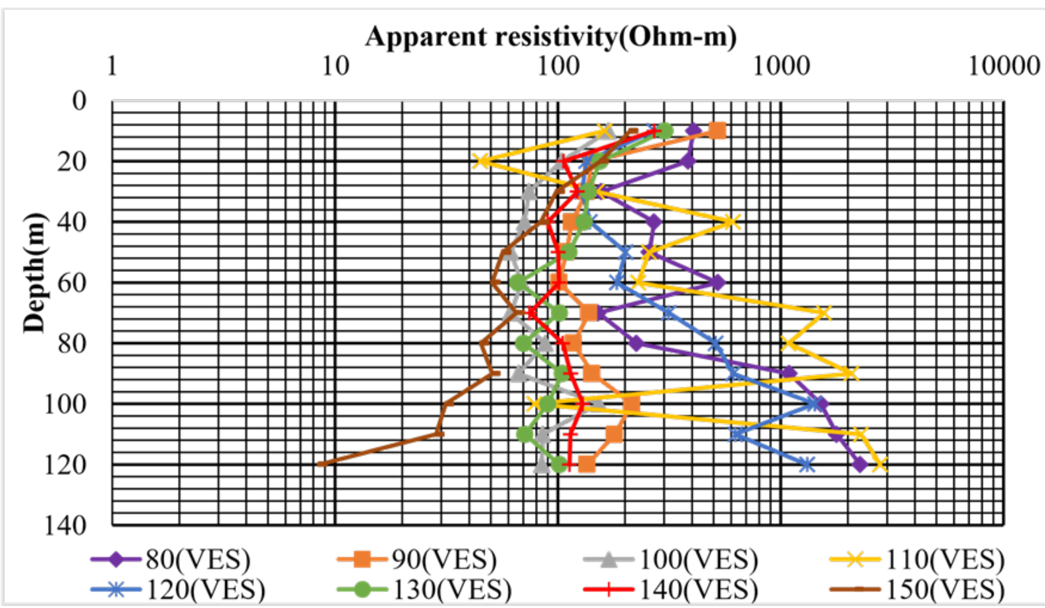

Fig. 6: 1-D Plot of Subsurface Resistivity Values for Stations on Traverse Line 2

From depths 30 to 120m, there are variations of low apparent resistivity values within the range of 23 to 67 Ωm which extend to a depth of about 60m. This account of low apparent resistivity values may be attributed to the weathered zones in the sandstone formation. These weathered zones may hold some amount of moisture and would reduce the apparent resistivity values. The relatively low apparent resistivity within the range of 16 to 85 Ωm found from depths 90 to 120m from stations 100 and 110m may be attributed to the water-bearing fractures within the fresh hard sandstone. The very low apparent resistivity values within the range of 6 to 38 Ωm shown from depths 70 to 120 m at stations 70, 80, 90m and from depths 100 to 120m at station 120m may also be attributed to water-bearing fractures within the fresh hard sandstone.

A similar investigation conducted at the successful borehole shows that low apparent resistivities within the range of 11 to 21 Ωm may be an indication of potential drilling points for groundwater. Stations 84, 90 and 120m are recommended points for drilling. The subsurface apparent resistivity images for 2-D and 1-D plots are shown in Fig. 7 and 8.

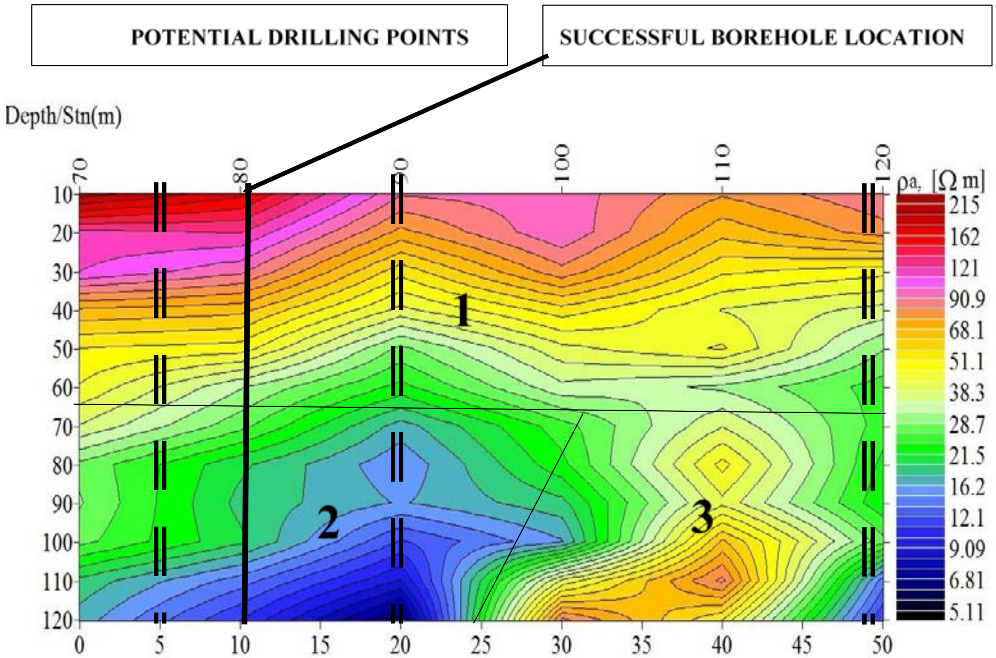

Fig. 7: 2-D Image of Subsurface Resistivity Distribution of Traverse Line 3

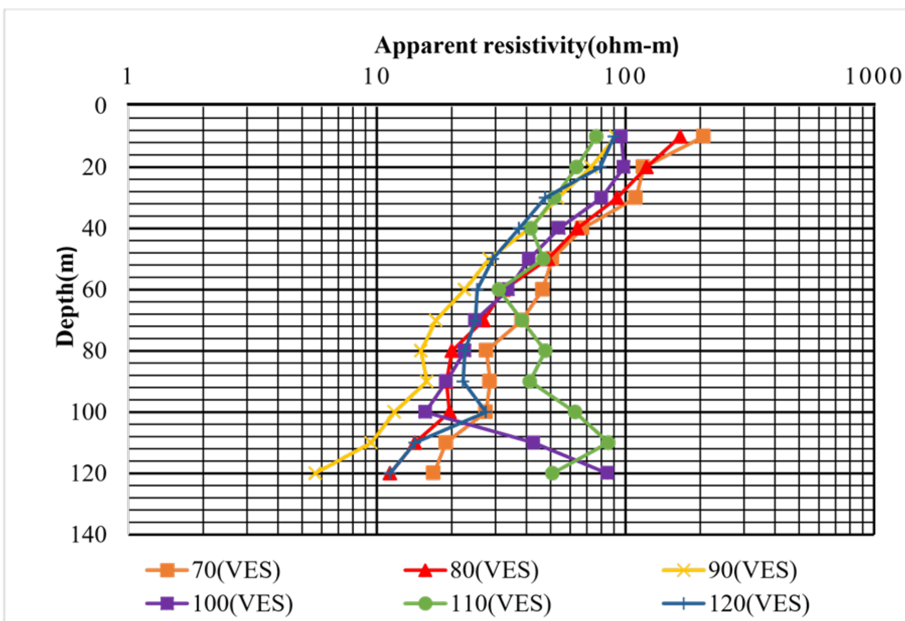

Fig. 8: 1-D Plot of Subsurface Resistivity Values for Stations on Traverse Line 3

6. Conclusions and Recommendations

The Tadieso community is underlain by uniform rock type material that is, sandstones from the literature and the secondary drilling data. The low success rate of the Voltaian formation may be due to drilling depths which appear too shallow for the region. Also the 1-D investigation carried out in such a terrain provides discrete information which makes the delineation of potential water zones a big challenge. Generally, most of the stations on the traverse lines show low to moderately high apparent resistivity values (Fig. 9) which gradually reduce with depth as shown in Fig. 3, 5 and 7.

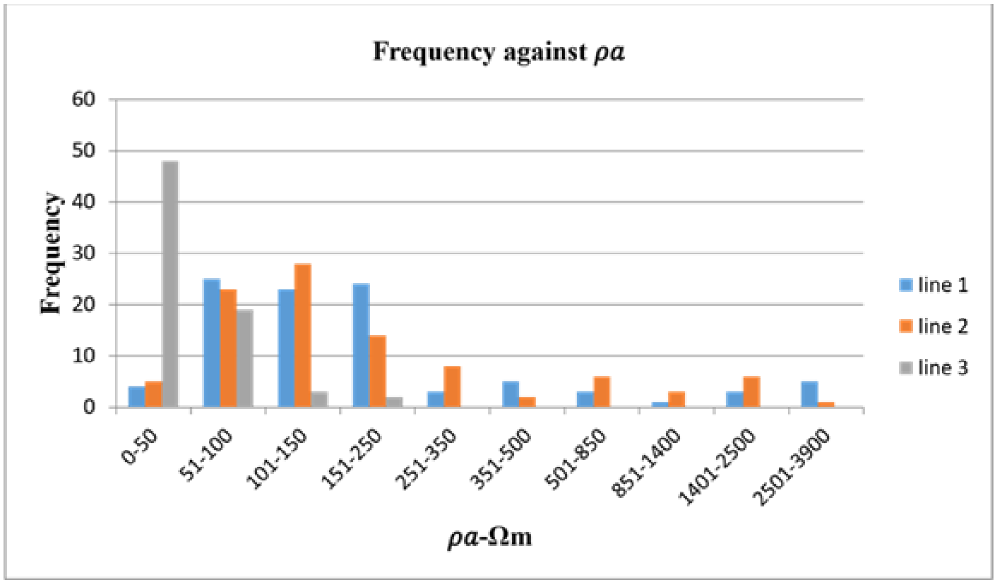

Fig. 9: Histogram Plot showing Apparent Resistivity Values

The hydrogeology of the area is generally controlled by the presence of fractured and thick weathered zones in the bedrock (Unihydro, 2006). The continuous decline in apparent resistivity values at the deeper depth could be due to the presence of water-bearing fractures in the sandstone formation. Investigations carried out at the successful boreholes indicated that lower apparent resistivity values within the range of 11 to 51 Ωm normally yielded groundwater. These lower apparent resistivity values occur between depths 100 and 120 m and fall within the fresh hard sandstones; hence the search for groundwater is actually a search for water-bearing fractures within the fresh dry sandstones. Results of the 2-D pseudo section profiles show that the technique is effective in interpolating between adjacent stations to locate favourable areas for siting potential points for drilling. It gave a detailed view of the subsurface resistivity and also showed an accurate picture of the lateral and vertical variations in lithology.

Finally, results from this study indicates that station 100 m on traverse line 2 shows an indication of potential groundwater zone but after drilling there was a dry borehole hence further studies should be done to ascertain the anomaly. Also, in order to increase the success rate of water in the Voltaian formation, the following recommendations would be made;

- A 2-D subsurface resistivity technique instead of the common 1-D resistivity technique should be used for the investigation due to the much relative information it provides.
- Also, Investigation and drilling may be done to depths of more than 100m.

References

Dapaah-Siakwan S. and Gyau-Boakye P. (2000). Hydrogeologic framework and borehole yields in Ghana, hydrogeology Jnl, volume 8. No. 4, 416pp.

Darko P. K., (2001). Quantitative aspects of hard rock aquifers: Regional evaluation of groundwater resources in Ghana (unpublished), PhD Thesis, Charles Univ., Prague Gech

Dogara M. D., B. M. Dewu and C. O. Ajayi, 1998. Groundwater potential of Romi, Kaduna, Nig. J. N. physics, 90pp.

Ewusi A., 2006, Groundwater exploration and management using geophysics in the Northern Region of Ghana, Unpublished PhD. thesis: Brandenburg Technical Univ., Chair of Environmental Geology, Germany, 171pp.

Ministry of Food & Agriculture, Republic of Ghana, (2015). MOFA Publications. http://mofa.gov.gh php?id=293. Assessed on 05/06/2016.

Schlumberger C., and Schlumberger M., 1932. Depth of investigation attainable by potential methods of electrical exploration. A. I. M. E Trans., Geophys. Prospect. 133pp.

Student & Youth Travel Organisation, (2011). SYTO Publications.www.Sytoghana.org/projects. /site/?page_id=877. Assessed on 9/10/2015.

ISSN (Online) 2348 – 7968
www.ijiset.com

Telford E., Geldart W. M., Sheriff R. E., 1990. Applied Geophysics. Cambridge University press, U.K. 760 pp.

Unihydro Ltd. (2006). Hydrogeological investigation at Sekyere-West District. Report submitted to Community Water and Sanitation Agency, Ashanti Region (unpublished).

Authors

Elvis Baffoe currently holds a Bachelor's degree in Geological Engineering from Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. His area of research includes Groundwater Exploration, Environmental Geophysics and Geostatistics, Soil and Rock Mechanics and Geotechnical Engineering.

Isaac Ahenkorah is currently a Masters (research) student in Civil Engineering at the University of South Australia, Adelaide, Australia. He received his BSc in Geological Engineering from the University of Mines and Technology (UMaT), Tarkwa, Ghana. His areas of research include Geotechnical Ground Improvement, Land and Water Resources Management and Protection and Soil and Rock Mechanics.

Amoako Kojo currently holds a Bachelor's degree in Geological Engineering from Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. His areas of research includes, soil and rock mechanics and Geotechnical engineering.

Isaac Kotei holds a Bachelor of Science degree in Geological Engineering from Kwame Nkrumah University of Science and Technology (KNUST), Ghana. He is currently a Masters student in Water Resource Engineering and Management at Civil Engineering Department, Kwame Nkrumah University of Science and Technology (KNUST), Ghana. His current area of research includes; Geophysics, Water Resource Planning, Water and Environmental law and Hydrogeological studies of Ghana

Theophilus A. Aryeetey holds a Bachelor of Science degree in Geological Engineering from Kwame Nkrumah University of Science and Technology (KNUST), Ghana. He is currently a Masters student in Water Resource Engineering and Management at Civil Engineering Department, Kwame Nkrumah University of Science and Technology (KNUST), Ghana. His current area of research includes; River Basin Management, Water Resource Planning, Water and Environmental law and Hydrogeological studies of Ghana.