The Use Of Electromagnetic And Electrical Resistivity Methods In Assessing Groundwater Resource Potentials In Adoe, Sunyani, Ghana.

Alfred K. Bienibuor, Kwasi Preko, David D. Wemegah, Evans Manu

Abstract— Electromagnetic and electrical resistivity geophysical methods, were used to map out potential groundwater sites for boreholes drilling in the Adoe community in the Sunyani west district of Ghana. The electromagnetic data was taken with the Geonics EM-34 conductivity meter while the electrical resistivity data was taken with the ABEM SAS 1000 C Terrameter using the Schlumberger electrode configuration. Results from the measurements revealed four subsurface geological layers of the following resistivity and thickness ranges: quartzitic sandstone with clay (42-118 Ωm, 1-2.2 m); sandy clay with silt (27-487 Ωm, 9-12 m); lateritic sandstone (13-728 Ωm, 6-14 m); and clayey shale (20-29 Ωm, 6-14 m), The overburden ranged in thickness from 14 m to 24 m. Sites selected for borehole drilling had a groundwater yield range of 0.94 -12 m^3/h.

Index Terms— groundwater, electrical resistivity, potential, sounding, borehole

1 INTRODUCTION

ASSESSIBILITY to potable water is a challenge in most rural and urban communities in Ghana and most especially in the Sunyani West District. People in affected communities are often left with no choice than to rely on unsafe surface water sources like rivers, lakes, ponds, dug-out wells, etc. These surface waters, unlike groundwater, are unprotected and are often left to the mercy of all forms of contaminations. For instance, people defecate close to these water bodies while others walk in them or even bath in them. These same waters are fetched for domestic use. This makes surface water prone to diseases like cholera, diarrhea, bilharzia, etc. Ghana, like many nations, has increasing demand for water supply due to its daily increase in population growth and the subsequent expansion of the industrial and the agricultural (irrigation) sectors. This project thus seeks to use the Electromagnetic (EM) and the VES methods to help locate aquifer zones in the Adoe community in the Sunyani West district.

The main objective of this study was to assess the groundwater resources for the Adoe community in the Sunyani West District. Other specific objectives include: to identify high groundwater potential zones in the community, to select suitable sites of the zones identified for drilling and subsequently, to map the depths and thicknesses of selected aquifers. The EM and the VES methods have been used by other researchers over the years and according to Barker (2007) the resistivity method is the most cost effective and most powerful geophysical tool in exploring for groundwater. In 2012 both the electromagnetic and the resistivity methods were used for groundwater exploration in the Ago-Iwoye area of Southwestern Nigeria. Very low frequency (VLF) electromagnetic (EM) method and the vertical electrical sounding (VES) method were employed to delineate fracture zones, aimed at exploiting groundwater within the permanent site of the Olabisi Onabanjo University at Ago-Iwoye. The site is underlain predominantly by gneissic rocks. The VLF-EM method was carried out at 10 m intervals along 8 traverses in the East–West direction which ranged from 350 m to 500 m long. In all eight prominent fracture zones were identified for the vertical electrical sounding to be conducted. Seventeen vertical electrical soundings were carried out at appropriate locations within the prominent fracture zones. At the end the basement fractures that were identified using the VLF-EM method were confirmed by the interpretation of the VES, therefore the use of the two methods did help in the location of prominent groundwater areas (Bayewu et al., 2012). In the Assin district of the Central Region of Ghana the electrical resistivity method was also used to explore the granitic basement for groundwater potentials. Regions of fracturing, jointing and thicknesses of the top overburden, conductivity and impermeable strata which, according to Tetteh et al. (2011), are key indicators of the presence of groundwater, were delineated. The electrical resistivity technique, based on the Schlumberger array protocol, were then employed in both profiling and sounding. Drilling was done to confirm deductions from the interpretation of the geophysical data sets. The sounding results indicated a three-layered subsurface structure, where the first layer was found to be laterite with an average thickness of 3.1 m and an apparent resistivity of 30 Ωm, the second layer had a mean thickness of 50 m and an apparent resistivity of 938 Ωm and with the third layer (the basement rock) having a thickness of 69.5 m and an apparent

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resistivity of 3802 Ωm. An average yield of 0.94 m^3/h was achieved at the end of the project (Bosu, 2004). In another development the electrical resistivity method was used in Okenugbo area of Ago-Iwoye, Southwestern Nigeria for the evaluation of groundwater potential. The aim of this study was to evaluate the subsurface geologic and geoelectric properties that could contribute to the availability of low groundwater in the area. VES data were collected at eight different points in the study area at random, using the Schlumberger configuration. Groundwater potential in the area were generally observed to be very low. Two data points (VES 2 and VES 3) were however, discovered to have high groundwater potential since they would give high yield of groundwater if boreholes are drilled or if wells are dug at those points (Oladunjoye et al., 2013). In this project, the main objective was to assess the groundwater resources for the Adoe community in the Sunyani West District using the electromagnetic and the VES methods. The electromagnetic method was used to explore for groundwater in the Voltaian in the Northern region of Ghana in 2009. The data were presented on a one-dimensional (1-D) plots; then based on the plots the EM highs along parallel traverses of the data plotted were identified. The results showed terrain conductivity distribution which ranged from 10 to 70 mS/m in the vertical dipole (V-D) mode and from 22 to 79 mS/m in the horizontal dipole (H-D) mode according to the general conductivity distribution of the area, using a 20 m inter coil separation cable. At the end the conductivities were higher for the horizontal dipole (H-D) mode than for the vertical dipole (V-D) mode (Larry et al., 2009).

2 MATERIALS AND METHODS

2.1 Description of Project Site

This work was done in Adoe, a village in the Sunyani West district of the republic of Ghana. The Adoe community (Fig. 1) is about 11.2 km from Odumase, the District Capital. It has a population of about 800 people with farming being their main occupation. The community lies between latitudes 7º 45´N and 7º 84´N and longitudes 2º 35´ W and 2º 82´ W while the Sunyani West District lies between latitudes 7º 19´N and 7º 35´N and longitudes 2º 08´ W and 2º 31´ W. It is one of the 27 districts of the Brong Ahafo Region of Ghana. It shares boundaries to the North-East with Wenchi Municipality and to the North with Tain district. Berekum municipality and Dormaa East districts lie to the West, with the Sunyani Municipality to the South and the Tano North and Ofinso North districts to the East. The district has a total land area of about 1658.7 km^2. According to the 2000 and 2010 population and housing census outcomes the district's population stands at 78,020 and 113,623 respectively for 2000 and 2010, implying that it has a growth rate of 3.8 %.

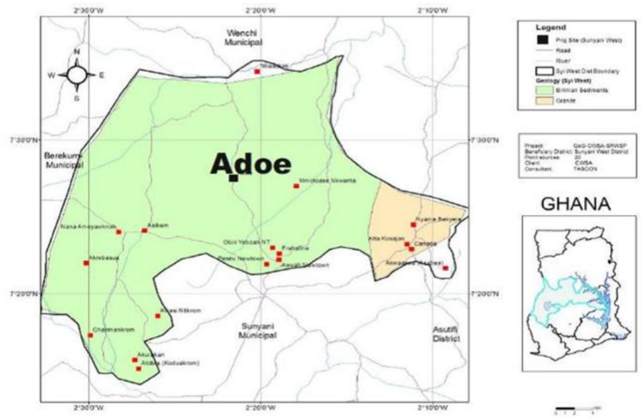

Fig. 1: A map of Sunyani West District showing the Adoe community

2.2 Instrumentation and Data Collection

Data were acquired using basically the Geonics EM 34-3 conductivity meter and the Abem SAS 1000 C terrameter. The Geonics EM 34-3 conductivity meter was used as a reconnaissance geophysical tool while the Abem SAS 100 C terrameter which employed the Schlumberger array protocol was used in the resistivity data collection. Both methods are geared towards detecting fracture zones and other subsurface features which control groundwater occurrence (Ndlovu et al., 2010).

2.3 EM Data Collection

Prior to the Geonics EM 34-3 data collection the ground was studied, paying particular attention to places of prohibition like the cemetery or places close to toilets or refuse dumps. When the area was fully demarcated and suitable sites found for the survey the equipment was then set up by connecting the transmitter and the receiver coils to their respective consoles and also by connecting the two coils to each other with the 20 m inter-coil cable. The transmitter's operator took the lead and the receiver's operator followed throughout the survey process. At each position both the vertical and the horizontal dipole mode measurements were taken. Measurements were taken at 10 m station intervals. A single profile was traversed in the study area where potential fracture zones were identified for vertical electrical soundings to be conducted.

2.4 Resistivity Data Collection

Data were taken by employing the conventional four electrode system of the Schlumberger protocol. Two potential electrodes were sandwiched between two current electrodes. The distance between the two potential electrodes (or the midpoint of the electrodes) was kept constant while the distance between the current electrodes was systematically increased so that deeper depths could be probed. The wider the distance between the current electrodes the deeper the current were forced into the subsurface so that resistivities of the subsurface layers were recorded.

3 DATA PROCESSING AND INTERPRETATION

The EM data were processed using Microsoft Excel whereas the VES data were processed using Zond geophysical software (ZondIP2 version 5.1, 2001 – 2015). The processed data were then interpreted. The interpretation of any geophysical data is often based on identifiable geological condition. There must be a physical contrast between the physical properties of the target and that of the environment.

3.1 EM data processing

The EM data were processed using Microsoft Excel into curves of apparent conductivity against station intervals. Conductive zones were represented by peaks and thus the higher the peak, the higher the conductivity of the subsurface. Buried conductive bodies in the subsurface like the water table, ion, gold or metallic minerals can result in higher peaks (Chegbeleh et al., 2009). Also, the nature of the peaks suggests the depths of burial. Sharp rising peaks indicate that the water table or the conductive body is shallowly buried while gentle rising peaks signify deeply buried water tables or conductive bodies. Peaks of the horizontal dipole mode represent conductivity at shallower depths while that of the vertical dipole mode represent conductivity at deeper depths. Higher peaks of the plot of the vertical dipole mode over that of the horizontal dipole mode are termed as anomalous zones and are selected for further investigation using the VES method.

3.2 Resistivity Data Collection

The VES data were processed using the Zond geophysical software (zondIP2 version 5.1). The software models the data into curves, displaying the number of subsurface layers, the thicknesses and depths to each layer as well as the apparent resistivities of the layers. The resistivity values of each layer is compared with standard fresh groundwater resistivity values. The standard fresh groundwater resistivity values range from 10 to 100 Ωm (Loke, 2000). In effect VES points with appropriate layer thicknesses, appropriate depths and resistivity values within the 10 to 100 Ωm range are selected for borehole drilling. The water table together with other considerations are also taken into account and therefore, points outside this range could also be selected.

4 RESULTS AND DISCUSSION

The results of the EM data (both in the horizontal and vertical dipole modes) and the VES data are displayed and interpreted below:

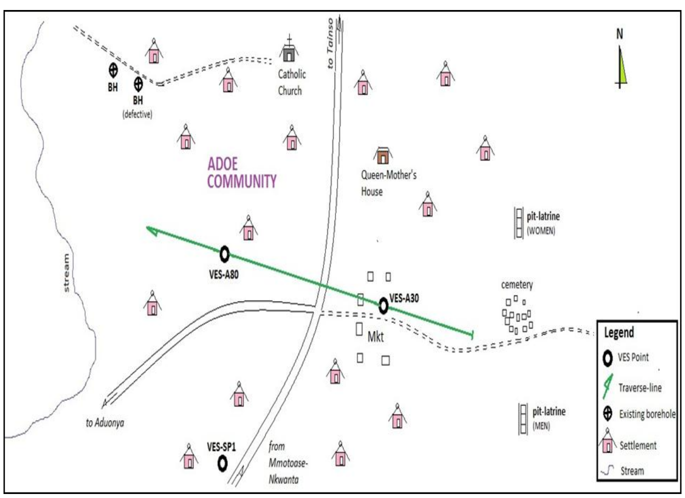

Fig. 2: Layout of Adoe community showing traverse line and VES points

4.1 EM Results

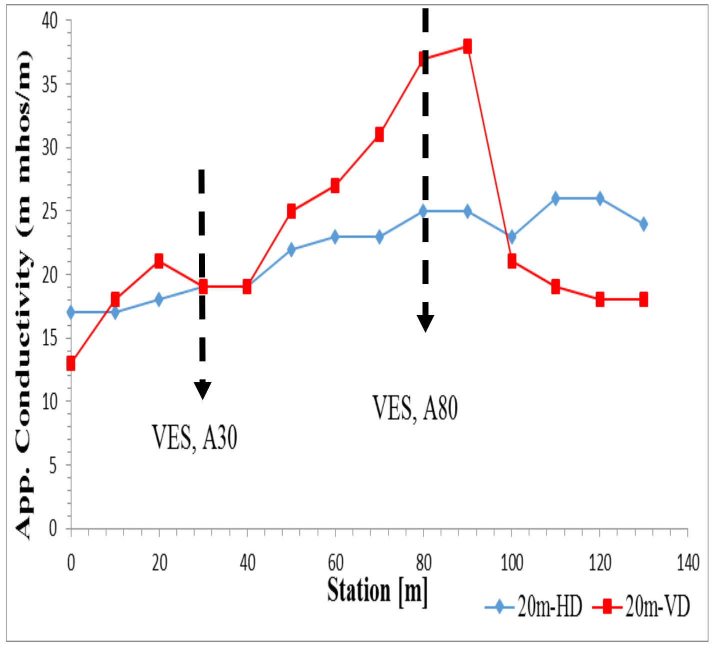

Fig. 3: EM curve along traverse-A, Adoe

The EM survey in this community was conducted on a 130 m profile length and the apparent conductivities recorded were presented as plots of apparent conductivity against station intervals as shown in Fig. 3. Values of the apparent conductivities recorded were generally higher in the vertical dipole mode than in the horizontal dipole mode. In the horizontal dipole mode the values ranged from 17 to 26 S/m while in the vertical dipole mode they ranged from 13 to 38 S/m. Before a distance of 100 m the horizontal dipole mode consistently recorded lower apparent conductivity values than the vertical dipole mode. However, after the 100 m mark to the end of the profile the apparent conductivity values for the vertical dipole mode drastically dropped while that of the horizontal dipole mode appreciated abruptly. Two VES points (A30 and A80) were selected on the profile while two other points (BH and SP1) were also earmarked outside the profile for VES to be conducted (Fig. 2). BH was sited closed to an existing borehole for calibration purposes while SP1 was closed to the main road coming from Odumase, the district capital. SP1 was chosen because there were a cluster of trees there with grasses there looking very fresh. This is a major indicator of the presence of groundwater (Gyau-Boakye and Dapaah-Siakwan, 2004).

4.2 VES Results

Three things are considered when selecting sites for drilling. They include the nature of the curve, the bedrock or layer resistivity and the overburden. For a good site for drilling the end of the curve is expected to point downwards, indicating that the resistivity decreases at depth; the bedrock resistivity is expected to be lower than the overlying layer resistivities, or preferably the resistivity of the bedrock should fall within the standard fresh groundwater resistivity value range of 10 to 100 Ωm (Loke, 2000). The aquifer could be intercepted in any of the overlying layers and such layers are also expected to record low resistivities. A thicker overburden will be difficult to drill through, but it will be easier drilling through a thinner overburden; therefore for a good site the overburden should not be too thick. If the overburden is also too thin the aquifer will be liable to pollution from surface waters and thus such aquifers are not recommendable.

4.2.1 Summary of VES Models and Pseudosections

Fig. 4 shows the VES models and pseudosections for selected sounding sites in the Adoe community. See also Figs 2 and 3.

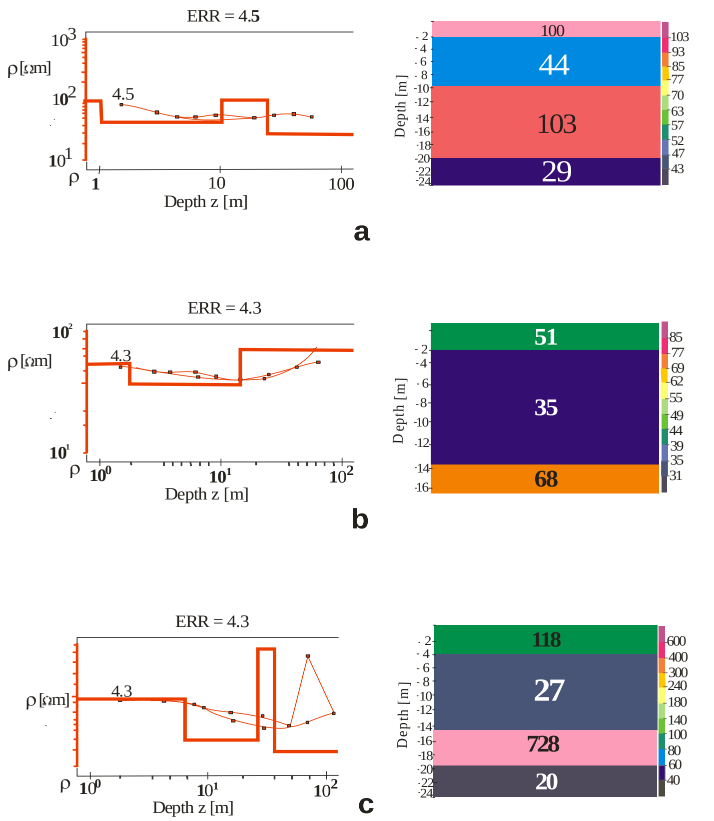

Fig.4: VES models and pseudosections for selected sounding points – a: A30; b: A80 and c: SP1

TABLE 1 Summary of VES Results

Station	Layer	Resistivity [Ωm]	Thickness [m]	Depth [m]	Lithology
	1	100	1.03	0.00	
	2	44	9.18	1.03	Quartz-biotite with schist, lateritic sandstone
A30	3	103	14.09	10.22	
	4	29	-	24.30	
	1	51	2.17	0.00	
A80	2	35	11.61	2.17	lateritic sandstone, basalt
	3	68	-	13.78	
	1	118	5.22	0.00	
	2	27	12.60	5.22	Granite, Quartzitic sandstone
SP1	3	728	6.40	17.81	
	4	20	-	24.21	
	1	42	1.12	0.00	
BH	2	487	11.63	1.12	granite, phyllites,
	3	13	-	12.75	

The study area is underlain predominantly by Birimian sediments. Generally Birimian rocks are highly folded and fractured and sometimes, with intrusions of quartz veins in them. Their water yielding potential is high due to the intense fracturing and the quartz veins (Anornu et al., 2009) which introduce secondary permeability to the rocks. The study area therefore, generally has high groundwater potential. Three or four layers were produced in total. Layer one has apparent resistivity values ranging from 42 to 118 Ωm with an average thickness of 2.4 m. The bedrock resistivity of the study area was also found to range from 13 to 35 Ωm while the overburden was between 13.78 and 24.30 m, averaging at 18.76 m. Four layers were produced at station A30 (Table 1, Fig. 4). The nature of the curve, the layer resistivities and thicknesses suggest that layers 2 and 4 are potential groundwater zones. The two layers are located at depths of about 1 and 24 m respectively. The overburden of this station is 10 m and the bedrock is of a less resistivity. With these characteristics it is prudent to site a borehole at this location. For station A80, three layers were revealed as shown on the modelled curve (Fig. 4). The depth to the bedrock (or the overburden thickness) is just about 14 m. However the bedrock resistivity of 68 Ωm is higher than the resistivities of the two upper layers (Table 1), implying that the bedrock could be crystalline with probably no fracturing and hence the probability of groundwater getting accumulated in it could be less. It is also obvious from the layer resistivities (Table 1, Fig. 4) that layer 2 may be porous or could have groundwater accumulation and percolation structures like fractures or joints. However, because the bedrock appears to be highly resistive the water in layer 2 may not be sustainable and this station is therefore not a favourable site for drilling a borehole. Point BH was chosen for calibration purposes since it was sited very close to an existing borehole. The curve at station BH also produced 3 layers (Fig. 4), with an overburden of about 13 m and with bedrock resistivity of 13 Ωm. This resistivity is very small as compared to that of the overlying layer of 487 Ωm. The overlying layer is 12 m thick and could possibly be highly consolidated. The nature of the curve also gives the impression that the resistivity of the bedrock could continue to decrease since the end of the curve points downwards (Fig. 4) and this is a positive sign of possible and sustainable groundwater accumulation in the subsurface. It thus confirms that this location could have high groundwater potentials. The investigation at station SP1 revealed 4 layers (Fig. 4, Table 1). The resistivity values of layers 3 and 4 are respectively 27 and 20 Ωm while layers 1 and 3 recorded higher values of 118 and 728 Ωm respectively (Table 1). The aquifer is therefore expected to be intercepted in the second and fourth layers, but because of the very high resistivity of layer 3, the probable groundwater in layer 2 will not be sustainable. However, groundwater in the fourth layer is potentially very sustainable since the curve shows a continual decrease in the layer's resistivity with depth as shown on SP1 model (Fig. 4). Depth to the bedrock is 24 m while the overlying resistive third layer is only 6.4 m thick. This makes station SP1 the best location to site a borehole over the other VES points in this community.

4.2.2 Summary of Selected Sites for Drilling

Though three VES points were identified to be groundwater potential zones, two points were selected for drilling. The two points include SP1 and A30 (Table 2).

TABLE 2 SUMMARY OF VES RESULTS

Community	GPS Coordinates	Elevation (amsl)	1st ranked VES Point	2nd ranked VES Point	Estimated Depth (m)
Adoe	2.35822 °W 7.45839 °N	293	SP1	A30	> 30

VES points SP1 and A30 were selected for borehole drilling. The two points were selected, owing to the fact that their bedrocks have very low resistivity values of 20 and 29 Ωm (Table 1) respectively which could be attributed to groundwater accumulation in them. Among the two however, point SP1 was recommended to be drilled first since it has the lowest bedrock resistivity and its bedrock is thus expected to be more fractured than that at point A30. SP1 is located at GPS coordinates of 7.45796°N and 2.35878°W at an altitude of 293 m above mean sea level (amsl) while point A30 is located at coordinates 7.45839°N and 2.35822°W at altitude 285 m amsl (Table 2). Groundwater potential in this community could be low-to-moderate and the estimated depth to the aquifer is projected to be above 30 m.

5 CONCLUSION

The main objective of this research work was to assess the groundwater resources for the Adoe community in the Sunyani West District. At the end of the work the results of the assessment indicate that, groundwater resources potential in the community ranges from 0.94 – 2 m^3/h. The community forms part of the Birimian sub-province of the basement complex which has a very good success rate. Three (3) groundwater potential zones were identified in the community. These potentials could vary from site to site, and with varied ease of access. The depth to the aquifers, layer thicknesses and other considerations were critically analysed as to which site should be considered first for drilling. At the end, two of the points identified as groundwater potential zones were selected for borehole drilling. The two points were ranked as first and second, with the first point expected to be drilled first. The depths of the selected aquifers ranged from 14 m to 24.3 m while the thicknesses ranged from 1 to 14 m. A borehole was drilled at the first ranked station and the aquifer was intercepted in the fourth layer with a very good yield of about 12 m^3/h.

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REFERENCES

[1] G.K. Anornu, B.K. Kortatsi, and M.S. Zango, Evaluation of groundwater resources potential in the Ejisu-Juaben District of Ghana. African Journal of Environmental Science and Technology, Vol. 3 (10), pp. 332-340, 2009.

[2] H.T. Oladunjoye, R.K. Odunaike, P. Ogunsola, and O.A. Olaleye, Evaluation of groundwater potential using electrical resistivity method in Okenugbo area, Ago – Iwoye, Southwestern Nigeria. International Journal Engineering and Applied sciences. Vol 4 No.5, 2013.

[3] J.K. Bosu, Groundwater Exploration in the Granitic Basement in the Assin District of the Central Region Using the Electrical Resistivity Method. MSc thesis submitted to the College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, 2004. *http://hdl.handle.net/123456789/1872*. Date assessed: September 10, 2015.

[4] L.P. Chegbeleh, A.J. Akudago, M. Nishigaki, and S.N.K. Edusei, Electromagnetic geophysical survey for groundwater exploration in the Voltaian of Northern Ghana. Journal of environmental hydrology, paper 9, volume 17. ISSN 1058-3912, 2009.

[5] M.H. Loke, "Electrical imaging surveys for environmental and engineering studies. A practical guide to 2-D and 3-D surveys." 1-4. (Copyright 1997, 1999, 2000).

[6] O.O. Bayewu, M.O. Oloruntola, G.O. Mosuro, and F.G. Watabuni, Groundwater exploration in Ago-Iwoye Area of Southwestern Nigeria, using Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity methods. Int. Journal of Applied Sciences and Engineering Research, vol. 1, No. 3, ISSN 2277 – 9442, 2012.

[7] P. Gyau-Boakye, and S. Dapaah-Siakwan, Groundwater as a source of water supply in Ghana. Journal of Applied Science and Technology, 5(1): 77 – 86, 2004.

[8] P.C. Larry, A.A. John, N. Makoto, and N.K.E. Samuel, Electromagnetic geophysical survey for groundwater exploration in the Voltaian of Northern Ghana. Journal of environmental hydrology, vol. 17, 2009.

[9] R.D. Barker, Electrical resistivity methods for borehole siting in hard rock region. Springer Link, pp 26 – 60, 2007.

[10] S. Ndlovu, V. Mpofu, D. Manatsa, and E. Muchuweni, "Mapping Groundwater Aquifers Using Dowsing, Slingram Electromagnetic Survey Method and Vertical Electrical Sounding Jointly in the Granite Rock Formation: A Case of Matshetshe Rural Area in Zimbabwe". Journal of Sustainable Development in Africa (Volume 12, No.5), 2010.

[11] T.A. Tetteh, F. Richmond, M. Piotr, and A. Dickson, Hydrogeochemical Evolution and Groundwater Flow in the Densu River Basin, Ghana. Journal of Water Resource and Protection, 3, 548-561, 2011.