

# Electromagnetic Method and Vertical Electrical Sounding for Groundwater Potential Assessment of Kintampo North Municipality of Ghana

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## Abstract

Electromagnetic (EM) profiling and Vertical Electrical Sounding (VES) of electrical resistivity method have been employed to explore for groundwater in the Kintampo-North Municipality in the Brong Ahafo Region of Ghana. The EM profiling data were obtained with GEONICS EM 34-3 equipment at 20 m intervals along 20 profiles of length ranging between 70 to 240 m to determine conductive anomalous zones for further investigation within the unconsolidated overburden and/or water-bearing fissures in the bedrock. Subsequently, using the ABEM Terrameter, VES employing the Schlumberger electrode configuration was carried out at previously selected 53 promising anomalous points on the EM profiles. The modelled VES data using RES1DINV software revealed a number of subsurface layers and their corresponding apparent resistivity values and thicknesses. The results indicated that the EM terrain conductivity anomaly in the study area varied in the range 6-87 m mhos/m with the average and maximum apparent conductivity values of 48.5 and 76 m mhos/m respectively. The VES revealed three to four-layered lithological subsurface sequence, indicating decreasing apparent resistivity with depth. This depicted the general trend of  $\rho_1 < \rho_2 >> \rho_3 \leq \rho_4$ , where  $\rho_1$ ,  $\rho_2$ ,  $\rho_3$  and  $\rho_4$  are the apparent resistivity of the layers 1, 2, 3 and 4 respectively. The results further showed that both the average apparent resistivity and thickness of layers 1, 2, 3 and 4 are respectively 368  $\Omega$ m, 3.9 m; 435  $\Omega$ m, 17 m; 50  $\Omega$ m, 53.5 m and 332  $\Omega$ m, >53.5 m. Thus aquifer zones were estimated to be located between 15-30 m depth. These layers were inferred to be the sandy-clay topsoil, weathered/fractured layer and the fresh bedrock. However, the weathered layer and the fractured basement constituted the aquifer zones across the study area within the Voltaian Sedimentary Basin, which is otherwise regarded as a difficult area in locating groundwater resources.

**Keywords:** Groundwater potential, aquifer, apparent resistivity, terrain conductivity

## 1. Introduction

Groundwater resource is known to be relatively safe and a more useful source for potable water supply as it has relatively low levels of biological and chemical contaminants. It usually requires little or no purification before use. Unlike surface water, groundwater sources are less affected by physical factors such as odour, colouration, climate change and variability. Moreover, groundwater has relatively high storage capacity per unit area as compared to that of surface water (Ademilua and Talabi, 2012).

Over half of the world's population depends on groundwater for drinking water supplies. In Ghana about 52% of rural inhabitants have access to potable water mainly from groundwater sources (Ewusi, 2006; Gyau-Boakye and Dapaah-Siakwan, 1999). Groundwater has been found to be sufficient in quantity and quality for sustainable development of a nation. About 2 billion people worldwide depend on groundwater for drinking (Mygatt, 2006). If it is managed properly and used effectively, it can provide a sustainable contribution in solving regional water crises on earth. With the increasing population explosion, urbanization, industrialization and agricultural growth, the demands on potable water supply has increased tremendously (Ariyo and Adeyemi, 2009). In many developing countries, availability of potable water has become a critical and urgent problem and it is a matter of great concern to families and communities. About 80% of all diseases in Ghana are caused by unsafe water and poor sanitation but more than nine million people don't have access to safe drinking water (Water Aid Ghana, 2002). Water resources in Ghana play a significant role in the promotion of living standards, enhancing economic growth, provision of food security and livelihood, and eventually alleviation of poverty. As in most parts of the world, Ghana is also experiencing population growth with its associated demand for increased food production. Therefore, increased demand for water supplies results in excessive pressure on the available few water resources.

Availability of sources water supply is a challenge in the Kintampo-North Municipality as the inhabitants rely mostly on surface water sources such as shallow dugout wells, streams and dams, which are prone to pollution by grazing animals such as cattle, sheep and goats. These sources also face drastic condition of drought during long dry seasons (www.ghanadistrict.com). The groundwater sources available include insignificant number of hand-dug wells and boreholes. Groundwater is a preferred water supply option in the area as it is generally available even in drought condition and it has relatively good quality. According to Gyau-

Boakye and Dapaah-Siakwan, (1999), groundwater resources are the most feasible and economic source of potable water supply for the rural settlement due to their dispersed nature. Ewusi *et al.* (2009) used the 2D Multi-Electrode Resistivity Tomography to locate suitable sites for groundwater in the Voltaian Sedimentary Basin of the Northern Ghana. His results revealed distinct lithological boundaries, fractures, and weak geological zones, which are good indicators for groundwater availability in the basin.

Mohammed *et al.* (2012) also used Electrical Resistivity Sounding to delineate and evaluate groundwater potential of Araromi Akungba-Akoto Ondo State Southwestern Nigeria. He concluded that weathered and fractured layers constituted the dominant aquifer zones, with the tendency for low groundwater potential rating due to clayey and thin overburden. Thus, all these results show that weathered and fractured zones constitute subsurface geological structures with the potential for groundwater storage. Essentially these geological structures tend to have higher porosity and permeability for groundwater accumulation and transmission.

A number of other researchers (Kearey and Brooks, 1984, 1991; Dobrin and Savit, 1988; Sharma, 1986, 1997; Telford *et al.*, 1994) have all stated the importance of electrical conduction in most rocks as being essentially due to electrolytic rather than electronic process. Thus electrical conduction and its electrolytic nature in rocks suggest the presence of aqueous medium (water) and ions as facilitators of the conduction process. This implies electrical conductivity and resistivity of rocks are physical properties that influence their electrical conduction. Therefore, to locate the presence of accumulated groundwater or aquifers, there is the need to employ geophysical methods such as the EM and electrical resistivity methods to aid the exploration process. Other authors (Aked, 1995; Fitterman, 1986; McNeill, 1995) have also mentioned the importance and use of electromagnetic traversing (EMT) method in search for groundwater. Traversing with EM 34-3 GEONICS equipment has proved to be more rapid and productive. Electrical resistivity surveys have also been routinely used in groundwater exploration to locate zones of relatively low resistivity (high conductivity). In weathered crystalline bedrock, aquifers in faulted zones are more conductive than their host rocks. Thus, by using the electromagnetic method together with electrical resistivity technique conductive features can accurately be located to result in wells with high yields (Kearey and Brooks, 1984). Hence, in this study EM and electrical resistivity methods have been used for the purpose of locating aquifers.

## 2. The Study Area

The study area (Fig. 1) is the Kintampo North District of Ghana. The Municipal Capital, Kintampo, lies east at about 130 km away by road from Sunyani, the regional capital of the Brong Ahafo Region. The Municipal has a surface area of about 5,108 km<sup>2</sup>, thus occupying a land area of about 12.9% of the total land area of the Brong Ahafo Region (39,557km<sup>2</sup>).

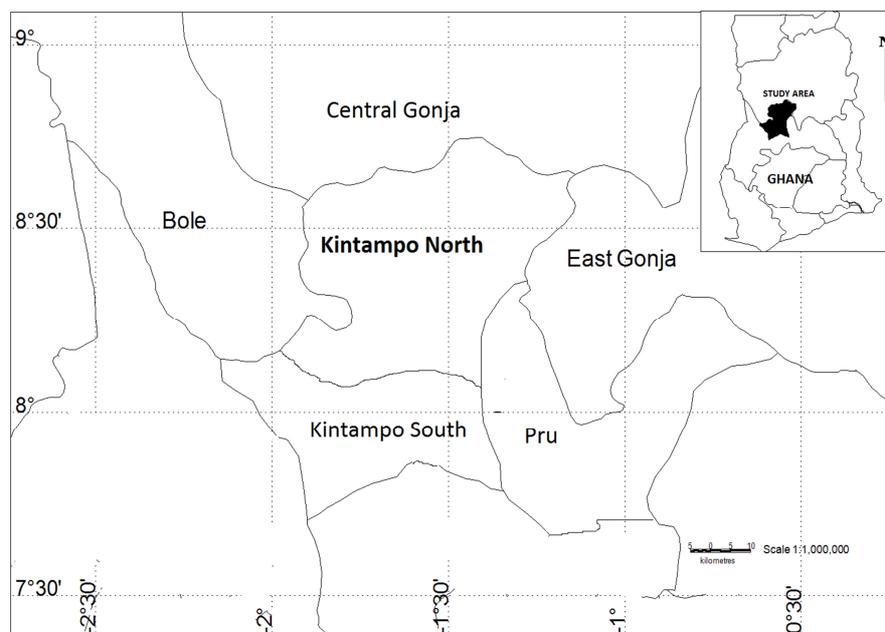


Figure 1 Location Map of Kintampo-North and its neighbour districts (Modified, after Rarelibra, 2006)

### 2.1 Location and Accessibility

The district is a sparsely populated rural region with underdeveloped infrastructure and services; thus it has been

identified as a critical water deficit area based on the water supply coverage (Unihydro Limited, 2000). It shares boundaries with five districts in the country, namely; Central Gonja District to the North; Bole District to the West; East Gonja District to the North-East (all in the Northern Region), Kintampo South District to the South; and Pru District to the South-East (all in the Brong Ahafo Region) as shown in Fig. 1. It is located between latitudes 8°45'N and 7°45'N and Longitudes 1°20'W and 2°1'E (Fig. 2).

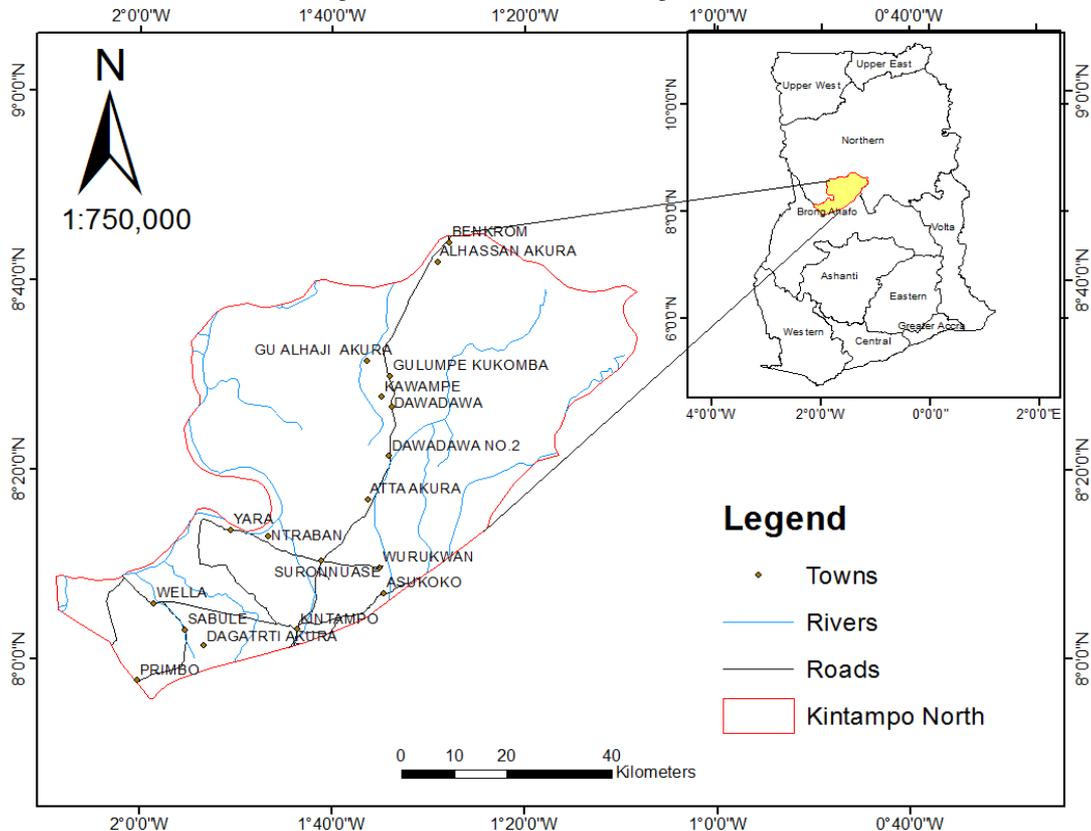


Figure 2 Map of Kintampo-North Municipality showing some communities within the study area.

## 2.2 Geology and Hydrogeology

The Municipality is predominantly underlain by the Voltaian Super group which covers about 45% of the surface area of Ghana and about 80% of the District's land surface. The remaining 20% of the District's land surface is covered by the Buem formation as shown in Fig. 3. The sub-lithologic units in the Voltaian Super group include the Lower Voltaian, Middle Voltaian (Obosum and Oti beds) and the Upper Voltaian. The Upper Voltaian consists of massive quartz-sandstone containing shale, mudstone and thin-bedded sandstones whilst the Middle Voltaian rocks consist of arkoses, mudstones, shale with sandstones, conglomerates, limestone quartz-sandstones and grits and weathers to form residual coarse-sand and clay (Table 1).

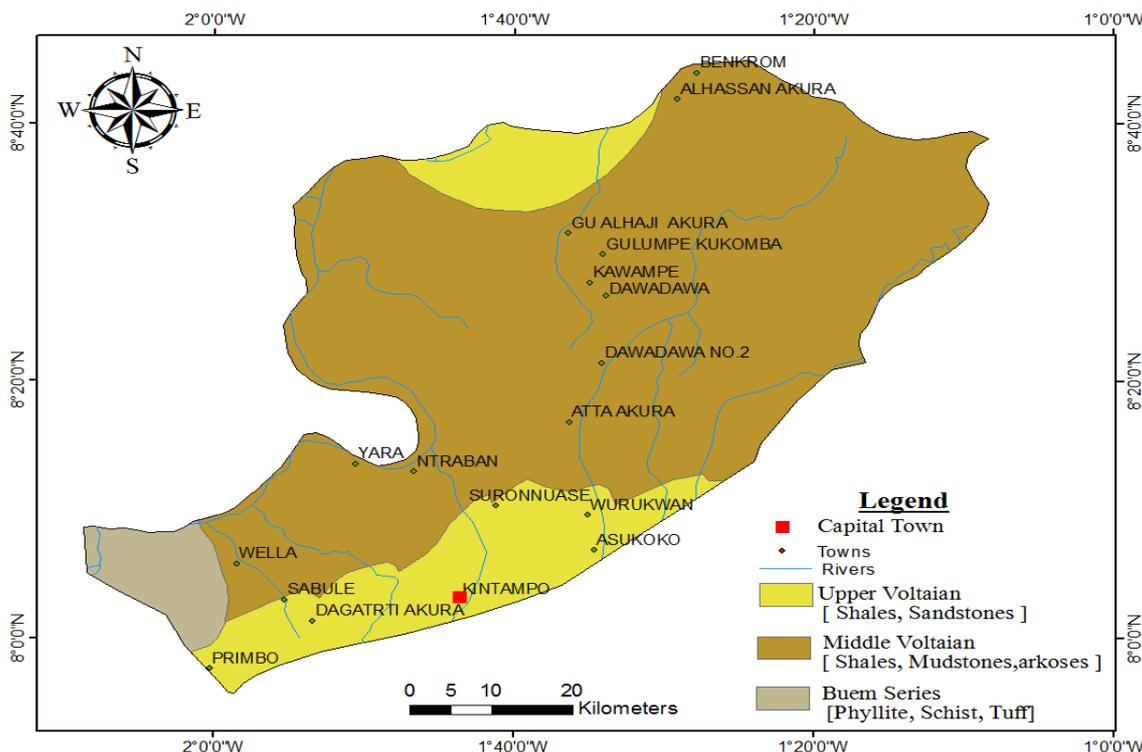


Figure 3 Geological Map of the Kintampo-North Municipality.

Hydrogeologically, the rocks in the Voltaian have almost completely lost their primary porosity through low-grade metamorphism. They are generally well consolidated and are not inherently permeable (Kesse, 1985). Thus, mudstone, sandstone and shale in the Voltaian exhibit little or no primary permeability (Kwei, 1997). However, they possess a secondary and variable permeability as a result of weathering, fractures, joints and fissures due to some amount of tectonic activities, thereby contributing to groundwater storage.

Table 1 The Major Lithologic Units in the Voltaian (Modified after Carrier *et al.*, 2008)

System	Stratigraphic Division	Dominant lithology
Voltaian System	Upper Voltaian	Massive sandstone, conglomerate with thin beds of shale and mudstone locally
		Obosum beds - Mudstone, shale, sandstone, conglomerate, some limestone
	Middle Voltaian	Oti beds - Arkose, sandstone, conglomerate, mudstone, shale, limestone
	Lower Voltaian	Basal quartz sandstone with pebbly grits and grits
-	Buem Series	Shale, sandstone, lava and tuff with some limestone, grit, conglomerate

### 3. Materials and Methods

The GEONICS EM34-3 Equipment and the ABEM Terrameter SAS 1000C resistivity equipment were used in the data collection. The GEONICS EM34-3 conductivity meter is a portable instrument which measures the electrical properties of the subsurface using electromagnetic induction (McNeil, 1980). Particularly, it has been used successfully for mapping deeper groundwater contaminant plumes and for potable groundwater exploration (Chegbeleh *et al.*, 2009; Okrah *et al.*, 2012). The instrument was used for profiling followed by vertical electrical sounding (VES) using the ABEM Terrameter SAS 1000C. In the vertical dipole mode, the EM34-3 device is particularly sensitive to vertical geologic structures, and is widely used for applications within weathered, fractured and faulted bedrock systems. In this work, twenty (20) profiles of total length 3,140 m were surveyed in the beneficiary communities using 20 m inter-coil separation at 10 m station intervals along the traverse-lines. The VES were conducted at 53 selected points using the ABEM Terrameter in the Schlumberger electrode array. VES in the Schlumberger array was carried out with half-current electrode spacing (AB/2) ranging from 1.5 - 83 m while the potential electrode separation MN/2 was chosen from the range 0.5 – 5 m. The EM conductivity data (vertical and horizontal dipoles) were plotted against station intervals as profiles. The apparent resistivity data were modelled against half current electrode spacing (AB/2) with a number of iterations to obtain sounding

curves. From the curve matching technique initial estimates of the resistivity and thickness of the various geoelectric layers at each VES station were obtained. These were later used as a starting model for a fast computer iteration using RES1DINV software (Loke, 1999). The modelled VES curves were interpreted with the minimum number of layers that are deemed necessary, which are qualitatively recognizable on the modelled curves. The layer resistivity, thickness and depth were taken into consideration in selecting potential drill sites.

#### 4. Results and Discussions

The results of the terrain apparent conductivity from EM method and apparent resistivity from VES technique are presented as profiles and model curves respectively. However, only some selected EM profiles and VES model curves have been presented for the analysis and discussion.

##### 4.1 EM Conductivity Profiles

Figure 4 shows some selected EM profiles out of a total traverse-length of 2,940 m from the study area. The EM anomaly in the entire area varies extensively in the range 6-87 m mhos/m with an average value of 48.5 m mhos/m. The apparent conductivity anomaly of the shallow subsurface terrain ranges between 6-88 m mhos/m at 15 m deep whilst the deeper zones apparent conductivity ranges between 8-113 m mhos/m at 30 m deep. Fifty-three (53) major anomalous points with sharp peaks were identified on the output curves. The crossover points, where the VD mode conductivity values are greater than the HD mode conductivity values, were mostly selected for further investigation. The crossover points may be fractured or weathered zones at deeper depth. In some cases 'necks', where the VD mode conductivity values become equal to the HD mode conductivity values were considered for further VES investigation. These 'necks' may be deep weathered zones. Therefore, the crossovers and 'necks' were regarded as priority areas for groundwater development as they are often associated with relatively high apparent conductivity anomaly involving fractures (Ariyo *et al.*, 2009; Sharma, 1997). Atta Akura recorded the highest apparent conductivity anomalous values with an average of 76 m mhos/m along two profiles of 270 m long. Asukoko area (Fig. 4b) gave relatively low apparent resistivity values with an average value of 11 m mhos/m along a traverse-line of 200 m long. Potential points of VD values higher than or equal to the HD value at a location along the traverse-line was noted for vertical electrical sounding such as VES-A70 at Dagarti Akura (Fig.4a), VES-A30 at Asukoko (Fig. 4b), VES-A40 and A140 at Ntraban (Fig.4c) and VES-B60 also at Ntraban as shown in Figure 4d.

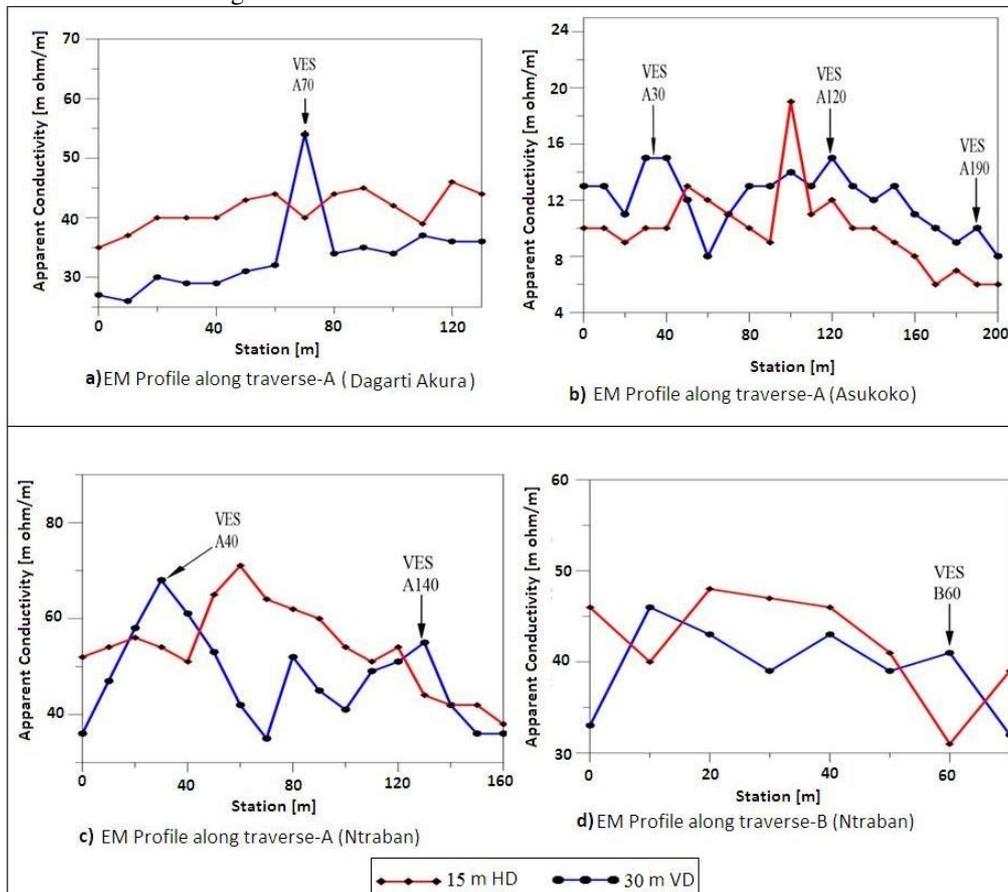


Figure 4 Selected EM Profiles for three communities within the Study Area.

#### 4.2 VES Model Curves

Figure 5 shows typical VES curves of the study area (A70 at Dagarti Akura, A30 at Asukoko and A140 and B60 at Ntraban), which depicts the general trend of  $\rho_1 < \rho_2 >> \rho_3 \leq \rho_4$ ; where  $\rho_1$ ,  $\rho_2$ ,  $\rho_3$  and  $\rho_4$  are apparent resistivities of the layers 1, 2, 3 and 4 respectively. Thus the results obtained from VES modelled data gives the apparent resistivity curves shown in Fig. 5. Generally, three to four subsurface layers were revealed in the area. These show decreasing apparent resistivity with depth, but the topsoil of the terrain showed a maximum thickness of about 3.9 m and an average of 1.8 m thickness. The topsoil has varying apparent resistivity with an average of 368  $\Omega$ m. The second layer has varying apparent resistivity with an average of 435  $\Omega$ m and mean thickness 5.6 m. The third layer has varying apparent resistivity with an average of 50  $\Omega$ m and mean thickness of 26.4 m within a deep weathered zone. The study area is underlain by a bedrock with a mean apparent resistivity of 332  $\Omega$ m. Thus the aquifer zone is expected to lie within the weathered zone.

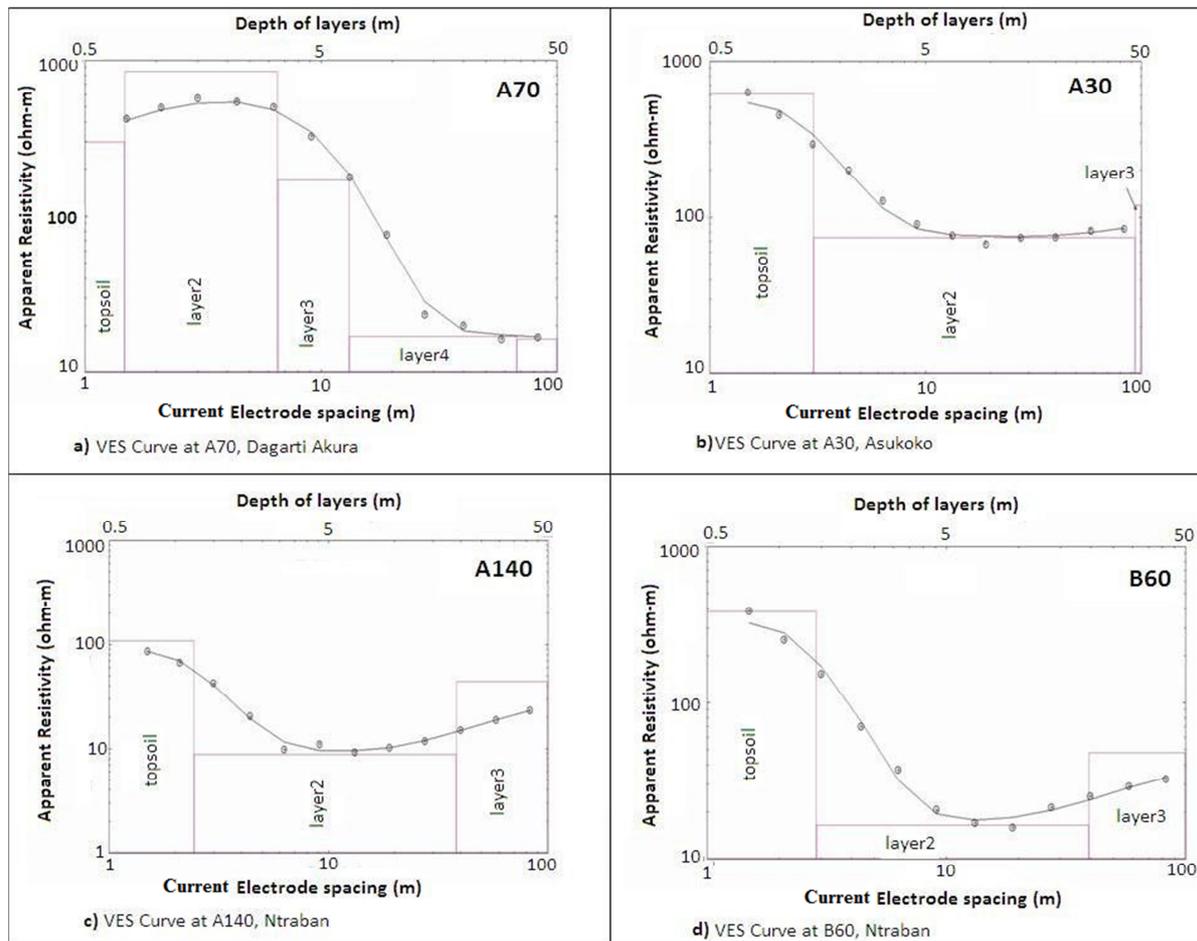


Figure 5 Selected VES Curves for the three communities whose EM profiles are indicated in Fig.4

#### 4.3 Suggested Drill Sites for Boreholes

In the Dagarti Akura community, VES point A70 m is recommended for drilling. Its coordinates are 08° 02.017' N, 001° 53.387' W with altitude 203 m above average mean sea-level (amsl). At Asukoko community, three VES points were recommended for drilling. The first choice is VES A30 m with coordinates 08° 05.199' N, 001° 29.845' W and altitude of 238 m above amsl. The second suggested drill site is VES A120 m with coordinates 08° 05.244' N, 001° 29.838' W and altitude 222 m above amsl. The third proposed drill site in this community is A190 m with coordinates 08° 05.286' N, 001° 29.835' W and altitude of 213 m amsl. At the Ntraban community, two drilling sites were also selected. The first choice is B60 m with coordinates 08° 13.199' N, 001° 48.248' W and altitude of 118.5 m amsl. The alternative is A40 m with coordinates 08° 13.184' N, 001° 48.184' W and altitude of 129.8 m amsl.

From the foregoing it is most likely to intercept some groundwater or aquifer zones at the subsurface of the selected points. However, the yield is expected to be moderately above the Community Water and Sanitation Agency (CWSA) standard of 13.5 litres per minute (*lpm*) for a successful borehole. Otherwise the drilled borehole may be declared unproductive if the yield is far less than the expected. Thus expected depth of

drilling a successful borehole in the study area should reasonably be up to about 60 m below ground level.

## 5. Conclusion

The EM survey showed that apparent terrain conductivity anomaly in the Kintampo-North Municipal vary in the range 6-87 m mhos/m with an average value of 48.5 m mhos/m. Atta Akura and its close environs have the highest apparent conductivity anomaly with an average of 76 m mhos/m and the lowest values were measured around Asukoko area with an average value of 11 m mhos/m. The VES model curves revealed three to four-layered subsurface lithological units in the area indicating decreasing apparent resistivity with depth. The average apparent resistivity and maximum thickness of the sandy-clay topsoil are 368  $\Omega$ m and 3.9 m respectively. For the second and third beds their respective average apparent resistivity and maximum thickness are 435  $\Omega$ m, 17 m and 50  $\Omega$ m, 53.5 m. The fourth bed had average apparent resistivity of 332  $\Omega$ m and maximum thickness greater than 54 m. Thus, aquifer layers can be most probably intercepted within the weathered zone, which is likely to support groundwater accumulation, storage and transmission. This is expected between 15-30 m depth. Hence, test drilling is recommended to be drilled up to a depth of about 45 m in order to intercept the aquifer zone in the Kintampo North Municipal. Therefore the study has shown that the Kintampo-North Municipal has a great potential for groundwater accumulation, which can be exploited for the supply of potable water for the rural communities within the study area.

## 6. Acknowledgement

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