GEOPHYSICAL INVESTIGATIONS FOR GROUNDWATER IN THE MIDDLE PRECAMBRIAN PROVINCE OF UPPER DENKYIRA DISTRICT USING ELECTROMAGNECTIC AND ELECTRICAL RESISTIVITY METHODS

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ABSTRACT
In this study, geophysical investigations were carried out in twelve (12) communities in the Upper Denkyira District located in the Birimian and the Tarkwaian Formations of the Central Region of Ghana with the aim of delineating groundwater potential zones, drilling the selected sites, and subsequently comparing the geophysical results with those of the drilling. The geophysical methods employed included electromagnetic profiling and resistivity sounding using the Schlumberger array. Six (6) boreholes were drilled and the results revealed a lithology that consists of laterite, clay, sandy-clay and slightly-to-highly weathered sap-rock including phyllite as the regolith which determines the groundwater potential. Groundwater was generally found at the depth of 20.0-38.0m in the Birimian Formation and 17.0-40.0m in the Tarkwaian Formation. It was found that boreholes drilled within the Tarkwaian and Birimian Formations were successful in producing groundwater, thus indicating that the area has a relatively high groundwater potential since the characteristic geological structures of the basement rocks favour groundwater transmissivity and storativity. The surface geophysical results were correctly validated by the drilling results thus confirming the geophysical exploration technique as a paramount and a pre-requisite tool for borehole siting.

INTRODUCTION
Groundwater resource is the principal source of potable water to many communities in Ghana today. The importance of groundwater is becoming increasingly significant in Ghana as rural communities and small towns water supply systems are mainly based on groundwater resource.

From Gyau-Boakye and Dapaah-Siakwan (1999), only 0.6% of the communities in the Central Region of Ghana depend on borehole facility for freshwater whilst about 61.8% of the communities rely on surface water with the rest on other sources. Surface water is, however, highly vulnerable to microbial infection (e.g. guinea-worm), toxic chemical contamination from the mines and industry (e.g. cyanide), pesticides and fertilizer infiltration from agriculture, radiological hazards and insanitary environmental effects. The vulnerability of surface water resources to contaminant plume remarkably outweighs groundwater resources under the same environmental condition (CIDA, 2006).

According to Cherry *et al.* (1975), the dependence on such contaminated water is usually accompanied by traumatic waterborne diseases (e.g. cholera, bilharzias, diarrhea, typhoid fever, etc.) and blood related diseases (e.g. leukemia, hepatitis A, etc.) and the consequences on the victim cannot be over-emphasized.

In several communities within Upper Denkyira District, access to potable water is a major challenge. According to the District's Statistical Assessment, 45% of the district population has no access to potable water. The major sources of drinking water in the district include limited number of boreholes, hand-dug wells, rivers, and streams (http://www.ghanadistricts.gov.gh, 2007).

By the close of the year 2007, there were about 187 boreholes spread throughout the district with about 155 of them functioning according to the database of Upper Denkyira District Assembly. Thus, about 32 boreholes fitted with hand-pumps were dysfunctional because of high population pressure exerted on the available borehole facilities and the inability of the community water point committees to raise sufficient funds to rehabilitate the defective borehole facilities (Darko, 2002).

Consequently, the communities concerned have been compelled to drink from streams and rivers. Whilst some of these rivers or streams dry up during the dry season, others have been rendered unsuitable for human consumption as a result of illegal mining operations (also known as "galamsey") in those water bodies (e.g. River Offin). The common water and sanitation related problem in Upper Denkyira District according to the Ministry of Health at Dunkwa, the District Capital, are malaria, typhoid fever and dental cases over the years with malaria leading the list followed by typhoid fever.

There is therefore the need to carry out geophysical investigations to identify suitable sites for the drilling of boreholes to provide potable water to the communities.

This paper presents the results of the geophysical exploration for groundwater in some communities located in the Tarkwaian and Birimian Formations of the Upper Denkyira District.

MATERIALS AND METHODS

Geology and hydrogeological settings of the study area

The Middle Precambrian hydrogeological unit underlies the Upper Denkyira District which is extensively dominated by Birimian and Tarkwaian Formations aligned in the north-eastern and south-western directions (Fig. 1). The rock types are similar, consisting of phyllite in relative abundance, even though the ages of the Formations differ. The Birimian Formation is characterized by strong foliation and fracturing which make percolation easy for groundwater rechargeability. Like the Birimian, the Tarkwaian is folded along the north-eastern axis which enhances the groundwater potential (Kesse, 1985). Moreover, according to the CSIR-WRI Database (2007), the Birimian and Tarkwaian Formations of Upper Denkyira District are marked with extensive weathering, availability of quartz vein and presence of buried river channel (Dickson and Benneh, 1988) as contributory factors to promote groundwater potential in the terrain (Kortatsi, 1994).

The Upper Denkyira District has a relatively rich aquifer of average borehole yield ranging from 0.3 to 19.1 L/min with the average yield of groundwater from the Birimian and Tarkwaian Formations as 12.7 and 8.7 L/min respectively with respective success rates of 75% and 83% (Dapaah-Siakwan and Gyau-Boakye, 2000). Analysis of fifteen (15) selected boreholes drilled for seven (7) communities in the early 1980s within the Birimian and Tarkwaian Formations of Upper Denkyira District shows that phyllite is the major rock type and the depth of boreholes falls within the range of 34-60m with the exception of few outstanding cases. The average depth of the existing boreholes is 53m.

The average yield of the 15 sampled boreholes is 68.75 L/min with the maximum yield being 250 L/min at Abora and minimum yield of 5 L/min occurs at Brofoyedru at 24.0m depth even

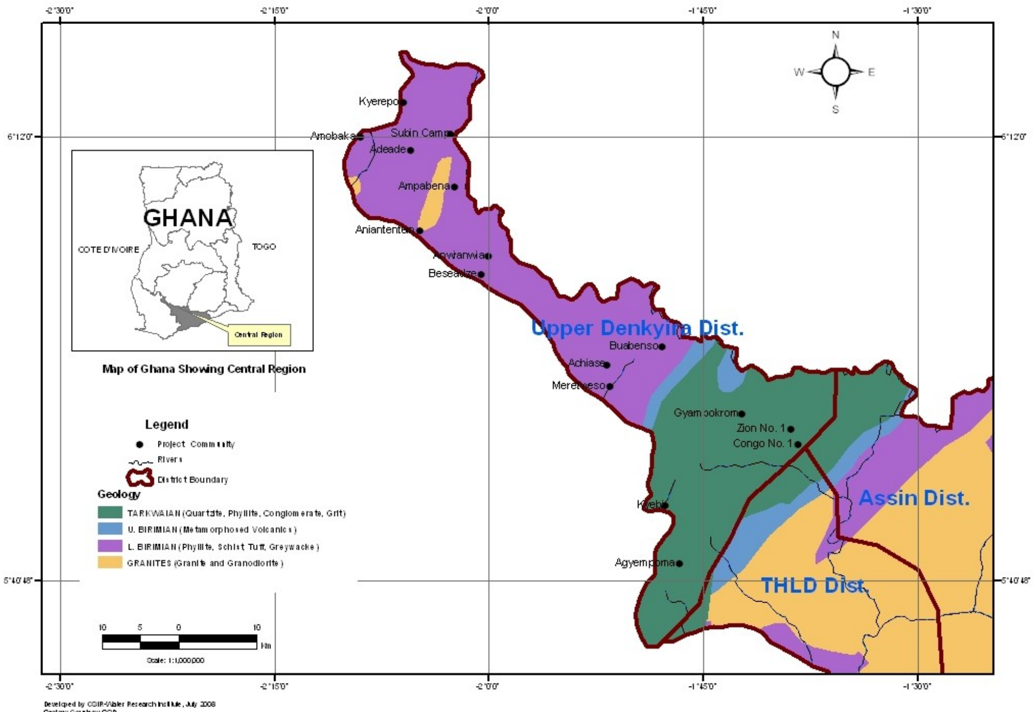


Fig. 1: Location map of Study Area (Upper Denkyira District) showing the geology and project sites.

though the second borehole in the same vicinity yielded 60 L/min at 48m depth (CSIR-WRI Database, 2007). This indicates that drilling to the right depth to intercept the fractured zone yields much water from the borehole (Wyllie, 1963).

The physico-chemical analysis of the water obtained falls within the acceptable level required by the World Health Organisation (WHO, 1996) and the Environmental Protection Agency (EPA) of Ghana. Hence the water obtained from the boreholes sampled was recommended for safe drinking. The undulating topography with remarkable alternating highlands and lowlands of Upper Denkyira District dictates the overburden thickness which determines the aquifer horizon at any site. According to a facility map produced by the Geological Survey Department, the northern sector of Upper Denkyira District has groundwater yield between 5.0-7.0 L/min and the southern part around Dunkwa-on-Offin is above 7.0 L/min indicating high groundwater potential.

Geophysical Field Surveys

An integrated geophysical technique was employed to explore the sub-surface layers of the earth with standard modern equipment to delineate discontinuities and low resistive zones marked with relatively high primary and secondary porosity. The investigation involves electromagnetic profiling followed by vertical electrical resistivity sounding.

Electromagnetic (EM) profiling

The apparent conductivity in microsiemens-per-centimetre (µS/cm) was measured directly at 10m intervals along the selected traverses using Geonics EM 34-3 Conductivity Meter which works under the principle of electromagnetic induction (Dobrin, 1976). A transmitter coil (T) radiates an electromagnetic field ($\mathbf{B}_p$), which induces electrical currents (eddy currents, $\mathbf{J}_e$) in the earth below the coil. These eddy currents in turn generate a secondary magnetic field ($\mathbf{B}_s$) which is detected and measured by a receiver coil (R). The instrument output is calibrated to read apparent conductivity, which is obtained by comparing the strength of the phase component of the secondary field to the strength of the primary field (Robinson, 1988). The apparent conductivity measurement represents a weighted average of subsurface conductivity from the ground surface to the effective depth of exploration of the instrument (Patra and Mallick, 1980).

The two main orientations employed during ground conductivity measurements are vertical dipole (VD) mode and the horizontal dipole (HD) mode. The VD mode is responsive to deep seated conductive anomalous bodies whilst the HD mode detects shallow conductive anomalies (Keller and Frischnecht, 1966). According to Darko and Krasny (2000), the average depth to aquifer within the Tarkwaian and Birimian Formation is 8.9m. Therefore, the 20m intercoil separation cable was used which probes to a maximum depth of 15m for the HD and 30m for the VD modes. Thus, the HD probes to 75% of the intercoil spacing whilst the VD probes to 150% of the intercoil spacing (ABEM, 2006).

Plots of measured electrical conductivity against stations are analyzed quantitatively. The main criteria for selecting a point on the curve includes accessibility by drilling rig and water users, noting cross-over zone where the VD values exceed the HD values (Labo, 1986), separation of neighboring selected points over 50m apart, amongst others. Thus, zones of relatively high apparent conductivities are noted and recommendation made for further detailed work such as Vertical Electrical Sounding (VES) to be carried out.

According to Freeze and Cherry (1979), the resistivity of fresh groundwater ranges between $1.0 \times 10^{-1} - 1.0 \times 10^{3}$ Ωm; however, mineralized zones are generally marked with relatively high order of resistivity except sea-water, iron and clay which are characterized with very low resistivity. External sources of noise in the data acquisition such as roof effect, high tension cables and buried metal scrapes are not considered for sounding even though high apparent conductivity would be registered.

Vertical Electrical Sounding

Vertical Electrical Sounding (VES) was conducted at the selected points using ABEM Terrameter SAS 1000C Equipment which has high sensitivity and standard resolution power. The basic principle of operation of the equipment is meant to determine the subsurface resistivity variation with depth by measuring the resistance of the ground to compute the apparent resistivity of the sub-surface.

The symmetrical-schlumberger electrode spread technique was used to sound to a maximum of 83m depth at each selected point and the field data are recorded and plotted in-situ on pre-designed logarithmic forms to preview the aquifer characterization and also to minimize noise by repeating measurements until acceptable readings were obtained at a standard deviation in the order of 10^{-2}%. The existing boreholes in some communities such as Agyempoma, Adeade and Ampabena within the study area were calibrated to assess the groundwater potential at the local hydrogeological unit and thereby estimate the success rate of the drilling program.

Test Drilling and Well Development

Drilling proceeded with the sub-surface geophysical results as a guide to study the degree of correlation between the geophysical interpretations proposed earlier and the drilling results. If the test drilling is proven successful, the well could be pump-tested and developed for the local community. Since the groundwater is meant for drinking, water quality analysis is vital to provide safe drinking water for the people.

The boreholes were drilled by T.B.L Resource Drilling Company Ltd with a rig equipped with rotary top head drive and down-the–hole hammer bit of diameter 165 mm to carry out air circulation which could drill above 500m depth at 5m long per rod. During the drilling process, rock samples were examined for logging at regular intervals of 1m depth whilst the relatively hard basement rocks were consistently hammered till appreciable depth of borehole was obtained. The estimated yield of the aquifer was quickly determined for a successful well in the cause of drilling. The successful well was then developed and constructed into a production borehole.

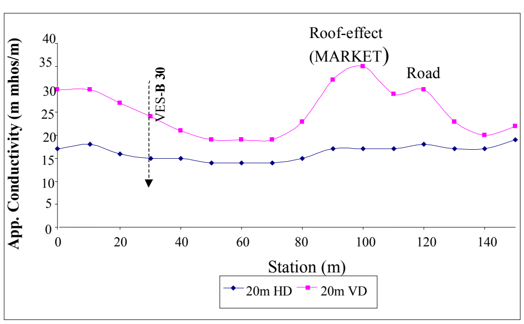
RESULTS AND DISCUSSION

Electromagnetic (EM) Profiling Results

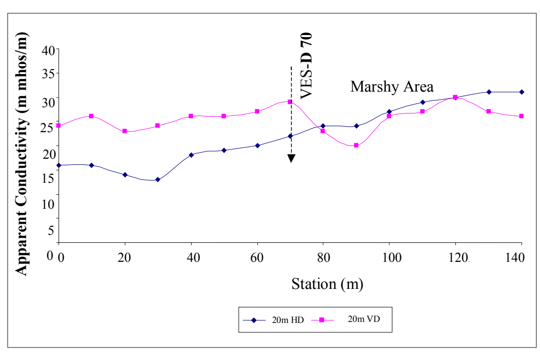
The conductivity measurements in the VD and HD modes yielded results which were plotted on the same axes for easy correlation. A relatively high VD conductivity value is recommended for boreholes whilst high HD conductivity value is preferred especially for hand-dug wells. For this reason, high conductivity values devoid of external influences such as roof, high tension cables, buried metals to obtain high signal-to-noise ratio and insanitary areas such as waste dump, cemetery, toilet facility and septic tank were selected at least 50 m apart along the traverse for vertical electrical sounding (VES).

In most communities under study, the HD and the VD values of conductivities range from 7.0-19.0m mho m^{-1} except in Buabinso and Meretweso where measurements fall within the range of 21.0-32.0m mho m^{-1} (Table 1). Few readings such as 56.0m mho m^{-1} were accompanied by noise due to roof effect and 59.0m mho m^{-1} coincided on a road recorded in Meretweso as shown in Table 2. The local conductivity signatures of the chosen communities within the various geological terrains are discussed as follows:

Fig. 2 shows some of the EM response curves measured at two locations (A and B) in the Tarkwaian Formation at Buabinso. The terrain is undulating with average altitude of 128m above mean sea level in the River Offin basin. The alluvial dredging and offshore galamsey activities carried out by the inhabitants pollute the river with extremely high turbidity level and poisonous chemical infiltration such as mercury which render the river unsafe for drinking. The conductivity signatures along the 140m long traverses B and D indicate in general higher VD values above the HD values which imply highly weathered deeper zones than the shallow sub-surface zones. Generally, the terrain has HD values ranging between 11.0 -31.0m mho m^{-1} with an average value of 17.0m mho m^{-1} whilst the VD values vary within 13.0-32.0m mho m^{-1} with an average of



A: EM Response Curve - Traverse **B**



B: EM Response Curve - Traverse **D**

Fig. 2: EM Response Curves along two traverses at two locations (A and B) in Buabinso showing the results in VD and HD-modes.

Table 1: Terrain analysis of selected communities in the Tarkwaian Formation

Community (Tarkwaian)	**Altitude** (m)	**Source of water**	**Top-soil**	**Conductivity** (m *mho* m^{-1}) Background	VES
Buabinso	128	Stream, HDW	Laterite	13-26	16-29
Twifo-Kyebi	118-143	BH, Stream	Laterite	7-12	13-17
Gyampokrom	150	Stream	Laterite	11-17	17-22
Congo No.1	-	-	Laterite, Clay	7-12	13
Zion No.1	-	-	Laterite, Clay	7-13	14-16

23.0m mho m^{-1}. The aquifer system therefore has large coverage in the terrain which is recharged from sustainable sources like the Offin River.

Similarly, Fig. 3 illustrates the EM response curves recorded at Adeade in the Birimian Formation. Adeade is a farming community located on highland of lateritic soil. The inhabitants solely rely on a small stream in a valley which dries up quickly during unfavorable climatic conditions. The conductivity signature along the two traverses A and B as shown in Fig. 3, generally shows higher VD responses than HD with the maximum VD=55m mho m^{-1}. The background responses have average VD value of about 17.0m mho m^{-1}. Noise due to roof effect influenced the signal in some cases. Therefore a suitable peak is marked for further investigation to seek for the best borehole site in the community.

Table 1 gives a general summary of apparent conductivities of the communities selected from the Tarkwaian belt and Table 2 shows similar information for the Birimian Formation of the Study Area.

Vertical Electrical Sounding (VES)

The potential points selected with optimal precision were subjected to vertical probing using the electrode expansion method of Schlumberger technique to plot in-situ logarithmic curve of apparent resistivity in ohm-metre (Ωm) against depth in metre (m) to determine the vertical variation of rock resistivity with depth in order to resolve the thickness of the regolith and the zone of weakness which might possibly become the aquifer zone.

Three (3) VES points were selected in each community in Upper Denkyira District. Existing boreholes were calibrated as evidence of

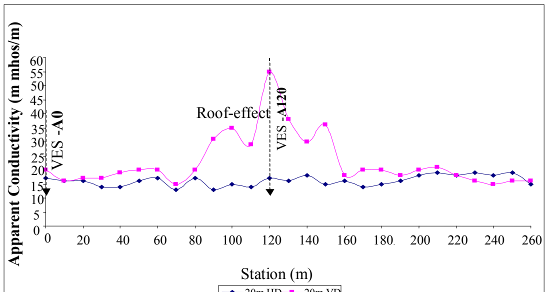


Fig. 3a: EM Response Curve - Traverse **A**

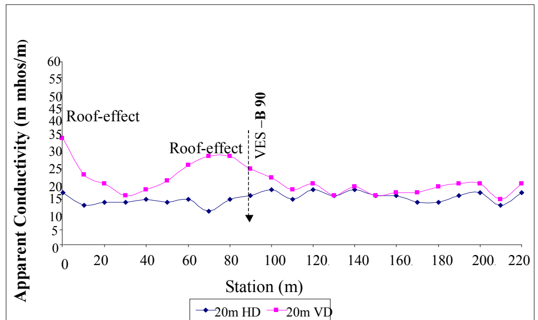


Fig. 3b: EM Response Curve - Traverse **B**, Adeade

Fig. 3: EM Response Curve at Adeade

Table 2: Terrain analysis of selected communities in the Birimian Formation

Community (Birimian)	Source of water	Top – soil	Conductivity (m *mho* m^{-1})	
			Background	VES
Adeade	Stream	Laterite	15-38	20-55
Achiase	Spring	Sandy clay	14-29	17-23
Ampabena	BH, HDW	Sandy	8-15	15-25
Anwianwia	Stream, BH	Sandy-clay	8-15	15-31
Meretweso	-	Sandy, Clay	21-59	28-31

the groundwater situation in the communities under investigation. Borehole of number BH257-01 at Ampabena is a typical example. The VES results were analyzed using RESIST Software to produce modeled curves showing the various layers and their corresponding thickness and apparent resistivity of each site.

In the Tarkwaian Formation, five (5) communities were selected for critical analysis. The geophysical interpretation (Fig. 4) of the Formation of the study area is summarized as follows:

i) It mostly consists of three (3) layers of type $\rho_1<\rho_2>\rho_3$ with some sites having four (4) layers of type $\rho_1<\rho_2>\rho_3>\rho_4$. In Buabinso for instance, the first two layers of 2.0m thick have resistivity between 1156.1 and 1931.1 Ωm which is gravel-clayey mix. The third layer is 11.8m thick with resistivity of 409.9 Ωm which could be weathered bedrock. The fourth layer which constitutes the water bearing zone has resistivity of 172.7 Ωm indicating weathered basement of extended thickness.

ii) The aquifer would be located mostly in the third bed with few other sites located in the fourth bed. The average resistivity of the aquifer zone is 415.05 Ωm.

iii) The borehole sites are located at altitudes between 122-148m above mean sea level.

iv) The average resistivity and thickness of the top layer are 491.82 Ωm and 2.38m respectively.

v) The depth of the borehole to be drilled is estimated to be between 40.0-75.0m with average depth of 55.0m.

In the Birimian Formation, on the other hand, the general geophysical interpretation of the Formation is as follows:

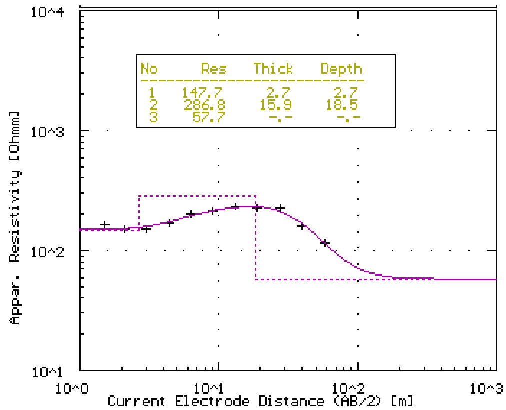
i) It mostly consists of four (4) layers. In Adeade for example, the terrain was located at about 141 m high above mean sea level and was made up of four layers, especially on the highlands. A thin sheet of gravels mixed with clay of 0.6m thick and resistivity of 60.3 Ωm forms the topsoil. The second layer of 5.3m thick has resistivity of 107.9 Ωm which might be a moderately weathered basement rock whilst the fourth layer is extended to the fresh basement which is deep-seated beyond 17.8m depth. The fourth layer is expected to be highly weathered phyllite overlying the fresh bedrock and considered as the water bearing zone. The average resistivity of the aquifer zone is 16.9 Ωm.

ii) The borehole sites are located between 122-168m *amsl*. The average resistivity and thickness of the top layer are 355.72 Ωm and 1.42m respectively.

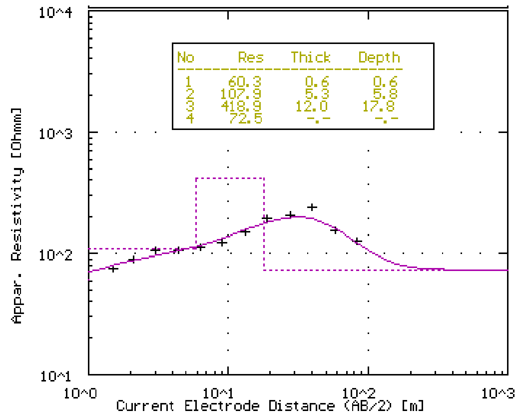
iii) The depth of the borehole to be drilled is estimated between 45-60m with average depth of 55.0m.

Drilling Results and Interpretation

The drilling results were to confirm the predictions drawn from the geophysical interpretation. The results obtained from the test drilling



A: VES Curve at Buabinso, Tarkwaian Formation



B: VES Curve at Adeade, Birimian Formation

Fig. 4: Typical VES Curves of Tarkwaian and Birimian Formations

were interpreted meaningfully to establish the extent of correlation between the geophysical and drilling results.

Only six (6) boreholes in five (5) communities out of the twelve (12) communities selected for analysis in the study area had been drilled as a result of a technical hitch in the rig during the test drilling process. Four (4) communities within Tarkwaian Formation and only one (1) community within the Birimian Formation in Upper Denkyira District were subjected to test drilling. The overburden consisted of laterite, clay and sandy-clay in most parts of the study area with exception of a few communities such as Congo No.1 and Zion No.1 which also has gravel and pebble patches. Mud drilling method was adopted especially within much of the clayey overburden zone otherwise air rotary mechanism was employed throughout the test drilled boreholes. The bedrock encountered was mainly phyllite and granite. In all situations the bedrock was partly weathered and fresh. The extent of the weathering contributed to the groundwater potential in the area.

The Tarkwaian Formation generally consists of four (4) layers of sandy-clay, laterite, weathered phyllite and granite. The topsoil is mainly sandy-clay and laterite patches of about 3 m thick whilst the bedrock is phyllite and granite in some cases showing different degrees of weathering. The average depth to bedrock is 16m with few locations having depth of 3m and a deepest point of 24m. The aquifer zone occurs within the third bed and beyond with an average potential yield of 19 L/min ranging between 12-30 L/min. All the boreholes drilled were wet, thus confirming the availability of groundwater.

In the Birimian Formation, however, the geological sequence of the 38m depth borehole penetrated at Achiase includes laterite (0-2m), grayish-clay (2-7m), highly weathered granite (7-23m), moderately weathered granite (23-32m), and fresh granite (32-38m). The water bearing zone was between 20-38m occurring within the third up to the fifth beds of granitic medium. The well was constructed using PVC casing of 19m long with gravel packing, fine sand backfilling and cement grouting at appropriate portions to admit the seepage of clean water into the borehole at the rate of 60 L/min.

DISCUSSION OF DRILLING RESULTS

The boreholes drilled in the study area eventually recorded 100% success rate since all the boreholes were wet and productive and the drilling yield ranged between 12.0 - 60.0 L/

min. The lowest yield of 12.0 L/min obtained at Zion No.1 was basically due to the existence of a 21.0m thick layer of clay which is impermeable. The average depth of the successful boreholes was 38.8m with the deepest well of 49.0m drilled at Gyampokrom and the shallowest well of 24.0m at Congo No.1.

Correlation of Geophysical and Drilling Results

It is worth noting that rock formation is anisotropic with diversity of petrophysical properties like attitude of the bedding plane, texture, sorted grains, pore size and interconnection between pores or fractures which are influenced by agents such as weathering, sedimentation, compaction or crystallization to define the characterization of the Formation. In spite of the uncertainty prevailing, appropriate geophysical techniques were employed to achieve suitable results during test drilling. This minimized cost of drilling, saved human effort and provided the freshwater needs of the people to improve their livelihood.

Table 3 validates the geophysical results with the drilling results to declare the extent of correlation between them. Even though geophysical analysis cannot estimate the yield, it is capable of giving a highlight to the number of layers intercepted, the depth to bedrock, depth-to-aquifer, and the lithology based on the resistivity variations and in most cases estimate the aquifer horizon as a guide to test drilling.

From geophysical point of view, the bedrock is competent with relatively high resistivity value depending upon the rock type whilst in drilling it may be limited to only the fresh rock or may include the weathered component of the basement rock. The size of the drilling bit was usually changed from the 10½ inch (262.5mm) bit or 8½ inch (212.5mm) rock bit to 6½ inch (162.5mm) bit prior to encountering the fresh basement rock.

Considering Table 4, the following deductions have been made:

i) At Buabinso, the depth to bedrock recorded from geophysical analysis (0.7m) clearly shows the slightly weathered part

Table 3: Correlating lithology deduced from geophysics with the drilling results

BOREHOLE SITE		DRILLING LOG		GEOPHYSICS		
Community	**VES-Point**	**Lithology**	**Thickness (m)**	**Resistivity (Ωm)**	**Thickness (m)**	**Layer**
Buabinso	B30	Sandy-clay and gravel	0-2	147.7	2.7	1
		Sandy-clay Sandy-clay and gravel	2-10 10-18	286.8	15.9	2
		Rusty weathered phyllite	18-38	57.7		3
		Weathered Granite	27-33 m	-	-	-
		Fresh Granite	33-51 m			

Table 4: Comparison between drilling and geophysical results

Community	VES Point	No. of Layers		Depth to Bedrock (m)			Aquifer Horizon (m)	
		Geophy. Interpret.	Borehole Drilling	Geophysical Interpretation	Borehole Drilling: Weathered	Borehole Drilling: Hammered	Geophysical Interpret. (Estimated)	Borehole Drilling
Buabinso	B30	3	4	2.7	18.0	deep-seated	40.0-50.0	25.0-36.0
	C100	4	4	0.7	3.0	7.0	20.0-40.0	32.0-39.0
Congo No. 1	B80	3	5	42.8	18.0	deep-seated	15.0-40.0	17.0-23.0
Zion No.1	A40	3	4	27.9	24.0	33.0	40.0-60.0	31.0-40.0
Achiase	B100	4	5	3.0	7.0	19.0	10.4-Extended	20.0-38.0

of the bedrock intercepted at 3.0m and 7.0m for the fresh basement which is too shallow. Thus, the yield was minimal and also stands the risk of contamination and drying up during harsh climatic conditions since any contaminated surface water can easily percolate to fill the borehole within the zone of aeration.

ii) At Congo No.1, the fresh basement rock was not encountered since it was deep-seated which confirms the geophysical result of 42.8m depth even though the weathered bedrock was intercepted at 18.0m depth. The weathered thickness of the bedrock is therefore favorable to tapping high yield of groundwater. The aquifer horizon estimated by geophysical analysis (10.0 - 40.0m) rightly overlapped that of the drilling results of 17.0 - 23.0m.

iii) The number of layers obtained from the geophysical analysis (Table 4) was not exactly the same as that obtained from the drilling logs in some cases due to the ambiguities existing among the adjoining beds. For special situations, the product and/or ratio of the thickness-to-resistivity of the neighboring beds is the same. Thus, the shape of the simulation curve will not be altered and the beds are said to be equivalent from the geophysical point of view. The drilling log of Buabinso for instance declared four (4) layers but the geophysical investigation showed three (3) layers. The first layer of about 2m thick was isolated by both the geophysical analysis and drilling whilst the second layer of about 16m thick was an aggregate of 2 sub-layers consisting of sandy-clay and gravel since they are equivalent as indicated by Table 4. The third layer deduced from the geophysics considered the rusty-weathered and fresh phyllite to be equivalent. This explains the extent of correlation of lithology with drilling log and geophysical analysis.

iv) The aquifer horizon predicted from the geophysical interpretation conformed to the water bearing zone intercepted during the drilling process.

Generally, geophysical interpretations give vivid and adequate information to explore the sub-surface resources of the earth to make way for the necessary exploitation to be carried out with minimal uncertainties provided suitable geophysical techniques are deployed to delineate borehole drilling points. Thus, geophysical interpretation and drilling results really correlate.

CONCLUSION

After extensive geophysical exploration for groundwater within the Birimian and Tarkwaian Formations of the study area using integrated geophysical techniques, the predictions declared were validated from the drilling results. It was therefore found out that most communities have four (4) strata except Congo No.1 which has five (5). The Tarkwaian and the Birimian Formations have an average of four (4) layers according to both geophysical subsurface analysis and the drilling results; the weathered overburden zone in the Formations consists of laterite, clay, sandy-clay and slightly -to-highly weathered bedrock which includes phyllite; the depth to bedrock varies between 3.0-24.0m with an average depth of 14.3m whilst the depth to aquifer ranges between 15.0 -40.0m in the phyllite basement; the thickness of the weathered overburden rock contributes to the groundwater potential in a locality. Thus, the shallower the bedrock, the smaller the regolith and the lower the groundwater potential and vice versa; the success rate of tapping water from the aquifer of the Tarkwaian and Birimian Formation is 100%. This indicates that the Formation has appreciable groundwater potential with regards to the limitation of CWSA requirement of at least 13.0 L/min per successful borehole for rural water supply; the potential yield of groundwater within the phyllite basement of the Tarkwaian Formation ranges between 13.0-30.0 L/min with an average yield of 20.0 L/min; and the deepest well is borehole no. GYA-01 of Gyampokrom drilled to 49.0m and the shallowest well is borehole no. CON-01 of Congo No.1 in the Tarkwaian Formation also drilled to 24.0m.

The results of the study indicate that geophysical techniques have proved to be effective scientific tool in groundwater exploration.

RECOMMENDATIONS

In order to establish reliable sub-surface exploration and accessible groundwater exploitation, there is the need to identify avenues for future development in the groundwater industry. It is therefore recommended that test drilling should be carried out exactly at the site (s) located by the geophysical exploration and strictly according to the ranked results to enhance the success rate of tapping groundwater; the drilled boreholes must be pump-tested to determine the aquifer characteristics such as transmissivity and storage capacity of the underground water in order to guide the users to withdraw the required amount at a time. This would ensure a sustainable supply of water even during harsh climatic conditions; physico-chemical and bacteriological analysis should be carried out to necessitate the production of satisfactory quality water for potability; the borehole should be well protected against contamination from surface infiltration. The surrounding with at least 50.0m radius of about the borehole should be maintained with high standard sanitary conditions; high yielding boreholes should be mechanized to mitigate the stress of users in drawing water from the well; installation of filters is paramount especially for boreholes where salinity level is quite moderate to improve the colour, odour, taste and remove turbidity for clean drinking water to be tapped; the collaboration between the University and the Research Institutions and other Agencies of related fraternity should be well promoted to enrich the Student's technical knowhow on water related issues; stakeholders of water management such as the District Assembly, the Environmental Protection Agency, the Water Research Institute, and other concerned bodies should carry out an Action Plan geared towards education of the people on the effects of dumping refuse indiscriminately or using the water bodies as waste disposal points; the GWCL, the CWSA, the Water and Sanitation Team in the District/ Municipal Assemblies, Water and Sanitation Development Board and Water Management Committees in the district should address the water related issues based on the quantity and quality of water, monitor constant delivery of clean water and maintain the available water facilities; and the District Assembly should improve sanitation and waste management in the district in the areas of provision of public latrines (KVIP) and a geotechnical demarcated zone for landfill site to avoid indiscriminate defecation and waste dumping which could pollute groundwater.

The recommendations stated above among many others need to be addressed to enhance the accessibility of freshwater for a sustainable socio-economic development and improvement of the general health status of the users of groundwater facility in the country.

REFERENCE

ABEM, (2006). Instrument Manual, ABEM Terrameter SAS 1000 / SAS 4000. ABEM Instrument AB, Hamngatan 27, S-172 66 Sunbybreg, Printed Matter, Sweden. No. 93109.

Bear, J. (1972). *Dynamics of Fluids in Porous Media*. American Elsevier, New York.

Cherry, J. A., Gillham, R. W. and Pickens, J. F. (1975). Contaminant hydrogeology: Part 1: Physical processes, *Geosci. Can.,* 2: 76-84.

CIDA (2006), Report on Hydrogeological Assessment of the Northern Regions of Ghana, Oct. 2006.

CSIR-WRI Database (2007). Existing Boreholes in Upper Denkyira District.

Dapaah-Siakwan, S. and Gyau-Boakye, P. (2000). Hydrogeologic framework and borehole yields in Ghana, *Hydrogeology Journal,* (Spring-Verlag), 8: 405-416.

Darko, P.K. (2002). Estimation of natural direct groundwater recharge in SW Ghana using water balance Simulations. *J. Hydrol. Hydromech.* 50(3): 198-212.

Darko, P.K. and Krasny, J. (2000). Adequate depth of boreholes in hard rocks: a case study in Ghana. In: Oliver Sililo et al. (eds) Groundwater: Past Achievements and Future Challenges - *Proc 30th IAH Congress*, Cape Town 121-125.

Dickson, K.B. and Benneh, G. (1988). A New Geography of Ghana, revised ed., Longman Group, UK.

Dobrin, M.B. (1976). Introduction to Geophysical Prospecting, 3rd ed., McGraw-Hill, New York.

Freeze, R.A. and Cherry, J.A. (1979). Groundwater, Prentice- Hall, Inc., Eaglewood Cliffs, N. J. USA.

Gyau-Boakye, P. and Dapaah-Siakwan, S. (1999). Groundwater: Solution to Ghana's rural water supply industry, The Ghana Engineer, Available on-line, May 1999.

http://www.ghanadistricts.gov.gh, (2007). Link to the various Districts of Ghana showing the location, climate, relief & drainage, vegetation, population, history, political, cultural & economic situation.

Keller, G.V. and Frischnecht, F.C. (1966). Electrical Methods in Geophysical Prospecting, Pergamon, Oxford.

Kesavulu, N.C. (1993). Engineering Geology, Rajiv Beri for Macmillan India Ltd. New Delhi.

Kesse, G.O. (1985). The Mineral and Rock Resources of Ghana, A.A. Balkema Publishers, Netherlands, pp. 65-67.

Kortatsi, B.K. (1994). Groundwater utilization in Ghana, *Proceedings of the Helsinki Conference,* IAHS Publ. No. 222.

Labo, J. (1986). A Practical Introduction to Borehole Geophysics. Society of Exploration Geophysicists, Tulsa, Okla.

Patra, H.P. and Mallick, K. (1980). Geosounding Principles, Vol. 2, Elsevier, Amsterdam, pp. 420.

Robinson, E.S. (1988). Basic Exploration Geophysics, John Wiley and Sons, Inc., New York.

WHO (1996), Guidelines for drinking –water quality, 2nd ed. Vol. 2, Health criteria and other supporting information and addendum. World Health Organization, Geneva.

Wyllie, M.R.J. (1963). The Fundamentals of Well log Interpretation. Academic Press, New York.