Assessment of Groundwater Potential in the Sunyani and Techiman Areas of Ghana for Urban Water Supply

B. K. Kortatsi[1] and J. Quansah[2]

[1] *CSIR-Water Research Institute, P. O. Box M32, Accra*

[2] *KDD Engineering Services (Gh) Ltd, P. O. Box C762, Cantonments, Accra*

Abstract

The groundwater potential of the Sunyani and Techiman areas were assessed to determine the feasibility of using groundwater for water supply to Sunyani and Techiman urban areas. The investigations involved field reconnaissance, geophysical survey, test drilling, pumping test and water quality analysis. The results of the investigations indicate that the regolith varied in thickness from 12.0 m to 52.3 m with a median value of 20.4 m in the Sunyani area, and in the Techiman area the regolith thickness is in the range 10.1-50.0 m with a median value of 20.5 m. In the Sunyani area, borehole yields vary from 3.0 m^3h^{-1} to 19.2 m^3h^{-1} with median value of 3.0 m^3h^{-1} while in the Techiman area, the yields are in the range 4.3-104.5 m^3h^{-1} with median value of 63.2 $m^3 h^{-1}$. The range and median transmissivities in the Sunyani area are 0.2-3.4 $m^2 d^{-1}$ and 0.7 $m^2 d^{-1}$. For the Techiman area, they are 10.4-124.6 $m^2 d^{-1}$ and 95.0 $m^2 d^{-1}$. Apart from slight taste problem that boreholes, particularly those in Sunyani area, may have as a result of low *p*H, the groundwaters in both areas are physico-chemically and bacteriologically good for drinking purposes. Although approximately 75% of test borehole in the Sunyani area yielded higher than the required minimum yield of 3.0 m^3h^{-1} for urban water supply, pumping test results indicate that the aquifers are limited in extent and, therefore, can not support sustained pumping. Boreholes from Techiman area signify good potential aquifers with higher sustainable yields than those obtained from the Sunyani area. Therefore, the groundwater basin in the Techiman area can be developed for water supply to the townships of Sunyani and Techiman.

Introduction

Potable water is supplied to Sunyani, the capital of the Brong Ahafo Region of Ghana, and Techiman, lying north-east of Sunyani from the River Tano. The Abesim head works at Sunyani that supplies water to an estimated population of 150,000 was estimated to produce less than half the 1995 estimated demand of 12,430 m^3/day (Brown and Root Ltd, 1999). The water problem was not associated with the main towns alone; the surrounding villages also face acute water shortages. Consequently, communities in the study area have resorted to using water from streams and dug-outs. Some of these water points are visibly clean sources of water but may contain pathogenic organisms that are detrimental to human health. Thus, these sources act as channels for the propagation of water borne diseases.

Similar to the Sunyani situation, the water supply to Techiman is obtained from a 4,500 m^3day^{-1} water treatment plant at Tanoso, about 15 km south of Techiman. It supplies a population of about 50,000 resulting in many areas within Techiman not having access to piped water supply and, thus, also resorting to the use of water from mostly polluted sources. The Department for International Development (DFID), which has entered into agreement with the Government of Ghana to establish a water project aimed at ameliorating the problem of potable water supply for the people of Ashanti and Brong Ahafo regions has engaged the services of Brown and Root Ltd, a British consulting firm, to carry out detailed studies into improving the water supply of both Sunyani and Techiman. Prior to this, consultants for the DFID in 1992 assessed the water supply from the Tano river as grossly insufficient to cater for the needs of the rapidly growing population of Sunyani and its surrounding communities. The consultants noted that without impoundment, the Tano river at Abesim could not provide enough raw water to the Sunyani system. However, impoundment would create problem for communities that depend on the river downstream. Nonetheless, recent limited groundwater studies on domestic wells and boreholes have indicated the existence of promising groundwater resources to supplement the grossly inadequate supply of raw water from the Tano river.

Upon consultation with the DFID and the Government of Ghana through the Ghana Water Company, Brown and Root Ltd in 1999 decided to explore the possibility of using groundwater for the augmentation of the water supply for the two townships, and, consequently, a contract was awarded to carry out hydrogeological assessment that included surface geophysical investigations, exploratory borehole drilling, pumping test and water quality analysis. This paper uses some of the data generated in this project to compare the groundwater potential in Sunyani and Techiman areas with regard to obtaining adequate groundwater for the augmentation of raw water from the Tano river.

Materials and methods

Site description and geomorphology

The study area (Fig. 1) lies between latitude 7^0 15^1 N and 7^0 40^1 N, and longitude 1^0 45^1 W and 2^0 34^1 W. It falls under the Wet Semi-Equatorial climatic region, which is characterized by two rainfall regimes (Dickson & Benneh, 1980). The major rainy season occurs between March and July with peak in June while the minor rainy season occurs between September and November with its peak occurring in October. The mean annual rainfall is between 1250 and 1400 mm (Mote, 1998). The highest mean monthly temperature is about 30 °C while average monthly humidity is generally between 75% and 80% (Dickson & Benneh, 1980). The physiography of the Sunyani area is mainly Forest Dissected Plateau. Ground elevation rises to between 240 m and 300 m above sea level, and the landscape is either undulating or rugged. The physiography of the Techiman area is the Forest Savanna High Plains. This is a gentle rolling landscape. Ground elevation in the Techiman area is between 180 and 300 m above sea level. The major river that drains the area is the River Tano.

Hydrogeological conditions

Sunyani area is underlain by rocks of the Middle Pre-Cambrian age, which are mainly Lower Birimian rocks that comprise phyllite, schist, tuff and greywacke (Kesse, 1985). Other rock types found in the area include rocks of the Upper Birimian Formation (metamorphosed lavas, pyroclastic rocks and hypabyssal Basic Intrusives) and Cape Coast Granitoids (granites, biotite and muscovite granites, granodiorite, pegmatite, aplite with biotite schist). Sandstones of the Upper Voltaian underlie Techiman. Due to the moderately high rainfall the rocks are largely weathered into a mixture of sand and clay. The depth of the weathered rocks varies from 20 to 50 m. In the Sunyani area, the yield of a standard 125-mm diameter

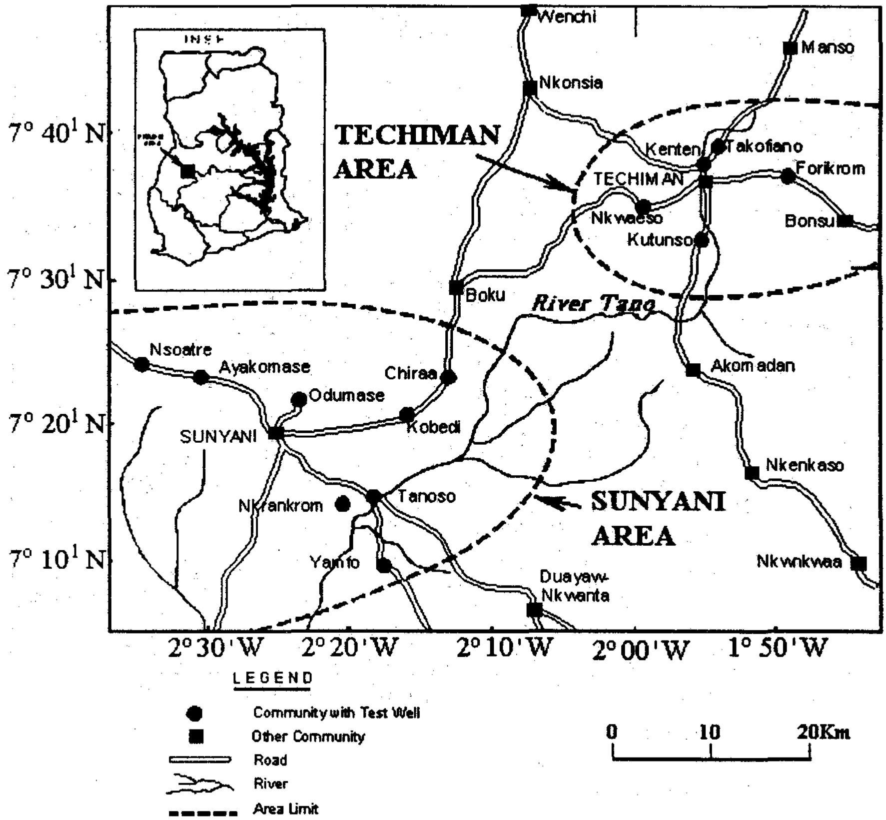

Fig. 1. Location map of the Sunyani and Techiman areas

and 60-m deep borehole is in the range 0.2-16.0 $m^3 h^{-1}$ with a median value of 3.5 $m^3 h^{-1}$. In Techiman, the yield of a standard borehole ranges from less than 0.2 $m^3 h^{-1}$ to about 29.0 $m^3 h^{-1}$ with a median value of 8.5 $m^3 h^{-1}$. The geological map of the study area is shown in Fig. 2.

Desk studies

Geological and topographic maps on the scale 1:50,000 were studied in order to identify lineaments, their approximate locations and co-ordinates. Additionally, records of boreholes and hydrogeological reports and information in the area were studied. Desk study enabled the inventory and diagnosis of lineaments, the possible presence of aquifers, static water levels, aquifer depth, the thickness of the overburden and the aquifer zone, and the lithological successions pertaining in the study area.

Reconnaissance survey

The field reconnaissance survey undertaken was aimed at identifying the location of lineament in the field through the use of GPS (Garmin 45) and setting out traverse lines for geophysical profiling. It also involved the appraisal of topographic, structural, water points, soil, pollution point sources and the accessibility or otherwise of heavy machinery (drilling Rig). The reconnaissance survey was limited to a radius of 7 km around each of the selected towns since contractually the boreholes

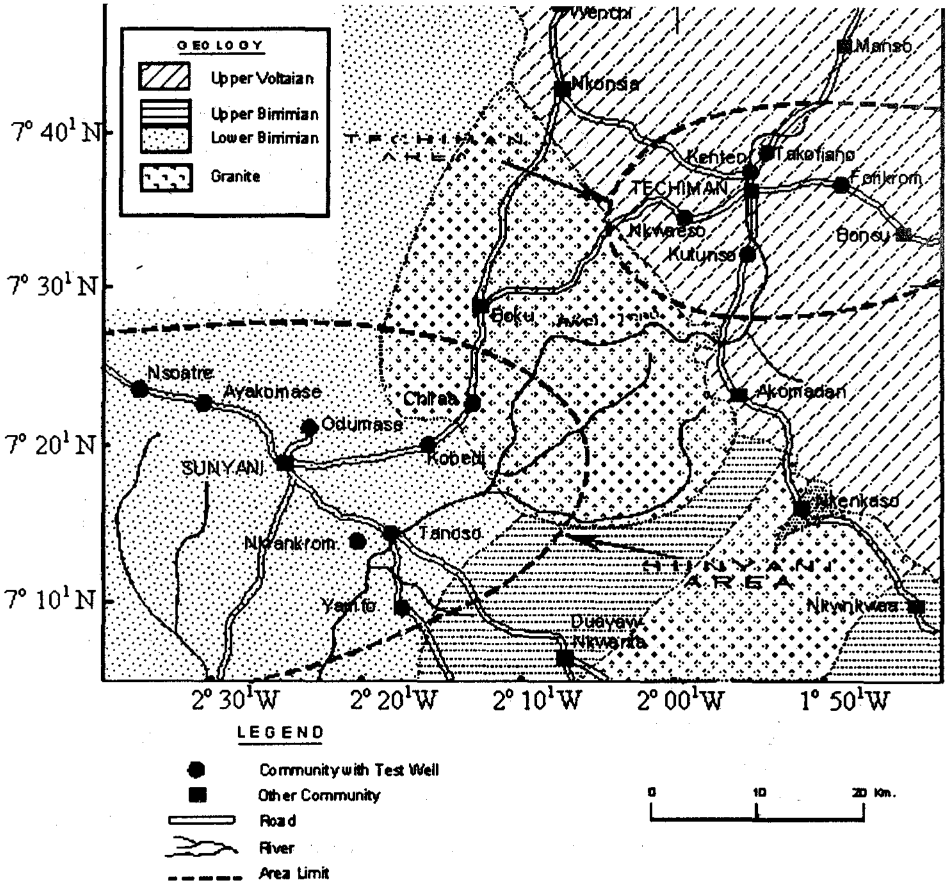

Fig. 2. Geological map of the Sunyani and Techiman areas

were to be within 7 km radius of each major town. In all 12 sites consisting of seven in the Sunyani and five in the Techiman areas were investigated. The names of the communities in which the sites are located are contained in Table 1. The locations of the communities are also shown in Fig. 1.

Geophysical survey

The main aim of the geophysical survey was to detect fissured zones that would produce high yielding boreholes for the groundwater augmentation since it is a common knowledge that in crystalline terrain typical of the study area, comparatively larger volume of water are produced from the fissured zones than the overburden (Acworth, 1987; Barker *et al.*, 1992; Hazell *et al.* 1992; Wright, 1992). However, under the highly weathering conditions of the area, it would be extremely difficult to determine these fissured zones at depth. Therefore, it was assumed that the frequency of encountering fissures is greatest where the regolith was thickest. Thus, the aim of the geophysical investigation was narrowed down to detecting zones of the thickest regolith. Consequently, the geophysical investigation was conducted by the combined use of Electromagnetic (EM)

TABLE 1

Summary of geophysical and borehole data

	Geophysical results			Drilling results				
Location Community	*VES point*	*Depth (m)*	*Resistivity (ohm-m)*	*Depth (m)*	*Yield (m^3h^{-1})*	*SWL (m)*	*Aquifer zone (m)*	*Formation (Lithology)*
Sunyani Area								
Abesim	A530	1.2	257.0	61.45	3.6	7.0	55.5-58.5	Sandy clay, quartz
Nkrankrom		2.3	2876.0					flints, clay, weathered
		52.3	175.0					chlorite schist
		-	1537.0					
Ayakomase	B80	1.4	621.0	79.6	3.0	19.1	50.0-62.0	Dry silty clay, clay,
		15.9	912.0				65.0-76.0	sandy clay,
			105.0					moderately weathered
								granite
Nsoatre North	A310	2.7	357.0	80	19.2	13.	55.5-79.0	Gravel, clay, silty
		12.0	479.0					clay, sand
		-	233.0					weathered quartz and
								phyllite
Nsoatre South	B70	1.7	429.0	70	6.0	10.2	11.5-29.0	Sandy soil, clay,
		14.1	330.0				44.0-62.0	weatheed quartz
			91.0					flints and granite
Odumasi	B50	2.4	430.0	96	3.0	3.8	44.0-52.0	Clay, silty clay
		36.6	127.0				55.0-94.0	quartz, weathered
			436.0					granite, amphibolite,
								green schist
Tanoso	A330	2.1	195.0	64.2	4.3	7.5	18.0-42.0	Silty, clay, weathered
		20.4	90.0				45.0-63.0	chlorite schist
		-	699.0					
Yamfo	A400	1.7	174.0				13.5-25.5	Gravel, silty clay,
		18.9	52.0	100	3.0	5.2	28.5-73.5	quartz, chlorite schist
		-	519.0				76.5-82.5	
Techiman area								
Forikrom	A30	2.9	225.0	91.8	90.0	8.6	79.0-91.0	Lateritic clay, shale
		50.0	32.0					sandstone
		-	62.0					
Kenten North	A920	1.5	232.0	60.9	63.2	-0.1	23.0-41.0	Sandy clay, silty clay,
		16.4	26.0				43.0-55.0	clay, shale
		-	385.0					moderately weathered
								sandstone
Kuntunso	B480	1.5	332.0	71.71	30.0	7.7	39.0-45.0	Clay, shale,
		10.1	877.0				48.0-60.0	moderately weathered
		-	35.0				63.0-69.0	sandstone
Nkwaeso	C300	1.6	68.0	80	4.2	16.4	18.0-56.5	Lateritic clay, quartz
		26.5	1136.0				59.0-62.0	vein slightly
		-	387.0					weathered sandstone
Takofiano	A190	2.1	500.0	79.9	104.5	13.1	45.0-77.0	Sandy clay, clay,
		40.1	22.0					shale, sandstone
			57.0					

profiling and Vertical Electrical Sounding (VES) technique. This technique has been well documented to be very effective in detecting thick regolith and fissure/fracture zones in crystalline basement rock terrains (Jones, 1985; Jones & Beeson, 1985; Reynolds, 1987; Beeson & Jones, 1988; Hazell *et al.*, 1988).

The EM profiling was carried out with the Geonics EM34-3 ground conductivity meter. This equipment allows the direct reading of the ostensible conductivity in the region of the measuring coils. Three inter coil separation cables (10 m, 20 m, 40 m) are available and, depending on whether the coils are operated in the horizontal or the vertical dipole mode, the depths of investigation are 3.8 m, 7.6 m and 15.2 m in the horizontal dipole mode, and 8.7 m, 17.4 m and 34.8 m in the vertical dipole mode (Barker *et al.*, 1992). The ground conductivity meter was used firstly as a fast reconnaissance tool to profile across the selected target areas in order to locate probable areas of thick overburden for further investigation with the VES technique, and, secondly, to locate precisely linear features already observed on air photographs/lineament map, such as joints, faults and dykes, as well as narrow faults and fracture zones not identified on aerial photographs in otherwise topographically featureless areas (Baker et al., 1992).

The method of application of Geonics EM34-3, its advantages and disadvantages are well documented by Mac Neill (1980). In areas where the static water level is less than 15 m, the inter coil separation cables of 20 m should be used but if it is greater the 40 m cable should be used instead (Beeson & Jones, 1988). The median value of static water level in the existing wells prior to the investigation was 15.5 m. This means that approximately one half of the static water level values is less than 15.0 m while the other half is greater than 15.0 m justifying the use of both 20 m and the 40 m coil separation cables. Thus, the profiling was conducted in both the horizontal and vertical dipole modes using the 20 and 40 m inter-coil separation cables. The station interval was 10 m.

The vertical electrical-resistivity sounding (VES) technique involves introducing synthetically generated direct current or a low frequency alternating current into the earth through two current electrodes. The resulting potential difference is measured by another pair of potential electrodes in the region of the current flow. Expanding the electrode system varies the depth of investigation. An ABEM SAS 300C Terrameter was used for the VES measurement and, for the ease of the fieldwork, the Schlumberger four-electrode configuration was used. The main objectives of the VES were to determine the formation resistivities, the depth to the bedrock, and the depth to the aquifer. These determinants would give ample information about the depth and intensity of the weathering of the regolith as well as a conjecture of its porosity and permeability, and, thus, a measure of the usefulness of the formation as an aquifer. Consequently, optimum well site and borehole depth can be determined from VES results. The VES results were analysed using the Sondel software, which is resistivity invasion software.

Test drilling

Test wells were drilled using the combined direct circulation rotary method and down-the-hole hammer with air as the circulating fluid and mud where the rock formation was very soft or unstable. The test hole diameter was 279 mm with 152 mm casing with screens installed in each hole. This was to enable the installation of electrical submersible pumps that could pump at least 3 m^3h^{-1} of water from the test borehole. The variations in lithology and intensity of weathering were determined by directly examining the drill cuttings. Time (minutes) taken for drilling every metre was continuously monitored using a stop clock. The flow (l sec^{-1}) was estimated by moving water pads through a 45° V-notch located 5 m away from the well. Verticality and alignment tests were carried out on all drilled holes to ensure that hole deviations were within 50 mm of every 10 m of borehole tested. Both step-drawdown and constant discharge (duration 24-72 h) tests were conducted on each borehole.

Water sampling and analysis

During the pumping test, water samples were collected for both physico-chemical and bacteriological analyses. Sampling collection for physico-chemical analysis was based on the techniques of Gale & Robins (1989), and sampling protocols described by Claasen (1982) and Barcelona *et al.* (1985) were strictly adhered to. Analyses were carried out using standard methods for the examination of water and wastewater (APHA-WWA-WPCF, 1994). The analyses of heavy metals were carried out using the Unicom 969 atomic adsorption spectrometer (AAS). Delagua (University of Surrey, UK) dual-incubator kit was used for faecal and total coliform bacteria analyses. At each site, duplicate water samples were filtered through sterile filters and the latter placed on paper pads impregnated with sterilized membrane lauryl-sulphate broth. Incubation period was for 24-36 h at 44°C and 37 °C for heat-tolerant faecal and total coliforms, respectively. A colour change of cultural medium from red to yellow indicated positive colonies, which were counted and expressed in colony-forming units (CFU) 100 ml^{-1} or counts × 100 ml^{-1}.

Results and discussion

Electromagnetic profiling

The results of the electromagnetic profiling along the traverses at the various locations have been cast into dipole response curves. Typical Geonics EM34-3 dipole response curves along traverses at Tanoso in the vicinity of Sunyani (underlain by Birimian rocks) and Takofiano in the Techiman area (underlain by the Voltaian formation) are presented in Fig. 3ab. At Tanoso (Fig. 3a) and Takofiano (Fig. 3b) the 20 m inter coil separation cable was used to profile in both the horizontal and vertical dipole modes over a distance of 230 m and 220 m, respectively. The average traverse length for this particular study was 250 m. However, depending on local conditions traverse lines could be shorter or longer. Very crucial for the determination of the thick weathered zones is the crossover point or zones where the vertical dipole response curve exceeds the corresponding horizontal dipole response curve. In Fig. 3a, the apparent conductivity values were low at the beginning of the traverse but increased gradually and peaked up in the region 135-150 m. Within the same region, the 20-m vertical dipole (20 m-VD) exceeded the 20-m horizontal dipole (20 m-HD) suggesting higher conductivity at depth than near the surface since the depth of investigation of the 20 m-VD is greater than

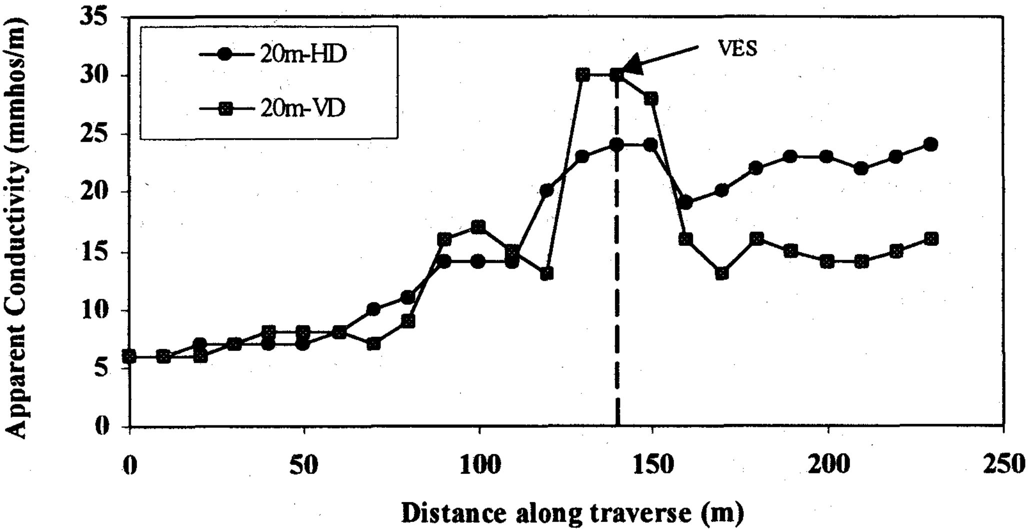

Fig. 3a. Geonics response curve along a traverse at Tanoso in the Sunyani area (Birimian Formation)

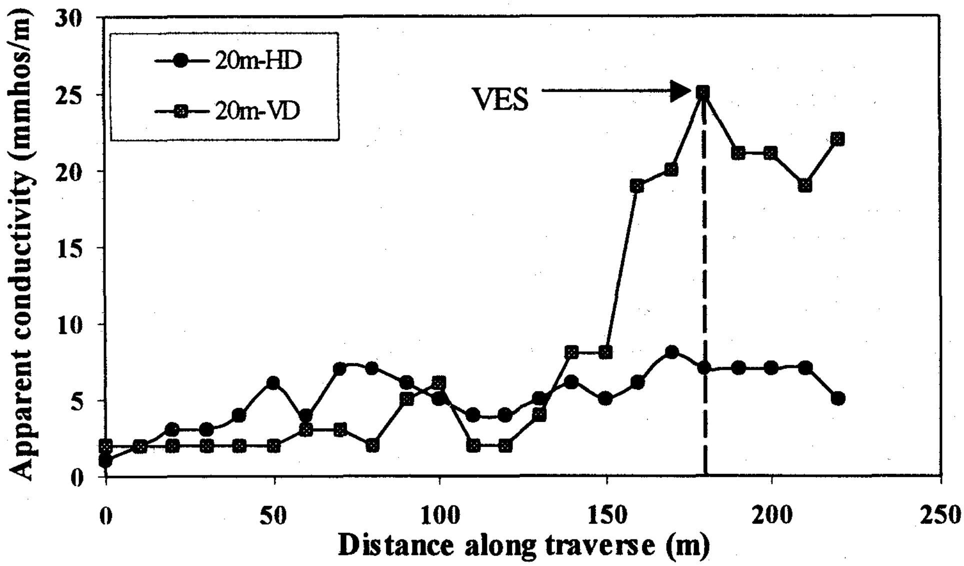

Fig. 3b. Geonics response curve along a traverse at Takofiano in the Techiman area (Voltaian Formation)

that of 20 m-HD.

Though electrical properties of a rock matrix are largely controlled by the quality of water it contains, porosity generally increases with increasing conductivity (decreasing resistivity). In the crystalline terrain porosity results from fissuring accompanied by weathering. Thus, the region 135 – 150 m in Fig. 3a is probably the most deeply weathered or fissured along the traverse. Thus, the selection of a point within this region for further investigation with VES is very necessary. Similarly in Fig. 3b, both the horizontal and the vertical dipole response were low, in fact, less than 10 mmhos m^{-1} until the point 150 m along means that this aquifer occurs in the saprock. Similarly, the regolith depth at Forikrom and Takofiano in the Techiman area where the highest yields were obtained are 50.0 m and 40.1 m, respectively, while the aquifers were obtained at the 79.0 m and 45.0 m, respectively. Again water was obtained from the saprock. Consequently, to obtain appreciable quantity of groundwater in the Sunyani and Techiman areas, the saprock must be targeted, i.e. drilling must go beyond the regolith and penetrate appreciable thickness of the saprock.

Borehole yield and formation resistivities

Sieve analysis of the aquifer materials revealed that the aquifers are composed of various grain sizes. In the Techiman area, the relatively high yielding aquifers are generally composed of uniformly fine sand with 10-20% coarse sand with uniformity coefficients between 2.5 and 5.3 and median value of 3.5. The apparent resistivities of aquifer materials are in the range 22-62 ohm-m. In the Sunyani area, only one high yielding well was encountered at Nsoatre North. The aquifer materials for this well consisted of medium to coarse sand mixture with apparent resistivity of 233 ohm-m.

Fig. 5 illustrates the grain size distribution curve for the aquifer materials at Yamfo in the Sunyani area, Kenten North (sandstone aquifer near Techiman) and Nsoatre North also in the Sunyani area. Fig. 5a is grain size distribution curve for the aquifer materials at Yamfo. The curve is similar to the Class A curve of the U. S. Geological Survey (USGS) soil classification. This suggests that the sample tested consists typically of fine, uniform sand (materials) that may have high porosity but low permeability and, therefore, only yield limited quantity of water. The grain size distribution curves of most of the aquifers in the Sunyani area are similar to that of the aquifer from Yamfo. This is quite consistent with borehole yields obtained in the Sunyani area (Table 1). On the contrary, aquifer materials from few locations in the Sunyani area show grain distribution that follows the Class C curve of the USGS classification-curve indicating medium to coarse material mixture and, thus, good permeability.

Fig. 5b, which is the grain size distribution curve of aquifer materials from Nsoatre North, resembles a typical Class C. This borehole yielded 19.2 $m^3 h^{-1}$. This yield is approximately six times higher than the yield of the Yamfo well. Example of grain size distribution curves typical of aquifer materials from the Techiman area is illustrated in Fig. 5c. The grain sizes distribution curve of aquifer materials from the borehole at Kenten North is presented in this diagram. This curve is similar to the Class B curve in the U. S. Geological Survey (USGS) classification curve (Johnson Division UOP Inc., 1975). This implies that the aquifer materials consist of fine-grained sand (materials) with approximately 10-20% coarse materials. The permeability is thus greater that the aquifer materials with a class A type-curve.

Generally, there is little difference between the regolith thickness in the Sunyani and Techiman areas. However, the regolith in the Sunyani area contains a lot of uniformly fine materials mainly clay and silt that make water transmission to wells difficult and drastically reducing the yield of boreholes. In the Techiman area, the fine materials are mixed with some coarse material making it more permeable. Consequently, the intensity and depth of the weathering of the regolith traverse. Within the region 150–220 m, the vertical dipole suddenly rose and oscillated between 19 mmhos m^{-1} and 25 mmhos m^{-1} suggesting higher conductivity at depth and, therefore, deeper regolith (overburden) development within that region. The point along traverse where the peak conductivity value (25 mmhos m^{-1}) occurred in that region was, therefore, selected for further investigation with VES. Typical VES response curve is presented in Fig.4.

VES and lithology

The summary of VES and the corresponding drilling results obtained in each community are presented in Table 1. The VES results indicate that the regolith varied in thickness from 12.0 m (Nsoatre North) to 52.3 m (Abesim Nkrakrom) with median value of 20.5 m and the resistivity ranges from 22 ohm-m (Takofiano) to 1136 ohm-m (Nkwaeso) with a median value of 308 ohm-m. Comparison between the VES and test drilling results in Table 1 indicates the regolith consists of sandy-clay, clay, gravels and weathered rocks. The topsoil that consists mainly of dry sandy-clay has higher resistivity than underlying formation due to dryness. The resistivity of the regolith is low mainly due to the fact that it has high argillite content (clayey and fine grained materials).

In both the Sunyani and the Techiman areas, aquifers are mostly found in the saprock (the moderately to the slightly weathered zone or in the transition zone between the highly weathered rock and the

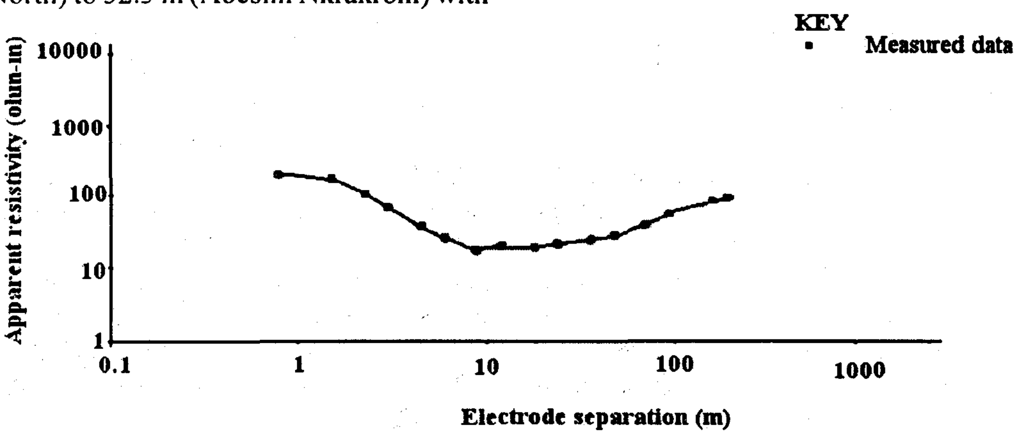

Fig. 4. Vertical Electrical Sounding (VES) curve from Oforikrom near Techiman

a median value of 20.4 m while its resistivity varied from 52 ohm-m (Yamfo) to 912 ohm-m (Ayakomase) with a median value of 456 ohm-m in the Sunyani area (median values are much more robust descriptors of non-normal distributions than mean values). In the Voltaian Sandstone in the Techiman area the regolith thickness varied from 10.1 m (Kuntunso) to 50.0 m (Forikrom) with a

fresh rock) below the regolith. For example at Tanoso, the VES result indicates that the boundary between the highly weathered regolith with resistivity value of 90 ohm-m and the slightly weathered bedrock (saprock) with resistivity of 699 ohm-m is at a depth of 20.4 m. To a good approximation, this correlates with the top of the first aquifer that extends from 18.0 m to 42.0 m. This means that this aquifer occurs in the saprock. Similarly, the regolith depth at Forikrom and Takofiano in the Techiman area where the highest yields were obtained are 50.0 m and 40.1 m, respectively, while the aquifers were obtained at the 79.0 m and 45.0 m, respectively. Again water was obtained from the saprock. Consequently, to obtain appreciable quantity of groundwater in the Sunyani and Techiman areas, the saprock must be targeted, i.e. drilling must go beyond the regolith and penetrate appreciable thickness of the saprock.

Borehole yield and formation resistivities

Sieve analysis of the aquifer materials revealed that the aquifers are composed of various grain sizes. In the Techiman area, the relatively high yielding aquifers are generally composed of uniformly fine sand with 10-20% coarse sand with uniformity coefficients between 2.5 and 5.3 and median value of 3.5. The apparent resistivities of aquifer materials are in the range 22-62 ohm-m. In the Sunyani area, only one high yielding well was encountered at Nsoatre North. The aquifer materials for this well consisted of medium to coarse sand mixture with apparent resistivity of 233 ohm-m.

Fig. 5 illustrates the grain size distribution curve for the aquifer materials at Yamfo in the Sunyani area, Kenten North (sandstone aquifer near Techiman) and Nsoatre North also in the Sunyani area. Fig. 5a is grain size distribution curve for the aquifer materials at Yamfo. The curve is similar to the Class A curve of the U. S. Geological Survey (USGS) soil classification. This suggests that the sample tested consists typically of fine, uniform sand (materials) that may have high porosity but low permeability and, therefore, only yield limited quantity of water. The grain size distribution curves of most of the aquifers in the Sunyani area are similar to that of the aquifer from Yamfo. This is quite consistent with borehole yields obtained in the Sunyani area (Table 1). On the contrary, aquifer materials from few locations in the Sunyani area show grain distribution that follows the Class C curve of the USGS classification-curve indicating medium to coarse material mixture and, thus, good permeability.

Fig. 5b, which is the grain size distribution curve of aquifer materials from Nsoatre North, resembles a typical Class C. This borehole yielded 19.2 $m^3 h^{-1}$. This yield is approximately six times higher than the yield of the Yamfo well. Example of grain size distribution curves typical of aquifer materials from the Techiman area is illustrated in Fig. 5c. The grain sizes distribution curve of aquifer materials from the borehole at Kenten North is presented in this diagram. This curve is similar to the Class B curve in the U. S. Geological Survey (USGS) classification curve (Johnson Division UOP Inc., 1975). This implies that the aquifer materials consist of fine-grained sand (materials) with approximately 10-20% coarse materials. The permeability is thus greater that the aquifer materials with a class A type-curve.

Generally, there is little difference between the regolith thickness in the Sunyani and Techiman areas. However, the regolith in the Sunyani area contains a lot of uniformly fine materials mainly clay and silt that make water transmission to wells difficult and drastically reducing the yield of boreholes. In the Techiman area, the fine materials are mixed with some coarse material making it more permeable. Consequently, the intensity and depth of the weathering of the regolith

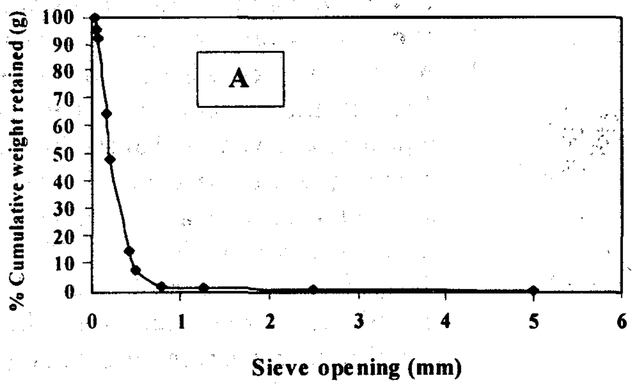

Fig. 5a. Class A-type curve of the U.S. Geological Survey (USGS) soil classification from Yamfo in the Sunyani area

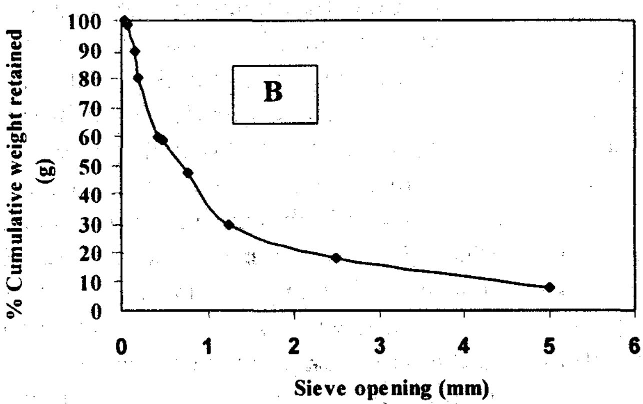

Fig. 5b. Class C-type curve of the U.S. Geological Survey (USGS) soil classification from Nsoatre North in the Sunyani area

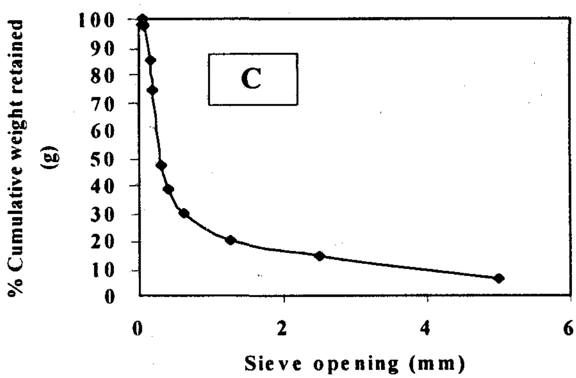

Fig. 5c. Class B-type curve of the U.S. Geological Survey (USGS) soil classification from Kenten South in the Techiman area

Fig. 5. Grain size distribution curves of aquifer materials from the Sunyani and Techiman areas

alone are not necessarily the determining factors of the formation being a good aquifer. Other factors including the composition of the regolith has to betaken into consideration.

Aquifer parameters

Test boreholes in the Sunyani area vary in yield from 3.0 m^3 h^{-1} to 19.2 m^3 h^{-1} with median value of 3.0 m^3 h^{-1}, while those in the Techiman area are in the range 4.3-104.5 m^3 h^{-1} with median value of 63.2 m^3 h^{-1}. Box plot comparison of yield of test boreholes in the Sunyani and Techiman areas is presented in Fig. 6. As can be seen from Fig. 6, 50% of the boreholes in the Sunyani area fall within the narrow inter-quartile range 3.0-12.6 m^3 h^{-1}. In the Techiman area, however, the inter-quartile range (20-90 m^3 h^{-1}) is relatively large.

Pumping test was conducted on each borehole. Due to limited funding, observation wells were not drilled. Pumping wells were used for water level measurements during pumping and recovery. Under this circumstance, the residual drawdown approach was used for the pump test analysis. Sample residual drawdown plot of wells in both the Sunyani and Techiman areas are presented in Fig. 7ab. A cursory look at Fig. 7a reveals that if the curve were extended towards the left it would intercept

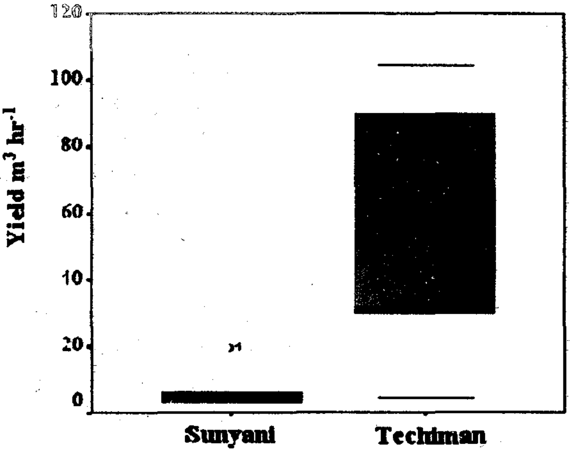

Fig. 6. Boxplot comparison of yield of test boreholes from the Sunyani and Techiman areas

the residual drawdown axis below zero indicating incomplete recovery over extended period for recovery. This sort of situation would arise when the aquifer is limited in extent with no recharge during pumping (Johnson Division UOP Inc., 1975). Since most of the aquifers from the Sunyani area exhibited this characteristic, they could be said to be limited in extent and unable to withstand sustained pumping.

Conversely, extending the residual drawdown curve in Fig. 7b towards the left would record residual drawdown of zero when t/t' equaled 3. This situation would arise when the aquifer received recharge during pumping so that full recovery would be attained within a relatively short time (Johnson Division UOP Inc., 1975). Since most of the wells from the Techiman area showed this characteristic, i.e. receiving recharge during pumping, the aquifers in the Techiman area will be able to sustain long duration pumping. The range and median transmissivities computed for the Sunyani area are 0.24-3.4 $m^2 d^{-1}$ and 0.7 $m^2 d^{-1}$, respectively, and for the Techiman area, they are 10.4-124.6 $m^2 d^{-1}$ and 95 $m^2 d^{-1}$, respectively. The mean specific capacities for both Sunyani and Techiman after 24 h pumping are 0.4 $m^3 h^{-1} m^{-1}$ and 3.2 $m^3 h^{-1} m^{-1}$, respectively. Using the thickness of the main water zone as the saturated thickness of the aquifer, the permeability of the formation in the Sunyani area is in the range 0.02-1.6 m d^{-1} with a median value of

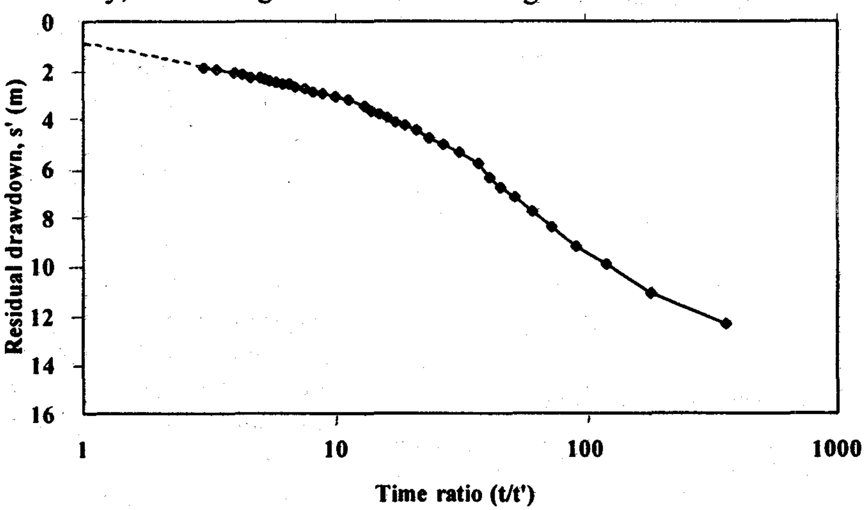

Fig. 7a. Residual drawdown curve for test boreholes at Tanoso (Sunyani area)

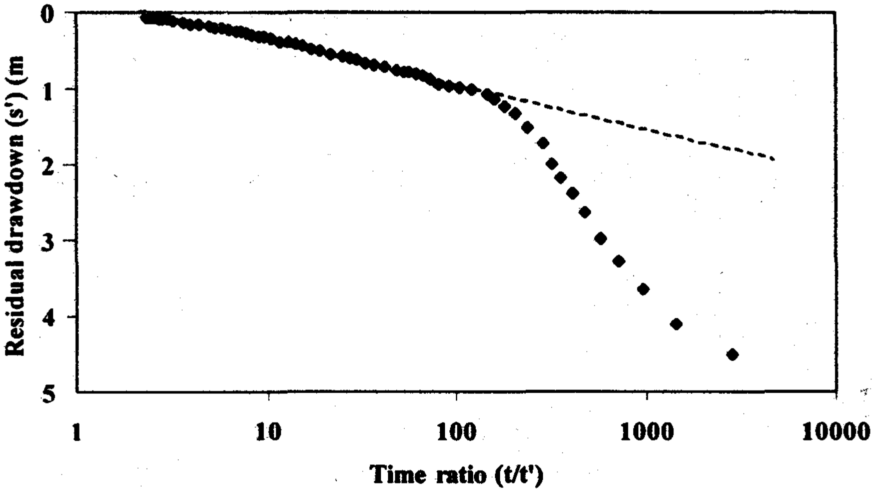

Fig. 7b. Residual drawdown curve for test boreholes at Kenten North (Techiman area)

0.4 m d^{-1}, while in the Techiman area the range and the median value are 0.6-13.2 m d^{-1} and 6.4 m d^{-1}, respectively.

Hydrochemistry and water quality

Statistical summary of the major chemical constituents, selected trace elements (those that have WHO (1993) guideline limits for drinking water) and bacteriological analyses of groundwater samples from both the Sunyani and Techiman areas are presented in Tables 2 and 3. Trilinear diagram of the major dissolved ion constituents of all samples from both Sunyani and Techiman areas is presented in Fig. 8 (Hill, 1940; Piper 1944). This diagram was plotted to help identify and distinguish between the chemical water types that exit in both the Sunyani and Techiman areas. A close look at the diagram reveals that groundwaters from both areas, except one location in the Techiman area, have similar chemical water type (Ca-Mg-HCO_3 water) suggesting simple history of rainwater infiltration and short residence time. At the only exception, Oforikrom, the water was obtained from a relatively deeper zone, 79-90 m. This means that the water had a longer pathway and resident time and, therefore, evolved from Ca-Mg-HCO_3 to Ca-Mg-SO_4 water type (Chebotarev, 1955).

Comparison of the results in Table 3 for the two areas indicates that, generally, median values of chemical constituents are slightly higher in the Techiman area than the Sunyani area. Comparison of the results in Table 2 with the WHO (1993) guideline limits for drinking water also in Table 2 indicates that apart from *p*H and total hardness, all major chemical constituents in the groundwater from both areas are within the limit of WHO (1993) guideline limits for drinking water. The median *p*H values of groundwater from both areas are lower than 6.5, which means that more than half of the boreholes from these areas have *p*H values outside the WHO (1993) guideline limits for drinking water. However, the groundwaters are more acidic in the Sunyani area than the Techiman area. Acidity increases the capacity of the water to attack geological materials and leach toxic trace metals into the water and, thus, making it potentially harmful for human consumption.

parameter	Guideline maximum value (mg l^{-1})	Concentrations in mg l^{-1}, Conductivity in µS cm				Concentrations in mg l^{-1}, Conductivity		
		Range	Mean	Median	SD	Range	Mean	Median
Bicarbonate		4.9 – 241	48.7	34.2	56.2	10.9 –180	42.5	34.2
Calcium		3.2 – 44.0	12.7	7.1	12.5	2.5 – 40.0	11.7	12.1
Chloride	250.0	0.4 – 66.0	8.3	1.8	19.3	1.2 – 32	4.5	6.7
Magnesium		2.4 – 13.1	6.4	4.1	4.3	2.4 – 10.1	5.5	5.2
Phosphate		0.0 – 4.3	1.4	1.0	1.5	0.0- 8.43	3.4	2.3
Potassium		0.2 – 6.2	1.5	1.0	1.6	0.7 – 5.3	1.5	1.1
Silica		6.1 – 29.1	19.5	21.1	7.5	7.1-34.1	22.5	23.1
Sodium	200.0	2.8 – 25.6	11.6	9.8	8.1	3.8 – 25.9	12.0	9.8
Sulphate	250.0	0.1 – 9.8	3.5	2.7	8.2	0.1 – 5.8	2.4	2.3
Total iron	0.3	0.0 – 3.9	1. 0	0.3	3.3	0.0 – 9.9	1.7	0.3
Alkalinity		4.0 – 198.0	62.0	38	71.5	10.0 –167.0	52.0	45.0
Colour	5.0	< 5	< 5	< 5	< 5	< 5	< 5	< 5
*P*H	6.5-8.5	5.4 – 6.9	5.9	6.1	0.9	5.7-7.6	6.1	6.4
Conductivity		55.0 – 434.0	196.0	197.0	133.0	104.0 – 580.0	199.0	202.0
(TDS)	1000.0	29.0 – 201.0	110.0	111.0	67.4	67.0 – 371	29.2	64.0
Total hardness	100.0	19.8 – 164.0	57.8	34.6	46.2	21.6 – 144.0	52.8	44.6

		Range	Mean	Median	SD	Range	Mean	Median
Al	200	0 –159	39	37	39	0 – 115	25	11
As	10	0 – 9	3	1	4	0 – 5	4	0
Ba	700	0 –10	4	2	6	0 – 1	0	0
B	300	0 – 43	7	4	11	0 – 45	7	3
Cd	3	0 – 3	2	2	1	0 –3	1	1
Cr	50 p	1 – 26	12	8	10	0 – 35	24	14
Cu	2000 p	300 – 700	500	500	100	111 – 400	255	264
F	1500	6 – 233	54	56	57	12 – 381	96	70
Mn	500	0 – 46	9	6	14	0 – 37	8	4
Pb	10	0 – 9	5	2	5	0 – 4	0	0
Sb	5 p	0 – 2	0	0	1	0	0	0
Se	10	0 – 9	4	3	6	0 –2	0	0
Zn	3000	12 – 112	54	33	56	0 – 260	98	94
Bacteriological parameter								
Total coliform (Counts ×.102 ml^{-1})		0 – 3	1	1	2	0 – 2	0	0
E-Coliform (Counts × 102 ml^{-1})		0 – 1	0	0	0	0	0	0

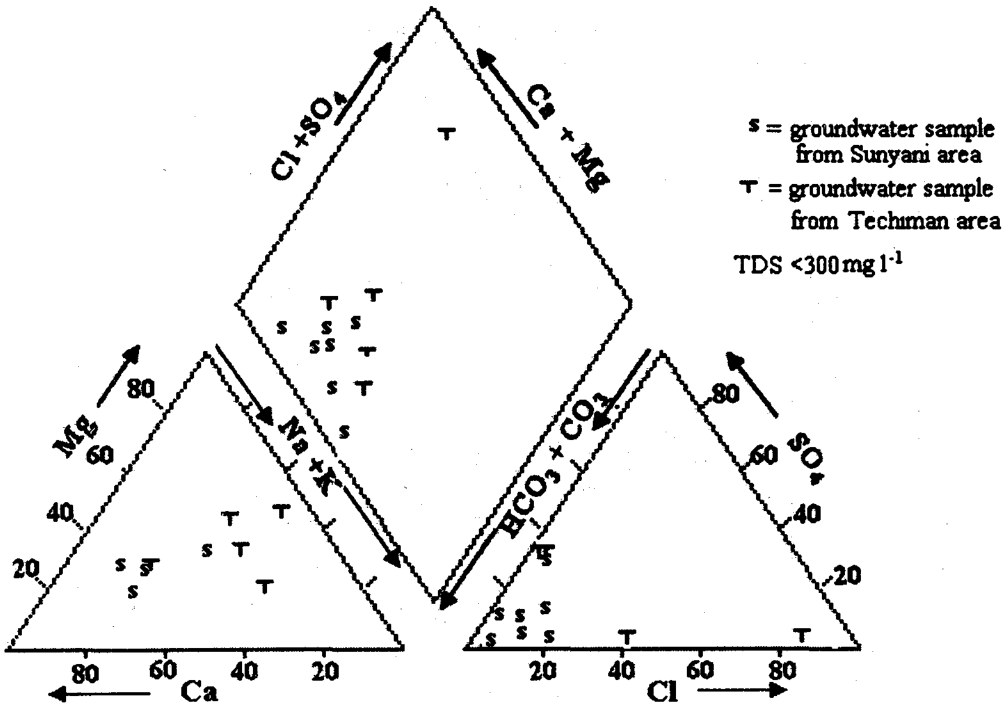

Fig. 8. Trilinear diagram of water samples from test boreholes from both Sunyani and Techiman areas (after Hill, 1949 and Piper, 1944)

Furthermore, low *p*H or acidity gives sour taste to water. For the reason of taste, the WHO (1993) limits the *p*H range for water potability to 6.5-8.5. Thus, the groundwaters from both areas, particularly the Sunyani area, may have slight problem with taste. Total hardness is an important criterion for ascertaining the suitability of water for domestic, drinking and many industrial uses (Karanth, 1994). Nonetheless, only the effect of hardness on the usability of the wells for domestic and drinking purposes is considered in this paper. Hardness of water for domestic use relates mainly to its reaction with soap. Since principally Ca^{2+} and Mg^{2+} precipitate soap, hardness is defined as the sum of the concentrations of these ions expressed as mg l^{-1} of $CaCO_3$. Water with hardness in the range 0-60 mg l^{-1}, 61-120 mg l^{-1}, 121-180 mg l^{-1} and > 180 mg l^{-1} are regarded as soft, moderately hard, hard and very hard, respectively (Hem, 1970). Groundwaters from both the Sunyani and Techiman areas vary largely in total hardness from soft to hard (Table 2).

The use of the groundwaters for domestic purposes may pose soap wastage problem or upsurge of soap requirement for washing in only a few cases. The median values, however, indicate that more than half of the boreholes in both areas have soft waters. A comparison of median values of trace metal concentrations in groundwaters from both areas indicates that the trace metal load in the Sunyani area is slightly higher than that of Techiman area. However, their concentrations are within the WHO (1993) guideline limits for drinking water. The WHO recommends that drinking water should contain no faecal coliforms. Microbial population in the boreholes was determined to see whether there were pathogens in the water. The bacteriological results (Table 3) indicated zero faecal coliform in both areas though a few total coliform counts were registered in the groundwaters from both areas. Thus, the groundwaters from both Sunyani and Techiman areas are bacteriologically safe for drinking purposes.

Conclusion

The hydrogeological investigations at both Sunyani and Techiman revealed that adequate groundwater exists within the Voltaian Sandstones around Techiman that can be tapped for the augmentation of the water supply to the Sunyani and Techiman townships. Boreholes with yields between 60 $m^3 h^{-1}$ and 105 $m^3 h^{-1}$ that can withstand long duration pumping are common in the Techiman area .The quality of the water is good except that there may be slight taste problem due to the moderate acidic character of the water. The yields of the boreholes from the Sunyani area are much lower than those from Techiman area inspite of the fact that they exceeded the minimum required yield of 3 $m^3 h^{-1}$ for urban supply. The aquifers are composed of fine uniform materials and, therefore, have low permeability. They are also limited in extent and, therefore, cannot withstand prolonged pumping. Thus, the Sunyani area aquifers are not suitable for urban water supply.

Acknowledgement

The paper is based on part of the data generated for Brown and Root Ltd, 1999. The author is grateful to the U.K. Department for International Development (DFID) for providing funding for the project.

References

Acworth R. I. (1987). The development of crystalline basement aquifers in a tropical environment. *Q. Jl Engng Geol.* **20**, 265-272.

APHA-WWA-WPCF (1994). *Standard methods for the examination of water and wastewater.* Washington DC, USA: American Public Health Association (APHA).

Barcelona M., Gibb J. P., Helfrich J. A and Garske E. E. (1985). *Practical guide for groundwater sampling.* Illinois State Water Survey ISWS Contract Report 374.

Barker R. D., White C. C. and Houston J. T. F. (1992). Borehole siting in an African accelerated drought relief project. In *The Hydrogeology of Crystalline Basement Aquifers in Africa.* E. P. Wright and W. G. Burgess, ed.), pp. 183-200. London: Geological Society. Geological Society Special Publication No. 66.

Beeson S. and Jones C. R. C. (1988). The combined EMT/VES geophysical method for siting boreholes. *Ground Wat.* **26**, 54-63.

Brown and Root Ltd. (1999). Proposal for feasibility studies on the Sunyani water supply. Accra: Ministry of Works and Housing/ DFID (British High Commission).

Claasen H. C. (1982). Guidelines and techniques for obtaining water samples that accurately represent the water quality for an aquifer. *U.S. Geological Survey Open File Report* 82-1024. 49 pp.

Chebotarev I. I. (1955). Metamorphism of natural waters in the crust of weathering. *Geochim. cosmochim. Acta* **8**:22-48, 137-170, 198-212.

Dickson K. B. and Benneh G. (1980). *A New Geography of Ghana.* London: Longmans Group Ltd.

Gale I. N. and N. S. Robins (1989). The sampling and monitoring of groundwater quality. *British Geological Survey Hydrogeology Report No. 89/37.*

Hazell J. R. T, Cratchley C. R. and Preston A. M. (1988). The location of aquifers in crystalline rocks and alluvium in Northern

Nigeria using combined electromagnetic and resistivity techniques. *Q. Jl. Engng Geol.* **21**: 159-175.

Hem J. D. (1970). Study and interpretation of the chemical characteristics of natural water, second ed. *U.S. Geol. Survey Water Supply Paper* 1473. **363** pp.

Hill R. A. (1940). Geochemical patterns in Coachella Valley, California. *Trans. Am. geophys. Un.* **21**.

Johnson Division UOP Inc., (1975). *Groundwater and Wells*. pp. 142-143.

Jones M. J. (1985). The weathered zone aquifers of the basement complex areas of Africa. *Q. Jl Engng Geol.* **18**, 35-46.

Jones C. R. C. and **Beeson S.** (1985). The EMT/ VES Geophysical Technique for Borehole Siting, Kano State. In *Advances in groundwater detection and extraction* (Oguntona T., ed.). Maiduguri, Nigeria: International Conference on Arid Zone Hydrology and Water Resources.

Karanth K. R. (1994). *Groundwater Assessment Development and Management*. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Kesse G. O. (1985). *The Mineral and Rock Resources of Ghana*. A.A/ Balkema/ Rotterdam/ Boston.

Mac Neill J. F. (1980). *Electromagnetic terrain conductivity measurements at low induction numbers*. Geonics Ltd Technical Note TN6, 15.

Mote F. K. (1998). The meteorology of Ghana. Information Building Block. Ghana Water Management Study. *Unpublished Consultancy Report for the Ministry of Works and Housing, Ghana/ DANIDA/ World Bank.*

Piper A. M. (1944). A graphic procedure in the Geochemical interpretation of water analyses, *Trans. Am. geophys. Un.* **25**: 914-923.

Reynolds J. M. (1987). The role of surface geophysics in the assessment of regional groundwater potential in Northern Nigeria; In *Planning and Engineering Geology*. (M. G. Culshaw, F. G. Bell and O'hara, ed.) Engineering Geology Special Publication **4**: 185-190. London: Geological Society.

WHO (1993). *Guidelines for drinking water quality*. Revision of the 1984 guidelines. Final Task Group Meeting. Geneva, 21-25 September 1992.

Wright E. P. (1992). The hydrogeology of crystalline basement aquifers in Africa. In *The Hydrogeology of Crystalline Basement Aquifers in Africa*. (E. P. Wright, and W. G. Burgess, ed.). Geological Society Special Publication **66**: 183-200. London Geological Society.