Reconnaissance Survey of Arsenic Concentration in Ground-water in South-eastern Ghana

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Abstract

Arsenic (As) analysis of 150 boreholes in the south-eastern part of Ghana (Accra, Eastern and Volta regions) revealed low to medium concentrations in the range of 2-39 µg l^{-1}, with only 2% of boreholes tested having arsenic concentration exceeding 10 µg l^{-1} of the WHO (2004) maximum permissible level of arsenic in drinking water. The measurements were carried out in the field using the Wagtech Arsenator field test kit (Wag-We 100500) equipment, which gives direct readout of arsenic concentration in the critical range 2-100 µg l^{-1}. Arsenic concentrations were in the range < 2–39 µg l^{-1} with mean (< 2 µg l^{-1}) and median (< 2 µg l^{-1}). Out of 150 samples analysed, 147 had As concentration below 10 µg l^{-1}. Three boreholes in the Recent Sand Formation in southern Volta Region at Atitekpo, Mafi Devime and Woe Aklorbordzi had arsenic concentrations of 28 µg l^{-1}, 19 µg l^{-1} and 39 µg l^{-1}, respectively. Though the sample of boreholes tested was only approximately 10% of the total number of boreholes in the study, the distribution within the sample makes the generalization that the risk of arsenic contamination of rural water supply in southeastern Ghana is generally low plausible. In spite of this assertion, boreholes in the Recent Sandy Formation have to be critically assessed to determine the extent of arsenic contamination and, if possible, monitored.

Introduction

Traditionally, most communities in rural Ghana obtained their drinking water from surface sources (ponds or rivers) and as a result many people have been affected by waterborne diseases, e.g. bilharzias and guinea worm (Kortatsi, 1994). To remedy this situation, efforts were focused on encouraging the shift of rural water supply from surface to groundwater sources. Consequentially, boreholes have become the principal and, sometimes, the only source of drinking water for most rural communities, tapping water from shallow aquifers (30-60 m). DANIDA has been at the forefront of championing this noble course. DANIDA, therefore, within the last decade, had funded the construction of approximately 1500 point sources in south-eastern Ghana (Greater Accra, Eastern and Volta regions).

Though water quality assessment had been carried out on these point sources, due to cost constraint and the fact that target formation for trace metal investigations in Ghana like Birimian formation are absent in south-eastern Ghana, unless specifically targeted, many trace elements and metals including arsenic had not been part of routine analytic suites in groundwater risk assessments under the DANIDA point sources water project in the south-eastern Ghana. However, the recent news of widespread occurrence of arsenic in boreholes within many sedimentary aquifers which were thought to be deficient in arsenic in many parts of the world, particularly in Bangladesh and India (Rahman *et al.*, 2003), and Taiwan (Tseng *et al.*, 1968) prompted the need for screening the boreholes to determine arsenic concentrations in bore-holes in south-eastern Ghana in spite of the fact that the type of geological environment – young alluvial and deltaic deposits, where arsenic have been found in thousands of boreholes in Bangladesh, is not likely to be found to a great extent in Ghana.

Like many contaminants in drinking water, arsenic is potentially hazardous at levels or concentrations that do not impart a noticeable taste, odor, or appearance to the water (PHED & UNICEF, 1999). The toxicity of arsenic is well documented (Tseng *et al.*, 1968; Carlos, *et al.*, 1997)); after a few years of continued high level of arsenic exposure, many skin ailments may appear. These include hypo pigmentation (white spots), hyper pigmentation (dark spots), which are collectively called melanosis by some physicians and dyspigmentaion by others. Other adverse health effects include hypertension, cardiovascular diseases, cerebrovascular disease, diabetes and reproductive deffects, including low birth weight, higher occurrence of spontaneous abortions and stillbirths, and congenital malformations in the offspring, damage to the blood vessels, decreased production of blood cells, and a feeling of ‘pins and needles’ in the hands and feet. Long term oral exposure (contaminated water) has resulted in stomach disorders, anaemia, ‘pins and needles’ feeling in the hands and feet, and liver and kidney damage (Carlos *et al.*, 1997). In Ghana, there is no clinical evidence to suggest the occurrence of these diseases because of arsenic exposure. The objective of this project was, therefore, to determine the arsenic status of boreholes in south-eastern Ghana.

Materials and methods

Study area

The study area is within latitude 5.5° N–8.6° N and longitude 1.1° W–1.1° E, a total area of 46744 km^2. It covers the Eastern, Greater Accra and Volta regions of Ghana (Fig. 1).

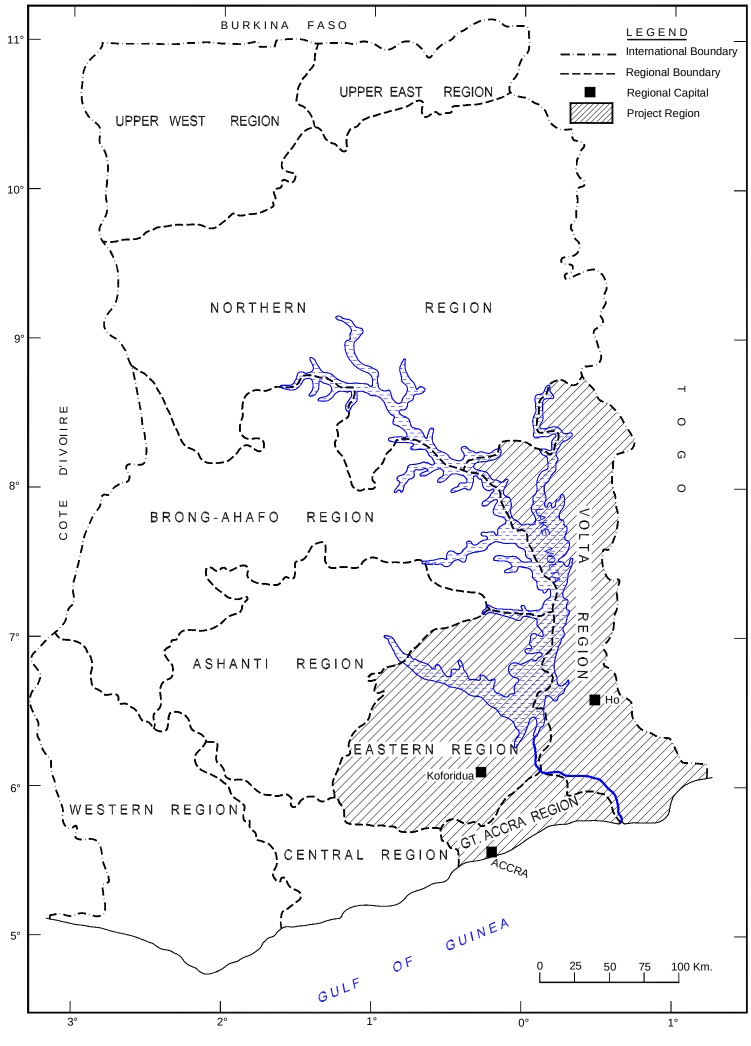

Fig. 1. Map of Ghana showing the study region

Climate and vegetation. The region lies within three climatic zones. The south (Greater Accra Region and southern Volta Region) has dry equatorial climate, the northern part of the Eastern Region and the central part of the Volta Region experience the wet semi-equatorial climate, and the northern part of the of the Volta Region is influenced by tropical continental climate or the Guinea savanna. There are two rainfall maxima for all the climatic zones, however, the intensity of rainfall differs for the three climatic zones. The major rainy season occurs between May and July with the peak occurring in June while the minor one occurs between September and October with the peak occurring in October (Dickson & Benneh, 2004). The mean annual rainfall generally varies between 740 mm and 890 mm for the dry equatorial climate while in the tropical continental climate, the mean annual rainfall is in the range 1150–1250 mm. The mean annual rainfall is between 1250 mm and 2000 mm in the wet semi-equitorial climate. Mean monthly temperature ranges from 26 ^{o}C and 30 ^{o}C.

The original vegetations were Guinea savanna in the north, moist semi-deciduous forest type with thin undergrowth in the middle belt, and coastal grassland scrubs and mangroves in the south. However, the activities of man over the years have greatly eroded the forest vegetation, which grades gradually to tree savanna with isolated patches of thickets. The soil type in the central zone comprises forest ochrosols and forest ochrosols-oxysol intergrades developed over a wide range of highly weathered parent material of varying rock formations. The soils in the north consists of groundwater lateritic soils and savanna ochrosols while in the south the soil type is mainly lateritic sandy soils, tropical black clays, tropical grey earths, sodium vleisols and coastal sandy soils (Dickson & Benneh, 2004).

Geomorphology. Geomorphologically, the study area is generally flat and undulating with a few isolated inselberg that seldomly rise to 70 m above mean sea level in the south and south-west (Dickson & Benneh, 2004). The middle and the north-west are hilly while the northern portion is undulating. Major rivers and streams that drain the study area include the Kpasa river (a tributary of the Oti river) in the north; the Dayi, Asukawkaw and Menu in the central area; and the Aka, Agblala and Tordzie in the extreme southern zone. River Afram, River Birim and River Densu in the west and south-west. Most of the drainage system flows into the Volta river/lake with a few flowing into the sea. There are a number of lagoons along the southern coastal belt. The most important of these lagoons are the Keta, Aka, Denu and Ke lagoons. Apart from the Ke, the water in these lagoons is too saline for human consumption. Springs also constitute an essential component of the drainage system (WRRI, 1993).

Hydrogeological setting. The study area can be broadly divided into three hydrogeological provinces (Precambrian Crystalline Rocks, Consolidated Sedimentary Formation and Cenozoic and Mesozoic Formations). The first hydrogeological province consists of the Precambrian crystalline igneous and metamorphic rocks formations that include the Dahomeyan, Togo, Buem, Tarkwaian, Birimian, and Granites formations (Kesse, 1985). Groundwater occurrence in this hydro-geological province is controlled mainly by the development of secondary porosity, e.g. fractures, faults, joints and the associated weathered zones since the rocks are inherently impermeable. The Togo, Buem and Birimian formations, which are more fissured that the Dahomeyan and the Granitic formations have more groundwater potential than the Dahomeyan and Granitoids formations. Borehole yields are largely varied (0.2–100 m^3h^{-1}) but generally low (median 3.7 m^3h^{-1}) (Nii Consult, 1998). Transmissivities are also generally very low (0.5–70.0 m^2d^{-1}) (WRRI, 1996).

The second hydrogeological province consists mainly of the Voltaian formations, which, though is sedimentary, has similar properties as the basement complex due to the degree of consolidation. Thus, groundwater occurrence in this hydro-geological province is also controlled by the development of secondary porosity. Groundwater yield in this hydrogeological province is also highly variable (0.4–58.0 m^3h^{-1}). The median yield is 3.1 m^3h^{-1}). Transmissivities are equally low.

The third hydrogeological province is the Caenozoic (Quarternary-Recent and Tertiary-Eocene) formations that include unconsolidated sands and clays of lagoon, delta and littoral area, partly consolidated red continental deposits of sandy clay and gravel. This hydrogeological province is located in the southern part of the study area. It consists of a thick section of marine sands, clay, shale, limestone, sandstone and some gravel which underlie more recent sediments in the coastal areas and dips towards the southeast): The Recent deposits comprise unconsolidated sand, clay and gravels of river valleys especially along the lower Volta river, marine clays along the northern banks of the lagoon and marine sands along the coastal littoral stretch from Aflao to Anyanui (Junner & Bates 1945). Groundwater occurrence in this hydrogeological province is controlled by matrix flow. Borehole yields for standard size well (125 mm diameter) reaching a mean depth of 52 m is generally in the range 0.7–27.5 m^{3}h^{-1} with a mean value of 2.7 m^{3}h^{-1}. Transmissivity values are generally low due to high clay content of the regolith. They vary from 0.23 m^{2}h^{-1} in the clayey regolith to 4.0 m^2 h^{-1} in the fissured zones (WRRI, 1993). These ranges are often exceeded the Keta basin.

Sampling methods are always essential part of environmental arsenic assessment. The result of a chemical analysis is no better than the sample on which it is based. For this reason, the sampling protocols described by Claasen (1982) and Barcelona *et al.* (1985) were strictly adhered to. Prior to sample taking, clear pumping was carried out. This was done in order to avoid sampling of stagnant annulus water that would be in the region of pump and pump systems. The mean time for clear pumping was 10 min. A sample was collected at each site using laboratory cleaned high density linear polyethylene (HPDE) 1000-ml bottle that was rinsed three times. The samples were then conveyed to a temporary field laboratory created in each district for analytical measurement.

In the field laboratory, arsenic was determined using the field test kit Digital Wag-WE10500 commercialized by the Wagtech International Ltd. It gives direct readout of arsenic within the critical range of 2 ppb to 100 ppb. The kit also contains a colour comparison chart, with a range between 2 ppb up to 500 ppb (Wagtech, 2003; Ahmed & Feroze, 2001,2002; Boerschke *et al.,* 2001).

The sampling operation was divided in two parts (Durham & Kosmus, 2002; Boerschke *et al.,* 2001; Goessier *et al.,* 2002); the preparatory and the arsenic measurement process. In the preparatory process, the Arsenator was calibrated using a blank arsenic collection filter. Fifty ml of sample was then measured into a plastic graduated cylinder and transferred into an Erlenmeyer flask. Two reagents were added, and a bung device (previously loaded with the arsenic collection filter and the arsine removal filter) was pushed down immediately to close the flask. The reaction time was 20 min (the Arsenator includes a timer). In the measurement phase, the slide with the arsenic collection filter was removed. A visual measurement was possible by using the colour chart (up to 500 ppb) but this was not done in this project. Since the concentrations encountered in the project were below 100 ppb, the slide was able to accurately measure the arsenic concentrations without dilution. However, if the concentration were to have exceeded 100 ppb, a dilution would have been necessary for a more precise measurement (Ali *et al.,* 2001; Kinniburgh & Kosmus, 2002; Wagtech, 2003; Rahman *et al.,* 2002).

Results and discussions

The results are divided into three (Greater Accra, Eastern Region and Volta Region). Table 1 presents the statistical summary of results from the three regions. Results from Greater Accra Region are presented in Table 2. Tables 3 and 4 contain the results from the Eastern and Volta regions, respectively. Similarly, the maps showing spatial distribution of arsenic concentration super- imposed on geological maps of the various regions are presented in Fig. 2, 3 and 4, respectively.

TABLE 1

Summary statistic of arsenic concentration in the groundwater

	Concentration (μg l^{-1})				
	Min	*Max*	*Mean*	*Median*	*St. dev.*
Greater Accra	<2.0	5	<2.0	<2.0	1.1
Eastern Region	<2	9	<2.0	<2.0	2
Volta Region	<2.0	39	2.6	<2.0	7.7
Study area	<2.0	39	2.2	<2.0	5.9

TABLE 2

Results of arsenic testing in selected boreholes in the Greater Accra Region

Community	*Water point ID*	*Geology*	*Arsenic concentration ($\mu g/l$)*
Afiadenyigba	069-D-001-BH1	Acid Dahomeyan	< 2.0
Tugakope	066-C-076-BH1	Tertiary	< 2.0
Akunakope	101-D-091-BH1	Granite	3.0
Osuwem Gbese	101-I-062-BH3	Basic Dahomeyan	< 2.0
Amartekope	101-I-005-BH1	Basic Dahomeyan	< 2.0
Lawerkope	065-A-036-BH1	Basic Dahomeyan	5.0
Sodikope	056-A-002-BH1	Basic Dahomeyan	< 2.0
Okortorbu	059-A-074-BH1	Granite	< 2.0
Domeabra Old Town	061-E-084-BH1	Granite	< 2.0
Dzotepe Obom	059-A-016-BH1	Granite	< 2.0
Kwame Anum	061-E-006-BH1	Granite	< 2.0
Odontia	059-B-033-BH1	Granite	3.0
Dome Faase	061-H-094-BH1	Granite	3.0
Opa Alafia	059-B-033-BH1	Granite	< 2.0
Olebu	059-B-094-BH1	Acid Dahomeyan	< 2.0
Mayera Agbodzikope	059-C-056-BH1	Acid Dahomeyan	< 2.0
Gbolokope	059-A-079-BH1	Granite	< 2.0
Ochiamba	061-I-056-BH1	Acid Dahomeyan	< 2.0
Sesemi	060-A-004-BH1	Acid Dahomeyan	< 2.0
Amanfro	060-B-084-BH1	Basic Dahomeyan	< 2.0
Gonten	062-E-092-BH1	Acid Dahomeyan	< 2.0

TABLE 3

Results of arsenic testing in selected boreholes in the Eastern Region

Community	*Borehole No.*	*Longitude*	*Latitude*	*Lithology*	*As concentration ($\mu g\ l^{-1}$)*
Koranteng	178-H-031-BH3	W000 9.46	N07 03.50	Conglomerate	4.0
Supom	181-A-091-BH1	W000 0.17	N07 10.60	Conglomerate	<2.0
Adampa	096-E-005-BH1	W000 34.80	N06.54.70	Sandstone	<2.0
Yaw Donkor	174-I-055-BH1	W000 31.20	N07 06.67	Sandstone	<2.0
Abrewaso No.2A	140-A-080-BH1	W000 10.03	N06 56.30	Sandstone	<2.0
Tinorga	139-D-066-BH1	W000 19.53	N05 51.64	Shale	<2.0
Okorase	097-I-060-BH1	W000 15.60	N06 02.03	Granite	5.0
Yensiso	062-B-051-BH1	W000 09.74	N05 57.24	Phyllite	<2.0
Korkormu	062-A-060-BH1	W000 10.46	N05 57.35	Quartzite	<2.0
Asifaw South	098-G-040-BH1	W000 10.35	N06 03.94	Sandstone	<2.0
Abonse	062-C-018-BH1	W000 01.24	N05 59.92	Sandstone	<2.0
Anoff	061-H-031-BH1	W000 24.67	N05 48.42	Granite	<2.0
Panpanso T- Junction	061-E-065.BH1	W000 22.27	N05 52.37	Granite	<2.0
Kwakyekrom	061-F-074-BH1	W000 24.67	N05 48.42	Granite	<2.0
Boahenekrom	061-F-044-BH2	W000 17.70	N05 53.02	Migmatite	4.0
Danskrom	0600C1C93BH2	E000 10.94	N06 25.12	Gneiss	<2.0
Saisi	103-D-095-BH1	E000 02.08	N06 20.27	Sandstone	9.0
Kudikope	103-A-078-BH1	E000 04.22	N06 28.28	Sandstone	<2.0
Osebeng	0600C/C9/BH2	E000 02.00	N06 23.78	Schist	<2.0
Afabeng	0600C/C9/BH2	E000 05.15	N06 23.78	Slate	<2.0
Owusu Betom	097-B-023-BH4	W000 23.81	N06 14.22	Granite	<2.0
Birim Agya	094-F-005-BH1	W000 32.59	N06 09.88	Phillite	<2.0
Akim Juaso	096-I-030-BH1	W000 30.44	N06 18.84	Phillite	<2.0
Miaso	137-G-033-BH1	W000 28.43	N06 33.09	Sandstone	<2.0
Subraso	137-I-003-BH1	W000 20.09	N06 33.09	Sandstone	<2.0
Besea	099-C-072-BH1	W000 19.09	N06 27.47	Sandstone	<2.0

Dorminase Quarters	138-G-094-BH1	W000 13.81	N06 30.63	Sandstone	<2.0
Dome	099-D-078-BH1	W000 26.43	N06 21.33	Clay	<2.0
Mmofra Mfa Adwene	093-I-081-BH1	W000 49.47	N06 00.73	Greywacke	<2.0
Okyenso Amanfrom	093-C-028-BH1	W000 46.21	N06 13.59	Greywacke	<2.0
James town	093-I-081-BH1	W000 59.52.	N06 13.59	Schist	<2.0
Mpeasem	093-I-081-BH1	W000 40.50.	N06 07.90	Schist	<2.0
Atuobikrom	133-D-35-BH1	W000 57.69	N06 38.33	Greywacke	<2.0
SE Odortorkor	134-H-019-BH1	W000 35.26	N06 31.35	Sandstone	<2.0
Awesasu	134-F-070-BH1	W000 29.04	N06 37.20	Sandstone	<2.0
Ataaso	133-H-016-BH1	W000 52.11	N06 34.56	Schist	<2.0
Abobeng Gbadagle	100-I-078-BH2	W000 01.11	N06 17.18	Sandstone	<2.0
Akumersu Astey	099-F-040-BH1	W000 15.38	N06 23.25	Sandstone	<2.0
Bormase Tenya	100-H-052-BH2	W000 09.91	N06 17.91	Sandstone	2.0
Bisa Kabu Ternya	100-E-057-BH1	W000 07.52	N06 22.72	Sandstone	<2.0
Sutapong Agbleze	100-I-028-BH1	W000 15.87	N06 19.08	Shales	6.0
Suhyen Mpaemu	097-E-020-BH1	W000 20.22	N06 09.33	Granite	<2.0

TABLE 4

Results of arsenic testing in selected boreholes in the Volta Region

Name of community	*BH No.*	*Geology*	*As concentration ($\mu g\ l^{-1}$)*
Mawoekpor	B01	Basic Dahomeyan	<2.0
Degorme	B02	Recent sand	9.0
Mafi Devime	B03	Recent sand	4.0
Atitekpo	B04	Recent sand	28.0
Manya	B05	Recent sand	<2.0
Manya	B06	Recent sand	<2.0
Memordzi	B07	Recent sand	4.0
Kpomkpo	B08	Acid Dahomeyan	<2.0
Ayiram Dorfor	B09	Basic Dahomeyan	3.0
Gidikpoe	B10	Basic Dahomeyan	<2.0
Mafi Devime	B11	Recent Sand	19.0
Ave Atanve	B12	Basic Dahomeyan	<2.0
Avega Agornu	B13	Acid Dahomeyan	<2.0
Have	B14	Acid Dahomeyan	<2.0
Hadadakope	B15	Acid Dahomeyan	<2.0
Matsrikasa	B16	Acid Dahomeyan	<2.0
Wute	B17	Acid Dahomeyan	<2.0
Asafotsi Amenopekope	B18	Tertiary	<2.0
Adzikame	B19	Acid Dahomeyan	<2.0
Agbagblakope	B20	Acid Dahomeyan	<2.0
Atsiteme	B21	Acid Dahomeyan	<2.0
Wodome Logakope	B22	Acid Dahomeyan	<2.0
Atidzive	B23	Tertiary	<2.0
Fiato West	B24	Tertiary	<2.0
Anfoeta Wadamaxe	B25	Basic Dahomeyan	<2.0
Anfoeta Dzinu	B26	Basic Dahomeyan	<2.0
Dededo	B27	Basic Dahomeyan	<2.0
Abutia Kloe	B28	Basic Dahomeyan	<2.0
Abutia Kissiflui	B29	Basic Dahomeyan	<2.0
Avee Tokor	B30	Basic Dahomeyan	<2.0
Avee Tokor	B31	Basic Dahomeyan	<2.0
Takla Gbogame	B32	Acid Dahomeyan	<2.0l
Hodzo Achianse	B33	Acid Dahomeyan	<2.0
Akpokope	B34	Basic Dahomeyan	<2.0
Akpafu Todzi	B35	Buem Formation	<2.0
Alavanyo Wudidi	B36	Buem Formation	<2.0
Ve Kolenu	B37	Buem Formation	<2.0
Ve Dafor	B38	Buem Formation	<2.0
Liati Tadzi	B39	Togo Series	<2.0
Logba Klikpo	B40	Togo Series	<2.0
Tafi Dekpokope	B41	Buem Formation	<2.0
Nyagbo Gagbefe	B42	Togo Series	<2.0
Agate Akofafanami	B43	Togo Series	<2.0
Lolobi Ashiambi	B44	Togo Series	<2.0l

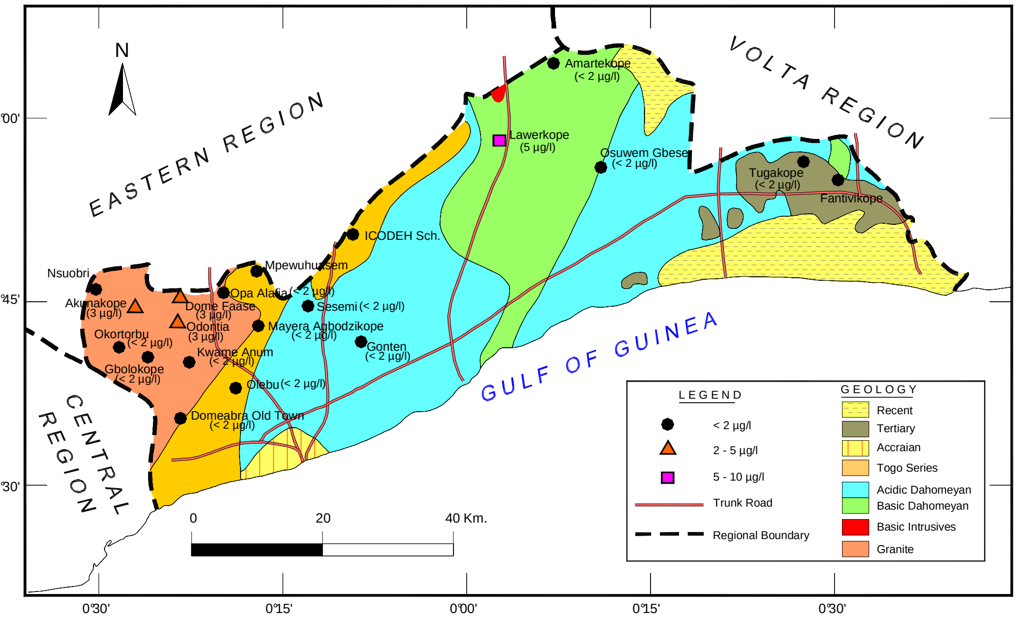

Fig. 2. Geological map of Greater Accra Region showing arsenic levels in selected communities

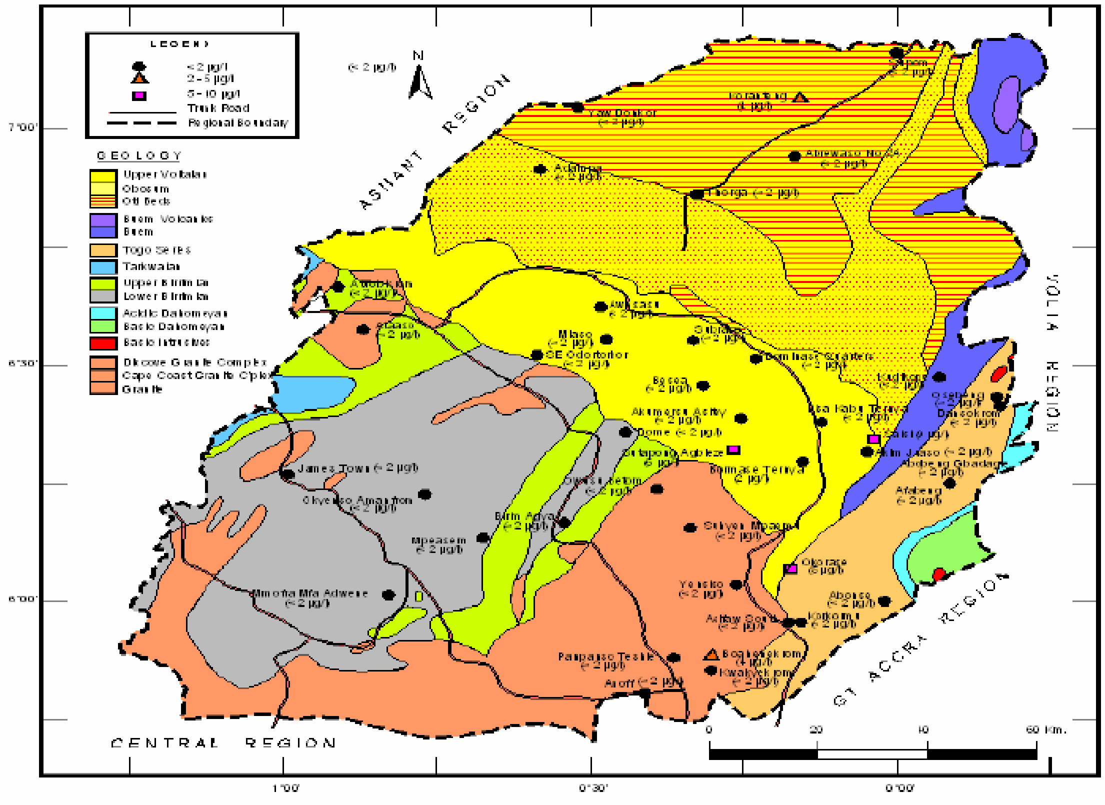

Fig. 3. Geological map of Eastern Region showing arsenic levels in selected communities

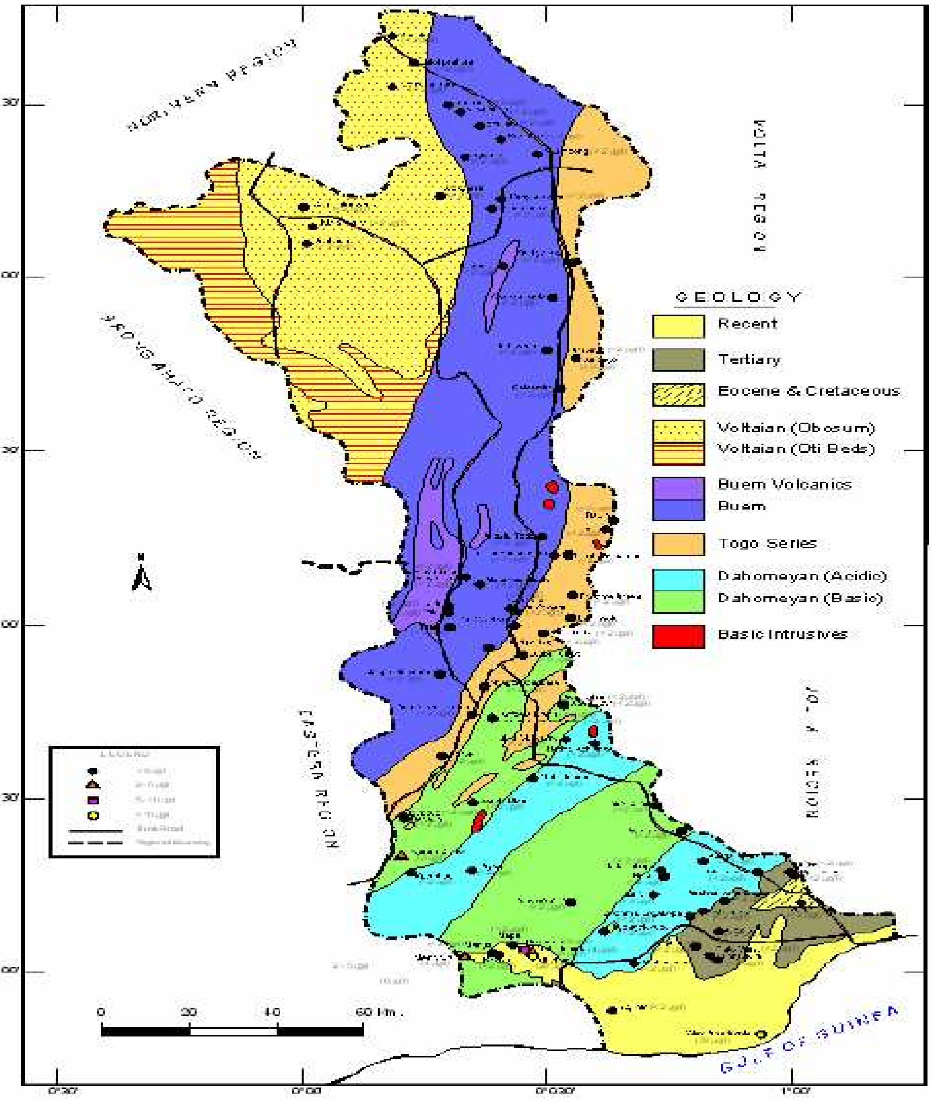

Fig. 4. Geological map of Volta Region showing arsenic levels in selected communities

Table1 indicates that the boreholes tested in the study area have median arsenic concentrations levels lower than 2 μg l^{-1} (detection limit of Digital Wag-WE10500, the instrument used in the measurement) and, thus, lower than 10.0 μg l^{-1} (WHO, 2004 maximum permissible limit for As in drinking water). Median values were used instead of mean values because median values are much more robust descriptors of non-normal distributions than the mean values (Caritat *et al.,* 1998; UNESCO/WHO/UNEP, 1996) and in treating the data in this study statistically, half the detections were assigned to those values below the detection limit of the instrument (Caritat *et al.*, 1998).

Concentrations of arsenic in the study area are comparable to values (median < 2 μg l^{-1}) obtained from the Bolgatanga area of the Upper East Region where only 2% of the samples exceeded the WHO (2004) maximum permissible limit for As in drinking water and much lower than values (median < 4 μg l^{-1}) from the mining district of Obuasi where 20% of boreholes have As concentration higher than WHO (2004) maximum permissible limit for As in drinking water (Smedley *et al.*, 1995). For those samples tested in the Greater Accra Region, arsenic concentrations were, to a large extent, below the detection limit of the equipment (2.0 µg l^{-1}).

Only four out of 21 (approximately 19%) of the boreholes tested had concentrations above the detection limit. These four samples had concentrations varying from 3.0 µg l^{-1} to 5.0 µg l^{-1}, which are lower than the maximum concentration (10 µg l^{-1}) of arsenic permitted in drinking water (Gomez-Caminero, 2001; WHO, 2004). Thus, the 21 boreholes had not shown any sign of arsenic contamination. Fig. 3 does not reveal any spatial variation in arsenic concentration with regards to geographical location or geology. Since, the sample of boreholes tested is evenly distributed over all geological formations in the Greater Accra Region. It is, therefore, reasonable to state that there is little risk of arsenic contamination of boreholes in the Greater Accra Region.

It can be seen from Table 3 that most (approximately 86%) of the sample of boreholes tested in the Eastern Region had arsenic concentration below the detection limit of the equipment (2.0 µg l^{-1}). Approximately six boreholes out of the sample (42 boreholes in the Eastern Region), i.e. approximately 14% of the sample tested in the Eastern Region had concentrations above the detection limit but below the maximum concentration (10 µg l^{-1}) of arsenic permitted in drinking water (Gomez-Caminero, 2001; WHO, 2004). Conse-quently, the sample tested did not show arsenic contamination. In Fig. 4, it can be observed that, though arsenic concentration is spatially low, the southern part of the upper Voltaian had pockets of relatively level of arsenic concentration. Particularly, borehole 103-D-095-BHI at Saisi had arsenic concentration of 9.0 µg l^{-1}, which is very close to the WHO (2004) guideline limit for arsenic concentration in drinking water. This borehole and a few others in the Voltaian need to be monitored.

Arsenic concentration is generally low in the sample of 82 boreholes tested in the Volta Region as can be observed from Table 4. In fact, the values were below the instrument's detection limit (2.0 µg l^{-1}) in most (92%) of the boreholes tested. Approximately 3% of the sample had some measurable arsenic concentration but the values were in the range 2.0–4.0 µg l^{-1} and, thus, close to background (Table 4). The remaining 5% of the boreholes within the sample had moderate to high arsenic concentration. Borehole (BH3) with community code ADE08 at Atitekpo situated in the Recent Sedimentary Formation, had arsenic concentration of 28.0 µg l^{-1} (Fig .4). Similarly, boreholes (B02) with community code ADE06 at Mafi Devime, B01 with community code ADE03 at Degorme and KEB14-B03 at Woe Aklorbordzi, also situated in Recent Sedimentary Formation, had arsenic concentration of 19.0 µg l^{-1}, 9.0 µg l^{-1} and 39 µg l^{-1}, respectively. These values were significantly higher that the WHO (2004) guideline upper limit (10 µg l^{-1}) and comparable to values found in Obuasi area (Smedley *et al.*, 1995). Thus, the possibility of moderate risk of arsenic contamination could be associated with these wells. However, as pointed out by Wang & Huang (1994), no morbidity cases could result where arsenic concentration in drinking water is less than 100 µg l^{-1} and, therefore, no mobility cases could be expected.

Possible sources of arsenic in ground-water in the lower Volta Region

The presence of arsenic in ground water is largely the result of arsenic-bearing minerals shales, phosphorites, and iron and manganese ores but especially arsenopyrite (FeAsS), realgar (AsS), and orpiment (As_2S_3) dissolving naturally over time as certain types of rocks and soils are weathered. Arsenic can also dissolve out of certain rock formations when groundwater levels drop significantly allowing atmospheric oxygen to penetrate into the aquifer, and to oxidize arsenopyrite, leading to desorption of the adsorbed arsenic according to Eq. (1) (Nickson *et al.*, 2000; Gautheir, 2004; Smedley & Kinniburgh, 2001)).

$$FeAsS + 5.50 + 1.5H_2O \rightarrow H_3AsO_3 + SO_4^{2}- + Fe^{2}+ \qquad (1)$$

The iron-oxyhydroxides (FeOOH) reduction is also a widely accepted method through which arsenic can naturally enter the groundwater system (Gautheir, 2004). Basin sediments are usually very rich in such ores in which numerous cations including arsenic are sorbed. The strongly reducing conditions at near-neutral *p*H values make the ore reduced according to Eq. (2), and contribute to the release of the arsenic ions (Nickson *et al.,* 2000; Gautheir, 2004).

$4FeOOH + CH^2O + 7H^2CO_3$ ® $4Fe^{2+} + 8HCO_3$- + $6H_2O$ (2)

Arsenic in groundwater could come from anthropogenic sources, which include intensive use of fertilizers, pesticides and insecticides in agricultural areas, as well as industrial effluents and waste disposal. Other anthropogenic sources include alloying agents, wood preservatives and combustion of fossil fuels. Arsenic infiltrates into the groundwater through the soil. General contributions from these anthropogenic pollution sources are, however, negligible compare to the natural contamination sources (Nickson *et al.*, 2000)

The reason for the high level of arsenic in groundwater in Recent Sand, particularly in the Adidome area, is not understood. However, Adidome is a zone of intense agriculture and the rate of fertilizers and pesticides application in the area is very high. Therefore, if a particular brand of fertilizer or pesticide in use contains arsenic, this could be a source of arsenic in groundwater. Arsenopyrite is not known in the rock formations of the Recent Sand formation, thus, arsenopyrite oxidation does not look likely. Nonetheless, iron-oxyhydroxides (FeOOH) reduction from the sediments of Recent Sand Formation looks very likely since shales and phosphorites, which are part of the Recent Sand Formation, contain iron ore. However, there is the need to carry out detailed hydro-geochemical studies in the area to determine the real origin of arsenic in groundwater in the area.

Conclusion and recommendations

The results of the survey indicated that arsenic concentration in groundwater in south-eastern Ghana is generally low. Approximately 88% of borehole samples tested had arsenic concentrations below the detection limit (2.0 µg/l). Approximately 10% of the sample had arsenic concentration above the detection limit but below the WHO (2004) guideline limit for drinking water. Only 2% of the boreholes within the sample showed arsenic concentrations, which were significantly higher than WHO (2004) guideline limit for drinking water. These boreholes occurred in the Recent Sand formation in the southern part of the study area.

The origin of high arsenic concentration is not known but it probably comes from anthropogenic sources (fertilizer and pesticide application in the area) or natural sources as a result of iron-oxyhydroxides (FeOOH) reduction from the sediments of Recent Sand formation. It is recommended that detailed survey of all wells and boreholes for arsenic concentration is carried out in all areas underlain by Recent Sedimentary formation to determine the extent of the arsenic problem. Additionally, detailed hydro-geochemical studies should be carried out in areas underlain by Recent Sedimentary formation, particularly in the Volta Region, to determine the extent, origin and movement of arsenic in groundwater.

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References

Ahmed M. Feroze (2001). *An Overview of Arsenic Removal Technologies in Bangladesh and India.* Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh. (*http://www.unu.edu/env/Arsenic/Ahmed.pdf.*)

Ahmed M. Feroze (2002). *Alternative Water Supply Options for Arsenic Affected Areas of Bangladesh*. Centre for Water Supply and Waste Management. A theme paper for presentation and discussion at the International Workshop on Arsenic Mitigation in Bangladesh. ITN-Bangladesh, Dhaka.

Ali M. Ashraf, Badruzzaman A. B. M., Jalil M. A., Hossain M. Delwar, Hussainuzzaman M. M., Badruzzaman M., Mohammad and **Akter O. I. N.** (2001). Development of Low-cost Technologies for Removal of Arsenic from Groundwater. In *Technologies for Arsenic Removal from Drinking Water* (M. Feroze Ahmed, Ashraf Ali, Zafar Adeel, ed.) International Workshop on Technologies for Arsenic Removal from Drinking Water organized by Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh and the United Nations University, Tokyo, Japan.

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.*

Boerschke Roy K and **Stewart Donna K**. (2001). Evaluation of Arsenic Mitigation Technologies for Use in Bangladesh. In *Technologies for Arsenic Removal from Drinking Water* (M. Feroze Ahmed, Ashraf Ali , Zafar Adeel, ed.) International Workshop on Technologies for Arsenic Removal from Drinking Water organized by Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh and the United Nations University, Tokyo, Japan.

Carlos D., Da Rosa J. D., Lyon J. S., Udall S. L. and **Hocker P. M.** (1997). *Golden Dreams, Poisoned Streams.* Mineral Policy Center. Washington. D. C. 2006

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 82–102*. 49 pp.

Dickson K. B. and **Benneh G.** (2004). *A New Geography of Ghana*. Longmans Group Limited, London.

Durham N. and **Kosmus W.** (2002). Sustainable environmental sanitation and water services. *Analytical consideration of arsenic contamination in water. 28th WEDC Conference. Calcutta, India.*

Gautheir Julien (2004). *Arsenic Contamination in North 24-Parganas. Mapping and Capacity Building*. (MSc. Thesis.) Technical University of Denmark.

Goessier Walter and **Kuehnelt Doris** (2002). Analytical Methods for the Determination of Arsenic and Arsenic Compounds. In *The Environment of Environmental Chemistry of Arsenic* (William T. Frankenberger, Jr, ed.) Marcel Dekker Inc., New York, New York.

Gomez-Caminero A., Howe P., Hughes M., Kenyon E., Lewis D.R., Moore M. Ng, J., Aitio A. and **Becking G.** (2001). *Arsenic and arsenic compounds. Environmental health criteria,* 2nd edn. World Health Organization, Geneva.

Junner N. R. and **Bates D. A.** (1945). Reports on the geology and hydrology of the coastal areas east of the Akwapim ranges. *Ghana Geological Survey Memoir No. 7.*

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

Kinniburgh D. G. and **Kosmus W.** (2002). Arsenic contamination in groundwater: some analytical considerations. *Talanta* **58**: 165–180.

Nickson R. T., McArthur J. M., Ravenscroft P., Burgess W. G. and **Ahmed K. M.** (2000). Mechanism of Arsenic Release to Groundwater, Bangladesh and West Bengal. *Appl. Geochem*. **15**: 403–413.

Nii Consult (1998). Information Building Block. Ghana Water Management Study. *Unpublished Consultancy Report for the Ministry of Works and Housing, Ghana, DANIDA, World Bank.*

PHED, UNICEF (1999). *Joint plan of action to address arsenic contamination of drinking water.* Govt of West Bengal and UNICEF, Public Health Engineering Department, Govt of West Bengal.

Rahman Md. M., Mukherjee D., Sengunta M. K., Chouwdhury U. K., Lodh D. and **Ranjan Chanda C.** (2002). Effectiveness and Reliability of Arsenic Field Testing Kits: Are the Million Dollar Screening Projects Effective or Not? *Envir. Sci. Technol.* **36**: 5385–5394.

Rahman Md. M., Mandal B. K., Chowdhury U.K., Sengunta M. K., Chowdhury T. R. and **Lodh D.** (2003). Arsenic Groundwater Contamination and Suffering of People in North-24 Parganas, One of Nine Arsenic Affected Districts of West Bengal, India. *J. Envir. Sci. Hlth.* **A38**: 25–59.

Smedley P. L., Edmunds W. M., West J. M., Gardner S. J. and **Pelig-Ba K. B.** (1995). *Vulnerability of Shallow Groundwater Quality due to Natural Geochemical Environment.* Health Problems related to Groundwater in the Obuasi and Bolgatanga Areas, Ghana. Report prepared for ODA under the ODA/BGS Technology Development and Research Programme, Project 92/5.

Smedley P. L. and **Kinniburgh D. G.** (2001). A Review of the source, behaviour and distribution of arsenic in natural waters. *Appl. Geochem*. **17:** 517–568.

Wagtech (2003). Official Web Page. *wellowner.org/awaterquality/basics.shtml.*

Wang L. and **Huang J.** (1994). Chronic arsenism from drinking water in some areas of Xinjiang, China. In *Arsenic in the environment, Part II: Human Health and Ecosystem Effects.* (J. O. Nriagu, ed.), pp. 1259–172. Wiley, New York.

WHO (1993). *Guidelines for drinking-water quality,* 2nd edn. Vol. 1. Recommendations. Geneva, World Health Organization. pp. 131–143.

WHO (1997). *Environmental health criteria 194: Aluminium.* International Programme on Chemical Safety. World Health Organization, Geneva. p. 11. Retrieved 29-07-04 from *http://www.inchem.org/documents/ehc/ehc/ehc194.htm*

WHO (2004). Guidelines for drinking water quality: Addendum World Health criteria, 3rd edition. World Health Organization, Geneva.

WRRI (1993)**.** Inventory of hand dug wells and assessment of shallow groundwater in the Volta Region (1993) *Unpublished consultancy project for Volta Rural Water Supply and Sanitation Programme / DANIDA.*

WRRI (1996) Groundwater assessment report on the Accra Plains. *Unpublished Technical Report, Water Resources Research Institute (CSIR), Accra.*