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Underground water quality at Bogoso and its environs, a mining enclave in Ghana

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Abstract

This study was conducted to assess the contamination status and physicochemical quality of ground water at Bogoso and its environs. The selected areas receive drainage and effluent from mining processing and waste containment facilities of a mining company and activities of small-scale miners. Representative samples of water from hand-dug wells and boreholes were analyzed for Mn, Fe, Cu, Pb, and As using Varian 220 Atomic Absorption Spectrometer. Other water quality parameters such as pH, conductivity, turbidity, total dissolved solids, chloride, and sulphate were also determined. pH values were generally low and no borehole water sample met the set WHO guidelines. Conductivity, sulphate, chloride, total dissolved solids and copper concentrations were below the WHO guidelines for drinking water for both Hand-dug wells and boreholes. Turbidity values ranged from 1 NTU to 334 NTU ± 7.491 for hand-dug wells. 50 % of water samples from hand-dug wells recorded iron concentrations below the WHO guidelines whereas 81.25 % of water samples from boreholes were within range. Three boreholes recorded abnormally high iron concentration of between 6.510mg/l and 11.404mg/l. The dominant major groundwater contamination is through acid mine drainage (AMD) in areas where high concentrations of Fe and SO42- and low pH coincide.

Keywords: Heavy metals; Contamination; Underground; hand-dug wells; Mining enclave; Bogoso - Ghana

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1. Introduction

West Africa has been one of the world's most important gold mining regions of the World for centuries and the most significant gold producing country in the area is Ghana (Hilson, 2002a). Gold mining constitutes a greater proportion of the country's Gross National Product (GNP) and has been the bedrock of the country's Economic Recovery Program (ERP) (Amonoo-Neizer and Amekor, 1993). Since the ERP the mining industry has seen a phenomenal growth and the gold production has increased by 700 % (Hilson, 2002a). Both small-scale miners and large-scale mining are currently operating in Ghana and about 237 (154 Ghanaian and 83 foreign) enterprises are prospecting for gold and another 18 are operating gold mines (Hilson, 2002a, b). The main gold prospects in Ghana occur at Obuasi, Prestea, Bogoso and Tarkwa (Smedley, 1996). Large-scale mining in the Bogoso-Prestea region is conducted as both deep-pit and surface mining. Cyanidation is the most common technique in the region and is used for treatment of non-sulphidic palaeoplacer ore (Akosa et al., 2002; Kortatsi, 2004). The management of waste from large scale mining is done in accordance to approved environmental plans. However, the monitoring of these activities is poor. Small-scale mining as defined by the Government of Ghana (1989), is ''mining by any method not involving substantial expenditure by any individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons''. In the Bogoso-Prestea-Tarkwa area, small-scale mining is found all around, both in the forest and along the rivers (Bhattacharya et al., 2012). It is practiced in about 20,000 small-scale mines in the Wassa West district throughout the year. Among these small-scale miners about 90% are illegal. Currently, 168 small-scale mining concessions are valid in the region (Asklund and Eldvall, 2005; Balfors et al., 2007).

The area has three main gold deposits. Placer or alluvial deposit, non-sulphidic pale placer or free milling ore and oxidised ore (Kortatsi, 2004). This study is focused on an area in southwestern Ghana that has a long history of mining activities where groundwater serves as the main source of drinking water supply for local population. Most major towns in the area including the Bogoso-Prestea townships rely solely on groundwater. To match the demand for potable water the number of boreholes and hand dug wells is increasing rapidly (Kortatsi, 2004). The exploitation of gold (Au) in Ghana has become a serious problem due to environmental pollution. There are apprehensions that the mining activity is causing serious metal pollution to the water resources by contaminants such as arsenic, lead, cadmium, mercury, and cyanide. Earlier studies have shown that metal levels in groundwater exceed WHO guidelines for drinking water in many areas in western Ghana (Kortatsi, 2004; Kuma, 2004).

In these areas gold is associated with sulphide minerals, especially arsenopyrite (Smedley, 1996). Previous studies have reported that mining activities have resulted in arsenic (As) contamination of surface soil plant, food items and humans in Obuasi which is the most important mining area in Ghana (Amasa, 1975; Amonoo-Neizer and Amekor, 1993; Golow et al., 1996; Smedley, 1996; Smedley et al., 1996; Smedley and Kinniburgh, 2002). Extremely high concentrations of As were observed in dam water (2250 µgl-1) and drinking water (1400 µgl-1) (Amasa, 1975). Smedley et al. (1996) reported As concentrations of up to 175 µgl-1 in stream water affected by mining pollution. These levels are over the WHO drinking water guideline value (10 µgl-1) for As (WHO, 2004) At least 10 % borehole wells in the rural areas of Ghana have As concentrations exceeding 10 µgl-1 (Mead, 2005). Since inorganic As is carcinogenic (WHO, 2001), human exposure to As through the consumption of contaminated drinking water and food in these areas may cause serious health problems.

Mercury contamination by Au mining activities is also of great concern in Ghana because mercury is used effectively to extract gold in artisanal gold mining. The optimal Hg to Au ratio is about 1:1 (v/v) but most gold washers in Ghana commonly add greater quantities (Hg: Au = 4:1) to ensure that all available gold is amalgamated (Babut et al., 2003). Therefore Hg may be inhaled by the workers and also contaminate soils, tailings and stream sediments and water bodies close to the processing sites. Hg pollution of river water, sediments, soils and mine workers in Ghana has already been reported (Golow and Adzei, 2002; Adimado and Baah, 2002; Golow and Mingle, 2003; Babut et al., 2003). It is likely that some artisanal miners have died through Hg intoxication but there are no official records on such casualties (Adimado and Baah, 2002).

In general, the management of waste in small-scale mines, particularly the illegal ones, lacks waste management plan and simply leave the waste unmanaged. Additionally, mining has led to conflicts among communities, displaced by mining operations, and health and social problems, pollution of the community water sources, and depletion of groundwater resources (Fonseca 2004).

Although there are several reports of contamination due to mining activities in Obuasi such information in other mining areas is still limited (Golow and Adzei, 2002; Adimado and Baah, 2002; Golow and Mingle, 2003; Babut et al., 2003). Moreover the aforementioned studies have reported mainly on As and Hg contamination, but very few data are available for other trace elements.

Underground water can be contaminated from both natural and anthropogenic means. Also in underground water are dissolved ions leached from the rocks and soils. Bogoso and the selected communities in this study have no access to treated pipe borne water and therefore depend on natural sources of water. Since the commencement of surface mining activities in Bogoso the surface waters within the township and suburbs have been made unsafe for drinking() and other uses because treated pit waters pumped into the environment normally enter the surface waters. Following the cyanide spillage into river Aprepre a tributary of the Ankobra river, in October, 2004, the inhabitants of these areas have had to rely on water supplied by the tankers of BGL which in not sustainable. The most sustainable source of water for drinking and other domestic activities is groundwater. Two forms of groundwater found within the area are Hand-dug wells which can be located in individual houses and boreholes located in the communities.

Groundwater in mining areas as the Bogoso–Prestea area is known to be vulnerable to pollution from mining that may have a serious effect on human health. In gold mining areas sulphides oxidation leads to low pH in the groundwater that encourages the mobility of trace metals which are found in the groundwater in very high concentrations as reported by Kortatsi (2004). In the study of Asante et al. (2007) groundwater As was compared with urinary As levels of local residents in Tarkwa and no difference was found compared with a control group from Accra. Nevertheless, urine levels were high and the authors suggested a presence of undetected sources of As in Ghana.

The study assesses the level of contamination of underground water by Iron, copper, manganese, lead and arsenic in Bogoso-Prestea and other communities which lie within mining concessions. Water quality parameters such as the pH, conductivity, turbidity and total dissolved solids are also determined in order to evaluate their role in the contamination of ground waters in these areas. The outcome of the study will be used to assess the vulnerability of groundwater quality due to natural geochemical environment, hydrogeochemical characteristics and distinguish it from mining pollution of the groundwater resources specifically in the re region around the Bogoso-Prestea mining area.

2. Materials and methods

2.1. Geology and hydrology

2.1.1. The study area

The study was done at Bogoso and its environs which lie within the miningconcession area located in the Wassa West district which occupies the mid-southern part of the Western region of Ghana. Mining is the main industrial activity in the area (Avotri et al., 2002). The area lies within the main gold belt of Ghana that stretches from Axim in the South west, to Konongo in the northeast Kortatsi 2004). Location of the Bogoso and Prestia and the study area is shown in fig. 1. The Bogoso/Prestea property consists of 145 km2 of Bogoso concessions, the surface mining rights to the adjoining 129-km2 Prestea property, a 90 % interest in the Prestea underground mine, and a number of contiguous properties west and north of the Bogoso property. On the inception of surface Gold mining in Bogoso and its environs, trees, topsoil from hills and entire slopes were bulldozed, and the three streams in the area were made unwholesome for use. A lot of illegal gold mining operations had also taken place in this area before the commencement of large scale gold mining operations.

2.1.2. Climatic characteristics

The climate of the area is tropical and is characterized by seasonal weather patterns. The Wassa West district is situated at the border of two climatic regions. The area is very humid and warm with temperatures between 28–30 °C during the wet season and 31–33 °C during the dry season (Dickson and Benneh, 1980; GSR, 2004).

2.1.3. Geological and geomorphologic characteristics

The regional geology of Ghana is represented by a wide variety of Precambrian igneous and metamorphic rock comprising the Basement Complex and covers about 54% of the country, mainly the southern and western parts (Fig 1). The Basement complex is divided into different sub provinces including the metamorphosed and folded rocks of the Birimian and Tarwaian system (Gyau-Boakye and Dapahh-Siakwan, 2000) with gneiss, phyllites, schists, migmatites, granite-gneiss and quartites as the predominant lithology. The lithology of the Tarkwaian System is characterised by a sequence of metasediments comprising quartzites, grits, phyllites and conglomerates of the Kawere Group, a predominant quartzite, grit, conglomerate sequence of the Banket Series, Tarkwa phyllites and Huni Sandstones, grits and quartizes with bands of phyllites. In several places these systems are intruded by sills and dykes of igneous rocks ranging from felsite and quartz porphyry to metadolerite, gabbro and norite (Kortatsi, 2004). The rest of the country is underlain by Palaeozoic sedimentary rocks referred to as the Voltaian Formation consisting mainly of sandstones, shale, mudstone, sandy and pebbly beds and limestones (Gyau-Boakye and Dapaah-Siakwan, 1999). Sulphide minerals, like arsenopyrite are widely reported in Ghana. There is a close association between sulphide minerals, especially arsenopyrite, and gold in most parts of Ghana (Dzigbodi-Adjimah, 1993; Smedley, 1996). The problems associated with AMD can therefore be expected in many gold mining areas in Ghana. Acid mine drainage (AMD) has been reported from a number of mines in the Bogoso–Prestea–Tarkwa area of southwestern Ghana (Kortatsi, 2004). Monitoring of a large spoil dumps in the Tarkwa area show water quality consistent with AMD characteristics. The pH is consistently below 4, the outflow from the waste dumps has high concentrations of sulphate, silica, aluminium, iron, and manganese, and shows little variation during year (Kuma, 2003). The major minerals associated with AMD that occurs in the Bogoso–Prestea–Tarkwa area are Arsenopyrite (FeS, $FeAs$, $FeAsS$), Bournonite ($PbCuSbS_3$), Chalcopyrite ($CuFeS_2$) Galena (PbS), Pyrite (FeS_2), Sphalerite (ZnS), and Ternalite [(Cu, Fe, Zn,)As_4S] (Kortatsi, 2004).

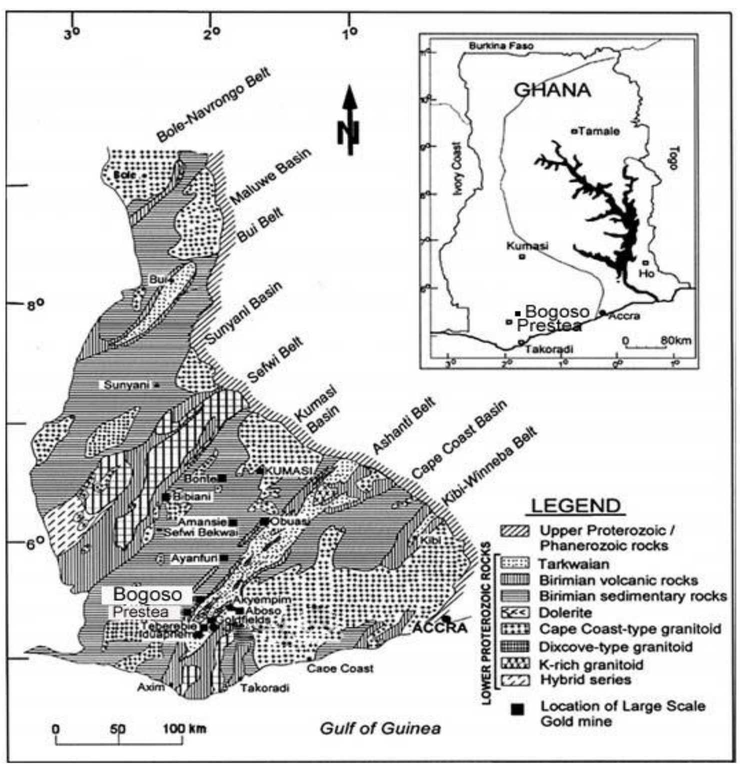

Figure 1. Location of the study area and simplified regional geological map of southwest Ghana (modified from Kuma, 2004).

2.1.4. Hydrogeology

In the Tarkwa–Prestea area groundwater occurrence is associated with the development of secondary porosity through fissuring and weathering. The weathering depth is maximum in the Birimian System in granites, porhyrites, felsites and other intrusive rocks, where it reaches from 90 m to 120 m. Groundwater flow in the region is mainly localised due to numerous low hills that act as groundwater divides. The rocks underlying the area lack primary porosity and the groundwater flow is mainly restricted to preferential flow zones along the fissures and joints, quartz veins, and other intrusives (Kortatsi, 2004). The discrete nature of aquifers within the Bogoso–Prestea–Tarkwa area coupled with the general physiography has given rise to many local flow systems. The numerous low hill crests form natural groundwater divides (Bhattacharya et al., 2012). Groundwater circulation is therefore mainly restricted within quartz veins and fissured–fault–brecciated zones. Within the local system, flow is from the highlands towards valleys and low order streams that drain the basin. Groundwater within these local systems is likely to be lost by evapotranspiration in discharge zones or by base flow in surface water drainage.

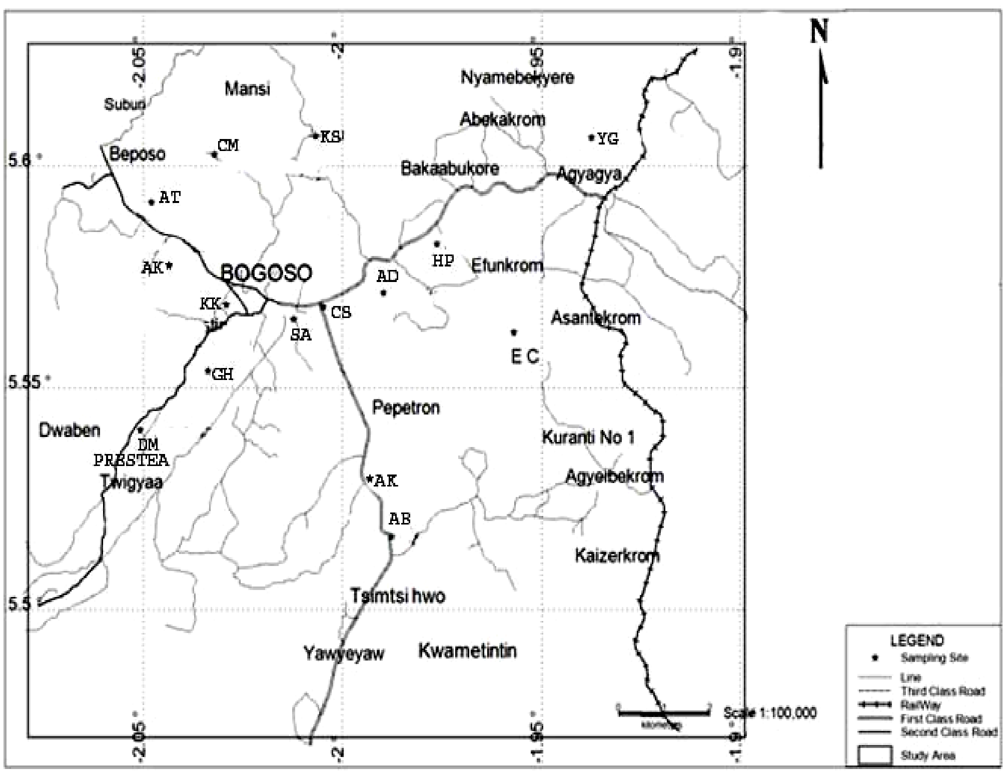

Figure 2. Location of the sampling points in the Bogoso-Prestea area.

2.2. Sampling and Analysis

Convenience sampling sites were selected among already existing Hand-dug wells and boreholes. The sampling areas are shown in fig. 2. The closest access to the water from the hand-dug wells and boreholes was at the exit point. A total of 30 wells, 14 hand-dug wells and 16 boreholes were sampled and analyzed for the various parameters. Grab samples were collected into properly labeled high-density linear polyethylene sample containers since according to Gasparon (1998) these are ideal media for water sample for trace element analysis. For hand-dug well water samples the containers were rinsed thrice with the water to be sampled prior to sampling and for borehole water samples water was pumped for three minutes to avoid annulus water which is usually found in the pump systems and also to prevent mixing water with air (Barcelona et al., 1985). The samples were filtered, capped and placed in an ice chest containing ice packs before transporting to the laboratory for analysis. Samples were preserved to ensure that the water quality of the samples did not change between the time of collection in the field and the time of analysis in the laboratory.

The pH and conductivity of the samples were determined on the field at the sampling points. The total dissolved solids (TDS) of the water were determined by the Hanna instrument TDS meter. Chloride ion determination was done by precipitation titration (Mohr's method). Pb, Mn, Cu and Fe determinations were done by the use of Varian 220 Atomic Absorption Spectrophotometer whilst arsenic determination was done by hydride generation atomic absorption spectrometric (HG-AAS) method. The sulphate concentration was determined using the Hach 4000 (DR) Spectrophotometer at a wavelength of 450 nm. Quality assurance samples analyzed included blanks, replicate samples and pre-digestion of spikes. The results of the blanks were subtracted from the results of all samples analyzed.

3. Results and discussion

The mean values of the physicochemical and heavy metal analysis determined are given in tables 1and 2. The pH of Hand-dug well water samples ranges from 4.28 to 6.78 ± 0.69 with both the mean and median 5.60 and 5.775 respectively whilst that of the boreholes ranges from 5.08 to 6.24 ± 0.405 with both the mean and median 5.506 and 5.305 respectively. They all fall below the World Health Organization (WHO) recommended range of 6.5 - 8.5 (WHO, 2011a). Thus the underground water in the area under study is generally acidic.

The conductivity of the Hand-dug well water shows values ranging from 71.3 μS/cm to 801 μS/cm ± 251.399 with mean and median values of 309.1 μS/cm and 209.4 μS/cm respectfully. In the case of the borehole water, conductivity ranges from 43.5 μS/cm to 842 μS/cm ± 220.419 with mean and median values of 289.54 μS/cm and 247.6 μS/cm. Both well-water and borehole water samples recorded significant variations among themselves as indicated by the large standard deviations though they were all below the WHO recommended value of 1000 μS/cm (WHO, 2011a).

The turbidity for sampled Hand-dug well water from the various sites ranges from 1 to 334 FTU ± 93.894 with mean and median values of 50.50 and 14.0 respectively. However the turbidity values of the boreholes water samples ranges from 0 to 25 FTU ± 7.491 with mean and median values of 5.375 FTU and 1.50 FTU respectively. The US Environmental Protection Agency has recommended a turbidity value of 5 FTU ( ). On the whole the boreholes can be considered free from suspended matter or particles.

There were significant variations in the levels of total dissolved solids among the ground water samples. The total dissolved solids levels range from 16 mg/l to 444 mg/l ± 130.964 with mean and median values of 111.88mg/l and 44.35 mg/l for from Hand-dug wells samples. The range for boreholes is 13.9 mg/l to 421 mg/l ±117.430 with mean and median values of 110.89 mg/l and 54.35 mg/l respectively (Tables 1 and 2). These values were however lower than the maximum recommended value of WHO of 1000 mg/l (WHO, 2011a).

The levels of chloride ions vary in well water samples and boreholes water as presented Table 1and 2. The levels of chloride ions for well water samples fall within the range of 12 mg/l to 121.96 mg/l ± 39.582 with mean and median values of 50.70 mg/l and 35.99md/l whereas the borehole water samples ranges from 11 mg/l to 123.96 mg/l ± 34.324 with mean and median values of 41.74 mg/l and 37.482 mg/l tables 1and 2. However, all these values fall below the WHO guideline value of 250 mg/l (WHO, 2011a).

There were significant variations in sulphate ion levels among water samples obtained from Hand-dug wells as well as boreholes. The levels of sulphate range from 0.2 mg/l to 25.2 mg/l ± 9.028 for samples obtained from wells as shown in Tables 1and 2 with mean and median values of 109.70 mg/l and 10.65 mg/l respectively. Sulphate levels for samples obtained from boreholes fell within the range of less 0.1 mg/l to 21.4 mg/l ± 7.645 with mean and median values of 6.182 and 1.450 mg/l respectively as shown in Tables1 and 2. In both cases the levels were relatively low and far below the WHO guideline of 500 mg/l (WHO, 2011a).

Iron levels in well water samples ranged from 0.004 mg/l to 5.282 mg/l ± 1.409 with mean and median values of 0.89 mg/l and 0.343 mg/l respectively as shown in Tables 3 and 5. Borehole samples gave iron levels ranging from 0.026 mg/l to 11.404 mg/l ± 3.661 with mean and median values of 1.861 mg/l and 0.088 mg/l respectively also shown in Tables 4 and 5. 42 % of well water samples and 31.25 % exceeded the WHO guideline for iron level in drinking water of 0.3mg/l (WHO 2011a). Boreholes samples for iron levels are relatively higher than well water samples.

Copper levels in wells-water samples ranged from less than 0.005 mg/l to 0.11 mg/l ± 0.042 with mean and median values of 0.046 mg/l and 0.034 mg/l respectively. In the borehole samples copper levels range from less than 0.005mg/l to 0.101 mg/l ± 0.030 with mean and median values of 0.045 mg/l and 0.051 mg/l respectively Tables 1 and 2. These values are far below the WHO limit in both well and borehole water samples which is set at 2.0 mg/l (WHO, 2011a).

Manganese levels in well water samples as presented in Tables 1 and 2 range from 0.038 mg/l (to 0.933 mg/l ± 0.304 with mean and median values of 0.347 mg/l and 0.222 mg/l respectively. Manganese levels in borehole water samples range from 0.034 mg/l to 1.37 mg/l ± 0.447 with mean and median values of 0.376 mg/l and 0.181 mg/l respectively Tables 1 and 2. 35.71 % of Hand-dug well water samples and 18.75 % of boreholes water samples had levels higher than the WHO recommended value of 0.4 mg/l in drinking water (WHO, 2011a, 2011b).

Table 1. Mean Levels of field parameters and concentration of selected contaminants in Boreholes and Hand-dug Wells

Sample	Location	Well type	Cl^- (mg/l)	pH	Conductivity (µS/cm)	Turbidity (FTU)	TDS (mg/l)	SO_4^{2-} (mg/l)	Fe (mg/l)	Cu (mg/l)	Mn (mg/l)	Pb (mg/l)	As (mg/l)
AB01	Atobrakrom	HDW	18.99	5.85	225.8	24	46.10	0.900	0.874	0.078	0.177	0.220	0.222
AB02	Atobrakrom	HDW	12.00	5.63	152.3	12	35.00	0.800	0.040	0.110	0.148	0.245	0.245
AD01	Adjeikrom	BH	50.98	5.27	270.0	11	54.40	6.400	6.510	b/d	0.177	0.035	0.003
AD02	Adjeikrom	HDW	16.99	4.86	83.30	334	17.20	10.20	1.738	b/d	0.038	0.007	0.004
AK01	Akokobediabro	BH	36.98	5.28	252.6	7	59.40	1.000	0.578	0.051	0.178	0.141	0.045
AK02	Akokobediabro	BH	45.99	6.24	507.0	10	217.0	13.80	1.505	0.051	1.370	0.165	0.029
CS01	Chapel Square	HDW	37.99	6.10	258.8	13	52.30	23.40	0.254	0.012	0.105	0.016	0.009
CS02	Chapel Square	HDW	20.00	5.98	147.6	21	26.80	11.10	1.279	b/d	0.070	b/d	0.009

Sample	Location	Well type	Cl^- (mg/l)	pH	Conductivity (µS/cm)	Turbidity (FTU)	TDS (mg/l)	SO_4^{2-} (mg/l)	Fe (mg/l)	Cu (mg/l)	Mn (mg/l)	Pb (mg/l)	As (mg/l)
CS03	Chapel Square	HDW	90.00	6.78	291.6	12	67.50	19.02	0.432	b/d	0.817	0.034	0.009
CS04	Chapel Square	HDW	13.00	5.44	111.4	63	23.40	25.20	5.282	0.042	0.179	0.080	0.014
CS05	Chapel Square	HDW	33.99	5.74	193.	180	42.60	21.20	0.689	0.012	0.275	0.030	0.009
EC01	Electricity	HDW	12.00	4.66	71.30	2	16.00	6.900	0.043	0.011	0.058	0.236	0.236
GH01	Golden Hotel	HDW	100.97	6.15	670.0	2	291.0	0.200	0.062	0.026	0.544	0.052	0.008
HP01	Hospital	HDW	50.98	5.81	102.3	15	29.50	2.400	0.037	0.096	0.266	0.238	0.238
KK01	Kokoase	BH	46.99	6.11	487.0	b/d	211.0	7.300	0.115	0.049	1.239	0.154	0.015
AS01	Ayensukrom	BH	20.99	6.06	148.0	b/d	33.50	1.900	0.166	0.052	0.049	0.185	0.017
AT01	Atekyem	BH	89.97	5.23	465.0	b/d	205.0	21.40	0.039	0.073	0.375	0.196	0.006

Sample	Location	Well type	Cl^- (mg/l)	pH	Conductivity (µS/cm)	Turbidity (FTU)	TDS (mg/l)	SO_4^{2-} (mg/l)	Fe (mg/l)	Cu (mg/l)	Mn (mg/l)	Pb (mg/l)	As (mg/l)
AT02	Atekyem	BH	94.97	5.33	515.0	12	251.0	21.20	0.062	0.101	0.394	0.206	0.007
AT03	Atekyem	BH	43.99	5.28	242.6	b/d	54.30	b/d	0.044	0.057	0.184	0.195	0.006
CM01	Community 4	BH	123.96	5.62	842.	b/d	421.0	12.40	0.037	0.093	1.098	0.202	0.005
DM01	Dominase	BH	16.00	5.34	139.9	25	32.80	0.500	11.404	0.017	0.208	0.038	0.008
DM02	Dominase	BH	13.00	5.62	189.6	1	38.10	0.600	9.016	0.022	0.162	0.039	0.008
SA01	St Augustine	BH	11.00	5.08	62.30	b/d	14.50	0.500	0.040	0.065	0.034	0.190	0.013
SA02	St Augustine	BH	11.00	5.12	67.00	b/d	13.90	0.600	0.083	0.053	0.050	0.165	0.014
KS01	Kumso	BH	11.00	5.26	89.10	2	21.50	0.300	0.093	b/d	0.043	0.007	0.004
KS02	Kumso	BH	13.00	5.12	43.50	2	23.40	b/d	0.026	0.007	0.047	0.007	0.009

Sample	Location	Well type	Cl^- (mg/l)	pH	Conductivity (µS/cm)	Turbidity (FTU)	TDS (mg/l)	SO_4^{2-} (mg/l)	Fe (mg/l)	Cu (mg/l)	Mn (mg/l)	Pb (mg/l)	As (mg/l)
GH01	Golden Hotel	BH	37.99	6.13	312.0	16	123.4	11.01	0.053	0.032	0.407	0.051	0.008
YG01	Yebedanagya	HDW	82.97	4.28	557.0	1	226.0	0.700	0.004	0.086	0.721	0.221	0.221
YG02	Yebedanagya	HDW	121.96	6.15	801.0	26	444.0	14.00	1.695	0.093	0.933	0.240	0.240
YG03	Yebedanagya	HDW	97.97	4.93	662.0	2	249.0	13.80	0.055	0.082	0.539	0.230	0.230
WHO Limit			250		1000	5.00	1000	500	0.300	2.00	0.400	0.010	0.010

Abbreviations: BH; Borehole; HDW: Hand-dug Well; b/d: below detection.

Lead levels in Hand-dug well water samples are given in Tables 1 and 2 and fall within the range below 0.010 mg/l to 0.245 mg/l ± 0.107 with mean and median values of 0.132 mg/l and 0.150 mg/l respectively. The levels in borehole water samples fall within the range of 0.007 mg/l to 0.202 mg/l ± 0.078 with mean and median values of 0.124 mg/l and 0.159 mg/l respectively Tables 1 and 2. Lead levels in well water (85.71 %) and borehole water (87.50 %) samples were generally higher than the WHO guideline value of 0.01 mg/l (WHO, 2011a). This is an indication of lead contamination of the aquifers in the area from both natural and anthropogenic sources.

Arsenic levels in Hand-dug well fall within the range of 0.008 mg/l to 0.245 mg/l ± 0.011 with mean and median values of 0.121 mg/l and 0.117 mg/l respectively whereas levels in boreholes fall within the range of 0.003 mg/l to 0.045 mg/l ± 0.007 with mean and median values of 0.012 mg/l and 0.008 mg/l respectively (Tables 1 and 2). Arsenic levels in Hand-dug wells recorded generally much higher values than boreholes. 57 % of Hand-dug wells and 37.0 % of boreholes recorded levels much higher than the WHO guideline for arsenic in drinking water which is below 0.01 mg/l (WHO, 2011a). The relatively high concentration of As in waters may reflect the oxidation/weathering of arsenopyrite and other sulphide-bearing ores and mine tailings which contaminate the aquifers in the area under study. High concentrations of As has been reported in river-water around mining areas in Obuasi, Ghana. Amasa (1975) has reported As concentrations of 2.250 mg/l in dam water and 1.40 mg/l in drinking water around mining areas. Mean concentrations of As of 5.190 mg/l have been reported by Amonoo-Neizer and Amekor (1993) in water samples from Obuasi. Smedley et al. (1996) found higher concentrations of As up to 0.175 mg/l in drinking water from shallow wells and boreholes around gold mining towns.

Table 2. Heavy metal concentration and physicochemical properties of underground water from Bogoso and its environs

Location	pH	Cond./ μScm^{-1}	Turb./ FTU	Tds./ Mgl^{-1}	Cl^{-}/ Mgl^{-1}	SO_4^{2-}/ Mgl^{-1}	Fe/ Mgl^{-1}	Cu/ Mgl^{-1}	Mn/ Mgl^{-1}	Pb/ Mgl^{-1}	As/ Mgl^{-1}
Borehole (n=16)											
Mean	5.506	289.54	5.375	110.89	41.74	6.182	1.861	0.045	0.376	0.124	0.012
S.D.	0.405	289.54	7.491	117.44	34.32	7.579	3.661	0.030	0.447	0.078	0.011
Min	5.08	43.50	0.00	13.90	11.00	0.000	0.026	0.000	0.034	0.007	0.003
Max	6.24	842.0	25.0	421.0	123.96	21.40	3.661	0.101	1.370	0.206	0.045
Median	5.305	247.6	1.50	54.35	37.485	1.450	0.088	0.051	0.181	0.159	0.008
WHO	.	1000	5.00	1000	250	500.0	0.300	2.000	0.400	0.010	0.010
Well (n=14)											
Mean	5.60	309.1	50.50	111.88	50.70	109.70	0.89	0.046	0.347	0.132	0.121
S.D.	0.69	251.38	93.89	134.39	39.58	371.48	1.408	0.042	0.304	0.106	0.116
Min.	4.28	71.30	1.0	26.00	12.00	0.200	0.004	0.000	0.038	0.000	0.004
Max	6.78	801.0	334.0	444.0	121.96	25.20	5.282	0.110	0.933	0.245	0.245
Median	5.775	209.4	14.0	44.35	35.99	10.65	0.343	0.034	0.222	0.150	0.117
Kumasi Tap(n=1) value											
WHO Drinking Water guidelines		1000	5.00	1000	250	500.0	0.300	2.000	0.400	0.010	0.010

The groundwater in some wells in the study area has values of Mn, Fe, As, and Pb exceeding the WHO guidelines. Out of the thirty wells twenty had Pb content exceeding the WHO guidelines for drinking water; Fe exceeds the guideline in eleven wells, Mn in eight wells and total As in twelve wells. Based on the comparison with simplified geological map (Fig. 1), it can be seen that Fe, Mn, As and SO_4^{2-} concentrations do not exhibit any major differences in the pattern of distribution in the Tarkwaian and Birimian system of rocks. The ground water generally has neutral to acidic pH. The dominant major groundwater contamination is through acid mine drainage (AMD) in areas where high concentrations of Fe and SO_4^{2-} and low pH coincide. Principal areas affected by AMD are Akokobediabro, Kokoase, Dominase and Adjeikrom. The occurrence of As at all the sampled wells is most probably of both natural origin as well as anthropogenic activities and is considered as a major problem. The rest of the metals exceeding the guidelines are also components of common minerals and they probably origin from natural processes and anthropogenic activities.

Both Mn and Fe show similarity in distribution pattern almost all areas with Fe concentration above WHO guidelines also have high Mn concentration. However there is no visible trend between these parameters plotted (R^2= 0.00) (not shown). For Fe and SO_4^{2-} there is negative correlation (R^2= 0.06) .There is a positive trend for Cu and SO_4^{2-} (R^2= 0.35), Mn and SO_4^{2-} (R^2= 0.28) and Pb and SO_4^{2-} (R^2= 0.18) (figs. 4; f, g, h), for deep wells (Bore holes). The trend between Mn and SO_4^{2-} could migrate from dissolution of carbonate minerals like kutnohorite, $Ca(Fe, Mn)(CO_3)_2$, during neutralization of AMD. For certain areas such as Akokobediabro, Kokoase, Dominase and Adjeikrom concentration of Fe, SO_4^{2-} and low pH values indicate the impact of acid mine drainage. For Mn and SO_4^{2-} it is difficult to see any trend for shallow wells (hand-dug wells) (fig. 4c). There is negative correlation for Cu and SO_4^{2-}, Pb and SO_4^{2-} but positive correlation for Mn and SO_4^{2-}. For Akokobediabro, the location that display the highest levels of both Fe and Mn, there are small scale mining activity taking place some distances from the sampling points. Precipitation of Fe-oxyhydroxides can explain low concentration between Fe and SO_4^{2-}. Oxidation of Fe(II) and precipitation of Fe-oxyhydroxides occur at lower redox level than oxidation of Mn(II) and precipitation of Mn-oxyhydroxides and thus, Mn remains dissolved even under relatively oxidizing conditions, when most Fe has already precipitated (Drever, 1997). However many samples display both low Fe and SO_4^{2-} values and thus they are not affected by acid mine drainage.

There is positive correlation between pH and Mn concentration (R^2= 0.45) (fig. 3g) for Borehole water. There is however no correlation between pH and Fe (R^2= 0.002), pH and Cu (R^2= 0.004) and pH and Pb (R^2= 0.009) (fig. 3e, f, h) for Borehole water. There are subtle differences in major ion chemistry which are perhaps caused by the differential lithological characteristics of the wells and the groundwater flow pattern (Bhattacharya et al., 2012). There is no correlation between Fe, Mn and As. Minerals like siderite, vivanite, and rhodochrosite are sinks for dissolved Fe and Mn and their precipitation can disturb correlation between Fe, Mn and As (Sracek et al., 2004; Hasan et al., 2007, 2009; von Bromssen et al., 2008; Bhattacharya et al., 2009).

All soil types in the Tarkwaian system are clayey and the soils of the Birimian system most likely have the same composition. The presence of clay minerals and abundance of Al/Fe oxides/hydroxides like goethite and montmorillonite in the soils provide significant sites for sorption. Heavy metals as Cu, is strongly bounded to these sites and this explains its low dissolved concentrations. The area is very hilly and there are several groundwater divides (Bhattacharya et al., 2012). This gives rise to multiple local groundwater systems with short groundwater residence times. The ground water systems also prevent mining to affect larger groundwater systems on a regional scale. However there is the possibility that some sites local mining pollutants have not yet reached the wells and the groundwater quality in some wells might deteriorate in the near future. Groundwater is generally undersaturated with respect to minerals containing sulphates. These wells have very low pH values and this indicate an impact of acid mine drainage. In wells with low pH groundwater is supersaturated with respect to silicate minerals and the dominant aqueous species are Fe^{2+}, Mn^{2+}, Al^{3+} and $H_2AsO_4^-$. Arsenic is present as oxidized anionic species as As(V), which is more adsorbed than As(III) under the observed pH conditions (Bhattacharya et al., 2002; Smedley and Kinniburg, 2002).

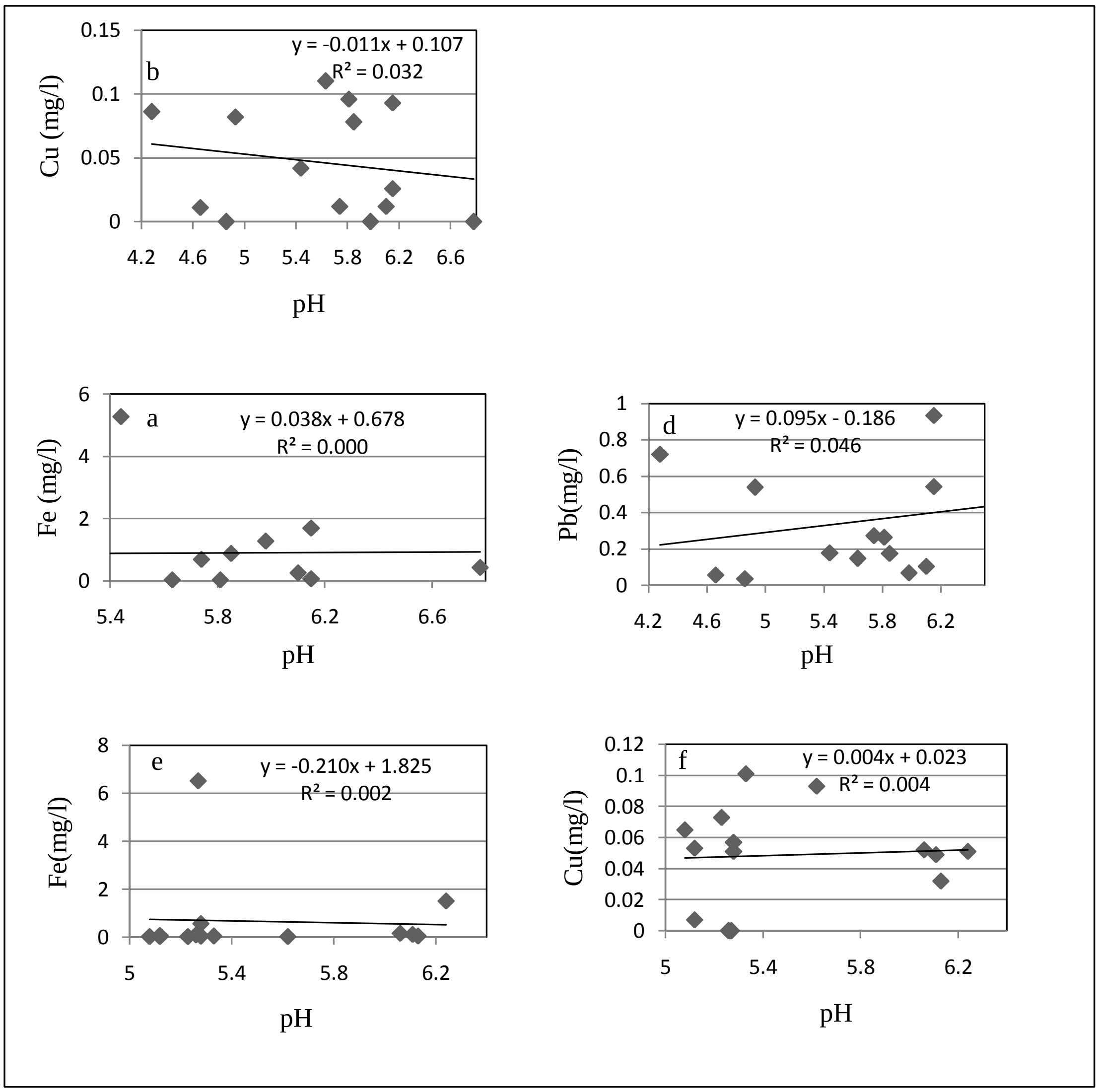

Figure 3. Bivariate plots showing correlation of : (a) Fe vs pH, (b) Cu vs pH, (c) Mn vs pH, (d) Pb vs pH for hand-dug wells; (e) Fe vs pH, (f) Cu vs pH , (g) Mn vs S pH , (h) Pb vs pH for Bore Holes .

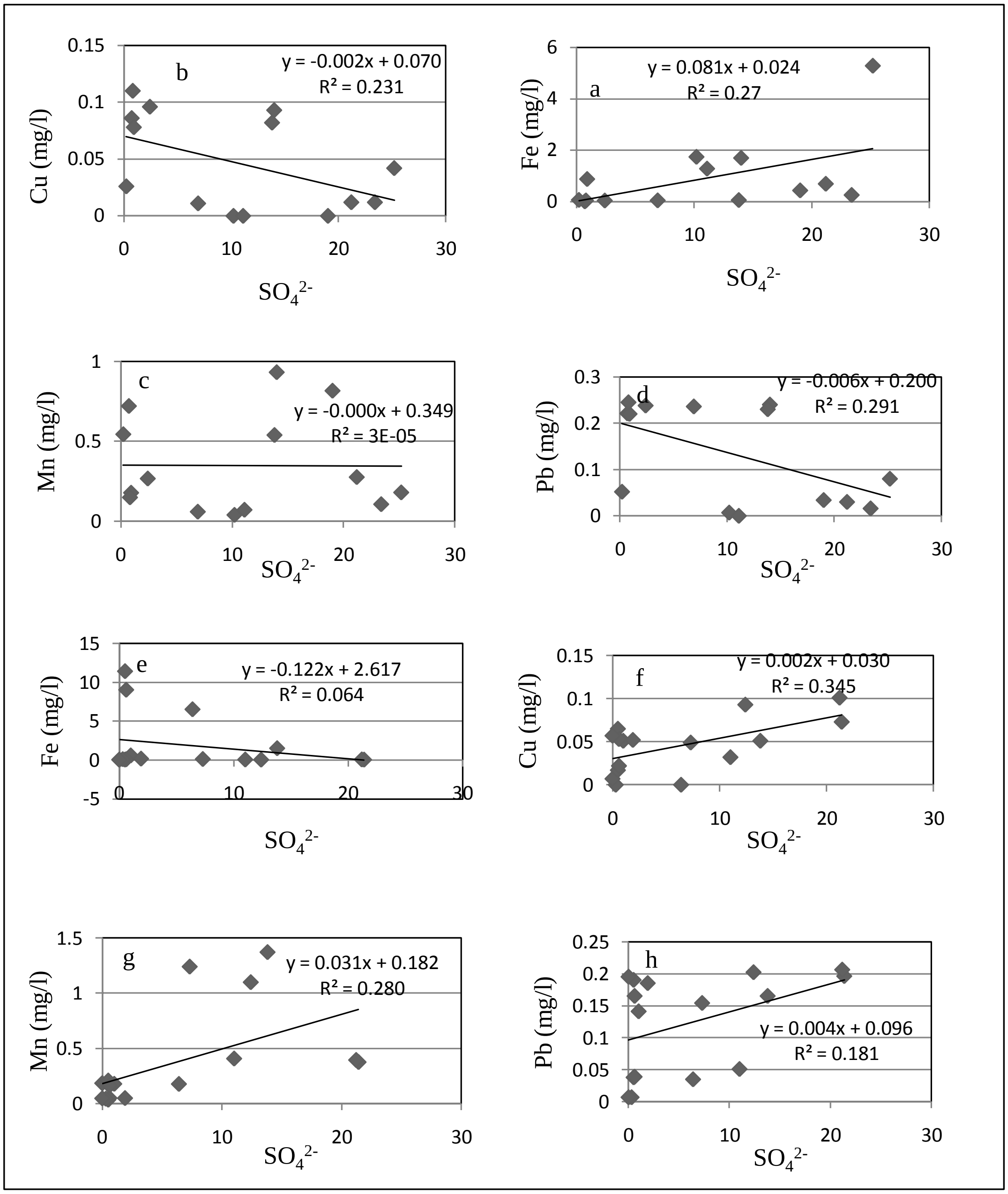

Figure 4. Bivariate plots showing correlation of : (a) Fe vs SO_4^{2-}, (b) Cu vs SO_4^{2-},(c) Mn vs SO_4^{2-},(d) Pb vs SO_4^{2-}, for hand-dug wells; (e) Fe vs SO_4^{2-},f) Cu vs SO_4^{2-},g) Mn vs SO_4^{2-},(h) Pb vs SO_4^{2-} for Bore Holes.

4. Conclusion

The ground waters in some wells in the study area have values of Mn, Fe, As, and Pb exceeding the WHO guidelines. The ground waters generally have neutral to acidic pH. The dominant major groundwater contamination is through acid mine drainage (AMD) in areas where high concentrations of Fe and SO_4^{2-} and low pH coincide. Principal areas affected by AMD are Akokobediabro, Kokoase, Dominase and Adjeikrom. The occurrence of As at all the sampled sites is most probably of both natural and anthropogenic in origin. This is considered as a major problem since as many as twenty-two wells had values exceeding the WHO guideline value. The rest of the metals exceeding the guidelines are also components of common minerals and they probably originate from natural processes as well as anthropogenic sources owing to both large and small scale mining activities in the area under study.

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