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RESEARCH PAPER

EFFECTS OF SURFACE GOLD MINING ON SURFACE AND GROUNDWATER BODIES IN BIBIANI, GHANA

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ABSTRACT

A study of the water sources from Bibiani and its environs was conducted between November, 2009 and April, 2010 to determine whether contamination (of water sources) from (these parameters) physical, chemical and trace metal in Bibiani is as a result of mining or geochemical and biochemical processes within the environment. This was done by collecting water samples from two streams, two rivers, three boreholes (BHs) and three hand dug wells (HDWs). These were analysed in the laboratory. Levels of Arsenic (As), Iron (Fe), Manganese (Mn), pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature, Alkalinity, Hardness, Phosphate (P) and Cyanide (CN) in water sources were determined. Mining related contaminants detected in water samples were As, CN, Mn and Fe. It was observed that surface water pH values were generally higher than that of groundwater samples. As concentrations in surface water samples were higher compared to that of groundwater samples. Also, CN concentration in ground water samples was higher than that of surface water. Ground water contained higher concentration of Mn than surface water; the opposite can be said of Fe concentration in surface water which was higher than that of ground water. The study also observed that pH, TDS, EC, total alkalinity, total hardness , Arsenic and total cyanide levels in the HDW and BH samples showed 100% compliance with the WHO and EPA limits while Mn and Fe levels indicated traces of non – compliance. Compared to WHO / EPA guidelines, few water sources had one or more trace metal (Fe, As and Mn) levels outside acceptable limits for drinking. However, most of the levels were safe for human consumption.

Keywords: *Surface, gold mining, quality, degradation, Bibiani*

INTRODUCTION

In Ghana surface gold mining operations generate substantial revenue for the nation. However, if these activities are not well monitored and proper measures put in place, it will be a major cause of environmental degradation (e.g. loss of farm land, air pollution, water resource contamination etc.).

Gold is the main mineral commodity in Ghana, contributing over 90% of the country's total mineral export (Doso *et al*, 2015). Surface gold mining involves the extraction and exploitation of gold minerals from the ore in the earth's crust by surface mining operation. Surface gold mining can be a major source of pollution to the surrounding water bodies. Metallurgical plants employ processing methods that may be categorized into flotation, gravitational, washing, magnetic separation, crushing and sorting, carbon-In- leach (CIL), Carbon-In Pulp (CIP), heap leach etc each of which uses water (Annane - Acheampong *et al*, 2013). The processes used in the gold extraction and the leachate from the waste and / or ore dumps turns to affect the hydrology, physical and chemical nature of the environment such as water bodies, air and land.

Most mining communities in Ghana depend on groundwater (wells and boreholes) as their main source of water (Addo *et al.,* 2016). Generally, mining in Ghana is faced with a lot of environmental challenges such as water pollution arising from poor handling of ore processing, tailings facilities and waste dump sites, land degradation through loss of vegetation cover and soil erosion (Smedley *et al*., 1996). Many water resources in developing countries are unhealthy, because they contain harmful physical, chemical, and biological agents as a result of geological formation which may impact negatively on the water quality and thus affect human health (Aghazadeh and Mogaddam, 2010). There are fears among residents that the operations of the mining company (Central African Gold) in the area are causing serious contamination of the water sources and thus make them unsafe. Arsenic, copper, iron, manganese, and cyanide are among the contaminants likely to be released from mining operations. It has been anticipated that metal levels in ground and surface water may not comply with WHO guidelines for drinking water in many mining areas in Ghana. This has been confirmed by earlier studies within the Wassa mining areas in Ghana (Addo *et al.*, 2016).

This paper is focused on the water sources of Bibiani where gold mining activities occur. It seeks to determine the levels of heavy metals as well as physical and chemical parameters of the water sources under study. It will also find out whether metal concentrations in water in the area are within World Health Organisation (WHO) guidelines and thus meet the Environmental Protection Agency (EPA) of Ghana standards.

MATERIALS AND METHODS

Study area

Bibiani is located in the Western Region of Ghana. It had a population of about 19,076 in 2010. The Bibiani gold mine lies within the Sefwi belt and its the second most significant gold-bearing belt in Ghana after the Ashanti belt. The mining concession area of approximately 49km² is closely adjoined to the town of Bibiani, approximately 80km southwest of the Ashanti capital, Kumasi. Factors considered in choosing the sampling points include proximity, purpose and population.

Sampling

Ten (10) sampling points comprising four surface water bodies located at surface water 1, surface water 2, surface water 3 and surface water 4 and six groundwater samples taken from groundwater 1, groundwater 3 and groundwater 5 (Hand dug wells, HDWs)) and groundwater 2, groundwater 4 and groundwater 6 (Bore holes (BHs)) were chosen for this investigation. As indicated in Fig.1, surface water 2, ground water 3, and ground water 6 are within the vicinity of the mines while surface water 1, surface water 3, surface water 4, ground water 1, ground water 2, ground water 4 and ground water 5 are outside the mining concession.

Surface water sampling

Samples were collected between November, 2009 and April, 2010. This was done at one month interval from the ten (10) sampling

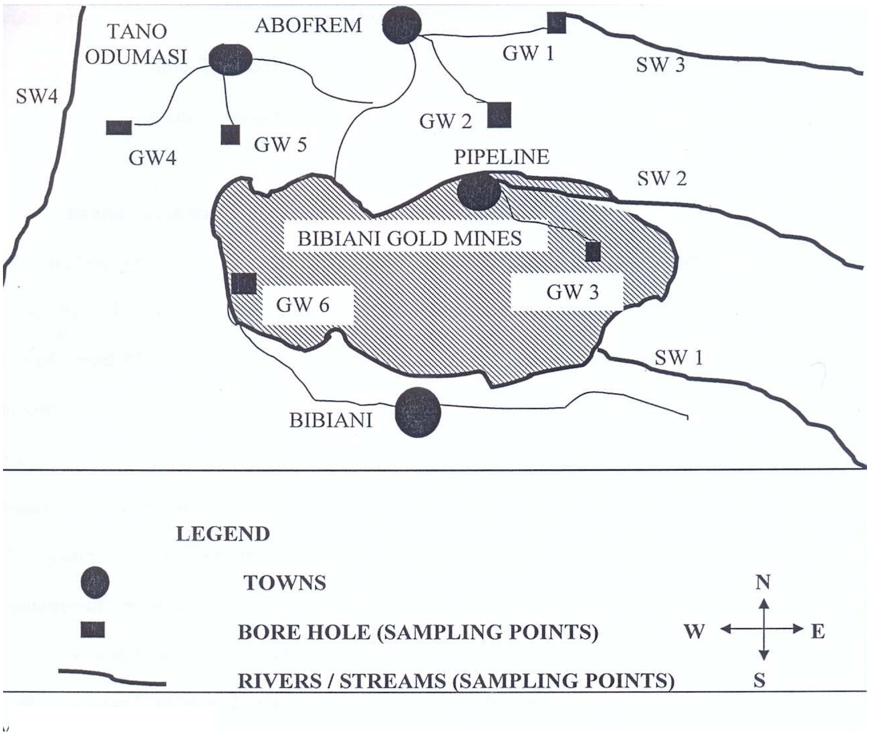

Fig. 1: Map of the sampling area showing the sampling points
**SW - Surface water*
**GW- Ground water*
Map not drawn to scale

points. Water samples for physico-chemical analysis were collected in 500ml plastic containers. This was done by dipping the plastic container into water to collect the sample from below the water surface. Bottles were filled directly from the water body after rinsing and capped immediately. In the case of SW1, sampling was done with the aid of a bailer.

Groundwater sampling

In sampling groundwater more than three casing volumes of water were removed before sampling. All samples were kept in an ice-chest and transported to the Health Safety and Environment laboratory of Central African Gold (CAG), stored in a refrigerator at a temperature below 4 ^{o}C and analysed within 12 hours. Temperature, pH, TDS and electrical conductivity were measured *in situ*.

Sample preparation

To obtain reliable results, sampling procedures which eliminate or minimise potential contaminants were adopted. This was achieved by soaking sample containers in HNO3 solution overnight and thoroughly washing the container with distilled water and finally rinsing them with de-ionized water and dried in a drying cabinet. Samples were transported (in an ice chest containing ice) to the laboratory, stored in a refrigerator and analysed within 12 hours.

Physical analysis (Measurement of pH, conductivity, TDS)

The physical parameters were determined by probe method on the field. The pH of the samples was measured using a pH meter that had a limit of 0 to 14 pH units. Total Dissolved Solids (TDS), Electrical Conductivity (EC) and temperature were determined with HACH Sension 16 Portable Conductivity Meter. The instrument could measure maximum concentration of 5000 mg/l, 2000 µS/cm and 40 ^oC for TDS, EC and temperature respectively.

Chemical analysis

The HACH chart Comparator (detection limit between 0.0 and 0.2 mg/l) was used in measuring the arsenic content in the water samples. Phosphate, iron and manganese content in the samples were determined using the HACH Pocket Colorimeter. The instrument had the following limits of detection: iron from 0.02 to 5.0 mg/l and phosphorus from 0.02 to 3.0 mg/l.

Phosphorus was determined by first filling a 10 -ml sample cell with the samples. The content of one phos Ver 3 phosphate reagent was added to the sample cell, capped and shaken gently to mix (Prepared sample). Three minutes waiting period was allowed. A second sample cell was filled with 10 ml of sample (as blank) and wiped of any liquid or fingerprints. The blank was placed in the cell holder to "zero" the instrument. The blank was then removed from the cell holder. Within 3 minutes after the reaction period ends, the prepared sample was placed in the cell holder, covered with the cap and the result recorded in mg/l phosphate. The same procedure was followed for iron and manganese but different reagents were used. Buffer Reagent Powder pillow, citrate type and Ferro Ver Reagent were the reagents used for manganese and iron respectively. Copper was also measured by means of a HACH comparator box. The sample was prepared for total cyanide determination using alkaline picrate.

Digestion procedure for heavy metal

Metal digestion was done using the Milestone Acid digestion method. Samples of water were weighed into 100 ml polytetraflouroethylene (PTFE) Teflon bombs which had been previously acidified. Six (6) ml of nitric acid (HNO_3, 65%), 3 ml of hydrochloric acid (HCl, 35%) and 0.25 ml of hydrogen peroxide (H_2O_2, 30%) were added to each sample in a fume chamber. The samples were then loaded on the microwave carousel and the vessel caps secured tightly using a wrench. The complete assembly was microwave irradiated for 26 minutes using milestone microwave lab station ETHOS 900, INSTR: MLS-1200 MEGA and employing the microwave programme. The teflon bombs were cooled in a water bath after digestion to reduce internal pressure and allowed for the volatized materials to re- stabilize. The digested sample was made up to 20 ml with double distilled water (Tiimub *et al.*, 2015). The liquid extract was then used for the determination of arsenic, manganese, iron, cyanide and copper.

Statistical analysis

The data obtained from the physical and chemical analysis were subjected to Analysis of Variance (ANOVA) (mean, range and standard deviation at 95% confident limit).

RESULTS

A summary of results recorded for physico-chemical parameters and trace metals analyses have been presented in figures 2 to 11. Where available, these values have been placed alongside WHO and/or EPA (Ghana) guidelines for surface and ground waters.

pH

The pH values ranged from 5.77 to 7.14 units Fig. 2. This gives the general indication that the water bodies under study ranged from being acidic to neutral.

The highest desirable level for pH stipulated for drinking and domestic purposes is within the range of 6.5 to 8.5 (EPA, 1997; WHO, 2004). The pH value of surface water varied from a minimum of 6.57 to a maximum of 7.14 whereas 7.14 whereas between 5.77 and 6.56

Fig. 2. Minimum and maximum surface water pH values were recorded at SW1 (within mine concession) and SW4 (outside mine concession) and those of groundwater were obtained at GW1 and GW4 both of which are outside the mine concession and processing facilities. Mean pH for HDWs (GW1, GW3 and GW5) ranged from 5.87 units at GW5 to 6.56 units at GW1 whereas those of BHs (GW2, GW4 and GW6) ranged from 5.77 units at GW4 to 6.45 units at GW2 (Fig. 2).

Total dissolved solids (TDS)

TDS concentrations for water samples ranged from 162.45 to 552.38 mg/l. Surface water TDS concentration ranged from a minimum of 208.12 to a maximum of 552.38 mg/l (Fig. 3). These surface water TDS values were obtained at SW2 and SW1. Groundwater concentration values ranged from 162.45 to 524 mg/l. These minimum and maximum values for groundwater samples were recorded at GW5 and GW2 which were located outside the mines.

It can also be observed from Fig. 3 that all the BHs contained higher concentrations of TDS than the HDWs. Mean TDS values for HDWs ranged from minimum of 162.45 mg/l to maximum of 343.33 mg/l whiles a range of 355 mg/l to 524 mg/l were obtained from the BH samples. However, all these values were within the WHO detection limit of 1000 mg/l.

Temperature

The mean temperature value of all the water samples analysed ranged from 27.57 to 29.8^{o}C. Surface water temperature ranged from a minimum value of 27.57 to a maximum of 28.13^{o}C occurring at SW3 and SW4 respectively. SW3 and SW4 were both located outside the mines. Groundwater recorded values ranging from 27.87 to 29.08^{o}C which occurred at GW1 and GW2 respectively.

Electrical conductivity (E.C)

Recorded E.C. values for water in the study area varied between 360.167 and 957.12 µS/cm. These values were within the WHO guideline limit of 1000 µS/cm (WHO, 2004) stipulated for drinking and domestic water. The conductivity values for groundwater ranged from 360.167 to 957.12 µS/cm whereas surface water values were from 451.67 µS/cm to 774.72 µS/cm. (Fig. 4).

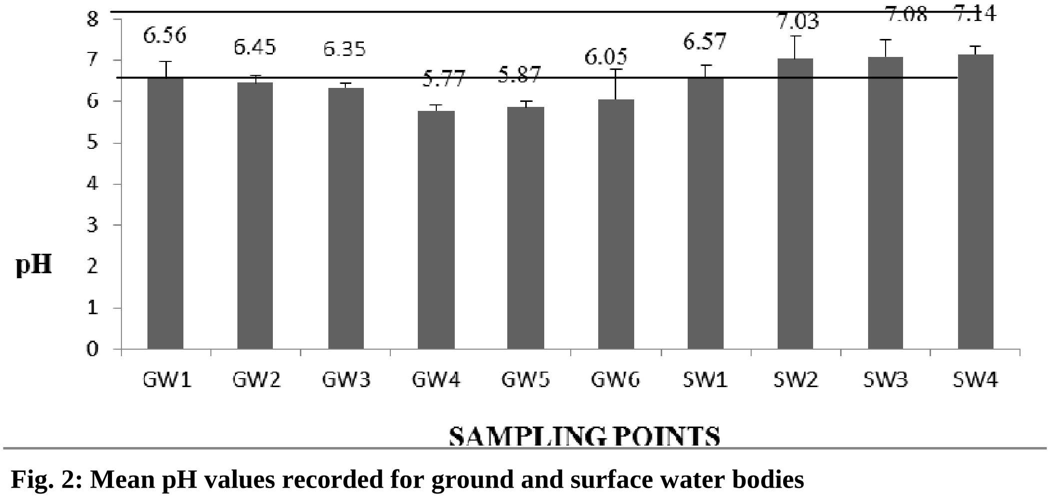

Fig. 2: Mean pH values recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples. The lines indicate the pH range stipulated by the WHO (2004)

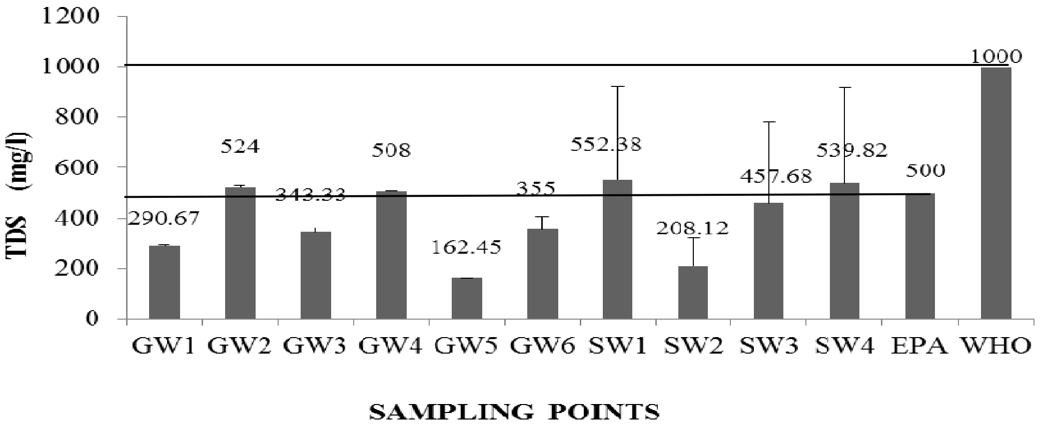

Fig. 3: Mean TDS values (mg/l) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples. The lines indicate the EPA (1997) and WHO (2004) guideline values

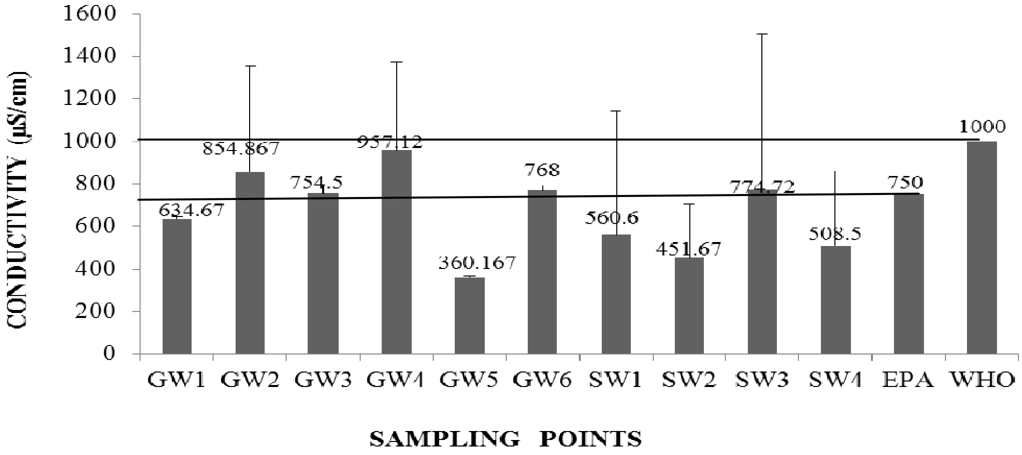

Fig. 4 : Mean conductivity values (µS/cm) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples. The lines indicate the guideline values prescribed by the EPA (1997) and WHO (2004)

The conductivity variation between ground and surface water bodies were statistically insignificant (P = 0.25). Conductivity values for HDW samples (360.167 µS/cm to 754.5 5 µS/cm) were lower than those recorded for BH samples (768 µS/cm to 957 µS/cm).

Phosphate

From Fig. 5, Phosphate concentrations for the water samples varied between 1.067and 2.13 mg/l. Concentrations in groundwater samples ranged from 1.067 to 2.03 mg/l whereas surface water samples recorded concentrations between

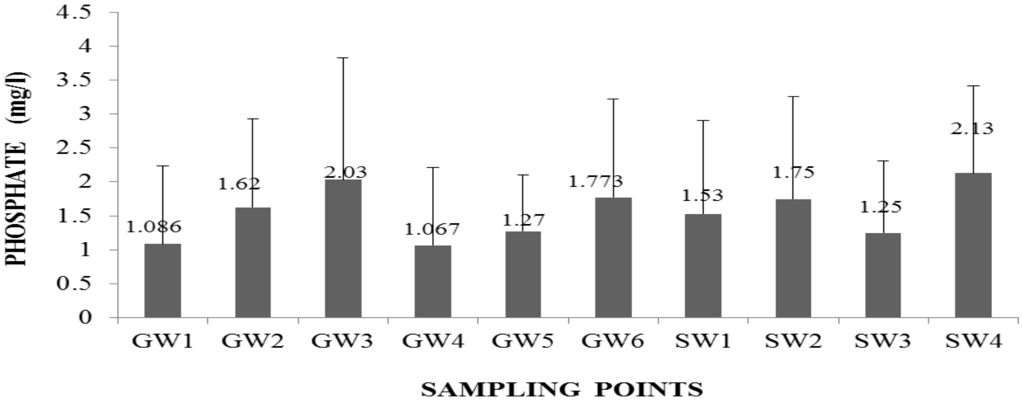

Fig. 5: Mean phosphate values (mg/l) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples

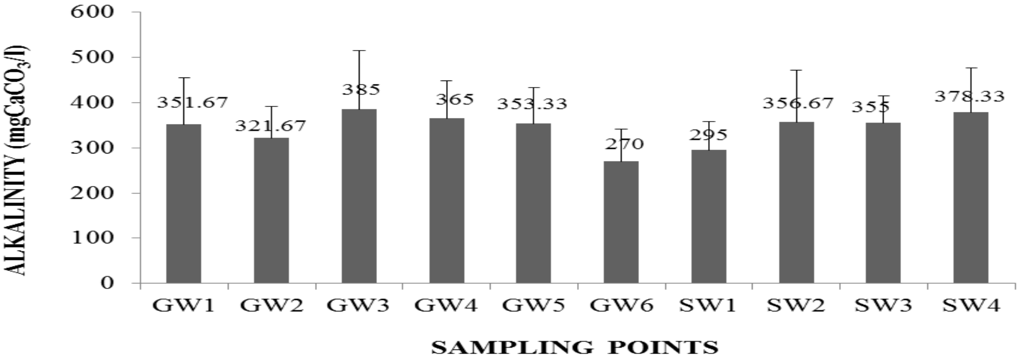

Fig. 6: Mean alkalinity values (mg$CaCO_3$/l) recorded for ground and surface water bodies
Bars indicate standard deviation of the water samples

the ranges of 1.25 and 2.13 mg/l. These values are higher than the WHO (1993), permissible limit of 0.1 mg/l in drinking water.

Total alkalinity

Alkaline concentration ranged from 270 to 385 mg$CaCO_3$/l for groundwater and surface water sources (Fig. 6). Surface water bodies had alkaline levels ranging from 295 to 378.33 mg$CaCO_3$/l. Groundwater samples had concentrations ... Total alkaline concentrations in HDW samples (351.67 mg$CaCO_3$/l to 385 mg$CaCO_3$/l) were found to be higher than the levels in BH samples (270 mg$CaCO_3$/l to 365 mg$CaCO_3$/l).

Total hardness

Total hardness concentrations recorded during the study ranged from 320 to 458.3 mg$CaCO_3$/l. (Fig. 7). The hardness value for groundwater ranged between 351.67 and 458.3 mg$CaCO_3$/l whereas surface water values were from 320 to 405 mgCaCO$_3$/l. BH samples contained higher concentrations (376.67 mgCaCO$_3$/l to 458.3 mgCaCO$_3$/l) than HDW samples (351.67 mgCaCO$_3$/l to 423.3 mgCaCO$_3$/l).

Arsenic (AS)

The concentration for the water samples in Bibiani ranged from values below 0.001 to 0.02 mg/l (Fig. 8). Surface water As concentration ranged from 0.002 to 0.02 mg/l whereas groundwater recorded concentrations from values below 0.001 to 0.0017 mg/l. Minimum and maximum surface water As concentrations were recorded at SW4 (outside the mines) and SW2 (within the mines). Concentrations for

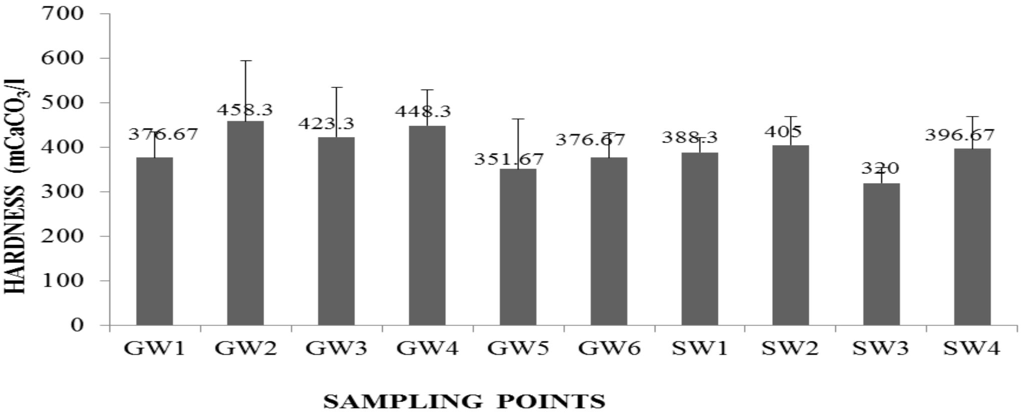

Fig. 7: Mean hardness values (mgCaCO$_3$/l) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples

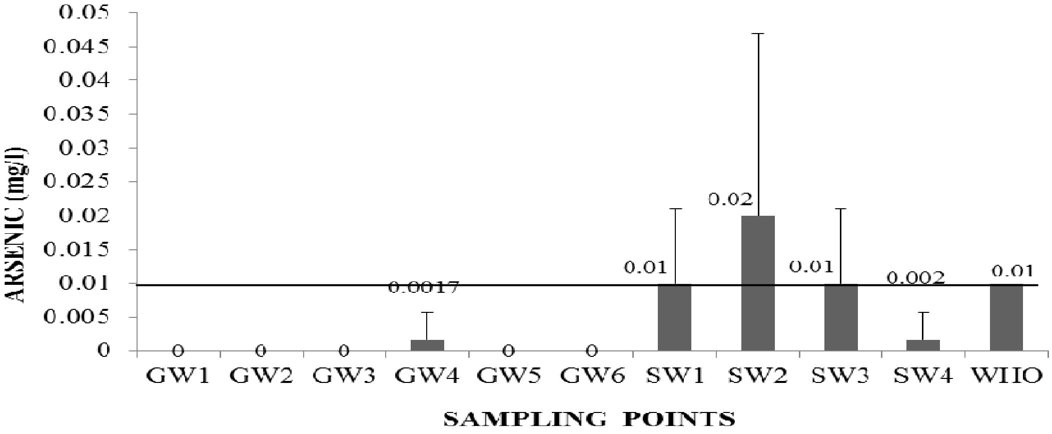

Fig. 8: Mean arsenic values (mg/l) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples. The line indicates the arsenic range stipulated by the WHO (2004) groundwater samples were below detection limit except at GW4 (outside the mines) where a value of 0.0017 mg/l was recorded. All three sampling points for HDWs contained no As concentrations. Only one sampling point (GW4) for BHs contained As concentration.

Total cyanide (CN)

Cyanide concentrations for the water samples understudy varied between 0.002 and 0.036 mg/l (Fig. 9). This falls within the Maximum Compliance Limit (MCL) of 0.07 mg/l and 0.1 mg/l recommended by WHO (2004) and EPA (1997) respectively. The concentration of CN in groundwater ranged from 0.002 to 0.036 mg/l whiles surface water recorded values from 0.008 to 0.02 mg/l. These values were recorded at GW6 and GW3 for groundwater and at SW1, SW2 and SW4 for surface water. The sampling points GW6, GW3, SW1, and SW2 are located within the mines whereas SW4 is not. Cyanide levels in surface water bodies showed significant variations (P = 0.7) from that of groundwater. The HDWs contained higher cyanide concentrations (0.006 mg/l to 0.036 mg/l) than the BHs (0.002 mg/l to 0.017 mg/l).

Manganese (MN)

Values recorded for water samples were between 0.1 and 0.72 mg/l. Groundwater Mn concentration ranged from 0.1 to 0.72 mg/l at GW6 and GW3 (Figure 10). Mn concentrations for surface water were between 0.22 and 0.23 mg/l occurring at the sampling points SW1 and SW3 for the minimum and SW2 and SW4 for maximum concentration. This study also observed that HDW samples contained higher Mn concentrations (0.23 mg/l to 0.72 mg/l) than BH samples (0.1 mg/l to 0.17 mg/l) (figure 10). All these concentrations are within the WHO guideline limit of 0.5 mg/l. Samples from study location GW3 (located within the mines) indicated non - compliance to the WHO guideline limit of 0.5 mg/l stipulated for drinking and domestic purposes.

Total iron (Fe)

Iron (Fe) values for both ground and surface water samples ranged from 0.32 to 3.04 mg/l (Fig. 11). Concentrations obtained for groundwater varied between 0.32 and 1.47 mg/l occurring at GW2 (located outside the mines) and GW3 (located within the mines). Fe concentra-

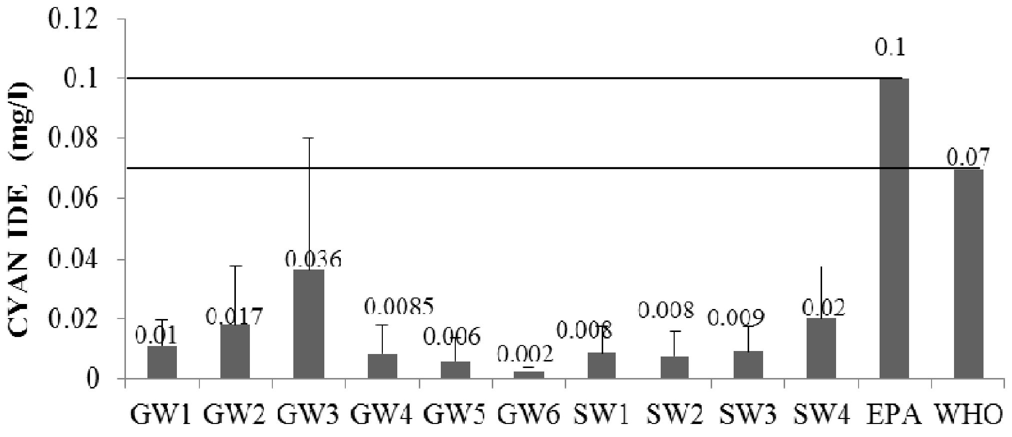

Fig. 9: Mean cyanide values (mg/l) recorded for ground and surface water bodies

Bars indicate standard deviation of the water samples. The lines indicate the cyanide range stipulated by the EPA (Ghana), (1997) and WHO (2004)

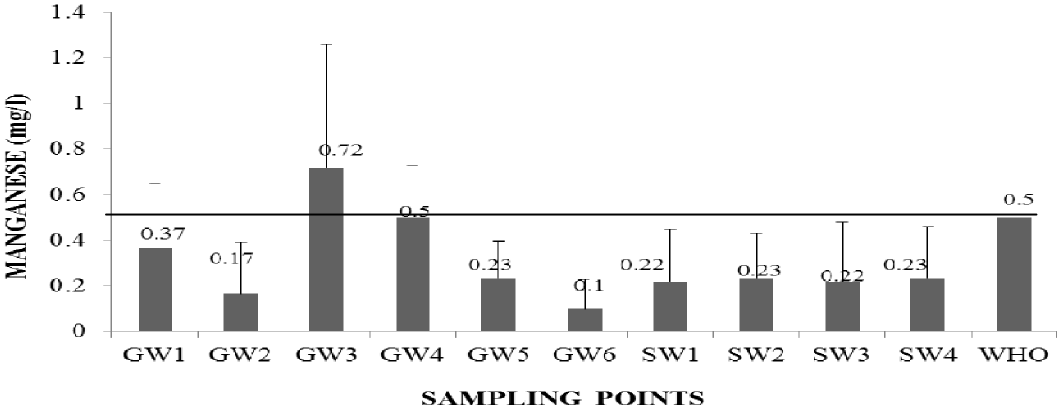

Fig.10: Mean manganese values (mg/l) recorded for ground and surfacewater bodies

Bars indicate standard deviation of the water samples. The line indicates the manganese range stipulated by the WHO (2004)

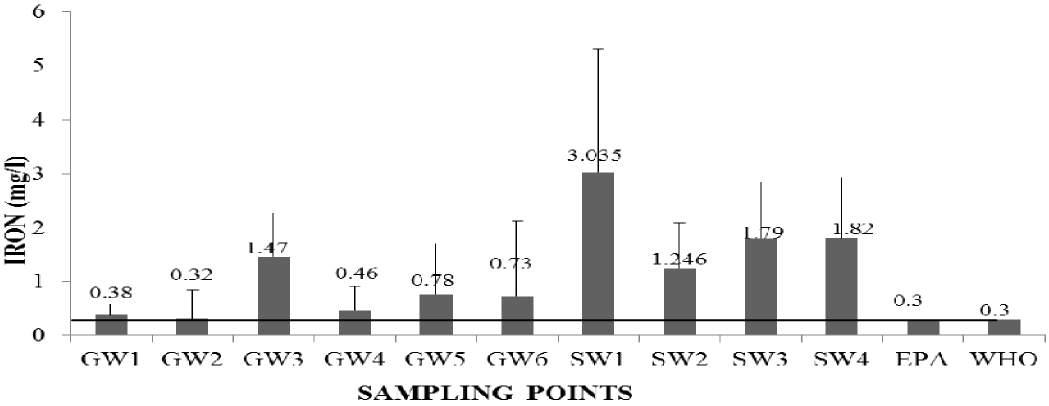

Fig. 11: Mean iron values (mg/l) recorded for ground and surface water bodies

Bar indicate standard deviation. The line indicates the iron range stipulated by the EPA (Ghana), (1997) and WHO (2004)

tions recorded for surface water sources ranges from 1.246 to 3.035 mg/l at the sampling points SW2 and SW1 both of which are located within the Bibiani mines. All the values recorded from the study locations indicated non – compliance with the WHO (2004) and EPA (1997) guideline limit of 0.3 mg/l. HDW samples contained higher concentrations than BH samples. The variations of Fe concentrations between ground and surface water bodies were statistically significant at P = 0.008.

DISCUSSION

pH: With the exception of SW1, all the surface water bodies can be described as neutral (pH range 7.03-7.14). From the study, surface water pH was within the range 6.5 to 8.5 as stipulated for drinking and domestic purposes by the WHO (2004). Based on these guideline limits, the pH of surface water sources from Bibiani would not adversely affect its suitability for drinking, domestic and recreational purposes as well as aquatic ecosystem.

The pH for groundwater samples were below the stipulated range of 6.5 to 8.5 (except at GW 1 with pH of 6.56) suggesting possible acidity. The low pH in groundwater may be due to natural geochemical and biochemical processes within the aquifers (Edwards, 1981). The presence of sulphides and carbonaceous matter in the ore formations may be due to the rocks undergoing natural geochemical and biochemical degradation (oxidation). When these rocks are in contact with oxygen gas containing water, there is an increase in hydrogen ion activity in the waters with which they are in contact (Edwards, 1981).

Bio-oxidation of sulphur-containing materials may also take place in tailing dumps in abandoned mine areas. This can result in hydrogen ions migrating into aqueous environment and, thereby, increase the acidity of groundwater (Edwards, 1981). Acidity gives sour taste to water. It is for this reason of taste that the EPA (1997) and WHO (2004) limit the pH range for water potability from 6.5 to 8.5. Consequently, from Fig. 2, pH values for most of the groundwater sources in the study area were lower than the WHO and EPA limits which suggests a potential taste problem. The BHs within the project vicinity recorded slightly lower values than HDWs (Fig. 2). Thus though both water sources (BHs and HDWs) are slightly acidic, BHs are more acidic than HDWs. This means BHs from the study area are more likely to cause health problems such as acidosis (Nkansah *et al.*, 2010) than HDWs. The BHs are likely to also corrode reactive metal fixtures.

Total dissolved solids (TDS): Total dissolved solid (TDS) is a measure of total inorganic and organic substances dissolved in water (Bakobie *et al.*, 2015). It is one of the characteristics which determine the quality of drinking water (Bakobie *et al.*, 2015). TDS values recorded for ground and surface water sources were within the WHO (2004) limit of 1,000 mg/l. This indicates that the water bodies in the study area are generally fresh (WHO, 2003). Water is regarded as fresh if the TDS value is less than 1,000 mg/l (WHO, 2003). The taste of water with TDS level less than 600 mg/l is generally considered to be good whereas water with TDS above 1,200 mg/l becomes increasingly unpalatable (WHO, 2004). The highest groundwater TDS concentration was recorded at GW2. Since the sampling point GW2 is outside the mining and processing facilities, it is possible seepage of effluent discharges, as well as agriculture and domestic waste substances might have contributed to the high TDS values recorded. TDS values for both HDW and BH samples were within WHO limit. WHO (2004) reported that water with a TDS level less than 600 mg/l is more palatable and generally considered to be good. Hence, the HDW and BH samples are of good quality and potable since the values are all less than 600 mg/l.

***Temperature*:** Minimum and maximum temperature values for ground and surface water bodies were both recorded at sampling points outside concession of the mines and processing activities and facilities. The EPA of Ghana (1997) stipulates that water for drinking and domestic purposes should have a temperature not exceeding 30 ^{O}C. The temperature values recorded for water in the study area were within the EPA limit of 30^{O}C. Thus suggesting the quality of water in Bibiani with respect to temperature could be suitable for drinking as well as for domestic uses.

***Electrical conductivity (EC)*:** There is a relationship between conductivity and the total concentration of dissolved ions in water (Oyelude *et al.*, 2013). The EC values fell within the WHO (2004) compliance limit of 1,000 μS/cm for drinking water (Fig. 4). The sampling points at GW2 and GW4 however recorded much higher conductivity values than the other groundwater sampling points (Fig. 4). Since GW2 and GW4 are outside the mining and processing facilities, it is possible seepage of effluent discharges, as well as agriculture and domestic waste substances might have contributed to the high conductivity values recorded. Weathering of sulphide-bearing rocks greatly facilitated by mining, accounting for the elevated ion concentrations in GW2 and GW4. Electrical conductivity (EC) of water is a direct function of its total dissolved salts (Kusi, 2016). The conductivity levels of BH samples were generally higher than the values recorded for HDW samples. EC is an index to represent the total concentration of soluble salts in water (Kusi, 2016). BH samples recorded higher EC values than HDW samples. This may be directly responsible for the TDS concentrations being higher in BH samples than HDW samples.

Thus according to Kusi (2016), the dissolutions of cations and anions in the host-rock by groundwater in the course of its movement accounts for the higher concentration of total dissolved solid (TDS). At sampling point SW3, a high conductivity value was recorded. SW3 is located outside mine activities. For this reason, the high value recorded might be due to Surface and agricultural run-offs as well as domestic effluent discharges. Since conductivity values for ground and surface water samples fell within the WHO, (2004) guideline limit of 1,000 μS/cm for drinking water, it could be concluded that no adverse health effects may be associated with the water bodies in Bibiani and its environs

***Phosphate*:** The permissible limit of phosphate in drinking water has been fixed at 0.1 mg/l by the WHO (1993). Comparing the recorded phosphate values with the WHO (1993) value of 0.1 mg/l it could be concluded that phosphate concentrations for ground and surface water samples were high. This can be attributed to eroded materials from waste rock dumpsites and old tailings coming in contact with the water table via seepage. For sampling points not close to mining activities and processing facilities, the high phosphate concentrations might be as a result of detergents from domestic activities that infiltrate the topsoil. High phosphate concentrations in surface water bodies indicate the presence of pollution and are largely responsible for eutrophic conditions.

Total alkalinity: Alkalinity ($CaCO_3$) is the capacity of a solution to neutralise acids (Addo *et al*., 2016). It is also a measure of the presence of bicarbonate, carbonate or hydroxide constituents. Generally, all the sampling sites analyzed achieved 100% compliance (Addo *et al*., 2016) with the WHO (2004) and GSA (2009) guidelines. The WHO (2004) and GSA (2009) recommended concentrations of 1000 mg$CaCO_3$/l and 500 mg$CaCO_3$/l respectively for both surface water and groundwater. It can thus be inferred that the water sources in Bibiani per this parameter are suitable for drinking purposes and other domestic uses.

Total hardness: All the concentrations recorded were within the WHO (2004), guideline limit of 500 mg$CaCO_3$/l. Hardness is an important criterion for ascertaining the suitability of water for domestic, drinking and many industrial supplies (Addo *et al*., 2016). In this study the hardness criterion was used exclusively for determining the usability of the water supplies under study for domestic and drinking purposes. Water has been classified on the basis of hardness as follows by WHO; soft (0 to 50 mg $CaCO_3$/l), moderately soft (50 to 100 mg $CaCO_3$/l), slightly hard (100 to 150 mg CaCO3/l), moderately hard (150 to 200 mg $CaCO_3$/l), hard (200 to 300 mg $CaCO_3$/l) and very hard (over 300mg $CaCO_3$/l) (WHO, 1984). Based on this, the ground water studied is generally very hard which implies that it contains enough calcium that is essential for good health. It also affects the lathering ability of water when used for washing. The higher values recorded might have resulted from effluent discharges from the mines that seeped underground. It could also be attributed to weathering of limestone, sedimentary rocks and calcium bearing minerals largely facilitated by mining activities. Other sources such as excessive application of lime to the soil in agricultural areas might have contributed to the hardness of the water in the study area. From Fig. 7, HDW samples contained relatively lower concentrations than BH samples. The relatively lower values recorded in HDWs, in this study for the hardness of water may be due to the presence of lower concentrations of dissolved calcium and magnesium in these water sources.

Surface water from the study recorded varying levels of hardness between 320 and 465 mg$CaCO_3$/l (Fig. 7). The WHO (2004) recommends 500 mg$CaCO_3$/l as the guideline value for surface water. Comparing the recorded values with the WHO (2004) value of 500 mg$CaCO_3$/l surface water bodies in Bibiani could generally be described as safe. Thus surface waters in Bibiani and its environs can be used for domestic purposes without any human health concerns.

Arsenic (As): As was discovered in all surface water bodies in the study area, the concentrations were within the limits of the WHO (2004) guideline of 0.01 mg/l. Even though 75% (three sampling points) of all the sampled locations for surface water were within the Maximum Compliance Limit (MCL) of 0.01 mg/l for As, there were marginally high levels of As recorded in SW2 (Fig. 2). This raises some concerns since arsenic is a known carcinogen.

In spite of the high presence of pyrite and arsenopyrite associated with the gold ore, As concentrations in groundwater samples were very low. This suggests that, there might be a level of co-precipitation of As with ferric oxyhydroxide in the creeks before possible infiltration into the aquifer (Kortatsi, 2006). Arsenic levels in groundwater differed significantly from that of surface water (Fig. 8). It could be deduced that surface water bodies were more affected by As contamination. As is not only a known carcinogen (an agent producing and exciting cancer), but a toxin (Smedley *et al.*, 1996). Skin cancer has been associated with long-term, low-level exposure to arsenic through drinking water (Kortatsi, 2006). Thus, people living in communities where significant As concentrations were detected could potentially, be at risk of diseases associated with long-term low-level As ingestion. However no morbidity case is expected where concentration in drinking water remains less than 0.01 mg/l. It is important therefore to constantly monitor drinking water in the area in order to forestall any physiological problems that may arise due to unexpected increases in arsenic concentration.

Total cyanide (CN): Cyanide is a poisonous substance that can infiltrate and pollute groundwater (Tiimub *et al.*,2012). It is mostly introduced into water bodies as a result of mining activities and improper waste disposal. Cyanide acts by blocking the cells of humans from effectively utilizing oxygen (Tiimub *et al.*,2012). Cyanide was detected in all the water bodies in Bibiani (Fig. 9). The levels detected were however, less than the 0.1 and 0.07 mg/l guideline limits set by the WHO (2004) and EPA (1997) respectively. The low levels detected provide a useful early warning of potential problems. HDW samples contained higher levels of cyanide than BH samples though both water sources recorded levels within WHO (2004) and EPA (1997) Minimum Detection Limits (MDL). Blanc *et al.*, (1985); Chandra *et al.*, (1980) and El Ghawabi *et al.*, (1975) have all stated that chronic low exposure to hydrogen cyanide causes neurological, respiratory, cardiovascular and thyroid effects. It is therefore important to constantly monitor CN levels in water bodies (drinking water in particular) in Bibiani and its environs.

Manganese (Mn): Surface water bodies investigated in this study had Mn concentrations below the WHO guideline value of 0.5 mg/1

(WHO, 2004) prescribed for drinking and domestic purposes (Fig. 10). Ground water samples also had concentrations within the WHO guideline.

HDW samples recorded values higher than BH samples. Samples from GW3 (located within the mines) indicated non - compliance with the WHO guideline limit of 0.5 mg/l stipulated for drinking and domestic purposes. Manganese occurs naturally in many surface water and groundwater sources and in soils that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas (WHO, 2011). The high levels of manganese recorded at GW3 could be attributed to probable interaction of groundwater and rock layers or soil minerals. It could also be as a result of natural geochemical and biochemical processes such as weathering of manganese bearing minerals and rocks within the aquifers. Moreover, GW3 is located within concession of the mines and the high Mn concentration detected could also be attributed to anthropogenic sources such as effluent discharges and acid-mine drainage from mining activities. Apart from the possible health effects, high levels of manganese in drinking water cause brownish coloration of water which also affects its taste (Tiimub *et al.*,2012).

Iron (Fe): Iron is the fourth most abundant element, by weight, in the earth's crust (Ahmed and Eyaife, 2014). The amount of Fe in water varies depending on the geology of the area and other chemical constituents of the water. Underground water normally contains Fe^{2+} due to lack of enough oxygen in the aquifer (Ahmed and Eyaife, 2014). Fe concentration in water samples from the study locations were non – compliant with the 0.3 mg/l guideline set by the WHO (2004) and EPA (1997) (Fig. 11). The major minerals found in igneous rocks; amphiboles, ferromagnesian micas, ferrous sulphide (FeS), ferric sulphide or iron pyrite (FeS_2), and magnetite (Fe3O4) form the natural sources of iron (Todd, 1980). The geology of the Bibiani area is such that rock mineral types present include arsenopyrites (FeAsS), magnetite, pyrite (FeS_2), (PbS) and iron-rich carbonates. The presence of FeAsS, FeS_2 and PbS in the study area is a major natural source of iron in the water samples. Iron in recommended amounts is beneficial for blood building. The presence of iron in water is attributed to rock water interaction and effluents from industries like tanning and dyeing etc. However, iron in water becomes a nuisance when it occurs in excess. For instance, excess iron produces a metallic taste and orange brown stains in water. Surface water samples recorded higher Fe concentrations than groundwater samples (Fig. 11). The high Fe concentrations found in surface water samples compared to that of groundwater might be suggestive of the mineral-water interactions and oxidation-reduction reactions taking place in such systems. Effluent discharges as well as leachate from waste rock dump and tailing dams might also have contributed to the high Fe levels in surface water.

CONCLUSION

Groundwater had lower pH ranging from 5.77 to 6.56 pH units than surface water ranging from 6.57 to 7.14. The differences in pH between ground and surface waters may be due to natural geochemical and biochemical processes within the aquifers. Groundwater samples had higher concentrations of dissolved ions (ranging from 360.167 to 957.12 µS/cm) and so contains more minerals than surface waters (ranging from 451.67 to 774.72 µS/cm). Mining related contaminants detected were As, CN, Mn and Fe. Groundwater in the study area was established to be contaminated by Mn and Fe. Mn contamination may be due to natural geochemical and biochemical processes within the aquifer. Anthropogenic sources such as effluent discharge and acid-mine drainage from mining activities might also have contributed to the high Mn concentration in groundwater. High Fe concentrations may also be attributed to mineral water and oxidation – reduction reactions taking place in the system. Effluent discharges possibly from mine activity together with leachate from waste rock dumpsite and tailing dams may also contribute to the excessive Fe levels in groundwater. It was also observed from the results that pH, TDS, EC, total alkalinity, total hardness , Arsenic and total cyanide levels in HDW and BH samples showed 100% compliance with the WHO and EPA permissible guidelines while Mn and Fe levels indicated traces of non – compliance.

Surface water bodies were found to be contaminated by As and Fe. Arsenic contamination may be due to the high presence of arsenopyrite in association with the gold ore. Fe levels in all the surface water bodies exceeded WHO/EPA guidelines. The high levels of Fe in surface water samples can be attributed to mineral-water and oxidation – reduction reactions taking place in the system. Inflows from waste rock dumpsites and old tailing dams might also have contributed to the increased Fe level. Compared to WHO / EPA guideline, few of the ground and surface water supplies had one or more trace metal (Fe, As and Mn) levels outside acceptable limits set for drinking water. Most of them however have levels safe for human consumption.

REFERENCES

Addo, M. G., Oti-Boateng, W. and Obiri-Danso K. (2016). Bacteriological quality and metal levels of boreholes and hand-dug well within the Golden Star Wassa mining areas in Ghana. *African Journal of Microbiology Research. 10(17): 586-590.*

Aghazadeh, N. and Mogaddam, A. A. (2010). Assessment of groundwater quality and its suitability for drinking and agricultural uses in the Oshnavieh Area, Northwest of Iran. *Journal of Environmental Protection, 1:30-40.*

Ahmed S. and Eyaife O. C. (2014). Physico-chemical and Bacteriological quality of ground water at Abubakar Tatari Ali Polytechnic Bauchi, Nigeria. *European Scientific Journal, 10(18):473-477.*

Anane-Acheampong, O.P., Darkwah, L. and Owusu-Boateng, G. (2013). Mine water and the environment: a case study at Central African Gold Bibiani Limited, Ghana. *Global Advanced Research Journal of Physical and Applied Sciences, 2(2): 39-4*6.

Bakobie, N., Fuseini, M.A. and Duwiejuah, A. B. (2015). Water quality assessment of hand-dug wells in Janga, Ghana. *International Research Journal of Public and Environmental Health, 2(12): 199-104*

Blanc, P., Hogan, M., Mallin, K., Hryhorczuk, D., Hessl, S. and Bernard, B. (1985). Cyanide intoxication among silver-reclaiming workers. *Journal of the American Medical Association 253:367-371.*

Chandra, H., Gupta, B. N., Bhargave, S. H., Clerk, S. H. and Mahendra, P.N. (1980). Chronic cyanide exposure – A biochemical and industrial hygiene study. *Journal of Analytic Toxicology. 4:161-165.*

Doso, S. Jnr, Ayensu-Ntim, . A, Twumasi-Ankrah, B., Twum Barimah, P. (2015). Effects of Loss of Agricultural Land Due to Large-Scale Gold Mining on Agriculture in Ghana: The Case of the Western Region. *British Journal of Research, 2: 6.*

Edwards, R. W. (1981). The impact of coal mining on river ecology, scientific section symposium on mining and water pollution. Institute of Water Engineers and Scientists. *International Journal of Basic and Applied Science. 5(10): 874-880.*

El-Ghawabi, S. H., Gaafar, M. A., El-Saharti, A. A., Ahmed, S. H., Malash, K. K. and Fares, R. (1975). Chronic cyanide exposure: a clinical, radioisotope, and laboratory study. *British Journal of Industrial Medicine 32: 215-219.*

EPA (1997). General environmental quality standards. Environmental Protection Agency, Ghana.

GSA-Ghana Standards Authority (2009). Limits for Drinking water, 3rd Edition.

Kortatsi, B. K. (2006). Groundwater Quality in the Wassa West District of the Western Region of Ghana. *West African Journal of Applied Ecology, 11: 31-34.*

Kusi, Y.O.A. (2016). Prevalence study of microbiological and physicochemical quality of water from Boreholes and Hand-dug wells located in Ejisu-Juaben Municipal District's urban communities. *Journal of Environmental and Occupational Science. 5(2): 35-40*.

Nkansah, M. A, Boadi, N. O and Badu, M. (2010). Assessment of the quality of water from hand-dug wells in Ghana. *Environmental Health Insights. 4(7): 43-48*.

Oyelude, O. E., Densu, A.E and Yankey, E. (2013). Quality of groundwater in Kassena-Nankana District, Ghana and its health implications. *Advances in Applied Science Research*. 4(4): 445-450.

Smedley, P. L, Edmunds, W. M, Pelig-Ba, K. B (1996). Mobility of arsenic in groundwater in the Obuasi gold-mining area of Ghana: Some implications for human health. *Environmental Geochemistry and Health,* 113:163-181.

Tiimub, B. M., Kuffour, R. A. and Akwatia, G. A. (2012). Quality Determination of Groundwater for Drinking at Nkawkaw in the Eastern Region of Ghana. *Civil and Environmental Research*, 2(9): 58-65.

Tiimub, B. M., Dartey, E and Avornyotse, C. K. (2015). Determination of selected heavy metals contamination in water from downstream of the Volta Lake at Manya Krobo, District in Eastern Region of Ghana. *International Research Journal of Public and Environmental Health, 2(11): 168-174*.

Todd, D. K. (1980). *Groundwater hydrology,* 2nd edn. John Wiley and Sons, Inc. N.Y, Chichester, Brisbane, Toronto.

WHO (1984). Guidelines of drinking water quality, Vol. 1, Recommendations, WHO, Geneva, 19-115.

WHO (1993). Guidelines for drinking water quantity. 2nd. Ed.,1993, World Health Organization, Geneva.

WHO (2003). Total dissolved solids in drinking: Background document for the development of WHO Guidelines for Drinking – Water Quality. Geneva, 2003.

WHO (2004). WHO guidelines for drinking water quality, 3rd. ed. Volume 1. World Health Organization – Geneva.

WHO (2011). Manganese in drinking water. Background document for development of WHO Guidelines for Drinking-water Quality .