The Impact of Small Scale Mining on Irrigation Water Quality in Asante Akim Central Municipality of Ghana

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Abstract

Small scale mining is a major threat to water resources and agricultural activities in most mining communities across Ghana. This study investigated the effect of small scale mining on the quality of water for irrigation from some selected sites along a river and a reservoir which was used as a control. The physical and chemical parameters of the water samples were measured using standard methods for water quality analysis. The samples were acid digested and assayed using Atomic Absorption Spectrophotometry (AAS). The study revealed that several of the physico-chemical parameters (turbidity, pH, conductivity, TDS) and heavy metals such as Pb and Hg were significantly higher (5% level of significance) at the river sites compared to the reservoir. Whilst most of the parameters measured were within range of the Food and Agriculture Organisation (FAO) limit for irrigation water quality, Hg, Cd, K and turbidity levels were higher than FAO permissible limits for irrigation water. Hazard assessment based on the sodium adsorption ratio (SAR), US Salinity laboratory classification and the Wilcox diagram for irrigation water quality showed the water to be within acceptable salinity and sodium limits for irrigation. It is inferred from the findings that activities of small scale miners along the river affects the quality of the water. The high turbidity and detection of some level of heavy metals in the water should be a major concern to stakeholders in the Municipality as continuous influx of small scale miners in the area could increase heavy metal concentration beyond the acceptable thresholds.

Introduction

Mining, which involves the extraction of naturally occurring minerals from the earth's crust, is considered the world's second oldest and most important industry after agriculture (Amponsah-Tawiah, 2011). In Ghana, the history of mining dates back to the 4th century with small scale mining being the main form of mineral exploration at the time, when gold was used in diverse ways by indigenous craftsmen (Hayford *et al.*, 2008). Small scale mining in Ghana has experienced tremendous growth in the past two decades with gold as the main mineral extracted in commercial quantity. The industry has contributed immensely to the socio-economic development of the country. It has over the years created numerous employment, especially, in rural areas where there are limited formal sector jobs and paid job opportunities. It is estimated that, about 1,000,000 people are directly employed in the small scale mining industry of Ghana (Hilson, 2009; Kwatia, 2015). It contributes significantly to Gross Domestic Product (GDP) of the country. In the year 2011, small scale mining contributed about 28% of total gold production in Ghana, which had significant effect on the 14.4% GDP growth attained in that year (Aryee, 2012).

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Mining, regardless of the level of operation has some degree of impact on the environment. In spite of the numerous benefits derived from the industry, small scale mining has been implicated in recent times as a source of pollution to water systems. However, the extent of damage varies and depends on the scale of mining and processing methods adopted (Aryee *et al.*, 2003). In small scale gold mining, minerals are mostly extracted from alluvial deposits along waterways. Rudimentary tools such as chisels, hammers, shovels, pick-axes and pans are used in collecting the ore (Aryee *et al*., 2003). The gold is then extracted by crushing and grinding the ore, followed by the addition of mercury to form an amalgam which is roasted to get the metal gold (Hayford *et al.*, 2008; Donkor *et al.,* 2015). The waste product which contains heavy metals and other forms of pollutants are discharged directly into water bodies thereby polluting the water. The tailings from mine sites are therefore often toxic and pose serious threats to human, animals and aquatic life (Hayford *et al.*, 2008; Cobbina *et al.,* 2015). Water from such areas are most often considered unsafe for domestic and industrial use.

Vegetable farming largely depends on availability of fertile soil and constant supply of water (Gyau & Spiller, 2007). However, like many parts of the developing world, farmers in Ghana depend on rainfall for crop production. This is an exercise which restricts productivity since farmers are only able to actively produce vegetables in the wet season (Yidana *et al.,* 2011). With recent changes in rainfall pattern, quantity and periodic droughts, farmers are expected to experience more problems if there are no alternate sources of water. In effect, rain-fed agriculture alone is no more sustainable and therefore irrigation schemes are being encouraged as means of ensuring continuous crop production to meet the increasing world population growth (Yidana *et al.,* 2011). Irrigated agriculture contributes substantially to the global fight against food insecurity and poverty reduction in the developing world. In Ghana, it is estimated that over 75% of vegetables consumed in the urban centres are from irrigated vegetable farms (Drechsel and Bernard, 2014). However, there are instances of the use of unwholesome water for irrigation purposes. Akoto *et al.,* (2015) reported of the use of untreated wastewater for irrigation during the dry season in Ghana. In a study, it was found out that nearly 800 farmers in the national capital, Accra, made use of untreated wastewater for irrigation (Akoto *et al*., 2015). Thus, while irrigated agriculture is contributing immensely to food security and the livelihood of farmers, in some instances the quality of water used for irrigation is compromised. Several studies have reported very high levels of faecal coliform, viruses and *E. coli* in water used by urban farmers across the country (Silverman *et al.,* 2013; Donkor *et al*., 2010; Amoah *et al*., 2005,). It is therefore important to assess the quality of the water used in order to prevent situations of crop failure, retarded growth and food contamination (Diouf, 1997) since the quality of water used in irrigated vegetable production has effect on the productivity of crop, soil and consumers' health (Drechsel *et al.,* 2015).

Due to the scarcity of good quality water for irrigation purposes especially during dry season, vegetable farmers in many parts of Ghana including Asante Akim Central Municipality tend to use water from rivers polluted by mining activities for vegetable production. The persistent use of such water for irrigation could increase the concentration of heavy metals in the soil and uptake of metals by plants (Lente, *et al.,* 2014), thereby affecting the quality and safety of the vegetables for human consumption. Several studies have shown that increasing concentration of heavy metals in soil could increase the potential of crop uptake (Sharma *et al.,* 2008; Mapanda *et al.,* 2007; Akoto *et al.,* 2015). Also the persistent nature of heavy metals enhances its accumulation in both the edible and non-edible parts of vegetables (Arora *et al.,* 2008). Suffice to say that, the interaction between irrigation water, soil and vegetables produced, may be a major pathway for heavy metal transfer to humans (Alam *et al.,* 2003; Akoto *et al.,* 2015). The consumption of such vegetables may serve as a source of heavy metals poisoning to humans. This can pose significant health risk to consumers, leading to various chronic diseases, particularly, in high concentrations or in prolonged dietary intakes (Sharma & Prasad, 2009).

There have been several works on irrigation water quality in Ghana. However, most of these studies are focused on urban wastewater reuse for irrigation and its implication on vegetables produced (Ackah *et al.,* 2014; Akoto *et al.,* 2015; Lente *et al.,* 2014; Samuel *et al.,* 2013). Similarly, most studies on water quality in mining communities were focused on the impact of mine operation on water quality for drinking and domestic use only, with no emphasis on agriculture or irrigation. This study bridges the gap by seeking to evaluate the effects of small scale mining on irrigation water in the Asante Akim Central Municipality.

Materials and methods

Study area

The study was conducted in the Asante Akim Central Municipality of the Ashanti region of Ghana. The municipality covers a land area of 1,160 square kilometers with a total human population of 71,508 (Ghana Statistical Service [GSS], 2014). The Municipality shares boundaries with five districts within the Region, namely Asante Akim North in the north, Ejisu-Juaben and Sekyere east in the west, Asante Akim South in the east and south and Bosome-Freho in the south-western part (Fig. 1). The geology of the Municipality is characterized by varied underlying rock materials such as granite, biotite, muscovite etc. (GSS, 2014). The forest and Savanna ochrosols are the main soil types in the area. The Asante Akim Central Municipality is within the moist semi- equatorial belt. The area experiences double rainfall maxima with an average annual rainfall range of 125-175cm. Agriculture is the main economic activity in the area, employing about 50% of the household population in the Municipality. The Asante Akim Central Municipality is also noted for the abundance of gold deposits. This has attracted a lot of people to the municipality making it one of the notable gold mining areas in Ashanti Region. Small scale mining is the main form of mining with only one large scale mining company based in Konongo. Both legal and illegal (galamsey) small scale mining are practiced in the Municipality. However, the studied sites were dominated by illegal small scale miners.

River Anuru as well a reservoir as control study site. River Anuru bounds the Asante Akim Central Municipality to Ejisu-Juaben Municipality at the west. The river was selected because of its function as a source of water for irrigational farming and a receptacle for tailings from illegal small scale mining activities (popularly called "*galamsey*"). The sites along the river were chosen due to the presence of

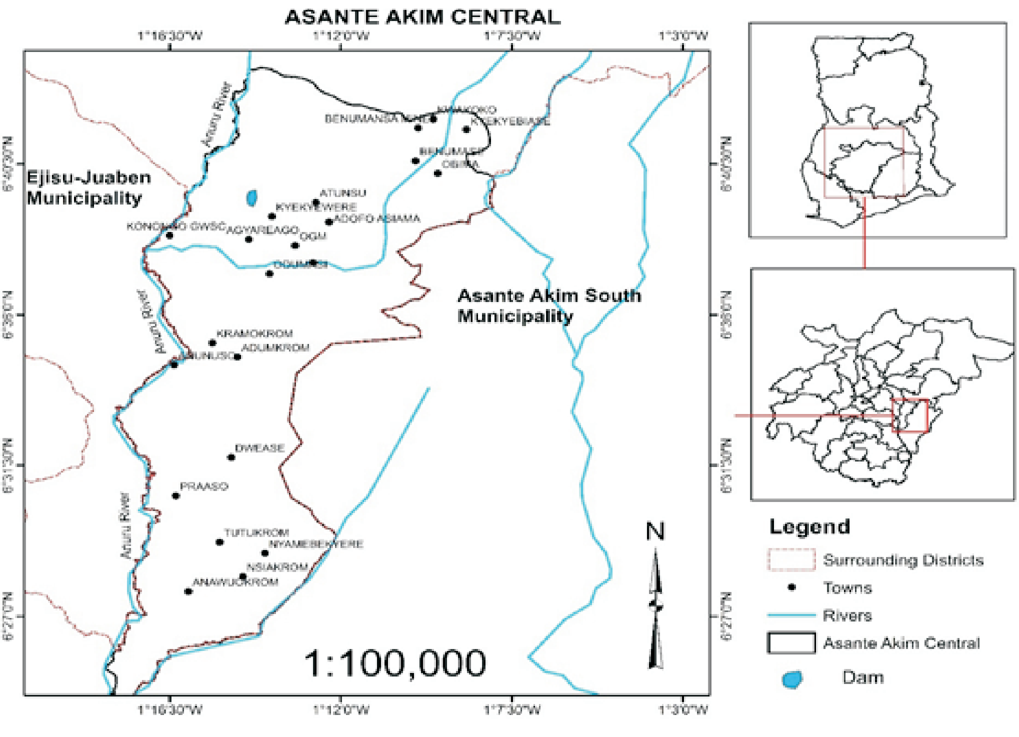

Fig. 1: Map of Asante Akim Central Municipality and other neigbouring districts

Sampling design

Factors such as accessibility, activities around the sites and sources of water were considered in selecting the sampling sites. The water samples were collected from the upstream, midstream, and downstream of irrigated vegetable farming around them. In addition, the upstream and midstream sites were particularly selected because they were the points of operation for some small scale miners. The reservoir was selected as a control because of the presence of irrigated vegetable farming in the area and the fact that there was no small scale mining operation in the area at the time of the study; therefore, the water used for irrigation was not affected by mining activities. The reservoir is about 5km away from the closest mine sites. These sampling sites were identified and selected with the help of the District Extension Officer.

Water sampling

A total of sixty-four (64) water samples were collected from the four sampling sites in the study area. Each site had two sampling points. Four replicates were collected monthly from each sampling site from November 2015 to February 2016. This period was selected because it is the dry season and the period for irrigated vegetable farming in the area. The high demand of vegetable in this period serves as an incentive for farmers to enhance their income hence the use of these water sources for irrigated vegetable production. The water samples were collected using a well-labelled 500ml polyethylene sample bottles that had been cleaned with tap water and rinsed with deionized water prior to sampling. At each sampling point, the bottles were once again thoroughly rinsed with the sourced water to prevent any possible contamination. Two water samples were taken at each point per visit; one for heavy metals and the other for physico-chemical parameters analyses. The samples for heavy metal analyses were acidified with two drops of concentrated nitric acid (HNO_3) on the field. The samples were kept in an iced chest at a temperature of about 4°C and transported to the laboratory for analysis.

Physical and chemical analysis

Parameters such as electrical conductivity (EC), total dissolved solids (TDS), and temperature were determined *in-situ* using sens ION 5 HACH conductivity meter. The pH was also measured *in-situ* using Jenway pH meter. All the instruments were calibrated using standard solutions prior to the measurements. The pH meter was calibrated using pH 4, 7 and 10 buffer solutions while potassium chloride solution of concentrations 0.01 M and 0.1 M were used to calibrate the conductivity meter. Turbidity of the water was measured using Hach DR/890 Colorimeter. Chemical analysis of sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), nitrates (NO_3), phosphates (PO_4^{3-}) and sulphates (SO_4^{2-}) were conducted in the Ecological Laboratory of University of Ghana using standard procedures (APHA,1999). The water samples were digested for heavy metal analysis using the hot plate digestion method. Concentrated nitric acid (HNO_3, 66%) and hydrochloric acid (HCl, 67%) were used as reagents for the digestion. Digested samples were assayed for the presence of heavy metals using the VARIAN AA 240FS- Atomic Absorption Spectrophotometer in an acetylene-air flame. The metals measured include mercury (Hg), arsenic (As), cadmium (Cd), lead (Pb), iron (Fe), manganese and zinc (Zn).

Determination of water quality for irrigation

The suitability of the water sample for irrigation was determined by using the Sodium Adsorption Ratio (SAR). The sodium percentage and the electrical conductivity were used to generate the Wilcox and US Salinity Laboratory (USSL) irrigation water diagrams (Yidana *et al.,* 2011). These diagrams were used to categorise the quality of the water samples for irrigation. These systems of classification were selected because they are the most accepted and commonly used criteria for irrigation water assessment. Based on this classification, farmers or researchers are able to develop good irrigation schemes. It also plays an essential role in determining the appropriate types of soils for a particular irrigated farm as well as the selection of crops since some crops are sensitive to some parameters such as salinity, sodium etc. Additionally, the SAR was used to characterise the water based on the Food and Agriculture Organisation (FAO) guideline. SAR was determined from the total concentration of sodium (Na), magnesium (Mg) and calcium (Ca) ions in the water samples by using the formula:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

Where cation measurements are expressed in milliequivalent per litre meq/l) (Hussain *et al.,* 2010).

The sodium percentage in the water samples was determined from the mean concentrations of sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) ions by using the formula below:

$$Na\% = \frac{Na}{(Na+K+Mg+Ca)} \times 100$$

Where cation measurements are expressed in milliequivalent per litre (meq/l) (Hussain,*et al.,* 2010).

Data analysis

The means and ranges of the physico-chemical parameters and the heavy metals were determined using the Statistical Package for Social Science (SPSS) software version 20.0. A one-way analysis of variance (ANOVA) was used to determine if differences exist among the parameters measured in the water from the different sites at $P \leq 0.05$. The differences in means between the sites were identified using Tukey's honestly significant difference (HSD) multiple comparison.

Quality control and quality assurance

Quality control and assurance measures were strictly observed in order to ensure that the results obtained were devoid of errors. It was ensured that deionized water was used at all instances in dilution and also rinsing of apparatus. High quality reagents and chemicals were used. Reference standards, blanks and duplicates were used as internal positive controls for the analyses. The duplicates and blanks were digested using the same procedure and conditions as the research samples. All the equipment/instruments used were calibrated. The blanks were used to monitor contaminations during sample preparation whilst the standards also checked the efficiency of the equipment being used. The duplicate was also used to monitor the reproducibility of the method used.

Results and discussion

Physico-chemical parameters

The results of the study showed that most of the physico-chemical parameters measured were significantly higher (5%

level of significance) at the river sites compared to the control site. Table 1 presents the mean concentrations of the physico-chemical parameters of the water samples. The upstream and control sites recorded the highest and least values in pH, total dissolved solids, phosphate, sodium, calcium, and magnesium respectively. Similarly, parameters such as turbidity, conductivity, sulphate and potassium were higher at the midstream. However, the temperature of the water samples were generally higher at the control as compared to the sites on the river.

pH is one of the most important parameters for water quality assessment and this is due to its influence on the chemical, biological and geological processes that take place in the environment (Robinson, 2012). With the exception of the control and the midstream samples that had mean pH of 5.4 and 6.4 respectively, all the other sampling sites recorded mean pH that were within the FAO permissible limits of 6.5–8.5 (Ayers & Westcot, 1994). The irrigation water for the study area was moderately acidic; however, the control site was more acidic than the sites along the river. This observation may be due to the presence of algae and other aquatic plants on the surface of the reservoir. Algal respiration leads to the release of carbon dioxide which reacts with the water to produce carbonic acid, which result in decrease in pH and an increase in acidity (Robinson, 2012). Similarly microbial utilization of

TABLE 1

Physico-chemical parameters of water samples measured at vegetable growing sites in the Asante Akim Central Municipality

Sites	*Downstream*	*Midstream*	*Upstream*	*Control*	*P-values*	*FAO Limits*
Parameters	*Mean concentrations and standard deviation*					
Turbidity (NTU)	62.8 ± 3.23	125.6 ± 22.9	80.7 ± 5.34	35.2 ± 2.10	0.001*	35
pH	6.5 ± 0.43	6.4 ± 0.29	6.6 ± 0.26	5.4 ± 0.60	0.001*	6.5–8.5
Electrical conductivity (µS/cm)	196.6 ± 8.23	238.7 ± 24.50	225.6 ± 9.23	123.2 ± 12.35	0.022*	3000
Total dissolved solids (mg/l)	98.8 ± 7.11	113.5 ± 10.98	113.9 ± 12.12	57.3 ± 4.20	0.012*	2000
Nitrate (mg/l)	0.44 ± 0.10	0.52 ± 0.06	0.56 ± 0.11	0.49 ± 0.10	0.257	10
Phosphate (mg/l)	0.31 ± 0.01	0.49 ± 0.01	0.64 ± 0.02	0.29 ± 0.01	0.001*	2
Sulphate (mg/l)	17.1 ± 2.98	17.4 ± 4.34	16.8 ± 1.10	16.5 ± 2..21	0.807	2000
Sodium (mg/l)	46.2 ± 3.12	49.5 ± 2.01	49.8 ± 5.70	36.6 ± 4.50	0.061	920
Calcium (mg/l)	14.9 ± 1.11	20.9 ± 1.97	22.9 ± 2.35	9.1 ± 1.32	0.001*	800
Magnesium (mg/l)	8.57 ± 0.89	10.9 ± 1.01	13.8 ± 1.24	5.1 ± 0.20	0.003*	120
Potassium (mg/l)	13.23 ± 1.22	16.3 ± 2.34	14.85 ± 1.01	12.89 ± 1.57	0.014*	2
Temperature (pC)	26.2 ± 0.39	26.3 ± 0.25	25.5 ± 0.54	26.6 ± 0.87	0.001*	——

*Significant when $P \leq 0.05$

FAO Limits (Ayers & Westcot, 1994).

dissolved oxygen releases carbon dioxide which reacts with water to produce carbonic acid resulting in a lower pH. Additionally, the geology of the area could be a factor that influences the pH level recorded in this study as reported by Okoffo (2016). According to Jeong *et al.* (2016) the greatest hazard associated with an abnormal pH in irrigation water is its impact on the equipment used for irrigating. Very low pH in water can hasten the corrosion of irrigation facilities. Also, irrigation water with a pH outside the recommended limits may affect the availability of some plant nutrients as well as the solubility of heavy metals and other potentially toxic pollutants (Department of Water Affairs and Forestry [DWAF], 1996). Furthermore, crop foliage is damaged when it gets wet by water with abnormal pH, this could result in reduction in yield and also depreciation of the quality of marketable material (crops) (Hussain *et al.,* 2010; DWAF, 1996).

With the exception of the control site which recorded mean turbidity of 35.2 NTU which was slightly above the FAO limits of 35 NTU (Ayers & Westcot, 1994) for irrigation, all the sites along the river recorded mean values that were far above the standards for irrigation water. This may indicate the presence of particulate matter such as clay/silt, decomposed organic matter and other forms of pollutants that reduce the transparency of the water (Murhekar, 2011; Gyamfi *et al.,* 2012). Activities such as the use of excavators, earth moving equipment, shovels and pick axe in the excavation of ores could enhance the dissolution and or washing of silt into the river. The presence of algae in the reservoir could also increase turbidity. Additionally, the discharge of tailings as well as alluvial mining in the river could also be a contributing factor to the level of turbidity observed in this study. There was a significant variation among the sites ($p = 0.001$) with a mean turbidity range of 35.2–125.6 NTU. Akpan-Idiok *et al.* (2012) in a similar study in Nigeria, reported mean turbidity levels of 5.0–49.3 NTU for irrigation water which was lower than the values obtained in this study. However, Keraita *et al.* (2008) recorded a mean turbidity of 325 NTU which was higher than the highest level measured in this study. The higher levels of turbidity reported along the river could largely be due to the activities of small scale miners as reported by Yidana *et al.* (2011). Irrigating vegetables with turbid water could affect the quality of the vegetables produced, since bacteria and viruses could attach and migrate to the vegetables through solid particles in the water (Jeong *et al.,* 2016). Also high turbidity levels in irrigation water affects the aesthetic quality of the vegetables produced as reported by some farmers from the study area.

Electrical conductivity of water is a significant parameter in determining the suitability of water for irrigation as it affects the salinity of the water which subsequently affects the productivity and yield of crops (Bauder *et al.,* 2011). The conductivity levels obtained in this study were all below the 3000 µS/cm permissible limits set by FAO for irrigation water (Ayers & Westcot, 1994). This is a clear manifestation of low level of dissolved solids in the water as conductivity is usually associated with salinity and total dissolved solids (Hussain *et al.*, 2010). However, the values recorded at the main river sites were higher than at the control site. This may be due to the small scale mining activity along the stretch of the river. The results in this study are similar to the findings by Yidana *et al.* (2011) who recorded low levels of electrical conductivity in irrigation water in the southern and some coastal areas of Ghana.

Total dissolved solids is the measure of the total organic and inorganic materials dissolved in the water (WHO, 2004). The Food and Agricultural Organisation (FAO) standard for TDS in irrigation water is 2000 mg/l (Ayers & Westcot, 1994). The total dissolved solid concentrations observed (57.3–113.9 mg/l) in this study were far below the FAO limits. However there was significant variation among the sites ($p = 0.012$). TDS level were generally high at the midstream and upstream, and this could be attributed to the presence of anthropogenic activities such as farming and small scale mining activities at these points. These activities are known to influence the dissolution of minerals in rock, soils, organic and inorganic salts into the water bodies (DWAF, 1996). Since EC and TDS are indicators of salinity hazard in irrigation water, the result obtained in TDS suggest a low salinity hazard of the water used for irrigation. High concentrations of TDS in irrigation water may lead to accumulation of salts in soil. This could reduce yield in crops that are sensitive to soil salinity (Ayers & Westcot, 1994; DWAF, 1996). The TDS concentration in the water in this study were lower than 110 – 1384 mg/l reported by Ackah *et al.* (2011) in irrigation water in the Ga East municipality.

Nitrate in irrigation water is often considered as beneficial to crop production. The nitrate levels recorded in this study ranged from 0.44 to 0.56 mg/l. All the concentrations of nitrate recorded during the entire study period fell within the FAO permissible limit of 10mg/l for irrigation water use (Ayers & Westcot, 1994). This result also compares favourably with the 0.25 to 0.73 mg/l values reported by Shaki & Adeloye (2006) in a similar study. DWAF (1996) reported that, very high levels of nitrate may stimulate the growth of aquatic plants in reservoirs and water canals which could choke irrigation facilities. High concentration of nitrate in irrigation water can also cause excessive vegetative growth, poor quality and delay maturity in crops (Bauder *et al.,* 2011; DWAF, 1996). The presence of nitrate in the water may be due to surface-runs or leaching from the soils of surrounding farms which indicates the use of nitrogen fertilizer by farmers. This was confirmed by the farmers that they use fertilizers in crop production. Furthermore, indiscriminate defaecation around water banks and farms by miners/ farmers due to lack of places of convenience might also influence the concentration of nitrogen in the water.

The presence of phosphate in water may be an indication of an anthropogenic source of pollution to the water (Okoffo, 2016). However, phosphate may also occur naturally in water and sometimes in high amounts during low biological productivity (Gyamfi *et al.,* 2012).

Phosphate concentrations recorded in this study were all within the FAO permissible limit of 2 mg/l for irrigation water (Ayers & Westcot, 1994). The mean phosphate concentration was generally lower at the control site. The low levels observed may possibly be due to the uptake of the nutrient by algae and other aquatic plants, particularly, in the reservoir. Water enriched with phosphorus could enhance the rapid growth of algae and other aquatic plants (Bright, 2015). The presence of phosphates in the water at all the sites might be as a result of the use of organophosphate pesticides and phosphate fertilizers by farmers (Oyelude *et al.,* 2013).

The mean sulphate concentrations from the water samples were all within the FAO standard of 2000 mg/l for irrigation water (Ayers & Westcot, 1994). The mean sulphate levels measured ranged between 16.5–17.4 mg/l with no significant difference among sampling sites (p = 0.807). The concentrations in this study were greater than those reported by Mensah (1997) who reported mean range of 0.02–0.44mg/l. The sulphate might be from weathering of rocks or leaching from rocks that contain calcium sulphate, magnesium sulphate and/or sodium sulphate (Okoffo, 2016). Other possible sources could be anthropogenic activities, most likely, farming and small scale mining. However, the relatively low concentrations recorded from the study sites rules out these anthropogenic sources. Sulphate and phosphate are also essential plant nutrients hence their presence in irrigation water in the right amount will enhance plant growth.

Sodium concentration in water is a critical factor in determining the suitability of water for irrigation. In small quantities, sodium is an essential element for the growth of some plants. However, high concentration of sodium in irrigation water has severe toxicity (sodium hazard) effect on both plants and soil physical properties (Bauder *et al.,* 2011; DWAF, 1996). The concentrations of sodium in the water for the entire study period were far below the FAO permissible limits of 920 mg/l for irrigation (Ayers & Westcot, 1994). The highest mean level was recorded at the upstream with a mean value of 49.8mg/l. This result is similar to the findings of Akpan-Idiok *et al.* (2012) which indicated a highest mean value of 34.23mg/l from Okpauku River in Nigeria.

The FAO limits for potassium in irrigation water is 2 mg/l (Ayers & Westcot, 1994). The mean concentration of potassium recorded ranged between 12.89 to 16.3 mg/l, that is, about six times higher than FAO limits of 2mg/l at the control and also about seven to eight times higher along the river. Potassium occurs naturally in water through weathering of rocks. However, the concentration can increase if there are anthropogenic sources. The higher concentration of potassium in the water analysed could be due to the farming activities going on at the various sites. This indicates high patronage of potassium containing fertilizers by farmers due to its high demand by plants for growth and development (Kordlaghari *et al.,* 2013). It is estimated that about 95% of potassium chemical production goes into agricultural fertilizers.

Calcium and magnesium also occur naturally in water through weathering of geological materials that contain these elements (Anim *et al.,* 2011). These elements are very important in irrigation water analysis as they are used in determining the sodium adsorption ratio (SAR), which affects the permeability of water in soil, plant growth and yield (Yeboah & Mensah, 2000). The level of calcium recorded (9.1–22.9 mg/l) in this study were all within the FAO limit of 800 mg/l for irrigation purposes (Ayers & Westcot, 1994). The mean magnesium levels (5.1–13.8 mg/l) recorded at all the sites were also within the FAO standards of 120mg/l for irrigation water. The level of these elements were relatively higher at the sites along the river and this could be attributed to the activities of small scale miners as the excavation and processing of ore materials could enhance the dissolution of these elements in water (Nigam *et al.,* 2001).

Sodium and salinity hazard assessment

The salinity levels recorded in this study according to the USSL classification of salinity hazard fell within the excellent class (Fig. 2). In addition, the range of SAR values were within acceptable threshold and not included in the restriction categories of the FAO classification of SAR for irrigation water (Table 2). The results indicated that the water from the various sites met the standard for irrigation purposes based on the salinity and cations analysed. This was again confirmed by the low class and the 'excellent to good' positions observed on the USSL salinity hazard diagram and the Wilcox diagram respectively (Fig. 2 and 3). The findings in this study are similar to observation made by Yidana *et al.* (2011) who had 90% of their samples plotted within low class of the USSL diagram, possibly due to the low concentration of physico-chemical parameters recorded.

Concentrations of heavy metals in water samples from the study area

The mean concentrations of heavy metals measured in the water sample are presented in Table 2. The mean concentrations of lead (Pb) measured in this study were all within the FAO threshold of 5 mg/l for irrigation water (Ayers & Westcot, 1994). However the concentrations recorded at the control site (0.002 mg/l) were comparatively lower than the concentrations at sites along the river (0.012 mg/l, 0.04 mg/l and 0.03 mg/l). This indicated the presence of a possible anthropogenic source of pollution along the river. The high concentration of lead can be attributed to the small scale mining activity going on along the river particularly at the mid and upstream sections. Similar studies on irrigation water quality in Ghana have reported slightly higher concentrations of lead. Drechsel & Benard, (2014) reported a mean concentration range of 0.01–0.06 mg/l and 0.00–0.06mg/l in irrigation water at Accra and Kumasi respectively. Additionally, Lente *et al.* (2014) reported mean concentration of 0.08mg/l of lead in irrigation water which was two times higher than the highest mean observed in this study.

The FAO permissible limits for arsenic (As) in irrigation water is 0.10

TABLE 2

Mean sodium adsorption ratio for irrigation water at vegetable growing sites in the Asante Akim Central Municipality

Sites	EC (µS/cm)	Concentrations in meq/l				SAR	% Na	Degree of restriction on use
		Na^{+}	Mg^{2+}	Ca^{2+}	K^{+}			
Downstream	196.6	2.01	0.71	0.75	0.34	2.35	52.9	None
Midstream	238.7	2.15	0.91	1.05	0.42	2.18	47.69	None
Upstream	225.6	2.17	1.15	1.15	0.38	2.02	44.86	None
Control	123.2	1.59	0.43	0.46	0.33	2.40	56.9	None

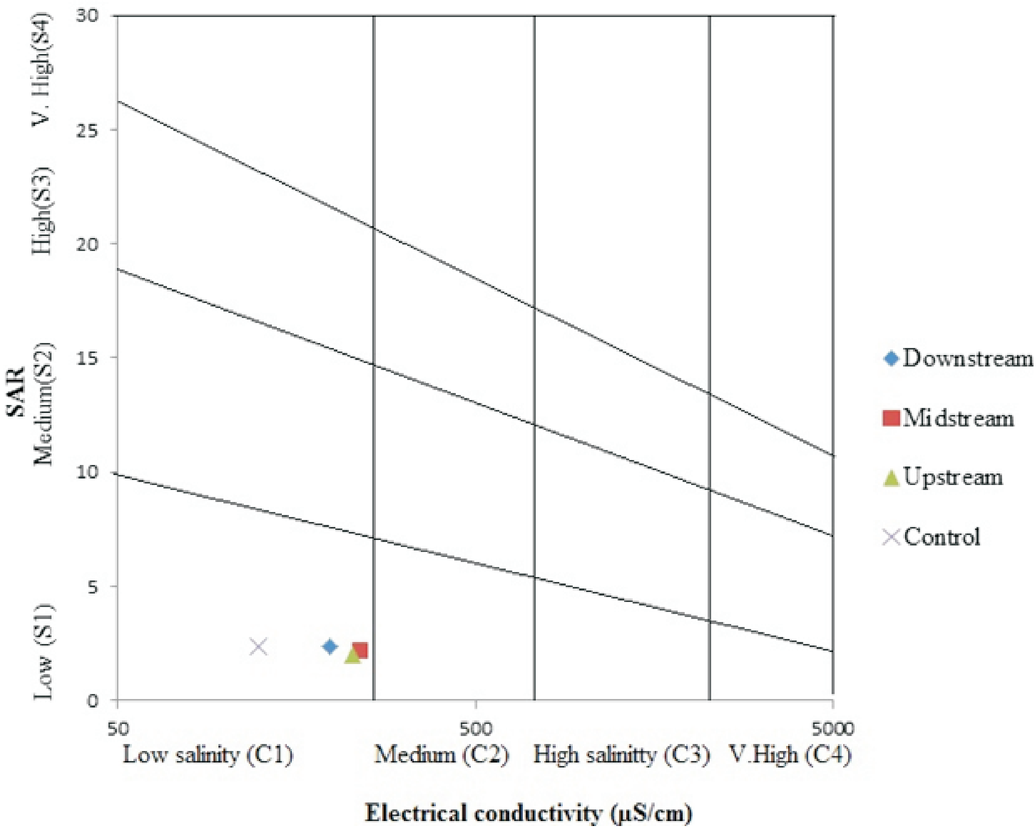

Fig. 2. Suitability of the water samples for irrigation in the Asante Akim Central Municipality base on the USSL diagram

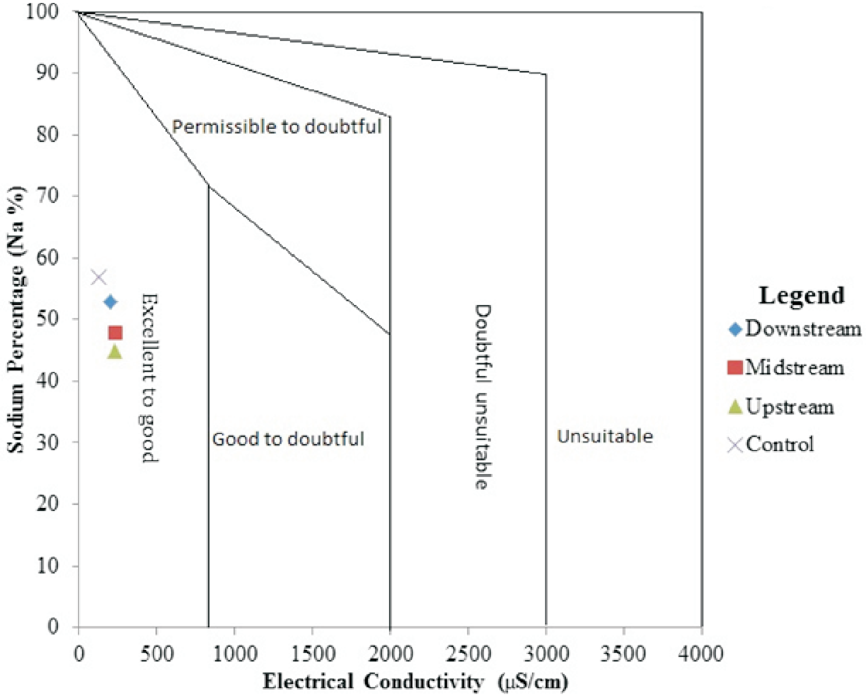

Fig. 3. Classification of irrigation water quality in the Asante Akim Central Municipality with respect to conductivity and sodium percentage based on Wilcox's diagram.

mg/l (Ayers & Westcot, 1994). The level of arsenic recorded (0.001 to 0.03 mg/l) from the various sites were lower than the limits set by the Food and Agriculture Organisation for irrigation. There was no significant variation among the sites though the concentrations of arsenic were higher along the river. The concentrations of arsenic recorded in this study were similar to the mean values reported by Drechsel & Benard (2014) in their assessment of irrigation water in Kumasi and Accra. The contamination from arsenic could be attributed to the small scale mining activity along the river and the use of pesticide by farmers in the study area. Some pesticides are known to contain some level of arsenic hence the possible source of pollution to water.

The pollution of water resources by mercury has become a common problem in most mining communities in Ghana (Donkor *et al.*,2015). This problem has been confirmed by Akabzaa *et al.*, (2009).The findings of this study demonstrated trends similar to those observed by other researchers (Akabzaa *et al.*, 2009). The mean concentrations of mercury in the water analysed ranged between 0.001 to 0.03 mg/l. With the exception of the control (0.001mg/l) and downstream (0.01mg/l) sites which recorded a mean concentration of Hg within the FAO limit of 0.01 mg/l for irrigation water respectively, all the other sites recorded mean concentrations that were above the FAO permissible limits (Ayers & Westcot, 1994). The high concentration of mercury recorded at the mid and upstream sites may be a result of the use of mercury by small scale miners in the processing of the ore for gold. These findings are consistent with the findings by Bambara *et al.* (2015) who reported mean concentration range of below detection (BD) to 0.034 mg/l of mercury in irrigation water at Burkina Faso. However, a recent study by Hogarh *et al.* (2016) found a decreasing trend in the use of mercury by small scale miners due to the regulation of the chemical by legislation. The law has restricted the use and sale of mercury in the country, hence, small scale miners have adopted an economical way of recovering used mercury in amalgam for reuse due to the cost and difficulty in acquiring the chemical. This could be the reason for the low levels of mercury observed in this study as compared to the levels observed by Tay and Momade (2006) around the same study area.

The mean concentration of manganese determined for the entire study period was within the FAO permissible threshold of 0.2 mg/l for irrigation purposes. The concentration of manganese observed along the river were higher than the control site. The high levels observed in the water can be attributed to anthropogenic activities, particularly small scale mining within and at the banks of the river. Mining in general is known to have an influence on the flux of metals from geological materials to the hydrosphere through dissolution of minerals (Akabzaa *et al.,* 2009). Tay and Momade (2006) similarly reported mean concentration of 0.05 mg/l in surface water from Bomfa a mining community in the Ashanti region of Ghana.

Iron was the most abundant metal detected in all the water samples from the various sites. The mean concentration of iron ranged from 1.60 to 3.30 mg/l and within the FAO permissible limit of 5.00 mg/l for irrigation water (Ayers & Westcot, 1994). The least concentration was recorded at the control site. The findings indicated a high occurrence of iron at the study area and this was confirmed by the high levels of the element detected in soils from the various farms. The presence of iron in the water samples could be attributed to natural geological weathering. However, the higher levels recorded along the river could be due to the activities of small scale miners. The excavation and processing of ore by mine operators exposed the geological material to the agents of weathering, hence, increasing the rate of minerals dissolution into water bodies (Akabzaa *et al.,* 2009). Abdul-Razak *et al.* (2009) and Bambara *et al.* (2015) reported mean iron values of 0.23–1.12 mg/l and 1.05–1.29 mg/l from water samples from Oti river in Ghana and Burkina Faso respectively which were lower than those recorded in this study.

The mean concentration of zinc measured at all the sampling sites were found to be less than the FAO permissible limits of 2.00 mg/l for irrigation water use (Ayers & Westcot, 1994). The concentration of the metal range between 0.02 to 0.10 mg/l for all the sites. Related studies on irrigation water have shown similar trend. In Burkina Fasso, Bambara *et al*. (2015) reported a mean concentration of 0.034 mg/l in irrigation water which is similar to the values recorded at the downstream (0.02mg/l), control (0.03 mg/l) and upstream (0.05 mg/l). Additionally, Lente *et al.* (2014) also reported a mean concentration of 0.14 mg/l of zinc in irrigation water in Accra, Ghana, which is also similar to the observation made at the midstream of the river. The concentrations of zinc measured in this study could be due to weathering of geological materials and possibly small scale mining as the highest values was recorded at the midstream which was a point of operation for miners. In addition to that, runoffs from farms could also affect the concentration since some agrochemicals contain zinc (Thorpe & Harrison, 2008).

With the exception of the water samples from the midstream that had a mean cadmium value of 0.02 mg/l which was greater than the FAO permissible limits of 0.01 for irrigation, all the other sampling sites recorded concentrations that were within the FAO permissible limits (Ayers & Westcot, 1994). The high concentration of cadmium observed at the midstream can be attributed to small scale mining in the area. There was a significant positive correlation between cadmium and mercury. The significant relation between cadmium and mercury shows a possible common source of pollution for the two elements as reported by Hogarh *et al.* (2016). The result obtained in this study is similar to observation made by Odai *et al.* (2008) who reported concentration of 0.01 to 0.02 mg/l in irrigation water at Kumasi, Ghana.

Conclusions

The findings of the study showed that the level of physico-chemical parameters of the water samples were generally acceptable for irrigation. With the exception of turbidity and potassium whose mean concentration were higher than the Food and Agriculture Organisation's (FAO) standards for irrigation, all the other physico-chemical parameter such as TDS, conductivity, sodium, calcium, nitrate, magnesium, sulphates and phosphates in the water samples from all the sites were within the permissible limits for irrigation. The pH of the water samples were all within the limits except at the control site. The assessment of the suitability of the water samples using the SAR, USSL and Wilcox diagram showed that the water was good for irrigation using parameters such as EC (salinity) and SAR for the assessment. Furthermore, the concentrations of heavy metals were all within the FAO permissible limits for irrigation, except mercury and cadmium which were slightly above the limits at the mid and up streams of the river. Even though the concentrations were all below the FAO standards for irrigation, the concentrations of the parameters measured in the water samples were generally higher at the sites along the river as compared to the reservoir. This observation indicated that the activities of small scale miners along the river affected the quality of the water although several of the parameters were within suitable range for irrigation. The detection of some level of heavy metals in the water should be a major concern to the various stakeholders in the Municipality as continuous influx of small scale miners in the area could increase heavy metal concentration beyond the acceptable threshold.

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