Environmental Impacts of Illegal Small-Scale Mining Activities on the Aboabo Stream, Ahafo Region, Ghana

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Abstract

The Aboabo stream serves as a source of drinking water to the Krapoo village in Ahafo region, Ghana. The presence of illegal small-scale miners around the stream poses health threats to the inhabitants as there have been concerns about physical changes in the water body, death of fishes and skin infections by community members. This study was carried out to assess the impacts of illegal small-scale mining operations on the water quality of the Stream. Levels of physico-chemical and microbiological parameters were determined by standard methods. Three plant species growing within the stream; *Alchornea cordifolia, Chromolaena odorata* and *Spigella anthelmia* were taken to assess their bioaccumulation to aid in possible remediation measures. The result of the study revealed that, turbidity, faecal coliforms and E-coli readings exceeded Ghana's Environmental Protection Agency (GS 1212) and World Health Organisation (WHO) permissible guidelines for drinking water. The pH values were within GS 1212 guidelines. Total suspended solids readings at the midstream were higher than the recommended standard. However, levels of total dissolved solutes and dissolved oxygen recorded, were below GS 1212 and WHO guidelines. The mean temperature and electrical conductivity readings were within the permissible limits. Heavy metal concentrations in both sediments and stream waters were generally higher than the GS 1212 and WHO recommended guidelines for drinking water. All the three plants species had bioaccumulation factor (BF) greater than 1 for cadmium. *Alchornea cordifolia* also had bioaccumulation factor greater than 1 for mercury. The general trend in the levels of the parameters from the stream suggests negative environmental influence from the small-scale mining activities on the Aboabo stream. The plants species are potential hyper accumulators (BF > 1) for mercury and cadmium hence are suitable for phytoremediation.

Keywords: Illegal mining, Heavy metals, Stream contamination, Phytoremediation

1 Introduction

Despite the importance of mineral resources for socioeconomic development, mineral extraction with its associated release of heavy metals has caused serious environmental damage to Ghana and the world at large (MacFarlane and Burchett, 2000; Nadmitov *et al.*, 2015; O'Neill *et al.*, 2015; Sanliyuksel *et al.*, 2016). Gold mining and metallurgical operations can therefore be described as an anthropogenic source of heavy metals in the Ghanaian environemnt (Armah and Gyeabour 2013; Koomson and Asiam, 2013; Obiri *et al.*, 2016). According to Amegbey and Eshun, (2003), waste rocks and tailings material from mining operations undergo oxidation in the process of acid mine drainage (AMD) and mobilise heavy metals into the environment.

Also, small scale miners make extensive use of mercury in gold recovery through a process known as amalgamation. The process causes spillages, thereby resulting in mercury drainage into nearby streams (UNIDO, 2001; Peter Van, 2002). Some studies have also shown increased concentrations of heavy metals and other contaminants in water bodies around mining communities in Ghana (Obiri, 2007; Quansah and Amankwah, 2010). Work done by Adiyahba (2015) and Adjei-Kyereme *et al.* (2015) for instance, have shown the presence of heavy metals in the Ahafo region with high concentrations in Kenyasi and its environs. Examples of such heavy metals are mercury (Hg), arsenic (As), cadmium (Cd) and lead (Pb).

Heavy metals can exist in sediments and freshwater systems for several years and can affect aquatic environments and human health (Mackevičiene *et al.*, 2002; Salomons and Brils, 2004). According to the World health organization (WHO) (WHO, 2004) and the Ghana Environmental Protection Agency (GEPA, 1997), exposure to mercury can cause serious skin infections and death of fishes in water bodies.

Different approaches to reducing heavy metals in the environment have been studied (Koomson and Asiam, 2013; Afrous *et al.*, 2011; Belford, 2017). In particular, plants have been used to accumulate

toxins. Bennicelli *et al.,* (2004) found that a small water fern (*Azolla caroliniana*) could remove up to 93 % of mercury in water within a 12-day period. Kamal *et al.,* (2004) discovered that aquatic plants; parrot feather, creeping primrose and water mint removed up to 99.8 % of mercury from contaminated water after 21 days. Therefore, ascertaining the impacts of illegal small-scale mining on the quality of the Aboabo stream and identifying the potential of available plant species for remediating such effects are the focus of this work.

2 Materials and Methods Used

2.1 Study Area

Asutifi District is located between latitudes 6°40' and 7°15' North and Longitudes 2°15' and 2°45' West. It shares boundaries with Sunyani Municipal Assembly to the north, Tano South District to the north- east, Dormaa District to north-west, Asunafo North and South Districts to the south-west and Ahafo Ano South and North Districts (Ashanti Region) to the south-east. With a total land surface area of 1500 sq. km, the district is one of the smallest in the region. The District falls within the wet semi-equatorial climatic zone of Ghana. It is characterized by an annual double maxima rainfall pattern occurring in the months of May and July and from September to October with a mean annual rainfall between 125 mm and 200 mm.

2.2 Samples Collection and Preparation

Samples of water, sediments and plants were collected from three points which were purposefully selected to cover the whole stream namely; Upstream (US), Mid-stream (MS) and Downstream (DS). Global Positioning System (GPS) was used to collect the coordinates of sampling points (SP). Quality control processes were based on the method outlined by (Brady *et al.,* 2014). Samples were collected 100 m apart at the sample points and 10 m within replicates. Water samples were collected by submerging sampling bottles at a depth of 20 cm into 500 ml plastic containers. Sediment samples were taken at the bottom of the stream using a plastic scoop and stored in a zip-lock. Levels of physico-chemical and microbiological parameters were determined by standard methods. pH of water samples was recorded on site using Hanna (HI 9828) multi-parameter probe. Plants samples were harvested using a cutlass.

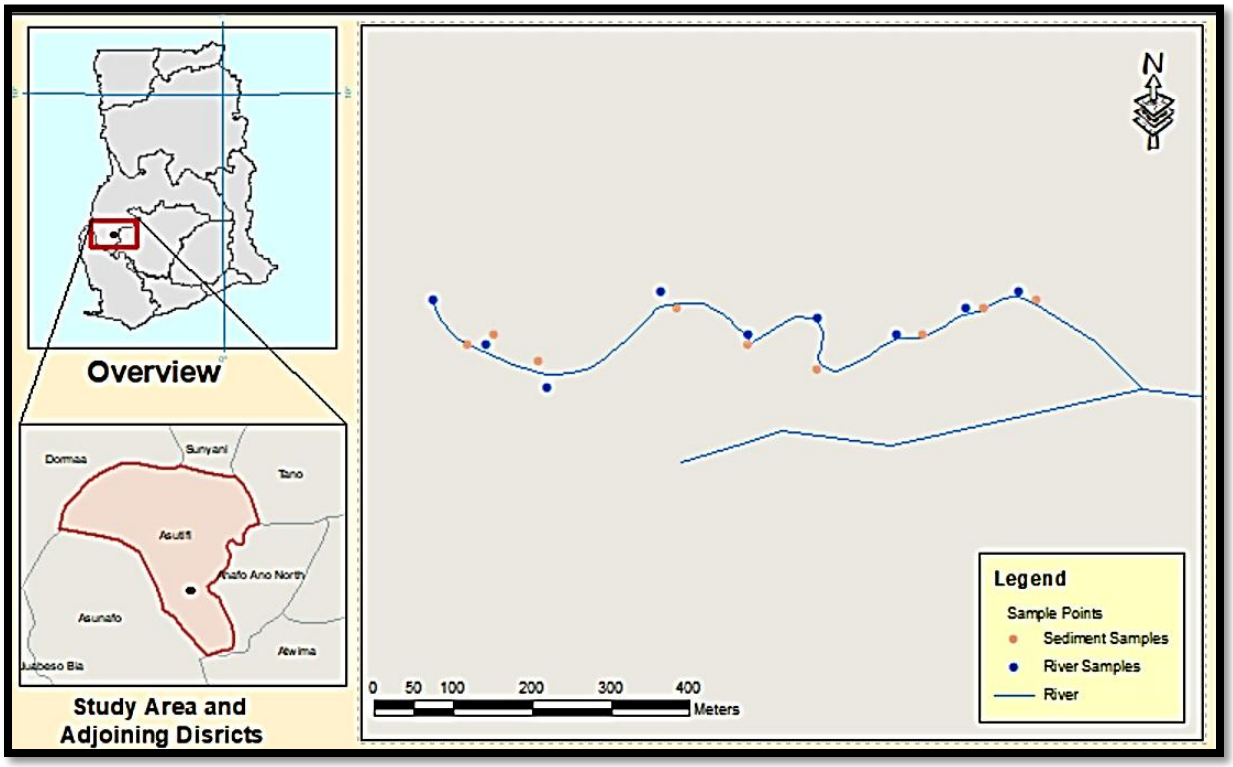

Figure 1 Map of the Study Area showing the Sampling Points

2.2.1 Chemical Analysis of Water Samples

Digestion of the water samples was based on the method outlined by (Brady *et al.,* 2014; Hadzi *et al.,* 2018). A 30 ml water sample was taken into a beaker. A 6 ml HNO_3 was added under fume chamber. The mixture was heated on a hot plate at 100 ^{o}C. It was left to cool at room temperature.

About 18 ml HCl was added and heated. The mixture was filtered with a Whatman filter paper (Grade No. 41) and topped to 30 ml with distilled water. Total As and Total Cd were analysed using Flame Atomic Absorption Spectrophotometer (FLAAS) whiles Total Hg was analysed using Cold Vapour Atomic Absorption Spectrophotometer (CV-AAS; model 200 AA (Agilent Technologies).

2.2.2 Chemical Analysis of Sediment Samples

Sediment samples were oven dried for twelve hours. Organic debris and other unwanted large particles were handpicked from each sample. Sediment samples were placed in a crucible and ashed in a furnace at 65 ºC for 2 hours. The dried sample were milled, and sieved through a 2 mm plastic mesh sieve. 1 g of the sediment samples were weighed into a beaker and 6 ml HNO_3 was added and heated on a hot plate at 100 ºC for 10 minutes and left to cool at room temperature. About18 ml HCl was added and heated. The samples were then diluted with distilled water and filtered with a Whatman filter paper (Grade No. 41) and topped to obtain 30 ml. Total As, Cd and Hg were analysed using FLAAS and CV-AAS respectively.

2.2.3 Chemical Analysis of Plant Samples

Oven dried plant samples were put in different crucibles and ashed in a furnace at 65 ºC for 2 hours. A quantity of the ash (1g) from each plant sample was weighed separately into a beaker. To each, 6 ml of concentrated HNO_3 was added and heated on a hot plate at 100 º C for 10 minutes and left to cool at room temperature. 18 ml of HCL were added and heated. The solutions were filtered through a Whatman filter paper (Grade No. 41) topped with distilled water to obtain 30 ml. Samples were then analysed using FLAAS and CV-AAS for Bioaccumulation of As, Cd and Hg respectively.

2.3 Bioaccumulation Factor (BF)

The plants' ability to accumulate heavy metals from the soil was determined by the ratio of concentration of heavy metals in plant to the heavy metal concentration in soil (Nazir *et al.*, 2011) known as bioaccumulation factor shown in Equation (1)

$$BF = \frac{\text{concentration of metal in plants}}{\text{concentration of metal in soil}} \quad (1)$$

Plants with a high BF value (BF>1) are potential hyperaccumulators and suitable for phytoextraction. (Rotkittikhun *et al*., 2006 and Nazir *et al*., 2011).

2.4 Data and Statistical Analysis

Data obtained for heavy metal concentrations in water, sediments and water plants were subjected to analysis of variance (ANOVA) using Gen-Statistical Software, Version 12.1. Mean differences between concentrations of heavy metals in soil and water plants were compared using Tukey-B at 5 % significance level. Means that do not share the same letters are significantly different at α=0.05, significance level by Tukey's 95 % confidence intervals comparison tests. $\pm$ are standard deviations.

3 Results and Discussion

3.1 Physicochemical Properties of Water Samples

Tables 1 to 4 present results of the physicochemical analysis of water samples collected from the Aboabo Stream.

From Tables 1 and 3 the mean temperature values at all sampling points were within the recommended permissible limits of <30 º C (GS 1212:2019 and WHO, 2010) for both seasons. Cool water is generally more palatable than warm water, and temperature will impact on the acceptability of a number of inorganic constituents and chemical contaminants that may affect taste. High water temperature for instance enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems (WHO, 2011). There was a general rise in temperature readings in the dry season at all sampling points (Table 3). Statistically, there were significant differences in temperature ($p<0.05$) between the sampling points. The observed mean temperatures are consistent with a study by Agyapong *et al*. (2012).

Table 1 Physical Properties of Water from Aboabo Stream for the Wet Season

Sampling Points (SP)	Temperature (ºC)	pH	EC (µs/cm)
US	23.55 ± 0.3a	7.91 -7.93	276.2 ± 1.91a
MS	24.10 ±2.4a	8.01 - 8.03	406 ± 1.7b
DS	24.15±0.18a	7.93 – 8.10	361.67 ± 2.05b
GS1212 (2019); WHO (2010)	**< 30**	**6.5 - 8.5**	**1500**

Table 2 Physical Properties of Water from Aboabo Stream for Wet Season

TDS (mg/l)	TSS (mg/l)	Turbidity (NTU)	DO (mg/l)
136.05 ± 2.64a	10.83 ± 0.9a	5.76 ± 1.95a	3.65 ± 0.25a
204.38 ± 3.39a	57.5 ± 2.3a	44.17 ± 4.4a	4.57 ± 0.68a
191.8 ± 3.27a	52.83 ± 2.8a	44.16 ± 2.1a	4.6 ± 0.96a
< 600	**50**	**5**	**5**

Table 3 Physical Properties of Water from Aboabo Stream for the Dry Season

SP	Temperature (ºC)	pH	EC (µs/cm)
US	25.3 ± 1.77a	7.94 - 8.02	280.33 ± 1.93a
MS	26.85 ± 1.32a	8.13 - 8.35	432.67 ± 3.86b
DS	26.86 ± 2.53a	8.09 – 8.24	410.5 ± 2.41b
GS1212 (2019); WHO (2010)	**< 30**	**6.5 - 8.5**	**1500**

Table 4 Physical Properties of Water from Aboabo Stream for the Dry Season

TDS (mg/l)	TSS (mg/l)	Turbidity (NTU)	DO (mg/l)
140 ± 0.31b	12.67 ± 1.17a	6.2 ± 2.01a	3.96 ± 0.77a
217.33 ± 3.49b	47.5 ± 2.37b	61.75 ± 2.68b	4.26 ± 0.89a
204.85 ± 2.32b	38.23 ± 2.89b	56.90 ± 1.78b	4.38 ± 1.02a
< 600	**50**	**5**	**5**

Mostly in water quality analysis, pH is determined to indicate the quantitative measure of acidity or basicity of water. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, arsenic, mercury etc.) in the water. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically (Perlman, 2016). The pH of the water samples from the Aboabo stream were slightly higher at the midstream than the downstream for both seasons (Tables 1 and 3). The higher values at the midstream and downstream sampling locations indicate anthropogenic influence from the illegal small-scale gold mining operation located at that point. Comparing the results with the GS1212/WHO (6.0 to 9.0 /6.5 – 8.5) standards and guidelines, the pH range levels of the stream investigated are within the permissible range for freshwater bodies. However, the upstream sampling point recorded the lowest pH reading in both wet and dry season. The low pH range obtained may be as a result of the production of CO_2 from microbial respiration which leads to the lowering of the pH of water (Pelig-Ba *et al.,* 1991). The slight increase in pH levels at the mid and down streams for both seasons may be attributed to the influence of runoffs from the illegal mining spot at the mid-stream area (Oram, 2014; Obiri *et al.*,2016; Hadzi, 2018). Statistically, there were no significance difference ($p>0.05$) in the pH values between the three sampling points. This indicate no systematic variations between sampling points.

Generally, high pH readings were recorded in the dry season (8.05 - 8.35) due to high temperatures during this period. Agyapong *et al*., (2012), have reported similar pH ranges in surface waters in the Bogoso mining area in Ghana's Western Region. The range of pH recorded in the study is also consistent with a study by Nartey *et al*., (2011), who reported a pH range of 7.1-8.5 in water samples from Bibiani-Anwiaso-Bekwai District, a typical mining community in Ghana. Ionization and the amount of hydrogen ions active in solution typically increases with temperature and hence the increase in pH during the dry season.

High conductivities were recorded at the midstream and downstream in both seasons (Tables 1 and 3). Statically, there were no significant differences ($p>0.05$) in the mean EC readings at the sampling points in both wet and dry season. All the conductivity values were low compared with the GS 1212 and WHO recommended guideline value (1500 µS/cm) for drinking water. The low values indicate that contaminations due to dissolved ions were low. However, the increase in conductivity values at midstream and downstream could be due in part to human activities (mainly, small-scale mining) along the banks of the stream. Such low conductivity values in a mining area have been reported in previous studies (Agyapong *et al*., 2012; Ansa-Asare and Gordon, 2012).

The levels of total dissolved solids (TDS) recorded at all sampling sites in all seasons were far below GS 1212/WHO guideline value of 600 mg/l. Hence, the stream appeared to be suitable for drinking. However, higher mean values at midstream and downstream (Tables 2 and 4) may be attributed to extensive activities of the miners through excavations. Such activities increase the rate of weathering and susceptibility to erosion. From Table 4, higher TDS concentrations were recorded in the dry season, this may be as a result of high temperatures at this period that enhances dissolutions of solids. Too low or too high TDS contributes to a decrease in photosynthesis and lead to an increase in water temperature which limit growth and lead to death of many aquatic organisms (Bruvold and Ongerth, 2001).

The mean values of the TSS recorded at all sampling points in dry season were below GS 1212 and WHO guideline value of 50 mg/l. However midstream and downstream sampling points had mean readings of 57.5 ± 2.3mg/l and 52.83 ± 2.8mg/l respectively during the wet season. These are above the guideline. The only human activity around the stream which could contribute to the levels of TSS is gold mining. The high total suspended solids in the midstream may be attributed to the excavations made by the miners; such activities increase the rate of weathering and vulnerability to erosion (Ghrefat and Yusuf, 2006). Generally, high TSS

concentrations recorded during the wet season may be due to high erosion and runoff materials in tandem with low temperatures to enhance dissolution of particles that find their way in the water.

All mean turbidity readings were above GS 1212 and WHO standards for drinking water and effluent discharge of 5 NTU. The mean turbidity levels were higher at the midstream followed by the downstream in both seasons (Tables 2 and 4). A significant difference ($p<0.05$) was recorded between the mean turbidity readings in the dry and wet seasons within the midstream and downstream. The statistical study identifies anthropogenic activities as a major cause of higher turbidity of the stream. The difference in the levels of turbidity according to seasons might be as a result of the proportions of water to suspended solids in the solution. Thus in the dry season there may have been higher suspended solids in a relatively small proportion of water and vice versa in the wet season.

Dissolved oxygen (DO) values recorded were lower than the GS 1212 and WHO recommended limit of 5.0 mg/l (Tables 2 and 4) in both seasons at all sampling points. When DO is below 2 mg/l, many aquatic organisms perish as a result of biological respiration including those related to decomposition processes which reduces the concentration of DO in water bodies (Hasan *et al.*, 2016). The values recorded in the study area indicate that the organisms in the stream will be likely affected. Statistical analysis showed a significance difference in DO values between the sampling points, however, Tukey's multiple comparison test showed no significance difference in mean DO values between the seasons. This reveals no systematic seasonal variations within the sampling points.

3.2 Microbial Parameters of Water Samples

Tables 5 and 6 presents results for microbiological analysis of water samples collected from the Aboabo Stream.

For water to be considered no risk to human health, the faecal coliform bacteria and Escherichia coli in water sample should be zero (WHO, 2010). If fecal indicator bacteria or pathogens commonly associated with humans are present in ground water in measurable quantities, there is most likely a nearby connection with a contaminated surface environment. These include seepage from a waste lagoon / a contaminated surface water, a subsurface source of contamination such as a septic tank, a broken or leaking sewer line, or an old or improperly designed landfill.

Table 5 Microbial Parameters of Water Samples from Aboabo Stream for the Wet Season

Sampling points	F. Coli (MPN/100ml)	E. Coli (MPN/100ml)
UP	10.64 ± 0.49a	10.18 ± 1.05a
MD	11.47 ± 0.50b	10.48 ± 0.57a
DS	11.55 ± 0.59b	10.45 ± 0.66a
GS1212 (2019); WHO (2010)	**0**	**0**

Table 6 Microbial Parameters of Water Samples from Aboabo Stream for the Dry Season

Sampling points	F. Coli (MPN/100ml)	E. Coli (MPN/100ml)
UP	10.34 ± 0.51a	10.15 ± 1.64a
MD	11.54 ± 0.63b	10.38 ± 0.70a
DS	11.38 ± 0.72b	10.84 ± 0.69a
GS1212 (2019); WHO (2010)	**0**	**0**

Results for *E. coli* and Faecal coliform were significantly higher than the GS 1212/WHO standard. Hence stream is unsafe for domestic use. A positive E. coli result is much serious than the coliform bacteria alone because it indicates that human or animal waste is entering the water supply and can cause diarrhea, dysentery and hepatitis (Braun *et al.*, 2013; CDC, 2014). It is the first organism of choice in monitoring programmes for verification, including surveillance of drinking water quality (Asbolt *et al.*, 2001).

The presence of coliforms is also an indication of potential health risk such as dysentery, typhoid fever, urinal and bacteria gastroenteritis and hepatitis (Fatoki and Muyima, 2003). Statistically, there were no significant difference in the E Coli counts between all sampling points. However, *E. coli* and total coliform values were not affected by seasons thus, levels recorded during the dry season were not significantly different from values recorded in the wet season ($p>0.05$).

3.3 Heavy Metals Concentrations in Water and Sediment

Results of heavy metals (Arsenic, Cadmuim and Mercury) concentration in the water and sediments of the Aboabo stream are presented in Tables 7 to 10.

Table 7 Concentration of Heavy Metals in Water for the Wet Season

SP	As (mg/l)	Cd (mg/l)	Hg (mg/l)
US	0.815 ± 0.28a	0.003 ± 0.02a	0.90 ± 0.61a
MS	2.84 ± 016a	0.006 ± 0.01a	3.98 ± 0.53a
DS	2.93 ± 0.27a	0.01 ± 0.001a	3.50 ± 0.24a

GS1212 (2019); WHO (2010)	**0.01**	**0.003**	**0.001**

Table 8 Concentration of Heavy Metals in Water for the Dry Season

SP	As (mg/l)	Cd (mg/l)	Hg (mg/l)
US	1.13 ± 0.22a	0.011 ± 0.02a	1.20 ± 0.84a
MS	3.21 ± 038b	0.010 ± 0.01a	5.1 ± 2.03b
DS	3.29 ± 0.47b	0.02 ± 0.003a	4.76 ± 1.76b
GS1212 (2019); WHO (2010)	**0.01**	**0.003**	**0.001**

Table 9 Concentration of Heavy Metals in Sediments for the wet Season

SP	Total As (mg/kg)	Total Cd (mg/kg)	Total Hg (mg/kg)
US	13.92 ± 0.91a	0.31 ± 0.07a	9.34 ± 1.09a
MS	27.27 ± 3.07a	0.48 ± 0.11a	105.77 ± 2.1a
DS	34.7 ± 4.21a	0.62 ± 0.13a	91.99 ± 3.7a
GS1212 (2019); WHO (2010)	**20.0**	**0.05**	**2.0**

Table 10 Concentration of Heavy Metals in Sediments for the Dry Season

SP	Total As (mg/kg)	Total Cd (mg/kg)	Total Hg (mg/kg)
US	15. 38 ± 1.09b	0.40 ± 0.12a	11.53 ± 2.02b
MS	26.78 ± 7.17b	0.92 ± 0.18b	106.15 ± 3.4b
DS	35.80± 5.01b	0.93 ± 0.19b	101.14 ± 6.7b
GS1212 (2019); WHO (2010)	**20.0**	**0.05**	**2.0**

3.3.1 Total Arsenic (As)

From Tables 7 to 10 mean total arsenic concentrations in the water and sediment samples were above GS 1212 and WHO guidelines of 0.003 mg/l for water and 0.05 mg/kg for sediment. There was a significance difference in the mean total arsenic sediment concentrations at all seasons. Gold in the area occurs with pyrite and is commonly associated with disseminated sulphides such as arsenopyrite (Macdonald, 2016). After ore comminution and panning by the illegal small-scale gold miners, arsenic from residual arsenopyrite in the tailings material and waste rock may be released into the environment. This gradually finds its way into surface water and sediment. The miners also dump waste rocks in the stream and this leads to the release of arsenic from the ores into the stream through the process of Acid Rock Drainage (ARD) Dold, B. (2017). Arsenic in water causes skin and nail changes (hyperkeratosis and hyperpigmentation); sensory and motor polyneuritis, elevated risk of skin cancer, and cancers of lung, liver, bladder, kidney and colon (Hoekman, 2008).

3.3.2 Total Cadmium (Cd)

From Tables 7 to 10, mean levels of total cadmium determined in the samples were above the permissible limit of 0.003 mg/l (water) and 0.05 mg/kg (sediment) by WHO. Cadmium metal is used both as an anticorrosive material for steel, and a major component of batteries. Hence, the presence of some appreciable levels of total cadmium in the water and sediment samples is an indication of anthropogenic contribution from comminution equipment used in the milling of ores to recover gold. The observed total cadmium mean readings in water and sediments are consistent with a study by Adiyahba, (2015).

3.3.3 Total Mercury

The mean total mercury concentrations for both water and sediments were above GS 1212 and WHO guidelines of 0.001 mg/l and 2.0 mg/kg respectively. Mercury does not have a natural source in the area, it is introduced into the environment during gold processing (amalgamation) (Nartey *et al.*, 2011; Hadzi, 2018).

Generally, total mercury concentrations for both water and sediment samples at midstream and downstream sampling points, were relatively higher than the values obtained at the upstream in both seasons (Tables 7 to 10). This trend could be explained by the fact that there is intensive mining activities at the midstream resulting in mercury contamination at the downstream. For instance, Armah *et al.* (2006) and Nartey *et al.* (2011) reported higher mercury concentrations in an extensive mining area. At the midstream, large quantities of mercury is used and therefore ends up in the stream. Occasionally, there are accidental spillage of mercury into the environment due to careless handling. Through rain-washing the spilled mercury also gets into stream and sediment. Dumping of mercury-containing ashes from coal-pots used for roasting the amalgam also accounts for the presence of total mercury in the water bodies and sediment. The midstream has the highest distribution of mercury in the water samples (Tables 7 and 8). It was realized that apart from the activities of the permanent galamsey workers, the midstream also serve as treatment site for other illegal miners who do not have treatment sites of their own. They bring their gold bearing rocks and sediment from other places to the midstream area for treatment to obtain gold. This contributes to the total mercury load in the aquatic environment. This important

factor among others, could be used to explain the highest values of mercury in the sediment samples at midstream. Also, work done by Oppong Kyekyeku (2011) shows that, mercury is more stable in sediments than in air hence, the observed trend where mercury concentrations in the sediment samples were far higher than in the water samples within the middle stream and downstream (Tables 9 and 10). Another factor which may increase the mercury content of the sediment, is the tendency of heavy metals to form hydro-oxo compounds or complexes (in aqueous medium) which precipitate out of solution hence, increasing the concentration in the sediment. Heavy illegal mining activities at the midstream is the cause for the higher concentration of Hg at the downstream. The detection of mercury in water and sediments at the upstream may be attributed primarily to workers washing their cloths, cleaning their tools and equipment at the upstream. The observed mercury concentrations in water and sediments are consistent with the study by Nartey *et al.* (2011); Agyapong *et al*. (2012); Adiyahba, (2015). Statistically, mean mercury values for water and sediments were significant different ($p<0.05$) within sampling points and seasonal periods.

Results of heavy metal concentrations in plant species are represented in Tables 11 to 16.

Table 11 Concentration of Heavy Metals in *Alchornea Cordifolia* for the Wet Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	3.64 ± 0.66a	1.07 ± 0.08a	10.81 ± 1.93a
MS	10.43 ± 1.76a	1.46 ± 0.30a	87.79 ± 5.7a
DS	10.51 ± 0.25a	1.35 ± 0.26a	84.14 ± 2.73a

Table 12 Concentration of Heavy Metals in *Alchornea Cordifolia* for the Dry Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	11.13 ± 0.6b	1.08 ± 0.05a	29.8 ± 1.0b
MS	22.01 ± 2.16b	6.74 ± 0.21b	141.4 ± 5.0b
DS	39.93 ± 0.55b	4.75 ± 1.01b	108 ± 1.73b

Table 13 Concentration of Heavy Metals in *Chromolaena Odorata* for the Wet Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	0.89 ± 0.13a	0.27 ± 0.22a	1.16 ± 0.14a
MS	1.66 ± 0.37a	1.05 ± 0.18a	2.92 ± 0.21b
DS	1.15 ± 0.04a	0.93 ± 0.15a	2.7 ± 0.22b

Table 14 Concentration of Heavy Metals in *Chromolaena Odorata* for the Dry Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	1.13 ± 0.25b	2.27 ± 0.27b	1.60 ± 0.35a
MS	1.83 ± 0.73a	2.06 ± 0.21b	3.3 ± 0.61b
DS	1.28 ± 0.02a	1.93 ± 0.66b	3.0 ± 0.39b

Table 15 Concentration of Heavy Metals in Spig*ella Anthelmia* for the Wet Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	0.94 ± 0.08a	0.61 ± 0.03a	1.35 ± 0.16a
MS	1.36 ± 0.20a	0.80 ± 0.06a	4.7 ± 0.32a
DS	1.27 ± 0.06a	0.70 ± 0.06a	3.48 ± 0.34a

Table 16 Concentration of Heavy Metals in Spig*ella Anthelmia* for the Dry Season

SP	Arsenic (mg/kg)	Cadmium (mg/kg)	Mercury (mg/kg)
US	0.99 ± 0.01a	0.93 ± 0.07a	1.39 ± 0.06a
MS	1.7 ± 0.41a	2.18 ± 0.16b	5.3 ± 0.56b
DS	1.39 ± 0.36b	1.06 ± 0.41b	3.62 ± 0.27b

3.4 Bioaccumulation (Hyperaccumulating) Potential of Plants for Heavy Metals

Tables 17 to 19 presents result for bioaccumulation potentials of plant species studied.

Table 17 Bioaccumulation Factor for *Alchornea Cordifolia*

SP	Arsenic	Cadmium	Mercury
US	0.49	**3.26**	**1.88**
MS	0.63	**5.06**	**1.11**
DS	0.63	**3.53**	**1.04**

Table 18 Bioaccumulation Factor for *Chromoleana Odorata*

SP	Arsenic	Cadmium	Mercury
US	0.07	**3.3**	0.13
MS	0.07	**2.1**	0.03
DS	0.04	**1.75**	0.03

Table 19 Bioaccumulation Factor for *Spigella Anthelmia*

SP	Arsenic	Cadmium	Mercury
US	0.07	**2.26**	0.13
MS	0.06	**1.46**	0.05
DS	0.04	**1.14**	0.04

From Tables 17 to 19, the Bioaccumulation factor of all plant species for total Cd were greater than 1 with *Alchornea cordifolia* recording the highest ratios; 3.26 at the upstream, 5.06 at the midstream and 3.53

at the downstream. This indicate that all plant species used in the study are suitable for phytoextraction of total Cd.

Alchornea cordifolia had bioaccumulation factor greater than 1 for total Hg at all sampling points. This shows that *Alchornea cordifolia* is the only plant used in the study that is suitable for phytoextraction of total Hg.

According to Sherene (2010) the metal available concentration in soil may be a better predictor for environmental impact of historical and current release of metals in a contaminated area. This statement was evident in the study. The concentration of total As in plants compared to concentrations in sediments showed that the plants could not accumulate total arsenic (Tables 17 to 19). This implies none of the plant species studied can be used for total arsenic phytoextraction. The observed bioaccumulation factors are consistent with a study by Belford (2017).

4 Conclusions and Recommendations

Following the discussions of this study, it can be concluded that the Aboabo stream is polluted. The mean Turbidity readings were above GS1212 and WHO standards for drinking water and effluent discharge, respectively, but were higher in the wet season than the dry season. Total suspended solids readings at the midstream and downstream were higher than the recommended standard during the wet season.

This can be attributed to the high runoffs and erosion in the wet season leading to more suspended particles in the river. pH range were within GS1212 and WHO guidelines. The levels of Total Dissolved Solids and Dissolved Oxygen recorded at all sampling sites were far below GS1212 and WHO guideline value of 600 mg/l and 5.00 mg/l respectively. However, higher value of TDS was recorded at midstream. Nevertheless, the mean Temperature and Electrical Conductivity values were all below the recommended permissible limits in all the samples at all the sampling points and seasons. Faecal coliforms and E-coli were present and very high in the water samples indicating possible contamination of the stream water by faecal matter and hence harmful pathogens in the water samples.

Heavy metal concentrations in both sediments and stream water from all the sampling points were generally higher than the WHO and GS1212 recommended guidelines values for water quality. Sediments accumulated the highest concentration of heavy metals and exceeded the standards. This raises serious concern about the quality of drinking water being used by residents in the study area.

Based on the results obtained from the laboratory, the study has demonstrated that all the plants used in the study are moderate accumulators of total arsenic but are potential hyper accumulators (BF > 1) for total Cadmium. The study again has demonstrated that *Alchornea cordifolia* can be used be used to remove total mercury from a contaminated media such as water.

To prevent or minimize any further pollution of the Aboabo Stream by the illegal small-scale mining operations, the following mitigatory measures are seriously recommended:

i. There is the need to embark on an intensive educational campaign by regulatory agencies to bring the findings of this research to the notice of the people of the study area to discourage them from using these untreated stream as a source of drinking water to prevent any future bacterial epidemics.
ii. Measures should be put in place to control the discharge of effluents from the illegal mining activities into the Aboabo stream.
iii. Waste rock dumps should be sited far away from the stream to avoid contamination by run-off water from the waste rocks.
iv. Waste rocks can be used to back-fill pits to prevent Acid Mine Drainage.
v. Genetic engineering approach to develop transgenic plants with characters of high biomass production, more metal accumulation, tolerance against metal toxicity and well adapted to a variety of climatic conditions, might be more beneficial in this respect hence, further research is needed in the field of genetic engineering to improve the heavy metals removal capacities of the plants studied.

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