

Original Research Paper

Mapping, Characterization and Dispersion of Metallic Pollutants within a Catchment of Illegal Gold Mining Activities in Ghana

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Abstract: The illegal gold mining activities prevalent in most part of Ghana have caused substantial havoc to the environment especially water bodies which serve as sources of water for domestic, industrial and agricultural purposes. The Ghana Water Company Limited (GWCL) recently shut down their water treatment plant due to the extreme pollution and high cost of treatment. This study focusses on the impact of mining activities on water quality of the affected water bodies, to assess the level of pollution of the river sediments and the extent of dispersion of the heavy metallic pollutants and to map out areas within the Konongo Municipality where illegal mining activities are prevalent. In this regard, both water and sediment samples from two rivers namely; Owerri and Asuokofi in Konongo (in the Asante Akim Central Municipality) were collected at different locations and analysed using Flame Atomic Absorption Spectrometry (FAAS) to assess the concentrations and dispersions of metallic pollutants. Geographical Positioning System (GPS) coordinates of these sample locations were also taken for mapping the sampling points and area. Four different metals; mercury (Hg), Lead (Pb), Arsenic (As) and Cadmium (Cd) were analysed. For sediments, the mean levels of Pb, Hg, As and Cd for the owerri river were found to be 52.2 ± 2.0 , 0.3 ± 0.5 , 492 ± 365 and 1.7 ± 2.0 mg kg⁻¹ respectively; whilst those for Asuokofi river were 12 ± 0.7 , 2.7 ± 0.4 , 21.2 ± 13.5 and 1.6 ± 0.4 mg kg⁻¹ respectively. The mean levels of Pb, Hg, As and Cd for water of the owerri river are respectively 2.5 ± 3.7 , 0.20 ± 0.4 , 0.28 ± 0.2 and 3.1 ± 0.4 mg L⁻¹; whilst those for Asuokofi river were 8.2 ± 1.3 , 2.3 ± 1.8 , 25.4 ± 22.2 and 0.45 ± 0.7 mg L⁻¹ respectively. Comparing these levels with the WHO standards for water discharges, these concentrations far exceeded the recommended values. This will impact negatively on the quality of both rivers with dire consequences since they serve as the main raw water resource for drinking water production. Samples of sediments and water from the upstream of these rivers where no activity of alluvial mining is taken place were recorded and they showed lower levels of these metals. It can therefore be concluded that the activities of alluvial gold mining in the study area impacts negatively on both the quality of water in the river and the sediments thereof.

Keywords: Heavy Metals, Illegal Mining, Pollutant and Water Quality

Introduction

The illegal gold mining activities prevalent in most part of Ghana have caused irreparable havoc to the environment especially water bodies which serve as sources of water for domestic, industrial and agricultural

purposes. Pollution of surface water bodies with mercury, cadmium, Arsenic and lead etc. have been the order of the day due to illegal mining. For instance, it is reported that the Birim and Densu Rivers in the Eastern region which serve as a source of raw water for several communities have gravely been affected by small-scale

gold mining activities. The ten regions in Ghana have most of their urban and peri-urban communities supplied with drinking water that is produced from surface water bodies'. The Pra and Ankobra Rivers in the Western region as well as other smaller rivers and streams have also not been spared (Amankwah, 2013). A research conducted by Oduro *et al.* (2012) found out that the main Pra river and its tributaries have 48 ± 26 and 27 ± 18 ppb average dissolved Hg concentration respectively which are far above the WHO guideline value of 1.0 ppb. This has been attributed to illegal gold mining activities along that stretch. In two of the regions (Eastern and Brong Ahafo regions) the GWCL recently shut down their water treatment plant due to the extreme pollution and high cost of treatment being incurred by the company.

In Ghana, it is established that human activities is the basic source of environmental Hg and other metallic pollution (Hilson and Pardie, 2006) and this is due to the inappropriate method of amalgamating the gold particles (Swain *et al.*, 2007). Metallic pollutants generally do not remain at the place of discharge but travel along the flow lines of the receiving rivers. (Amankwah, 2013).

The general question raising concern with regards to today's mining activities includes the following: To what extent are these metallic pollutants dispersed, what levels of pollution these activities are generating, what is the impact on the water quality generally of the receiving water bodies and how these activities do affects the characteristics of the river beds (sediments). To address these issues, this study had the following objectives: To map out areas within the Konongo Municipality (Ashante Region) where illegal mining activities are prevalent and surface water bodies that are directly affected, To assess the impact of the mining activities on the water quality of the affected water bodies and To assess the level of pollution of the river sediments and the extent of dispersion of the metallic pollutant.

Materials and Methods

Study Area

The Asante Akim North Municipal Assembly is one of the 27 Districts in the Ashanti region. It has Konongo-Odumase as its twin capital town. The municipality is located in the Eastern part of the Ashanti Region and lies between latitude $60^{\circ} 30'$ North and $70^{\circ} 30'$ North and longitude $00^{\circ} 15'$ West and $10^{\circ} 20'$ West. It covers a land area of $1,160 \text{ Km}^2$ with an estimated population of 142,434 in 2006 (Source: National population and housing census 2000). The Municipality shares boundaries with Sekyere east on the North, Kwahu South on the east, Asante Akim South on the south and Ejisu Juabeng Municipality on the west. The Municipality lies within semi-equatorial belt characterized by double rainfall maxima. The first rainy season starts from May to July and the second from

September to November. The dry harmattan season occurs between December and April and is associated with drought condition (Boadi *et al.*, 2013). The annual rainfall of the Municipality averages between 150-170 mm. The daily temperature ranges from $22-30^{\circ}\text{C}$ with minimum monthly temperature of 26°C and maximum temperature of 30°C recorded in March and April. The average humidity in the area is 75-80% (Boadi *et al.*, 2013).

Sampling and Physicochemical Analysis

Water and sediment samples were taken from seven different locations within the rivers catchment. Two control points from the upstream where no mining activities is being carried out were sampled for each of the two streams and are shown on the map. A Geographical Positioning System (GPS) "Garmin 62SC" was used to take coordinates for each of the sampled points. Using WGS 84, both sediment and water samples for each of the sampling points were taken with all the coordinated points converted into shapefiles using the geographic coordinate system. Geographic bound was considered to limit us on the extent of the geographic area mapped but not the entire Konongo Township. Four different metals; Arsenic (As), Mercury (Hg), cadmium (Cd) and Lead (Pb) were considered for the analysis. Physicochemical parameters such as p^{H} , conductivity, Total Dissolved Solids (TDS) and turbidity were also measured. For heavy metal determination, complete digestion of sediment was done. The sediment samples were oven dried, grinded with mortar and pestle then sieved through 2 mm sieve. One gram of the sediment sample was weighed into a 250 mL conical flask. Ten milliliters of acid solution (HNO_3 and HClO_4 in the ratio 9:4) was added to each of the sample. The mixture was heated gradually to 180°C until production of red nitrite fumes ceased. After which it was filtered using *Whatman No. 1* filter paper in a 100 mL volumetric flask. The metals; As, Hg, Cd and Pb were analysed using Buck Scientific 210 VGP model (Flame Atomic Absorption Spectroscopy).

Results

From the survey of the study area and the coordinates taken using the GPS system, the following map (Fig. 1) was developed using the shape files.

Statistics

Means and standard deviations were reported where appropriate. Turkey's test was applied to identify significant differences in measured parameters among sampling points using IBM SPSS Statistics 20 software package. Pearson's correlation analysis was performed to evaluate potential relationships among the different variables.

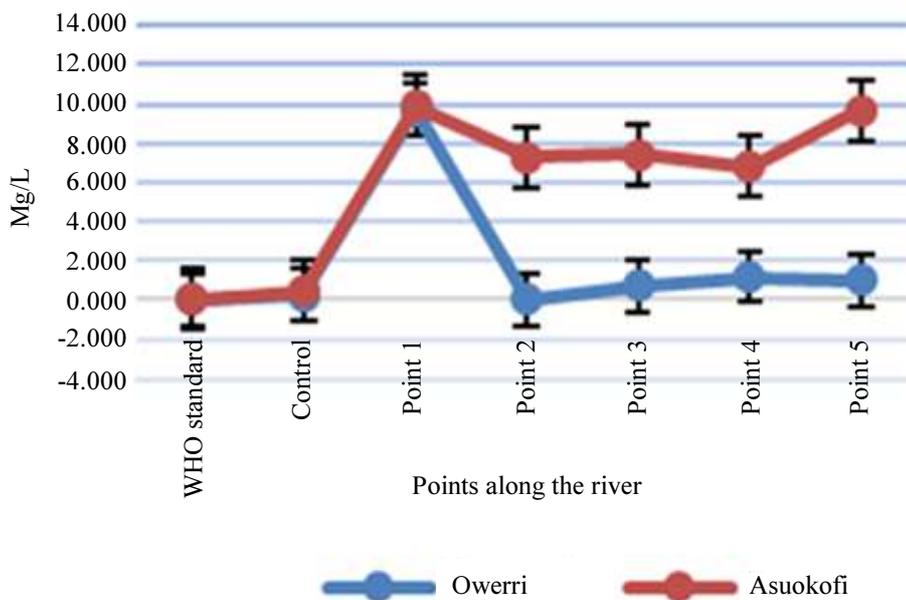


Fig. 3: Dispersion of Lead within both streams

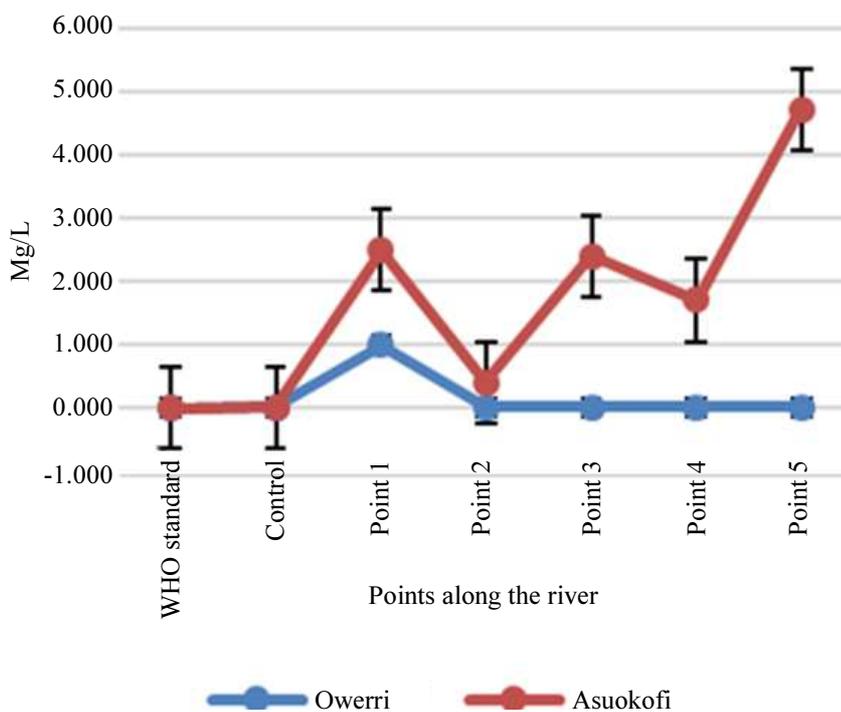


Fig. 4: Dispersion of Mercury within both streams

Concentrations of Heavy Metals in Water

Figure 3 to 6 indicate the concentration of the metal pollutants in the Owerri and Asuokofi streams. The mean concentrations of *Pb*, *Hg*, *As* and *Cd* in Owerri stream are respectively 2.5 ± 3.7 , 0.2 ± 0.4 , 0.2 ± 0.2 and 3.1 ± 2

mg L^{-1} . The mean concentrations of *Pb*, *Hg*, *As* and *Cd* in the Asuokofi stream are 8.2 ± 1.3 , 2.3 ± 1.8 , 25.3 ± 22.2 and $0.4 \pm 0.1 \text{ mg L}^{-1}$ respectively. From Table 1, the levels of *Pb*, *Hg*, *As* and *Cd* within the two streams are very significant, having their respective significant levels less than 0.05 confidence levels.

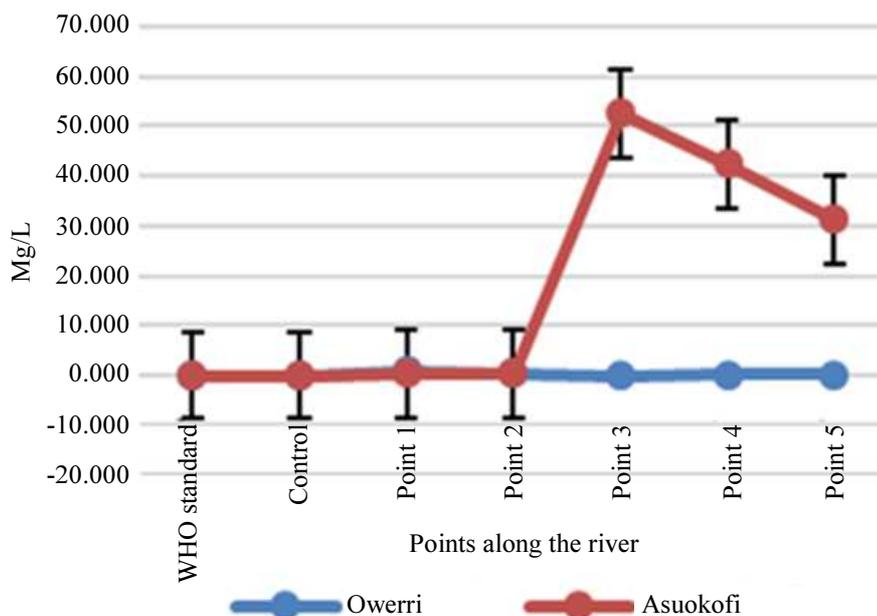


Fig. 5: Dispersion of Arsenic within both streams

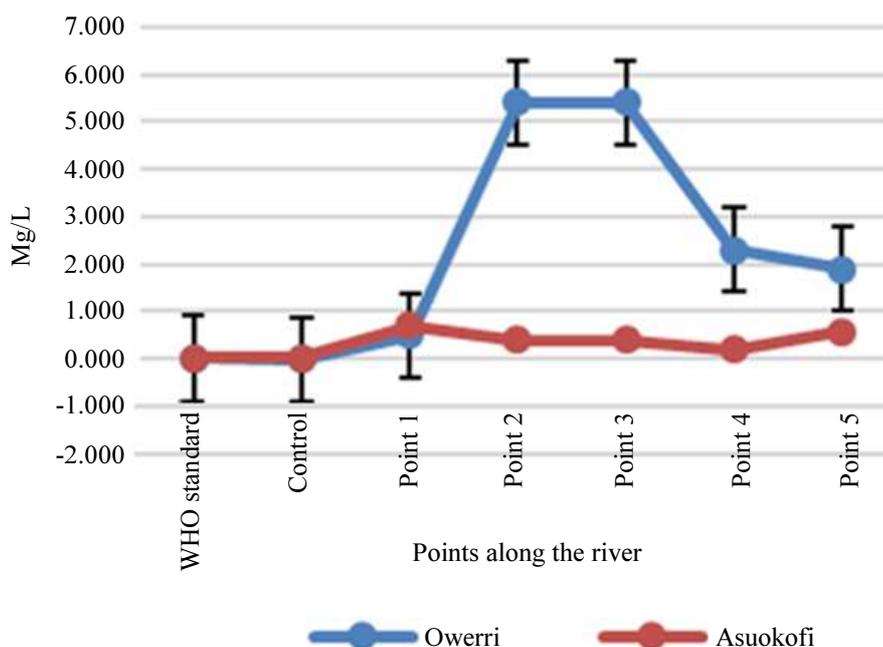


Fig. 6: Dispersion of Cadmium within both streams

Concentrations of Heavy Metals in the River Sediments

Figures 7 to 10 indicate the concentration of the metal pollutants in the sediments of Owerri and Asuokofi streams. The mean concentrations of *Pb*, *Hg*, *As* and *Cd* in Owerri stream are 52.2 ± 28 , 0.35 ± 0.5 , 492.5 ± 365.8 and 1.7 ± 2.08 mg kg^{-1} respectively. The mean concentrations of *Pb*, *Hg*, *As* and *Cd* in the

Asuokofi stream are 12 ± 0.7 , 2.7 ± 0.4 , 21.2 ± 13.5 and 1.6 ± 0.4 mg kg^{-1} respectively. From Table 2, the difference in the concentration of *Pb* between the two streams is very significant (*P-value* of 0.00). This is indicative of the fact that the levels of *Pb* are significantly higher in the Owerri stream than the Asuokofi stream. The differences in concentrations of *Hg* are significantly higher in the Asuokofi stream than that of the Owerri stream (*P-value* of 0.00).

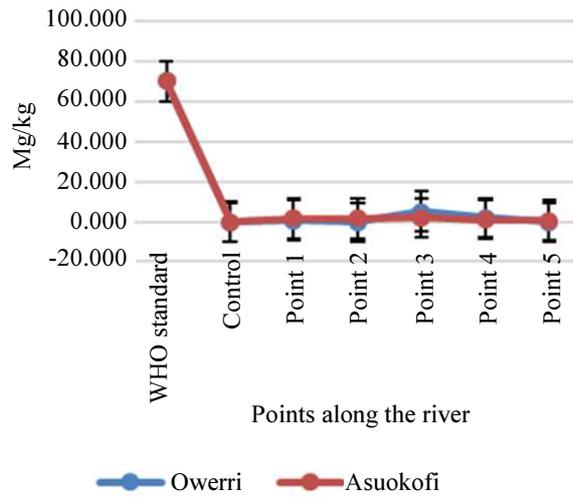


Fig. 7: Dispersion of Cadmium within sediments

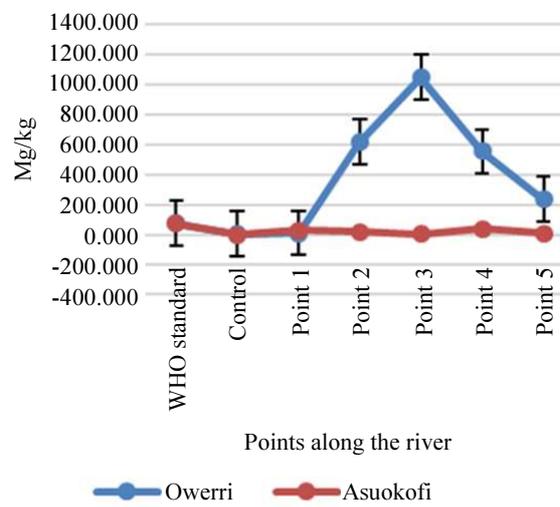


Fig. 8: Dispersion of Arsenic within sediments

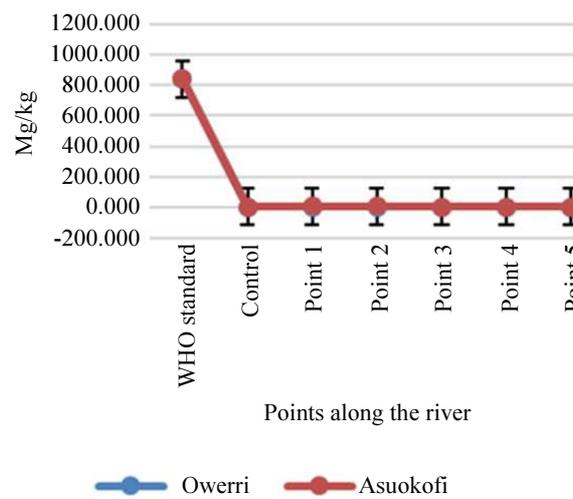


Fig. 9: Dispersion of Mercury within sediments

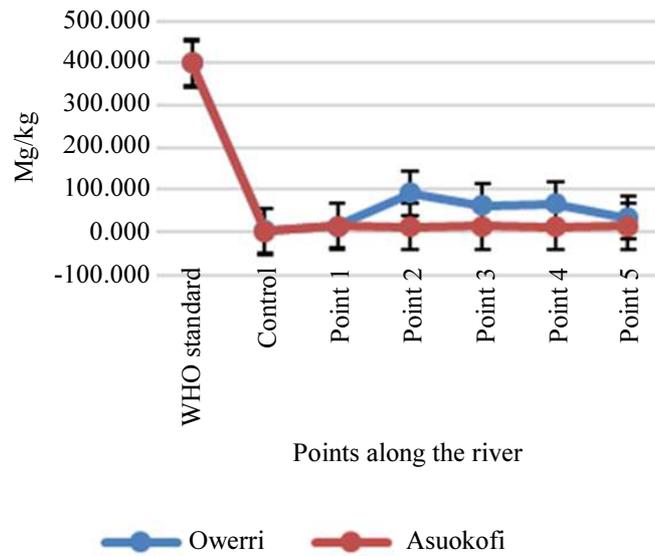


Fig. 10: Dispersion of Lead within sediments

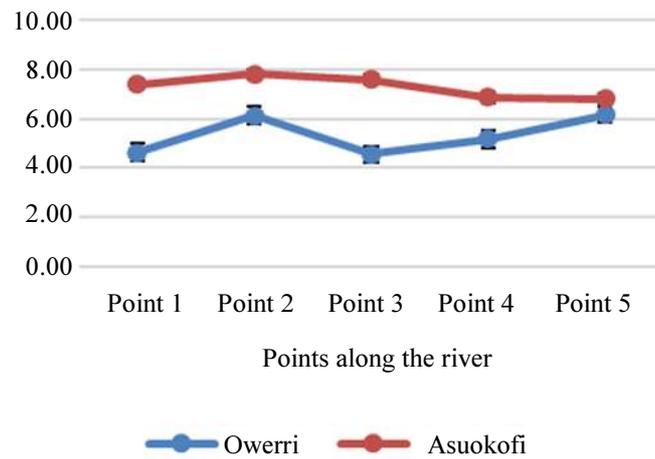


Fig. 11: Levels of P^H along the streams

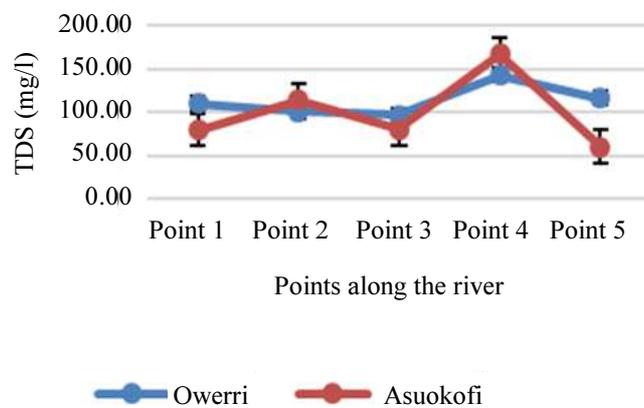


Fig. 12: Levels of TDS along the stream

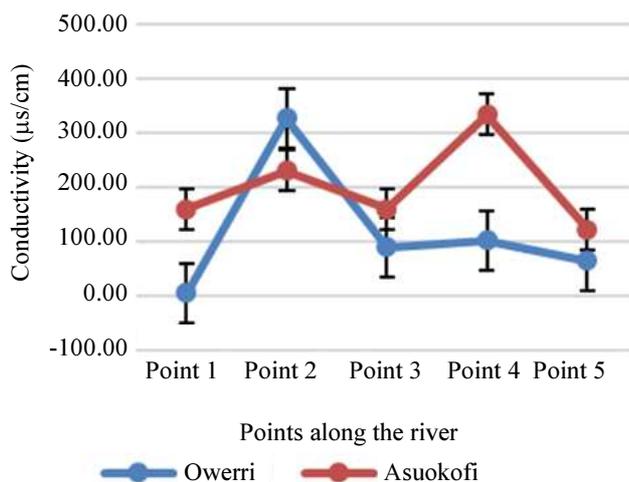


Fig. 13: Levels of Conductivity along the streams

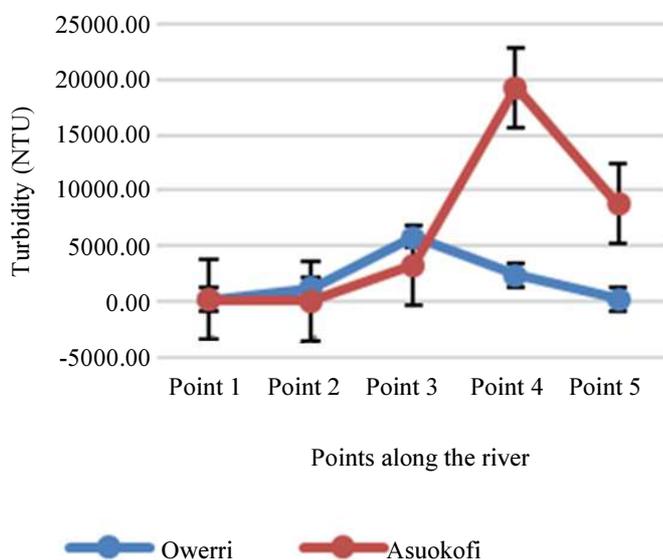


Fig. 14: Levels of Turbidity along the streams

Table 1: Levels of significance of pollutant within the streams

t-test for equality of means

Independent samples test	t	df	Sig. (2-tailed)	Mean difference	Std. error Difference	95% confidence interval of the difference	
						Lower	Upper
Lead (Pb)	-5.534	28.000	0.000	-5.7018000	1.0302711	-7.8122146	-3.5913854
	-5.534	17.705	0.000	-5.7018000	1.0302711	-7.8689107	-3.5346893
Mercury (Hg)	-4.307	28.000	0.000	-2.1383133	0.4964505	-3.1552460	-1.1213807
	-4.307	15.338	0.001	-2.1383133	0.4964505	-3.1944464	-1.0821803
Arsenic (As)	-4.360	28.000	0.000	-25.0910000	5.7551009	-36.8797898	-13.3022102
	-4.360	14.004	0.001	-25.0910000	5.7551009	-37.4340935	-12.7479065
Cadmium (Cd)	5.000	28.000	0.000	2.6446667	0.5289233	1.5612164	3.7281170
	5.000	14.215	0.000	2.6446667	0.5289233	1.5118440	3.7774893

Table 2: Independent samples test in sediments

Dependent variables	t-test for equality of means		Sig. (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
	t	df				Lower	Upper
Lead (Pb)	5.545	28.000	0.000	40.2066667	7.2509744	25.3537190	55.0596143
	5.545	14.018	0.000	40.2066667	7.2509744	24.6567502	55.7565831
Mercury (Hg)	-12.580	28.000	0.000	-2.4241033	0.1926997	-2.8188307	-2.0293759
	-12.580	25.923	0.000	-2.4241033	0.1926997	-2.8202603	-2.0279463
Arsenic (As)	4.986	28.000	0.000	471.2400000	94.5135942	277.6376787	664.8423213
	4.986	14.038	0.000	471.2400000	94.5135942	268.5801590	673.8998410
Cadmium (Cd)	0.131	28.000	0.897	.0726667	0.5535669	-1.0612637	1.2065971
	0.131	15.548	0.897	.0726667	0.5535669	-1.1036240	1.2489574

The differences in concentrations of *As* are significantly higher in the Owerri river than that of Asuokofi (*P-value* of 0.00). But the differences in concentrations of *Cd* between Owerria and Asuokofi is not significant (*P-value* is 0.897 > 0.005).

Physicochemical Analysis

Four physicochemical parameter analysed within the catchment are p^H , Total Dissolve solids, conductivity and turbidity with their respective mean values shown the Fig. 11-14.

Discussion

The results of dispersion of the metallic pollutants within the Owerri and Asuokofi streams are clearly shown above. The levels of almost all the heavy metallic pollutants under consideration in both streams especially Asuokofi are well dispersed well above the WHO guidelines and the control point levels along the flow lines. There is a gradual increase in the levels of pollutants from the upstream to the downstream. Though the samplings were done during the raining season yet the levels in both the water and sediments are high, it can be envisaged that there might be much higher levels of the heavy metals in the water and sediments during the dry season. There is the tendency of the concentrations of pollutants in the sediments to further dissolve in the water whenever there is a disturbance at the bed of the streams which may further increasing the levels of the metal way above the World Health Organisation (WHO) standards thereby endangering the lives of the communities. From the map shown in Fig. 2, most of the vegetation/farmlands and settlements are very close to these streams where the illegal mining is being carried out of which the communities rely heavily for irrigation and other domestic use. The high levels of the heavy metals in the sediments give rise for concern on the impact of food security in the area. There is the tendency for the crops grown within the mining enclave to pick up some of the heavy metals and subsequently to be consumed by both man and animals.

The Physicochemical parameters analysed from the two streams are; P^H , Conductivity, TDS and Turbidity. The p^H values obtained ranged from 5.3 to 7.2. With the exception of Turbidity, all the samples fell within the WHO range for potable water. The mild acidic increase in the water samples increased the capacity of the water to attack geological materials and leach toxic trace metals into the water.

In the case of turbidity, the values ranged between 1946.6 to 2177.5 NTU far above, the limit 5 NTU. The Electrical Conductivity (EC) for all samples fell within the permissible limit of 500 $\mu S\ cm^{-1}$ set by WHO. EC is an indicator of water quality and soil salinity, hence the relatively high values observed in some water samples showed high salinity; thus the waters might not be very suitable for domestic and agricultural use. TDS values are generally below 250 $mg\ L^{-1}$ which was within the WHO permissible limit for potable water this showed that the two stream water in the area was quite fresh in most locations. The presence of the TDS in the water samples as observed in Fig. 12 above indicated the presence of solid materials or solutes in the water.

Conclusion and Recommendation

The results of this study supply valuable information about some heavy metal contents of sediments and water from different sites along Owerri and Asuokofi streams and we can conclude and recommended that:

- The activities of illegal mining in Konongo area has really polluted the water bodies especially their main source of water; Owerri and Asuokofi streams
- The distribution pattern of the heavy metals under investigation in stream sediments and water reflected a high significant difference ($p < 0.01$) for the all measured metals
- The levels of the metals are higher in the sediments than the water
- All the streams in the study area showed high levels of turbidity and conductivity

- It is recommended that the activities of the illegal mining must be curtailed immediately
- The metals in the sediments and water of the streams should be remediated preferably engaging the phenomenon of phytoremediation

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Authors Contributions

Wiafe, Samuel: Participated in all the experiments, coordinated the data analysis and contributed to the writing of the manuscript.

Richard Buamah: Designed the research plan and organized the study.

Helen Essandoh: Participated in the experiments and data analysis.

Lawrence Darkwah: Participated in the experiments and writing of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

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