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PHYSICAL CHARACTERISTICS AND HEAVY METAL POLLUTION OF THE UPSTREAM OF BIRIM RIVER

Richard **Amfo-Otu**
Department of Environment and Public Health, University of Environment and Sustainable Development, Somanya, Ghana

***Corresponding author**: ramfo-otu@uesd.edu.gh

Article Info **Abstract**

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Purpose — The study aimed to assess the physical characteristics and heavy metal pollution of the Birim River upstream.
Methods — A Pearson correlational test was conducted to assess the association between the physical parameters and the heavy metals.
Findings — The pollution index revealed that Hg and Fe were the most polluting heavy metals, with Ankase and Ayinam being the most affected areas due to increased mining activities. Correlational analysis indicated positive relationships between turbidity and Hg ($r = 0.972$), As ($r = 0.994$), and Cr ($r = 0.789$).
Conclusion & Recommendation — In conclusion, illegal and small-scale mining activities within the catchment of the Birim River have polluted the water quality. There is a need to regularize mining activities, promote sustainable mining practices, and implement reclamation plans to safeguard the river's water quality.
Keywords — Heavy metal pollution, Birim River, Small-scale and illegal mining, water quality, pollution index

Introduction

It is a common knowledge that surface water has provided various benefits to societies since antiquity. These benefits which can be broadly classified as consumptive and non-consumptive can be affected by various anthropogenic activities in and around surface water resources. Rivers, lakes, streams and ponds have been susceptible to environmental variabilities and human activities, causing different levels of pollution, destabilizing aquatic ecosystem and water uses. Such occurrences threaten water security and safety for the growing world population. Pollution of surface water have been attributed to farming activities, mining, industrial discharges within the catchment areas of water bodies, especially those within short distances.

One of such activities that is impacting on surface water in Ghana has been the artisanal gold mining activities of small-scale and illegal mining (galamsey). Some studies have identified the environmental impact of small-scale gold mining in developing countries and sub-Saharan Africa including Ghana (Hilson, 2002, Mireku-Gyimah, & Suglo, 1993) as well as galamsey operations.

The mining sector currently contributes approximately 41 percent of total exports earnings, 14 percent of total tax revenues, and 5.5 percent of Ghana's Gross Domestic Product (GDP). Gold contributes over 90% of Ghana's total mineral exports and makes up 49% of the country's total export value (MoF, 2022). In 2019, total workforce engaged directly by the producing member companies of the Ghana Chamber of Commerce was 11,899 (GCM, 2019).

Such impact includes the pollution of water bodies especially surface water bodies with high mineral deposit or prospects, contributing). Surface water bodies, including Birim River, within the mining communities are visually seen to be turbid, milky, brownish and unattractive to community members. Beneath the aesthetic objection is the real poison from heavy metal pollution from the natural environment and those that are used for the mining activities such as the mercury (Hg) (Afum & Owusu, 2016). The fact is that such mining activities are impacting negatively on the surface water resources in the country, and threatens our environment and our lives. Already, access to potable water supply in Ghana is challenged as 11% of the population still drink from surface and other unsafe water sources and 66% of households are at risk of drinking water that is contaminated with faecal matter (UNICEF, 2023). Moreover, the Population and Housing Census report indicate that four in five households (79.9%) using unimproved sources of drinking water rely on surface water (GSS, 2022). This makes it important to protect surface water resources from activities that can compromise water quality and work toward the SDG 6 clean water and sanitation for all.

A lot of studies have been done on mining activities in Ghana, especially the small-scale and illegal (Hilson, 2002) mining and its impact on the environment. Some studies have been done on water quality in mining areas, heavy metal pollution (Duncan, De Vries, & Nyarko, 2018). Specifically, Afum and Owusu, (2016) studied heavy metal pollution in the Birim River of Ghana which concluded that the river is polluted with heavy metals as concentration measured as dissolved were lower than WHO standards with the exception of Fe but there were high accumulations of heavy metals in the suspended mineral fractions of the river and in the sediments. These studies only focused on the pollution level without looking at how the physical parameter also contribute to the pollution in general and specifically the heavy metals. Hence this study looked at the heavy metal pollution of the upstream of the Birim river, and association of heavy metals with the physical parameters.

Materials and Methods

Description of Study Area

The Birim river is in the Eastern region of Ghana. The river takes its source from the Atiwa range in the Atiwa West district of the Eastern Region of Ghana. Geographically, the basin is located between longitude 0^0 25′ and 1^0 15′ west of the Greenwich Meridian and latitude 5^0 50′ and 6^0 30′ north of the Equator (Fig. 1). The Birim River, which takes its source from the Atewa mountain is one of the most important freshwater bodies in Ghana, which discharges into Pra River. It flows for about 181 km before joining the Pra River. Akim Apapam is the first community to see the river, and it flows through Kyebi, Osino, Bonsu, Anyinam, Kade, Akwatia, Oda and host of communities. The Birim river basin has experienced a of surface mining operations through open pits, direct dredging and panning. Apart from mining, the main socio-economic activities along the river-course are farming, palm kennel and palm oil production.

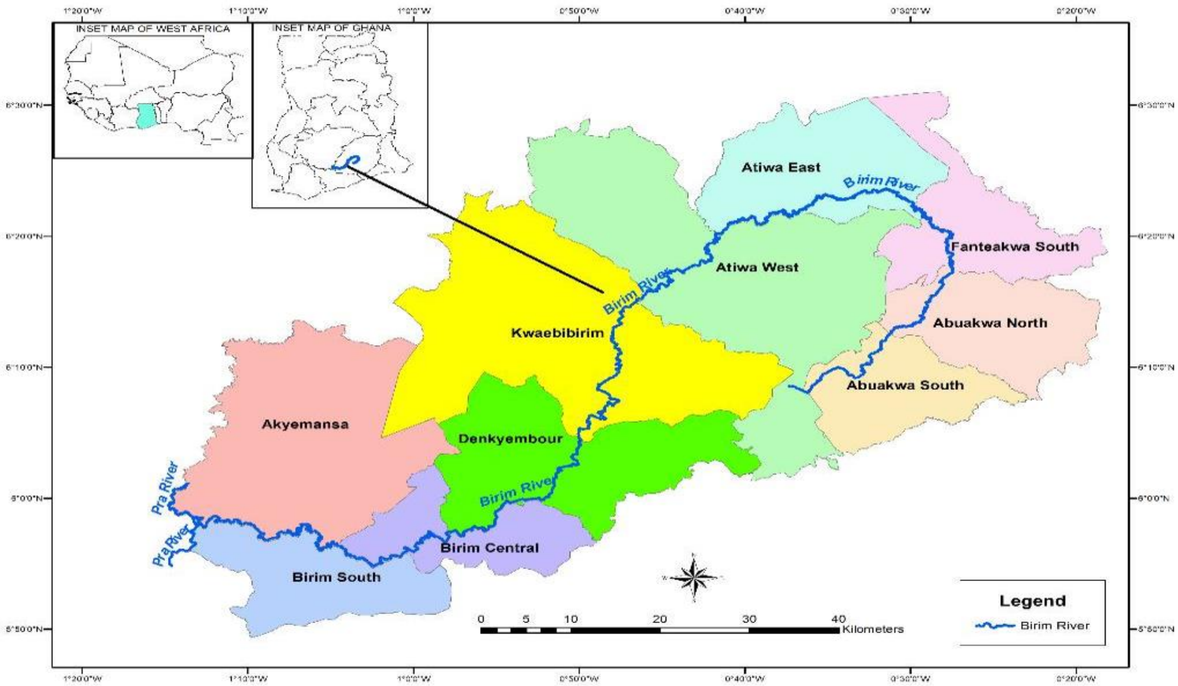

Figure 1: Map of Study Area showing Birim River
Source: INSTI – CSIR, 2023

Sampling Locations

Ten (10) samples (which include tributaries) were taken along the course of the Birim River from five locations or sites of the river. These are Akim Apapam, Kyebi, Bonsu University of Agriculture and Environmental Studies, Ankase and Ayinam. The sampling stations were chosen based on accessibility and safety as the waters have been taken over by galamsey operators. These are Birim-Apapam, Birim-Ayinam and Birim-Ankaase as shown in Figure 2. Sampling was confined to the banks due to a lack of boats except for one Ankaase where sampling was done in the midstream. The samples were taking in June, 2023.

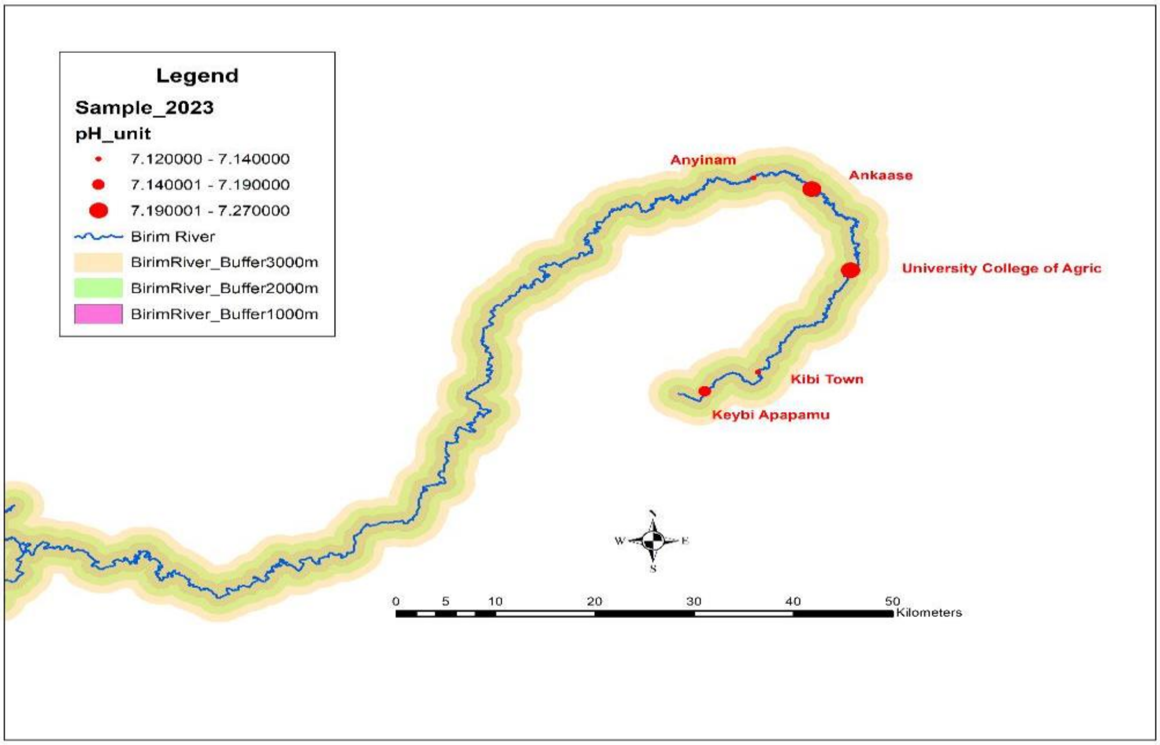

Figure 2: Map of Birim River showing the sampling points for the study

Source: INSTI – CSIR, 2023

The waters were extensively used for drinking and other domestic and agricultural activities before it was taken over by the activities of the Galamsey operators which has rendered it unusable.
Water samples for Physico-chemical analyses were collected directly into 10 different clean 750ml plastic bottles and stored in an ice-cooler at a temperature of below 20^{o}C for 24 hours before transporting to the Water Research Institute, Environmental Chemistry Division of the Center for Scientific and Industrial Research (CSIR).

Laboratory Analysis
Samples were analysed for pH, TDS, TSS, Colour, turbidity using the standard methods for examination of water and wastewater (Clesceri, 1998). The heavy metal concentrations for As, Cr, Cu, Cd, Fe, Hg, Mn, Pb and Zn, were determined using the Perkin-Elmer AA analyst 400 Atomic Absorption Spectrophotometer (AAS), and the Agilent 7700 Inductively Coupled Plasma – Mass Spectrometer (ICP-MS). The physicochemical parameters of the collected water sample formed the basis for assessing the heavy metal quality of the river. The results were compared to the World Health Organisation's drinking water guidelines and National Drinking Water Standards of Ghana.

Statistical analysis
The mean and standard deviation of each measured parameter was computed for the five sample locations to make it for easy comparison of the data and values are presented in Table 1. Pearson correlation was used to examine the relationship or association between two variables which gives the indication that the changes in one variable are associated with those in another variable. The Microsoft

Excel Software was used in carrying out the statistical analysis at 95% confidence interval. The correlation co-efficient, are presented in Table 2.

Pollution of Index

Nemerow's Pollution Index (NPI). NPI is an index that measures the extent of pollution caused by individual parameters. In this regard, the measured concentration of the parameter is compared to its standard value as indicated in equation (1). 'e calculated value from equation (8) represents the pollution caused by a particular parameter:

$$\mathrm{NPI} = \frac{Ci}{Li}$$

Where:

Ci is the observed concentration of the ith parameter.

Li is the permissible limit of the ith parameter.

A calculated NPI of less than or equal to 1 indicates the absence of pollution, and any value above 1 indicates pollution, the higher or bigger the value, the more significant the pollution effect (See Table 3).

Results and Discussions

The averages of the physicochemical parameters analysed as shown in Table 1 provides insight into the quality of the Birim River. The pH values recorded for all the sampled locations (7.12-7.27 pH units) indicate that river water was slightly alkaline and within WHO's guidelines for drinking wate. This is very good for consumption and has more benefit for the human body as well as aquatic ecosystem. The electrical conductivity showed minimal variation in values recorded (126 - 159 **µS/cm**) with a range of 33, from Apapam to Ayinam.

The colour of the water changes from clearer at Apapam to milky-brown at Anyinam as shown in Table 1. The colour though is pretty good at Apapam, its higher than the value recommended by WHO guidelines and the national standard for drinking water. The colour of the water along the river course after the first community were all above the required standard and it will be difficult to use such water for domestic or agricultural purpose. Again, it will take a lot of effort to deal with the colour during treatment for public supply for consumption. All the samples exceeded the level of turbidity for drinking water, even though Apapam had a better turbidity (17.7 mg/l) compared to all the other locations with Ankase recording the highest (342 mg/l). the results confirm the findings of Karikari and Ansah-Asare (2006) that the quality of river water in Ghana is generally poor, due to the high levels of turbidity which affect the performance of water treatment plants in effectively removing contaminants. The authors concluded that the poor performance of the plant in removing DOM and heavy metals was due to the high levels of these contaminants in the raw water. The total suspended solids (TSS) values recorded were all high and increased from 18<85<109<189<229 mg/l with Apapam recording the lowest and Ankases recording the highest, were all above WHO drinking water standard. Total dissolved solids (TDS) values were pretty high but within WHO's guidelines for drinking water (100mg/l). Total Dissolved Solids provides surface for adsorption of heavy metals and other contaminants. The heavy metal concentrations in the water samples results are shown in Table 1 concentration of the different metals varied from site-to-site. Interestingly, lead (Pb) was below detection level of 0.005, and therefore does not present any threat to the water environment.

Table 1: Physicochemical Analysis Results of Birim River

Sample	Ayinam	Ankase	Apapam	Kyebi	Bonsu	WHO Guidelines	National Standards
pH (pH Unit)	7.12	7.26	7.19	7.14	7.27	6.5-8.5	6.5-8.5
Cond (μS/cm)	131	129	132	159	126	1000.00	
Col (Hz)	150	100	20	150	200	15.00	5.00
Turb (Mg/l)	275	342	17.7	194	141	1.67	1.67
TSS (Mg/l)	189	229	18	109	85	10.00	
TDS (Mg/l)	72.1	71	72.6	87.5	69.3	100.00	
Fe (Mg/l)	1.72	1.59	0.72	1.45	1.04	0.30	0.3
Mn (Mg/l)	0.07	0.06	0.06	0.16	0.08	5.00	0.4
Zn (Mg/l)	0.03	0.007	0.005	0.01	0.01	0.10	3.0
Cu (Mg/l)	0.02	0.01	0.01	0.01	0.02	2.00	2.0
Cr (Mg/l)	0.02	0.02	0.01	0.02	0.02	0.10	0.05
Cd (Mg/l)	0.01	0.01	0.01	0.01	0.01	0.10	0.003
Hg (μg/l)	5.5	6.6	0.3	2.5	1.8	1.00	0.001
As (μg/l)	6.5	7.4	0.5	2.7	2.2	10.0	10.0
Pb (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	0.01

Source: Laboratory Results, 2023

The concentrations of Pb, Cd, Cr , As and Zn were below the WHO permissible limits within the sample points in the study area. However, Hg and Fe recorded average concentrations that were all above the WHO permissible limits within the sampled points as shown in Table 1. The average concentration of Fe measured for the river ranged between 0.72 – 1.72 mg/l. Iron is known for staining of laundry and plumbing equipment at concentrations above 0.3 mg/l (WHO, 2003; Department of National Health and Welfare (Canada), 1990). The concentration of Hg measured in the river ranged between 0.30 - 6.60 µg/l, with four of the point exceeding the WHO guideline values for drinking water (See Table 1). The lowest values for all the parameters analysed were observed in the samples for Apaapam and the highest were in the samples for Ankase. Increased level of Hg is of particular concern to human health due to its biomagnification nature and can cause several neurological and physiological disorders including kidney failure when it is high in drinking water (Hossain, Ahmed, & Sarker, 2018). The implication of these heavy metals in water treatment has been mentioned by Akoto et al. (2019) who reported that the performance of the Owabi water treatment plant in Ghana was not effective at removing heavy metals.

Level of Pollution

The level of pollution as determined by the pollution index in Table 2 shows that the highly polluting heavy metals in the study area and in the Birim river are the Fe and Hg. Iron pollution is high at Ayinam compared to all the sampled sites while mercury was high at Ankase compared to the other sites. The pollution index also shows that the pollution level at Apapam where the river enters the first settlement is lower for mercury and iron and increases as the river flows through the mining and farming areas. Ankase has more intesed mining activities among all the sampled points which follows Osino with high mining activities recorded high mercury pollution. This confirms the finding by Afum and Owusu (2016) that areas with high heavy metals concentrations are located in areas where small scale mining is dominant, indicating that the major contamination source in the water body is resulting from small scale mining activities. These are point to the fact that the mercury source in the river is likely to be from the mining activities. The implication is that users of the water along the river course have higher risks of exposure to Hg towards the downstream and in areas with incensed small-scale or illegal mining activities using mercury.

Table 2: Pollution Index for Heavy Metals Analysed

Heavy metals	Ayinam	Ankase	Apapam	Kyebi	Bonsu
Fe	5.7	5.3	2.4	4.8	3.5
Mn	0.0	0.0	0.0	0.0	0.0
Zn	0.3	0.1	0.1	0.1	0.1
Cu	0.0	0.0	0.0	0.0	0.0
Cr	0.2	0.2	0.1	0.2	0.2
Cd	0.1	0.1	0.1	0.1	0.1
Hg	5.5	6.6	0.3	2.5	1.8
As	0.7	0.7	0.1	0.3	0.2

Source: Field data, 2023

A correlational analysis in Table 2 shows that the higher the Turbidity the higher the Hg ($r = 0.972$) and As ($r = 0.994$) levels in the water. The increase in total Hg concentration was associated with increase in As ($r = 0.998$), Cr ($r = 0.887$) concentrations and TSS ($r = 0.994$). These positive correlations mean that the raw water with high amount of TSS and turbidity allow for binding of heavy metals and increase the concentration in the water medium. Again, Fe correlated positively with Hg and As, (see Table 3) implying that increase in Hg is associated with Fe and As. It is therefore, not suppressing that these three heavy metals exceeded the WHO and National drinking water standards. Some studies have found similar relationship. The positive strong correletion among Hg, As, Cr, and Fe metals indicate that they are from the same source or are released into the environment by the same activity along the banks of the water course. Similar finding has been reported by Fagbenro, Yinusa, Ajekiigbe, Oke, and Obiajunwa, (2021) that positive correlations between heavy metals indicate that they have the same source of anthropogenic input which could be derived mainly from gold mining and agricultural activities (manure and pesticides applications) since these sources are noted for contributing one or the pair correlated metals to the natural environment.

Table 3: Correlation Results for Physicochemical Parameters Analysed

	pH	*COND*	*COL*	*TURB*	*TSS*	*TDS*	*Fe*	*Mn*	*Zn*	*Cu*	*Cr*	*Cd*	*Hg*	*As*
pH	1													
COND	-0.569	1												
COL	0.069	0.080	1											
TURB	0.013	-0.031	0.378	1										
TSS	0.016	-0.130	0.299	0.991	1									
TDS	-0.569	1.000	0.081	-0.028	-0.127	1								
Fe	-0.331	0.192	0.432	0.933	0.913	0.195	1							
Mn	-0.382	0.932	0.400	0.013	-0.111	0.932	0.203	1						
Zn	-0.520	-0.143	0.533	0.381	0.403	-0.142	0.578	-0.077	1					
Cu	-0.060	-0.333	0.795	0.192	0.187	-0.333	0.279	-0.085	0.820	1				
Cr	-0.069	0.047	0.617	0.956	0.925	0.050	0.950	0.163	0.543	0.418	1			
Cd	-0.279	0.351	-0.748	-0.789	-0.775	0.349	-0.691	0.117	-0.552	-0.674	-0.868	1		
Hg	-0.006	-0.180	0.217	0.972	0.994	-0.177	0.893	-0.191	0.410	0.160	0.887	-0.736	1	
As	-0.015	-0.219	0.220	0.961	0.989	-0.216	0.887	-0.229	0.448	0.197	0.880	-0.746	0.998	1

Source: Field data (2023)

From the findings it is obvious that the illegal and small-scale mining activities along the river is contributing heavy metal pollution into the environment and the river. It is common knowledge that the illegal miners have been using mercury in their amalgamation process to purify the gold during the mining operations and such practices contribute high amount of mercury into the environment. The implication of the water quality results on water treatment for consumption, usage for agriculture and others will require substantial investment to make the water fit for purpose. Treatment plants operations will be affected by the high level of turbidity and colour require the use of more coagulants for dealing with colloids accounting for the high turbidity and colour of the water. The cost of treating such water for domestic use will be expensive and will affect access to clean and potable water in the communities along the river. This will affect the country's quest to work toward achieving the SDG 6 on "clean water and sanitation for all". The ultimate effects are on quality of life and health of the people as well as the water ecosystem.

Conclusion and Recommendations

The physico-chemical analysis of the Birim river indicated high levels of turbidity, TSS, and colour compared to WHO guidelines and National drinking water standard while pH and TDS were within the acceptable limits. The concentrations of Pb, Cd, Cr, As and Zn were below the WHO and national drinking water permissible limits whiles Hg and Fe recorded average concentrations that were all above the WHO and national permissible limits for drinking water. The general observation was that, the Birim river was relatively clean compared to the other sampled point along the course of the river. The implication is that environmental activities along the river bank is impact on the water quality. The pollution index for Hg was about 7 times the acceptable level at Ankase and 6 times at Ayinam but lower at Apapam. It is safer to use the water at Apapam for consumptive and non-consumptive purposes than all the other sampled points. High correlation between turbidity, Fe, Cr and Hg were observed, emphasising the fact that the turbid environment provides the required interface for binding Fe, Cr and Hg. High level mercury in the water samples indicate that mining activities within the catchment area and at the bank of the river is contributing to the Hg levels in the river.

To deal with the pollution of the river it is important for Water Resources Commission, security agencies Municipal and District Assemblies and Community member to enforce the law on not undertaking any development activities including farming with the 100m from the bank of the river. Reclamation plan which should include, levelling, planting of trees and crawling plants to check erosion from contributing runoffs that may be ladened with heavy metals and clay should be developed and implemented. Environmentally safer alternative ways of mining for gold without the use of Hg such as bioleaching where bacteria are used to extract metals from ores and hydrometallurgy which uses water to extract metals from ores should be considered for adoption.

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Conflict of Interest
There is no conflict of interest as far as this study is concern as I have no personal interest in mining related activities.

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