Gold Mining Effects on Water Quality in Domenase and Nkotumso along River Offin, Upper Denkyira West District

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Abstract

Artisanal gold mining (ASM) has been an important source of primary livelihood activity for poor populations in Ghana. The sector now functions as a vital social safety-net and in some cases, provides the only source of income in employment-constrained economies and helping copious poor households survive during increasingly uncertain times. However, artisanal mining is linked to the release of heavy metals into the mainstream environment causing water pollution. In this study, heavy metals namely mercury (Hg), arsenic (As), manganese (Mn), lead (Pb) and iron, (Fe) were quantitatively analysed using PinAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer. The samples were taken from the core water source area of Domenase and Nkontomisa on the Offin River in the Upper Denkyira West District of the Central region of Ghana. The decreasing trend of metals was observed in water as Hg > Pb > As > Mn >Fe, whiles the average distribution of these heavy metals in water was 0.11, 0.02, 0.02, 0.122, 0.184 mg/L respectively for Nkotumso. In Domenase, the decreasing trend of metals was observed in water as Pb > Hg > As > Fe >Mn, and their averages were 0.028, 0.09, 0.018, 0,188, 0.090 mg/L, respectively. The concentration of Hg, As, and Pb in the water samples were above the WHO (2011) permissible limits except Mn and Fe which were below the guideline limit. The pH range of 6.24-6.53 was noted for Nkotumso and 5.24-5.83 (strongly to moderately acidic) for Domenase. The pH of water samples collected from Nkotumso was within WHO (2011) guideline values whereas the values of Domenase were not.

The results indicate that the water is not suitable for drinking and other domestic purpose such as cooking since heavy metals such as Hg, As, and Pb which are known to be carcinogenic were high. The study recommends that continuous monitoring of Hg, As and Pb in the water and other aquatic biota of Nkotumso and Domenase along the River Offin should be assessed to ensure the safety of the ecology in the vicinity of the river.

Keywords: Heavy metals, Artisanal gold mining, Water quality, Nkotumso, Domenase, Offin River

Introduction

Artisanal gold mining (ASM) has been on the ascendancy as an important source of primary livelihood activity for poor populations in Ghana. The sector now functions as a vital social safety net and in some cases, provides the only source of income in employment-constrained economies, helping numerous poor households survive during increasingly uncertain times. The principal product mined is gold. While these artisanal or small-scale mining operations provide jobs, they are also linked to the release of heavy metals into the mainstream environment causing pollution (Bansah, et al., 2018).

The Offin River is a national level water source protection zone and the ecological safety of its water quality and surrounding ecosystem is of great significance to settlements along its basin. The geographic focus of the study was Nkotumso and Domenase (also spelt Domenose) which is sited along the tributary of River Offin where artisanal gold mining is highly concentrated. Mining activity, though recurrent and of economic importance, it offers employment to the local people. The principal mineral mined in the area is gold and the type of environmental effects includes water pollution, interruption of the flow of minor rivers; and dug mined-pits. The negative consequence of the mining occurs when the mineral is extracted from the margins of rivers. When that happens, it leads to river-bank erosion during floods thus transporting more solids into streams, degradation of the landscape including watersheds and local flora and fauna are usually hunted excessively around temporal mining camps (Ciszewski, & Grygar, 2016). In practice, artisanal mining is a subsistence that works independently, using simple locally produced tools (Veiga, et. al., 2019). In artisanal gold mining, gold is extracted mainly from alluvial deposits along rivers, waterways and terrestrial soils (Donkor et al., 2006; Hayford et al., 2009). Gold is then processed by crushing and grinding the gold-bearing ore. The gold is extracted from the concentrate by adding mercury to form gold amalgam which is normally roasted in the open air to obtain raw gold (Mantey, et. al., 2020). The elemental Hg, its reaction and carcinogenic effect has been widely discussed (Larceda & Salomoms, 1998). Mercury, once exposed to the atmosphere, aquatic and terrestrial environment, may undergo a series of transformations, eventually becoming methylmercury which is a neurotoxin (the most toxic form of the metal), poses a serious threat to the food chain and human health (Cleary & Thornton, 1994; Donkor, et al., 2006; Rahmanikhah, et al., 2020). In addition to the aforementioned environmental impacts, artisanal gold mining contributes significantly to the release of other heavy metals into waterways, and to other distant uncontaminated locations, making those habitats vulnerable to heavy metals pollution. This may cause the deterioration of air and water quality and subsequent lethal effects on living organisms as well as humans (Donkor et al.,2006; Beckers et al., 2017), loss of biodiversity and conservation of natural resources (Schiesari et al., 2018).

Artisanal gold mining refers to the winning of gold dust by people who do not have the authorization of the government (Donkor et al., 2006). The enactment of the small-scale gold mining law in 1989 which effectively legalized small-scale gold mining in the country not only increased industrial operations in gold mining contributions to socio-economic growth but also boosted artisanal gold mining and increased environmental complications namely, mercury pollution and land degradation (Hilson, 2002).

In Ghana, most of the gold-bearing ores are known to be pyrites (FeS) and arsenopyrites, ($FeSAs_2$) (Kesse, 1985; Obkirchner, 2019). Metals like cadmium, chromium, copper, manganese, arsenic, iron and zinc are natural components of gold-bearing sulphide and arsenopyrites ores (Kesse, 1985). The miners use nitric acid (HNO_3) during the gold recovery process first, the valuable minerals are separated from the gangue through concentration. The final concentrate is obtained by repeated processing and is smelted or leached in order to get a Dore bar. Since artisanal gold operators have no system in place to recover the acid used, the by-product of the acid is released into the environment and leaching into rock piles, tailings and soils thus liberating heavy metals such as cadmium, lead, arsenic, copper, chromium, manganese, iron, zinc and gold which can cause pollution of soil, water and food (Donkor et al., 2006). The term "heavy metals" is a general collective term, which applies to group of metals and metalloids with an atomic density greater than 4 g/cm^3, or 5 times or more, greater than water (Ali, 2021; Nashmi et al., 2020) or any metallic element that has a relatively high density and is toxic or poisonous even at low concentration (Lenntech, 2009; Joseph, 2019). Heavy metals are pollutants in the environment which cause objectionable effects, impairing the welfare of the environment, reducing the quality of life and may eventually cause death. Such a substance has to be present in the environment within a tolerance range, which could be either a desirable or acceptable limit. The presence of heavy metals poses detrimental impact on the environment; air, water and soil. They pose a serious threat to the environment and life which needs to be investigated and monitored

(Mantey, et. al., 2020). To a small extent, they enter the mainstream environment through food, air, and water and bio-accumulate over a period of time (Masindi & Muedi, 2018).

Heavy metals occur as natural constituents of the earth's crust and are persistent environmental contaminants since they cannot be degraded or destroyed. In rocks, heavy metals exist as ores in different chemical forms, from which they are recovered as minerals (Fashola et al., 2016). Heavy metal ores including sulphides, such as iron, arsenic, lead, lead-zinc, and oxides of aluminium, manganese, and gold, exist in the environment in different proportions. Literature points to the fact that these metals are released into the environment by both natural and anthropogenic sources, especially mining and industrial activities (Duruibe et al., 2007).

Impact of mining on water

The impact of gold mining on the environment is countless, nevertheless one of the most outstanding is the intimate relationship between gold mining and water and its effect on livelihood (Lahiri-Dutt, et al., 2018). The gold mining industry depends on steady and abundant supplies of clean water. Generally, mining companies and other miners rarely invest in infrastructure to secure water supplies that they would need for their operations but rather would rely upon the natural rivers for their mining activities (Simutanyi, 2008). Mining affects fresh water through heavy use of water in processing ore, water pollution from discharged mine effluent, seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which the communities depend. The determination of physicochemical parameters of water is deemed relevant since such parameters are important water quality test (Nazir et al., 2015; Diamantini et al., 2018). The pH of natural water is a measure of its acid-base equilibrium and determines the corrosivity of water (Reardon, 1995). The pH of most raw water lies within the range of 6.5–8.5; the higher the pH, the lower the level of corrosion (WHO, 2011). Organisms that are exposed to high pH levels in water may experience eye, skin irritation, lesions, exacerbation of skin disorders, and swelling of hair fibres (Napacho & Manyele, 2010). Other health challenges may include insensitivity in individuals and gastrointestinal irritation (White et al., 2016), toxicological effects on human health and aquatic life (Balasubramaniam & Panda, 2014; Asif & Chen, 2016).

Mercury and lead from mining sites when exposed to consumers through water may cause skin irritation, respiratory problems, immunological toxicity, and reproductive disorders (Rahman & Singh, 2019). As it happens in most cases during the processing of the ores for the gold metal, the separation process does not extract all the minerals present. The finely ground material from processing produces contaminants such as arsenic, cadmium, chromium, copper, iron and zinc, bound up in solid rock accessible to water (Vardhan et al., 2019). The tailings are released directly into rivers and this introduces large amounts of suspended solids and contaminants directly into aquatic habitats (Förstner & Wittmann, 2012). The miners add metallic mercury to the impure gold dust obtained to form a mercury-gold amalgam. Though the optimal mercury to gold ratio (Hg, Au) is about 1(v/v), it has been established that the miners add more mercury in order to be sure that they have amalgamated all the available gold (Buccella, 2013). Raw gold is recovered through the process of amalgam roasting on an open fire. The artisanal gold miners have no system for recovering the mercury used; therefore, all the mercury is released into the environment. Mercury, once exposed to the atmosphere, aquatic and terrestrial influence, may undergo a series of transformations, eventually becoming Methyl-mercury which is a neurotoxin and the most toxic form of the metal; easily incorporated in living organisms and accumulates in the food chain (Díez, 2008).

Gravimetric material flow analysis shows that between 20 to 30 % of the mercury introduced is lost to soil tailings, stream and river sediments, and water bodies close to the processing sites, and between 70 to 80 % of the mercury is lost to the atmosphere during the processing (Serfor-Armah et al., 2005). Manganese is an essential nutrient for humans but too much exposure will be toxic to human body development, reproduction and the nervous system (Schwarzenbach et al., 2010). It is indicated that most rivers near mine sites have their dissolved and suspended sediments contaminated by toxins from mine sites and can be very harmful to aquatic life, water supply and consumption (Mehta et al., 2020). Furthermore, Honlah et al. (2019) observed that most rivers have been polluted exposing consumers to health challenges. For example, the Birim River has been polluted beyond treatment, hence, cannot provide safe drinking water for residents and beyond (Afum & Owusu, 2016). Dissolved and suspended sediments are well among the pollution pressures impacting water quality in mined-landscape (Zipper & Skousen, 2021). Harmful to aquatic life, dissolved and suspended trace metals are often partitioned with iron, manganese and sulphur minerals in mining-contaminated sediment, therefore the dissolution and precipitation of these minerals may influence the mobility of potentially toxic trace metals (Byrne & Reid, 2012). Mining impacted catchments are known to play a critical role in the distribution of dissolved and suspended metal contaminants through river systems while diffuse sources of pollution are known to contribute significantly to total contaminant metal flux to rivers (Lynch & Byrne, 2014).

Contaminants can be deposited in a particulate form on riverbanks and floodplains several hundreds of kilometres from the main mining area. As a result, thousands of tons of trace metals can be stored along riverbanks and floodplains and can remain in the sediment for hundreds of years potentially posing a long-term threat to rivers, aquatic life and agricultural land (Lynch, Batty, & Byrne, 2014). Since communities' livelihood is highly dependent on the Offin River, assessing the presence of heavy metals in the water body is an important step in addressing the problem of water quality in the area.

Background to the study

Small-scale gold mining (SSGM) and Artisanal gold mining (AGM), popularly called 'galamsey' has been a vibrant indigenous industry for many centuries in Ghana. There was a major shift in gold mining after the liberalization of small-scale mining in 1989, following the enactment of the small-scale gold mining law: PNDC law 218 of 1989 and the mercury law: PNDC law 217 of 1989 (Appiah, 1998). These laws were aimed at: to regularise and streamline small-scale gold mining, regulate the use of mercury by small-scale gold miners, and provide official marketing channels for sales of gold, stop the use of explosives in gold mining operations. The temporary ban placed by the government in 2018 on galamsey operations managed to halt water pollution briefly but pollution intensified when the ban was lifted the same year.

The state of social condition leaves much to be desired; the majority of communities in the study area live with inadequate or poorly functional services such as roads, water, and sanitation facilities while pollution from these communities has severe economic and health implications for downstream users and impact on the ecosystem. Water quality problems from mining areas arise where waste produced, reach the downstream settlements. The effects of mining on water resources are felt in many ways, large and small. Mining sludge, in few instances, remains in the river channels, working its way further downstream as sandbars in occasional flood events and where deposition is active (Rudorff et al., 2018). These scour the riverbeds that provide habitat for aquatic life and fill the pools that shelter the fish. Sludge is also still present on old floodplains, forming a hard crust that inhibits the growth of plants.

Literature available on mercury pollution in Ghana deals with survey data on some of the rivers draining the south-western gold belt (Donkor et al., 2006). Apprehensions about mercury and other heavy metals released during the gold extraction process are based on their effect on the aquatic ecosystem and human health. The study, therefore, investigates the quality of water based on its physicochemical properties and the presence of heavy metals such as mercury, arsenic, manganese, lead and iron. This is necessary because of their wider detrimental effects on quality of water and aquatic life which would require periodic monitoring to maintain the ecological integrity of the rivers.

Study area

The study area (Domenase and Nkotumso) is situated along the River Offin in the Upper Denkyira West District which lies within latitudes 5º 30" N and 6º 02" N of the equator and longitudes 1º W and 2º W of the Greenwich Meridian. It is the northernmost district in the Central Region and shares common boundaries with the following districts, Bibiani-Anhwiaso-Bekwai District (Western North Region) to the north, Amansie West and Amansie Central Districts (Ashanti Region) to the east, Wassa Amenfi East and Wassa Amenfi West districts (Western Region) to the west, and Upper Denkyira East Municipality to the south. The district has a total land area of 579.21 km^2 which represents 3 % of the total land area of the Central Region. Domenase and Nkotumso are two communities along the Offin River that are into artisanal gold mining employing local indigenes in the mining operations. The Offin River connects local places into networks of social relationships up and down river valleys and across the near-undulating terrain into neighbouring watersheds. Gold mining gained prominence in present day Offin when two dredges commenced operation in the vicinity of the Offin River near Dunkwa as gold investors began withdrawing interests from South Africa during the Boer War (1899–1902) (Hilson, 2001). Geologically, this area falls within the Birimian and Tarkwaian gold belts (Kesse, 1985). Episodes of erosion spanning millions of years led to a re-deposition and reconfiguration of gold-aggregated ores resulting in gold deposits ranging in complexity and form, suitable for both large- and small-scale extraction (Hilson, 2001). Figure 1 shows the upper Denkyira West District indicating the areas in which the study was undertaken.

Relief and Drainage

The district falls under a forest-dissected plateau, rising to about 250 m above sea level. The topography of the district is generally

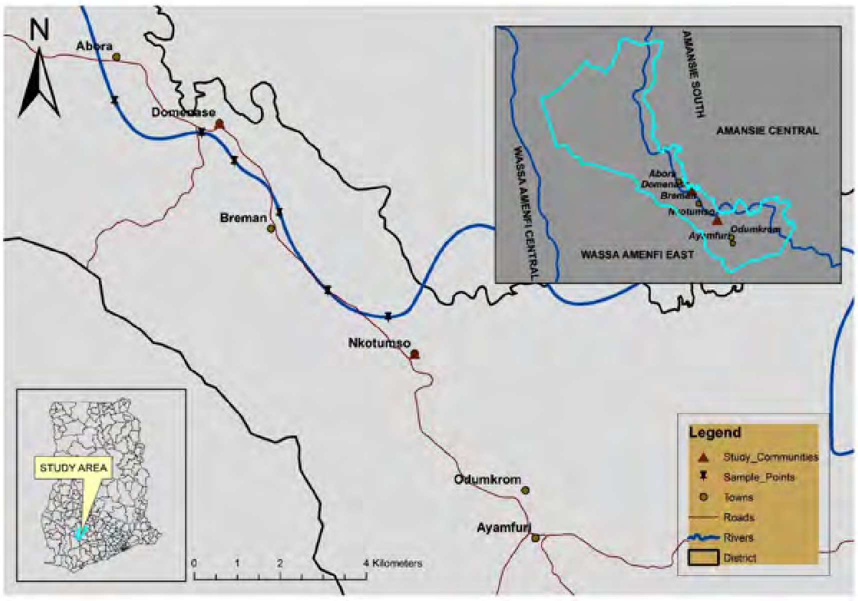

Figure 1 Map of the study area showing Domenase and Nkotumso

undulating with pockets of steep-sided hills alternating with flat-bottomed valleys. The major river in the area is the River Offin and River Dia. Several streams which are tributaries of either the Offin and Dia flow through the district and serve as major sources of water for farming activities and domestic use. Prominent among them are the Subin Ninta, Afiefi and Subin in the northern part of the district.

Materials and Methods

Small-scale miners around the world employ several methods in their activities (Hilson, 2002). The differences in the methods are a result of the type of mineral deposit that is extracted, location and tools used (Ntibrey, 2001). The poor financial status of small-scale miners permits most of the miners to rely on primarily the labour-intensive methods of mining. The two forms of small-scale mining extraction of minerals include hard rocks and alluvial materials. In Ghana, the artisanal gold mining and small-scale mining methods are shallow alluvial, hard rock and deep alluvial mining (Ayee et al., 2003). Shallow alluvial mining commonly known as the 'dig and wash' is the most widely practiced in the study area. The mineral deposits are found in low-lying or valleys areas that do not exceed 3 metres in depth. The area is first excavated until the mineral-rich layer is reached and treated; In shallowest alluvial mining areas, dredging is involved.

The two sampling stations are Nkotumso (upstream) and Domenase (downstream) with each station having five sampling points. The water sample was collected from a mid-stream flow of 5 metres in depth. Each sample collected has a volume of 1000 mL; these were mixed together to obtain a unified sample of 5000 mL out of which 1000 mL was collected for the analysis; the same process was done for Domenase, located downwards stream of Nkotumso. The choice for selection of these two sites is based on the location of the mining activity and the dependency of the two communities on the Offin River as their main source of drinking water which would help to determine the possible impact of mining on the quality of the river and its ecological safety.

Water sampling was carried out from downstream to upstream on the basis of hydrological conditions, lithological and land use. Sampling was conducted in the month of August 2021 during the wet season. All samples were collected into a 500 mL acid-washed polyethythene container. Physicochemical parameters such as pH, electrical conductivity, total dissolved solids, and dissolved oxygen were measured in situ using EZDO 7200 multimeter while total suspended solids, odour, and alkalinity were measured in the laboratory based on the standard methods for the examination of water and wastewater. For the determination of heavy metals, the water samples were filtered through a 0.45μm filter membrane on site. Heavy metal samples were acidified to pH ≤ 2 using nitric acid. All water samples were well labelled and stored in an ice chest at 4°C, and transported to the Ecological Laboratory of the University of Ghana for analysis. The samples were then kept under refrigeration at 4°C until analysis. Total suspended solid (TSS) is measured on a sample of water (which has been settled) and on those particles which will not pass through a very fine filter (usually 0.45 microns). The filter was pre-weighed prior to the passing of the water, and post-weighed. The difference between the two weights is the TSS concentration in mg/L.

Determination of Heavy Metal

A series of calibration standards containing known amounts of analyte elements were also prepared (2.00 mg/L, 5.00 mg/L,10.00 mg/L etc.) and used to calibrate the PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer. Blanks were atomized followed by the standards and calibration graphs plotted showing responses from the AAS. Responses of standards were used to establish the precision of the machine and concentration values of elements. The

PINAAcle 900T Perkin Elmer AAS was calibrated after every ten samples analysed. The light was generated from a hollow cathode lamp at a wavelength characteristic to each analyte. Each analyte was then atomized using an atomizer to create free atoms from the samples. The concentration of lead (Pb) and cadmium (Cd) were determined using a flame atomic absorption spectrophotometer (FASS) while As and Hg were measured using a flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Hydride generation technique) and (Cold vapour technique) respectively. Air-acetylene gas was used as the source of energy for the production of free atoms for lead and cadmium and argon-gas for mercury and arsenic. For dissolved metal analysis, water samples were directly aspirated into the atomic absorption spectrophotometer to determine the metal content. Procedural blanks were determined between every ten (10) samples to control the accuracy while method precision was controlled by re-determining two (2) known standards after every ten samples.

Data analysis

Data were analysed using SPSS 26.0 (SPSS Inc., USA) software and Microsoft Office Excel 2019. Descriptive data were generated for all variables and presented as a minimum, maximum, mean, standard deviation, and coefficient of variation. Levene's test of equality of variance and independent t-test was used to test for the equality of two means (upstream and downstream) for the selected water quality parameters. The mean significance was different at the 0.05 level. Pearson's correlation coefficient was used to establish the relationship between physicochemical properties and heavy metals to identify possible sources of contamination and measure the strength of the relationships between variables.

Results and discussion

This investigation was conducted to determine the level of heavy metals, total dissolved solids and total suspended solids contamination

TABLE 1

Physical and chemical parameters of river water at Nkotumso and Domenase

Parameter	Statistics	Nkotumso (Upstream)	Domenase (Downstream)	P-value	WHO Limits (2011)
pH	Range	6.23 - 6.74	5.31 - 6.61	p<0.05	6.5-8.5
	Mean±SD	6.50±0.16	5.83±0.42		
EC (µS/cm)	Range	220 - 583.3	39 -160	p<0.05	1000
	Mean±SD	350.0±122.77	93.0±39.93		
TDS (mg/L)	Range	132 - 350	22 - 91	p<0.05	1000
	Mean±SD	210.0±73.67	53.0±22.67		
TSS (mg/L)	Range	546 - 2245	3614 - 8751	p<0.05	500
	Mean±SD	1332±592.83	6456±1586.2		
T-Alk (mg/L)	Range	35.05 - 148.3	11.0 - 41.0	p<0.05	200
	Mean±SD	78.40±41.95	24±10.30		
DO (mg/L)	Range	1.25 - 4.12	0.45 - 1.96	p<0.05	10
	Mean±SD	2.79±0.99	0.82±0.43		
Pb (mg/L)	Range	0.004 -0.051	0.016 - 0.048	p<0.05	0.01
	Mean±SD	0.020±0.018	0.028±0.010		
As (mg/L)	Range	0.004 - 0.051	0.010 - 0.028	p<0.05	0.01
	Mean±SD	0.021±0.014	0.018±0.006		
Hg (mg/L)	Range	0.002 - 0.021	0.012 - 0.171	p<0.05	0.001
	Mean±SD	0.011±0.007	0.09±0.050		
Mn (mg/L)	Range	0.027 - 0.254	0.043 - 0.85	p<0.05	0.4
	Mean±SD	0.122±0.09	0.09±0.042		
Fe (mg/L)	Range	0.072 - 0.461	0.105 - 0.321	p<0.05	0.3
	Mean±SD	0.184±0.133	0.188±0.064		

*EC – Electrical conductivity, TDS – Total dissolved solids, TSS – Total suspended solids, DO – Dissolved oxygen, T-Alk – Total alkalinity in water from small-scale mining activities. The results of physical and chemical quality parameters such as pH, electrical conductivity, total dissolved solids, total suspended solids, alkalinity, dissolved oxygen, lead (Pb), arsenic (As), mercury (Hg), manganese (Mn), and iron (Fe) of river water at Nkotumso and Domenase analysed are presented in Table 1. The results of the analysis were compared with WHO's Guidelines for Drinking-water Quality, 2011; the international reference point for standard setting and drinking-water safety.

The pH values of river water at Nkotumso and Domenase ranged from 6.23 to 6.74 and 5.31 to 6.61 respectively. The highest mean pH value of 6.50±0.16 was recorded at Nkotumso while the lowest pH value of 5.83±0.42 at Domenase. There was a significant difference in the values of pH at Nkotumso and Domenase [$t(18) = 4.757, p < 0.012$] (Table 1). The pH at Nkotumso ranged from slightly acidic to neutral whereas Domenase ranged from strongly acidic to neutral with a mean pH value indicating slightly acidic and moderately acidic respectively. The pH of water samples analysed was within the WHO (2011) permissible limit of 6.5 – 8.5 for surface water. The pH of water from Domenase is 5.83, a little below the WHO recommended range, of 6.5-8.5.

The electrical conductivity (EC) of river water at Nkotumso ranged from 220 to 583.3 µS/cm with a mean value of 350±122.77 µS/cm whereas Domenase ranged from 39 to 160 µS/cm with an average of 93.0±39.93. Conductivity values demonstrated a statistically significant difference at the study site [$t(18) = 6.295, p < 0.020$]. The results of conductivity obtained in this study were below the WHO (2011) permissible limits of 1000 µS/cm (Table 1). Electrical conductivity measures the ability of water bodies to conduct an electrical current. The higher the concentration of dissolved charges and salts in the water system, the greater the electrical current that can be conducted. Examples of charged ions that naturally occur in river water include calcium, potassium, chlorides, sulphate and nitrate. The presence of these charged ions can significantly increase the electrical conductivity which indicates that pollutants have entered the river.

Total dissolved solids (TDS) of river water at Nkotumso ranged from 132 to 350 mg/L with a mean of 210±73.67 mg/L while that of Domenase ranged between 22 and 91 mg/L with a mean of 53.0±22.67 mg/L. The highest value of TDS was recorded at Nkotumso whereas the least at Domenase. The mean concentration of TDS at Nkotumso was significantly different from the mean concentration of TDS at Domenase [$t(18) = -6.442, p < 0.017$] (Table 1). The concentration of TDS was below the WHO (2011) permissible limit of 1000 mg/L. Total dissolved solids refer to the mineral content of water as well as dissolved organic materials. High levels of TDS in surface water such as rivers come from the solvent action of water in contact with minerals in the earth, agricultural and residential runoff, leaching of soil contaminants, and waste water from industrial or sewage treatment plant.

The mean values of total suspended solids (TSS) at Nkotumso and Domenase were 1332±592.83 mg/L and 6456±1586.2 mg/L respectively. The levels of TSS at Nkotumso ranged from 546 to 2245 mg/L while levels were from 3614 to 8751 mg/L at Domenase. Total suspended solids from Domenase, 6456 mg/L are nearly five times as much as those of Nkotumso 1332 mg/L. The mean values of TSS at Domenase demonstrated a statistically significant difference in the levels of TSS at Nkotumso [$t(18) = -9.569, p < 0.036$] (Table 1). Total suspended solids are a vital water quality that needs to be measured for wastewater treatment and environmental health. Low TSS from the investigation could be attributed to low surface run-off which results in the low discharge of solid matter and dissolved substances into the main stream-water. High suspended solid might have accounted for a lower pH in Domenase since TSS particle-size distribution and their chemical composition could lower the pH value of water. Total suspended solids (TSS) are an extremely important cause of water quality deterioration leading to aesthetic issues, higher costs of water treatment, a decline in the fisheries resource, and the serious ecological degradation of the aquatic environment (Bilotta & Braziera, 2008).

The levels of alkalinity in river water at Nkotumso ranged from 35.05 to 148.3 mg/L with a mean content of 78.40±41.95 mg/L. On the other hand, the alkalinity content of Domenase ranged from 11.0 to 41.0 mg/L with an average value of 24.00±10.30 mg/L. There was a statistically significant difference in the levels of alkalinity at both locations [t(18) = 4.001, p< 0.002]. The levels of alkalinity at both locations were below the WHO (2011) permissible limit of 200 mg/L (Table 1). Alkalinity is a measure of the capacity of the water to resist a change in pH that would tend to make the water more acidic. It is therefore equivalent to the buffer capacity of the water body's ability to resist changes in pH. Both odour and alkalinity are low which reflect the low pH of the two study sites since low pH could inhibit nitrification, the microbial conversion of ammonium to a nitrate; pH in laboratory studies, states that decreasing pH will impact the N cycle by decreasing nitrification (Huesemann et al. 2002; Srna & Baggaley 1975; Ward, 2008).

The dissolved oxygen content of river water at Nkotumso ranged from 1.25 to 4.12 mg/L while those at Domenase ranged from 0.45 to 1.96 mg/L. The average values of DO at Nkotumso and Domenase were 2.79±0.99 mg/L and 0.82±0.43 mg/L respectively. The concentration of DO at Nkotumso was significantly different from that of Domenase [t (18) = 5.786, p< 0.001] when independent t-test was performed. The dissolved oxygen content at both locations was below the WHO (2011) permissible limit of 10 mg/L (Table 1).

At the two locations, heavy metal concentrations slightly exceeded the concentration admitted by the guidelines. The mean concentration of lead was 0.020±0.018 mg/L and 0.028±0.010 mg/L in water for Nkotumso and Domenase respectively. The concentration of Pb at Nkotumso ranged from 0.004 to 0.051 mg/L while Domenase ranged from 0.016 to 0.048 mg/L. There was a significant difference in the concentration of Pb at Nkotumso and Domenase [t(18) = -1.063, p< 0.003]. The mean concentration of Pb measured at both locations was above the WHO (2011) permissible limit of 0.010 mg/L (Table 1).

Arsenic was 0.020±0.014 mg/l and 0.018±0.006 mg/l in water for Nkotumso and Domenase respectively. Arsenic content at Nkotunso ranged from 0.004 to 0.051 mg/L whereas at Domenase, it ranged from 0.010 to 0.028 mg/L. There was a significant difference in the concentration of As at Nkotumso and Domenase [t(18) = 0.613, p< 0.019]. The mean concentration of As measured at both locations was above the WHO (2011) permissible limit of 0.010 mg/L (Table 1).

Mercury was 0.011±0.007 mg/L in water for Nkotumso, and 0.090±0.05 mg/l for Domenase. The levels of Hg at Nkotumso ranged from 0.002 to 0.021 mg/L while at Domenase, they ranged from 0.012 to 0.171mg/L at Statistically, significant differences were observed between the concentration of Hg at both locations [t (18) = -5.224, p< 0.001]. The mean concentration of Hg measured at both locations was above the WHO (2011) permissible limit of 0.001 mg/L (Table 1).

The mean concentration of manganese was 0.122±0.09 mg/l in water for Nkotumso and 0.090±0.042 mg/L for Domenase. The content of Mn in river water at Nkotumso ranged from 0.027 to 0.254 mg/L and from 0.043 to 0.850 mg/L at Domenase. There was a significant difference in the concentration of Mn at Nkotumso and Domenase [t(18) = 1.046, p< 0.009]. The mean concentration of Mn measured at both locations was below the WHO (2011) permissible limit of 0.4 mg/L (Table 1).

Iron concentration was 0.184±0.133 mg/l in water for Nkotumso and 0.188±0.064 mg/L for Domenase. The iron content in river water at Nkotumso ranged from 0.072 to 0.461 mg/L while it ranged from 0.105 to 0.321 mg/L at Domenase. There was a significant difference in the concentration of Fe at Nkotumso and Domenase [t(18) = -0.085, p< 0.041]. The mean concentration of Fe measured at both locations was below the WHO (2011) permissible limit of 0.3 mg/L (Table 1).

The mean recorded concentrations in the sensitive areas, apart from iron and manganese, the remaining measured parameters exceeded slightly the recommended limit of WHO, UESP and Environmental Protection Agency-Ghana. Hence the levels of heavy metal contamination have spread beyond control and have potential effect to cause further contamination.

Mining in this area has potential deteriorating effects beyond its immediate geographical environment because of the high discharge volume of the river and its tributaries that join other water bodies. Mining and related activities have a very great negative environmental impact with resultant morphological changes in the landscape, massive consumption of wood fuel, over-exploitation of the indigenous fauna by the concentrated populations of the mining camps, lowering of the water quality, air pollution, and aquatic life.

Other environmental impacts that are associated with artisanal gold mining in the study area include interruption of the flow of minor rivers; degradation of the landscape; and excavation of large pits, especially noticeable in clay and limestone quarries, and sand pits. Another very negative effect of mining is when gold is extracted from the margins of rivers since it leads to river-bank erosion during floods. Also, the removal of the plant cover, due to the direct action of the mine or from dumping tailings on slopes, and the degradation of forests as a result of increased use of fire wood by miners, adversely affects watersheds. The local fauna is usually hunted excessively around mining camps.

Pearson coefficient of correlation was employed to determine the association between physicochemical parameters of river water at Nkotumso and Domenase respectively. Table 2 shows the Pearson correlation matrix of physicochemical parameters. Electrical conductivity correlated strongly and positively with TDS ($r = 1.000$, $p < 0.01$) and TSS ($r = 0.802$, $p < 0.01$). TSS also strongly correlated positively with TDS ($r = 0.802$, $p < 0.01$) and alkalinity ($r = 0.717$, $p < 0.717$). Dissolved oxygen was moderate and correlated positively with alkalinity ($r = 0.676$, $p < 0.05$) and Pb ($r = 0.668$, $p < 0.05$). Mercury, on the other hand, showed strong positive correlation with EC ($r = 0.749$, $p<0.05$), TDS ($r = 0.749$, $p<0.05$), TSS ($r = 0.876$, $p<0.01$) but a moderate correlation with alkalinity ($r = 0.636$, $p<0.05$). Manganese also correlated strongly and positively with EC ($r = 0.799$, $p<0.01$), TDS (0.799, $p<0.01$), TSS ($r = 0.944$, $p<0.01$), and alkalinity ($r = 0.752$, $p<0.05$). Lastly, Fe strongly and positively correlated with alkalinity ($r = 0.716$, $p<0.05$) and DO ($r = 0.712$, $p<0.712$) but a moderate positive correlation recorded for Pb ($r = 0.638$, $p<0.05$).

TABLE 2

Pearson correlation matrix of physicochemical parameters of river water at Nkotumso (Upstream)

	pH	*EC*	*TDS*	*TSS*	*Alk*	*DO*	*Pb*	*As*	*Hg*	*Mn*	*Fe*
pH	1.000										
EC	0.153	1.000									
TDS	0.153	1.000**	1.000								
TSS	0.348	0.802**	0.802**	1.000							
Alk	0.115	0.388	0.388	0.717*	1.000						
DO	-0.216	0.082	0.082	0.217	0.676*	1.000					
Pb	-0.214	0.373	0.373	0.491	0.652	0.668*	1.000				
As	-0.106	0.045	0.045	0.003	0.541	0.574	0.425	1.000			
Hg	0.183	0.749*	0.749*	0.876**	0.636*	0.114	0.426	0.051	1.000		
Mn	0.233	0.799**	0.799**	0.942**	0.752*	0.468	0.621	0.084	0.812	1.000	
Fe	-0.013	0.314	0.314	0.616	0.716*	0.712*	0.638*	0.134	0.325	0.706	1.000

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at 0.05 level (2-tailed)

TABLE 3

Pearson correlation matrix of physicochemical parameters of river water at Domenase (Downstream)

	pH	*EC*	*TDS*	*TSS*	*Alkalinity*	*DO*	*Pb*	*As*	*Hg*	*Mn*	*Fe*
pH	1.000										
EC	0.220	1.000									
TDS	0.220	0.999**	1.000								
TSS	-0.033	0.249	0.244	1.000							
Alk	0.096	0.316	0.313	-0.057	1.000						
DO	0.456	0.162	0.165	-0.568	0.094	1.000					
Pb	0.497	-0.343	-0.343	-0.203	0.070	-0.203	1.000				
As	0.164	-0.252	-0.251	0.454	-0.444	-0.079	0.061	1.000			
Hg	-0.269	0.018	0.018	0.243	-0.476	-0.034	-0.442	0.217	1.000		
Mn	-0.085	0.728*	0.730*	0.012	0.229	0.075	-0.463	-0.479	0.271	1.000	
Fe	-0.806**	-0.195	-0.195	0.141	0.295	-0.541	-0.241	-0.057	-0.207	-0.045	1.000

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at 0.05 level (2-tailed

Table 3 showed strong negative correlation between Fe and pH ($r = -0.806$, $p<0.01$). Strong positive correlation was established between TDS and EC ($r = 0.999$, $p<0.01$) whereas Mn also correlated strongly and positively with EC ($r = 0.728$, $p<0.05$) and TDS ($r = 0.730$, $p<0.05$).

Conclusion

The study examines the presence of heavy metals in Nkotumso and Domenase Rivers in the central region of Ghana using the PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer.

The result for total suspended solids for the two study areas shows that TSS are far below the acceptable limit. However, for total suspended solids (TSS) show a slight increase of 6456 for Domenase as compared to 1332 for Nkotumso. The increase in TSS in Domenase can be attributed to a number of factors. First, there are large deposits of dredged materials close to the banks that could be easily washed into the river during rains; second, numerous scattered farming activities affect land cover and increase surface run off hence TSS; the soil is mostly clay and its fine nature increases suspension which poses a serious threat to water supply and aquatic life. The hydrological condition also leaves much to be deserved; many of the streams and rivers drain into the main river at Domenase transporting their sediment into the mainstream and thus raising its TSS. Apart from iron and manganese, whose concentrations slightly exceed the acceptable limit, the remaining heavy metal concentrations are less than the WHO permissible limit indicating that they are not toxic to the environment. However, there is the need to undertake periodic research and monitoring to determine the levels and trends of these substances for their effective control.

Reference

Afum, B. O., & Owusu, C. K. (2016). Heavy metal pollution in the Birim River of Ghana. *International Journal of Environmental Monitoring and Analysis*, **4(3)**:65-74.

Ali, M. M., Hossain, D., Khan, M. S., Begum, M., Osman, M. H., Nazal, M. K. & Zhao, H. (2021). *Environmental pollution with heavy metals: A public health concern* (pp. 1-20). IntechOpen.

Appiah, H. (1998). Organization of small-scale mining activities in Ghana. *Journal of the Southern African Institute of Mining and Metallurgy*, **98(7)**:307-310.

Aryee, B. N., Ntibery, B. K. & Atorkui, E. (2003). Trends in the small-scale mining of precious minerals in Ghana: a perspective on its environmental impact. *Journal of Cleaner production*, **11(2)**:131-140.

Asif, Z. & Chen, Z. (2016). Environmental management in the North American mining sector. *Environmental Science and Pollution Research*, **23(1)**:167-179.

Balasubramaniam, Y. & Panda, A. (2014). Tackling water management in mining. Water: *Journal of the Australian Water Association*, **41(1)**:36-40.

Bansah, K. J., Dumakor-Dupey, N. K., Kansake, B. A., Assan, E. & Bekui, P. (2018). Socioeconomic and environmental assessment of informal artisanal and small-scale mining in Ghana. *Journal of Cleaner Production*, **202**:465-475.

Beckers, F. & Rinklebe, J. (2017). Cycling of mercury in the environment: Sources, fate, and human health implications: A review. *Critical Reviews in Environmental Science and Technology*, **47(9)**:693-794

Bilotta, G. S. & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research*, **42(12)**:2849-2861.

Buccella, A. (2013). Can the Minamata Convention on Mercury Solve Peru's Illegal Artisanal Gold Mining Problem? Yearbook of *International Environmental Law*, **24(1)**:166-187

Byrne, P., Wood, P. J. & Reid, I. (2012). The impairment of river systems by metal mine contamination: a review including remediation options. *Critical Reviews in Environmental Science and Technology*, **42(19)**:2017-2077.

Ciszewski, D. & Grygar, T. M. (2016). A review of flood-related storage and remobilization of heavy metal pollutants in river systems. *Water, Air, & Soil Pollution*, **227**:1-19.

Cleary, D. and Thornton, I. (1994). The environmental impact of gold mining in the Brazilian Amazon. In Issues in Environmental Science and Technology (R. E. Hester and R. M. Harrison, ed.), vol. 1, p. 17.

Diamantini, E., Lutz, S. R., Mallucci, S., Majone, B., Merz, R. & Bellin, A. (2018). Driver detection of water quality trends in three large European river basins. *Science of the Total Environment*, **612**:49-62.

Díez, S. (2008). Human health effects of methylmercury exposure. *Reviews of environmental contamination and toxicology*, 111-132.

Donkor, A. K., Nartey, V. K., Bonzongo, J. C. & Adotey, D. K. (2006). Artisanal mining of gold with mercury in Ghana. *West African Journal of Applied Ecology*, **9(1)**:93-103

Duruibe, J. O., Ogwuegbu, M. O. C. & Egwurugwu, J. N. (2007). Heavy metal pollution and human bio toxic effects. *International Journal of physical sciences*, **2(5)**:112-118.

Fashola, M. O., Ngole-Jeme, V. M. & Babalola, O. O. (2016). Heavy metal pollution from gold mines: environmental effects and bacterial strategies for resistance. *International journal of environmental research and public health*, **13(11)**:1047.

Förstner, U. & Wittmann, G. T. (2012). Metal pollution in the aquatic environment. Springer Science & Business Media.

Hayford, F. K., Amin, A. Osae, E. K. and Kutu, J. (2009). Impact of gold mining on soil and some staple foods collected from selected mining communities in and around the Tarkwa-Prestea area. *West African Journal of Applied Ecology*, **14(1)**:1-12. DOI.10.4314/ wajae. v14il.44708

Honlah, E., Yao Segbefia, A., Odame Appiah, D., Mensah, M. & Atakora, P. O. (2019). Effects of water hyacinth invasion on the health of the communities, and the education of children along River Tano and Abby-Tano Lagoon in Ghana. *Cogent Social Sciences*, **5(1)**:619-652.

Hilson, G. (2002). The environmental impact of small-scale gold mining in Ghana: identifying problems and possible solutions. *Geographical Journal*, **168(1)**:57-72

Hilson, G. (2001). A contextual review of the Ghanaian small-scale mining industry. *Mining, Minerals and Sustainable Development*, 76 (September).

Huesemann, M. H., Skillman, A. D. & Crecelius, E. A. (2002). The inhibition of marine nitrification by ocean disposal of carbon dioxide. *Marine pollution bulletin*, **44(2)**:142-148.

Joseph, L., Jun, B. M., Flora, J. R., Park, C. M. & Yoon, Y. (2019). Removal of heavy metals from water sources in the developing world using low-cost materials: *A review. Chemosphere*, **229**:142-159.

Kesse, G. O. (1985). The Mineral and Rocks Resources of Ghana. A.A. Balkema, Rotterdam, 20–55.

Lacerda, L. D. & Salomons, W. (1998). Mercury from Gold and Silver Mining: A chemical Time Bomb? Springer-Verlag Berlin Heidelberg Publishers, New York

Lahiri-Dutt, K. (2018). Reframing the debate on informal mining. Between the plough and the pick: Informal, artisanal and small-scale mining in the contemporary world, 1-28.

Lenntech, W. T. (2009). Chemical properties, health and environmental effects of copper. *Lenntech Water Treatment and Purification Holding BV www. lenntech. com/periodic/ elements/cu. htm*.

Lynch, S. F., Batty, L. C. & Byrne, P. (2014). Environmental risk of metal mining contaminated river bank sediment at redox-transitional zones. *Minerals*, **4(1)**:52-73.

Mantey, J., Nyarko, K. B., Owusu-Nimo, F., Awua, K. A., Bempah, C. K., Amankwah, R. K., .. & Appiah-Effah, E. (2020). Mercury contamination of soil and water media from different illegal artisanal small-scale gold mining operations (galamsey). *Heliyon*, **6(6)**, e04312.

Masindi, V. & Muedi, K. L. (2018). Environmental contamination by heavy metals. *Heavy metals*, **10**:115-132.

Mehta, N., Cipullo, S., Cocerva, T., Coulon, F., Dino, G. A., Ajmone-Marsan, F., ... & De Luca, D. A. (2020). Incorporating oral bioaccessibility into human health risk assessment due to potentially toxic elements in extractive waste and contaminated soils from an abandoned mine site. *Chemosphere*, **255**:126-927.

Napacho, Z. A. & Manyele, S. V. (2010). Quality assessment of drinking water in Temeke District (part II): Characterization of chemical parameters. *African Journal of Environmental Science and Technology*, **4(11)**:775-789.

Nashmi, A. D., Hassan, A. F. & Hammady, M. M. (2020). Estimation the Level of Metals (Lead, Cadmium, Copper and Zinc) In Multiple Sclerosis Patients in Basra, Iraq. *Indian Journal of Forensic Medicine & Toxicology*, 14(3).

Nazir, R., Khan, M., Masab, M., Rehman, H. U., Rauf, N. U., Shahab, S., ... & Shaheen, Z. (2015). Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam Kohat. *Journal of pharmaceutical sciences and research*, **7(3)**:89.

Ntibrey, B. K. (2001). Small scale mining of precious minerals in Ghana-a strategy to improve environmental performance (Doctoral dissertation).

Obkirchner, C. E. (2019). The effects of gold mining on microbiome composition in a freshwater ecosystem (Doctoral dissertation, Sam Houston State University).

Rahman, Z. & Singh, V. P. (2019). The relative impact of toxic heavy metals (THMs) arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. *Environmental monitoring and assessment*, **191(7)**:1-21.

Rahmanikhah, Z., Esmaili-Sari, A. & Bahramifar, N. (2020). Total mercury and methylmercury concentrations in native and invasive fish species in Shadegan International Wetland, Iran, and health risk assessment. *Environmental Science and Pollution Research*, **27(7)**:6765-6773.

Reardon, E. J. (1995). Anaerobic corrosion of granular iron: Measurement and interpretation of hydrogen evolution rates. *Environmental science & technology*, **29(12)**:2936-2945.

Rudorff, N., Rudorff, C. M., Kampel, M. & Ortiz, G. (2018). Remote sensing monitoring of the impact of a major mining wastewater disaster on the turbidity of the

Doce River plume off the eastern Brazilian coast. *ISPRS Journal of Photogrammetry and Remote Sensing*, **145**, 349-361.

Schiesari, L., Leibold, M. A. & Burton Jr, G. A. (2018). Metacommunities, metaecosystems and the environmental fate of chemical contaminants. *Journal of applied ecology*, **55(3)**:1553-1563.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U. & Wehrli, B. (2010). Global water pollution and human health. *Annual review of environment and resources*, **35**:109-136.

Serfor-Armah, Y., Nyarko, B. J. B., Adotey, D. K., Adomako, D. & Akaho, E. H. K. (2005). The impact of small-scale mining activities on the levels of mercury in the environment: The case of Prestea and its environs. *Journal of Radioanalytical and Nuclear Chemistry*, **262(3)**:685-690.

Simutanyi, N. (2008). Copper mining in Zambia: the developmental legacy of privatisation. *Institute for Security Studies Papers*, 2008(165):16.

Srna, R.F. & Baggaley, A. (1975) "Kinetic Response of Perturbed Marine Nitrification Systems", *J. Wat. Pollut. Control Fed.*, **47(3)**:472-486, 1975.

Vardhan, K. H., Kumar, P. S. & Panda, R. C. (2019). A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *Journal of Molecular Liquids*, **290**:111-197.

Veiga, M. M. & Marshall, B. G. (2019). The Colombian artisanal mining sector: Formalization is a heavy burden. *The Extractive Industries and Society*, **6(1)**:223-228.

Ward, B. B. (2008). Nitrification in marine systems. In D. G. Capone, D. A. Bronk, M. R. Mulholland, & E. J. Carpenter (Eds.), Nitrogen in the Marine Environment, (2nd ed., pp. 199–261). Burlington, MA: Academic Press. https://doi.org/10.1016/B978-0-12-372522-6.00005-0

White, R. F., Steele, L., O'Callaghan, J. P., Sullivan, K., Binns, J. H., Golomb, B. A., ... & Grashow, R. (2016). Recent research on Gulf War illness and other health problems in veterans of the 1991 Gulf War: Effects of toxicant exposures during deployment. *Cortex*, **74**:449-475.

World Health Organization, WHO. (2011). Guidelines for drinking-water quality. *World health organization*, **216**:303-304.

Zipper, C. E. & Skousen, J. (2021). Coal's legacy in Appalachia: Lands, waters, and people. *The Extractive Industries and Society*, **8(4)**:100-990.