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Impacts of Artisanal Gold Mining on Water Quality: A Case Study of Tangandougou Commune in Sikasso Region, Mali

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ABSTRACT

Introduction: Unsustainable natural resources utilization is on the increase in the developing countries thus the ability of many local communities to meet their basic needs including food, water and shelter is jeopardized. Uncontrolled gold-mining in Sikasso region is one such an anthropogenic activity that is of great environmental concern to the local and national governments of Mali owing to its potential impacts on water quality, human health and environment. This study was conceived to assess the impacts of artisanal gold mining on water quality in Tangandougou in Sikasso region of Mali.

Materials and Methods: In this descriptive study, water samples were collected, processed and analyzed for heavy metals (Lead, Cadmium and Arsenic) according to APHA protocols. Measurements of physical parameters of water quality were done according to APHA protocols. Data were analyzed using both descriptive and inferential statistics.

Results: There were no significant spatial differences in physical and chemical parameters (pH, Temperature, Conductivity, Total Dissolved Solids and Salinity) of water quality amongst the sampling sites. However, the heavy metals concentrations in the sampled water exceeded WHO drinking water quality guidelines.

Conclusion: It was concluded that the water of Sankarani River and its tributaries is contaminated and may cause adverse effects on human health due to biomagnification and the bioaccumulative nature of heavy metals. Therefore, the study recommends continuous monitoring of the water quality in all water sources adjacent to gold-mining areas to protect human and environmental health.

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Introduction

Unsustainable natural resource utilization is on the increase in the developing countries especially the sub-Saharan Africa thus the ability of many local communities to meet their basic needs including food, water and shelter is jeopardized. Heavy metals pose a lot of concern to the general public having their toxic effects not only on man but also on all ecosystems. It is sad to note that man contributes more than 95% of the total heavy metal contaminants in the environment thus impairing his own health [1]. Studies in Brazil estimated total mercury loses during gold mining processes in the entire Amazon River basin to be about 100 tons per year with 45% being released into the river and 55% into the atmosphere [2].

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Uncontrolled artisanal gold mining in Sikasso region is such an anthropogenic activity that is of great environmental concern to developing countries including Mali, owing to its potential adverse impacts on water quality, human health and environment in general. The adjacent community depends on water drawn from Sankarani River for household use as well as livestock production. They also rely on fish caught from this river to supplement their protein requirements.

There are many health hazards associated with artisanal gold-mining. For example, consumption of mercury- contaminated fish and shellfish has been observed to cause visual impairments (Scotomata), visual field constriction (Ataxia), paresthesias (early signs), hearing loss, dysarthria, mental deterioration, muscle tremor, movement disorders, paralysis and death (with severe exposure), prenatal exposure, fetal toxicity, cognitive and motor delays and impairment [3, 4]. The highly toxic methyl mercury (MeHg) which forms 90% of total mercury (THg) has been shown to affect a child's neurodevelopment adversely. Research findings have also linked methylmercury exposure to an array of health conditions ranging from delays in walking and talking to lower scores on neurological tests. The latter includes retarded memory, motor, and behavioral functions in children [5]. The most common form of prenatal exposure is maternal fish consumption. Except for the carnivorous tiger fish, from Lake Turkana which had THg concentrations near or above the international marketing limit of 500 ng g^{-1}, THg concentrations in the studied fish were generally below those of World Health Organization's recommended limit of 200 ng g^{-1} for at-risk groups such as pregnant and breastfeeding women. However, with the increase of fishing, industrial and agricultural development in and around these lakes, there is a potential for elevated mercury contamination in the fish[5]. Further, mercury can cause neuropathologies which results in changes in the behavior of the bald eagle such as a disruption in foraging and reproduction. The changes result in poor forage and return to the nest with prey items to feed their young [6].

Arsenic inhalation and ingestion during copper, gold and metal mining activities may pose health outcomes as hyperpigmentation, depigmentation, bladder cancer, skin cancers, peripheral neuropathy and lung cancer [7]. In addition, the inhalation and ingestion of lead contaminated dust released by grinding ore to extract gold likely poses health problems related to death, lead encephalopathy, impaired neurocognitive development, abdominal colic, anorexia and premature birth [4, 8].

Elevated cadmium levels have been shown to be detrimental to survival, growth and reproduction of cladocerans, fish and birds [9]. Lead is a non-specific poison, affecting all body systems of various organisms. Increased metal loads in lake water and sediments are also a human health concern due to biomagnification of metals along the aquatic and terrestrial food chains and food webs. Overall, human health risks are primarily due to the elevated concentrations of Hg, Pb, Cd, As, and Se in water and fisheries that are part of the local people's diet. Consumption of arsenic-laden water and food crops rice in Southeast Asia including Bangladesh, India and the Bengal region in general has been linked to several health conditions such as cancer of the skin, kidneys, bladder and lungs [10, 11, 12]. Cadmium has also been linked to kidney and liver damage as well as osteoporosis and pulmonary emphysema that was the case in Japan where people consumed rice cultivated using cadmium-contaminated irrigation water.

Artisanal gold mining takes place nearby rivers and backwaters in Mali to facilitate gold washing. Further, the exploitation of this natural resource is characterized by open access, limited regulation and weak implementation that explain the rising levels of environmental degradation [13]. Owing to the release of wastewater containing mine tailings, the surface water is contaminated and thereby poses a health risk to communities living in the surrounding areas. A study by Gibb and O'Leary [14] demonstrates the consequences of artisanal gold mining on resident communities as well as those living in the riparian zones of rivers draining

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through gold-mining areas. The ill effects were due to consumption of Mercury –contaminated water and fish [7, 15]. It is against this background that this study was conceived to assess the impacts of artisanal gold-mining on water in Tangandougou Commune in Sikasso region of Mali.

Materials and Methods

Study Area

Sikasso is the third administrative region of Mali and is located on southern part of the country (Figure 1). It borders Segou to the Northern, the Republic of Cote d'Ivoire to the South, the Republic of Guinea to the West, Burkina Faso to the East and by the region of Koulikoro to the North-west. The region covers 71.790 km^2 representing 3.8% of country. The region is divided into 7 districts; including Sikasso, Bougouni, Kadiolo, Kolondieba, Koutiala, Yanfolila and Yorosso. In Sikasso region, there are 3 major urban centers, 144 rural settlements and 1,831 villages [16].

Tangandougou settlement is located in Yanfolila District. The study site, Farabacoura is located geographically on 11.57116° N and 008.262666° W about 160 km Southeast of Bamako, 10 km away from Selingué Dam. It is located on the confluence of Bale and Sankarani Rivers that are tributaries of the Niger River. Sankarani River is one of the major tributaries of the Niger River, and has 3 backwater tributaries in which gold-washing and other activities take place.

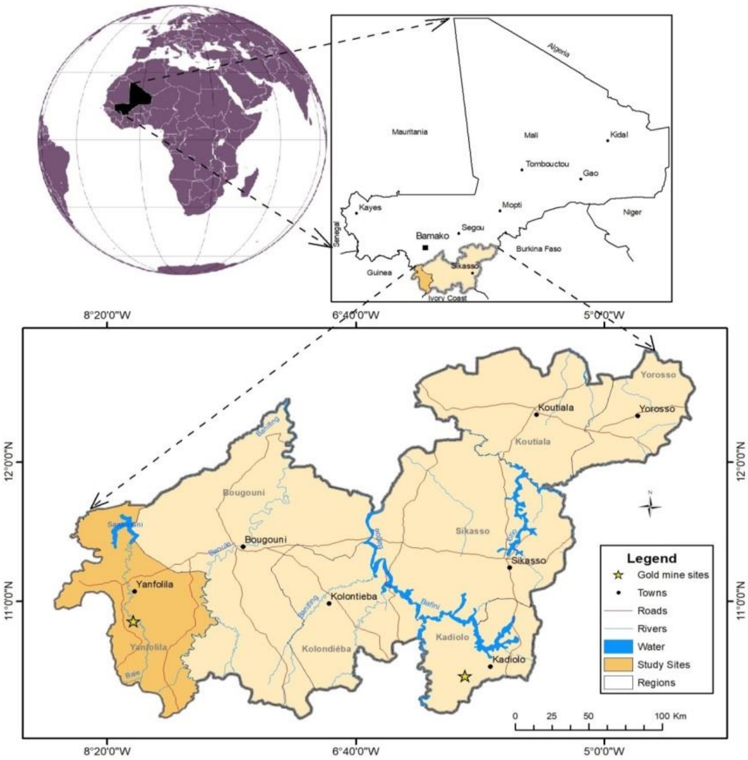

Figure 1: Global position of Africa, map of Mali (Inset) and Sikasso region (the study area)

Sample Collection, Processing and Analysis

In this descriptive, water samples were collected from three different points purposively selected to capture the impacts of gold-mining on water quality. Thus samples were collected from three sites: at the mining site, upstream, and downstream of the mining site. The equipment used for sample collection, storage and analysis of heavy metals were pre-cleaned with high-grade nitric acid in Chemical and Natural Resources Laboratory (CNRL) of the University of Sciences and Technology of Bamako in Mali. They were rinsed with copious amounts of Milli-Q water to ensure that they were free from any trace-metal. Water

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samples were collected in high-density polypropylene bottles and filtered immediately using GF/C Whatman filters of 0.45µm, and acidified with ultra-pure HNO_3 to pH < 2. The sample bottles were stored in double-bagged zip-lock polyethylene bags, stored at 4° C and transported to the lab for heavy metal analysis. The physical and chemical parameters that were analyzed were pH, temperature, conductivity, total dissolved solids (TDS) and salinity with the pH/Cond 3320 Set 4 WTW meters.

Water sample processing and analysis for heavy metals were done according to APHA protocols as described by Ogendi and Hannigan [17]. After application of the Dynamic Reaction Cell Inductively Coupled Plasma Mass Spectrometry (DRCII ICP-MS; Elan PerkinElmer) and followed by the use of EPA 200.8 methodology, heavy metal concentrations were determined [18]. Initially, we transferred 15 mL of the 0.45 µm-filtered water samples into an auto sampler vial into which an internal standard containing ^{6}Li, ^{75}Ge, ^{115}In, and ^{209}Bi was added. Later, in order to stabilize Hg, 40 ug/L of ^{196}Au was added to the sample solutions. A standard calibration curve was designed for all the analyses using the standards prepared in a 2% ultra-pure nitric acid in a linear range from 1 ppb to 300 ppb. In order to check the precision and accuracy, we applied the National Institute of Standards, Testing reference standard, NIST 1640, and procedural blanks.

The analysis of standard reference materials and blacks showed that the trace metal concentrations were within 3% of the reported values for NIST 1640. Finally, the Relative Standard Deviation (RSD) for sample trace metal concentrations were calculated and found to be < 5% for all analyses. The heavy metals that were analyzed included: Lead, cadmium and arsenic. Data from Laboratory measurements were analyzed using both descriptive and inferential statistics. The heavy metals concentrations were compared with those of the European Community (EC) and WHO guidelines for drinking water [19]. The Mean and Standard Deviation for the heavy metal concentrations were calculated as per equations i and ii.

$$\bar{X} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} \qquad \text{equation (i).}$$

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad \text{equation (ii).}$$

Results

There were no significant differences in physico-chemical parameters (p > 0.05) of water quality amongst the three sampling sites. There were significant spatial variations in cadmium concentration amongst the three sampling sites ($F_{2,6}$ = 964; p < 0.001). Cadmium concentration was the highest at site P1, followed by P3 and finally P2 (Table 1). P1, P2 and P3, represented the mining, upstream, and downstream sites, respectively. A similar trend was observed for Lead where there was a significant difference amongst the sites ($F_{2,6}$ = 1224; p < 0.001). Finally, significant differences in Arsenic concentrations were observed amongst the sampling sites ($F_{2,6}$ = 49; p < 0.001). The concentrations of Cd and Pb at the three sampling sites were significantly higher compared to the EC and WHO drinking water quality guidelines for these heavy metals. However, the concentration of Arsenic at the study sites was not significantly different from that of the EC and WHO drinking water quality guideline for this heavy metal (p < 0.05; Table 1).

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Table 1: Heavy metal concentration at 3 sampling sites adjacent the gold mining area at Farabacoura, Mali. P_1 represented the mining site, P_2 the upstream and P_3 downstream plus EC and WHO standards

Sites	Cadmium (Cd)	Lead (Pb)	Arsenic (As)
P1	0.405	0.374	0.005
P2	0.310	0.141	0.010
P3	0.340	0.245	0.005
EC	0.005	0.010	0.010
WHO	0.003	0.010	0.010

The Cadmium concentrations amongst the study sites are shown in Figure 2. In comparison, cadmium concentrations were higher than the references of European Community's drinking water (0.005) and also the World Health Organization guideline value for drinking water (0.003). The concentration of lead in the three sampling sites is shown in Figure 3. The Pb concentration in all the 3 sites exceeded the WHO and EC drinking water standards. Arsenic concentrations amongst the three sampling sites are shown in Figure 4. The results of Cadmium reported in term of $\bar{X} \pm SD$ lower and upper limits were for the point one $0.402 \leq P1 \leq 0.408$, at the point two $0.307 \leq P2 \leq 0.313$ and at point three $0.337 \leq P3 \leq 0.343$.

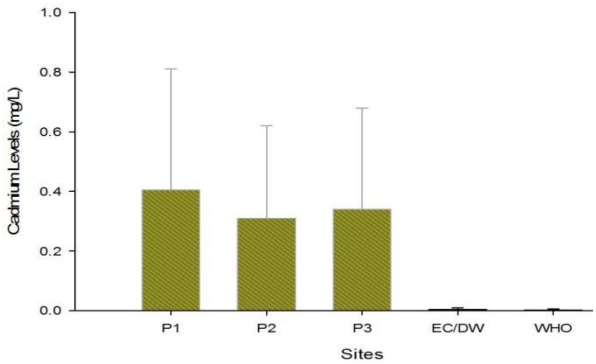

Figure 2: Mean and Standard Deviation values for cadmium concentration at Farabacoura study area. EC and WHO represent European Community, and World Health Organization guideline values.

The results were in terms of lower and upper limits of mean and Standard Deviation for lead at sampling site P1 $0.372 \leq P1 \leq 0.376$, at sampling site P2, it was $0.139 \leq P2 \leq 0.143$ and at the sampling site P3 $0.243 \leq P3 \leq 0.247$. The guideline values as proposed by EC (0.010) and WHO (0.010) were considerably lower than those measured in this study (Figure 3).

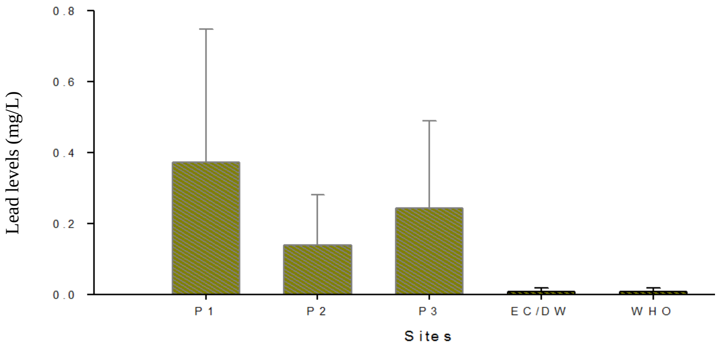

Figure 3: Mean and Standard Deviation values for Lead concentration at Farabacoura study area. EC and WHO represent European Community, and World Health Organization guideline values.

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The results of Arsenic were $0.003 \leq P1 \leq 0.007$ at sampling site P1, $0.006 \leq P2 \leq 0.014$ and $0.003 \leq P3 \leq 0.007$ at sampling sites P2 and P3, respectively. The results showed that arsenic concentration was lower or equal to the guideline values proposed by the EC (0.010) and WHO (0.010) (Figure 4).

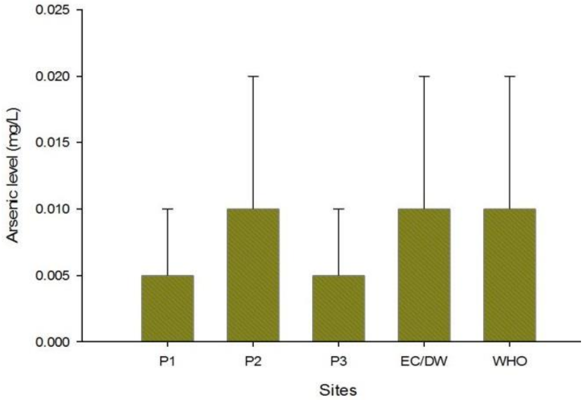

Figure 4: Mean and Standard Deviation values for arsenic concentration at Farabacoura study area. EC and WHO represent European Community, and World Health Organization guideline values.

Discussion

Heavy metals continue to pose a lot of concern to the general public given their toxic effects not only to humans but also to other organisms. However, it is sad to note that man contributes more than 95% of the total heavy metal contaminants in the environment thus impairing his own health[1]. Some of these heavy metals include arsenic, zinc, cadmium and mercury whose concentrations in water, air, soil, sediments and in food chains have been increased significantly through anthropogenic activities [20]. Environmental mercury contamination from natural and anthropogenic sources affects water quality and food resources from aquatic environments.

A study was conducted between 1997.98 and 1998.99 by Mansour and Sidky [21] in Fayoum Governorate that linked the elevated concentrations of heavy metals including zinc, cadmium and mercury in water and fish to human activities adjacent to the surface waters. Mercury has found widespread applications in industry including electrical and electronic applications, manufacture of measuring and controlling instruments, dental amalgams and paints. It has also been used for a long time in the extraction of gold and in some cases pesticides. Other studies also linked elevated concentrations of mercury in air to gold mining in the adjacent areas [22]. Studies also demonstrated a link between anthropogenic activities and elevated cadmium levels in water, sediments and fish. In most cases, there are elevated levels of lead in water and fish [23]. These were attributed to fishing vessels and trawlers that have galvanized metal coating.

Chemicals are used in the amalgamation of gold from its ore [24]. It has been estimated that about 200 tons of mercury are used in the recovery of gold from illegal mines in Indonesia [25]. Exposure to these chemicals as well as the mine-tailings poses a serious health risk not only to the miners but their families and the local community that derives a living by exploiting the fisheries and water from the adjacent Sankarani River. Artisanal gold mining in most cases causes elevated concentrations of mercury as well as the negative health impacts arising from exposure to mercury and mine-tailings [3, 15].

Heavy metals and other contaminants from gold mining processes have been reported to impair water quality [15, 26]. Water quality impairment of surface and underground water has been partly linked to mine tailings containing mercury, lead and cadmium [26]. These pollutants impacted heavily on drinking water, aquatic organisms and water used for agricultural production [27]. Therefore, gold mining is likely to impact on human and environmental health owing to consumption of metal-contaminated water by humans, animals and plants in the study area.

Wastewater from the gold-mining site in the study area contains chemical products. The wastewater is drained directly into the receiving waters without pre-treatment. This explains the elevated levels of heavy metals (cadmium and lead) in the receiving waters.

The present results showed that artisanal gold mining is the source of Cd and Pb. The concentrations of these two heavy metals are considerably higher than those of the upstream and downstream sampling sites. The presence of these metals in the upstream sampling site can be attributed to artisanal gold-mining activities at Machoko in Kadiolo District. The concentrations of lead and cadmium exceed the WHO standards for drinking water and the description of the release of mercury from the Chesso Company in Minamata Japan resulting in a rapid increase of mercury level in water, sediments and in fish caught at the bay and the adjacent water [20].

Conclusion

In conclusion, the water in the selected sites of Sankarani River and its tributaries in artisanal mining area of Farabacoura were contaminated with heavy metals. Artisanal gold mining was responsible for the elevated heavy metal concentrations at the study area. The heavy metals pose health risks to the local people through consumption of metal-contaminated water and fish. The environmental and human implications of these elevated levels are of grave concern. Consequently, public awareness programs are required to alert residents of the risks associated with heavy metal exposure and the fish consumption guidelines. A comprehensive study on the impacts of heavy metals on human and environmental health needs to be conducted in the study area. Such information can be used to determine the correct course of action that needs to be taken to regulate mining activities. Finally, the study recommends continuous monitoring of the water quality in all water sources surrounding mining areas to protect human and environmental health.

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Conflict of Interests

The authors declare they have no actual or potential competing financial interests.

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