Bamboo for Mining Reclamation and Renewable Energy

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Abstract

In Ghana, the small-scale mining industry severely damaged the environmental landscape of the country. The use of mercury and other heavy metals posed a serious threat to the public health and safety of local communities and ecosystems. To mediate this issue, our team worked with the community of Akyem Dwenase to understand the social framework of the mining industry. The objectives of this project were to analyze the environmental biochemistry of an inactive mining site and to map the site in preparation for soil remediation using the local bamboo species, Oxytenanthera abyssinica.

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1.0 Background

1.1 History of Gold Mining in Ghana

In Western Africa, there is a rich history of gold mining. From pre-colonial times to the present, the Ancient Kingdom of Ghana, the former Gold Coast Colony, and Ghana today, are heavily involved in mining activity and relevant events.

Ghana is home to some of the world's most significant gold deposits, formed by tectonic processes and erosion over millions of years. Gold trading with the Arab world started in the 9th century AD when North African merchants discovered the gold-rich region and established a monopoly. The Ancient Kingdom of Ghana was a powerful and wealthy state from the late thirteenth to the fifteenth century, which taxed and exported gold and other goods (Hilson, 2002).

Pre-colonial mining in Ghana was done with simple methods, such as using pans and sieves to extract gold from streams and rivers, then smelting to produce gold ornaments. When the British set foot on the ground of Ghana, scientific methods of mining were also introduced. In the late 1800s, the implementation of advanced scientific mining techniques in Ghana allowed European mining corporations to dominate the industry, effectively barring Ghanians from active participation in gold mining except for roles as laborers and artisanal miners (Ofosu-Mensah Ababio, 2011).

To control the hazard posed by the mining industry, preventative facilities and methods of quality controls should have already been constructed to cater to both active and inactive operations of the gold-mining industry; however, most of the gold mines in Ghana did not comply with these preventative measures (Bempah & Ewusi, 2016). This is due to the illegal methods acquire the mining areas that were not regulated by the government. The lack of regulation posed a threat not only to the local ecosystems but to the local communities of the villages. Approximately 13.1% of Ghana's land area (31,237 square kilometers) was under the maintenance of mining companies. With the increase of acquiring land and mining production, the plots of farmland were decreasing, which then directly impacts the agricultural economic sector. Many of those lands were severely contaminated with heavy metals and cannot be transformed back for their original use (Emmanuel et al., 2018). As a result, numerous sections of land cannot be utilized by local communities that heavily rely on agriculture to sustain themselves.

1.2 Gold Mining Process

There are two common ways of extracting metals from the environment: alluvial (placer) and hydraulic. Alluvial mining, also known as placer mining, is the practice of separating heavily eroded minerals like gold from sand or gravel through panning or shifting through the sediment. Because of gold's high density, this type of mining causes the gold to separate from lighter siliceous materials through moving water (*Placer Mining | Britannica*, n.d.). This method was the most common practice along the banks of the Ankobra, Odin, Tano, and Birim Rivers during the precolonial age in Ghana. Through the accumulation of gold from erosion spanning millions of years, the re-deposition of gold in those bodies of water was the core stimulant for participation in gold mining (Hilson, 2002). Hydraulic mining requires the use of a sluice, which is a sloping wooden box that allows gold and sediment to be moved by a stream of water. As the water carries the sediment, the riffles at the bottom agitate the current, which prevents lighter material from settling while retaining the valuable heavy material (*Placer Mining | Britannica*, n.d.).

1.3 Chemicals Used in Gold Mining

1.3.1 Mercury

Mercury (Hg) is a naturally occurring heavy metal. In galamsey, the wetting of gold by mercury is not a true alloying process, but a phenomenon of moderately deep sorption, involving interpenetration of the two elements. As the surface tension of mercury is greater than that of water but less than that of gold, it adsorbs onto the surface of gold particles (Wang et al., 2020). To extract gold from crushed ore, liquid mercury is added directly and mixed. For the recovery of gold from the amalgam, the solid is heated to vaporize the mercury and separate it from the gold, which can be done using a hand torch or a stove (Esdaile & Chalker, 2018).

1.3.2 Cyanide

Cyanide (CN^-) is a triple-bonded molecule with a negative charge, consisting of one atom of carbon in the +2 oxidation state and one atom of nitrogen in the -3 oxidation state. Sodium cyanide ($NaCN$) is used to separate gold from ore through cyanidation. This method is under the category of leaching, which is a gold extraction process in which the ore is treated with certain chemicals, which help to convert the precious metals into soluble salts while the impurities remain insoluble. This process has a high recovery of gold than plate amalgamation. It produces the final product in the form of practically pure gold. In order to maintain the ionic forms of cyanide and to prevent volatilization to hazardous hydrocyanic acid (HCN), the reaction must occur under strong alkaline conditions, typically a pH over 10 (Kuyucak & Akcil, 2013). The overall reaction, known as Elsner's equation, is shown as the following:

$$4\,Au + 8\,NaCN + O_2 + 2\,H_2O \;->\; 4\,Na[Au(CN)_2] + 4\,KOH$$

When fresh surfaces of gold are exposed to the cyanide in an aqueous solution containing free oxygen, a gold cyanide compound will be formed and a hydroxide. Lead nitrate may be added to act as an accelerator in gold cyanidation to increase precipitation (Michaud, 2016).

1.4 Environmental Impact of Gold Mining

Small-scale mining activities contribute to nearly a third of Ghana's total gold production (*Ghana Nature Hit Hard by Gold Mines - but Future Looking up – DW – 01/26/2018*, n.d.), but the prevalence of illegal mining presents a significant challenge. Gold mining has had a markedly adverse impact on the environment, leading to land degradation, water bodies becoming muddy and contaminated with heavy metals.

As one of the most commonly seen ways of mining, artisanal miners typically create numerous shallow pits spread out over extensive areas of land. They extract and process gold on-site before moving to the next location, often neglecting to refill the excavated pits. Additionally, they frequently employ mercury to extract gold from sediments, which can result in significant health concerns and prolonged soil and water pollution. Researchers from NASA, United States universities, and Ghanaian government agencies employed satellite data to evaluate the extent of vegetation degradation resulting from artisanal mining in the southwestern region of Ghana, where most of the country's gold mining occurs. Their findings indicate that artisanal mining activities caused approximately 24% of the region's vegetation loss between 2005 and 2019 (*The Large Footprint of Small-Scale Mining in Ghana*, 2021).

1.4.1 Soil and Water Pollution

Heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Fe, Mn, and Zn) pollution was also reported in local groundwater agricultural soils. This accumulation of these heavy metals has an increased potential for the deterioration of the ecosystems surrounding mining sites. Heavy metal contamination of surface water, groundwater, agricultural soils, and crops surrounding mining areas has been identified as one of the most serious global environmental issues (Bempah & Ewusi, 2016). In some areas, the communities halted fishing activities due to fish species dying from toxification. The increase in impurity implied increased turbidity, which indicates a drop in water pH levels. As a result, there would be an amplification of many aquatic reactions such as the dissolution of metal oxides (Emmanuel et al., 2018). In addition, mercury poses a point of concern for soil and aquatic ecosystems. Once emitted to the atmosphere, mercury can be transported in its elemental form [Hg(0)], which can cause deposition to soil or water bodies after oxidation to divalent mercury [Hg(II)]. Mercury cannot be degraded in ecosystems, and that creates a threat of bioaccumulation and biomagnification up the food chain (Wang et al., 2020).

1.4.2 Air Pollution

According to the Kenyasi community, they reported that the main source of air pollution originated from the vehicles transporting machines and other equipment to the mining sites. During the blasting process, the residual dust and chemical gases filled the atmosphere for some time (Emmanuel et al., 2018).

1.4.3 Noise Pollution

An unexpected area of pollution was influenced by the noise from the vehicles traveling to the mining sites and the heavy machinery for mining. In the excavation process, intense noise exposures occurred from the use of dynamite and generator-powered grinding machines for ore processing. Due to the high noise emission, a study found that 59 out of 252 miners at a large-scale mining company experienced noise-induced hearing loss (Emmanuel et al., 2018).

1.4.4 Microorganisms and Bacteria

Mercury is toxic to microorganisms, which can impact the rate of uptake by cells. The heavy metal can bind to the cell walls or cell membranes of the microorganisms. This influences the cell density and the concentration of mercury within the cell (International Programme on Chemical Safety, 1989).

For bacteria, they have mechanisms to adapt to high mercury concentrations in soils. The *mer* operon system present in certain bacterial genomes, coding for detoxification proteins, is a known bacterial defense system against Hg. The central gene for Hg resistance in the *mer* operon system is *merA*. This gene codes for the mercuric reductase enzyme, a flavoprotein located in the cytoplasm using NADPH as an electron donor, which catalyzes the conversion of Hg^{2+} to volatile Hg^0 (Frossard et al., 2018)

1.5 Observed Human Health Effects of Gold Mining

1.5.1 Effects of Mercury

Inorganic mercury can be methylated in the environment, and the resultant methylmercury (MeHg) is taken up into organisms readily. Once transformed into its organomercuric forms such as methylmercury, mercury acts as a potent neurotoxin, which impairs brain function. Also, this form has a high affinity for sulfhydryl ligands in amino acids, which reduces alteration in protein structures and leads to a loss of function (Wang et al., 2020). In mining sites, mercury contamination can be reflected in urine, blood, hair, diet, and other categories. The length of exposure affects the intensity of health complications (Eisler, 2002).

1.5.2 Effects of Cyanide

Even though cyanide does not bioaccumulate, it does have an affinity to bind to iron in the blood by forming complexes. This can inhibit oxygen transfer to cells, which causes suffocation of humans and animals. Liquid or gaseous hydrogen cyanide and alkali salts of cyanide can enter the body through inhalation, ingestion, or absorption through the eyes and skin (Kuyucak & Akcil, 2013).

1.6 Remediation by using Bamboo

To mediate the accumulation of mercury and other heavy metals in the mining site, we suggest planting a local bamboo species, Oxytenanthera abyssinica, to extract those toxins. Oxytenanthera abyssinica is a lowland bamboo, which is used frequently for restoration. It is mainly composed of cellulose, hemicellulose, and lignin. The extraction potential is based on the concentration of heavy metals in the aboveground plant tissues and plant biomass. Bamboo tissues in the rhizome and culm can accumulate a large amount of heavy metals that mainly accumulate in the cell wall, vacuole, and cytoplasm. Many bamboo species have very high endurance in heavy metal-contaminated soils with specific heavy metal absorption capacities. However, excessive concentrations of heavy metals beyond the tolerance range of bamboo may cause oxidative stress and damage to the grass species (Bian et al., 2020).

Phytoremediation poses an ideal method to reduce the concentration or toxic effects of contaminants in the environment. It is a low-cost method that highlights environmental friendliness and a lack of secondary pollution (Bian et al., 2020). In combination with hydroponic conditions to remediate bodies of water in a mining site, Oxytenanthera abyssinica can be a vital method for heavy metal extraction for Ghanaian villages.

Figure 1: Oxytenanthera abyssinica (Tolessa et al., 2017)

2.0 Methods

2.1 Perform literature analysis

To understand general information regarding the topic of the project, I gathered information by researching keywords in relation to mining in Ghana and soil remediation. Through that, I refined my search by recognizing essential elements of the project to observe, such as chemicals used in mining and the specific method of phytoremediation. It was essential to start with a general search of information and then slowly search for specific details of each component to have an overall understanding of the project. I searched for review articles and journal articles to increase the credibility of this literature analysis. This information was compiled into a document that highlighted key details from each article. In addition, I searched for methods on how to analyze the components after sample collection. By using the United States Environmental Protection Agency and journal articles, I organized possible methods of experimental procedure into a document that emphasized vital information from each source.

2.2 Assess the mining site

Before taking samples, we observed the overall structure of the site. We noted the placement of bodies of water and the presence of plant growth. It was imperative that I take pictures of the mining site at each visit. In addition, observations were taken through drawing the landscape alterations, photographs, and written notes about key details of the site. Each time we returned, we continued to observe the changes in the environment. Key factors to notice were the changes in plant growth, bodies of water, soil, and the landscape surrounding the mining site. This was in preparation for collecting samples.

2.3 Take samples of various locations at the mining site

After assessing the site, I sought out secure containers for sample collection. Using cost-effective containers, such as empty water bottles, would be feasible items to obtain due to their high availability. From that, I gathered soil/mud and water samples using easily accessible materials, such as shovels, and machetes. After each collection, the water bottle was labeled according to the detail of the specified location in Figure 2. The water bottles were stored in a shed to shield the bottles from external factors, like the weather and community members.

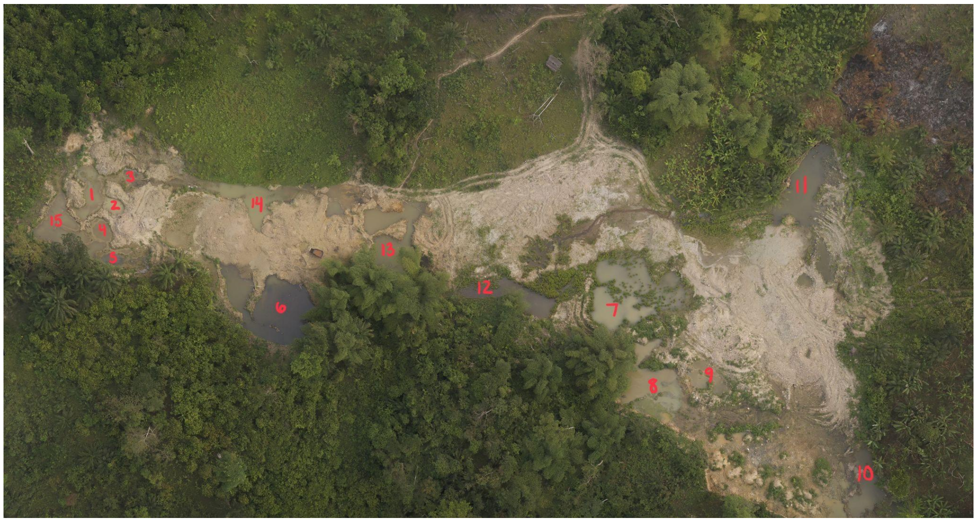

Figure 2: Aerial Photograph of Mining Site (Wu, 2023)

3.0 Results and Discussion

3.1 Observations

Our team learned that the site was farming land that transformed into a mining site. It became inactive for about six months before our arrival. We expected the site to have recent physical traces of human interaction: however, there were not. We went to the mining site four times. However, the mining site had a different appearance on each visit. According to Figure 3, there was limited plant growth and a limited presence of local animals and insects. The soil was rocky and uneven, which was extremely difficult to penetrate. There were several isolated bodies of water. In the past, there was a river running through the farmland, which was damaged by the galamsey operations. Around the bodies of water, there were physical traces of what seemed to be iron and other heavy metals due to the red metallic sheen. From each visit, the presence of plant life and animals increased, which was shown in Figure 3. This could be impacted by the few times of rainfall during the dry season that encouraged this growth. It seemed that the contamination of mercury and heavy metals did not suppress plant growth and interactions with local organisms. After many years of contamination in the local area, these organisms could have adapted to the high concentrations of mercury. However, it is not known how heavy metals have impacted the health of local animals and insects.

Figure 3: Photographs of the Mining Site taken about a Month Apart

[left: taken on January 13, 2023, right: taken on February 17, 2023]

(Desir, 2023)

3.2 Expected Results from Experimental Procedures

Due to not having access to a laboratory, we obtained analytical methods for heavy metal testing. Also, we could not test microorganisms and plants to determine how they were impacted by the heavy metals since we did not have proper storage to preserve the organisms. Because of the nature of the mining site, we researched methods of acid digestion to break down the sediments and other elements found in the water and soil samples. In total, I collected 32 samples. Two samples were taken from specified locations around the mining site as well as an area of fresh, uncontaminated water as a control area. If there were access to a laboratory setting, it would be difficult for one person to test all of the samples and analyze the data in a few weeks. As a result, we expected to obtain traces of mercury, iron, lead, chromium, cadmium, and other heavy metals. However, a factor to consider was obtaining the specific metals from the acid digestions once the reaction was complete. The main EPA methods observed were the following:

EPA 3010A: Acid Digestion of Aqueous Samples for Total Metals
EPA 3005A: Acid Digestion of Waters for Metals
EPA 3050B: Acid Digestion of Sediments, Sludges, and Soils
EPA 3200: Mercury Species Fractionation and Quantification

4.0 Conclusion

Overall, it was interesting seeing the progression of environmental efforts to correct the years of damage. Although testing of the samples was not performed, this literature analysis will provide another group to continue this project with a foundation. Moving forward with the help of the community, the area would be tested for the presence of heavy metals and other toxins. For soil remediation, implementing bamboo can provide economic aid to the village by increasing tourism with the attraction of bamboo goods, such as crafts and biofuel. In addition, a future project could observe the bioaccumulation of heavy metals within plant and animal sources to determine how those organisms were adapting to the altered ecosystem.

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