

Research Paper



# Phytoremediation potential of pioneer plants in mercury contaminated mined soil at an abandoned mined site in Ghana

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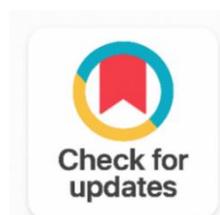
Mercury Contamination

Phytoremediation

Bioaccumulation Factor

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## ABSTRACT

Mercury contamination at abandoned mined sites poses serious environmental and public health risks in sub-Saharan Africa, while affordable and sustainable remediation options remain limited. This study evaluated the phytoremediation potential of three native plant species, *Mucuna pruriens* var. *utilis*, *Rottboellia cochinchinensis*, and *Elaeis guineensis* that naturally regenerated on an abandoned mined site in Amanchia, Ghana. Soil analyses showed a mean mercury concentration of  $2.55 \pm 0.15$  mg/kg, indicating very high contamination relative to background levels. Bioaccumulation factors for all species were below 0.05, demonstrating limited mercury uptake. Translocation factors ranged from 0.72 to 0.79, reflecting moderate internal mobility but insufficient transfer to shoots for effective phytoextraction. *R. cochinchinensis* recorded the highest mercury accumulation in both roots and shoots, although none of the species met the criteria for mercury hyperaccumulation. These findings support existing evidence that confirmed mercury hyperaccumulators are rare or absent and highlight phytostabilization as a more suitable approach than phytoextraction for mercury-impacted soils. The study underscores the ecological value of indigenous pioneer species in limiting mercury mobility and recommends further research into plant-microbe interactions and soil amendments to enhance stabilization outcomes in degraded mining landscapes.

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## 1. INTRODUCTION

Mining, especially artisanal and small-scale gold mining, has had a huge impact on the environment in developing parts of the world like sub-Saharan Africa. The most alarming outcome of mining is the big area of soil contamination with mercury, a heavy metal known for being toxic and for staying around for a long time. Mercury is a major threat not only due to its immediate toxic effect but also because it gets into food chains and living organisms, increasing the risk to the environment and human health significantly [1]. In Ghana, the vandalized landscape of gold mining is mainly in the Ashanti Region, where there would be no more land and water resources being polluted by mercury [2].

When mercury is dumped to the environment, it reacts with soil and water in an intricate manner. Various factors such as soil pH, organic matter, salinity, and soil microbes' activity determine the extent to which mercury can move and be absorbed by living organisms [3]. Rain and surface run off also help to disperse mercury from the mining areas to the adjacent regions, thus pollution and environmental crisis become more widespread [4]. When it comes to finding out how big the pollution problem is, researchers mainly depend on the contamination factor that assesses how much mercury there is in the soil by comparing it with its natural background levels. In case the contamination factor is considerably greater than one, that would indicate a severe pollution issue which indeed needs to be addressed on an urgent basis [5].

Traditional techniques for contaminated soil remediation, for example, soil excavation and chemical treatments, can yield positive results; however, these are typically costly, causing significant disruption and inapplicable on large areas [6]. As a more sustainable alternative, phytoremediation has gained attention. The process of using plants to detoxify soils and water bodies is called phytoremediation and it is an eco-friendly and economic solution that Mother Nature is offering to us [7]. The process of phytoremediation works through different mechanisms. Some plants might absorb metals from the soil and accumulate them in their upper parts; this is known as phytoextraction. Others may confine metals in the soil, which keeps them from dispersing, and this technique is referred to as phytostabilization. There are also plants capable of converting contaminants into less harmful forms that are released into the atmosphere, known as phytovolatilization, or filtering metals from water through their roots, known as rhizofiltration [8].

Two important measures help evaluate how effective a plant can be for phytoremediation: the bioaccumulation factor and the translocation factor. The bioaccumulation factor indicates how well a plant absorbs contaminants from the soil into its tissues. The translocation factor shows how efficiently a plant moves these absorbed metals from its roots to its shoots. Plants are characterized by having both measures and are therefore sink plants [9]. Heaps of studies have been done to assess the phyto-remediation capabilities of different plants [7], [10]. But still, there is limited research on the possibilities of *Mucuna pruriens* (bush mucuna), *Rottboellia cochinchinensis* (itch grass), and *Elaeis guineensis* (oil palm) in the treatment of heavy metal-plagued areas [2], [9]. The lack of knowledge is particularly striking regarding the contamination of mercury from artisanal mining, where the uncontrolled regrowth of plants, especially the pioneer ones, is often seen. The species that come first in the succession are characterized by their fast growth, their high tolerance to adverse conditions like poor, polluted, and barren soils, and by their roots that are skilled enough to get them in and out of the disturbed areas easily [11]. These characteristics make them good candidates for use in stabilizing the site and possibly phytoremediation in the future.

This research reviews the potential of phytoremediation of the three species which were discovered to have come in naturally at the abandoned mine location in Amanchia six months post-closure. More specifically, the study measures mercury concentrations in the roots, shoots, and soils around these

plants. Furthermore, the bioaccumulation and translocation factors will be computed to measure the capability of every species to take mercury from the soil, accumulate and hide it or even stabilize it [9], [12]. Thus, the documentation of this gap in knowledge will result in the exposure of the role of native and resilient species in the sustainable rehabilitation of mine sites in the case of Ghana, contributing to the larger environmental restoration goals and commitments under the Minamata Convention [1].

## 2. RELATED WORK

The capability of vegetation for mercury (Hg) remediation in polluted environments has been investigated by multiple researchers, especially in the regions that have suffered from artisanal and small-scale gold mining (ASGM) operations. One of the first systematic evaluations of native plant species in an Hg-contaminated mining district in Colombia was performed by Marrugo-Negrete et al [9], who found that the accumulation of Hg was higher in roots than in shoots and listed among the tolerant species *Jatropha curcas* and *Piper marginatum*, albeit none of the plants were classified as hyperaccumulators. In a similar fashion, [13] on the uptake of Hg in crops and wild plants in ASGM landscape in Uganda reported soils with Hg concentrations that were extremely high but a general trend of low bioaccumulation factors (BAF), thus suggesting phytostabilization rather than phytoextraction potential.

Studies in Latin America have continued to investigate the natural regeneration of vegetation in the soils contaminated with mercury. Durante-Yáñez and colleagues [14] showed that the plant *Clidemia sericea* is very tolerant to mercury, cadmium, and lead, and the metals are mainly found in the roots. On the other hand, [15] have studied the 46 plant species in the post-mining regions of northwestern Colombia and have found some species of plants that can accumulate metals but none of them have reached the threshold for hyperaccumulation of mercury that has been set. Research on pioneer species has produced similar conclusions. A study by [16] demonstrated that plants that spread on soil contaminated with mercury in urban areas in Brazil absorbed the mercury predominantly in their roots, thus supporting their role in the stabilization of the soil. The research [17] under controlled circumstances revealed that emulsifying *fosbergii* has a high tolerance for the presence of mercury, but at the same time, its translocation factors are under 1, which again restricts its capacity for phytoextraction. A number of reviews re-confirm the non-existence of established mercury hyperaccumulators and underline the role of mercury speciation and plant-microbe interactions as critical [15], [18].

Despite these advances, most evidence originates from Latin America or controlled settings, with limited focus on native African species. Few studies have evaluated pioneer plants naturally colonizing abandoned galamsey sites. This study addresses this gap by assessing indigenous species on a mercury-contaminated site in Ghana, providing field-based evidence on their phytostabilization potential for sustainable land reclamation.

## 3. METHODOLOGY

### Study Area

The study site, Amanchia, is a town within the Atwima Nwabiagya Municipality, located at 6.58333°N, -1.85°W and sitting 291 meters above sea level, with a population of 20,451 Figure 1. The site represents a degraded landscape due to past mining activities, where natural vegetation has started regenerating. Eventually, though, natural vegetation has begun to grow back and, thus, opened a door to investigate the possible use of the local plant species for the clean-up of mercury-contaminated soils. Amanchia, because of its geographical position, has the same climatic conditions and soil types as the larger Atwima Nwabiagya Municipality, which is mainly characterized by a tropical climate with two seasons of rain and, in general, fairly fertile soils outside the mining areas [19], [20]. This situation qualifies it as a perfect case study for evaluating the phytoremediation potential of the pioneer species as one of the environmental management and post-mining restoration strategies that are applicable to similar areas in Ghana.

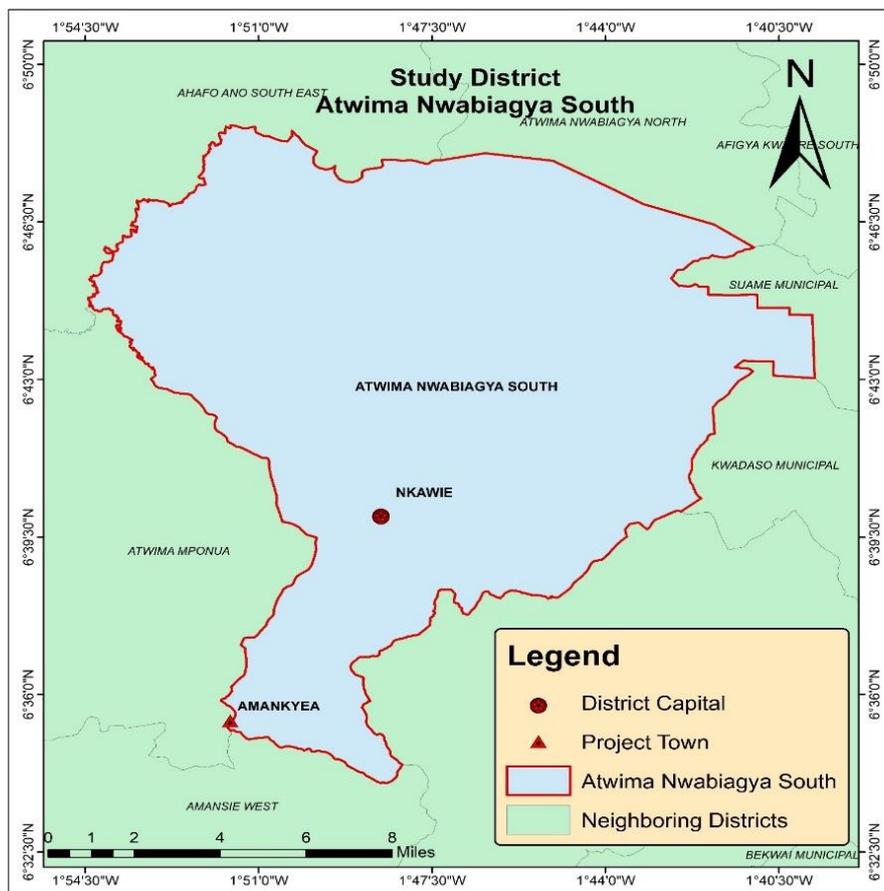


Figure 1. A Map of the Study Area

**Materials and Data Used**

The study focused on an abandoned and levelled mined site where natural plant regeneration had occurred without any formal reclamation interventions. The site’s vegetation cover was minimal and not uniformly distributed, and among the plant types only the ones capable of living in and even might be chemically polluted soils were the ones to gain the most. A random sampling method was applied for the purpose of getting both the plant diversity and the soil pollution unevenness throughout the site. The three plant types chosen were those most occurring, and also those that had been or could be discovered to take the heaviest metals up. The selected species included *Mucuna pruriens* (velvet bean), *Rottboellia cochinchinensis* (Itch Grass), and *Elaeis guineensis* (Palm) Table 1.

Table 1. Family of the Studied Plant Species

Plant Species	Life Form	Family
<i>Mucuna pruriens</i>	Climbing Legume	Fabaceae
<i>Rottboellia cochinchinensis</i> (Itch Grass)	Grass	Poaceae
<i>Elaeis guineensis</i> (Oil Palm)	Tree	Arecaceae

**Methods**

In order to make the statistical results reliable and to also take into consideration the different characteristics of the sites, three individual plants of each species (n = 3) were randomly selected from the different locations within the site. Each plant was treated as a biological replicate, so the use of inferential statistics like ANOVA and LSD tests was enabled. The individual plants were cut with care so as to get the shoots and the whole root system collected without damage. The plant samples were washed with distilled

water in order to take away soil particles, then roots and shoots were separated with a stainless-steel knife, and they were air-dried and put in paper bags for laboratory analysis.

At the same time, composite soil samples were taken from the rhizosphere (0–15 cm depth) of each individual plant using a soil auger. For each plant, several sub-samples around the root zone were mixed up to make one composite sample per sampling point. All soil samples were kept in air-tight plastic bags and sent to the laboratory for analysis. This sampling method gave rise to both replication and spatial representation over the site which in turn supported the statistical analysis and raised the trust in the mercury accumulation and mobility patterns observed.

### Soil Analysis

The soil samples were analyzed for mercury concentrations via Atomic Absorption Spectrophotometry (AAS) after acid digestion with  $\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$  in a ratio determined by the USEPA Method 7471B. Blank, duplicate, and certified reference material quality control measures were implemented.

The formula used for calculating the Contamination Factor (Cf) was as follows:

$$Cf = \frac{C_{\text{metal in soil}}}{C_{\text{background}}}$$

The previous recipe enables to convert the AI text into a more human-like tone. It is beneficial to ensure that the resulting trashes possess lower perplexity but higher burstiness, yet without modifying word count and HTML elements. This metric classifies the severity of contamination at the site.

### Mercury Analysis in Plant Tissues

Plant samples were oven-dried at 70°C for 72 hours, then ground into fine powder. Approximately 1 g of each powdered sample was weighed into a Kjeldahl digestion tube, after which digestion was carried out using a mixture of nitric acid and hydrochloric acid ( $\text{HNO}_3$ :  $\text{HCl}$ , 1:3 ratio). The digestion process took place at a temperature of 450°C and the solution was allowed to reach a whitish state which is an indicator of full organic matter breakdown. Distilled water was then used to dilute the digested samples to a final volume of 100 ml after cooling.

Then the plant tissues which had been digested were subjected to AAS for the determination of Mercury concentrations. The AAS was run under well-defined parameters, such as an air pressure of 50 to 60 psi, an acetylene pressure of 10 to 15 psi, and an operating voltage of 208 to 240 volts. A wavelength of 253.7 nm was used for the analysis, which is the best for mercury detection. Buck Scientific stock standards were used to create calibration curves which guaranteed the accuracy and reliability of the measurements. Mercury concentrations in the samples were then quantified based on absorbance readings and interpreted using the calibration equation generated from these standards.

### Bioaccumulation and Translocation Factors

The mercury concentrations in soil, plant roots, and shoots were recorded in mg/kg. Mercury accumulation in plant tissues was evaluated to determine each species' potential for phytoremediation. Some of the criteria for selecting hyperaccumulators are bioaccumulation factor (BAF) and translocation factor (TF), which provide an indication of how much the plant bioconcentrates heavy metals in tissues relative to the amount contained in the soil. BAF was calculated based on the concentration ratio of a metal in plant tissue (shoot and root) to the concentrations in soil, [21] (Equation 1). BAF can also show the efficiency of the plant in accumulating toxic elements.

$$BAF = \frac{\text{Conc of metal in plant}}{\text{conc of metal in soil}} \quad (1)$$

The TF evaluates the ability of a plant to transfer heavy metals from the roots to the above-ground parts, thus accounting for the removal from the soils. The TF is the ratio of heavy metal concentration in the plant shoot to the concentration in the root [22] as shown in Eq. (2).

$$TF = \frac{\text{Conc of metal in shoot}}{\text{conc of metal in root}} \quad (2)$$

### Statistical Analysis

The data were processed with R statistical software, a powerful statistical tool. A one-way ANOVA was used to test if the mercury concentration means for different plant species, plant parts (roots and shoots), and the corresponding soils are significantly different. The F-statistic was computed according to the following formula:

$$F = \frac{MS_{between}}{MS_{within}}$$

MS<sub>between</sub> denotes the variance that is found between groups, whereas MS<sub>within</sub> represents the variance that is found within the groups.

In order to determine the differences among specific groups, Fisher's Least Significant Difference (LSD) test was applied for post hoc comparisons. The LSD was computed using the following expression:

$$LSD = t_{\alpha, df} \times \sqrt{\frac{2 \times MS_{within}}{n}}$$

Where  $t_{\alpha, df}$  denotes the critical t-value for the significance level  $\alpha = 0.05$ ,  $df$  refers to the degrees of freedom, MS<sub>within</sub> indicates the variance within groups, and  $n$  stands for the number of samples in each group.

All of the statistical tests were performed with a significance level of 5% ( $p < 0.05$ ), thus guaranteeing that the reported mean differences were not just random but statistically significant.

## 4. RESULTS AND DISCUSSION

### Mercury Concentration in Soil

The buried contaminated place from where the soil samples were taken in Amanchia was the site that came to the conclusion of Contained Mercury Concentration of  $2.55 \pm 0.15$  mg/kg Table 2. Figure 2 is way above the background level of 0.369 mg/kg for natural soils and even the best situation with mercury soil content of below 0.1 mg/kg [23]. Consequently, the site has a Cf value of 6.92 which places it in the very high contamination category according to the thresholds given by Hakanson [20]. The level of contamination is still reflecting highly disturbed area due to human activities by artisanal miners which are corroborated by reports from other similar places in Sub-Saharan Africa where illegal gold mining is always leading to mercury-laced waste being deposited in soils [1], [6].

This type of contamination brings about a lot of dangers to the soil's biological activity, plants, and the drinking water sources, because mercury not only has a long life but is also very likely to convert into methylmercury which is much more toxic especially in soils with suitable conditions [3]. Moreover, if the problem is not mitigated, mercury could further move around through leaching and runoff, where it will be applying more pressure on the ecosystem by creating a degraded situation [4].

Table 2. Mean Mercury Concentrations in Soil from the Abandoned Mine Site in Amanchia, Ghana

Parameters	Hg
Soil (mg/kg)	$2.55 \pm 0.15$
Concentration factor (Cf)	6.92
Background (mg/kg)	0.369
Interpretation	Very high contamination

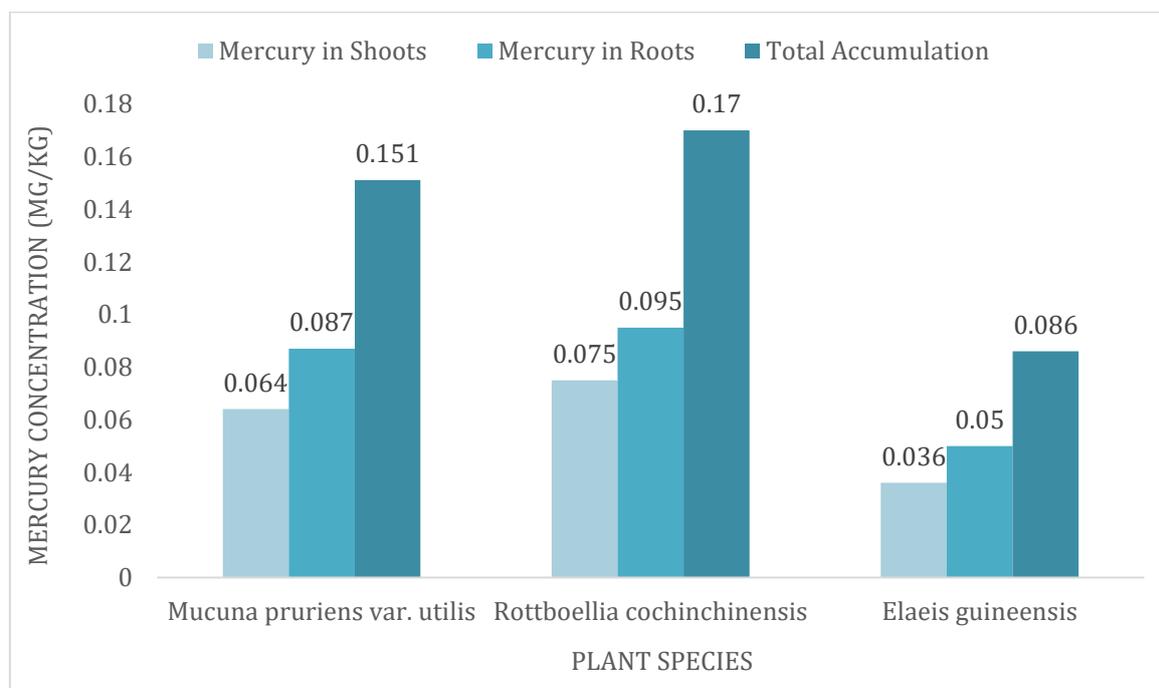
Contamination Factor (Cf) Classification:  $Cf < 1 \rightarrow$  Low contamination,  $1 \leq Cf < 3 \rightarrow$  Moderate contamination,  $3 \leq Cf < 6 \rightarrow$  Considerable contamination,  $Cf \geq 6 \rightarrow$  Very high contamination.

### Mercury Uptake in Plant Tissues

The mercury concentrations recorded in the roots and shoots of the three plant species sampled are presented in Table 3 and Figure 2 below:

**Table 3.** Mercury Concentrations Recorded in the Roots and Shoots of the Three Plant Species (Mg/Kg)

Plant Species	Mercury in Shoots (mg/kg)	Mercury in Roots (mg/kg)
<i>Mucuna pruriens</i> var. <i>utilis</i>	0.064 <sup>b</sup>	0.087 <sup>b</sup>
<i>Rottboellia cochinchinensis</i>	0.075 <sup>a</sup>	0.095 <sup>a</sup>
<i>Elaeis guineensis</i>	0.036 <sup>c</sup>	0.050 <sup>c</sup>
LSD (0.05)	0.006	0.004
S.e.d	0.005	0.003
P-value	<0.001	<0.001

**Figure 2.** Comparison of Mean Mercury Concentrations (Mg/Kg) in Shoots, Roots and Total Accumulation of the Different Plant Species

The results of the analysis revealed that there were major differences ( $p < 0.05$ ) in the amount of mercury accumulated in different plant species, both in their aerial parts and underground parts. *Rottboellia cochinchinensis* recorded the highest mercury concentrations in both shoots (0.075 mg/kg) and roots (0.095 mg/kg), followed by *Mucuna pruriens* var. *utilis*. Lowest concentrations were noted in *Elaeis guineensis*, which incorporated 0.036 mg/kg in the aerial parts and 0.050 mg/kg in the underground parts. These figures, although drastically lower than the mercury levels in the soil, do suggest that different plants possess fixed capacities to take up metal. This is in line with other research that asserts that *Rottboellia cochinchinensis* and other grass species are often the highest metal accumulators among legumes and trees [9].

#### Bioaccumulation and Translocation Factors

Moreover, the application of bioaccumulation factor (BAF) and translocation factor (TF) indices **Table 4** for further assessment showed that all species had BAF values very much less than 1, which is a strong indicator of their being non-mercury accumulators.

**Table 4.** Bioaccumulation and Translocation Factors of Mercury in Selected Plant Species

Plant Species	Bioaccumulation Factor (BAF)	Translocation Factor (TF)
<i>Mucuna pruriens</i> var. <i>utilis</i>	0.0341	0.7356
<i>Elaeis guineensis</i>	0.0196	0.7895

Rottboellia cochinchinensis	0.0373	0.7200
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BAF: This index demonstrates the ability of the plant to take up heavy metals from the ground. TF: This term refers to the plant's ability to transport the metals from the roots to the above ground parts which is indicated by it.

Even if the BAFs were low, the TFs were from 0.7200 to 0.7895, which shows that there was a moderate movement of mercury from the roots to the shoot. Nonetheless, none of the species had a TF value beyond one, which is commonly considered the limit for effective translocation essential for phytoextraction, yet still the moderate TF values indicate the internal movement of mercury in plant tissues to be quite high. This internal distribution of mercury, although not leading to hyperaccumulation, may still have an impact on plant physiology, which could be in terms of growth inhibition, oxidative stress, or altered nutrient transport as shown by earlier seminal studies [24], but more studies are needed to confirm these mechanisms under the prevailing environmental conditions. Moreover, the mercury shift from roots to aerial parts might impact herbivores or decomposers that are dependent on aboveground biomass for their food, thereby potentially affecting ecosystem trophic dynamics [25]. The mercury accumulation finally observed in total was nevertheless low, and none of the species displayed characteristics of mercury hyperaccumulators. This aligns with previous studies, which report no confirmed mercury hyperaccumulator species to date [10], [11]. The absence of such species still keeps direct phytoextraction methods nonviable. Nevertheless, the indigenous flora may be used for phytostabilization since they are already adapted to the locality and can also restrict the spread and absorption of contaminants in the environment [10].

### Ecological and Remediation Implications

The relatively higher mercury uptake by *Rottboellia cochinchinensis*, although still limited, corroborates with the results of other studies indicating that grasses usually have better metal accumulation than legumes and trees [9]. *Mucuna pruriens*, a legume, though not very efficient in mercury uptake, can help restore soil fertility by fixing nitrogen [26]. *Elaeis guineensis*, even if its metal accumulation is lower, can still play a role in the soil stabilization due to its deep and wide root system [27].

Taking into consideration all these results, phytostabilization is the best option for mercury management at the Amanchia site. Phytostabilization binds mercury, thus, preventing its movement and minimizing the chance of its dispersion and being taken up by organisms [28]. The co-planting of these species along with soil amendments and microbial enhancers, for instance, mycorrhizal fungi and plant growth-promoting rhizobacteria, could even further improve stabilization and soil conditions.

### Policy and Environmental Implications

The results of the research carry a strong message about the necessity of specialized rehabilitation techniques in the illegal mining locations of Ghana. The level of mercury contamination at the Amanchia site, which was very high, goes along with national assessments that indicate the presence of heavy metal pollution in an extremely large area including forest reserves and other nature-sensitive areas where artisanal mining is being done [29]. The case thus not only shows the environmental and public health risks of unauthorised mining and the necessity for appropriate aligned policies of the whole country that would lead to the stabilization of contaminated soils and restoration of degraded ecosystems.

On the one hand, the native plants' ability to limit mercury mobility, especially that of *Rottboellia cochinchinensis*, *Mucuna pruriens*, and *Elaeis guineensis*, has led to the conclusion that phytostabilization is the best option for dealing with these landscapes. Such a nature-based approach is not only in line with Ghana's commitments under the Minamata Convention on Mercury but also contributes to the country's objectives of achieving land degradation neutrality and ecological restoration. Besides, natives provide a lot of economic benefits since their natural occurrence, ecological compatibility and low maintenance requirements lead to lower costs when compared with other methods of rehabilitation on a large scale.

Nevertheless, effective long-term restoration seeks more than just biological interventions; it needs also powerful land governance systems monitoring degraded areas, managing spatial data, and

making decisions. [30] Point out that land information systems are very important for environmental supervision to be improved, for transparency to be increased, and for multi-agency interventions to be coordinated. Phytostabilization activities in such governance structures would make monitoring stronger, hold parties responsible, and maintain the recovery of the illegally mined terrains.

Considering the above, it would be the blending of the ecological, institutional and policy approaches that would be the greatest advantage as shown by the findings of the study since they would not only mitigate the contamination risks, but also ensure that the ecosystem services would be protected and sustainable land management would be promoted in Ghana's mining-impacted regions.

## 5. CONCLUSION

The research evaluated the capability of *Mucuna pruriens* var. *utilis*, *Rottboellia cochinchinensis*, and *Elaeis guineensis* to phytoremediate a site in Amanchia, Ghana that was previously contaminated with mercury due to galamsey activities. The site exhibited severe contamination, with a mean soil mercury concentration of  $2.55 \pm 0.15$  mg/kg and a contamination factor of 6.92, reflecting strong anthropogenic disturbance. Although all species accumulated mercury, bioaccumulation factors were well below 1, and translocation factors (0.72–0.79) indicated moderate internal mobility, confirming that none function as mercury hyperaccumulators, consistent with global evidence. Although the plant's ability to extract metals was restricted, the species still exhibited very good potential to clean up the soil by their mere presence. *R. cochinchinensis* showed considerably more mercury absorption, *M. pruriens* was helpful in the soil's fertility improvement, and *E. guineensis* provided support to the soil and stability to the site. Their natural regeneration underscores their ecological suitability for low-cost, field-based remediation.

In conclusion, the findings highlight phytostabilization using indigenous pioneer species as a practical and sustainable approach for managing mercury-contaminated mining lands.

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### Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Kwadwo Gyasi Santo	✓		✓				✓			✓	✓	✓		✓
Jeff Dacosta Osei	✓	✓		✓	✓				✓	✓	✓			
Sampson Owusu		✓	✓		✓	✓		✓		✓		✓		
James Kumah		✓			✓	✓		✓	✓	✓		✓		✓

C : Conceptualization	I : Investigation	Vi : Visualization
M : Methodology	R : Resources	Su : Supervision
So : Software	D : Data Curation	P : Project administration
Va : Validation	O : Writing - Original Draft	Fu : Funding acquisition
Fo : Formal analysis	E : Writing - Review & Editing	

### Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Informed Consent

There was no informed consent needed for this study.

### Ethical Approval

There was no ethical approval needed for this study.

### Data Availability

Data is available upon request.

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